23. EFFECTS OF THE ENVIRONMENT ON THE PROJECT

This chapter assesses the potential for the environment to affect the Project. In accordance with the Murray River Application Information Requirements and Environmental Impact Statement Guidelines (BC EAO 2013; CEAA 2013; Rescan 2013b), the following topics are considered in this assessment:

- extreme weather events, including:
  - heavy precipitation,
  - extreme temperatures,
  - flooding,
  - drought,
  - wind, and
  - lightning;
- natural seismic events and associated effects such as liquefaction or subsidence;
- fire; and
- slope stability and mass wasting events.

23.1 EXTREME WEATHER EVENTS

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

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

23.1.1 Regional and Local Climate Patterns

23.1.1.1 Regional Climate

The Project is in the Southern Rocky Mountain Foothills hydrologic zone (British Columbia Hydrologic Zone 7; Obedkoff 2003). The zone is characterized by a continental climate with low precipitation, moderately warm summers, and cold winters.

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

23.1.1.2 Local Climate

The elevation at the proposed mine site is about 800 masl. To monitor local meteorological conditions, a station was set up within the LSA in March 2011, and has been in operation ever since (Appendix 6-A). The meteorological station is located about three kilometres northwest (55.02ºN, 121.08ºW) of proposed mine site infrastructure at 1,055 masl, which is about 250 m above the proposed mine site elevation. This location was chosen to be representative of site weather conditions. Details of the meteorological station sensors and site layout are provided in the meteorology baseline report (Appendix 6-A). In the following sections, local climate is summarized using data from four sources:

1. **The on-site Murray River meteorological station**. These data provide a site-specific, but relatively short-term dataset.
2. **The computer program ClimateWNA**. ClimateWNA provides 30-year "climate normal" data for western North America on a 2.5 × 2.5 arcmin grid. ClimateWNA data are interpolated and adjusted for elevation effects based on gridded climatic datasets (from the Climate Research Unit and Global Historical Climatology Network; Wang et al. 2006; Wang et al. 2012).
3. **Environment Canada regional rankings of air temperature and precipitation** (Environment Canada 2014b). The Project area is within the "Southern BC Mountains" climatic region; 2011 and 2012 air temperature and precipitation were ranked in relation to the long-term regional climatic record (1948-2013).
4. **Climate data from regional meteorological stations**. These data are used here to assess air temperature and precipitation extremes from stations close to the Project area. Data from these stations are also summarized in the meteorology baseline and hydroclimatology report (Rescan 2013a, 2014b).

23.1.1.3 Regional Climatic Patterns

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

The PDO is a measure of the difference in sea level pressure between the Aleutian Low and the Hawaiian High pressure cell (Mantua et al. 1997). The PDO is characterized by positive phases (1925-1946, 1977-2005) and negative phases (1947-1976, 2005-present), which statistically exhibit a 23 year cycle. The phase and strength of the PDO have been shown to influence changes in river flow, glacial mass balance, and salmon abundance throughout the Pacific northwest (Dettinger et al. 1993; Mantua et al. 1997; Hodge et al. 1998; Bitz and Battisti 1999; Gedalof and Smith 2001; Neal, Walter, and Coffeen 2002).

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

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

Specifically, in the Project area, winter (December to February) air temperatures and precipitation have relatively strong correlation coefficients with the PDO (r = ~0.5 to 0.6; NOAA 2013). Stronger correlation coefficients between winter precipitation and the PDO exist in Northwestern BC, Alaska (positive correlation) and in eastern Washington State and Idaho (negative correlation). Studies from these areas have noted the importance of the PDO for affecting hydroclimatolgy (Stahl, Moore, and McKendry 2006).

23.1.2 Temperature and Precipitation

23.1.2.1 Typical Air Temperatures

Between 2011 and 2013, average annual air temperature at the Murray River meteorological station ranged from 2.2ºC to 5.6ºC. The coldest month was December 2012, when mean minimum daily air temperature was -17.3ºC. The warmest month was July 2012, when mean maximum daily air temperature was 22.4ºC (Rescan 2014b).

"Climate normal" air temperatures extracted from ClimateWNA suggest the mean annual air temperature in the Project area is 4.6ºC, based on the 1981-2010 dataset. The coldest mean minimum daily air temperature was -10.3ºC (February), and the warmest mean maximum daily air temperature was 21.4ºC (August). Average annual air temperature was lower for the 1961-1990 climate normal dataset at 2.7ºC.

Local and regional air temperature has historically been collected at numerous locations around Tumbler Ridge. Table 23.1-1 provides a monthly summary of air temperature measured at some of these weather stations.

23.1.2.2 Extreme Air Temperature

Long-term data from nearby weather stations reveal a wide range between extreme warm and extreme cold air temperatures. Air temperatures as warm as 34.5ºC, and as cold as -49.2ºC, have been recorded near the LSA (Table 23.1-2). The potential for extremes in cold and warmth is characteristic of the continental climate of the Project area.

Table 23.1-1. Murray River and Regional Air Temperature Values (°C)

Month	Murray River (2011-2013) (1,055 masl)	Chetwynd A (2011-2013) (610 masl)	Dawson Creek A (2011-2013) (656 masl)	Denison Plant (1982-1997) Climate Normals (854 masl)	Tumbler Ridge (1985-2002) Climate Normals (824 masl)	Bullmoose (1981-2010) Climate Normals (1,102 masl)	Chetwynd A (1981-2010) Climate Normals (610 masl)
January	-6.7	-8.1	-8.9	-8.0	-9.6	-8.0	-10.2
February	-2.7	-4.7	-6.0	-6.1	-6.9	-6.6	-7.2
March	-3.9	-5.0	-7.5	-2.2	-2.5	-4.2	-2.9
April	0.9	3.0	2.3	3.9	3.9	1.7	4.6
May	8.1	10.6	10.7	8.9	9.0	6.9	9.5
June	11.4	14.0	13.8	12.8	13.1	11.0	13.4
July	14.0	15.9	15.8	15.0	15.2	13.3	15.4
August	14.0	15.7	15.1	14.2	14.6	12.8	14.5
September	11.5	12.5	12.4	10.2	10.3	8.2	9.9
October	2.3	4.3	3.6	4.0	4.3	2.5	4.1
November	-5.5	-6.8	-8.8	-5.0	-4.0	-4.7	-5.5
December	-8.6	-10.3	-11.1	-7.0	-7.0	-7.4	-9.1
Average	2.9	3.4	2.6	3.4	3.4	2.1	3.0
Maximum	14.0	15.9	15.8	15.0	15.2	13.3	15.4
Minimum	-8.6	-10.3	-11.1	-8.0	-9.6	-8.0	-10.2

Table 23.1-2. Murray River and Regional Extreme Air Temperature Values (°C)

	2011-2013			Climate Normals			
	Murray River (1,055 masl)	Chetwynd A (610 masl)	Dawson Creek A (656 masl)	Denison Plant Site (1982-1997) Climate Normals (854 masl)	Tumbler Ridge (1985-2002) Climate Normals (824 masl)	Bullmoose (1971-2010) Climate Normals (1,102 masl)	Chetwynd A (1971-2010) Climate Normals (610 masl)
Extreme Maximum	30.7	33.7	31.6	33	35.5	32.5	33.8
Date	1-Jul-13	17-Aug-12	12-Sep-13	13-Aug-92	13-Aug-92	1-Sep-87	15-Aug-91
Extreme Minimum	-36.3	-37.4	-37.6	-46	-46	-39.5	-52
Date	17-Jan-12	1-May-11	17-Jan-12	26-Nov-85	17-Jan-96	31-Jan-90	25-Jan-97

Given the climatic setting of the Project area, effects on the Project might be expected from both extremely cold and extremely warm air temperatures. These extremes are more likely to affect workers at the surface, compared to the subsurface.

23.1.2.3 Freeze-Thaw Cycles

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

Effects of Extreme Cold on the Project

- Extremely low air temperatures could adversely affect workers' health, causing frostbite and hypothermia. Workers can become distracted and prone to accidents under extreme low temperatures.
- Equipment and machinery is more likely to malfunction or become damaged during extreme low temperatures, increasing the potential for worker-related exposure and accidents. Extreme low temperatures may be accompanied by blowing snow, which could affect surface transport of materials and personnel, and could temporarily slow mine operations.
- Increased heating requirements on site would result from extreme low temperatures, increasing power demand.
- Extended cold spells could result in an extended winter and increased snow accumulation. As a result, access roads, haul roads, and diversion channels would require more clearing.
- Cold spells could cause later melting of the winter snowpack, delaying spring runoff.

Effects of Extreme Warmth on the Project

- Extremely high air temperatures may also adversely affect workers' health, causing heat exhaustion, dehydration, and heat stroke. Workers can become distracted and more prone to accidents under extreme high temperatures.
- Equipment and machinery is more likely to malfunction during extreme high temperatures, increasing the risk of exposure and accidents / malfunctions.
- Increased air conditioning requirements on site would result from extreme high temperatures, increasing power demand.
- With sustained warm air temperatures, more precipitation would fall as rain than as snow, and earlier melting of the snowpack could cause increases in runoff during the late winter and early spring. Storms where precipitation falls as rain rather than snow could cause more rapid runoff, potentially increasing the erosive capabilities of flows. Costs of maintaining diversion channels and access roads could increase.
- Extremely high temperatures coinciding with dry periods could increase the likelihood of wildfires occurring in the area (discussed in Section 23.1.6).

Effects of Freeze-Thaw Cycles on the Project

Given that air temperatures in winter can transition above and below the freezing point, freeze-thaw cycles and frost heave in winter are likely. Frost heaving would affect transportation and utilities components of the Project; for example, by causing frost heave on road surfaces, the railway line, and the natural gas pipeline, and by destabilizing power transmission towers.

Mitigation Measures

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

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. Potentially vulnerable infrastructure will be built to withstand freeze-thaw cycles, especially infrastructure related to transportation and utilities.

Air temperature-related risks to the Project and mitigation measures are presented in the table below (Table 23.1-3), and discussed in the following sections.

23.1.2.4 Typical Precipitation

Average 2011 to 2013 mean annual precipitation (MAP) for the Murray River station was 485 mm (Rescan 2014b). This average was the result of 387 mm of precipitation in 2011, 485 mm in 2012, and 583 mm in 2013. The wettest months are typically in summer, when convective rainfall events occur (Table 23.1-4). Substantial rain events in autumn also take place. Snow depth is highly dependent on elevation, but at the Project meteorology station, monthly average snowpack peaked in December 2012 was 48.9 cm; in all years snow cover was depleted by June (Rescan 2014b).

Annual precipitation extracted from ClimateWNA for the 1981-2010 Climate normal period predicts that 665 mm of precipitation is expected at the Murray River meteorology station (1,055 masl). Annual precipitation for the 1961-1990 climate normal period was higher at 706 mm, annually. ClimateWNA predicts that between 22 and 35 percent of the total annual precipitation falls as snow at the meteorological station (depending on the climatic normal period used).

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

Table 23.1-3. Air Temperature-related Risks and Mitigation Measures

Category	Component	Project Effects	Mitigation Measures[a]
Transportation	Rail load-out	n/a	n/a
	Rail line, road surface, ditches, culverts.	Blowing snow, frost heave.	Frequent snow clearing. Use of appropriate design standards to minimize frost heave.
Surface infrastructure	Buildings (maintenance, administration, warehouse), coal conveyor, coal rejects storage area, coal stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile.	Effects to workers from cold: frostbite, hypothermia, distraction, accidents. Effects to infrastructure from cold: increased heating (and power) demands, freeze-thaw damage. Effects to workers from warmth: heat exhaustion, dehydration, heat stroke. Effects to infrastructure from warmth: increased air conditioning (& power) demands.	Staff will wear appropriate clothing, and be trained in risks and risk-mitigation relating to extreme temperatures. Suitable equipment will be used in mine infrastructure to withstand extremes of heat and cold.
Subsurface infrastructure	Groundwater extraction well, main access shaft, ramps, portals, tunnels, ventilation shaft for return air.	n/a	n/a
Utilities	Electric transmission line	n/a	n/a
	Natural gas pipeline		

[a] *Weather reports will be monitored to mitigate air temperature-related risks to the Project.*

Table 23.1-4. Murray River and Regional Precipitation Values (mm)

Month	Murray River (2011-2013) (1,055 masl)	Chetwynd A (2011-2013) (610 masl)	Dawson Creek A (2011-2013) (656 masl)	Denison Plant Site (1982-1997) Climate Normals (854 masl)	Tumbler Ridge (1985-2002) Climate Normals (824 masl)	Bullmoose (1981-2010) Climate Normals (1,102 masl)	Chetwynd A (1981-2010) Climate Normals (610 masl)
January	8.6	26.7	22.9	42.0	36.7	69.1	21.1
February	22.6	15.0	3.8	26.3	24.9	49.8	16.2
March	21.2	28.1	10.9	34.8	35.8	49.6	21.9
April	27.9	36.9	18.0	30.3	21.3	37.1	20.4
May	41.8	66.3	40.0	30.8	30.3	45.0	37.2
June	86.5	122.5	100.0	83.0	73.0	94.2	75.7
July	92.3	86.3	80.4	87.9	77.1	91.2	76.9
August	38.5	24.5	27.5	51.7	56.3	72.3	51.4
September	18.3	23.1	10.4	54.5	37.7	65.8	41.2
October	57.7	31.3	32.5	49.4	25.8	82.8	29.1
November	42.5	35.7	12.1	54.1	41.0	81.5	30.6
December	51.5	34.8	13.4	33.1	25.6	54.4	19.1
Annual Total	509.4	531.2	372.0	577.9	485.5	792.7	440.6

23.1.2.5 Extreme Precipitation

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

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

Heavy precipitation measured at regional meteorological stations can provide insight into the expected precipitation extremes. Nearby weather stations with records sufficiently long for 30-year Climate normals are included in Tables 23.1-1 and 23.1-4. Extremes of air temperature and precipitation data are available for these sites (Environment Canada 2014c) and are provided in Tables 23.1-1 and 23.1-5. The data demonstrate that the Project area is in a dry, continental location, on the leeward side of the Rocky Mountains. Extremely high-magnitude rainfall and snowfall events have not historically occurred in this region.

Effects of Heavy Precipitation on the Project

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

Buildings and Infrastructure

Increased precipitation in solid forms, such as sleet or hail, may damage building roofs. Snow should be shoveled off roofs after heavy snowfalls to prevent roof collapse from excessive loads. The plant site and other buildings will be constructed to withstand periods of heavy precipitation. Similarly, warm temperature cycles in the winter can act to increase the density of snow, and therefore the force on roofs, anchoring cables, covered walkways, etc. Current construction design criteria for buildings are likely sufficient to withstand the expected increases in heavy precipitation.

Table 23.1-5. Murray River and Regional Extreme Precipitation Values

	Murray River (2011-2013) (1,055 masl)	Chetwynd A (2011-2013) (610 masl)	Dawson Creek A (2011-2013) (656 masl)	Denison Plant Site (1982-1997) Climate Normals (854 masl)	Tumbler Ridge (1985-2002) Climate Normals (824 masl)	Bullmoose (1981-2010) Climate Normals (1,102 masl)	Chetwynd A (1981-2010) Climate Normals (610 masl)
Extreme Rainfall (mm)	45.2	72	54.4	59.8	51	76	64.4
Date	8-Jul-11	24-Jun-11	24-Jun-11	13-Jul-82	17-Jul-01	31-Jul-87	31-Jul-87
Extreme Snowfall (cm)	n/a	18.6	n/a	35	35	47	34.3
Date	n/a	16-Jan-11	n/a	28-Nov-90	7-Nov-99	19-Nov-94	27-Oct-86

Roads

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

Effects of Low Precipitation on the Project

Effects of low precipitation are much more likely in the Project area as compared to heavy precipitation. Low precipitation generally manifests as low stream flow (Section 23.1.3). Prolonged periods of low precipitation could also increase the risk of wildfires; this is discussed in detail in the wildfire section.

Mitigation Measures

Roadways will be cleared during or after snow events. Roadways will be repaired and maintained as needed. Ditches and culverts will be cleared of debris and monitored. Water seeping into mine shafts and declines will be pumped to the surface. Snow will be cleared from ventilation shafts.

Mitigation measures for the effects of low precipitation, and therefore low stream flow, on the Project are addressed in Section 23.1.3.

Precipitation-related risks to the Project and subsequent mitigation measures are presented below in Table 23.1-6 and discussed in detail in the following section (Surface Water Flows).

23.1.3 Surface Water Flows

23.1.3.1 Typical Stream Flow

Detailed results from the Project area hydrometric program are provided in baseline studies and the Murray River hydrometeorology report (Rescan 2013a, 2014a). The hydrometric baseline program involved monitoring a network of hydrometric stations in rivers/streams close to the Project to provide site-specific hydrologic data (Table 23.1-7). Baseline work also involved analyzing long-term datasets from regional Water Survey of Canada (WSC) stations. This regional analysis allowed prediction of recurrence intervals for floods and low-flows within the Project area.

The flow regime in the area is closely related to the seasonal distribution of precipitation and temperature. Rivers in this region are predominantly fed by spring snowmelt (freshet) and rainfall in the summer. High discharges occur from mid-April through July, with a low flow period during winter and early spring. Mean annual runoff varies from 134 to 924 mm in monitored watersheds. The range is primarily caused by increases in precipitation with elevation due to the orographic effect.

The typical flow regime of the Murray River, with its large upstream watershed area, is quite different from the regime of the smaller lower-order tributary watersheds in the LSA. For example, an average peak flow for the Murray River at the LSA is about 375 m^3/s, and occurs in the first week of June. Flow in the Murray River typically continues throughout the winter, with an average baseflow of about 20 m^3/s (Rescan 2014a).

Table 23.1-6. Precipitation-related Risks and Mitigation Measures

Category	Component	Project Effects	Mitigation Measures[a]
Transportation	Rail load-out	n/a	n/a
	Rail line, road surface, ditches, culverts	Infrastructure effects: erosion, sedimentation, flooding. Access effects: reduced access to mine site and reduced productivity due to downed trees, snow drifts, damaged roads.	Snow clearing, roadway repair, ditch and culvert clearing.
Surface infrastructure	Buildings (maintenance, administration, warehouse), coal conveyor, coal rejects storage area, coal stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile	Flooding, erosion and sedimentation, snow loading. Leading to damage of infrastructure and reduced mine productivity.	Flooding and drought related mitigation measures are discussed in Section 23.1.3.
Subsurface infrastructure	Groundwater extraction well, main access shaft, ramps, portals, tunnels, ventilation shaft for return air	Increased shallow groundwater seepage, flooding.	Pumping. Clearing of snow from ventilation shafts.
Utilities	Electric transmission line Natural gas pipeline	Erosion at footings, damage due to downed trees, leading to reduced mine productivity.	Periodic monitoring and repair as needed. Two principal transformers, with one serving as backup.

[a] *Weather reports will be monitored to mitigate precipitation-related risks to the Project.*

Table 23.1-7. Hydrometric Indices for Typical Flow Conditions in the Project Area

Hydrometric Station	Drainage Area (km²)	Annual Precipitation (mm)[a]	Annual Runoff (mm)[b]			7-day Low Flow[c]	June-Sept (m³/s) 7-day Low Flow[b]			Peak Daily Flow(m³/s)[b]		
			2011	2012	2013	Annual (m³/s)	2011	2012	2013	2011	2012	2013
MH-1	2,242	901	924	810	777[c]	7.30	28.99	17.25	19.52[c]	412	375	334[c]
MH-2	42.97	837	319	305	353	0.002	0.04	0.01	0.06	7.1	6.1	5.6
MH-3	6.62	764	n/d	135	n/d	0.000	n/d	0.00	n/d	n/d	0.4	n/d
MH-4	21.08	921	401	341	n/d	0.005	0.03	0.02	n/d	2.6	2.7	n/d
MH-5	4.12	815	433	134	n/d	0.000	0.01	0.00	n/d	0.8	0.2	n/d
MH-6	7.36	619	n/d	n/d	193	0.005	n/d	n/d	0.00	n/d	n/d	0.7
MH-7	52.39	675	n/d	n/d	187	0.009	n/d	n/d	0.00	n/d	n/d	5.4

Notes:

[a] *From the equation '$P = 0.696E - 19.54$', where E is median watershed elevation (equation derived in the Murray River hydrometeorology report (2013)*

[b] *Based on monitored data*

[c] *Based on regional analysis*

n/d no data

By contrast, watersheds of monitored streams that feed into the Murray River are two to three orders smaller than the Murray River watershed size. The most notable difference in the hydrologic regime of these small catchments is the reduced fraction of total annual runoff in winter.

Streams in these small watersheds tend to freeze completely in winter, or have extremely low winter discharge magnitudes (≤ 5 L/s; Rescan 2014a). For example, on Murray River in the 2011/2012 winter, 8% of the total annual runoff occurred from December to February. By contrast, in the smallest watershed (MH-5, 4.1 km^2), 2% ran off over the same period (Rescan 2014a). Peak flow can also be earlier in these small watersheds (up to about two weeks earlier), due to the rapid transport of meltwater in steeper headwater catchments (Rescan 2014a).

Typical stream flow indices for hydrometric stations throughout the Project area are provided in Table 23.1-7.

Normal flows will not have substantial adverse effects on Project infrastructure, since infrastructure will be designed to withstand floods with long return periods. The effects of floods are discussed in Section 23.1.3.2 with measures designed to mitigate damage due to flooding.

23.1.3.2 Extreme High Stream Flows

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

- rapid snow melt during freshet conditions in June or July; and
- rain falling on melting snow during freshet conditions in June or July, or during early winters in October and November.

Based on analysis of the regional WSC stations, high-flow events are regularly generated by both mechanisms. In the Project area, floods can be caused by both mechanisms, but because of the relatively gentle to moderate terrain, rapid snow melt is the dominant mechanism for generating peak flow.

Peak flows are characterized using a flood frequency analysis to obtain return period flows. The return period refers to the probability of occurrence of the flood event. For example, a 1-in 50-year return period (Q_{50}) event is a flow magnitude that has a 2% chance of being exceeded in any given year. To complete the analysis, a long-term data record (i.e., > 10 years) is required; therefore, data from several regional WSC stations were used. For each return period, regression equations were developed relating discharge and basin area. The equations were then applied to the monitored watersheds surrounding the Project, using the basin area to obtain return period flow estimates (Table 23.1-8). Notably, most of the stations incorporated in the regional analysis are rivers with large drainage areas (> 100 km^2). Extrapolation to smaller streams increases the uncertainty associated with the estimates; however, for the purposes of this assessment, these values are considered reasonable.

Table 23.1-8. Estimates of Peak Flows (m^3/s) for Regional Hydrometric Stations Surrounding the Project Area

Station Name	Drainage Area (km^2)	Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}
Pine River	12,100	1,453	2,142	2,721	3,381	4,411	5,336
Murray River at Mouth	5,550	578	794	947	1,100	1,309	1,474
Sukunka River	2,590	182	643	731	812	917	993
Dickebusch Creek	82.1	9.82	31.3	64	122	268	471
Quality Creek	29.5	2.91	6.74	11.2	17.5	30.2	44.4
Murray River above Wolverine	2,370	376	513	617	728	887	1,020
Moberly River near Fort St. John	1,520	67.5	91.8	108	123	143	158
Flatbed Creek	486	49.9	94.9	141	203	318	438

Return periods for watersheds monitored within the Project area are listed in Table 23.1-9. Return periods were calculated using data from long-term regional WSC stations. Results from the "quantile regression technique" (QRT), where watershed area is regressed against the estimated peak annual flows with different return periods, are presented below.

Table 23.1-9. Estimates of Peak Flows (m^3/s) at Project Area Hydrometric Stations Based on the Quantile Regression Technique (QRT)

Hydrometric Station	Watershed	Drainage Area (km^2)	Estimated Peak Flow Based on Regional QRT (m^3/s)					
			Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}
MH-1	Murray River	2,242	488	590	699	856	988	1134
MH-2	Lower Camp Creek	42.97	14.3	23.8	37.8	66.3	99.0	145.8
MH-3	Twenty Creek	6.62	2.1	4.3	8.0	17.1	29.3	49.3
MH-4	Upper Camp Creek	21.08	7.5	13.4	22.3	41.8	65.4	100.7
MH-5	Mast Creek	4.12	1.4	2.9	5.6	12.5	22.1	38.3
MH-6[a]	Mile 17 Creek	7.36	3.0	5.7	10.3	21.2	35.5	58.4
MH-7[a]	Mile 19 Creek	52.39	17.1	28.0	43.8	75.4	111.2	161.7

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

In addition to the event return period presented for the Project area (Tables 23.1-8 and 23.1-9), climate change should be considered while assessing flood risk. Projections show an increase in median precipitation in future, with the possibility of shorter return periods for heavy precipitation events. These issues are discussed in Section 23.3.

Effects of Extreme High Stream Flow on the Project

Floods can damage river crossing structures, including bridges and culverts. Floods can cause erosion and deposition of sediment, negatively affecting water quality. Floods can cause rapid channel avulsion, and could cause damage to any infrastructure in the new channel. Floods can trigger mass wasting, when stream beds undercut steep banks. According to Table 23.1-10, the probability of a 1-in-100-year event occurring during operations is 22%, during Operation and Decommissioning and Reclamation is 25%, and during the entire mine life there is a 45% chance.

Table 23.1-10. Return Period Probabilities in a Single Year, and the Operations, Decommissioning and Reclamation, and Post Closure Project Phases

Event	Probability for Any Single Year (%)	Probabilities for Project Phases[1] (%) Operation (YR 1 to YR 25)	Operation + Decommissioning and Reclamation (YR 1 to YR 28)	Operation + Decommissioning and Reclamation + Post Closure (YR 1 to YR 59)
1-in-10-year	10	92.8	94.8	99.8
1-in-20-year	5	72.3	76.2	95.2
1-in-50-year	2	39.7	43.2	69.6
1-in-100-year	1	22.2	24.5	44.7
1-in-200-year	0.5	11.8	13.1	25.6
1-in-500-year	0.2	4.9	5.5	11.1

[1] *The probabilities of events occurring Project phases are calculated using the hydrology frequency analysis formula: Probability (risk) = $1 - (1 - P)^n$ where P is the probability for an event in any single year, and n is the Project phase length.*

Diversion Ditches

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

Mine Site Roads and Access Corridor

Floods occurring along the mine site roads and access corridor could result in road closures caused by excess water on the road surface, erosion of the road surface, damage to stream crossings, or debris blocking the roads. Under the most extreme flood events there is the potential for drainage structure washouts (bridges, culverts, and cross-drains). Stream crossings are designed to pass the 1-in-100-year instantaneous flood flow and riprap is placed at the inlet and outlet of bridges and culverts to protect the structures from erosion.

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

Mitigation Measures

Project infrastructure will be designed to withstand flood events. Specific mitigation measures for extreme high stream flow are presented in Table 23.1-11; specifically, flooding will be mitigated by:

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

Diversion Ditches

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

Mine Site Roads and Access Corridor

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

Effects of Extreme Low Stream Flow on the Project

Low flows are an important consideration for this Project because they could affect aquatic communities. While the annual low flow will occur during winter months, flow volumes during the summer season (June to September) are also important as they can strongly influence species presence. Low flows are characterized using different indices, with the most common measure being the 7-day low flow over a given time period. For example, the average annual 7-day low flow (7Q2) provides an estimate of the average base flow conditions of a stream. Another measure, the 7Q10, is the 7-day average minimum flow that is expected to occur once every 10 years.

Low flow return periods were calculated for each of the hydrology baseline monitoring sites. As the annual low flows occur in the winter months it was necessary to calculate low flows for both the open-water period (June to September; Table 23.1-12), as well as for the entire year (Table 23.1-13; Rescan 2014a). Low flow magnitudes are calculated using monitored site-specific and long-term regional hydrometric data.

All of the smaller streams within the Project area are predicted to have annual 7-day low flows near zero for all recurrence intervals. On February 13, 2014, flow at MH-6 was measured in the field as 0.003 m^3/s, and 0.039 m^3/s at MH-7, indicating that low flow data derived from regional analysis (Table 23.1-13) are within the same order of magnitude as actual on-site winter flows in these catchments.

Table 23.1-11. Stream Flow-related Risks and Mitigation Measures

Category	Component	Project Effects	Mitigation Measures[a]
Transportation	Rail load-out	n/a	n/a
	Rail line, road surface, ditches, culverts	Floods: erosion and sedimentation at ditches , culverts, and road surface. Negative effect on water quality if sediment concentrations increase. Delay of materials and personnel if access to mine site is limited. Droughts: negative effect on water quality through concentration.	Development of an appropriate water balance model and water management plan. Constructing infrastructure to withstand extreme flood events.
Surface infrastructure	Buildings (maintenance, administration, warehouse), coal conveyor, coal rejects storage area, coal stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile.	Drought: reduction in water quality in receiving environment. Reduction in water available for use in process, resulting in slowed production.	Development of appropriate water balance model, water management plan, and environmental management plans. Maintaining water quality by limiting sediment erosion, and reducing inputs of contaminated material.
Subsurface infrastructure	Groundwater extraction well, main access shaft, ramps, portals, tunnels, ventilation shaft for return air	Floods: increased need for pumping if shallow groundwater infiltration rates increase.	Increased pumping.
Utilities	Electric transmission line Natural gas pipeline	Floods: erosion or sedimentation where transmission lines or gas pipeline is near streams or areas prone to flooding. Drought: n/a	Constructing infrastructure to withstand extreme flood events.

[a] *Weather reports will be monitored to mitigate flood and drought-related risks to the Project.*

Table 23.1-12. Estimated June to September Low Flow Indices for the Watersheds in the Project Area

Hydrometric Station	Watershed	Drainage Area (km²)	5 Year 7-day Low Flow (m³/s)	10 Year 7-day Low Flow (m³/s)	20 Year 7-day Low Flow (m³/s)
MH-1	Murray River	2,242	17.4	14.10	11.6
MH-2	Lower Camp Creek	42.97	0.02	0.01	0.00
MH-3	Twenty Creek	6.62	0.00	0.00	0.00
MH-4	Upper Camp Creek	21.08	0.01	0.00	0.00
MH-5	Mast Creek	4.12	0.01	0.00	0.00
MH-6	Mile 17 Creek	7.36	0.00	0.00	0.00
MH-7	Mile 19 Creek	52.39	0.00	0.01	0.01

Table 23.1-13. Estimated Annual Low Flow Indices for the Watersheds in the Project Area

Hydrometric Station	Watershed	Drainage Area (km²)	5 Year 7-day Low Flow (m³/s)	10 Year 7-day Low Flow (m³/s)	20 Year 7-day Low Flow (m³/s)
MH-1	Murray River	2,242	6.05	5.59	5.28
MH-2	Lower Camp Creek	42.97	0.002	0.005	0.001
MH-3	Twenty Creek	6.62	0.000	0.000	0.000
MH-4	Upper Camp Creek	21.08	0.001	0.000	0.000
MH-5	Mast Creek	4.12	0.000	0.000	0.000
MH-6	Mile 17 Creek	7.36	0.001	0.000	0.000
MH-7	Mile 19 Creek	52.39	0.003	0.003	0.001

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

Mitigation Measures

Mitigation measures relating to reducing drought-induced water quality declines include:

- separating hazardous waste from non-hazardous waste to maintain water quality. Hazardous waste will be transported off-site for disposal;
- constructing storage areas to minimize spills of fuel and other hazardous materials;
- diverting clean water around mine site infrastructure;
- constructing drainage ditches to collect Project area contact water;
- developing a water management plan that accounts for low-runoff years; and
- developing and implementing an environmental management plan for waste (Chapter 24) that describes waste sources, waste types, and waste streams (recycling, re-use, off-site disposal).

23.1.4 Wind

Based on the approximate 36 month dataset from the Murray River meteorological station, 1 to 2 m/s winds were the most frequent, occurring 33% of the time. The average wind speed from March 8, 2011 to March 8, 2013 was 2.1 m/s. The frequency of calm winds (less than 1 m/s) was 17%, and winds over 6 m/s (21.6 km/h) occurred less than 2% of the time. On the Beaufort scale, 21.6 km/h is at the lower end of the "moderate breeze" category, where dust and loose paper are raised, and small branches are moved (Environment Canada 2014a). The maximum gust speed recorded on-site was 20.8 m/s (74.9 km/h) on December 1, 2011. This is classified as a gale force wind. A gale force wind is described as capable of breaking twigs off trees, generally impedes progress, and walking into the wind is almost impossible.

Effects on the Project

Overall, as described above, winds in the Project area are generally low velocity and are unlikely have significant effects on the Project. However, rare high velocity winds do occur. High winds during below-freezing air temperatures would contribute to lowered wind chill, and blowing snow. Blowing snow would reduce visibility, limiting access to and from the mine site. High winds could also:

- dislodge roofing;
- destabilize covered walkways;
- damage or remove equipment shrouds and covers, which could then present a safety hazard;
- cause downed trees, which could temporarily block roads and the rail line;
- damage power lines and building services if improperly designed or installed; and
- create electrical blackouts.

Mitigation Measures

The meteorological station is recording on-site winds, which will guide construction techniques necessary to mitigate potential damage by wind. Weather forecasts will be monitored to anticipate and prepare for severe winds. During blackouts, non-essential machinery will be shut down until power is re-established.

23.1.5 Lightning

Summer thunderstorms are common within the Project area. Thunderstorms may be accompanied by lightning strikes, hail, and occasionally tornadoes. A thunderstorm is classified as severe when it contains hail larger than ¾" (1.9 cm) in diameter, winds gusting in excess of 50 knots (92.6 km/h) and/or a tornado. Thunderstorms frequently accompany severe rain storm events, but the severity of the damages is often greater than what would have been caused by the precipitation event alone.

Lightning strikes and flashes are monitored on an on-going basis through the Canadian Lightning Detection Network. Although there are no data for Tumbler Ridge, data do exist for Fort St. John (130 km north of Project), Prince George (180 km southwest of Project) and Grande Prairie (145 km east of Project). On average, Fort St. John experiences 24 lightning strikes/100 km^2/year, Prince

George experiences 21 lightning strikes/100 km^2/year, and Grande Prairie experiences 39 lightning strikes/100 km^2/year (Canadian Lightning Detection Network, Environment Canada). Lightning strikes are defined as the sum of both cloud-to-cloud and cloud-to-ground strikes. It is expected that the frequency of lightning strikes will be similar at the Project site.

Effects on the Project

The direct effects of lightning strikes on the Project include initiating fires and electrical failures. Fires resulting from lighting strikes could include buildings, infrastructures, equipment and machinery, stockpiled materials and the forested area within, or adjacent to, the Project area.

Mitigation Measures

Mitigation of lightning strikes primarily includes maintaining compliance with building codes (electrical standards and fire suppression systems) and fire control standards. British Columbia building codes will ensure that electrical and fire suppression systems are adequate for the structures. Appropriate fire suppression equipment will be readily available in buildings, site infrastructure, machinery, and personnel.

23.1.6 Wildfires

Wildfires are common landscape disturbances throughout forested and grassland ecosystems in BC. On average, 2,000 wildfires occur in BC every year; approximately 40% are caused by human activity and 50% by lightning ignition (BC MOF 2012). Probability of wildfire occurrence is dependent on fire behaviour, ignition potential, and suppression capability.

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

DeLong (2010) has refined this system based on subsequent research for Northeastern BC that better reflects the disturbance regimes for this region. The system has been implemented in the Prince George Timber Supply Area and in a Fort St John Pilot area; together they represent over 12 million ha of land. Natural Disturbance Units (NDUs) replace NDTs in this system. NDUs are further divided into sub-units based upon differing natural disturbance regimes in these areas.

In the LSA, there are four BEC zones assigned to NDUs: the Boreal White and Black Spruce - Moist Warm (BWBSmw); the Sub-Boreal Spruce Zone - Finlay-Peace Wet Cool (SBSwk2); the Boreal White and Black Spruce - Murray Wet Cool (BWBSwk1); and the Engelmann Spruce - Subalpine Fir - Bullmoose Moist Very Cold (ESSFmv2).

The BWBSmw, SBSwk2, and BWBSwk1 occur in the Boreal Foothills - Valley NDU, while the ESSFmv2 occurs in the Boreal Foothills - Mountain NDU. The forests in all of these NDUs experienced stand initiating events that were generally the result of large wildfires (> 1,000 ha). The mean fire return interval is 120 for the Valley sub-unit (BWBSmw1, SBSwk2, BWBSwk1) and 150 years for the Mountain sub-unit (ESSFmv2; DeLong 2010). Occasionally, stand ages exceed 200 years and the resulting stand structure is large areas of mature forest with patches of young forest and old forest concentrated patches. Age class structure was predominantly mature forest with 33-55% of the forest between 100-140 years; however, in some watersheds where fire had been absent old forests were the primary structural stage and 15-25% of the landscape was historically over 250 years between disturbance events (Table 23.1-14). In these NDUs, stand replacing fires accounted for 80-90% of total disturbance area with gap replacement due to disturbances such as windthrow or disease accounting for only 10-20%. This indicates the historic prevalence of fires in these NDUs as a disturbance agent and helps to characterize fire hazard.

Table 23.1-14. The Natural Age Distribution of Forests in the Boreal Foothills – Mountain and Boreal Foothills – Valley NDUs and the Prevalence of Stand Replacing Fires

Natural Disturbance Unit	BEC Unit	Stand Replacement Disturbance Cycle	Time Since Disturbance Distribution (% Total of Forested Area)				
			> 250 Years	> 140 Years	> 100 Years	< 40 Years	% Stand Replacing Fire
Boreal Foothills – Mountain	ESSFmv2	150	15–25	33–49	43–62	19–36	80
Boreal Foothills – Valley	BWBSmw, SBSwk2, BWBSwk1	120	8-17	23-40	33-55	19-45	90

Source: DeLong (2010)

Forest health is also a consideration when addressing fire hazard. Extensive mortality associated with *Dendroctonus ponderosae* (mountain pine beetle) of *Pinus contorta* (lodgepole pine) has occurred in the LSA. Based on Provincial cumulative kill projections (Version 10), approximately 22% and 26% of pine volume was killed between 1999 and 2012 in the LSA and RSA respectively. This can result in increased ignition potential and fire behaviour due to cured standing and downed fuels. Fire behaviour is highest during the red-attack phase (1 to 2 years) and decreases in grey attack phases as fine fuels (< 7.5 cm in diameter) decrease over time (2 to 10 years). As the standing grey attack trees fall, they contribute to surface fuels. These surface fuels, in combination with tree regeneration during this stage, can result in an increase in expected fire behaviour during this stage (10 to 30 years approximately). As these fuels decay, fire behaviour decreases. Adjacent to valued infrastructure components, fuel mitigation measures in beetle attacked stands are important to consider to reduce the likelihood of fire related losses or impacts.

To provide a more locally specific assessment of fire history, the use of fire ignition records is pertinent. The BC Government Wildfire Management Branch (WMB) maintains a spatial database of fires back to 1951 (WMB 2013). The database indicates fire location, date, and cause (human or lightning), and is useful in determining wildfire probability for an area. In the 2,276 km^2 RSA, 48% of the fires were human caused, the remainder were started by lightning (43%) or have unknown causes (9%). Since 1951, there have been 187 fires recorded in the RSA (Table 23.1-15).

Table 23.1-15. Fire Occurrences for Each Decade by Cause in the LSA and RSA

	Number of Fires by Cause in the LSA				Number of Fires by Cause in the RSA			
Decade	Lightning	Human	Unknown	Grand Total	Lightning	Human	Unknown	Grand Total
1950	-	-	-	-	1	-	-	1
1960	-	1	-	1	13	3	-	16
1970	-	-	-	-	10	19	-	29
1980	4	1	-	5	20	26	-	46
1990	2	-	1	3	16	14	1	31
2000	-	2	-	2	15	19	13	47
2010	-	2	1	3	6	9	2	17
Grand Total	6	6	2	14	81	90	16	187

In the LSA, which is 149 km^2 in size, human and lightning ignitions are responsible for 43% of fires and 14% had unknown causes. There have been 14 fires recorded in the LSA since 1951.

Based on the wildfire record over the previous 63 years and the NDUs that dominate the LSA and RSA, probability of wildfire will generally be moderate. However, under high or extreme fire danger, high or extreme wildfire behaviour could occur.

Effects on the Project

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

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

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

Mitigation Measures

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

- incorporating Canada vegetation management and building design where possible (FireSmart Canada 2013);
- creating zones of 30 m around all structures where vegetation is maintained in a low hazard state;

- conducting hazard assessments to ensure risk of fire to structures is acceptable;
- training for designated permanent employees (e.g., Provincial S100 Basic Fire Suppression and Safety training) and ensuring sufficient trained personnel are on site during the fire season to action a fire;
- ensuring employees have access to appropriate personal protective gear to action a wildfire;
- developing an evacuation plan in case of wildfire, in particular consider loss of the egress route along the exploration access road;
- erecting fire danger signs in visible locations that are updated throughout the fire season to ensure personnel are aware of current fire hazard conditions;
- ensuring water sources have adequate volumes to action fires and that pumps or other water delivery systems can provide sufficient pressure for the effective use of hoses, sprinklers and other fire suppression tools;
- locating water pumps and fire-fighting equipment strategically around the Project to help contain/extinguish any fire;
- equipping a vehicle with firefighting tools (shovels, pulaskis, and axes), water, and portable pumps to supply initial attack to accessible fires;
- using mining equipment such as dozers in the case of a fire to remove vegetation around the infrastructure, thus removing fuel for the fire;
- providing backup generators for use in the event of transmission line loss. The generators will have enough power capacity to operate essential equipment (e.g., ventilation, fire suppression, etc.);
- properly storing flammable materials, banning heat and flame in these areas, and providing proper signage;
- training personnel in fire response and containment, including:
- use of fire extinguishers for small fires in buildings;
- raising an alarm and seeking assistance;
- monitoring British Columbia Ministry of Forests, Lands and Natural Resource Operations fire alerts; and
- complying with all relevant legislation in the BC *Wildfire Act*.

23.2 GEOPHYSICAL EFFECTS

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

23.2.1 Natural Seismic Events

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 American Plate. However, the Project is distant from these faults (more than 600 km); earthquake frequency and size decrease moving inland from the coast. As a result, seismic activity is relatively low in the Project region.

An analysis of seismic hazards was performed using the 2010 National Building Code of Canada seismic hazard calculator (NRC 2013). Peak Ground Acceleration (PGA) is a measure of how hard the earth shakes, and is measured in units of acceleration due to gravity (g). PGA was calculated for the Project area for three return periods, assuming firm ground (Table 23.2-1). The United States Geological Survey (USGS) has developed a table of intensity descriptions for PGA (USGS 2013). A PGA of 0.025 g would be perceived as “light”, and would not cause structural damage. A PGA of 0.080 would be perceived as a moderate quake, with “very light” potential structural damage.

Table 23.2-1. Exceedance Probability, Risk, and Peak Ground Acceleration for Seismic Events at Murray River

Event	PGA (g)	Probability for Any Single Year (%)	Probabilities for Project Phases[1] (%)		
			Operation (YR 1 to YR 25)	Operation + Decommissioning and Reclamation (YR 1 to YR 28)	Operation + Decommissioning and Reclamation + Post Closure (YR 1 to YR 59)
1-in-100-year	0.023	1	22.2	24.5	44.7
1-in-500-year	0.06	0.2	4.9	5.5	11.1
1-in-1,000-year	0.085	0.1	2.5	2.8	5.7

[1] The probabilities of events occurring Project phases are calculated using the hydrology frequency analysis formula:
Probability (risk) = $1 - (1 - P)^n$ where P is the probability for an event in any single year, and n is the Project phase length.

23.2.1.1 *Effects on the Project*

The above analysis points towards the Project being at low risk of a damaging seismic event. For example, there is a 5.7% chance of a 1:1,000 year event occurring, with a PGA of 0.085, which would cause very light structural damage at the surface. However, where infrastructure is not built on firm ground, or where unconsolidated material is deposited on slopes, damage to infrastructure and risk to workers could be greater.

Other areas where earthquake-induced slope failures are a potential concern are the steep slopes of the Camp Creek watershed (potential rockfall and Creek blockage), and bluffs composed of glaciofluvial material on the east side of Murray River, especially about two kilometres north of the coal processing plant (potential localized slope failures).

23.2.1.2 *Mitigation Measures*

A mine rescue emergency response plan will be developed. The plan will ensure that there are always trained first response personnel on-site when there are workers employed underground.

The number and type of first responders depends on the number of workers employed underground. There will also be personnel on-site trained in first aid, firefighting, mine rescue, and hazardous material handling and clean up. Appropriate emergency equipment will be on-site. For more details, please refer to the Environmental Management and Monitoring Plans (Chapter 24).

Site infrastructure will be located in areas that avoid or minimize exposure to weak, unconsolidated soils or soils that are assessed to be potentially liquefiable, where practical. Where infrastructure is to be built on weak, compressible, or potentially liquefiable 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. All structures will be thoroughly assessed for stability and integrity after seismic events.

23.2.2 Slope Stability and Mass Movement

Evidence of mass movement and soil erosion has been noted near steeper slopes in the LSA: mostly slow mass movements and gullying. Slow mass movement typically refers to slope movement that occurs at a very slow rate and typically travels a short distance; conversely, rapid mass movement refers to a rapid, gravity induced down slope movement by sliding, falling, rolling or flowing of either bedrock or surficial material. The Project area is characterized by unconsolidated surficial materials overlying bedrock with occasional bedrock outcrops. Geohazard mapping for the Project area was completed in 2013 and is presented in detail in Chapter 10.

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

Terrain stability maps were based on terrain classification and slope gradient information prepared by Rescan and presented in the terrain stability and natural hazards baseline report in Chapter 10. The terrain stability maps provide a relative assessment of stability but provide no indication of the expected frequency, magnitude, or consequence of failure.

23.2.2.1 Effect on the Project

Effects of Liquefaction on the Project

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

Effects of Channel Debris Flows on the Project

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

Effect of Snow Avalanches on the Project

A combination of terrain and climatic conditions primarily influences the extent of snow avalanche hazards. Generally, snow avalanches occur in areas where there are steep, open slopes or gullies that are covered with 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).

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. Risks associated with avalanches are due to exposure to the high impact forces and the potential for extended burial.

The LSA does not contain avalanche prone terrain with slopes greater than 60%. For this reason it is not foreseeable that avalanches will have an effect on the Project.

Effects of Rock Falls on the Project

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

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

23.2.2.2 Mitigation Measures

Liquefaction: identify areas with high potential for liquefaction. Prevent construction of building in those areas. Use engineered piles for footings. Remove hazard if technically and economically feasible.

Channel Debris Flows: an assessment of creek bank stability and debris flow potential should be made at road crossings for bridge and culvert design.

Snow Avalanches: During construction and operational phases of the Project if work is to be conducted on terrain outside the LSA that is greater than 30% incline then an avalanche hazard assessment will be developed to identify and mitigate risks to personnel.

Rock falls: Mine Site buildings, infrastructure, machinery and work zones will be located away from overhead hazards to mitigate against rockfalls.

23.3 CLIMATE CHANGE

23.3.1 Past Climate Change

Climatic proxy records such as lake sediments, ice cores, and tree rings are used to reconstruct climate before instrumental records exist. At the last glacial maximum, from 25 to 14 thousand years before present (ka BP), ice sheets covered the entirety of northern North America (Bradley 1999). British Columbia was largely covered by the Cordilleran Ice Sheet until deglaciation began around 14 ka BP. Deglaciation ended around 10 ka BP, and temperatures largely cooled until the end of the Little Ice Age, which ended in the mid-19th century (Walker and Sydneysmith 2007). Air temperatures have warmed since the end of the 600-year long Little Ice Age, which initiated continuing widespread glacial retreat at lower elevations in the province.

Beginning in the early-to-mid 20th Century, instrumental meteorological data sets were of sufficient number and quality to produce province-wide climatic records. From 1900 to 2004, air temperature increased by 0.08 to 0.1°C per decade (Walker and Sydneysmith 2007).

23.3.2 Climate Change Projections for the Project Area

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

As noted in Section 23.1.1.3, several cyclical climatic patterns influence the climate of the Project area, including the PDO and ENSO. The effects of global warming on these patterns are poorly understood. However, in a review of GCMs results from the IPCC AR4 report, it was found that the negative phase of the PDO increased in frequency, especially after 2050. Overall, climate of the Project area is expected to warm and experience more precipitation in the future; however, if the PDO were to increasingly experience a negative phase, then these effects would be dampened, but not reversed (see below). The ENSO is expected to experience an "El Niño-like" mean state change, but no change in amplitude (Lapp et al. 2012).

Climate change in the Project area was assessed quantitatively using the computer program ClimateWNA (Wang et al. 2006; Wang et al. 2012). ClimateWNA aggregates downscaled global climate model (GCM) outputs for various greenhouse gas (GHG) emissions scenarios and time periods. Downscaling is performed for specific locations based on latitude, longitude, and elevation. For this analysis, data were obtained for the location and elevation of the Murray River Project area meteorological station (1,055 masl; 55.02°N, 121.08°W).

It is recommended that a range of GHG and GCM predictions be considered (BCWWA 2013b). Variability from two sources was considered:

- variability in GHG emissions scenarios; and
- variability between GCMs using identical emissions scenarios.

Variability in emissions scenarios was assessed by analyzing data from three GHG scenarios: A2, A1b, and B1. These scenarios present a range of possible climatic conditions based on assumptions of future population, economics, and technology. The A2 scenario assumes exponentially increasing atmospheric CO_2 levels continuing to the end of the 21st century, reaching 800 ppm by 2100. In the A1b scenario, concentrations stabilize at 720 ppm by the end of the century. The B1 scenario assumes that GHG emissions will plateau between 400 and 500 ppm by mid-century. In 2013, the average CO_2 concentration at Mauna Loa was 396.5 ppm. Details of the assumptions in Intergovernmental Panel on Climate Change (IPCC) emission scenarios are available in Nakićenović et al. (2000). Data were extracted for the decades of the 2020s, 2050s, and 2080s.

Variability between GCMs was assessed by extracting data from multiple GCMs using identical GHG forcing. For each scenario, and for each time period, data from six to seven GCMs were extracted (all available data in ClimateWNA were extracted). Results for each scenario and decade are presented as averages, and high and low extremes (Figure 23.3-1). Between-GCM variability is large; however, the direction of predicted change is consistent within individual GCM's: a warmer and wetter climate. Historic climate conditions are represented by presenting two "climatic normal": 1961-1990 and 1981-2010.

Monthly average air temperature and precipitation were also extracted and plotted for the A2 scenario and climatic normals (Figure 23.3-2; data shown are averages from all available GCMs). Climatic changes are generally less for the A1b and B1 scenarios (Figure 23.3-2).

23.3.2.1 Air Temperature

Generally, warming at higher latitudes in BC is expected to be greater than for southern BC, as positive feedbacks associated with climate change are more pronounced (PCIC 2011). ClimateWNA estimates that at 1,055 masl in the LSA, average annual air temperature was 2.7°C from 1961-1990, and 4.6°C from 1981 to 2010. By comparison, by 2080, average annual air temperature for the A2 scenario is predicted to be 6.3°C. The same magnitude of warming is predicted for the A1b scenario. For the B1 scenario, where GHG concentrations stop increasing by mid-century, average annual air temperature is expected to be 5.2°C by 2080 (Figure 23.3-1). The Post Closure phase should be ending around 2080.

Climatic normal maximum monthly air temperatures were about 22°C in the past (Figure 23.3-2B). By 2080, GCMs predict air temperatures of about 26°C for the A2 and A1b scenarios on average. Between-GCM variability is large compared to predicted warming (up to about 3.4°C). Given the small sample size, this variability cannot be statistically analysed, but should be kept in mind while interpreting results.

23.3.2.2 Precipitation

Precipitation is expected to increase more in the northern part of the province. Increases are expected to be especially great in winter, spring, and fall (PCIC 2011). This is corroborated by the Murray River GCM data. Monthly precipitation totals are expected to increase the most in fall and winter, and increase the least in summer (Figure 23.3-2C). As a result, the magnitude of the increase in snowfall is particularly great (Figure 23.3-2D). Depending on the GHG scenario, annual precipitation is expected to increase by 23 mm (A1b) to 81 mm (A2; Figure 23.3-1C).

Figure 23.3-1

Global Climate Model Predictions at the Murray River LSA: Annual Averages and Inter-GCM Variability

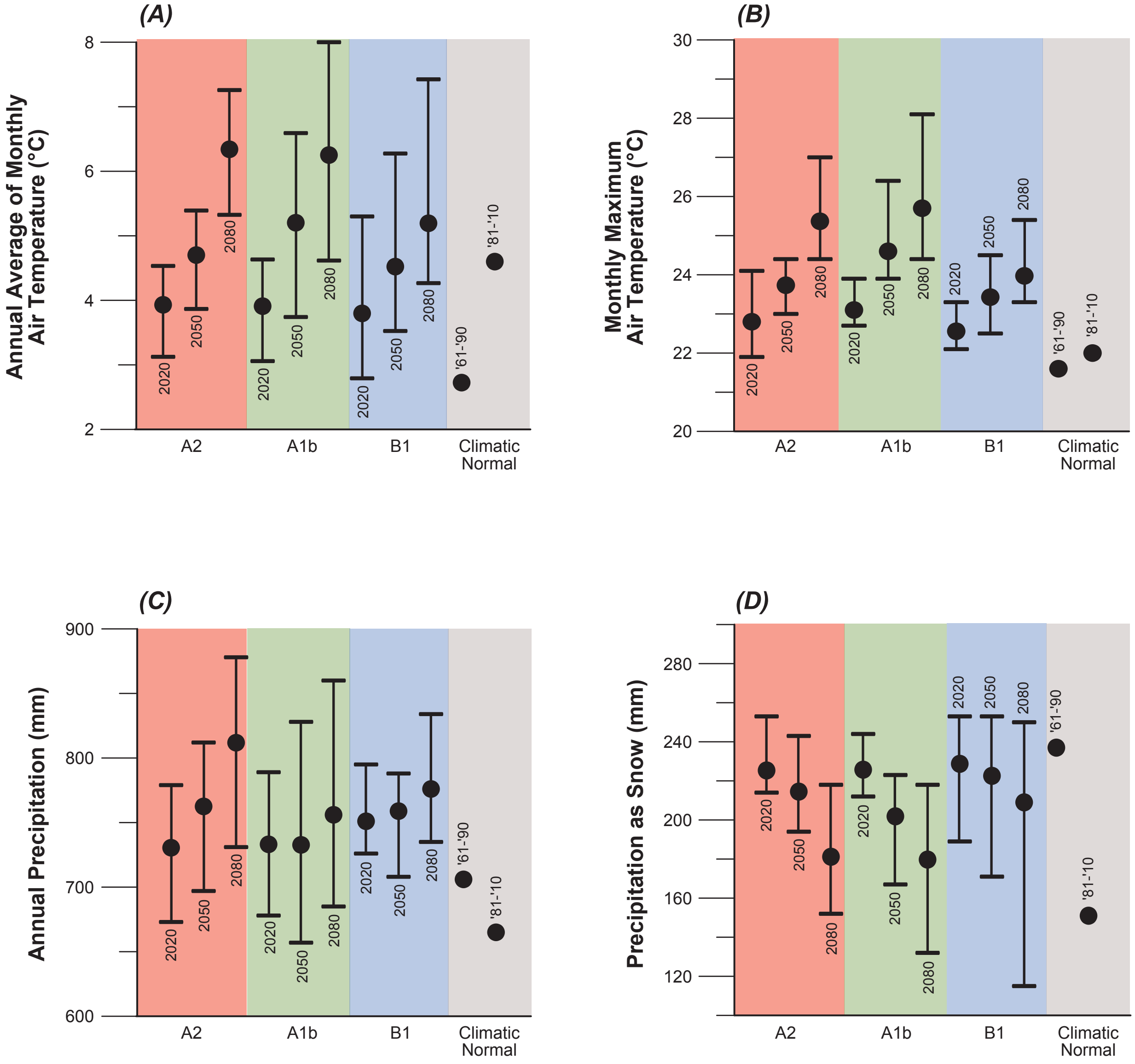
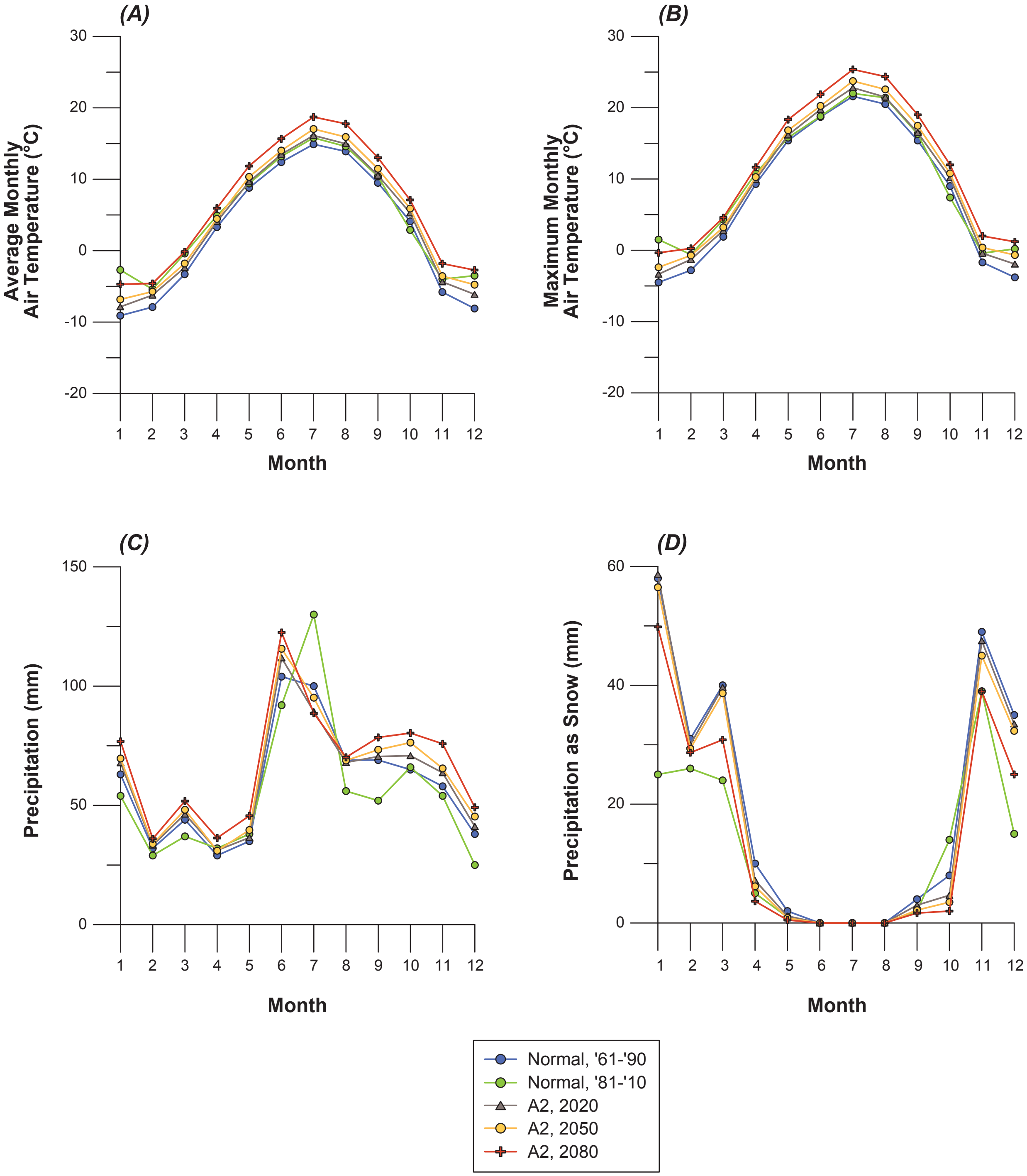


Figure 23.3-2

Global Climate Model Predictions at the Murray River LSA: Monthly Averages for the A2 GCM Scenario and Climatic Normal



Predicting the response of snowfall is particularly uncertain. Modern mean daily maximum air temperatures recorded at the Project area meteorological station are near freezing for most of winter, and above freezing for most of spring (Rescan 2014b). In the future, precipitation could increasingly fall as rain in winter and spring, especially at lower elevations in the Project area.

Modelled changes in snowpack are within the range of historic variability. For example, in the A2 scenario, in the 2020s, 2050s, and 2080s, January snowpack is expected to roughly double over the 1981-2010 time period. However, modelled snowpack is very similar to the 1961-1990 climate normal period (Figure 23.3-2D). The 1961-1990 climate normal reflects a cool and wet period compared to more recent conditions (Figure 23.3-1A, C).

23.3.2.3 Stream Flow

To evaluate climate change impacts on stream flow, hydrologic modelling results were obtained for the Murray River (Schnorbus, Werner, and Bennett 2012). Modelling was performed by the Pacific Climate Impact Consortium (PCIC) using the Variable Infiltration Capacity (VIC) hydrologic model (Liang et al. 1994; Gao et al. 2010). The model was calibrated and validated using historic data from the WSC hydrometric station "Murray River above Wolverine River" (ID 07fb006). The VIC model is a distributed hydrologic model, and was run with a 1/16 degree grid size (about 6-7 km in the Project area). Calibration and validation results are as follows: calibration 1990-1995 (Nash Sutcliff: 0.73, %Volume Bias: -1), Validation 1985-1989 (Nash Sutcliff: 0.58, %Volume Bias: -15).

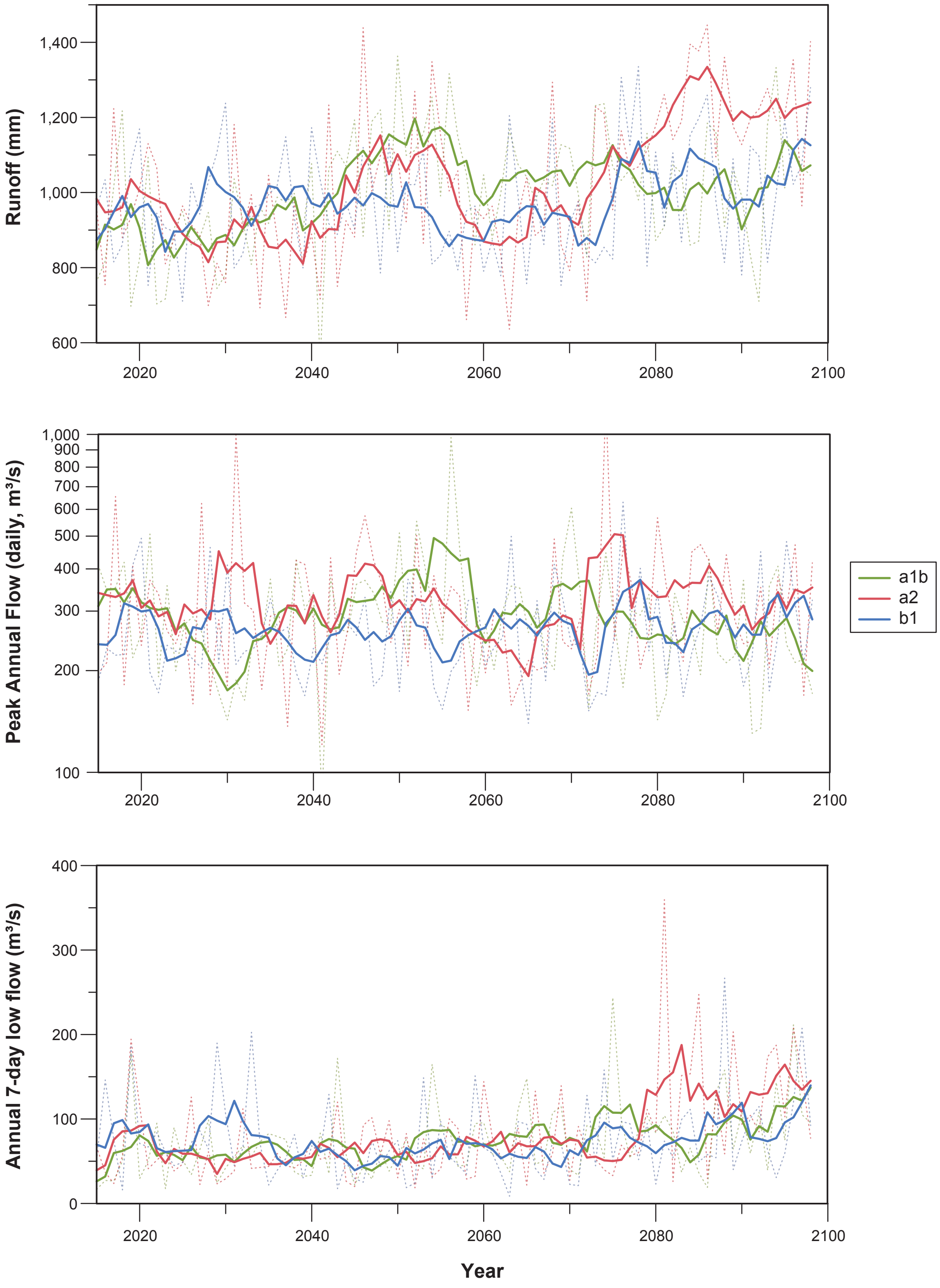
The model was run using statistically downscaled Global Climate Model (GCM) air temperature and precipitation predictions. Weather data were downscaled with the "bias-correction/spatial downscaling" (BCSD) technique (Werner 2011; Schnorbus, Werner, and Bennett 2012). The GCM CGCM3 was chosen based on its performance relative to other Coupled Model Intercomparison Project (CMIP) models (Werner 2011). The greenhouse gas (GHG) scenarios A1b, B1, and A2 were used (Sections 23.3.3.1, 23.3.3.2).

Annual hydrometric indices are presented in Figure 23.3-3. Annual runoff is expected to increase. The Q2 runoff for 07fb006 is currently 764 mm, and is expected to increase to 1,100-1,250 mm by the end of the century, depending on the GHG scenario. These runoff magnitudes are equivalent to the modern 20 to 100 recurrence intervals (Rescan 2014a). Modern peak annual daily discharge is modelled at 200 to 400 m^3/s, and typically currently occurs during freshet. Little change in the magnitude of peak annual flow is modelled throughout century. The Q2 annual 7-day low flow is currently 25 m^3/s. There is a large increase in annual low flow beginning around 2075 in the A2 scenario. It is likely that modelled winter air temperatures are sufficiently high for significant melt to continue through winter. For runoff and peak flow, the GHG scenario makes little hydrologic difference until mid-to-late century.

The effects of the changes on annual indices are investigated in Figure 23.3-4. Panel "A" shows average hydrographs for the decades of the 2010s, 2050s, and 2090s for the A2 GHG scenario. The shift to higher winter flows is particularly evident in the 2090s, when flows more than double. This represents results from the most pessimistic GHG scenario, towards the end of the century when effects are most pronounced, and after the post closure phase is complete.

Figure 23.3-3

Murray River (07fb006) Stream Flow Predictions for the 21st Century: Runoff, Peak Flow, and Annual 7-day Low Flow

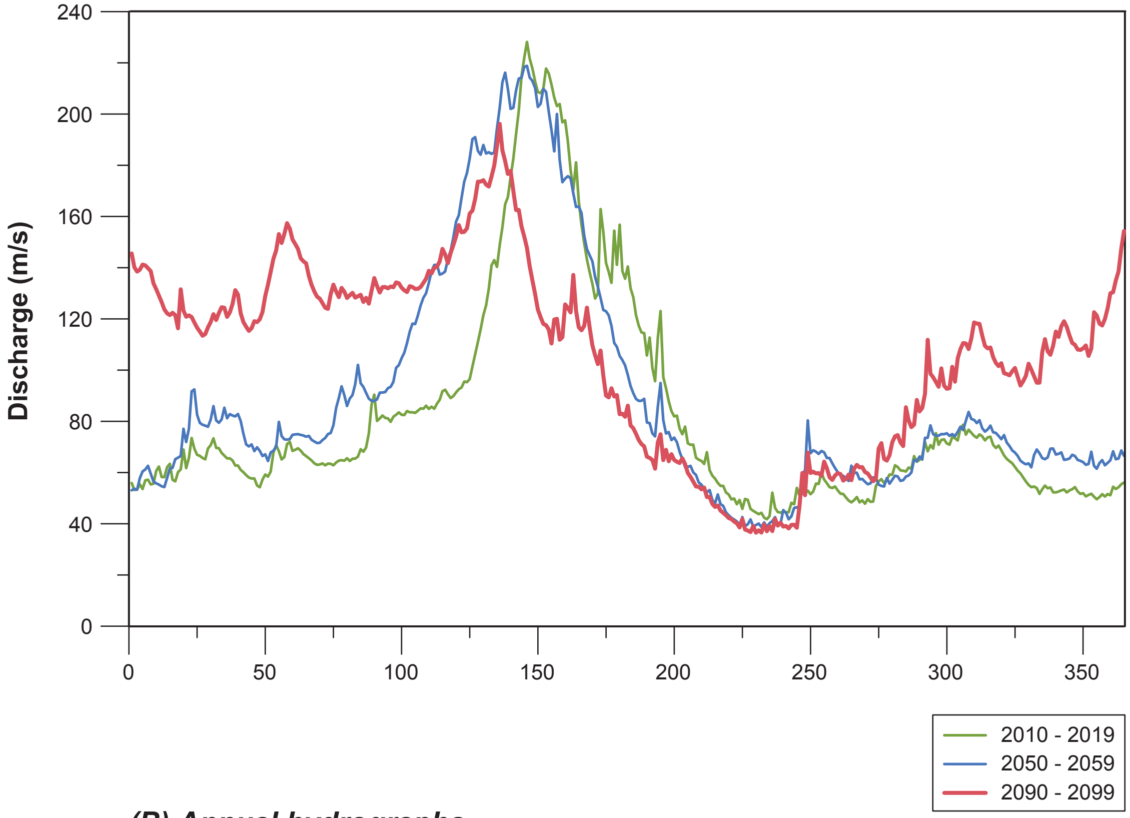


Note: Data includes annual and 5-year running averages.

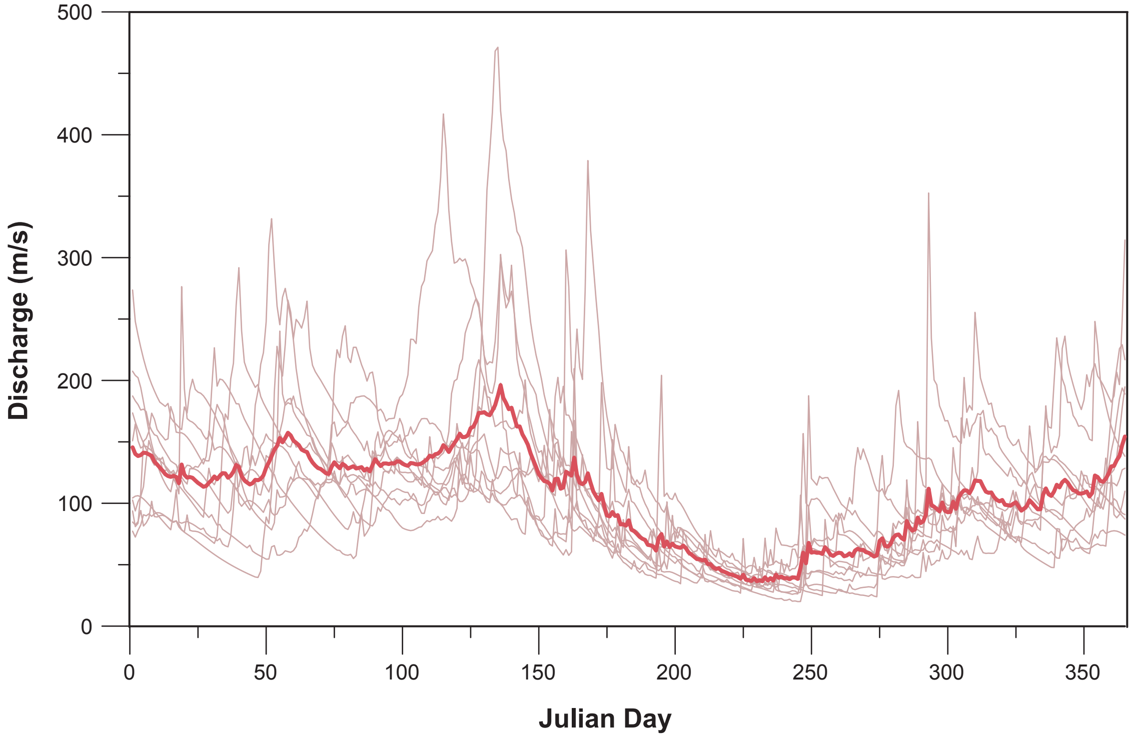
Figure 23.3-4

Murray River (07fb006) Mean Decadal Flows for the 2010s, 2050s, and 2090s under the A2 Scenario and Annual Hydrographs for the 2090s

(A) Mean decadal flows



(B) Annual hydrographs



Presenting decadal average data homogenizes annual hydrographs, and discrete flow events are not evident. Annual hydrographs for the 2090s are presented, with the decadal average in red (Figure 23.3-4, panel B). These hydrographs show considerable interannual variability in the timing and magnitude of peak flow. All show the importance of winter rainfall runoff events toward the end of the century. Winter flow is likely driven both by significant rainfall and by snowmelt, and represents a very different hydrologic regime from present day.

Decadal average flows also show progressive advancement of the date of peak flow. By the end of the century, under the A2 scenario, the date of peak flow is expected to advance by about two weeks (Figure 23.3-4, panel A). Again, this represents the most pessimistic GHG scenario analysed.

The decadal plots show peak flows remaining relatively constant throughout the century, despite an increase in total annual runoff. Precipitation increases, but is not being stored as snow (Figure 23.3-1), and therefore does not contribute to the freshet. Rather, runoff increases in winter (Figure 23.3-4).

The grid size of the VIC model precludes its use in smaller watersheds surrounding the mine site, so climate change effects on these rivers can only be qualitatively assessed. The date of freshet in these watersheds will likely advance, and runoff and winter flows will also likely increase.

23.3.3 Project-related Adaptation and Mitigation Measures

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

Components of the environment and Project affected by climate change are listed below. Each component is discussed and categorized in terms of the severity of their anticipated impacts. Categories are **negligible, low, moderate,** and **high** (Table 23.3-1). Each are defined relative to the likelihood of change in interaction, risk of effects to Project, and consequent effects to environment/ health and safety.

23.3.3.1 Air Temperature

Project components are designed to withstand a wide range of air temperatures, including the temperature ranges projected by GCMs for various GHG scenarios (Figures 23.3-1 and 23.3-2). Increasing the number of freeze-free days would be beneficial to the Project in some respects, such as reducing heating costs, and reducing exposure of personnel to extreme cold. Climate change is predicted to induce milder winters in this region, which would likely produce more freeze-thaw cycles. If improperly designed, this increase would accelerate roadway, railway, and natural gas pipeline deterioration, and increase maintenance costs. More frequent freeze-thaw cycling also has the potential to compromise the strength of other site infrastructure, including power transmission lines, building foundations, and mine portals and shafts.

Changes to air temperature and freeze-thaw cycles are expected to have **no impact** to **low impact** on personnel (Table 23.3-1).

Table 23.3-1. Potential Project Component Sensitivities Arising from Climate Change

		Air Temperature			Precipitation		Stream Flow			
Category	Component	Increase from Mean Modern	Freeze-Thaw Cycles	Extreme Heat	Increase from Mean Modern	Extreme Rain and Snow	Flooding	Drought	Increased Wind Velocity	Increased Wildfires
Transportation	Rail load-out	n/a	negligible	n/a	n/a	n/a	n/a	n/a	n/a	moderate
	Rail line, road surface, ditches, culverts	n/a	moderate	n/a	moderate	high	high	n/a	n/a	moderate
Surface infrastructure	Buildings (maintenance, administration, warehouse), coal conveyor, coal rejects storage area, coal stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile.	low	moderate	low	low	moderate	high	n/a	low	moderate
Subsurface infrastructure	Groundwater extraction well, main access shaft, ramps, portals, tunnels, ventilation shaft for return air	n/a	n/a	n/a	n/a	n/a	low	n/a	low	moderate
Utilities	Electric transmission line	n/a	moderate	n/a	low	moderate	high	n/a	low	moderate
	Natural gas pipeline	n/a	moderate	n/a	negligible	low	low	n/a	n/a	moderate

23.3.3.2 Precipitation

Project components are either designed to handle snow, or have management plans in place for handling snow and rain. It is possible that extreme snowfall events will increase in frequency and magnitude. Engineering systems in place could handle increases in snowfall from current ranges. During mine Operation, higher annual precipitation may increase the amount of groundwater seepage and precipitation that flows into mine shafts, which would increase dewatering costs (moderate sensitivity). Increases in the frequency and magnitude of extreme snow and rain may occasionally limit travel on access roads. All other Project components are ranked as having negligible to low sensitivities to increased precipitation due to climate change.

23.3.3.3 Stream Flow

Streams convey water to pipelines and ponds, and drainage ditches that have been designed to withstand floods with long return periods (**moderate** sensitivity). All other Project components are ranked as having **negligible** to **low** sensitivities to increased stream flow due to climate change.

23.3.4 Climate Change Regulatory Context and Adaptation

23.3.4.1 Regulatory Context of Climate Change

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

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

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

Climate change in the Project area will not increase risks to the public, public resources, the environment, other businesses or individuals. However, this chapter has discussed the effects of climate change on the Project and mitigation measures to allow the reader to make this assessment for themselves.

23.3.4.2 Climate Change Adaptation

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

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

To respond to these uncertainties, an adaptive management approach to climate change will be taken. Adaptive management involves using learning to continuously improve policies and practices. Adaptive management is useful because it allows for flexible responses to change whose timing and magnitude are not known. Adaptive management has six components: assess the problem, design a solution, implement the solution, monitor the results, evaluation, and adjustment (Ministry of Forests and Range 2013).

REFERENCES

Allen, M. R. and W. J. Ingram. 2002. Constraints on future changes in climate and the hydrologic cycle. *Nature*, 419: 224-30.

AMS. 2012. *American Meteorological Society. Cimate Change. An Information Statement of the American Meteorological Society*. Boston, MA.

APEGBC. 2010. *Association of Professional Engineers and Geoscientists of British Columbia. Report of the Climate Change Task Force*. Burnaby, BC.

APEGBC. 2012. *Association of Professional Engineers and Geoscientists of BC. Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC*.

BC EAO. 2013. *Murray River Coal Project. Application Infromation Requirements as Approved by the Environmental Assessment Office on September 3, 2013 For HD Mining International Limited's Application for an Environmental Assessment Certificate*. Issued by the British Columbia Environmental Assessment Office: Victoria, BC.

BC MOE. 2010. British Columbia Ministry of Environment. Preparing for Climate Change. British Columbia's Adaptation Strategy. http://www.env.gov.bc.ca/cas/adaptation/pdf/Adaptation_Strategy.pdf (accessed September 2013).

BC MOF. 1995. *Biodiversity Guidebook*. British Columbia Ministry of Forests, Forest Practices Code: Victoria, BC.

BCWWA. 2012. *BC Water & Waste Association. Position Statement. Climate Change Adaptation (March 2012 Draft)*. https://www.bcwwa.org/resourcelibrary/Position%20Statement%20-%20Climate%20Change.pdf (accessed September 2013).

BCWWA. 2013a. *BC Water & Waste Association. Climate Change Context Statement: Adopted by BCWWA Board of Directors January 25, 2013*. https://www.bcwwa.org/resourcelibrary/Position%20Statement%20-%20Climate%20Change.pdf (accessed September 2013).

BCWWA. 2013b. *BC Water & Waste Association. Position Statement. Adapting Infrastructure for a Changing Climate. Adopted by BCWWA Board of Directors January 25, 2013*. https://www.bcwwa.org/resourcelibrary/Position%20Statement%20-%20Climate%20Change.pdf (accessed September 2013).

Bitz, C. M. and D. S. Battisti. 1999. Interannual to decadal variability in climate and the glacier mass balance in Washington, Western Canada, and Alaska. *Journal of Climate*, 12: 3181-96.

Bradley, R. S. 1999. *Paleoclimatology: reconstructing climates of the quaternary*. San Diego, CA: Harcourt academic press.

CEAA. 2003. *Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment. Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners*. http://www.ceaa-acee.gc.ca/Content/A/4/1/A41F45C5-1A79-44FA-9091-D251EEE18322/Incorporating_Climate_Change_Considerations_in_Environmental_Assessment.pdf (accessed September 2013).

CEAA. 2013. *Canadian Environmental Assessment Agency. Environmental Impact Statement Guidelines. Guidelines for the preparation of an Environmental Impact Statement for an environmental assessment conducted pursuant to the Canadian Environmental Assessment Act, 2012. Murray River Coal Project HD Mining International Ltd.* Prepared by the Canadian Environmental Assessment Office: Ottawa, ON.

Cubash, U. and G. A. Meehl. 2001. Projections of Future Climate Change. In *Climate Change 2001: The Scientific Basis Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Ed. J. T. Houghton et al. New York: Cambridge Univ. Press.

DeLong, C. 2010. *Land Units and Benchmarks for Developing Natural Disturbance-based Forest Management Guidelines for Northeastern British Columbia*. BC Ministry of Forests and Range, Forest Sciences Program: Victoria, BC.

Dettinger, M. D., D. R. Cayan, G. J. McCabe, and D. R. p. Rodenhuis. 1993. *Decadal trends in runoff over the Western United States and links to persistent North Pacific sea-surface-temperature and atmospheric-circulation patterns. Proceedings of the Eighteenth annual climate diagnostics workshop*. Eighteenth annual climate diagnostics workshop. Boulder, CO, United States.

Environment Canada. 2014a. *Beaufort Wind Scale Table.* http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=80C039A3-1 (accessed February 2014).

Environment Canada. 2014b. *Climate Trends and Variations Bulletins.* http://www.ec.gc.ca/adsc-cmda/default.asp?lang=En&n=8C03D32A-1 (accessed February 2014).

Environment Canada. 2014c. *Historical Climate Data.* http://climate.weather.gc.ca/index_e.html #access (accessed February 2014).

FireSmart Canada. 2013. https://www.firesmartcanada.ca/become-firesmart/industry-partners/ (accessed October 2013).

Gao, H., Q. Tang, X. Shi, C. Zhu, T. J. Bohn, F. Su, J. Sheffield, M. Pan, D. P. Lettenmaier, and E. F. Wood. 2010. Water Budget Record from Variable Infiltration Capacity (VIC) Model. *Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model*: http://www.hydro.washington.edu/SurfaceWaterGroup/Publications/Water_Cycle_MEaSUREs_ATBD_VICmodel_submit.doc (accessed March 2014).

Gedalof, Z. e. and D. J. Smith. 2001. Interdecadal climate variability and regime-scale shifts in Pacific North America. *Geophysical Research Letters*, 28: 1515-18.

Groisman, P., R. W. Knight, D. R. Easterling, T. R. Karl, G. Hegerl, and V. N. Razuvaev. 2005. Trends in Intense Precipitation in the Climate Record. *Journal of Climate*, 18: 1326-50.

Hodge, S. M., D. C. Trabant, R. M. Krimmel, T. A. Heinrichs, R. S. March, and E. G. Josberger. 1998. Climate variations and changes in mass of three glaciers in Western North America. *Journal of Climate*, 11: 2161-79.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC. 2013. *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis. Summary for Policymakers.* Cambridge: Cambridge University Press.

Lapp, S. L., J.-M. St. Jacques, E. M. Barrow, and D. J. Sauchyn. 2012. GCM projections for the Pacific Decadal Oscillation under greenhouse forcing for the early 21st century. *International Journal of Climatology*, 32 (9): 1423-42.

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges. 1994. A Simple hydrologically Based Model of Land Surface Water and Energy Fluxes for GSMs. *Journal of Geophysical Research*, 99(D7): 14415-28.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society*, 78: 1069-79.

Ministry of Forests and Range. 2013. *Defining Adaptive Managment*. http://www.for.gov.bc.ca/hfp/amhome/Admin/index.htm (accessed June 2014).

Nakicenovic, N., J. Alcamo, G. Davis, B. Vries, J. Fenhann, and S. Gaffin. 2000. *IPCC Special Report Emissions Scenarios, Summary for Policymakers. A Special Report of IPCC Working Group III*. Intergovernmental Panel on Climate Change.

Neal, E. G., M. T. Walter, and C. Coffeen. 2002. Linking the pacific decadal oscillation to seasonal stream discharge patterns in Southeast Alaska. *Journal of Hydrology*, 263: 188-97.

NOAA. 2013. *Linear Correlations in Atmospheric Seasonal/Monthly Averages*. Earth System Research Laboratory, Physical Sciences Division.

NRC. 2013. Natural Resources Canada On-line Bulletin. Earthquakes Canada, GSC, Earthquake Search. http://earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-eng.php (accessed October 2013).

Obedkoff, W. 2003. *Streamflow in the Omineca-Peace Region (Supplement).* Province of British Columbia, Ministry of Environment, Lands and Parks, Water Inventory Section, Aquatic Information Branch.

PCIC. 2011. *Hydrologic Impacts of Climate Change on BC Water Resources.* Summary Report for the Campbell, Columbia and Peace River Watersheds. Pacific Climate Impacts Consortium.

Rescan. 2013a. *Murray River Coal Project, Hydrometeorology Report*. Prepared for HD Mining International Ltd. by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2013b. *Murray River Coal Project: Application Information Requirements. With respect to an Application for an Environmental Assessment Certificate pursuant to the Environmental Assessment Act [S.B.C. 2002] c.43.* . Submitted to: British Columbia Environmental Assessment Office. Prepared for HD Mining International Ltd. by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2014a. *Murray River Coal Project, 2011 to 2013 Hydrology Baseline Report*. Prepared for HD Mining International Ltd. by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2014b. *Murray River Coal Project, 2011 to 2013 Meteorology Baseline Report*. Prepared for HD Mining International Ltd. by Rescan Environmental Services Ltd.: Vancouver, BC.

Schnorbus, M., A. Werner, and K. Bennett. 2012. Impacts of climate change in three hydrologic regimes in British Columbia, Canada. *Hydrological Processes*:

Stahl, K., R. D. Moore, and I. G. McKendry. 2006. The role of synoptic-scale circulation in the linkage between large-scale ocean-atmosphere indices and winter surface climate in British Columbia, Canada. *International Journal of Climatology*, 26: 541-60.

USGS. 2013. *ShakeMap Scientific Background.* United States Geologic Survey, Earthquake Hazards Program. http://earthquake.usgs.gov/earthquakes/shakemap/background.php (accessed October 2013).

Walker, I. and R. Sydneysmith. 2007. British Columbia. In *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Eds. D. S. Lemmen, F. J. Warren, J. Lacroix, and E. Bush. 329-86. Climate Change Impacts and Adaptation Division, Earth Sciences Sector, Natural Resources Canada.

Wang, T., A. Hamann, D. L. Spittlehouse, and T. Murdock. 2012. ClimateWNA - High-Resolution Spatial Climate Data for Western North America. *Journal of Applied Meteorology and Climatology*, 51: 16-29.

Wang, T., A. Hamann, D. N. Spittlehouse, and S. N. Aitken. 2006. Development of scale-free climate data for western Canada for use in resource management. *International Journal of Climatology*, 26: 383-97.

Werner, A. 2011. *Selecting and using climate change scenarios for British Columbia. Hydrologic modelling project. Final Report (Part I)*. University of Victoria:

West Coast Environmental Law. 2012. *Preparing for Climate Change. An Implementation Guide for Local Governments in British Columbia*. Vancouver, BC.