34 Effects of the Environment on the Proposed Project

This assessment is consistent with Section 2(1)(c) of the *Canadian Environmental Assessment Act* (1992), which defines “environmental effects,” in part, as “any change to the Project that may be caused by the environment, whether any such change or effect occurs within or outside Canada.”

The Application for an Environmental Assessment Certificate/Environmental Impact Statement (Application/EIS) assesses the potential of natural hazards to affect the proposed KSM Project (the Project) during the construction, operation, closure, and post-closure phases. A range of climate conditions (including extreme weather events; wet, dry, and normal precipitation and extreme temperature spells; and freeze-thaw cycles, changes in permafrost) are considered. The Application/EIS describes and assesses how the potential for climate change, extremes in current climate, seismic activity, potential volcanic activity, and other extreme events, such as fires and floods, could affect the integrity of the proposed development infrastructure, particularly the Mitchell-Treaty Twinned Tunnels (MTT), the Tailing Management Facility (TMF), water management structures, pit wall stability, road operation, and the rock storage facilities (RSFs). Measures to mitigate these potential effects, and contingency plans and response options, are identified.

However, as a first course of action, the Project design adopted a traditional mitigation hierarchy, embedded within the proponents Environmental Management Strategy (EMS; described in Chapter 26.1), where avoidance of environmental sensitivities and natural hazards was the first consideration given to the configuration and design of the Project to ensure safe working conditions, avoid process upsets, and protect the environment. For example, diversion channels have been strategically located to avoid landslide and snow avalanche prone terrain wherever possible, and designed to minimize the risk of failure and to maximize channel efficiency. Landslides, debris flows, and snow avalanches are natural events that may occur, for example in the East Catchment Valley (see Chapter 9) that have the potential to affect Project components and processing facilities, and mine worker safety. The Project was designed to avoid natural hazards in this area by:

- Locating tailing dam centrelines to avoid debris flow paths.
- Developing tailing beaches to push the TMF pond to the west side of the tailing impoundment where there is less of a threat of snow avalanches or debris flows.
- Locating diversion channels to avoid landslide and snow avalanche paths where possible.
- Constructing the East Catchment diversion tunnel to divert creek flow below a landslide and snow avalanche area to the south tributary of Teigen Creek. The tunnel inlets and dam are located in an area of lower risk.

The site for the Explosives Manufacturing Facility in the Ted Morris Valley was also chosen (in consultation with potential explosives suppliers and plant operators) for its ease of use and access under extreme weather conditions, and for its remoteness from the influence of potential geohazard risks.

If all natural hazards could not be avoided, then effects of the environment on the Project were reduced through intelligent Project design (e.g., redundancies embedded within Project operating systems and facilities) and ensuring conservative engineering design safety factors were incorporated into major structures (e.g., RSF stability, dam stability). For a detailed discussion on engineering design and safety factors, see Chapter 35 Accidents and Malfunctions.

In accordance with the Application Information Requirements and comprehensive study Scope of Assessment, the following topics were considered in this assessment:

- climate and meteorology effects, including;
  - high, low, and normal precipitation;
  - high and low extreme temperatures;
  - freeze-thaw cycles;
  - changes in permafrost; and
  - climate change;
- geophysical effects, including;
  - landslides;
  - snow avalanches;
  - channel debris flow;
  - glaciers;
  - earthquakes; and
  - volcanic activity;
- wildfire effects;
- flooding effects; and
- wildlife effects.

34.1 Climate and Meteorology

The Project area lies in a transition zone between the very wet Pacific coastal region and the drier interior of British Columbia (BC). The regional hydro-climate of northwestern BC is dominated by weather systems generated by the Pacific Ocean, and is also influenced by orographic effects caused by the local mountainous topography and glaciers. The resulting interactions between incoming weather systems and local topography produce a degree of spatial variability in snowfall and rainfall.

Orographic effects result when Pacific air streams confront the west-facing slopes of the Coast Mountains, and the moisture-laden air is forced up the slopes. As the air cools and rises, it is less capable of holding moisture and releases it as rain or snow. The mountains also slow down cyclonic storms, which can lead to prolonged and sometimes heavy rainfalls.

Once over the mountain summit, the air descends and warms, which disperses the cloud and rain through evaporation. The result is a dramatic reduction of precipitation in the rain-shadow. Within BC, the series of mountain ranges that parallel the coast produce a decrease in precipitation with increasing distance from the coast as storms pass over the successive ranges.

The Project area is subdivided into two climatic regions: the western Sulphurets Creek watershed (Mine Site) and the eastern Treaty Creek watershed (Processing and Tailing Management Area [PTMA]). The two regions are 23 km apart and have significantly different climates. The two areas are separated by the Johnstone Icefield (ranging from 1,800 m to 2,200 m elevation), Treaty Glacier, and North Treaty Ridge. A summary of the Mine Site and PTMA temperatures, precipitation, and hydrology are given here. For more detailed information, refer to Chapter 6, Greenhouse Gas Emissions (Climate Change); Chapter 7, Air Quality; and Chapter 13, Surface Water Quantity of the Application/EIS.

34.1.1 Mine Site

Mine Site Temperature

Weather data recorded at the Mine Site (Sulphurets Creek station) between 2008 and 2011 (Appendix 7-B) indicated:

- the mean annual temperature is approximately 0.9ºC;
- mean monthly temperatures ranges from -9.9ºC in December to 13.6ºC in July;
- temperature extremes ranged from -27.1ºC (January 2011) to 30.2ºC (July 2009);
- mean daily temperatures are above freezing from May to October; and
- freezing temperatures could occur from October to May.

Canadian meteorological service data indicate that frost penetration for the area is typically 1.5 m or more (Environment Canada 2012).

Mine Site Precipitation and Hydrology

The mean annual precipitation was 1,251 mm from 2008 to 2011, at the elevation of the Sulphurets Creek station (880 masl). Precipitation increases at higher elevations within the Mitchell and McTagg valleys at a nominal rate of 5% per 100 m (UBC Faculty of Forestry 2012). Runoff at the Mine Site is influenced by the effects of both seasonal snowmelt and glacial melt. Both the Mitchell and McTagg glaciers are losing significant ice mass on an annual basis. Runoff from glacier-influenced catchments is therefore larger than the annual precipitation over these catchments. Effects of glacial meltwater are included in the analysis of flows and extreme events for the Mine Site.

34.1.2 Processing and Tailing Management Area

Processing and Tailing Management Area Temperature

Weather data recorded at the PTMA (Teigen Plant Site station) between 2008 and 2011 (Appendix 7-B) showed:

- the mean annual temperature is approximately 0.2ºC;
- the mean monthly temperatures ranges from -12.9ºC in December to 13.8ºC in July;
- temperature extremes ranged from -27ºC (January 2009) to 29ºC (July 2009);
- mean daily temperatures are above freezing from May to October; and
- freezing temperatures could be encountered from October to May.

Processing and Tailing Management Area Precipitation and Hydrology

Mean annual precipitation for 2009 and 2010 at the PTMA was 724 mm (elevation 1,085 masl). Precipitation increases at higher elevations within the Teigen Valley at a nominal rate of 5% per 100 m. Runoff at the PTMA is influenced by the effects of both seasonal snowmelt and glacial melt. Effects of glacial meltwater are included in the analysis of flows and extreme events for the PTMA.

34.1.3 Storms (High Precipitation)

The Project area lies in a climatic transition zone between the very wet Pacific coastal region and the drier interior of BC. This regional hydro-climate is dominated by weather systems generated by the Pacific Ocean, and is also influenced by orographic effects caused by the local mountainous topography. Therefore, on average, the Mine Site will likely receive greater precipitation due to its western position within the Project area and the high elevation of the surrounding topography in relation to the PTMA.

Mean annual precipitation in the Mine Site is expected to be less than 800 mm, which will vary depending on elevation. Annual precipitation is expected to be less at the PTMA than at the Mine Site, estimated to be approximately 1,350 mm. The majority of precipitation is received as snowfall in the fall and winter from October to April. June and July typically receive the least amount of precipitation on an annual basis.

The Unuk River–Eskay Creek regional meteorological station has a temperature data set extending from 1989 to 2007 (Environment Canada 2012). This station is the closest regional station to the Project area, approximately 19 km north of the Mine Site at an elevation of 887 m. The wettest year recorded at this station occurred in 1993, with a total annual precipitation of 2,450 mm.

The proposed pit areas are located within Sulphurets Creek and its tributaries. The Sulphurets Creek watershed is characterized by steep, narrow valleys and is highly glacierized. Both characteristics tend to result in a high percentage of precipitation resulting in surface runoff. Steep hill slopes tend to promote surface runoff of precipitation in the form of rainfall or snowmelt, while glaciers can produce high runoff volumes during the summer months regardless of precipitation. Consequently, annual runoff coefficients (percent of precipitation resulting in surface runoff) for the proposed pit area drainages are expected to be high, ranging from 80 to 100%.

The area of the proposed TMF is characterized by relatively low gradient hill slopes and a relatively wide valley bottom with a wetland complex. These characteristics tend to promote precipitation losses in the form of infiltration and evapotranspiration, thereby reducing the production of surface runoff. In addition, the proposed PTMA is located down gradient from the Sulphurets Creek watershed along a longitudinal precipitation gradient in the region that delivers less precipitation to areas further inland from the Pacific Ocean. Consequently, surface runoff from watersheds in the proposed PTMA is expected to be substantially less than for Sulphurets Creek.

A typical hydrological year for watersheds in the Project area can be divided into four main flow periods: winter, spring/freshet, summer, and fall. Winter (approximately November to April) is characterized by ice-covered streams with low-to-negligible stream flow, depending on the elevation of the stream and watershed area. The spring/freshet period (late April or May to July) is characterized by high flow rates due to snowmelt, and may contain the annual peak flow for any given year. For watersheds in the area of the proposed TMF, summer (approximately July or August to mid-September) is characterized by steadily decreasing high to moderate flows that are augmented by rainfall and meltwater from residual snow patches. In contrast, flows can continue to rise through the summer in Sulphurets Creek and its tributaries due to the presence of glaciers, which can provide substantial meltwater late into the summer. Fall (mid-September to November) is characterized by generally moderate to low flows but is interrupted by rain-fed storm events, which can generate peak flows in excess of freshet flows and may contain the annual peak flow for any given year. This is true for both the PTMA and the Mine Site.

34.1.3.1 Rainstorms and Thunderstorms

34.1.3.1.1 Effects on the Project

The Project area is located in a zone that receives frequent, relatively low-intensity rainfall. During typical rainfall periods, there would be no impact to Project operation. If rainfall intensity increases, there may be increased disruption in the Mine Site operation, including reduced speed of traffic along haul roads and access roads as well as increased dewatering requirements in the active pit areas. During mine operation, higher precipitation levels could increase the amount of groundwater seepage and precipitation that flows into the pits, which would increase pit de-watering costs. In addition, increased precipitation and groundwater seepage has the potential to reduce pit wall stability.

Severe rainstorms in the Project catchments could trigger flooding events, especially if they were to coincide with freshet conditions. Flood effects on the Project and corresponding mitigation measures are presented in Section 34.2. Related surface runoff could trigger debris flows on the steep valley walls of the Mine Site and access corridor. The debris flows could carry large volumes of surficial materials and woody debris down slope and could possibly threaten Mine Site and access corridor infrastructure. Landslide effects on the Project and corresponding mitigation measures are presented in Section 34.3.1.

Thunderstorms may be accompanied by hail, lightning, and damaging winds. A thunderstorm is classified as severe when it contains hail larger than 0.75 inch (1.9 cm) and winds gusting in excess of 50 knots (92.6 km/h). Cases involving either slow-moving thunderstorms or a series of storms that move repeatedly across the same area (sometimes called train-echo storms) frequently result in flash flooding (UIUC Department of Atmospheric Sciences 2010).

Large hail from severe thunderstorms could damage building infrastructure, cause temporary blockages in the diversion channels, and create unsafe working conditions. High-velocity winds related to thunderstorms could create large waves in the Water Storage Facility (WSF) and TMF, and could damage buildings, conveyor lines, and power lines. Access roads could also become blocked with downed trees. Lightning could cause forest fires (wildfires are discussed Section 34.4) under dry conditions, or could damage infrastructure such as buildings and power lines. Finally, thunderstorms within the region could temporarily prevent air traffic, disrupting the mobilization of personnel to and from the Project site.

34.1.3.1.2 Mitigation Measures

To mitigate against rainstorms and thunderstorms, and therefore against increased surface runoff levels, site infrastructure has been designed accordingly:

- Weather forecasts will be monitored for advanced warning of incoming thunderstorms to allow time for extreme storm preparation, such as securing buildings and equipment, mobilizing equipment to key areas for maintenance, providing site personnel safe refuge, and shutting down the Process Plant if necessary. To help mitigate the effects on all mine infrastructure (e.g., buildings, power poles, and bridges) from hail, high-velocity winds, lightning strikes, and tornadoes, various building supplies and power cables will be stored at site to facilitate timely repairs and reconstruction.
- The water management structures and all tailing containment dams are designed to Canadian Dam Association (CDA) standards (CDA 2007) and are discussed in more detail below. They will provide strong resistance to extreme storm events and will protect against waves created by high-velocity winds. Diversion tunnels and ditches are designed to be wide enough to accommodate clearing equipment in the event of a severe hailstorm.
- Access road stream crossings are designed for a 100-year flood with an additional 1.5-m freeboard for debris flow (Appendix 4-AH).
- The Mitchell Diversion Tunnels (MDT) will be designed to convey 24-hour average flows from a 200-year flood. In Year 26, underground mining will commence, and an additional set of tunnels (underground, or underground phase MDT) will be constructed parallel to the open pit phase tunnels in order to add the capacity required to protect the underground workings. These tunnels will be designed for a 1,000-year storm peak flow. Excess flows at the MDT will be directed to the WSF (Appendix 4-C and 4-J).
- The McTagg Twinned Diversion Tunnels (MTDT) are designed for a 200-year, 24-hour flood. Excess flows at the MTDT will enter the North McTagg Diversion Channel to the WSF (Appendix 4-J).
- Diversion channels throughout the site, including those that direct runoff away from the RSFs and the TMF, are designed for a 200-year, 24-hour average daily flood flow. Upon closure, the diversion channels maintained on the McTagg and Mitchell RSF surfaces during operation will be upgraded to closure channels capable of conveying the predicted maximum flood. Upon decommissioning of the mine, the RSFs will be contoured such that lined surface closure channels are present to route clean water flows around the

RSFs, in the event of failure of the diversion tunnels or to handle extreme flood events (Appendices 4-J and 4-AC).

- The WSF is designed to surpass the Canadian Dam Safety Guidelines (which call for an inflow design flood (IDF) of 2/3 between the 1:1,000 year flood and probable maximum flood (PMF;CDA 2007)), with the WSF spillway designed to pass the PMF; store seasonal freshet flows as well as a 200-year, wet year flood without discharge; and, the WSD will have over 60 m freeboard available under normal operation, with 10 m available during the 200 wet year event (Appendix 4-J).
- The TMF is designed for the PMF with a 1-m freeboard. The associated seepage collection ponds will be designed to store a 200-year, 24-hour flood with a spillway designed to pass a 500-year, 24-hour flood (Appendix 4-AC).
- Upon closure, a spillway around the Mitchell Pit closure dam will be constructed into the rock on the north side of the valley (Appendix 4-J).

Geohazard events may be triggered by rainstorms and thunderstorms and subsequent increases in surface flows. Facility and infrastructure locations have generally been selected to avoid geohazard areas. Where geohazard areas cannot be avoided, mitigation measures have included engineered designs and management procedures. For more details on specific mitigation measures for the Project relating to rainstorm-induced hazards, refer to Section 34.2.

Mine Site contact water will be treated with a high-density sludge lime Water Treatment Plant (WTP). Water balance calculations indicate that during the various stages of mine life, the treatment plant will operate year-round. During the late fall, winter, and early spring, the WTP will operate at average rates ranging from 0.1 m^3/s to 0.50 m^3/s due to low receiving environment stream flows (Appendix 14-I). The WTP will also have additional capacity in the form of spare clarifiers and reactors provided to treat up to 6.0 m^3/s (open pit phase until Year 26) and 7.5 m^3/s (underground phase after Year 26) to manage flow increases that may occur during the natural high flows of summer coinciding with natural hazards or extreme events (see Appendices 4-R, 4-S, 4-T, 4-U, and 4-V for more information on water treatment). The additional treatment capacity also allows sections of the WTP to be shut down for maintenance when required.

34.1.3.2 Snowstorms

34.1.3.2.1 Effects on the Project

The Project area is subject to substantial snowfall during the extended winter period, with much of the annual precipitation falling as snow between October and mid-April. Consequently, severe winter snowstorms are probable. Typical snowpack within the Project area ranges from 1 to 2 m, although high winds may create snowdrifts up to 10 m. High levels of snowfall could impede the movement of mobile equipment on the access roads, at the Mine Site, and at the Treaty Process Plant. Related problems could include reduced traction and visibility during snowstorms. Poor visibility could also become dangerous during a blizzard or fog. Reduced production can be expected when visibility is severely restricted.

Increased loads from snow accumulation on buildings and other infrastructure may cause structural damage. Snowstorms also have the potential to contribute rapidly to the snowpack in the landscape. Increased snow loading on the steep valley walls increases the likelihood of an avalanche occurring. Further details on the potential effects and mitigation measures associated with snow avalanches are presented in Section 34.3.2.

34.1.3.2.2 Mitigation Measures

Removal of excess snow from roadways, blast areas, and the active areas of waste and ore stockpiles will be managed and scheduled to maintain safe working conditions while minimizing interferences with production. Crushed aggregate will be available for distribution on the roads. Strategically located stockpiles of crushed rock will be established near mining and dumping areas so that the scrapers used to spread the rock will not need to "deadhead" between loads. The mine production fleet will include extra equipment—such as graders, loaders, trucks, and scrapers—to manage snow and to maintain production levels.

The diversion channels are designed to be wide enough for the purpose of channel maintenance, including debris and snow clearing.

Storm-related visibility issues at the Mine Site will be addressed with supplementary road lighting and global positioning systems in mobile equipment and communications protocols. Operating protocols will ensure safe and efficient traffic flow during periods of reduced visibility.

A strategically placed run-of-mine ore stockpile will allow for an uninterrupted, safe supply of mill feed during the most severe storms and could be used to supplement feed during more moderate storm conditions. This will help maintain operation at the Mitchell Ore Preparation Complex (OPC) and Treaty Process Plant at a constant normal rate in the event of a storm delaying the mining of ore within the pits.

All buildings and infrastructure are designed for predicted snow and hoarfrost loads. In addition, power cables are designed to be suspended above the snowpack on pole stands.

34.1.4 Drought (Low Precipitation)

The Unuk River–Eskay Creek regional meteorological station has precipitation data recorded from 1989 to 2007. This station is the closest regional station to the Project area, and is located approximately 19 km north of the Mine Site at an elevation of 887 m. The driest year recorded at this station occurred in 1995, with a total annual precipitation of 1,182 mm.

Effects on the Project

The Project area typically experiences high annual precipitation levels; the mean annual precipitation in the Project region is in excess of 1,000 mm, with distinct differences between the western (more coastal influenced) Mine Site and the eastern (more interior influenced) PTMA. The low precipitation estimates range from 1,614 mm and 1,083 mm per year in the Mine Site and PTMA, respectively. A significant reduction in the accumulated annual precipitation would reduce the runoff reporting to the TMF, the RSFs, the WSF, and the open pits, thus reducing the amount of water potentially requiring treatment. However, under drought conditions, the dilution capacity of the receiving environment would also be reduced. In the Mine Site, the substantial amount of glaciers would help to maintain freshwater flows in the receiving environment during extreme hot or dry periods through the summer months. Due to the much smaller amount of glacierized area in the watersheds around the TMF, augmentation of summer flows during periods with low precipitation would not be as significant.

The mini hydroelectric plants proposed for Sulphurets Creek, the MDT, and the MTD T, will be supplied by non-contact water diverted around the mining operation. These hydroelectric plants will rely on meltwater from nearby glaciers and ice fields during periods of low precipitation.

Prolonged periods of low precipitation would increase the risk of wildfires in the area (wildfires are discussed in Section 34.4).

Mitigation Measures

Mine Site contact water will be treated with a high-density sludge lime WTP. Water balance calculations indicate that during the various stages of mine life, the WTP will operate year-round. During the late fall, winter, and early spring, the WTP will operate at average rates ranging from 0.1 to 0.25 m^3/s due to low receiving environment stream flows. The WTP has been designed for significant variations in flow, including during drought conditions, to meet stringent selenium receiving water criteria in the streams. Water balance calculations indicate that the TMF North and South cells will have average surpluses of water of 0.14 to 0.20 m^3/s during their operating periods. During the five-year transition period between the North and South cells, the total excess flow from the flotation cells is projected to be up to twice this amount, as both the North and South cells will be active while the North Cell is being closed. During the life of the mine, excess water from the carbon-in-leach (CIL) Lined Pond varies from 0.23 m^3/s to 0.10 m^3/s. Management of surplus water during operation will use a combination of storage and discharge to Treaty Creek during freshet if water quality meets standards.

The decreased capacity of the receiving environment to dilute the mine discharge waters during a drought may be compensated to a degree by the decreased discharge volumes that would have to be pumped out of the tailing pond to the receiving environment due in part to a reduction in the volume of non-diverted runoff. The tailing impoundment will have capacity to provide 12 months of tailing storage, as well as the PMF of 51 Mm^3 with 1 m of freeboard, so pumping could be deferred until sufficient natural flows were available to accommodate the discharge.

In the case of an extreme drought and subsequent drying of the surrounding ecosystems, the risk of wildfires is increased. Mitigation measures for wildfires are described in Section 34.4.

34.1.5 Normal Precipitation

Effects on the Project

Precipitation levels within the normal range (approximately 1,250 and 724 mm for the Mine Site and PTMA, respectively) will have no effect on the Project since infrastructure has been designed to accommodate extreme events. Under normal precipitation levels, water management infrastructure would be over-designed, and the associated maintenance costs would be kept low.

Mitigation Measures

Because the Project has been designed for extreme precipitation events, the mitigation measures for the extreme events sufficiently cover those required under normal precipitation levels.

34.1.6 Extreme Temperatures and Freeze-Thaw Cycles

The Unuk River–Eskay Creek regional meteorological station has a temperature data set extending from 1989 to 2007. The extreme maximum temperature recorded at this station was 30ºC in August 1990. Meteorological stations installed specifically for the KSM Project have temperature data from September 2007. A maximum hourly temperature of 30ºC was recorded by the Sulphurets Creek station in July 2009. Between 1989 and 2007 at the Unuk River–Eskay Creek regional meteorological station, an extreme minimum temperature of -30ºC has been recorded on several occasions.

Effects on the Project

Extreme high temperatures may affect workers' health, which may include heat exhaustion, dehydration, and heat stroke. Workers can become distracted and more prone to accidents under extreme high temperatures. Additionally, equipment and machinery is more likely to malfunction during extreme high temperatures, increasing the risk of accidents and malfunctions.

Increased air conditioning requirements on site would result from extreme high temperatures. Subsequently, power demand would also increase.

Extended periods of high temperatures could induce heat waves and possibly trigger a wetter climate, which could in turn induce flooding. With warmer temperatures more precipitation would fall as rain than as snow, and earlier melting of the snowpack would cause proportional increases in runoff during the winter and early spring, and increased volumes of glacial meltwater would be experienced year-round. Higher precipitation and runoff levels could also potentially increase the frequency of landslides and channel debris flows. Costs of maintaining the diversion channels and access roads could subsequently increase. Conversely, high extreme temperatures coinciding with dry periods could increase the likelihood of wildfires occurring in the area (discussed in Section 34.4).

Extreme low temperatures could also have impacts on workers' health, which may include frostbite and hypothermia. Without immediate medical treatment, the effects of such conditions could be fatal. Workers can become distracted and more prone to accidents under extreme low temperatures. Additionally, equipment and machinery is more likely to malfunction or become damaged during extreme low temperatures, increasing the potential for worker-related accidents.

Increased heating requirements on site would result from extreme low temperatures. Subsequently, power demand could also potentially increase.

Extended cold spells could result in an extended winter, increased snowfall, and potential ice jams on rivers. As a result, access roads, haul roads, and diversion channels would require more frequent clearing, and bridge structures may be at risk from ice. Extreme low temperatures could also increase the risk of pipelines freezing and frost heave forming on pit walls and road cuts.

Extended cold spells could also cause later melting of the winter snowpack, delaying spring runoff and potentially reducing the time period available to pump tailing pond water to the receiving environment to meet water-quality criteria.

Freeze-thaw cycles are a well-recognized causal factor of cracked pavements and road surfaces. Northern BC experiences few freeze-thaw cycles due to the harsh winters; the subgrade of pavement structures remains frozen well into spring and therefore remains intact and strong. Climate change, however, is predicted to induce milder winters in this region (Walker and Sydneysmith 2008), which would in turn likely produce more freeze-thaw cycles. This would accelerate road deterioration and would increase maintenance costs. More frequent freeze-thaw cycling also has the potential to compromise the strength of other site infrastructure, including building foundations, pit walls, dam walls, and tunnels.

34.1.6.1.1 Mitigation Measures

Health and safety policies will be implemented, and risk assessments will be undertaken before working in adverse conditions. Staff will be educated through formal training programs to ensure they understand the risks of working under extreme high and low temperatures, and to ensure they have a good knowledge of the related procedures. Daily Job Safety Analysis will be conducted.

Suitable equipment and design systems will be purchased for the Project to enable operation under both extreme high and low temperatures. Equipment will be maintained to ensure proper operation.

Personnel will be required to wear appropriate personal protective equipment, including cold weather gear, while working outside. Personnel movement throughout the Project area will be monitored and tracked at all times, and radio communication will be maintained with anyone working in remote areas.

Access road stream crossings are designed for a 100-year flood with an additional 1.5-m freeboard for debris flow, which will provide sufficient clearance to accommodate ice jams.

Mitigation measures for freeze-thaw cycles are included in those for extreme cold weather above (e.g., relating to staff safety and training, equipment designed to operate under extreme high or low temperatures), but may also include more frequent road maintenance activities. .

Mitigation measures for floods are discussed in Section 34.2. Mitigation measures for increased precipitation are discussed in Section 34.1.1, and mitigation measures for wildfires are discussed in Section 34.4.

34.1.7 Changes in Permafrost

Studies conducted to date at the Project site have not identified permafrost as a concern at any of the areas where infrastructure is proposed (BGC 2011; Appendix 34-A).

34.1.8 Climate Change

Climate and weather are intrinsically related. Weather describes spatially and temporally variable meteorological phenomena that can be measured, such as temperature, precipitation, snowfall, and humidity. Appendix 7-B presents the baseline meteorological conditions measured for the

Project. Climate represents the average of weather over time, which is governed by large-scale drivers such as incoming solar radiation and atmospheric composition. Chapter 6 discusses the background science behind climate, and how greenhouse gas (GHG) emissions affect climate change, and focuses on assessing and mitigating Project GHG emissions.

Climate change is defined as the difference in climate over a period of time with respect to a baseline or reference period that is typically three decades long (i.e., 1961 to 1990), corresponding to a statistically significant trend of mean climate or its variability, persistent over a long period of time that is typically decades or more (CCCSN 2012b). Although many jurisdictions and industries have begun reducing GHG emissions to the atmosphere, the GHGs already accumulating in the atmosphere since the beginning of the industrial revolution are likely to continue to be a driver of climate change in the form of global warming in the coming decades (BC MWLAP 2003). Since the Project's timeframe is over 60 years long, climate change may affect the Project, warranting a more in depth treatment of potential climate change risks for the Project than for shorter projects.

34.1.8.1 Concerns Regarding Climate Change Risk to the Project

Nisga'a Nation, Tahltan Nation, Gitanyow Hereditary Chiefs Office (GHCO), and government regulators of the Project have expressed concerns related to how climate change adaptation provisions will be handled for the Project relating to changes to surface water flows and risks to infrastructure such as TMF dam stability. Concerns on the ecosystem and the valley were raised by the Tahltan, concerns pertaining to potential increases in raised river volume and speed that may affect the Project were raised by Nisga'a, and concerns on how potential adverse effects of climate change may affect the long-term stability of the TMF were raised by GHCO (Chapter 29, Nisga'a Nation Interests; Chapter 30, First Nations Interests).

34.1.8.2 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). Therefore, there is currently no specific legislation applicable to adapting Project components to climate change risk. Infrastructure design for water structures in BC, such as dams, is already 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.

The regulatory gap on addressing climate change risk means that the Proponent must work under a voluntary context to address potential climate vulnerability and risk to the Project. For guidance on this assessment, *Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners* (The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment 2003), has been used as a best practice reference to assess and make recommendations on managing potential adverse effects that climate change may have on the Project. Per the guidance document, this assessment will focus on areas where there may be elevated environmental/public risk arising from potential climate change effects on the Project. Private risk, such as risk to Project components that are likely to only affect the Proponent (i.e., economic loss) is not applicable to this assessment (The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment 2003).

34.1.8.3 Scope of Climate Change

34.1.8.3.1 Past Climate Change in the Project Region

Global observations suggest a number of trends during the twentieth century that indicate climate change, including increased average surface temperature, precipitation, frequency of heavy precipitation events, and cloud cover, together with reductions in the length of the freeze season, the frequency of extreme low temperatures, and the extent of snow cover and mountain glaciers (IPCC 2007). Regions in the higher latitudes of the northern hemisphere have exhibited some of the clearest evidence of climate change over the past century. Indicators of Climate Change for British Columbia (BC MWLAP 2002) notes the following climatic properties that have changed during the twentieth century for the region of BC that includes the KSM Project site based on analysis of historical data:

- average annual temperature has increased by 0.6ºC (coast) to 1.7ºC (northern BC);
- average annual precipitation has increased by 2% per decade in the Central Interior, Coast, and Mountains ecoprovinces (based on 70 years of data). The Intergovernmental Panel on Climate Change concluded that northwestern Canada experienced a gradual increase in annual precipitation of more than 20% from 1901 to 1995, about 2% per decade; and
- snow pack depth decreased by about 6% per decade in February in the Coast and Mountains ecoprovince (based on 51 to 66 years of data).

34.1.8.3.2 Climate Change Projections for Project Region

While it is reasonably sure that climate change has affected and will continue to affect the area of the Project, due to climatic variability, uncertainty remains as to exactly what the future climate change effects on the Project will be. Global climate models (GCMs) are a commonly used tool to project general future climate. GCMs simulate plausible scenarios of future GHG emissions based on physical models of climate that include atmospheric, ocean, ice, and land-surface components. Looking at the projections of several different models can help to address the uncertainty associated with any individual model.

An assessment of future projections for climate was conducted by Natural Resources Canada (Walker and Sydneysmith 2008). Applying large GCM grids to BC, three large-scenario regions (northern, southern, and coastal) were selected. The KSM Project is within a transitional climatic zone between the coastal region and the interior in the northern part of BC; therefore, the GCM results for the northern and coastal scenario regions are both applicable to the Project area. Scenarios displayed changes from an observed 1961 to 1990 mean climate to the 2020s, 2050s, and 2080s for temperature and precipitation. This GCM model predicts that the KSM Project can expect warmer annual mean temperatures and increased annual precipitation, as well as increased frequency of extreme weather events. These predictions may result in smaller glaciers, declining snowpack, and shifts in seasonal timing and amount of precipitation and runoff. These predictions are in line with those indicated for the various areas (such as Dease Lake) in the northern area of BC in Environment Canada's Climate Change Scenarios Network climate visualizer (CCCSN 2012c). As a result, the Project area may experience a variety of effects that may be beneficial (such as reducing the number of annual freeze-thaw days over time) or adverse to the Project (such as more frequent and severe events such as wildfires, avalanches, storms, and floods). Of particular import to the Project, shifts in precipitation regimes and decreased snow and glacial melt may also lead to hydrological shifts in the area.

To focus on climate change projections to the Project area, bioclimate profile models of several climatic parameters from the Climate Change Scenarios Network were analysed, the results of which are reported in Table 34.1-1. These climate change parameters represent the Regional CRCM4.2.3 (Run 1) SR-A2 and CSIROMk3.0 (Run 1) SR-A2 models that were run based on data from Dease Lake (northeast of the Project) and Prince Rupert (southwest of the Project). Dease Lake, being further inland and more northerly, typically experiences less rain than coastal Prince Rupert. The moderating effect of the Pacific Ocean also produces more temperate temperatures for Prince Rupert compared to Dease Lake. Projections of climate change variables for the Project are likely to fall between those of these two stations due to the Project's physiographic positioning between the two areas.

As shown in Table 34.1-1, average and extreme annual temperatures are projected to increase in both Prince Rupert and Dease Lake compared to measured baselines at both stations. This rise is also anticipated to occur in the general area of the Project, which is between the two stations for which the models were run. Related to this temperature change, the number of freeze-free days is projected to increase, and the number of freeze-thaw days to decrease progressively over the three climate change scenarios. The reduction of the number of days where temperatures drop below zero is may be a beneficial change for the Project, as it will reduce wear on equipment and will likely improve safety conditions in the absence of ice. The models also predict progressive increases in the frequency of precipitation (number of rain days), and in accumulated annual precipitation as well as decreases in the number of snow days across the scenarios, likely maintaining annual net water surpluses over the summer deficit and winter surplus.

Due to the importance of water balance to the Project, a hydrological climate change model (CCMA CGCM3) was run out of the University of British Columbia for the area of the KSM Project, as reported in Appendix 13-B. This model found that increases in discharge and runoff are predicted to occur in all modelled catchments and for all emissions scenarios simulated (with a one-year exception), with increasing importance of winter melt events toward the end of the century, especially for one of the emissions scenarios. It should be noted that the CGCM3 model tends to produce wet and warm climates relative to the two other assessed GCMs, so while this hydrological model for the Project can give an indication of future conditions based on inputs of changes to physical parameters, there is still uncertainty in model outcomes.

34.1.8.4 Mitigation Options Regarding Climate Change Uncertainty

Climate change adaptation measures are a challenge to devise at the project level as, though there is good confidence in climate change projections at the global scale (Parry et al. 2007), there is a higher degree of uncertainty in regional climate change models (Babite Group 2002; BCWWA 2012). This has led to differences in opinion on how to approach the issue of addressing potential project-level climate change risks.

Table 34.1-1. Climate Parameter Projections for Dease Lake, BC, and Prince Rupert, BC

Climatic Parameter		Dease Lake (58.43N 130.01W)				Prince Rupert (54.29N 130.44W)			
		Baseline Reference (1961-1990)	**First Projection (2011-2040)**	**Second Projection (2041-2070)**	**Third Projection (2071-2100)**	**Baseline Reference (1961-1990)**	**First Projection (2011-2040)**	**Second Projection (2041-2070)**	**Third Projection (2071-2100)**
Temperature Profile* (°C)	Winter mean	-15.5	-12.1	-11.4	-9.1	1.6	4.1	4.8	6.7
	Summer mean	11.4	12.7	13.7	14.9	12.3	13.6	14.3	15.4
	Ann. extreme max	35.3	35.8	36.8	37.3	28.7	29.7	30.2	31.5
	Ann. extreme min	-48.3	-44.1	-43.3	-41.2	-24.4	-21.5	-20.6	-17.6
Temperature Profile** (°C)	Winter mean	-15.5	-14.5	-13.3	-11.8	1.6	2.5	3.2	4.2
	Summer mean	11.4	13.0	13.6	15.0	12.3	13.8	14.3	15.7
	Ann. extreme max	35.3	36.2	37.3	38.7	28.7	30.3	31.1	32.3
	Ann. extreme min	-48.3	-46.9	-45.3	-44.4	-24.4	-23.8	-23.0	-22.0
Daily Frost*	Freeze-free days	119	161	182	204	257	308	317	328
Freeze-Thaw*	Ann. days	125	108.4	92.2	82.4	76	35.9	27.0	17.6
Frequency of Precipitation*	Ttl ann. rain days	81	107	108	119	223	235	235	237
	Ttl ann. snow days	84	65	59	53	28	9	8	4
Frequency of Precipitation**	Ttl ann. rain days	81	98	102	108	223	234	234	234
	Ttl ann. snow days	84	68	64	58	28	19	13	10
Accumulated Precipitation* (Ext from graph)	Max extreme (mm)	1,000	1,200	1,250	1,400	2,400+***	2,400+	2,400+	2,400+
	Min extreme (mm)	100	110	125	150	725	795	810	900
Accumulated Precipitation** (Ext from graph)	Max extreme (mm)	1,000	1,100	1,125	1,150	2,400+***	2,400+	2,400+	2,400+
	Min extreme (mm)	100	105	110	120	725	790	795	815
Water Balance Profile*	Ann. surplus (mm)	168	145	144	163	1,992	2,205	2307	2,436
	Ann. deficit (mm)	107	102	103	96	9	8	9	9

***GCM CRCM4.23 – SR-A2 Model; **GCM CSIROMk3.0 – SR-A2 Model; ***Max extreme precipitation data missing so assumed higher than 2,400 mm for every graph;**
Ann=annual, Ttl=total, Ext=extrapolated
Source: CCCSN (2012a).

34.1.8.4.1 The Adaptive Management Approach

Many engineers and planners feel that, given the levels of uncertainty in regional climate change projections, the current regulations and safety provisions adequately cover scenarios projected from climate change models within their current scope, and that the extra expenditures on infrastructure to provide additional assurance against potential climate change risks are not warranted (BCWWA 2012). To support this position, under current CDA regulations (2007), dams are subject to regular inspections and updates whereby changes to regulations based on progressively improving knowledge of climate change parameters can be iteratively incorporated into Project infrastructure upgrades, providing a degree of adaptive management for the Project.

34.1.8.4.2 The Pro-active Approach

This approach to addressing climate change in infrastructure design is taken by several scientific and professional organizations. For example, Engineers Canada and partners have formed a Public Infrastructure Engineering Vulnerability Committee that has stated that Canada's climate is known to be changing; that this may expose infrastructure to conditions that it was not originally designed to withstand, resulting in potential loss and disruption; and that engineers have a responsibility to "prevent and/or minimize such disruptions and reduce risks by designing, building and maintaining resilient infrastructure that can adapt to the impacts of a changing climate" (Engineers Canada 2007).

In line with this approach, there is currently work being done to update guidelines and best practices manuals on how to incorporate climate change provisions into water management infrastructure. For instance, the Association of Professional Engineers and Geoscientists of BC has established a climate change task force that has recently passed several resolutions including one referring to the "Professional Practice Committee for further consideration making climate change adaptation and/or mitigation a possible addition to practice guidelines" (BCWWA 2012). It is anticipated that recommendations from this kind of work could also be iteratively incorporated into dam upgrades throughout the life of the Project.

34.1.8.5 The Proponent's Management Approach to Mitigating Climate Change Risk

Given the regulatory gaps and debate within the field of engineering on the topic of addressing climate change risk, the Proponent has been left to choose a management position. Acknowledging that climate change poses potential risks to the Project and that uncertainty remains in the strength and magnitude of those risks, indicates that a combined approach is preferable for the Project.

In order to mitigate climate change risk, it must first be assessed for Project components. Toward this end, the sensitivities of several main Project components to potential changes in climatic conditions has been assessed (Table 34.1-2), as recommended by the applicable guidance recommendations (The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment 2003). Once Project component sensitivity is determined, a management approach will be applied as described below.

For Project components that could result in potential effects to surrounding environments/health and safety as a result of climate change (rated as medium to high sensitivity to climate change impacts in Table 34.1-2), a proactive approach will be taken, including ensuring that sensitive Project components incorporate reasonable design measures that address projected changes to climatic conditions. The flexibility of the Project component to be upgraded to adapt to climate change over the life of the Project will also be considered with this approach.

An adaptive management approach will be applied to Project components rated as having low to negligible sensitivity to potential climate change impacts indicated in Table 34.1-2 (i.e., camps and energy infrastructure). This approach is deemed reasonable as most Project components are flexible in that, as new knowledge of climate risks and/or adaptation legislation is developed over the Project life, components can be iteratively upgraded in response, allowing for efficient and informed management over the life of the Project.

The following sections will first assess the climate change sensitivity of Project components. For those components found to be medium to high sensitivity, further detail on the mitigations provided to address the risks posed by climate change impacts will be provided. For components found to be negligible to low sensitivity, it is assumed that no mitigation will be necessary or that adaptive management can be applied to these components over the life of the Project as required.

34.1.8.5.1 Project Component Climate Change Sensitivity

As shown in Table 34.1-1, the effects of climate change to the Project are expected to increase with time, corresponding to climate model projections for different GHG emission scenarios. The construction phase (5 years) and the first part of the operation phase of the Project is therefore anticipated to be at a lesser risk from climate change than the latter years. Project components have been conceptually ranked based on their sensitivity to mean potential climate change parameters in Table 31.4-2. The sensitivity ranking methodology combines a few factors: (1) the likelihood of a *change from the norm* in the interaction between the Project component and the climate change parameter, (2) the risk level to the Project component itself of an adverse effect from that change in interaction, and (3) the consequent risk level to the environment/health and safety.

If a Project component in Table 31.4-2 is not likely to interact with a given climatic parameter, it is assessed as n/a (not applicable). If a Project component may interact with a climatic parameter, but is not likely to be adversely affected (i.e., the component is resilient to that parameter either inherently in design or through management practices), the sensitivity is ranked as negligible. The more interaction with a given climate change parameter in the table a Project component faces—and level of environmental hazard the Project may pose to external systems as a result—the higher the sensitivity ranking, as detailed in the table legend. The rationale for the sensitivity rankings of the Project components in Table 34.1-2 are provided below.

Mean Temperature

Project components are already designed to withstand a wide range of temperatures that includes the temperature ranges projected for different climate change scenarios (Table 34.1-1), so direct effects from changes in temperature ranges over the Project life are anticipated to be negligible and will not be assessed further in the context of climate change. There may also be some benefits to the Project from overall increases in temperature such as the number of yearly freeze-free days increasing.

Table 34.1-2. Project Component Sensitivities Arising from Potential Interaction with Changes to Climate Parameters

Parameters Potentially Affected by Climate Change	Water Storage Infrastructure (WSF & TMF dams)	Linear Infrastructure (roads, diversion structures, MTT)	Large Structures (open pit and underground mines, RSFs)	Energy Infrastructure (power lines, hydro stations)	Camps (structures, personnel)
Mean temperature	Negligible	Negligible	Negligible	Negligible	Negligible
Mean precipitation	Low	Low	Low	Low	Low
Mean snowfall	Low	Low	Low	Low	Low
Extreme events	High	Medium	Medium	Negligible	Low
Mean glacial melt	Low	Low	Low	Low	Negligible
Glacier jökulhlaup*	n/a	Low	Low	n/a	n/a
Geohazard risk	Low	Low	Low	Low	Low
Sea level rise	n/a	n/a	n/a	n/a	n/a
Wind velocity	n/a	n/a	n/a	Low	Negligible
Wildfire	n/a	Negligible	n/a	Low	Low

WSF=Water Storage Facility; TMF=Tailing Management Facility; MTT=Mitchell-Treaty Twinned Tunnels; RSF=Rock Storage Facilities; Jökulhlaup=glacial outwash flood event

Notes:
Sensitivity ranking description:
n/a: no notable interaction between climate change parameter and Project component
Negligible: very low likelihood of change in interaction, risk of effects to Project and consequent effects to environment/health and safety
Low sensitivity: minor likelihood of change in interaction, risk of effects to Project and consequent effects to environment/health and safety
Medium sensitivity: medium likelihood of change in interaction, risk of effects to Project or consequent effects to environment/health and safety
High sensitivity: significant likelihood of change in interaction, risk of effects to Project and consequent effects to environment/health and safety

Mean Precipitation and Mean Snowfall

Runoff is projected to increase over the life of the Project (Table 34.1-1). This increase may translate to changes in seasonal water balance for the Project which may need to be incorporated iteratively into Project water management plans and infrastructure; however, the water containment and diversion structures for the Project are designed to contain the 1:100- to 1:1,000-year storm events (Section 34.2 on floods), and so should be able to safely manage the small changes in regular seasonal runoff flows anticipated over the life of the Project.

Project components also are either designed to handle snow, or have management plans in place for handling snow, and though snow is projected to decrease over the life of the Project, the systems in place could also handle increases in snowfall from current ranges. Hence, the sensitivity of all Project components to changes in mean snowfall has been ranked as low and will not be assessed further in the context of climate change.

During mine operation, higher annual precipitation may increase the amount of groundwater seepage and precipitation that flows into mining pits, which would increase pit dewatering costs, but would not pose an increase in adverse effects to the environment. Increased precipitation and groundwater seepage has the potential to reduce pit wall stability, but the pit monitoring and mitigation systems to address pit instability are anticipated to be able to accommodate any changes in this risk. Upon closure, the pits would fill up faster because of the warmer and wetter climate, which would have no negative consequences on the environment or the public, and may have the beneficial effect of submerging pit walls to subaqueous conditions, minimizing the production of acid rock drainage and formation of contact water.

Extreme Events

Extreme events, such as storms, may rise in frequency and duration due to increases in instability in oceanic and atmospheric circulation arising from stronger temperature differentials projected with climate change (BC MWLAP 2003). Storm tracks may also change depending on oceanic circulation, but there is uncertainty in how this may affect the area of the Project.

In Table 34.1-2, dam sensitivity is rated as high for extreme events (primarily for WSF and less so for the TMF) due to the combination of the potential for effect on the Project if the intensity and duration of extreme events goes up because of climate change (described previously in the UBC hydrological climate model and in Table 34.1-1), combined with the potential hazard posed to the environment by the Project in the unlikely event of consequent dam failure. Similarly, linear infrastructure (e.g., roads, diversion structures, and MTT) and large structures (e.g., open pits and underground mines) may be affected by extreme events as a result of climate change, but their sensitivity has been ranked as medium due to lower potential downstream effects.

Glaciers

Glaciers will potentially interact with Project components directly, as described in Section 34.3.3, through glacial melt effects on runoff and related water balance, and through potential glacier jökulhlaup events (glacial lake outburst flood events). There is also the chance that if climate change continues the current trend of glaciers diminishing and receding, the risks from glaciers may decrease over the Project life.

The risk of glacier outburst events has been assessed as part of the geohazard risk assessments for the Project as discussed in Section 34.3.3. It is anticipated that the mitigation plans in place to monitor and manage glacial risks will continue throughout the Project life, such that risks and required mitigation are not likely to greatly differ from those currently existing for the Project. In addition, a reduction in glaciers may affect runoff and seasonal water balance, which may affect the capacity of planned mini hydroelectric stations for the Project, but the potential effects on the environment from these risks are low. Therefore, potential risks from glaciers will not be discussed further in the context of climate change.

Geohazard Risk

Geohazards have been assessed for the Project, and are discussed in Sections 34.3.1 and 34.3.2. The projected increases in precipitation and runoff in the Project region may lead to secondary effects of increased risks of geohazards (BC MWLAP 2003). Geohazard risks and areas have been assessed in detail for the Project, and provisions have been made to mitigate those risks. Though the chances of a particular geohazard happening in a given area may go up with changes to precipitation regimes, since there are already monitoring and mitigation systems in place for the known geohazards, the change in the level of this risk to the Project is considered low, and will not be assessed further.

Wind Velocity

The speed and direction of winds can be affected by climate change, but there is uncertainty as to what these changes would be in the area of the Project. Changes in wind may affect power lines or workers in camps, but these effects are not anticipated to be high compared to current risks from wind in the area that infrastructure is already designed to handle.

Wildfire

The risks of wildfire to the Project are assessed in Section 34.4. The risks of wildfires in the region of the Project may be increased by climate change. However, as many Project components are resilient to wildfires, effects to the Project from wildfires are not likely to have secondary environmental effects, and it is anticipated that the mitigation measures in place to ensure safety of personnel will also address any increased risks of wildfires from climate change. Hence, wildfires will not be assessed further in the context of climate change.

34.1.8.5.2 Climate Change Project Component Mitigations

As discussed in the previous section and as illustrated in Table 34.1-2, the following three areas are identified as having medium to high sensitivity to changes in extreme events brought about by climate change: water storage infrastructure (high), linear infrastructure (medium), and large structures (medium). The management approach of the Project to address the climate change risk associated with these components—given the uncertainty also present in climate change projections—combines providing both high assurance in design features and adaptive management.

High Assurance in Design Features

Water management systems (including dams and diversion structures) are likely to be sufficient to handle changes in mean flow conditions as a result of climate change because infrastructure already incorporates provisions for extreme events and geohazard risks such as avalanche flood waves. Of greater concern is the impact of climate change altering the range in variability of extreme events (Walker and Sydneysmith 2008), but there is currently no reliable method to estimate the change in the frequency or magnitude of extreme events that will be associated with climate change. In the face of this uncertainty, having systems that are overdesigned for current conditions for sensitive infrastructure can help to reasonably address potential future increases in flood risks from climate change. The British Columbia Dam Safety Regulation (BC Reg. 44/2000), overseen by the British Columbia Ministry of Forests, Lands and Natural Resource Operations, is responsible for the regulation of dams in BC, overseeing that the construction, operation and maintenance of dams is done to enhance safety and to minimize a wide variety of risks such as flooding. For example, in terms of their capacity to handle flood and wave surcharge, the safety of embankment dams can be evaluated by the adequacy of their freeboard above the PMF level (Babite Group 2002). The CDA also provides recommendations for the design, operation, and maintenance of safe and effective dams.

Main Water Storage Infrastructure

Most KSM Project water management structures and operations, including diversion structures and collection and treatment facilities, have been designed to manage a 200-year flood event (Appendices 4-J and 4-AC), which provides a high degree of designed protection to future climatic conditions, which are not likely to go beyond this flow level, particularly within the construction phase and the first part of the operation phase.

The CDA provides what IDF and other safety features dams must have based on projections of hydrological maximum flows based on detailed historic data in a region, as well as the hazard consequence classification of downstream risks posed by the dam. For high hazard flood risk situations, the IDF should be designed to be able to safely contain the PMF, which is what the Project has been conservatively designed to contain.

The WSF is designed to store all the contact water for the Project at the Mine Site, and the 165 m high Water Storage dam (WSD) will be located 1.2 km downstream of the confluence to Mitchell and McTagg creeks (see Appendix 4-J; KCB 2012). Under the 2007 CDA *Canadian Dam Safety Guidelines*, the hazard consequence of the WSF at the Mine Site is rated as “very high”, but due to the length of the Project, this rating has been upgraded to “extreme”, which is the highest rating level. Hence, WSF dam features are designed to the most robust rating level (PMF) under the CDA, which provides a strong degree of assurance against potential climate change, particularly for the first few decades of the Project. At this level, the WSF must be able to handle a PMF that is the greater of a few scenarios of maximum precipitation, runoff, storm, and snow conditions. For the Project, the PMF of the spring probable maximum precipitation, combined with a 100-year snow accumulation melt, resulted in the largest flows, which were conservatively chosen as the IDF (2,653 mm). In addition to the above provisions, 60 m of freeboard will be available under normal operating conditions for the WSD, with 10 m during the 200-year wet year in the fall. This WSF freeboard provision is much higher than that normally required for similar sized dams, and though it has been raised for the Project to account for the case of a potential avalanche wave (Appendix 4-J; KCB 2012), it will also provide strong assurance against hydrological flow changes brought about by climate change.

It is anticipated that if precipitation increases as a result of climate change (by as high as +20% in 100 years by some models), the WSD may also need to be raised (Appendix 4-J; KCB 2012), which could be achieved via regular dam updates as a part of adaptive management.

Water management within the TMF is a key component of the Project and is sensitive to changes in the water balance as a result of climate change. The TMF is proposed to be located in the upper reaches of South Teigen and North Treaty creeks. This valley is free of glaciers and therefore does not receive annual glacier meltwater during the late summer. However, an increase in the length of the ice-free season would allow water from the TMF to be discharged over a longer period of the year. The projected wetter environment from climate change (Table 34.1-1) may increase the challenges of managing surplus water in the TMF. For example, within the receiving environment downstream of the tailing dam, a wetter climate will increase the dilution capability of North Treaty Creek. However, in late summer, predicted decreases in flows (Coulson 1997) may prevent the potential discharge of surplus water from the TMF directly as the dilution capacity of the receiving environment would be reduced. In this case, TMF water would be sent to the WTP for treatment prior to release to the environment to ensure discharge water quality criteria are met.

The PMF the TMF dam is also conservatively designed to hold is based on a 30-day probable maximum precipitation storm combined with a 100-year snowmelt. The north and south dams of the TMF will be raised on an annual basis to provide sufficient storage without discharge for the PMF with a 1-m freeboard (and these freeboard provisions could also be increased over the life of the Project as part of adaptive management). The seepage collection ponds will be designed to store a 200-year, 24-hour flood with a spillway designed to pass a 500-year, 24-hour flood (Section 34.1.3). These provisions are currently considered adequate assurance against the range of changes in extreme events brought about by climate change.

Linear Structures

Linear features of the Project that are rated as medium sensitivity to changes to extreme events are primarily water-diversion structures. For instance, tunnels, channels, and ditches may be affected by changes from the normal range to surface runoff from extreme events associated with climate change drivers, so it is expected that they will only be sensitive to changes in the magnitude and frequency of extreme events and not to annual precipitation or mean temperature.

Diversion tunnels, TMF channels, and all Mine Site surface diversion ditches have been designed to manage freshet flows and to convey a 200-year 24-hour flood flow, which is likely to provide reasonable assurance to handle near term fluctuations in the range of extreme event hydrological conditions. Over time, an increase in the magnitude and frequency of extreme flows may result in the capacities of these water conveyance systems to be exceeded, releasing water to contact areas. As the Project progresses, if it is assessed that existing structures do not provide enough assurance against extreme events, iterative upgrades to both diversion infrastructure and dam features will continue to adaptively safeguard against climate change in the later Project stages.

The likely increase in frequency and magnitude of extreme weather events expected to be associated with climate change could result in lost operational days due to closure of haul roads as a result of severe rainfall-runoff or snowfall events; however, this is not anticipated to pose significant environmental or health and safety risks beyond those already assessed. Potential effects on roads because of climate change will not be assessed further.

All bridge structures required along the access roads at stream crossings will be single-lane and designed with a minimum 1.5-m clearance above a 100-year flood level (Section 34.1.3). This clearance is considered acceptable under current building codes, and since the potential effects of climate change are uncertain on extreme events in the area, this is currently also deemed an acceptable mitigation for potential storm waters. In addition, in the event of a bridge or road washout, risk to downstream systems would be negligible to low, and current mitigation for safe travel of personnel would likely be able to restrict travel, preventing loss or damage, meaning that most of this risk would be private risk borne by the Proponent, rather than public risk.

Large Structures

The sensitivity of large structures of the Project has been ranked as medium primarily due to the sensitivity of underground mines to flood risks. This sensitivity is also related to the capacity of diversion structures to route flood waters away from open pits and underground structures, to prevent flooding.

The proposed diversion tunnels will be designed to convey a 200-year, 24-hour flood flow for their respective catchment areas, which provides a reasonable level of assurance against near-term climate change (Section 34.1.3). In the event that the MDT capacity is exceeded, an emergency spillway channel in Mitchell Pit will convey water around the south side of the pit to the Mitchell RSF. Under upset conditions, the surplus water may be directed into the Mitchell Pit, to be pumped to the WSF over time. This is considered to provide reasonable mitigation against safety risks to workers in underground works, in conjunction with emergency operating procedures to evacuate underground works in the event of potential flooding. In the event that the MDT and MTDT capacity is exceeded, a diversion ditch will direct the water around the toe of the McTagg RSF and discharge it into Mitchell Creek downstream of the WSF.

Summary

The risks of climate change for the first couple of decades of the Project are not anticipated to be much greater than the current risks that have already been incorporated into the conservative design of the main water management infrastructure for the Project. As the Project progresses, adaptive management should be able to address any changes in risk to WSF and TMF dams and other containment infrastructure. Dam features such as freeboard are flexible in that they will be inspected and updated per updated regulations over the Project life and into the post-closure phase. Similarly, the capacity of the WTP may require progressive upgrades to accommodate the extra contact water requiring treatment.

During the life of the Project, local and regional meteorological and hydrological conditions will be monitored. As the effects of climate change on local weather conditions and stream flows become more apparent, there will be opportunities to review infrastructure design criteria and to consider implementing adaptive management techniques, such as revising the TMF dam raise schedule. Management plans will be systematically internally reviewed and will also be subject to any recommendations on climate adaptation measures based on regular third party inspections, continuing into post-closure per the British Columbia Dam Safety Regulation (BC Reg. 44/2000).

34.2 Floods

Floods in northwestern BC are typically produced by three main mechanisms:

- rapid snowmelt, particularly during freshet conditions in late May, June, or July;
- rain falling on melting snow during freshet conditions in June or July, or possibly during early winter in October or November; and
- heavy rainfall during September or October.

In highly glacierized catchments such as those found in the Mine Site, floods can also be caused by rapid glacial melt during periods of high air temperatures in the summer.

The KSM Project regional study area lies within the humid environment of the northern Coast Mountains of BC. Proximity to the coast, high elevation, and substantial glacier coverage (as much as 38% for the Sulphurets Creek catchment and 54% for Mitchell Creek) produce relatively high precipitation and runoff from watersheds in the Project area. There are two distinct watershed groups relevant to the Project, in terms of their geographic location and hydrological characteristics.

The Teigen and Treaty Creek watersheds are sub-watersheds of the Nass and Bell-Irving rivers, and are snowmelt-dominated systems. Winter precipitation mainly falls as snow and remains in storage until spring melt. As a result, these regimes exhibit low flows through winter, and high flows in May, June, and July. These watersheds will drain the northern Project area, which includes the proposed Treaty Process Plant site and the TMF. For these watersheds, flood events are most likely to occur during the spring freshet or fall rainfall periods.

The upper Unuk River and Sulphurets Creek watersheds are sub-watersheds of the Unuk River, and are primarily glacier-augmented systems. These watershed systems differ from snowmelt-dominated systems in that the period of high flows extends from about May to August or September, as glacier melt contributes to increased stream flows once the annual snowpack is depleted. Low-flow conditions occur only when precipitation is accumulating in the snowpack, usually from November to March. The Mine Site area is drained by Sulphurets Creek and its tributaries, and is where the open pits are to be located as well as other supporting infrastructure (e.g., RSFs, WSF, and Mitchell OPC). In this area, flood events are most likely to occur during the summer glacial melt or fall rainfall periods.

Although floods can result in substantial damage and can impede Project operation, large events that would pose the greatest risk to the Project occur only rarely.

Table 34.2-1 provides the probability of occurrence of an event with a given return period during the operation phase, assuming a 51.5-year mine life.

Flood risks to the Project are summarized in Table 34.2-2.

Table 34.2-1. Exceedance Probabilities of Flood Events with Varying Return Periods

Event	Probability for Any Single Year	Probability over 51.5-Year Mine Life[1]
1 in 10 year	0.1	0.997
1 in 20 year	0.05	0.94
1 in 50 year	0.02	0.67
1 in 100 year	0.01	0.43
1 in 200 year	0.005	0.24
1 in 500 year	0.002	0.10

[1] The probability of an event occurring over the 51.5-year mine life is calculated using the hydrology frequency analysis formula: Probability (risk) = $1 - (1 - 1/T)^n$.
Source: Bedient and Huber (2002).

34.3 Geophysical Effects

The KSM Project is located in a rugged area, with elevations ranging from about 220 m at the Sulphurets-Unuk confluence to over 1,900 m at the top of the ridge above the Kerr deposit. Surrounding peaks, such as Unuk Finger, are in the range of 2,200 m in elevation. Glaciers and icefields surround the mineral deposits to the north, south, and east.

Recent and rapid deglaciation has resulted in over-steepened and unstable slopes in many areas. Recently deglaciated areas typically have limited soil development and are dominated by Regosols and Brunisols derived from glacial till and colluvium. Lower elevation areas with mature vegetation are characterized by Brunisols and Podzols. Organic horizon layers are thin to absent.

34.3.1 Landslide Geohazards

Landslide geohazards are abundant in the Project area. This can be attributed to three factors:

- Native geology: The Mine Site is underlain, in part, by weak rocks that can deform when subjected to stress or stress relief. They also tend to weather into a fine-rich matrix that can add mobility to debris flows when materials from these rock types are being eroded by debris flows.
- Glacier cycles: The area was repeatedly glaciated during the Pleistocene and Holocene epochs, which has led to over-steepening valley sides. Glacial scour followed by stress release from ice retreat has destabilized these valley slopes.
- Local climate: The high annual precipitations result in soil saturation, which increases landslide incidence in unconsolidated surficial materials. In addition, freeze-thaw cycles can facilitate fracture of consolidated bedrock.

Several geohazard and risk assessments have been completed for the Project (BGC 2010b, Appendix 9-F; 2012b, Appendix 9-B; 2012e, Appendix 9-G; 2012a, Appendix 9-C; 2012d, Appendix 9-E; 2012c, Appendix 9-A). These reports identify, describe, and assess landslide hazards and potential consequences in the vicinity of proposed infrastructure for the KSM Project. Terrain mapping techniques were used to delineate areas within the Project site with distinct surficial geology, terrain stability, erosion potential, and landslide hazard characteristics. Terrain stability has been classified based primarily on slope steepness, surficial material type, and geomorphological processes. These assessments were based on an interpretation of aerial photographs and helicopter overview flights, and on ground-based fieldwork.

Terrain stability classifications range from Class I (stable) to Class V (unstable). Terrain classified as unstable implies that the area is expected to contain a high likelihood of landslide initiation following disturbance activities such as timber harvesting or road construction. No substantial stability concerns are expected in Class I or Class II terrain, and minor stability problems are expected on moderately stable (Class III) terrain. Marginally stable (Class IV) terrain comprises slopes that are generally steeper than 60% and are often overlain surficial material veneers. The terrain may comprise gullied slopes steeper than 50% (27º) with steeper gully sidewalls. Terrain mapped as unstable (Class V) typically contains debris or rockfall initiation zones or failing ground.

Terrain hazards that have been identified at the KSM Project site include:

- debris flow;
- debris avalanche;
- rockfall;
- slope sagging;
- rock avalanche;
- rock slump; and
- snow avalanche (Section 34.3.2).

The more serious (i.e., moderate to high risk) landslide geohazards are described in Table 34.3-1. Landslide geohazards are also considered in Chapter 9, Geohazards, and Chapter 35, Accidents and Malfunctions.

34.3.2 Snow Avalanches

A combination of terrain and climatic conditions primarily influences the extent of a snow avalanche hazard. Generally, snow avalanches occur in areas where there are steep, open slopes or gullies that are covered with a deep snowpack. The initiation zone of an avalanche typically has an incline slope of greater than 60% (58º). Avalanches will begin to decelerate in the runout zone and stop on slopes less than 30% (17º). The dense-flowing component of an avalanche can reach speeds up to 200 km/h.

Table 34.2-2. Flood Risks Summary Table

Project Component	Area Affected	Risks to Project	Mitigation Measures
Coulter Creek Access Road	Major bridge structures required to cross Coulter Creek, Unuk River, Gingras Creek, and Mitchell Creek.	Worker safety compromised; access road closures; erosion of road surface; bridge washout.	Bridges designed with 1.5-m clearance above a 100-year flood level; culverts designed with 600-mm diameter and spaced at approximately 250-m intervals; rip-rap placed at inlets and outlets to prevent erosion.
Kerr, Sulphurets, and Mitchell pits	Only Mitchell Pit exposed to flood risk from the Mitchell Glacier and moraine-dammed lake east of pit.	Worker safety compromised; delay of mining operation; pit wall instability.	Runoff into Mitchell Pit will be controlled with sump pumps; diversion of runoff from Mitchell Glacier away from the Mitchell Pit via the MDT; Mitchell Pit closure dam has 30 m of freeboard to mitigate against extreme flood events.
MDT	Floods exceed tunnel capacity.	Water escape into Mitchell Pit and Iron Cap Block Cave Mine; worker safety compromised.	The MDT is a twined-tunnel design, with each side having sufficient capacity at start up to carry peak annual freshet flows; during open-pit phase, MDT will have capacity for the 200-year, 24-hour average event; during underground phase, MDT will have an additional set of tunnels constructed and will have total capacity for the 1,000-year instantaneous daily peak event.
MTDT	Floods exceed tunnel capacity.	Water escape into McTagg RSF and WSF.	The MTDT is a twinned-tunnel design, with each side having sufficient capacity at start up to carry peak annual freshet flows; MTDT will have capacity for a 200-year, 24-hour average event.
Mitchell, McTagg, and Sulphurets RSFs	Floods exceed RSF diversion ditch and MTDT capacities.	Exceeded storage capacity may result in discharge of untreated contact water to the downstream receiving environment.	RSF diversion ditches are designed for a 200-year storm event; MTDT has capacity for a 200-year, 24-hour average event; upon closure, the RSF diversion channels will be upgraded to closure channels capable of conveying the PMF. Upon decommissioning of the mine, the RSFs will be contoured such that lined surface closure channels are present to route clean water flows around the RSFs in the event of failure of the diversion tunnels or to handle extreme flood events.
WSF	Floods exceed WSD capacity.	Exceeded storage capacity may result in discharge of untreated contact water to the downstream receiving environment.	The WSD will be designed using industry best standards, specifically the Hydrotechnical Bulletin of the *Canadian Dam Safety Guidelines* (CDA 2007). Accordingly, the WSD will be designed to resist an IDF of two-thirds between the 1:1,000-year return and PMF, and will be designed to store a 200-year, wet year flood without discharge. The WSF seepage dam will be designed according to CDA (2007) standards. This dam will be designed to contain an environmental discharge flood equivalent to 14 days of WSF seepage and catchment runoff assuming failure of WTP system and a 200-year, 24-hour flood with snowmelt (diversions operational). The WSF seepage dam diversions will be designed to handle a 200-year, 24-hour average daily flow. This dam will also be designed to resist an IDF of 500-year, 24-hour flood with diversions failed.
WTP	Floods exceed WSD capacity.	Damage to WTP structure; worker safety compromised.	Placement has been designed to minimize floods; proper maintenance of WSF dams.
Mitchell OPC	Outbreak flood runout hazard from moraine-dammed lake identified in Mitchell Creek Valley.	Damage to OPC structure; worker safety compromised.	Protection berms and/or swales will be constructed if deemed necessary.
Treaty Process Plant Site	Outbreak flood runout hazard from moraine-dammed lake identified to the south of Plant site.	Damage to Treaty Process Plant structure and equipment; worker safety compromised.	Protection berms and/or swales will be constructed if deemed necessary.
Treaty Creek Access Road and Treaty Saddle Access Road	Major bridge structures required to cross the Bell-Irving River and North Treaty Creek. Smaller structures or culverts required to cross multiple low-order streams.	Worker safety compromised; access road closures; erosion of road surface; bridge washout.	Bridges designed with 1.5-m clearance above a 100-year flood level; culverts designed with 600-mm diameter and spaced at approximately 250-m intervals; road section crossing floodplain will be built atop a 1.2-m or greater berm; road closures as required; rip-rap placed at inlets and outlets to prevent erosion.
TMF	Floods exceed diversion infrastructure capacity.	Increased volume of water entering TMF and potentially becoming contaminated.	Surface water-diversion ditches will be constructed to intercept runoff from the surrounding valley slopes and divert the water around the TMF and into South Teigen Creek at the north end of the TMF and into North Treaty Creek south of the TMF. The diversion channels are designed to convey the 200-year peak flows. The TMF cells are designed not to discharge during extreme flood events. Instead, they are designed with sufficient freeboard to store the PMF, resulting from a 30-day probable maximum precipitation combined with a 100-year, 30-day snowmelt (all perimeter diversions inoperable). Tailing dam seepage and surface water runoff from the dam faces will be collected in seepage collection ponds. The seepage collection ponds will be designed to store a 200-year, 24-hour flood (diversions working) with a spillway designed to pass a 500-year, 24-hour flood (diversions failed). Upon closure, the seepage recovery dams will be retained in operation until long-term groundwater quality is confirmed.

Table 34.3-1. Landslide Geohazard Summary Table

Project Component	Area Affected	Risks to Project	Mitigation Measures
Coulter Creek Access Road	Rockfall and bedrock deformation along Eskay Creek Mine road; remaining portion of road is subject to potential rockfall, debris flows, flooding, deep-seated slumping in surficial material, and slope deformations.	Worker safety compromised; vehicle and equipment damage; road blocks; road damage.	Stabilization measures during construction; controlled blasting; measures to protect the road or vehicles, including engineered walls and mesh/nets draped over the rock face.
Mitchell Pit	Snowfield Landslide and sackungen (gravitational slope sagging) exist above pit.	Snowfield Landslide could compromise worker safety, damage tools and equipment, and trigger a rock avalanche from the sackungen area.	Active monitoring of pit walls to provide advance warning of potential slope instability; blast vibration monitoring; closure dam will have 30 m of freeboard to mitigate against potential waves created by geohazards.
Kerr Pit	Kerr Landslide exists directly below pit.	Worker safety compromised.	Active monitoring of pit walls to provide advance warning of potential slope instability.
MDT	Snowfield Landslide located near tunnel inlets could create a large cover of rock debris in area, potentially covering the inlets.	Flooding of Mitchell Pit.	Culvert or similar structure to provide protection from avalanches and rockfall.
MTDT	Tunnel portals and diversion dams subject to multiple debris flows, rockslides, potential failures from slope deformations, and rockfall.	Worker safety compromised; creation of an impoundment lake that may overtop and flood the North portal of the MTDT.	A short head cover may be required for worker safety during construction; culvert or similar structure to provide protection from avalanches and rockfall.
McTagg RSF	Subject to rock toppling, rock avalanches, debris flows, and rock slides.	Worker safety compromised; potential to dam diversion channels.	Active monitoring to provide advanced warning of potential slope stability; controlled blasting in cases where a risk to facilities or workers from falling rock exists.
WSF	WSF seepage dam subject to potential debris flows and flooding.	Damage to WSF seepage dam.	Active monitoring to provide advanced warning of potential slope stability.
MTT	Subject to minor risk of debris flows.	Worker safety compromised; blocked portals.	Culvert or similar structure to provide protection from debris flows.
Treaty Creek Access Road and Tunnel Saddle Access Road	Two moderate risk (unmitigated) landslide geohazards on Treaty Creek and Treaty Saddle access roads; other portions of road subject to minor risk of debris flows and floods, channel avulsions, and rockfall.	Worker safety compromised; vehicle and equipment damage; road blocks; road damage.	Stabilization measures during construction; controlled blasting; measures to protect the road or vehicles including engineered walls and mesh/nets draped over the rock face.
TMF	Moderate debris flow hazards exist in the impoundment, largely on the northeast side, potentially affecting the northeast diversion ditch, Upper East Catchment Diversion intake, Southeast diversion ditch, and Southeast dam.	Worker safety compromised; blockages and spills in diversion channels; overtopping of dams.	No specific mitigation strategies identified for landslide geohazards; mitigation strategies for avalanches will be sufficiently robust as to minimize Project risk from any potential landslide geohazards (described in Table 34.3-3).

Avalanche magnitude relates to the destructive potential of an avalanche, which is a function of its mass, speed, and density, as well as the length and cross section of the avalanche path. It is defined according to the Canadian avalanche size classification system (Table 34.3-2). Risks associated with avalanches are due to exposure to the high impact forces and the potential for extended burial.

Snow avalanche geohazard assessments were completed by Alpine Solutions Avalanche Services (Alpine Solutions Avalanche Services 2012a [Appendix A of Appendix 34-D]; 2012b [Appendix A of Appendix 34-E]). As part of these assessments, avalanche areas and avalanche paths were identified on locator maps. Avalanche chutes are common throughout the area, and management of snow avalanches will be required for the development and operation of the Project.

High and very high snow avalanche geohazard risk scenarios have the potential to affect the vast majority of the Project (BGC 2012b), including:

- Coulter Creek access road;
- Treaty Creek access road (km 0 to km 18);
- Mitchell Pit and diversion infrastructure;
- Kerr Pit;
- TMF diversions, tailing dams, and seepage dams;
- McTagg RSF and North McTagg Diversion Channel inlets and portal;
- Mitchell RSF;
- Mitchell OPC;
- Sulphurets-Mitchell Conveyor Tunnel portal (north); and
- MTT portal.

Risks to the Project from these avalanche geohazard risk scenarios, as well as mitigation measures, are described in Table 34.3-3. These mitigation measures include static structures such as snow sheds and deflection berms, as well as appropriate freeboard in dams so avalanche-induced waves are contained. These measures also include an active avalanche plan (Alpine Solutions Avalanche Services 2011), which describes measures to provide continuous monitoring of avalanche hazard and controlled release of avalanches by a dedicated team of on-site avalanche technicians. Controlled release of avalanches will be provided by explosive control measures, which may initiate from fixed exploders or from charges delivered by helicopters or artillery. Additional avalanche management is provided by snowpack-supporting structures installed at strategic locations in avalanche start zones.

34.3.3 Glaciers

Although the entire Project area is located in glaciated terrain, only the Mitchell Glacier is expected to pose a significant potential hazard to the Project. Effects of glacial meltwater from other Project-area glaciers are included in the analysis of flows and extreme events.

Mitchell Pit will extend into the current footprint of the Mitchell Glacier. Where necessary, ice from Mitchell Glacier will be removed to initiate open pit development.

Table 34.3-2. Canadian Classification System for Avalanche Size

Size	Destructive Potential	Typical Mass	Typical Path Length	Typical Impact Pressures
1	Relatively harmless to people.	<10 tonnes	10 m	1 kPa
2	Could bury, injure, or kill a person.	10^2 tonnes	100 m	10 kPa
3	Could bury a car, destroy a small building, or break a few trees.	10^3 tonnes	1,000 m	100 kPa
4	Could destroy a large truck, several buildings, or a forest with an area up to 4 ha.	10^4 tonnes	2,000 m	500 kPa
5	Largest snow avalanches known. Could destroy a village or a 40-ha forest.	10^5 tonnes	3,000 m	1,000 kPa

Source: McClung and Schaerer (1993).

Mitchell Glacier is a temperate glacier that flows within a V-shaped valley and over a thin sediment bed. The thickness of glacier ice generally thins out toward the glacier terminus, but generally ranges in thickness from 75 m to 130 m at distances of 400 m to 1,800 m from the 2008 glacier terminus. The current front of the glacier has near-vertical walls of ice up to 80 m high. Ice blocks naturally continue to break off, or calve, from the glacier front. At the glacier terminus there is a large ice cave, which is the outlet of a subglacial tunnel through which basal meltwater flows into Mitchell Creek. Sinkhole-like features are also visible on the glacier surface, which suggest that there are other subglacial cavities not currently visible.

Since 1982, Mitchell Glacier has been retreating at an average rate of approximately 31 m/year (see Appendix 13-C for a description of the on-going Glacier Monitoring Study of the Mitchell Glacier). There is no geomorphic evidence that the glacier has experienced a rapid advance (or surge event) at some point in the past. Mass balance studies indicate that the rate at which Mitchell Glacier retreats depends strongly on winter accumulation (i.e., faster retreat rates during dry winters and slower rates for winters with heavy snowfall). Comparison of surface topographic data between 1982 and 2008 indicates that the glacier front has lost a considerable volume of ice at the glacier terminus, as it has retreated and thinned at any given location. For example, at a location approximately 525 m from the 2008 glacier terminus, the elevation of the ice surface dropped by about 100 m and the cross-sectional area was reduced by about two-thirds. Between this location and the 2008 glacier terminus, it has been estimated that approximately 6 Mm^3 of ice has melted away from the glacier front in the 1982 to 2008 period.

Effects on the Project

The following impacts that could affect mine development were identified and assessed by BGC Engineering Inc. (2010a; Appendix 9-A):

- ***Glacier retreat or advance***: Whether a glacier retreats or advances depends strongly on climate. Based on current climate change projections for the region, the observed historical trend of glacier retreat is expected to continue over the next 20 years at similar overall rates (i.e., 31 m/year). However, there will be variability in the rates from one year to the next owing to climate variability, and there may even be some years where the glacier does not retreat and may even advance. Since glacier retreat or advance is governed primarily by climate, excavation of ice from the glacier front is not expected to significantly alter the rate or reverse the direction of glacier flow. Glacier advance or retreat may interfere with Mitchell Pit construction or operation scheduling, change the frequency or risk rating of geohazards, and/or expose or cover infrastructure near Mitchell Pit and Mitchell Glacier.

Table 34.3-3. Avalanche Geohazard Summary Table

Project Component	Area Affected	Risks to Project	Mitigation Measures
Coulter Creek Access Road	In the Sulphurets Creek Valley, a total combined road length of approximately 3 km could be affected by large magnitude snow avalanches occurring more than once per season.	Worker safety compromised; vehicle and equipment damage; road blocks; road damage.	Implementation of an avalanche-control program that would include, as necessary, regularly releasing accumulation of snow before potential hazard develops.
Mitchell Pit	Footprint is surrounded by avalanche terrain, which includes steep avalanche paths extending several hundred metres in size. These avalanche paths are expected to produce Size 3 (at least one time per season) and Size 4 (during exceptional winters). Potential for the pit to create avalanche terrain as it expands.	Worker safety compromised; damage to facilities in the Mitchell Pit; delay mining operation.	Installation of avalanche defense structures and earthworks; implementation of an avalanche-control program; snowcat will be used to transport workers when road access is restricted by snow conditions.
Sulphurets Pit	Specific hazard areas have been identified on the area surrounding the rock slabs and bluffs, as well as the steep start zones on the southeastern edge of the footprint. Due to the elevation and exposure to wind, these slopes are expected to avalanche on an annual basis (Size 2 to Size 3) and will require active avalanche control.	Worker safety compromised; damage to facilities in the Sulphurets Pit; delay mining operation.	Installation of avalanche defense structures and earthworks; implementation of an avalanche-control program; snowcat will be used to transport workers when road access is restricted by snow conditions.
Kerr Pit	The Kerr Pit will be exposed to snow avalanches on an annual basis due to its elevation and orientation to the prevailing wind, which allows deep snowpack to accumulate. Large avalanche starting zones have been identified at the broad down-sloping ridge that exists in the southern and western sections of the footprint.	Worker safety compromised; damage to facilities in the Kerr Pit; delay mining operation.	Installation of avalanche defense structures and earthworks; implementation of an avalanche-control program; snowcat will be used to transport workers when road access is restricted by snow conditions.
Iron Cap Block Cave Mine	The fresh air portal and return air portal locations are exposed to avalanches hazards.	Worker safety compromised; access to underground mine compromised; air supply to underground mine compromised.	Installation of an avalanche shed to cover and protect the main fan infrastructure. Also, an escape way will be installed so that personnel can exit the mine safely, with the additional purpose of providing access to clear snow build-up from the air intakes as necessary.
MDT	North portal inlets will become exposed to avalanche geohazards as Mitchell Glacier retreats.	Blockage of inlet, leading to flooding of Mitchell Pit; worker safety compromised.	Inlets to MDT will be located both underground (beneath the base of the ice) as well as on the surface. Both of these inlets are designed to continue functioning during avalanches.
MTDT	Diversion dams are exposed to large (Size 3 or Size 4) avalanche paths.	Potential overtopping of dam; blockages of MTDT; worker safety compromised.	Structural avalanche defenses and/or active avalanche control.
Mitchell OPC	Area exposed to several Size 3 or Size 4 avalanche paths, which could be triggered simultaneously.	Worker safety compromised; potential destruction of facility.	Comprehensive avalanche reduction strategy; mitigation measures may include avalanche defense structures, earthworks, and an active avalanche-control program.
Mitchell RSF	Most areas of Mitchell RSF are exposed to snow avalanche hazard.	Worker safety compromised.	Implementation of an avalanche-control program.
McTagg RSF	Most areas of McTagg RSF are exposed to snow avalanche hazard, including several large high-frequency avalanche paths that run from ridge top to valley bottom.	Worker safety compromised.	Implementation of an avalanche-control program.
Sulphurets-Mitchell Conveyor Tunnel	Large avalanches (Size 3 or Size 4) will occur on the ridge top above portal and may reach the portal.	Worker safety compromised; disruption of operation; equipment damage.	Installation of avalanche defense structures and earthworks; implementation of an avalanche-control program.
WSF	A snow avalanche path is located above the water storage pond and could be the source of several avalanches each winter that would reach the pond and dam.	May cause overtopping of dam; worker safety compromised.	Installation of avalanche defense structures and earthworks; implementation of an avalanche-control program; relocation of WSF seepage dam if necessary.

(continued)

Table 34.3-3. Avalanche Geohazard Summary Table (completed)

Project Component	Area Affected	Risks to Project	Mitigation Measures
Temporary Frank Mackie Glacier Access Route	Crosses through almost continuous avalanche exposure, as it passes through the eastern side of the Ted Morris Valley.	Worker safety compromised; road delays; equipment damage.	Implementation of an avalanche-control program.
MTT	Areas to the west and east of the south portal will be affected by snow avalanches, and the site may be affected by Size 2 and Size 3 avalanches annually depending on the portal placement on the slope. In addition, the access road to the south portal will be subject to Size 2 to Size 4 avalanches.	Worker safety compromised; tunnel portal blockage; damage to exposed pipelines in portals.	Installation of avalanche defense structures and earthworks; implementation of an avalanche-control program.
Treaty Creek Access Road and Tunnel Saddle road	Much of the roads are exposed to some avalanche risk, but the highest avalanche risks (unmitigated risk of High) occur between km 21 and km 30 of the Treaty Saddle access road and between km 1.3 and km 2.7 of the North Treaty upper road. These road sections are exposed to large (Size 3 or Size 4) avalanches.	Worker safety compromised; vehicle and equipment damage; road blocks; road damage.	Implementation of an avalanche-control program that would include, as necessary, regularly releasing accumulation of snow before potential hazard develops.
TMF	Much of the eastern side of the TMF is exposed to high and very high avalanche hazard, potentially affecting the majority of infrastructure within the TMF.	Worker safety compromised; overtopping of dams; blockages and spills in diversion channels.	Design of infrastructure to minimize exposure to avalanches; TMF designed with 1 m of freeboard above the peak PMF level; implementation of an avalanche-control program.

- ***Surge potential***: Because of the well-defined V-shaped valley in which Mitchell Glacier flows and the relatively steep overall bed slope angle, the potential for Mitchell Glacier to surge due to the loss of ice at the glacier front is considered very low and thus should not negatively affect open pit mining activities.
- ***Calving or toppling of ice blocks***: Ice blocks are currently breaking off naturally at the glacier front due to near-vertical high walls, crevassing, and melting from warm ambient temperatures. The detached ice blocks generally fall to the foot of the glacier, and hence the impacts of calving are limited to the area immediately in front of the glacier face. Risks to the Project from glacial calving include risks to worker and equipment safety.
- ***Collapse of subglacial tunnels or cavities***: Subglacial tunnels or cavities currently exist within Mitchell Glacier, although they have not yet been fully delineated. There is potential for glacier ice to collapse above the open void, and the safety of equipment and personnel working directly on the glacier surface requires detailed knowledge of the locations and dimensions of these tunnels and cavities, as well as the thickness of ice above these openings.

Mitigation Measures

The Mitchell Glacier terminus is currently unstable, with near-vertical walls of ice up to 80 m high and ice blocks breaking off along crevasses. If required to improve its stability, the glacier face will be flattened to an overall slope of 1H:1V by excavating the ice in benches, with bench heights and widths of 10 m to 15 m. Excavation will occur mechanically using a dragline with shovels and haul trucks, or by drill and blast. To minimize the safety risk for personnel and equipment working directly on the ice face, heavy equipment will not work directly on the glacier ice unless it has been verified through geophysics and/or drilling that there is sufficiently thick and solid ice beneath to provide bearing support.

A minimum setback distance of 200 m (or approximately twice the average glacier toe thickness) between the toe of the Mitchell Glacier terminus and the edge of the pit wall will be observed at all stages of pit development to provide a buffer zone between personnel and equipment working in the open pit and the excavated glacier front.

34.3.4 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 north-westward motion of the Pacific Plate relative to the North America Plate. Seismic activity in the region is associated with the known active faults in the region: Queen Charlotte Fault to the west and Eastern Denali, Fairweather, and Transition faults to the northwest. Moving inland from the coast and away from the active plate boundaries, however, earthquake frequency and size decrease. The KSM Project site is in an area of low seismic activity.

A site-specific seismic hazard assessment was conducted as part of the KSM Project pre-feasibility study to establish seismic ground motion parameters for the TMF and RSF sites (Tetra Tech-Wardrop 2012; Appendix 4-C). The seismic hazard assessment was conducted in accordance with the Canadian Dam Association (2007) recommendations for seismic hazard assessment.

As part of this study, historical earthquake data spanning from January 1700 to November 2009 was obtained from the Pacific Geoscience Centre and Natural Resources Canada (2012). These earthquake data indicated that the seismic activity within 200 km of the TMF in the last century was low. In fact, the largest recorded earthquakes within 100 km, 200 km, and 300 km of the TMF were magnitude 3.9, 4.5, and 5.0, respectively. The Queen Charlotte Earthquake on October 28, 2012, was approximately 450 km from the Mine Site. It would have been felt as approximately an intensity 3.6 earthquake at the Mine Site (US Geological Survey 2011).

The peak horizontal ground acceleration value of 0.14 *g* for the 1:10,000-year earthquake was defined as the maximum credible earthquake for the KSM Project. Based on the seismic hazard assessment, the peak ground accelerations (PGAs) listed in Table 34.3-4 are recommended for both the TMF and RSF sites. The 10,000-year return period PGA of 0.14 *g* for the TMF site should be associated with an earthquake magnitude of 7.0 at the TMF in seismic deformation and liquefaction assessments. For the TMF site, spectral accelerations corresponding to the 5% damped Uniform Hazard Response Spectra are recommended as listed in Table 34.3-5.

Table 34.3-4. Recommended Design Peak Ground Accelerations for Tailing Management Facility and Rock Storage Facility

Return Period (years)	PGA (g)
475	0.04
975	0.05
2,475	0.08
10,000	0.14

Table 34.3-5. Recommended 10,000-year Return Period Uniform Hazard Response Spectra for the Tailing Management Facility

Period (seconds)	Spectral Acceleration (g; 5% damped)
PGA	0.14
0.1	0.28
0.2	0.32
0.5	0.27
1.0	0.20
2.0	0.10
3.0	0.07
4.0	0.05

Effects on the Project

All of the Project components could be affected by a seismic event, but the TMF is the most at-risk structure. Based on the CDA (2007) assessment, the downstream consequences of the failure of the North dam, Saddle starter dam, and Southeast dam are considered to be extreme during construction, operation, and closure due to potential socio-economic, financial, and environmental losses. CDA (2007) ratings of the consequences of failure of the Splitter dam and

Saddle dam (post-stage 1) tailing dams are considered to be significant. CDA (2007) ratings of the consequences of failure for all associated seepage dams are considered to be significant.

The WSD and associated seepage dam have CDA consequence category ratings of very high and significant, respectively.

Mitigation Measures

Because of the high consequences of failure, the TMF and WSF dams have been designed to accommodate very significant seismic events.

Given the extreme consequence rating, the North dam, the Southeast dam, and the Saddle starter dam have been designed for the maximum credible earthquake, defined as the 1:10,000-year return period event (ground acceleration of 0.14 *g*), with a minimum static factor of safety (FOS) of 1.5. The Splitter dam and the Saddle dam have been designed for a 1:2,475-year return period (ground acceleration of 0.07 *g*), and a minimum static FOS of 1.5. All associated seepage dams have also been designed for a 1:2,475-year return period (ground acceleration of 0.07 *g*), and a minimum static FOS of 1.5.

The WSD and associated seepage dam are designed for a maximum credible earthquake ground acceleration of 0.14 *g* and a static FOS greater than 1.5 (end of construction).

Other 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 constructed on weak, compressible, or potentially liquefiable foundation 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.

On site seismic monitors may be installed to record actual ground shaking levels and used to inform stability assessments of structures and adaptive management responses after seismic events.

34.3.5 Volcanic Activity

The KSM Project area is located within the southern portion of the Stikine Volcanic Belt (also called the Northern Cordilleran Volcanic Province), which extends from just north of Prince Rupert into the Yukon Territory. Within 100 km of the Project site, this belt includes Lava Fork and Hoodoo Mountain to the northwest. Mount Edziza lies within 200 km to the north of the Project site, while Tseax Cone lies within 200 km to the south.

The area has been active in recent history, with an eruption at Tseax Cone as recently as 1775. This eruption resulted in a prolonged period of disruption by the volcano, and Nisg̲a'a oral tradition tells of "poisonous smoke" from the eruption that was responsible for the destruction of a Nisg̲a'a village and the death of some 2,000 people, most likely due to CO_2 gas inhalation (Canadian Geographic 2011).

Recent volcanic activity has also occurred at Lava Fork, with scientific dating techniques indicating that lava flows most likely occurred within the last 150 years.

Experts believe that Hoodoo Mountain last erupted approximately 9,000 years ago, while Mount Edziza has erupted on numerous occasions within the last 10,000 years, with the most recent activity (about 1,400 years ago) forming two large lava fields and several smaller cinder cones.

Volcanoes present a number of immediate hazards, although they are difficult to predict because they depend largely on the size of the eruption, the composition of the erupting magma, and the environment in which the eruption occurs. Hazards normally associated with eruptions include lava flows, ballistic projectiles, widespread ash, pyroclastic flows (avalanches of hot ash, hot gas, and volcanic rock), pyroclastic surges (similar to flows but less dense and can travel much faster), landslides and debris avalanches, and lahars (slurry of water and rock particles).

Effects on the Project

Lava flow from an eruption could potentially start wildfires (refer to Section 34.4) and could dam local rivers. The associated gas released during a volcanic eruption could poison the local atmosphere, and airborne ash could disrupt air traffic to and from mining camps. The ash and debris could pose health concerns for workers at the Mine Site and PTMA and could increase the levels of suspended solids in the tailing pond and diversion channels.

The greatest hazard predicted for renewed volcanism from Hoodoo Mountain is large-scale, rapid melting of the 3.2 km^3 ice cap and possibly the two glaciers on either side of the mountain, with subsequent flooding of the Iskut drainage (Russell et al. 1998). However, to generate catastrophic flooding, the eruption would need to be large enough to melt most of the ice cap in a period of days. Such flooding would not be likely to affect the Project given its location.

The pumice deposit near Mount Edziza highlights one of the important volcanic hazards associated with the Mount Edziza volcanic complex—the possibility of a large, explosive volcanic eruption (Souther 1992). An explosive eruption could produce an ash cloud that would affect large parts of northwestern Canada.

Future eruptions from Lava Fork pose little threat, as the style of eruption is expected to involve passive fluid lava flows. The extent of the effect is that ash clouds could potentially disrupt low flying aircraft and local watercourses.

Mitigation Measures

Should a volcanic eruption occur in the region, assigned site personnel will maintain contact with authorities to determine the likely hazards for the Project area. All site personnel will be informed of the eruption, and a risk assessment will determine whether normal operation should be adjusted.

In the event of an ash cloud, individual worker exposure will be limited and face masks or other respiratory devices will be used. Ongoing air monitoring will test for gases emitted, to protect human health against inhalation of volcanic gas such as increased CO_2 concentrations.

Diversion channels will be monitored and cleaned to ensure there is no blockage from ash and debris fallout from an eruption. Road maintenance crews will be available to clear debris from the access roads. An additional minimum 1.5 m of clearance has been included in stream crossing designs to allow for debris clearance.

34.4 Wildfires

A wildfire is an unplanned or unwanted natural or anthropogenic fire. Wildfires are a natural hazard in any forested or grassland region in Canada. About 2,000 wildfires occur in BC every year, approximately 40% of which are caused by human activity and 50% by lightning ignition (BC MOFLNRO 2012).

The number and size of forest fires in a region each year vary with annual weather (dry or wet years), natural disturbance type (which reflects climate), and suppression effort. Susceptibility of an area to fire depends on aspect, stand age, forest cover type, and, for human-caused fires, distance from a road (Daust, Price, and Fall 1998). The BC Wildfire Management Branch shows that the Project footprint area has experienced no fires within the last 10 years (BC MOFLNRO 2012). This is most likely due to a combination of factors: the area receives a high amount of annual precipitation, the ecosystems experience a short, harsh growing season where snow often remains well into the growing season, large areas and depressions are generally moist from meltwater, and the landscape offers low fuel vegetation. Forest fires are experienced in the region, however, and can contribute to poor visibility and air quality due to smoke.

Effects on the Project

The primary effects of a fire in the Mine Site and PTMA would be a potential loss of infrastructure (e.g., Process Plant, mill, conveyors, and accommodation complexes) and/or a loss of operating time/work days. Operating time could be lost if workers are required to help contain the fire, and if working conditions became unsafe as a result of dust and smoke. Worker safety could also be compromised during a wildfire.

The damage or loss of bridges along the access corridor in the event of a fire would hinder road access to the Mine Site and PTMA. Depending on the size of the crossing and the severity of the fire, a damaged/burnt bridge deck would result in road closures of half a day to two weeks.

A fire would 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 and could lead to more frequent landslides or avalanches (see Sections 34.3.1 and 34.3.2).

Mitigation Measures

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

- Water pumps and fire-fighting equipment (including one fire truck at the Mine Site and one at the Treaty Process Plant) will be located strategically around the Project to help contain/extinguish any fire.
- By design, the freshwater tanks at the Mine Site and Treaty Process Plant will be full at all times and will provide at least two hours of firewater in an emergency.
- Mining equipment such as dozers will be used in the case of a fire to remove vegetation around the infrastructure, thus removing fuel for the fire.
- Major bridge designs will incorporate steel sub-structures, leaving only the wooden decks vulnerable to fire.
- In the event of transmission line loss, backup generators at the Mine Site and the Treaty Process Plant will have enough power capacity to operate essential equipment around the sites.
- Spare transmission line conductors will be kept on hand to expedite repairs to the power line.
- The diesel and concentrate pipelines will be constructed of welded steel and will be buried where practical.

An Emergency Response Plan (Chapter 26.9) will be developed for the Project, which will describe appropriate procedures to effectively deal with hazards such as a forest fires, high winds, and lightning strikes. The plan will address hazard evaluation, appropriate control procedures and protocols (including action levels), personal protective equipment to be used, air and water monitoring protocols and specifications, and detailed fire-fighting procedures. All site personnel will be made aware of the Emergency Response Plan during orientation and follow-up training programs.

In the event of a fire, all personnel not involved in containing the fire will evacuate their work area or camp and gather at designated muster stations. Muster stations will be clearly identified around the Project area.

Any natural increased runoff high in total suspended solids will be transported via diversions around the PTMA and Mine Site facilities, and the diversion channels will be regularly monitored to ensure no debris blockage.

34.5 Wildlife

The region encompassing the proposed Project is home to many terrestrial wildlife species, including black and grizzly bears, mountain goats, moose, furbearers, avian species (e.g., birds of prey, migratory songbirds, and waterfowl), amphibian species, small mammals, and marmots. In addition, a number of listed species are known or expected to occur in the proposed Project area, including grizzly bears, wolverines, fishers, western toads, and various avian species.

Effects on the Project

Of those animals expected to pass through the proposed Project area, grizzly and black bears, moose, and wolverines have all been observed in the Project area, and are of the most concern to personnel safety. Any of these animals has the potential to interact adversely with site personnel. Further, bears and moose have the strength to damage Project equipment.

It is unlikely that wildlife would be attracted to a busy site with operating machinery. Project areas that are more remote and less busy are where animal encounters are most likely to occur. Wildlife may also be attracted to garbage or landfill related to the Project. Roads, particularly the main access roads, are a high-risk area for vehicle strikes of animals. This is most likely to occur with moose, which are large enough to cause serious vehicle damage and put the driver and any passengers' lives at risk.

Finally, mountain goats exist in the Project area, including in the identified Ungulate Winter Range, and are thus to be protected. Consequently, avalanche-control programs implemented within these areas may be modified to minimize or avoid the use of explosives where mountain goats are present.

Mitigation Measures

Wildlife presence, including that of large fauna, cannot be avoided. However, providing safe working conditions for site personnel is of the utmost importance. All site personnel will undergo training to teach them about the local wildlife. This training will cover safety procedures in the event of encountering certain animals. It will also highlight the importance of food management, so that no food or food scraps are left in areas that may attract wildlife. A Wildlife Management and Monitoring Plan, expanded from the plan that has been in effect on site since 2008, will be implemented to avoid bear-human interactions, and to manage those interactions when they do occur. A wildlife effects monitoring program will also be implemented to ensure waste management is effective. In addition, wildlife interactions with the Project will be monitored and additional mitigation measures implemented if necessary.

Speed limits and warning signs will be installed along roads to minimize the likelihood of animal strikes. Corridors (significant breaks in the vegetation) leading into the adjacent vegetation will be frequently spaced along the roads to encourage animals to move off the roads. Road bank heights, including those formed from snow ploughing activities during winter, will be maintained at a sufficiently low height at regular intervals to ensure that animals do not become trapped on roads.

The design of avalanche-control programs will take the mountain goat distribution and Ungulate Winter Range into consideration, so mitigation measures other than explosive use will be explored. The Active Avalanche Management Plan (Alpine Solutions Avalanche Services 2011) was designed to minimize the effects of avalanche control on mountain goats.

References

1992. *Canadian Environmental Assessment Act*, SC. C. 37.

British Columbia Dam Safety Regulation, BC Reg. 44/2000.

Alpine Solutions Avalanche Services. 2011. *Active Avalanche Management Plan for the KSM Project*. Prepared by BGC Engineering for Seabridge Gold Inc.: Squamish, BC.

Alpine Solutions Avalanche Services. 2012a. *KSM Project, British Columbia. Minesite and Coulter Creek Access: Snow Avalanche Hazard Assessment*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Squamish, BC.

Alpine Solutions Avalanche Services. 2012b. *KSM Project, British Columbia. Tailings Management Facility & Treaty Creek Access: Snow Avalanche Hazard Assessment*. Prepared by BGC Engineering for Seabridge Gold Inc.: Squamish, BC.

Babite Group. 2002. *Climate Change Impacts on the Safety of British Reservoirs: Final Report*. Prepared for DEFRA in Association with CEH Wallingford. http://www.britishdams.org/reservoir_safety/defra-reports/200201Climate%20change%20impacts%20on%20the%20safety%20of%20British%20reservoirs.pdf (accessed November 2012).

BC MOE. 2010. *Preparing for Climate Change: British Columbia's Adaptation Strategy*. British Columbia Ministry of the Environment. http://www.livesmartbc.ca/attachments/Adaptation_Strategy.pdf (accessed November 2012).

BC MOFLNRO. 2012. *Fire Averages, 2010-2012*. British Columbia Ministry of Forests, Lands and Natural Resource Operations, Wildfire Management Branch. http://bcwildfire.ca/History/average.htm (accessed October 2012).

BC MWLAP. 2002. *Indicators of Climate Change for British Columbia*. British Columbia Ministry of Water Land and Air Protection: Victoria, BC.

BC MWLAP. 2003. *Adapting to Climate Change in Northern BC*. Prince George, BC: British Columbia Ministry of Water, Land, and Air Protection, Canadian Impacts & Adaptation Research Network-BC, University of Northern BC.

BCWWA. 2012. *Position Statement: Climate Change Adaptation*. British Columbia Water and Waste Waste Association. https://www.bcwwa.org/resourcelibrary/Position%20Statement%20-%20Climate%20Change.pdf (accessed December 2012).

Bedient, P. B. and W. C. Huber. 2002. *Hydrology and Floodplain Analysis*. 3rd ed. New Jersey, NJ: Prentice Hall.

BGC. 2010a. *KSM Project, Mitchell Glacier Stability Study, Draft*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2010b. *Terrain Stability Field Assessment of the Proposed Coulter Creek, Teigen Creek, and Tunnel Spur Access Roads*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2011. *BGC Project Memorandum, Ground Temperatures and Permafrost*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2012a. *BGC Project Memorandum, KSM-Geohazards: OPC Pre-feasibility Geohazards Risk Reduction - Rev. C*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2012b. *BGC Project Memorandum, KSM Project Geohazard Risk Reduction Summary: Rev B*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2012c. *KSM Project Geohazard and Risk Assessment, Minesite & Coulter Creek Access, Revision C*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2012d. *KSM Project Geohazard and Risk Assessment, Tailings Management Facility, Treaty Creek and Teigen Creek Access, Revision C*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

BGC. 2012e. *KSM Project, Terrain Stability Field Assessment of the Proposed Treaty Creek, North Treaty and Tunnel Adit Access Roads*. Prepared by BGC Engineering Inc. for Seabridge Gold Inc.: Vancouver, BC.

Canadian Geographic. 2011. *Canada's Worst Natural Disasters of All Time*. http://www.canadiangeographic.ca/blog/posting.asp?ID=439 (accessed June 2013).

CCCSN. 2012a. *Bioclimatic Profiles for Dease Lake (ID: 11192340) and Prince Rupert BC (ID: 1066481). GCM Scenarios run for all time periods: Regional CRCM4.23 (Run 1) – SR-A2 and CSIROMk3.0 (Run 1) – SR-A2*. http://www.cccsn.ec.gc.ca/?page=viz-bioclimate (accessed December 2012).

CCCSN. 2012b. *Climate Change Concepts*. Environment Canada. http://www.cccsn.ec.gc.ca/?page=scen-intro (accessed December 2012).

CCCSN. 2012c. *Climate Localizer*. Environment Canada. http://www.cccsn.ec.gc.ca/tools/viz-localizer/localizer.pl (accessed December 2012).

CDA. 2007. *Canadian Dam Safety Guidelines*. Canadian Dam Association. http://www.imis100ca1.ca/cda/CDA/Publications_Pages/Dam_Safety_Guidelines.aspx (accessed January 2013).

Coulson, H. 1997. The impacts of climate change on river and stream flow in British Columbia and southern Yukon. In *Responding to global climate-change in British Columbia and Yukon Volume I of the Canada country study: climate impacts and adaptation*. Eds. E. Taylor and B. Taylor. Environment Canada and British Columbia Ministry of Environment Lands and Parks.

Daust, D., K. Price, and A. Fall. 1998. *Description of the Iskut-Stikine Landscape Model*. British Columbia Ministry of Forests, Research Branch: Victoria, BC.

Engineers Canada. 2007. *Adapting Infrastructure to a Changing Climate: Vulnerability Committee Overview*. Public Infrastructure Engineering Vulnerability Committee. http://www.pievc.ca/e/abo_overview_.cfm (accessed September 2012).

Environment Canada. 2012. Climate Data Online. http://www.climate.weatheroffice.gc.ca/climateData/canada_e.html (National Climate Data and Information Archive accessed 2012).

IPCC. 2007. Climate Change 2007: The Scientific Bases. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. In Eds. S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, J. H.L. Miller, and Z. Chen.

KCB. 2012. *2012 Geotechnical Design of Rock Storage Facilities and Design of Associated Water Management Facilities*. Prepared for Seabridge Gold Inc. by Klohn Crippen Berger Ltd.: Vancouver, BC.

McClung, D. M. and P. Schaerer. 1993. *The Avalanche Handbook*. 3rd ed. Seattle, WA: The Mountaineers.

NRCan. 2012. *Earthquakes Canada*. http://www.earthquakescanada.nrcan.gc.ca/index-eng.php (accessed January 2013).

Parry, M. L., O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, eds. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Cilmate Change*. Cambridge, UK: Cambridge University Press.

Russell, J. K., M. V. Stasiuk, J. Schmok, J. Nicholls, T. Paige, A. Rust, G. Cross, B. R. Edwards, C. J. Hickson, and M. Maxwell. 1998. The ice cap of Hoodoo Mountain volcano, northwestern British Columbia: estimates of shape and thickness from surface radar surveys. *Current Research 1998-A: Geological Survey of Canada*: 55-63.

Souther, J. G. 1992. *The Late Cenozoic Mount Edziza Volcanic Complex, British Columbia*. Memoir 420. Geological Survey of Canada: Ottawa, Ontario.

Tetra Tech-Wardrop. 2012. *2012 KSM (Kerr-Sulphurets-Mitchell) Prefeasibility Study*. Prepared by Tetra Tech-Wardrop for Seabridge Gold Inc.: Vancouver, BC.

The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment. 2003. *Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners*. Canadian Environmental Assessment Agency: Ottawa, ON.

UBC Faculty of Forestry. 2012. *Climate BC: A program to generate high-resolution climate data for climate change studies and applications in British Columbia*. http://www.genetics.forestry.ubc.ca/cfcg/ClimateBC/ClimateBC.html (accessed April 2012).

UIUC Department of Atmospheric Sciences. 2010. *The Weather World 2010 Project*. University of Illinois Urbana-Champaign. http://ww2010.atmos.uiuc.edu/(Gh)/home.rxml (accessed 2010).

US Geological Survey. 2011. Earthquake Hazards Program. http://earthquake.usgs.gov/earthquakes/dyfi/events/us/b000df7n/us/index.html (M7.8 - Queen Charlotte Islands Region accessed November 2012).

Walker, I. J. and R. Sydneysmith. 2008. British Columbia. In *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Ed. D. S. Lemmen, F. J. Warren, J. Lacroix, and E. Bush. 329-86. Ottawa, ON: Government of Canada.