2 Climate and Air Quality

This section provides revised estimates of precipitation, snowpack,, evaporation and is intended as a supplement and expansion to EAR Section 7.1 and is intended to be read with that document rather than stand-alone.

Table 2-1 provides a summary of the reviewer comments and the location of the response. Based on the reviews provided by Yukon Government, Department of Environment (Environment Yukon) and Environment Canada, the fundamental areas of uncertainty with respect to the climate include:

- monthly and annual precipitation values
- evaporation values
- seasonality of precipitation (rain vs. snow, summer vs. winter)
- depth and snow water equivalent of snowpack

Given these uncertainties, estimates of climate data must be understood to be estimates only. Any number presented should be understood to come with relatively broad error bars. This uncertainty arises from the sparseness of the regional climate network, from limited onsite data (i.e. the short duration and seasonal nature of the climate station measurements, one measurement of snow water equivalent, and no measurements of evaporation.) The revised precipitation estimates have been made in conjunction with input from Environment Yukon.

Climate data for the regional station was obtained from Climate, 2006 and the evaporation data was located in Environment Canada, 1980.

Table 2-1 Climate and Air Quality Table of Conformance

Reviewer	EAR Section	Reviewer Comment	Response Report Section Where Addressed
2 Climate and Air Quality			
YTG - Environment Yukon	Section 7.1.2.1	**Regional Data** A summary of the regional data used in the analyses would be useful to illustrate the variability between stations.	Government website referenced in Section 2
YTG - Environment Yukon	Section 7.1.2.1	**On-Site Data Collection** What is the make and model of the automated meteorological station and sensors? A listing of the available project data should be included in the appendices.	Section 2.1; Appendix A1
YTG - Environment Yukon	Section 7.1.2.2	**Temperature** What is the project site elevation? Variation in environmental lapse rate values - a more accurate procedure would be to calculate this flux using the regional meteorological station data and elevation.	Section 2.3
YTG - Environment Yukon	Section 7.1.2.2	**Mean Annual Precipitation** It would be worthwhile expanding the project area to include other meteorological stations.	Section 2.2.1; Section 2.2.2; Section 2.2.3
YTG - Environment Yukon	Section 7.1.2.2	**Mean Monthly Precipitation** The “summer” period should be defined, and, a graphical summary of this analysis should be provided for reference purposes. How was the monthly precipitation distribution derived?	Section 2.2.4
YTG - Environment Yukon	Section 7.1.2.2	**Hourly and Daily Rainfall** Environment Canada CFA program - a specific reference for the program should be provided, and the data used in the frequency analyses should be listed	Sections 2 and 5.1.1
YTG - Environment Yukon	Section 7.1.2.2; Figure 7.1-5	**Hourly and Daily Snowfall** Additional information on the conversion method is required and data used in the conversion should be listed.	Section 2.2.5
YTG - Environment Yukon	Section 7.1.2.2	**Frequency Analysis of Annual Snowpack** Sampled range in SWE is greater then these values and the maximum SWE may be significantly greater, which has implications respecting the frequency analysis.	Section 2.2.5
Environment Canada		**Precipitation Data Shortages** The regional data, local data, and any trends suggested herein should be presented.	Section 2.2; Appendix A1

2.1 Site Meteorological Station

The meteorological station at the Wolverine site is a HOBO® Weather Station, model H21-001 manufactured by Onset Computer Corporation, and that utilizes BoxCar Pro 4.3 software (see photo in EAR Figure 7.1-3). It measures rainfall, atmospheric pressure, solar radiation, wind speed, wind direction, air temperature, and relative humidity at 30 minute increments. The station was installed October 15, 2004 with three sensors, including temperature/relative humidity, solar radiation, and wind speed/direction. The station is also outfitted with a rain gauge. Data is downloaded manually. Data records for 2005 are presented in Appendix A1 and previous data will be supplied upon request.

2.2 Precipitation

There are several ways to estimate monthly and annual precipitation. Although none of these methods can be considered precise on their own, when taken together, the resultant answer increases in confidence if the same value is derived from each method. A discussion of two methods is provided below.

2.2.1 Annual Precipitation Estimate from Precipitation Isoline Maps

Mean annual precipitation is commonly mapped using isolines corresponding to a specified precipitation interval. Because of the spatial variability of precipitation areas within the precipitation contours will have an intermediate value. The Rainfall Atlas of Canada (Bruce, 1968) and an American source for the State of Alaska (Oregon State, 2006) both estimated precipitation in the Wolverine Project area to be within the range of 500 to 600 mm.

2.2.2 Annual Precipitation Estimate from Regional and Wolverine Climate Stations

The three climate stations within the regional study area, for which climate data is available, include Watson Lake, Tuchitua and Hour Lake. Climate measurements at the Wolverine site were collected during the summer of 1996 and 1997, and from October 2004 to September 2005. However, local precipitation was only measured during the spring-fall months as the automated precipitation sensor does not measure snowfall. Climate measurements were not made during 2005 at Tuchitua and Hour Lake, so the only station for which there is continuous overlap of measured monthly precipitation with the Wolverine site is Watson Lake.

A comparison of the monthly precipitation values measured at Wolverine to the measured monthly precipitation for the same months at Watson Lake indicates that observed monthly precipitation at Wolverine ranges from 59% (June 1997) to 169% (July 1996) of observed monthly precipitation at Watson Lake (Table 2-2). The average of the monthly Wolverine values are 116% of Watson Lake values, whereas the total precipitation over the observed interval at Wolverine is 106% of Watson Lake. However, if the precipitation at Wolverine is plotted against the precipitation at Watson Lake, the resultant regression equation has a low r-squared value, indicating the relationship is not statistically significant (Figure 2-1).

Table 2-2 Comparison of Measured Monthly Precipitation at Wolverine Climate Station and at Watson Lake

	Precip Measured – Wolverine (mm)	Precip Measured – Watson Lake (mm)	Ratio Wolverine to Watson Lake
1996			
Jul	59.8	35.4	1.689
Aug	73.1	56.2	1.301
1997			
May	19.1	24.6	0.776
Jun	51.2	86.9	0.589
Jul	96.2	73.1	1.316
Aug	49.2	67.8	0.726
2005			
March	15.8	10.5	1.505
April	16.2	10.6	1.528
May	51	66.5	0.767
Jun	62.8	61.8	1.016
Jul	83.6	61.8	1.353
Sep	53.2	38.4	1.385
Mean			1.162
Total	631.2	593.6	1.063

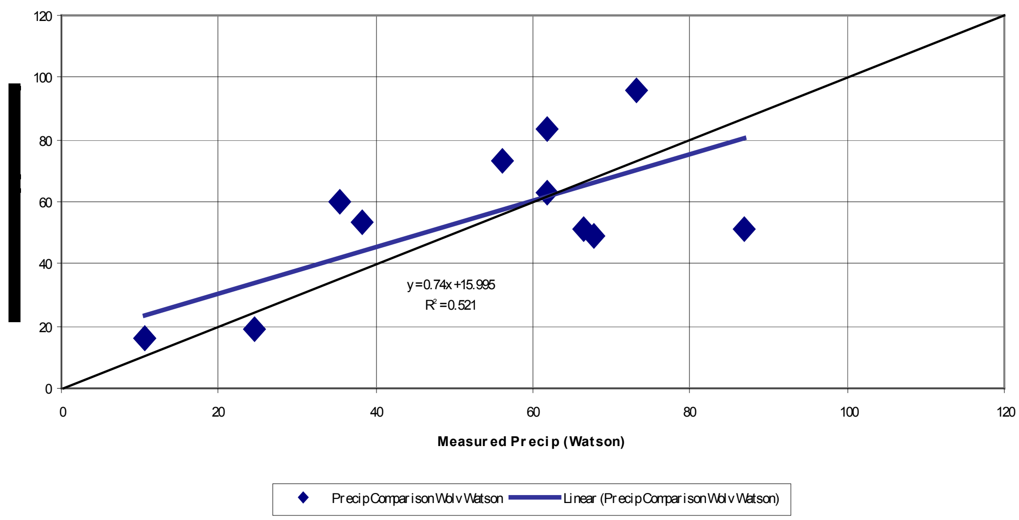

Figure 2-1 Monthly Precipitation at Watson Lake (mm) vs. Monthly Precipitation at Wolverine (mm)

Although the other two climate stations, Tuchitua and Hour Lake, cannot be compared directly to Wolverine data, they can be compared to Watson Lake. They are both at higher elevation than Watson Lake and receive more precipitation. It would be desirable to extend the regional analysis to include a greater number of climate stations and derive a relation between elevation and precipitation. However, because of the sparseness of the climate station networks within the regional area, it is difficult to compare stations in the same climatic zone at differing elevations. The nearest climate station at an elevation comparable to the Wolverine is at Cassiar, approximately 250 km south; annual precipitation at Cassiar is 750 mm, significantly higher than in the Wolverine region.

The three regional stations and the predicted Wolverine site value plus an estimate of the error are plotted in Figure 2-2. The predicted value of 556 mm annual precipitation for Wolverine project area was estimated by increasing the average precipitation for Tuchitua and Hour Lake by 111% (the average of the 116% and 106% increases estimated when comparing Wolverine to Watson Lake). The lower error bar represents the regional average precipitation for the three stations (481 mm) increased by 106%; the upper error bar represents the precipitation for Hour Lake (524 mm), the highest of the three stations, increased by 116%.

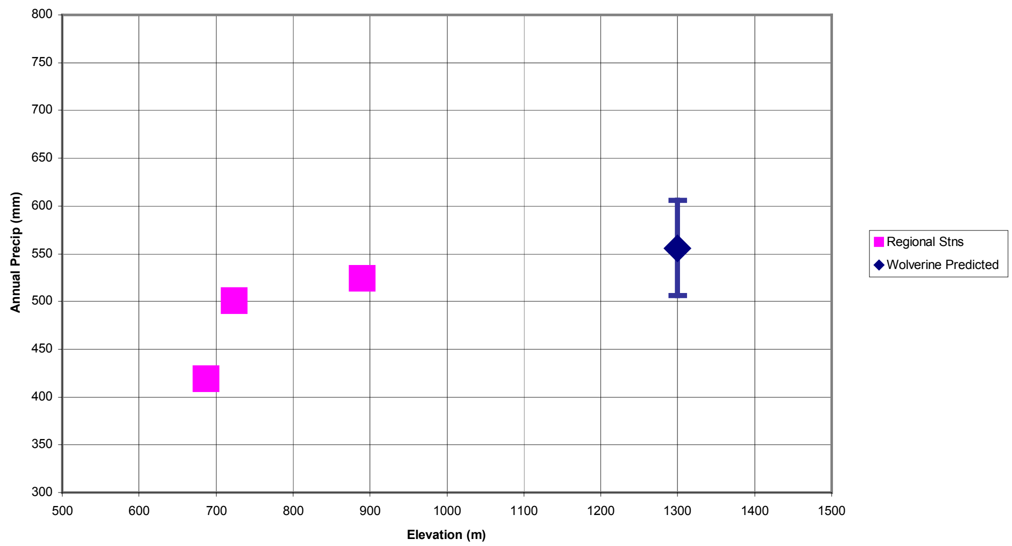

Figure 2-2 Observed Annual Precipitation at Regional Stations Plotted by Elevation

2.2.3 Annual Precipitation Estimate from Water Balance

The mean annual precipitation can also be estimated from the water balance. The water balance equation is:

Precipitation = Evaporation + Runoff + Change in Storage

Therefore, if runoff and evaporation are known and long-term change in storage is assumed to be zero, and then precipitation can be estimated. In theory, this is simple. In practice, it is complicated. For instance, change in storage is usually not zero at all scales. Small watersheds usually have a positive change in storage (water infiltrates into the ground) and thus runoff estimated for small watersheds will underestimate actual runoff. Likewise, for larger watersheds, there is a net negative change in storage (net recharge from groundwater to surface water flow) that will result in the runoff term being overestimated. The scale change in the net change in storage term varies with climate and permeability. For the purposes of this calculation, a figure of 100 km² was assumed to represent no net change in storage. Then the mean annual stream flow (in m³/s/km²) for a 100 km² watershed was calculated and the resultant figure converted to a figure of mm annual runoff/m² unit area.

The calculation for mean annual flow is:

$$\text{Mean Annual Flow} = 0.0041*(\text{watershed area})^{1.1041}$$

For a 100 km² watershed, this gives a mean annual flow of 0.0062 m³/s/km².

Then 0.0062 m³/s/km * 31557600 s/yr * 0.000001 m²/km² = 0.196 m or 196 mm of runoff. This is close to the regional value of 200 mm predicted for the 1300 m elevation for the Cassiar Mountains by Obedkoff (2000).

Mean annual evaporation has been estimated at approximately 400 mm (Section 2.3). Therefore, annual precipitation should be approximately 196 + 400 = 596 mm. This is close to both the 556 mm value estimated in Section 2.2.1 and within (but close to the upper boundary of) the 500-600 mm range estimated from regional precipitation maps. The error in the estimates of evaporation is approximately +/- 30 mm. This would give a range of 566-626 mm.

Averaging the three estimates of precipitation (550 mm, 556 mm, and 596 mm) derived above gives a value of 567 mm for total annual precipitation. For the purposes of calculating monthly precipitation values and for design criteria a value of 570 mm will be used. The overlap in the three error estimates gives the range of 566 to 600 mm.

2.2.4 Monthly Precipitation Estimates from Annual Precipitation

To estimate the monthly precipitation at Wolverine, the monthly fraction of annual precipitation has been determined by simply averaging the three regional station values (Table 2-3). In general, the proportion of mean monthly precipitation as a function of annual precipitation does not vary significantly between regional stations. The summer precipitation at Tuchitua and Hour Lake shows more of an increase compared to Watson Lake than does the winter precipitation; however, as there is no winter precipitation data from the Wolverine site, this trend cannot be verified against observed site data.

Table 2-3 Mean Monthly Precipitation at Wolverine Estimated from Regional Monthly Proportion of Annual Rainfall

Regional Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Watson Lake (mm)	30.9	23.3	19.2	15.6	31.2	52	56.6	45.2	42.5	34.8	32.6	34.6	418.6
Tuchitua (mm)	41.2	32.6	22.1	18.4	37.5	53.6	70.2	50.8	49.2	39.1	42.1	44.0	500.8
Hour Lake (mm)	36.2	28.0	25.8	16.6	38.5	59.7	70.0	62.0	53.1	49.7	43.4	41.5	524.4
Mean (mm)	36.1	28.0	22.4	16.9	35.7	55.1	65.6	52.6	48.2	41.2	39.4	40.0	481.3
% Monthly Precipitation	0.08	0.06	0.05	0.04	0.07	0.11	0.14	0.11	0.10	0.09	0.08	0.08	1.00
Site Data Precipitation (mm)	42.8	33.2	26.5	20.0	42.3	65.3	77.7	62.3	57.1	48.8	46.7	47.4	570.0

2.2.5 Snowpack

Because there is no precipitation data available from Wolverine for the winter months (snowfall), it is difficult to determine whether there is a seasonal variation in precipitation trend with elevation. Broadly speaking, there are three possibilities with respect to seasonal trends:

- Snowfall at Wolverine in the winter will be greater than the snowfall estimated from the monthly precipitation of the regional stations and scaled for elevation (the effect of elevation on precipitation observed for rain will be intensified for snow).
- Snowfall at Wolverine in the winter will follow the same trend with elevation as observed rainfall. The effect of elevation on precipitation observed for rain can be extended to snowfall. This is the default assumption.
- Snowfall at Wolverine in the winter will be less than the snowfall estimated from the regional stations and scaled for elevation. The effect of elevation on precipitation will be less for snow than is observed for rain.

Examining the monthly differences in precipitation observed at Watson Lake, Tuchitua and Hour Lake, there is no consistent seasonal trend in increased precipitation in winter at the higher elevation Tuchitua and Hour Lake stations when compared to the Watson Lake station in the summer months. This supports the default assumption that the scaling observed for Wolverine in summer will also apply in winter.

If all the snow that fell as snow persisted and accumulated, total snowpack water equivalent (SWE) in the spring would be simply the sum of the winter precipitation values. For the Wolverine Project area, assuming that all precipitation falling between October and March (from Table 2-3) falls as snow, this total would be 245 mm.

In early March 1997, the snow water equivalent at site was measured to be 128 mm. A depth was not recorded. Anecdotal reports suggest that observed snow depths at the industrial complex and camp sites do not exceed 1 m.

The snowpack at maximum depth is not the snowpack at maximum density. Maximum density occurs late in the season when the snow has been partially melted and condensed. At maximum depth, snowpack density will be higher than the 0.1 mm water/1.0 mm snow value for new fallen snow, but most likely lower than 0.2. Maximum density values of 0.2 to 0.25 are usually reached late in the season when the snowpack has begun to melt. The maximum SWE occurs at some point between maximum depth and maximum density.

Assuming only snow accumulation and applying sublimation estimated from the Hamon equation (Figure 2-3), if the snowpack begins to accumulate on October 1, then on April 1 the net SWE would be 245 mm of precipitation less 42 mm of sublimation, for a total SWE of 203 mm. With an assumed 0.2 snowpack density, this would equate to a snowpack depth of 1 m, similar to the maximum observed depth. However, it is likely that the actual mean SWE on April 1 will be lower than 200mm, because some of the precipitation in both October and March can fall as rain and is not stored as snow[1]. It is therefore likely that mean annual SWE at Wolverine is approximately 175 mm.

Mean SWE for the Liard Basin is 150-175 mm (EAR Section 7.1.2.2). Mean annual precipitation in the Liard Basin likewise varies between 300 mm and 1000 mm. Since the

[1] The automated climate station has recorded small amounts of rainfall in November and March.

mean annual precipitation at Wolverine is 570 mm and is in the midpoint of the range for the Liard Basin, it is assumed that the mean SWE at Wolverine would be relatively close to the mean SWE for the Liard Basin.

Finally, snow accumulation tends to be lower on south-facing slopes than on north-facing slopes. The Wolverine climate station, mine, and exploration camp (where climate measurements were made in 1996 and 1997) are both located on south-facing slopes; actual snowpack accumulation at these sites may be lower than 175 mm SWE. Likewise, on north-aspect slopes within the project study area, snowpack accumulation may be greater than 175 mm SWE.

Equation 2-1 Hamon Equation (1961)

$$\mathrm{ET}_t = 2.1 D_t^2 p_{\mathrm{sw}t}/(T_t + 273)$$

in which D_t is the number of daylight hours during day t and T_t here refers to the mean air temperature during day t (°C). The daylight hours variable can be determined by:

$$D_t = 24\omega_s/\pi$$

where ω_s is the is the sunset hour angle (radians), calculated from:

$$\omega_s = \arccos[-\tan(\phi)\tan(\delta)]$$

with ϕ equal to latitude (radians), and δ is the declination (radians) given by:

$$\delta = 0.4093 \sin[2\pi(284 + \mathrm{DOY})/365]$$

and DOY is the day of the year (1–365). $p_{\mathrm{sw}\,t}$ is the saturation vapour pressure in kilopascals on day t.

Equation 2-2 Hamon Equation (1963)

$$ET_t = (715.5 * \Delta * p_{sw\,t})/(T_t + 273)$$

where Δ is day length as fraction of day (length of daylight hours/24 hours).

Figure 2-3 Hamon Equations

In both the 1961 and 1963 equations, monthly average evaporation figures were computed by taking the mean monthly temperature from EAR Figure 7.1-4, and the day length computed for the 15th day of each month, rather by computing daily values and summing them, in order to reduce the number of computations to a manageable level.

2.3 Evaporation

Evaporation figures were estimated from the Hamon equations seen in Figure 2-3 compared to measured evaporation at Carmacks (EAR Figure 7.4-3). The average of the two annual totals from the two equations was approximately 400 mm.

Comments from reviewers suggested that lake evaporation figures from Atmospheric Environment Service (AES) data be included in the comparison. Lake evaporation figures have therefore been obtained for the period 1951-1980 (the last period for which such statistics were calculated) for four stations in the NWT, three stations in the Yukon and one station in northern BC. The observed values are presented in Table 2-4.

Table 2-4 Mean and Standard Deviation of Observed Lake Evaporation (mm) Northwestern Canada, 1951-1980

Station	Elev.	May		June		July		Aug		Sept		Annual
	(m)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Fort Selkirk	500	107.6	±13	120.3	±12.4	108.0	±16.1	79.8	±13.7	37.2	±5.3	453
Haines Junction	599	99.8	±38.2	139.1	±32.5	128.6	±23.4	88.8	±14.6	37.5	±11.3	494
Whitehorse	706	104.3	±1.6	124.8	±19.8	109.9	±8.1	96.0	±14.6	47.7	±9.4	483
Fort Smith	205	123.4	±20.5	129.3	±9.4	126.3	±15.4	100	±14.3	45.2	±12.9	524
Norman Wells	74	110.4	±29.8	139.9	±15.4	123.0	±15.3	81.4	±15.4	42.3	±4.3	497
Resolute	67	-	-	-	-	100.2	±29.3	52.0	±14.7	-	-	152
Yellowknife	206	-	-	164.1	±10.2	157.9	±12.6	109.6	±14.9	49.9	±8.5	482
Hudson Hope BC	498	102.4	±13.9	121.0	±15.1	111.1	±11.5	98.0	±16.2	48.4	±12.1	481

Annual evaporation figures range from 152 mm for Resolute to 524 mm for Fort Smith. Evaporation is a function of air temperature; temperature is a function of elevation as well as latitude. It is therefore reasonable to assume that the evaporation occurring in the Wolverine project area will be lower than these observed values because Wolverine is higher in elevation. However, the stations above vary too widely in latitude and not widely enough with elevation (elevations of the AES stations are between 0 and 700 m) to accurately determine a trend with elevation from the observed data for the latitude of Wolverine. The predicted evaporation values for Wolverine seem reasonable given the lower mean temperatures and 1300 m elevation of Wolverine.

With respect to the annual water balance for the site, lake evaporation is largely but not entirely appropriate. Lake evaporation only occurs during the open water season, and drops to zero when the lake is frozen over. However, evaporation from snow-covered ground can occur, particularly when dry air overlies wet snow (sublimation), and is enhanced under windy conditions. Therefore, the non-zero values estimated from the Hamon equation for winter conditions seen in EAR Figure 7.4-3 that may have some physical basis.

2.4 Air Quality

2.4.1 Air Quality Study Area Definition

The local study area (LSA) for the assessment of air quality consisted primarily of the zone of influence associated with the industrial complex.

It was estimated to be approximately 100 km^2 in area and encompasses a circular region 5 km in radius centered on the industrial complex. In addition, an area 1 km wide centered on the 24 km-long haul road from the Robert Campbell Highway to the industrial complex is identified to assess potential effects of dust and concentrate from mine access road construction and hauling activities. The LSA includes the industrial complex and the Robert Campbell Highway where there are potential effects from dust and air quality issues.

Regional study area was not defined as there are no other substantial sources of criteria air contaminants within a reasonable distance that could overlap with project effects and result in cumulative effects