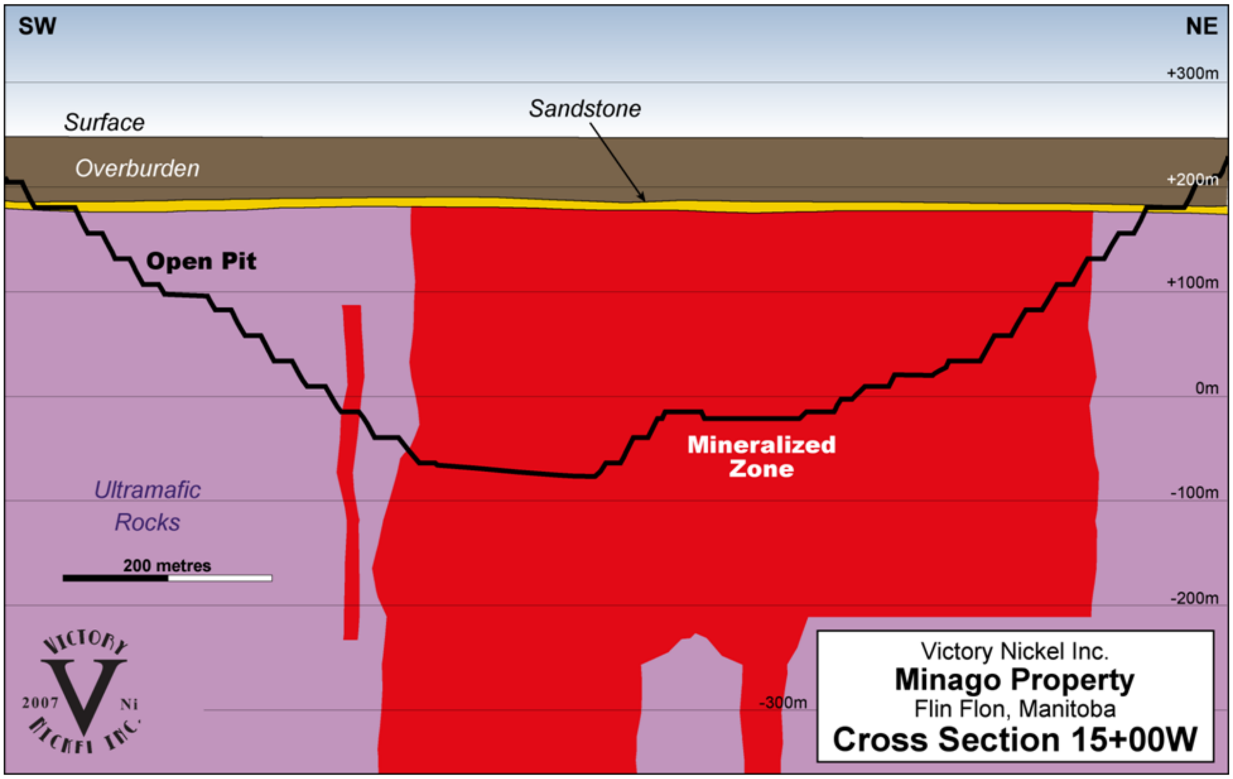

Chapter 7 – Environmental Assessment Findings

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7. ENVIRONMENTAL ASSESSMENT FINDINGS

7.1 Climate

Golder Associates Ltd. developed a comprehensive database of available climatic data and derived representative climatic characteristics for the Minago Project (Golder Associates, 2009). These characteristics are summarized below.

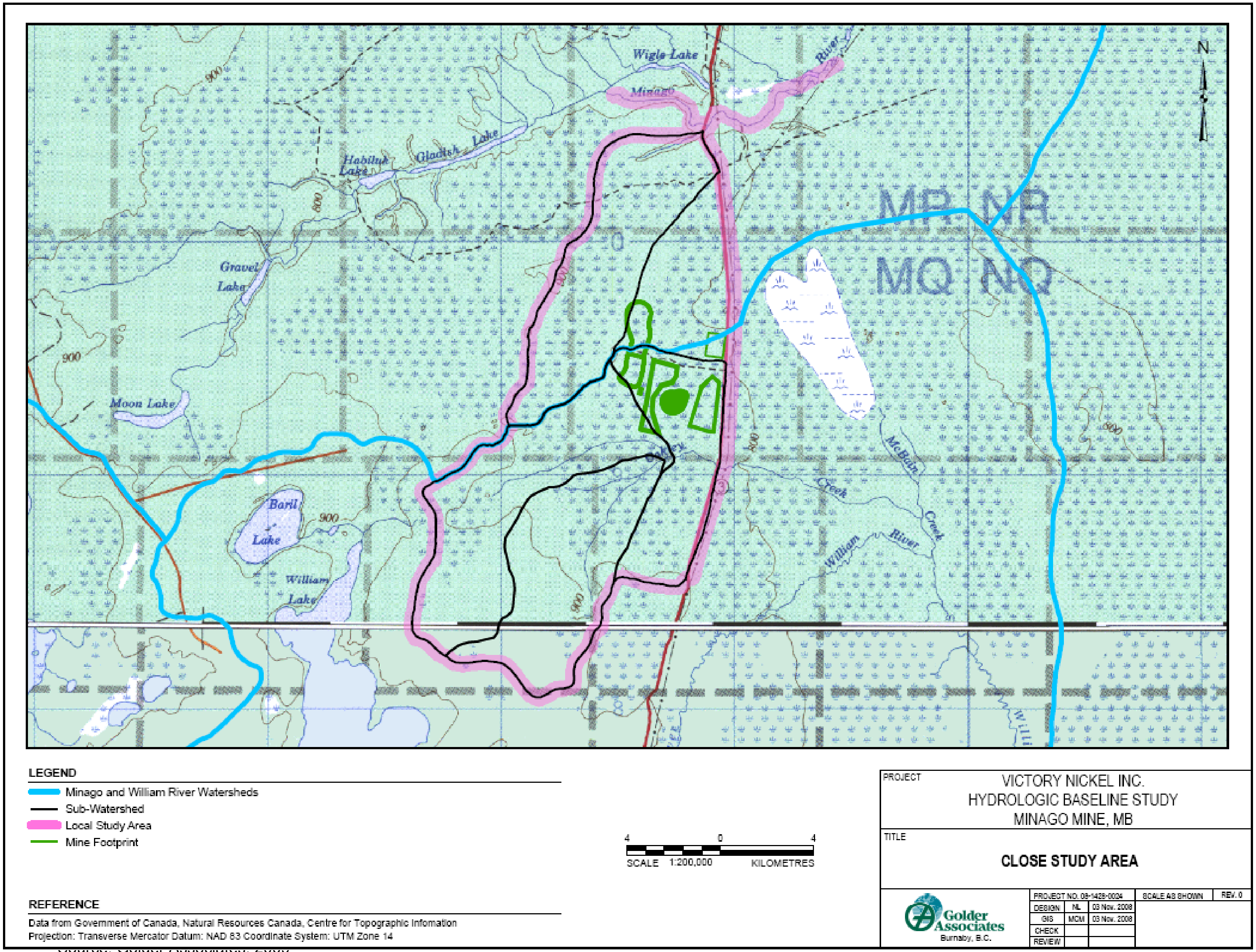
Two regions were identified for the climatic baseline study: a close study area (CSA) and an extended study area (ESA). The CSA encompasses areas that may be directly impacted by the development project. The ESA includes the CSA within a larger geographic and ecological context that may be considered in subsequent impact assessments. The ESA is defined as the region within which any effect from the development project would become negligible. Figures 7.1-1 and 7.1-2, which were developed using topographic maps of the region (NRC, 2008), illustrate the extent of the project CSA and ESA, respectively.

The CSA, (Figure 7.1-1), encompasses the watersheds of the watercourses and surface areas within which the footprint of the proposed mine development is located. Most mine activities are planned within the Oakley Creek watershed west of Highway 6. Oakley Creek is a tributary of the William River. The proposed infrastructure to the west of the mine will include a Tailings and Ultramafic Waste Rock Management Facility (TWRMF), and Waste Rock Dumps. The tailings area is located between Oakley Creek and the Minago River, in an area with no defined surface water runoff channels or streams.

The ESA (Figure 7.1-2) extends the CSA to the segments of the Oakley Creek, Minago River and William River watersheds within which any effect for the mine development are expected to become negligible due to a confluence with a significant watercourse or waterbody, and proposed water management planning for the site. The ESA extends to the northeast up to the Hill Lake outlet, where the Minago River joins the Hargrave River. The ESA also extends southeast to include the confluence of Oakley Creek with the William River, as well as the confluence of the latter with Limestone bay.

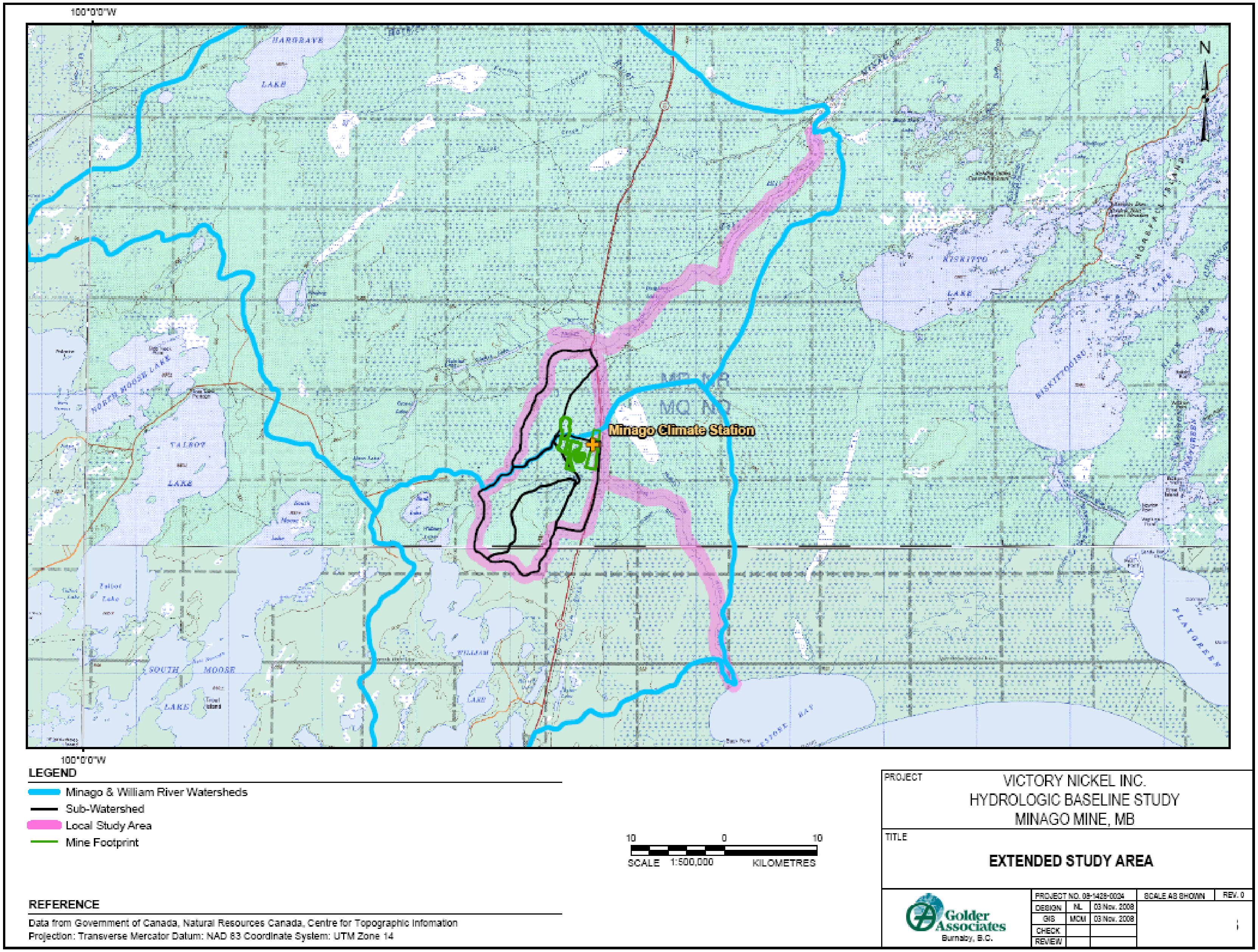
The CSA and ESA (Figures 7.1-1 and 7.1-2) are mostly located within the sub-arctic climate zone (i.e., Dfc zone under the Koppen-Geiger climate classification; Peel et al., 2007). This zone is characterized by a cold climate with relatively humid winters and summers, and less than four months with average monthly temperature above 10 ºC (Kottek et al., 2006). The southern portion of the William River watershed, near Grand Rapids and Lake Winnipeg, is within the humid continental zone (i.e., Dfb zone; Peel et al., 2007). This zone has characteristics similar to those of the sub-arctic zone; however, there is at least four months with average monthly temperatures above 10 ºC (Kottek et al., 2006).

Based on the above, the annual mean temperature at the Minago Project is expected to be about 0 ºC (Prowse, 1990), with significant seasonal variations. Mean monthly temperatures are expected to be between -20 and -25 ºC in January, and between 15 and 20 ºC in July (EMRC,



Source: Golder Associates, 2009

Figure 7.1-1 Close Study Area (CSA)



Source: Golder Associates, 2009

Figure 7.1-2 Extended Study Area (ESA)

1995). Mean annual total precipitation are expected to be between 400 and 600 mm, with a mean annual snowfall between 1,000 and 2,000 mm (EMRC, 1995).

7.1.1 Available Monitoring Data

The following provides an inventory of available local and regional climate data. The local climate data collection program for the Minago Project is supported by one climate station at the Minago site, which has been in operation since July 2007. The station records ambient air temperature, rainfall, wind speed and direction, relative humidity, and net radiation (Victory Nickel, 2008).

Select regional climate and hydrometric monitoring stations operated by Environment Canada (EC) have systematically collected data that are relevant to the Minago Project, such as air temperature, precipitation, wind, evaporation or streamflow. The sub-sections below provide details on the data at the stations that have been selected to characterize regional climate conditions for the Minago Project. The locations of these stations are shown in Figure 7.1-3. Availability of data over a long-term period and proximity to the proposed Minago project site were the main criteria were used to select the stations.

7.1.1.1 Air Temperature and Precipitation Data

Air temperature affects basin snowmelt, lake ice and water temperature regimes, while precipitation determines basin moisture input and is one of the most important climate parameters in hydrologic studies.

The climate stations selected for the compilation of regional air temperature and precipitation data are Cross Lake, Flin Flon, Grand Rapids, Norway House, The Pas and Thompson (Table 7.1-1 and Figure 7.1-3). These stations effectively cover the CSA and ESA of the proposed Minago project. Temperature and precipitation at these stations can be compared and assessed over a concurrent period of 41 years (1968 to 2008).

The Climate Research Division of Environment Canada has developed a database of long-term homogeneous precipitation data, specifically designed for climate change analysis in Canada. The Adjusted Historical Canadian Climate Data (AHCCD) database can be accessed for research purposes, and includes 495 stations where archived rainfall and snowfall data have been adjusted on a daily level for rain and snow separately (EC, 2008a). Flin Flon, Grand Rapids, Norway House, The Pas and Thompson stations are included in the AHCCD database.

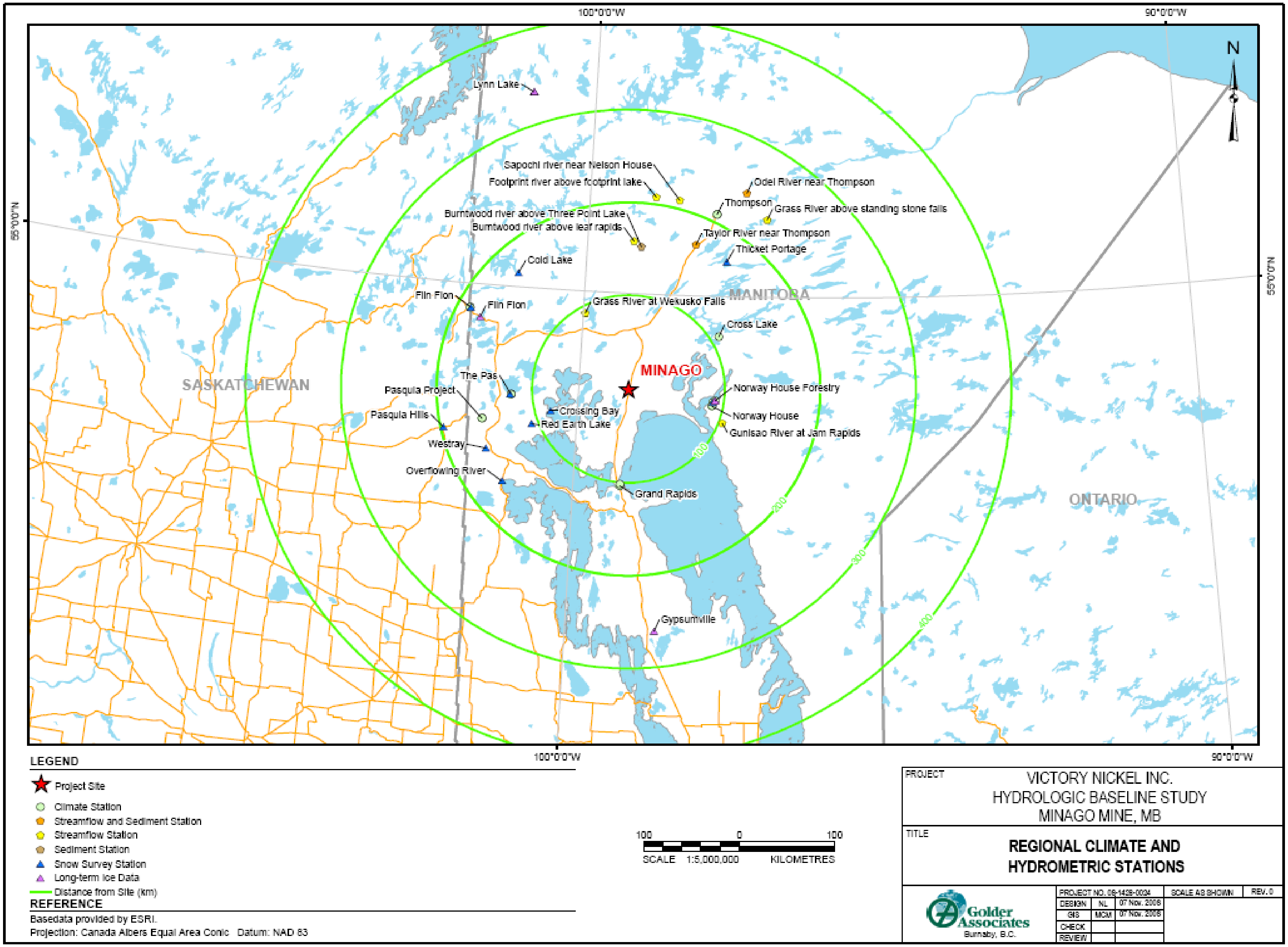
7.1.1.2 Humidity Data

Humidity impacts lake evaporation and inland evapotranspiration. The regional stations near the Minago Project with available records of relative humidity data are summarized in Table 7.1-1, and include the Norway House, The Pas and Thompson stations.

Table 7.1-1 Regional Climate Stations

Station Name	Environment Canada Station ID	Distance from Site (km)	Station Location		Elevation (m)	Recorded Data [1]		
			Latitude North	Longitude West		Data Type	Period of Record	Years of Record
Cross Lake	5060623	100 km to the North East	54° 37'	97° 46'	218.8	Temperature and Precipitation	1972 to 2008	37
Flin Flon	5050920	200 km to the North West	54° 46'	101° 52'	320	Temperature and Precipitation	1927 to 2008	82
						Snow on the Ground	1961 to 2008	60
Grand Rapids	5031111	100 km to the South	53° 09'	99° 16'	222.5	Temperature and Precipitation	1966 to 2008	43
						Evaporation (Pan and Lake)	1966 to 1967	2
	5031110		53° 10'	99° 16'	222.5	Evaporation (Pan and Lake)	1970 to 1978	9
Norway House	506B047	90 km to the East	53° 57'	97° 51'	223.7	Temperature and Precipitation	1970 to 2007	38
						Snow on the Ground	1973 to 2005	23
						Humidity	1975 to 2005	31
						Wind	1973 to 2005	33
	506B0M7		54° 00'	97° 48'	217	Evaporation (Pan and Lake)	1971 to 2000	30
The Pas	5052880	130 km to the West	53° 58'	101° 05'	270.4	Temperature and Precipitation	1944 to 2008	65
						Snow on the Ground	1955 to 2008	62
						Humidity and Wind	1953 to 2008	56
						Global Radiation	1972 to 1998	27
Pasquia Project	5052060	160 km to the West	53° 43'	101° 31'	262.1	Temperature	1960 to 2005	46
						Precipitation	1956 to 2005	50
						Snow on the Ground	1977 to 2005	29
						Evaporation (Pan and Lake)	1969 to 1985	17
Thompson	5062922	200 km to the North	55° 47'	97° 51'	223.1	Temperature, Precipitation, Snow on the Ground, Humidity and Wind	1967 to 2008	42

1. Source: Golder Associates, 2009 (Secondary source: Meteorological Service of Environment Canada (EC, 2008b and c)).



Source: Golder Associates, 2009

Figure 7.1-3 Regional Climate and Hydrometric Stations

7.1.1.3 Wind Data

Wind affects lake circulation patterns, lake currents, wave heights, wave runup, wind setup, and potential lakeshore ice ride-up and pile-up. Wind also affects sensible heat transfer between the air and the earth surface. This in turns affects lake evaporation, basin evapotranspiration, sublimation, snowmelt rate, lake ice freeze-up and break-up, and lake water temperature.

Wind directions usually vary spatially and stations located further away from the study area would be less relevant for derivation of local wind characteristics at Minago. The regional stations near the Minago Project with available records of wind data are summarized in Table 7.1-1, and include the Norway House, The Pas and Thompson stations.

7.1.1.4 Evaporation Data

Historic pan evaporation data are available from three regional Environment Canada stations as indicated in Table 7.1-1 (Grand Rapids, Norway House and Pasquia Project). Calculated lake evaporation amounts are also available for the same stations and periods of record.

7.1.1.5 Radiation Data

Short and long wave radiation from the sun and ground affects basin snowmelt, lake ice, and water temperature regimes. Radiation is recorded only at a few stations in Manitoba. Only data from the region were collected (i.e., The Pas; Table 7.1-1), since radiation varies with latitude. The regional radiation data available is global radiation (i.e., incident from the sun).

7.1.1.6 Snow Survey Data

Snow depth (or snow on the ground) is observed at the Flin Flon, Norway House, Pasquia Project, The Pas and Thompson stations. However, the snow water equivalent (SWE) is not measured at these stations.

Snow depth and SWE data from across Canada have been compiled in a database by the Meteorological Service of Canada, a branch of Environment Canada (EC, 2007). This database is available for research purposes and contains historic snow survey measurements taken by various organizations, in paper and digital formats, for point, bi-weekly and monthly sampling.

Table 7.1-2 lists the snow survey stations found in the region surrounding the study area. The compilation was restricted to the stations between latitude 52º and 56º north and longitude 97º and 101º west, with at least 10 years of snow survey data.

Table 7.1-2 Regional Snow Survey Stations

Station Name[1]	Station Identification	Distance from Site (km)	Latitude (North)	Longitude (West)	Elevation (m)	Period of Record	Years of Record
Flin Flon	SCD-MB049	200 km to the North West	54°46'	101°51'	320	1962 to 1985	24
Norway House	SCD-MB099	90 km to the East	53°59'	97°50'	220	1962 to 1977	16
The Pas	SCD-MB158	130 km to the West	53°58'	101°06'	271	1962 to 1997	36
Westray	SCD-MB185	160 km to the West	53°26'	101°25'	280	1962 to1985	24
Overflowing River	SCD-MB102	160 km to the West	53° 08'	101° 07'	259	1962 to 1985	24
Crossing Bay	SCD-MB037	90 km to the West	53°50'	100°26'	265	1966 to 1985	20
Pasquia Hills	SCD-SK116	200 km to the West	53°36'	102°07'	274	1962 to 1985	24
Red Earth Lake	SCD-MB120	105 km to the West	53°42'	100°43'	258	1965 to 1985	21
Thicket Portage	SCD-MB163	170 km to the North East	55°20'	97°40'	183	1962 to 1977	16

Note: 1. Source: Golder Associates, 2009 (Secondary source: Meteorological Service of Environment Canada (EC, 2007)).

7.1.2 Description of Local Site Data

Comparison of local and regional observations from August 2007 to July 2008 was made for: 1) temperature (Table 7.1-3); 2) relative humidity (Table 7.1-4); 3) precipitation (Table 7.1-5); and wind speed and direction (Table 7.1-6). The comparison was based on months with less than six days of missing data. The available data cannot support a comparison of local and regional radiation and evaporation. No evaporation data have been collected at Minago, and net radiation is collected at the Minago climate station while only global radiation is available at the regional stations.

The operation of the Minago climate station began in August 2007, although no observations were made from September 12 to November 12, 2007. The station provided measurements consistently from December 2007 to July 2008. Less than a year of data are available at Minago for comparison. However, the data indicate the possibility of deriving long-term climate characteristics for the study area based on the location of the Minago Project relative to the regional climate stations.

Table 7.1-3 Recorded Local and Regional Air Temperature for 2007 and 2008

Month	Mean Monthly Air Temperature[1, 2]						
	Minago	Cross Lake	Flin Flon	Grand Rapids	Norway House	The Pas	Thompson
Aug-07	13.9	14.3	15.1	16.3	15.1	15.3	12.5
Dec-07	-18.4	-19.1	-17.1	-	-8.8	-17.7	-22.8
Jan-08	-19.7	-19.8	-18.7	-17.7	-19.4	-19.7	-22.4
Feb-08	-21.1	-	-19.7	-19.5	-22.5	-20.4	-24.9
Mar-08	-12.8	-13.7	-10.6	-	-14.0	-12.0	-17.2
Apr-08	-0.6	-0.9	0.1	1.2	-0.5	-0.3	-3.0
May-08	6.7	6.1	8.7	-	7.0	7.2	4.9
Jun-08	14.2	14.5	16.4	14.9	14.7	15.5	12.9
Jul-08	16.4	16.8	18.2	-	17.3	17.6	15.7

1 Insufficient or no data available denoted by a – symbol.

2 Data source: Golder Associates, 2009 (Secondary source: Victory Nickel (2008) for Minago and EC (2008b) for all other stations).

Table 7.1-4 Recorded Local and Regional Relative Humidity for 2007 and 2008

Month	Mean Monthly Relative Humidity[1, 2]		
	Minago	The Pas	Thompson
Aug-07	74.9	75.2	74.6
Dec-07	71.1	74.8	81.3
Jan-08	71.1	70.7	78.1
Feb-08	71.6	64.1	70.2
Mar-08	72.2	66.1	69.1
Apr-08	58.6	58.1	56.8
May-08	62.7	54.1	56.4
Jun-08	62.5	60.3	63.5
Jul-08	73.5	72.3	73.5

1. Relative humidity observations are available at Norway House. However, the period of record extends from 1975 to 2005 only (Table 7.1-1).
2. Data sources: Golder Associates, 2009 (Secondary source: Victory Nickel (2008) for Minago and EC (2008b) for all other stations).

Table 7.1-5 Recorded Local and Regional Rainfall for 2007 and 2008

Month	Monthly Rainfall[1, 2]						
	Minago	Cross Lake	Flin Flon	Grand Rapids	Norway House	The Pas	Thompson
Aug-07	50.3	79.8	78.0	40.2	50.5	61.5	107
Dec-07	0.0	0.0	0.0	-	-	0.0	0.6
Jan-08	0.0	0.0	0.0	0.0	-	0.0	0.4
Feb-08	2.0	-	0.0	0.0	-	0.0	0.0
Mar-08	0.0	0.0	0.0	-	-	0.0	2.8
Apr-08	4.5	6.9	0.0	0.0	-	3.0	0.4
May-08	5.4	4.4	4.2	-	-	10.1	20.4
Jun-08	36.6	15.7	39.2	97.4	-	40.4	46.5
Jul-08	133	167	127	-	-	131	151

1. Regional rainfall data are not adjusted for the undercatch factor. Insufficient or no data available denoted by a - symbol.
2. Data sources: Golder Associates, 2009 (Secondary source: Victory Nickel (2008) for Minago and EC (2008c) for all other stations).

The same seasonal patterns of cold and warm temperatures for the winter and summer months, respectively, are noticeable at Minago and all the regional stations (Table 7.1-3). The coldest and warmest temperatures are observed at the northernmost (Thompson) and southernmost (Grand Rapids) climate stations, respectively. On a monthly basis, the temperatures at Minago are within the range of those measured at the regional stations.

Relative humidity varies spatially as a function of local temperature, altitude, wind conditions, vegetation, soil moisture content and the presence of waterbodies. The data suggest that the mean monthly relative humidity at Minago is within the range observed at The Pas and Thompson from August 2007 to July 2008 (Table 7.1-4).

The Minago station is equipped with a tipping bucket and therefore, only rainfall can be measured. A similar seasonal rainfall pattern is observed at Minago and all regional stations, with little or no rainfall during the winter months (December to April) and a high monthly rainfall amount in July. On a monthly basis, the rainfall amounts at Minago are within the range observed at the regional stations (Table 7.1-5).

Wind speed varies with the local topography. Measured wind speeds are on average higher at Minago than at The Pas and Thompson. The wind blows from two major directions (east and west) for 50% of the observations at Minago, while observations at the regional stations are more evenly distributed among the eight major directions (Table 7.1-6).

Table 7.1-6 Local and Regional Wind Speed Characteristics for 2007 and 2008

Direction [1, 2]	Minago			The Pas			Thompson		
	Mean Speed (km/hr)	Probability of Occurrence Excluding Calm (%)	Probability of Occurrence Including Calm (%)	Mean Speed (km/hr)	Probability of Occurrence Excluding Calm (%)	Probability of Occurrence Including Calm (%)	Mean Speed (km/hr)	Probability of Occurrence Excluding Calm (%)	Probability of Occurrence Including Calm (%)
N	12.0	3%	3%	13.1	21%	19%	13.8	15%	14%
NE	9.9	2%	2%	9.6	6%	6%	14.6	13%	12%
E	19.0	23.0%	22%	11.2	10%	10%	11.0	14%	13%
SE	33.9	17%	16%	14.6	17%	16%	10.5	8%	7%
S	18.1	2%	2%	13.9	13%	12%	11.5	8%	7%
SW	21.0	4%	4%	10.9	4%	4%	11.1	6%	5%
W	25.2	32%	31%	15.7	12%	12%	13.4	19%	18%
NW	24.1	17%	16%	18.3	17%	15%	15.2	18%	17%
Calm [3]	-	-	4%	-	-	7%	-	-	7%
All	20.4	100%	100%	13.4	100%	100%	12.6	100%	100%

1. Norway House is not included, since its wind observations record does not extend up to 2007 and 2008 (Table 7.1-1). Insufficient or no data available denoted by a – symbol.
2. Data sources: Golder Associates, 2009 (Secondary source: Victory Nickel (2008) for Minago and EC (2008c) for all other stations).
3. Calm refers to wind below the detection limit of the instruments (*i.e.,* the wind speed is assumed to be zero).

7.1.3 Baseline Climate Characteristics

This section presents long-term air temperature, humidity, precipitation, evaporation, and wind characteristics derived for the Minago project site area. The long-term characterizations for each of the climate parameters were based upon observations from the regional stations.

7.1.3.1 Air Temperature and Humidity

Air temperature data from the six regional climate stations listed in Table 7.1-7 were used to characterize long-term regional and temporal variations at the Minago Project. The concurrent period of air temperature for these stations extends from 1968 to 2008. Table 7.1-7 and Figure 7.1-4 show the mean annual temperature at the regional stations, while Figure 7.1-5 provides the mean monthly values at these stations. Monthly mean, maximum and minimum temperatures are also provided for each regional station in Appendix 7.1.

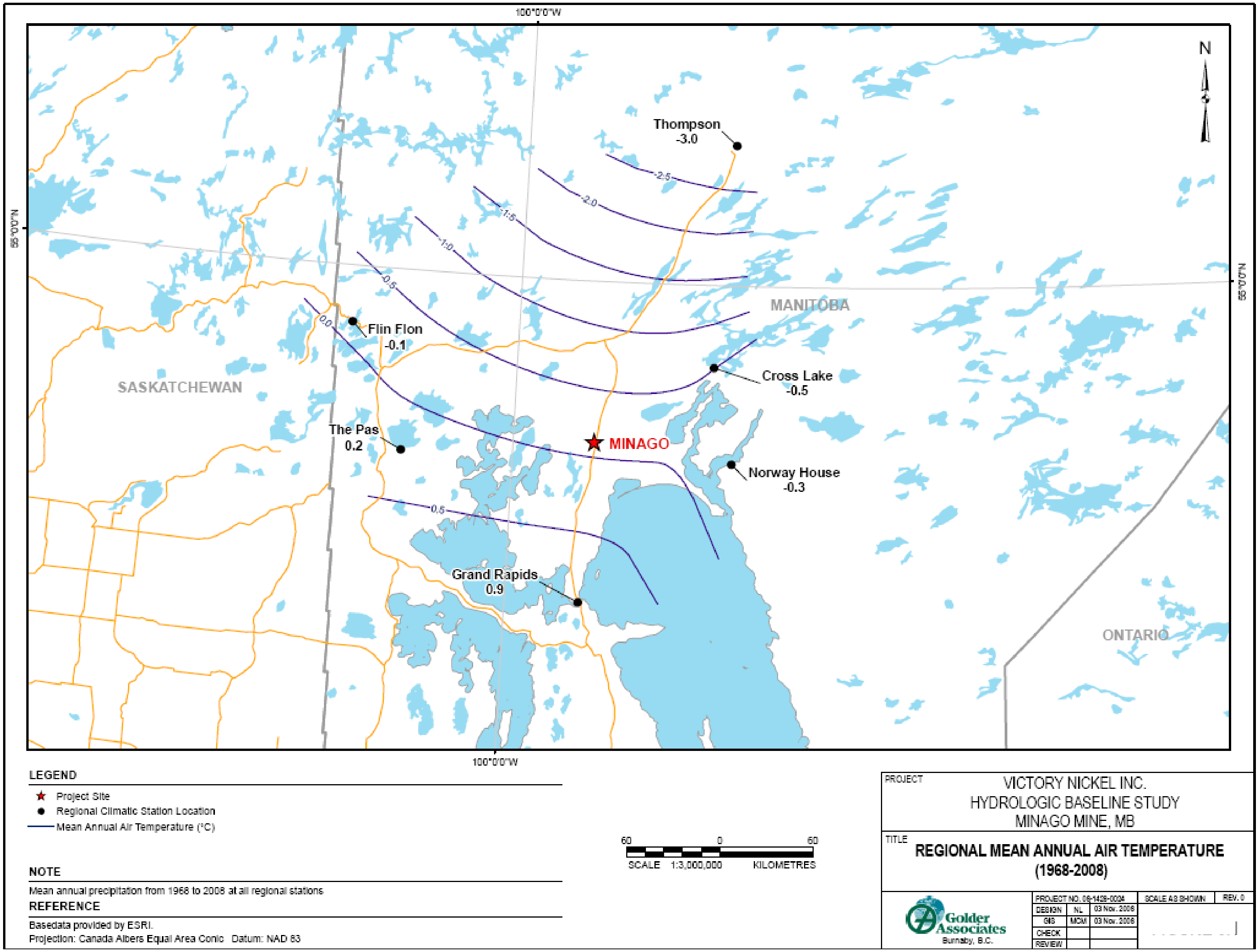
Temperatures tend to decrease with increasing latitude, with the warmest and coldest annual temperatures observed at the southernmost and northernmost stations of Grand Rapids (0.9 ºC) and Thompson (-3.0 ºC), respectively (Table 7.1-7 and Figure 7.1-4). Based on the regional spatial distribution of temperature in Figure 7.1-4 (i.e., isocontours), the mean annual temperature at the proposed Minago project site is estimated at -0.1 ºC from 1968 to 2008.

A similar seasonal variation of monthly temperature applies to all regional stations (Figure 7.1-5) and is expected to extend to the proposed Minago project site. The coldest and warmest mean monthly temperatures are observed in January and July, respectively, at all stations. Temperatures at Thompson are markedly lower than at other regional stations (Figure 7.1-5).

Table 7.1-7 Mean Annual Air Temperature at Regional Stations between

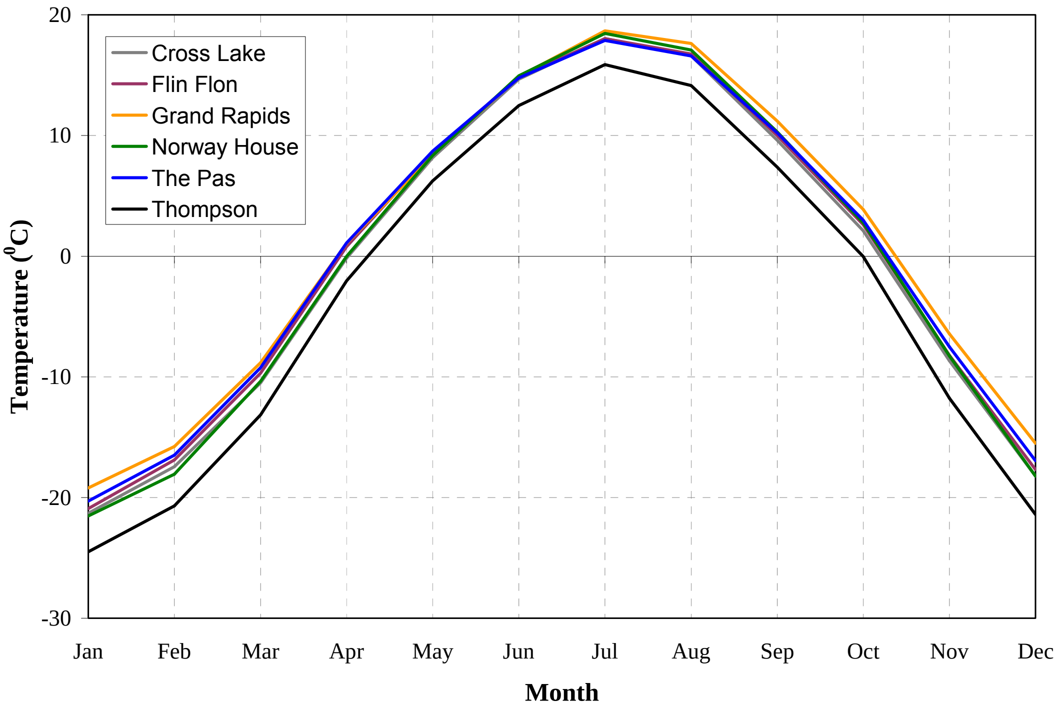
Station Name [1]	Months of Record [2]	Mean Annual Air Temperature (°C)
Cross Lake	422	-0.5
Flin Flon	471	-0.1
Grand Rapids	476	0.9
Norway House	445	-0.3
The Pas	488	0.2
Thompson	488	-3.0

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).
2. A complete record, from January 1968 to August 2008, equals to a total of 488 months. Only months with less than 6 days of missing data are considered.



Source: Golder Associates, 2009

Figure 7.1-4 Regional Mean Annual Air Temperature



Source: Golder Associates, 2009

Figure 7.1-5 Regional Mean Monthly Air Temperature

Long-term air temperature characteristics at Minago were derived using the data available from The Pas. This station is representative of regional variations, and has the advantages of having an extended period of temperature record and of being located relatively close to the proposed Minago project site.

Estimated long-term air temperature characteristics for the proposed Minago project site were obtained by subtracting a regional correction factor of 0.3 ºC from the observed values at The Pas for the period 1950 to 2008 (Table 7.1-8). This correction factor is based on the mean annual temperature of 0.2 ºC at The Pas and -0.1 ºC at Minago. Derived mean monthly air temperatures for the Minago project area are also provided from 1950 to 2008 in Appendix 7.1.

The derived mean annual temperature at Minago is -1.1 ºC for the 1950 to 1967 period, compared to -0.1 ºC from 1968 to 2008. This corresponds to an average mean annual temperature of -0.4 ºC for the 1950 to 2008 period. The coldest and warmest months are January (-21.5 ºC) and July (17.6 ºC), respectively. Sub-zero temperatures are observed from late October to late April.

Table 7.1-8 Derived Long-term Air Temperature and Relative Humidity Characteristics at Minago from 1950 to 2008

Month	Monthly Air Temperature (°C) [1, 2]			Monthly Relative Humidity (%) [1, 2]		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Jan	-26.3	-21.5 (-20.6)	-16.7	59.1	74.0 (74.0)	90.8
Feb	-22.9	-17.3 (-16.8)	-11.6	57.7	73.4 (73.2)	91.1
Mar	-16.4	-10.4 (-9.5)	-4.2	50.3	71.1 (71.1)	92.1
Apr	-5.6	0.2 (0.8)	6.0	43.7	66.3 (66.1)	92.5
May	1.9	8.2 (8.4)	14.4	42.0	65.5 (65.3)	93.9
Jun	8.5	14.3 (14.5)	20.1	48.1	69.8 (69.6)	95.8
Jul	12.0	17.6 (17.6)	23.2	55.2	72.4 (72.5)	92.0
Aug	10.6	16.2 (16.3)	21.7	57.1	74.5 (74.6)	94.5
Sep	5.0	9.8 (9.9)	14.6	59.1	78.2 (78.1)	96.7
Oct	-1.2	3.0 (2.7)	7.0	57.5	79.8 (79.8)	96.9
Nov	-11.6	-8.0 (-7.8)	-4.3	65.8	83.0 (83.0)	96.4
Dec	-21.7	-17.3 (-17.3)	-13.0	62.7	78.8 (78.8)	95.4
Annual	-26.3	-0.4 (-0.1)	23.2	42.0	73.9 (73.9)	96.9

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).
2. The values in parentheses are the mean air temperatures for the period from 1968 to 2008.

Long-term relative humidity characteristics were also derived for Minago using the data available from The Pas from 1953 to 2008. As the marginal difference in elevation and air temperature between The Pas and Minago would result in negligible changes in relative humidity, no additional adjustments were made to the The Pas data. The resulting long-term characteristics of relative humidity are provided in Table 7.1-8, while mean monthly values from 1953 to 2008 are given in Appendix 7.1.

As shown in Table 7.1-8, the months of August to January tend to be relatively humid compared to the months of February to July. However, relative humidity is dependent upon the air temperature. Humidity indicates the amount of water in the atmospheric column, and relative humidity is the ratio of observed over saturated water vapor pressures. Saturated water vapor pressure decreases with decreasing air temperatures. Therefore, relative humidity would be expected to increase with decreased air temperature given the same amount of water in the \atmospheric column.

7.1.3.2 Precipitation

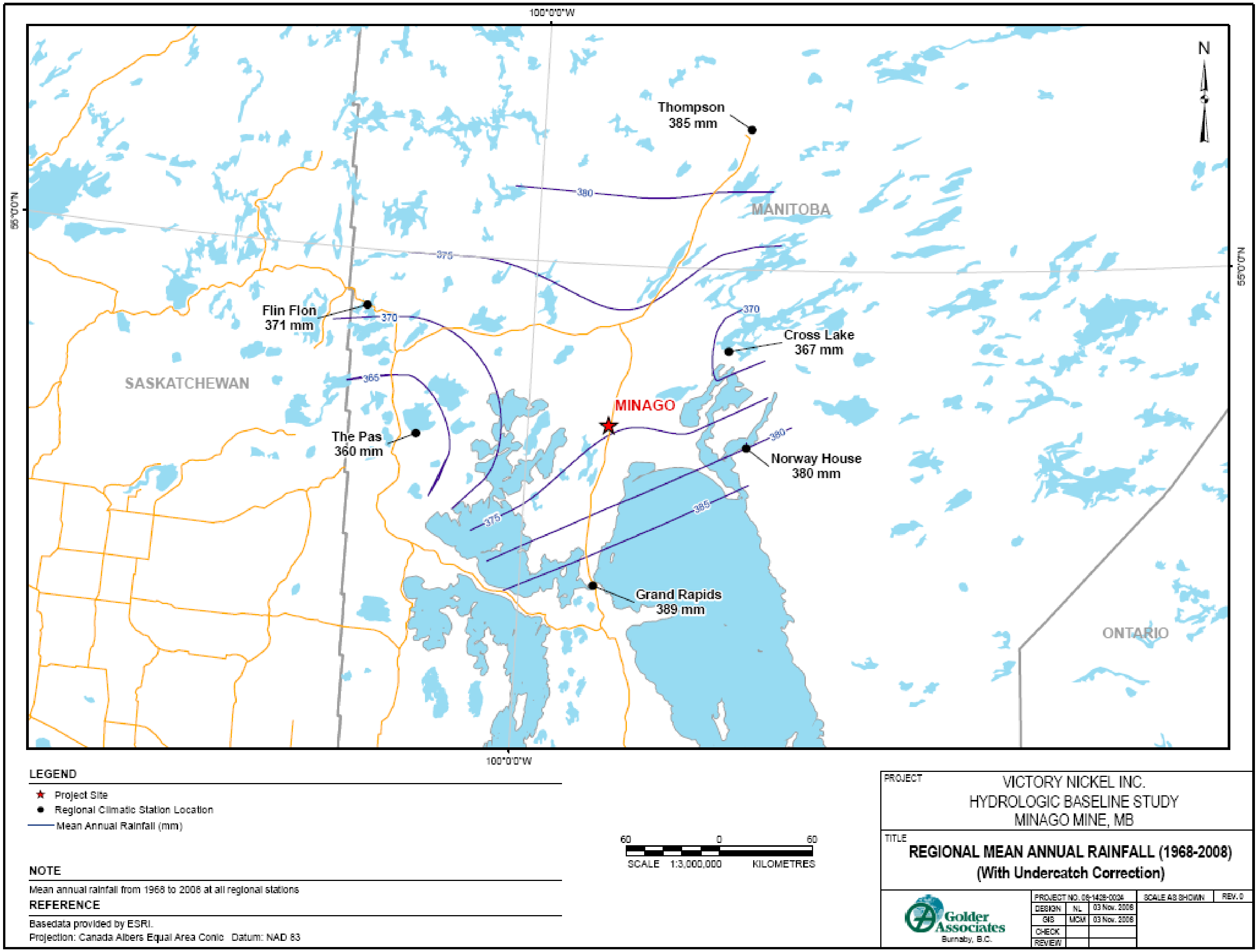
7.1.3.2.1 Long-term Precipitation

Data from the regional climate stations located at Cross Lake, Flin Flon, Grand Rapids, Norway House, The Pas and Thompson were also used to characterize long-term regional and temporal variations in precipitation at the Minago Project. The concurrent period of precipitation data for these stations extends from 1968 to 2008. Figures 7.1-6 to 7.1-8 and Table 7.1-9 present the mean annual rainfall, snow water equivalents and total precipitation for these stations over this period. Figures 7.1-9 to 7.1-11 provide the mean monthly values at the stations, respectively for rainfall, snowfall and total precipitation.

The snowfall water equivalent was estimated by multiplying the reported snowfall depth data by a consistent factor of 0.1 (rather than using varying snowfall densities). The total precipitation was estimated by adding the rainfall and snowfall amounts.

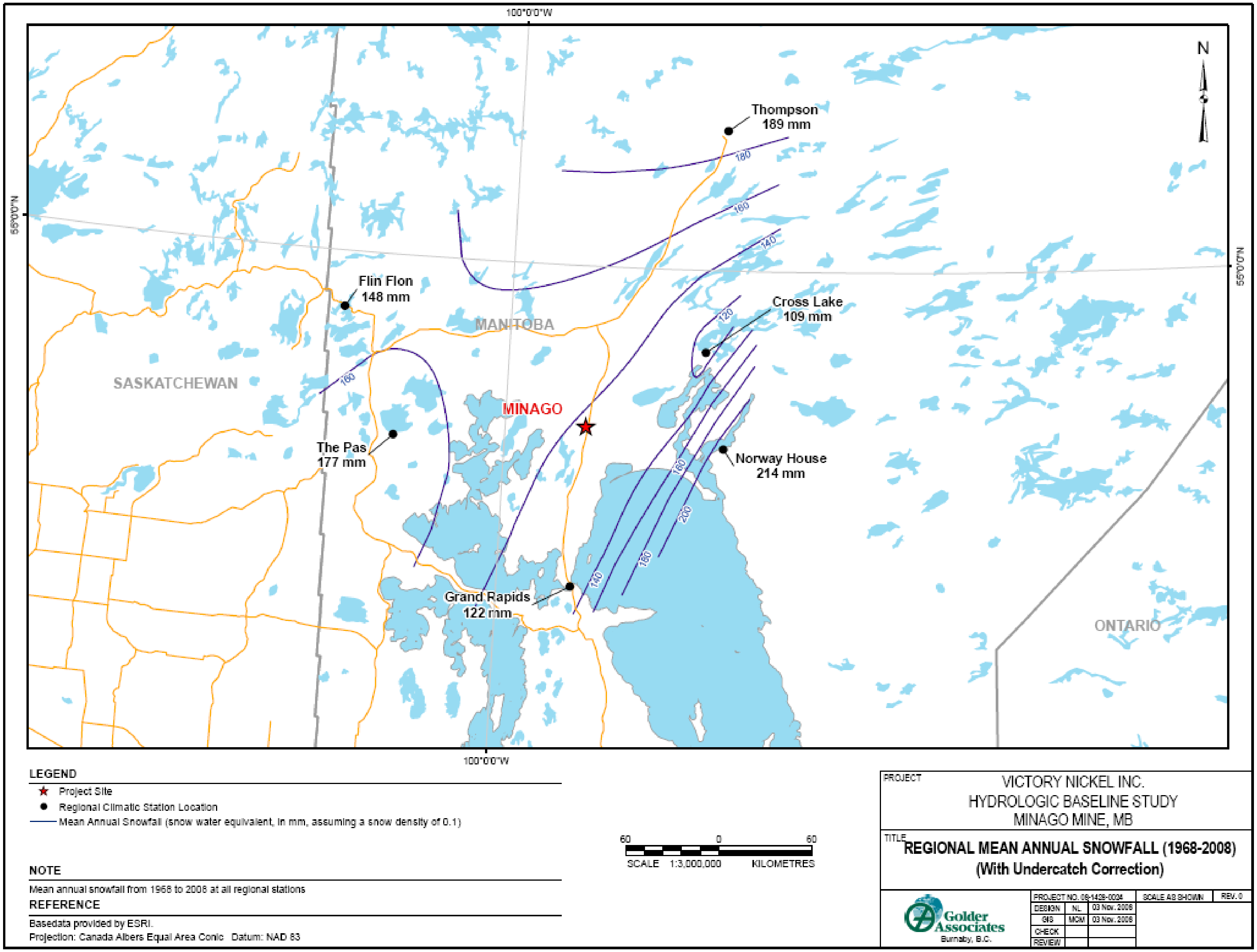
Rainfall and snowfall amounts were also adjusted using "under-catch" factors. Assessments of meteorological records in the Canadian north (Metcalfe et al., 1994) concluded that precipitation amounts are underestimated due to under-catch (i.e., the inability of a specific precipitation gauge type to accurately measure incoming precipitation depth owing to wind and sheltering effects, evaporative losses, etc.). Adjustments for the correction of precipitation under-catch were determined from adjusted precipitation data (Adjusted Historical Canadian Climate Data; EC, 2008d) for the stations listed in Table 7.1-9. The adjustments accounted for the following (Golder Associates, 2009):

- Wind under-catch and evaporation based on type of rain gauge;
- Gauge-specific wetting losses for individual rainfall events;
- Snowfall based on ruler measurements for period of record to minimize potential discontinuities associated with the introduction of the shielded Nipher snow gauge in the mid 1960s;
- Snow density corrections based on concurrent ruler and Nipher snow measurements; and
- Quantification of trace snowfall events.



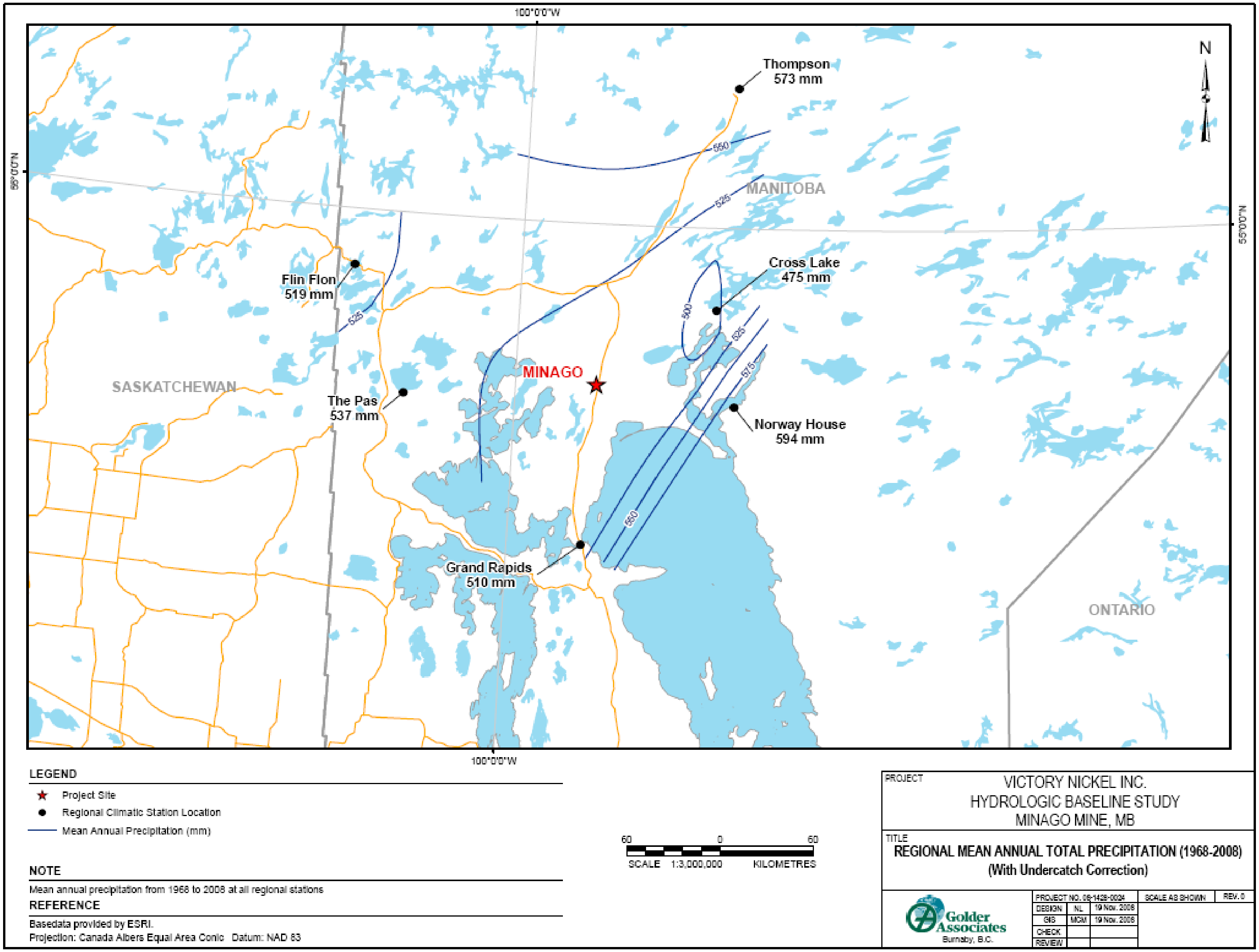
Source: Golder Associates, 2009

Figure 7.1-6 Regional Mean Annual Rainfall (1968-2008) (with Undercatch Correction)



Source: Golder Associates, 2009

Figure 7.1-7 Regional Mean Annual Snowfall (1968-2008) (with Undercatch Correction)



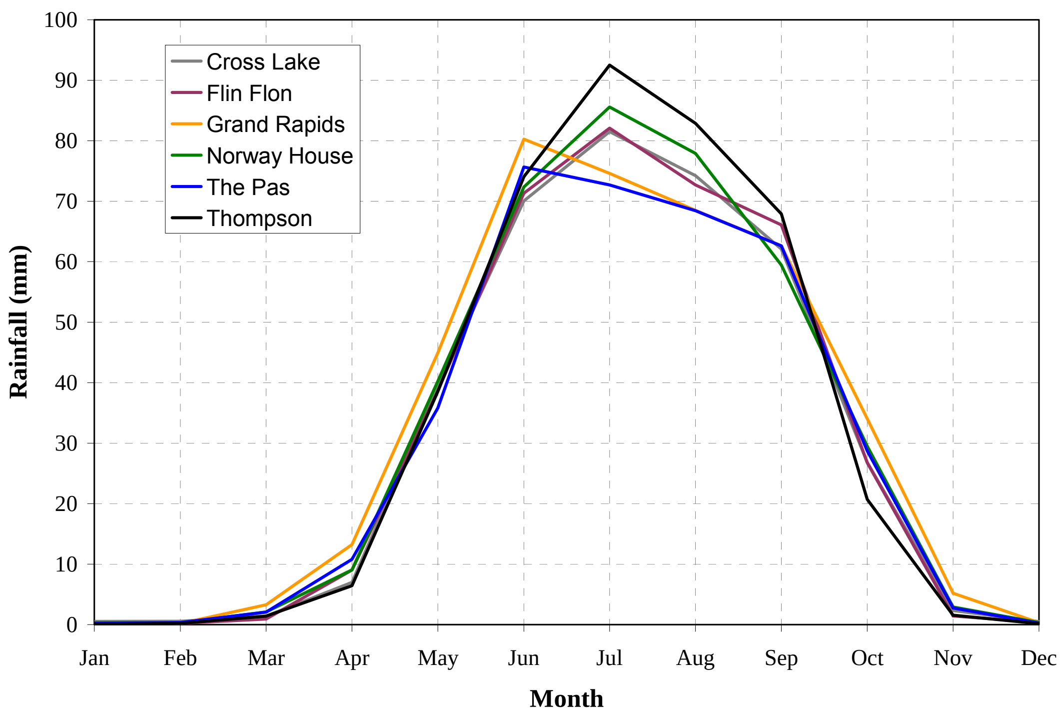
Source: Golder Associates, 2009

Figure 7.1-8 Regional Mean Annual Total Precipitation (1968-2008) (with Undercatch Correction)

Table 7.1-9 Mean Annual Precipitation at Regional Stations from 1968 to 2008

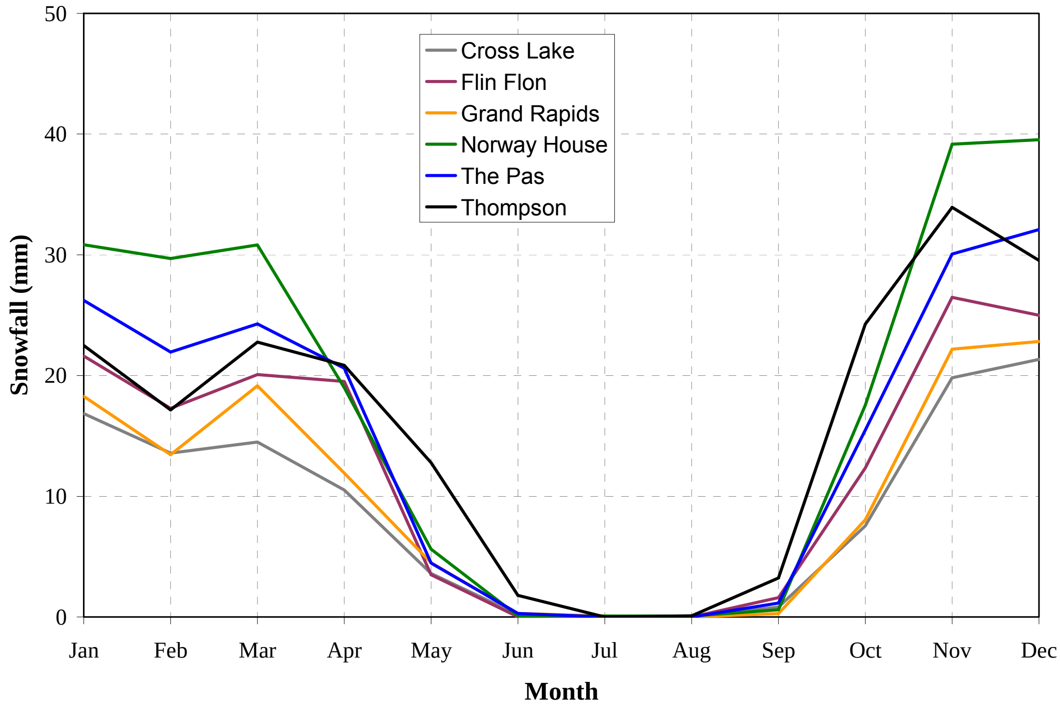
Station [1]	Months on Record [2]	Under-catch Factors [3]		Adjusted Precipitation (mm)		
		Rainfall	Snowfall	Rainfall	Snowfall [4]	Total Precipitation
Cross Lake	440	1.09	1.00	367	109	475
Flin Flon	488	1.07	1.00	371	148	519
Grand Rapids	488	1.05	1.09	389	122	510
Norway House	456	1.12	1.38	380	214	594
The Pas	488	1.10	1.14	360	177	537
Thompson	488	1.09	1.00	385	189	573

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).
2. A complete record, from January 1968 to August 2008, equals to a total of 488 months. Only months with less than 6 days of missing data are considered.
3. No adjusted data were available for the Cross Lake station. The under-catch factors applied to Cross Lake are those of the nearest neighboring station (*i.e.,* Thompson).
4. The snowfall water equivalent was estimated by multiplying the reported snowfall depth data by a consistent factor of 0.1 (as opposed to applying varying snowfall densities).



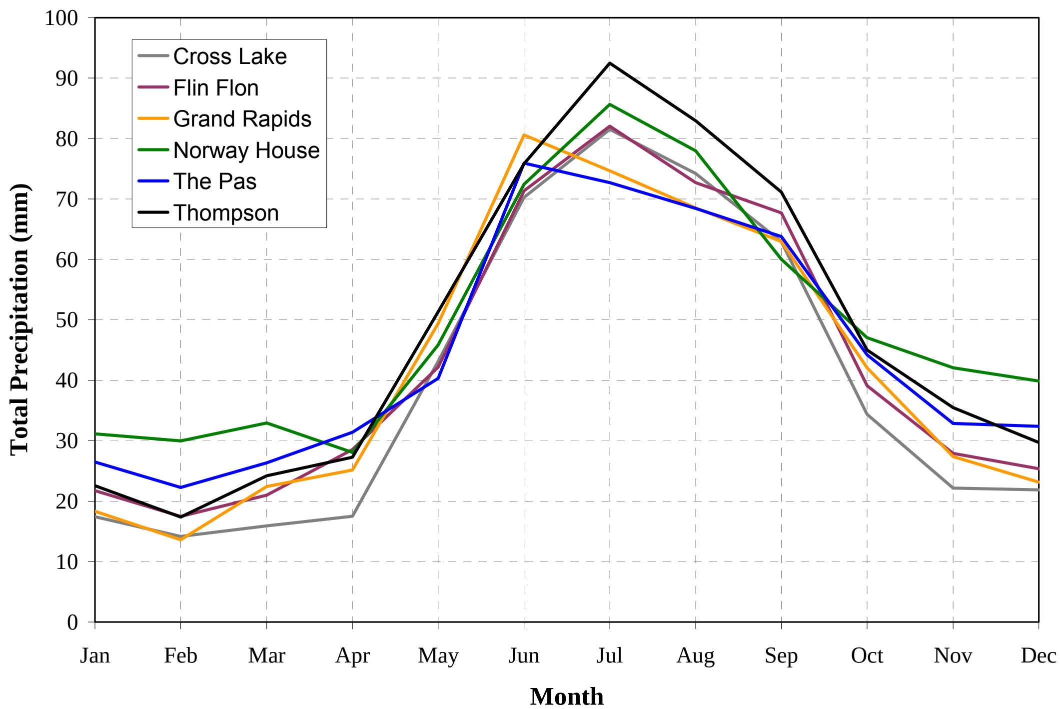
Source: Golder Associates, 2009

Figure 7.1-9 Regional Mean Monthly Rainfall



Source: Golder Associates, 2009

Figure 7.1-10 Regional Mean Monthly Snowfall (As Water Equivalent)



Source: Golder Associates, 2009

Figure 7.1-11 Regional Mean Monthly Total Precipitation

Figure 7.1-6 shows that annual rainfall is comparatively higher in close proximity to Lake Winnipeg than inland. Rainfall in regions away from Lake Winnipeg also tends to increase from south to north. Figure 7.1-7 indicates high snowfall (SWE) on the east side of Lake Winnipeg that gradually decreases westward. Snowfall eventually increases northward once inland to the west of Lake Winnipeg.

The data collected at the regional stations between 1968 and 2008 indicates that 73% of the precipitation in the region of the project site occurs as rainfall and consequently the spatial distribution of total regional precipitation shown in Figure 7.1-8 approaches that of rainfall as shown in Figure 7.1-6. Based on the regional spatial distribution of precipitation, illustrated in Figures 7.1-6 to 7.1-8 (i.e., isocontours), the estimated mean annual rainfall, snowfall (SWE) and total precipitation for the Minago project site from 1968 to 2008 are 375, 139 and 514 mm, respectively.

Figure 7.1-9 indicates a similar seasonal precipitation variation to all regional stations. Rainfall can occur at any time of the year, although it would be limited to isolated events during the months of November to March. Peak monthly rainfalls occur during the summer months of June and July (Figure 7.1-9).

Snowfall occurs at the regional stations from September to June, with the largest monthly amounts recorded from November to March (Figure 7.1-10). Based on the regional air temperature records, it is assumed that winter processes such as ground snow and ice covers are likely to be sustained from November to April. Any snowfall before November would be expected to melt in a few days, while those after April would contribute to the spring freshet.

Long-term precipitation characteristics at Minago were derived using the data available from The Pas. Both The Pas and Minago are located inland at roughly the same latitude and have relative warm air temperatures compared to most other regional stations. It is anticipated that the seasonal variation of precipitation would be the same at both stations.

In order to develop a precipitation record for the Minago Project, the precipitation data from The Pas for the period of 1950 to 2008 were adjusted based on the ratio of the annual precipitation at The Pas to the estimated annual precipitation at Minago. Specifically, rainfall amounts from The Pas were multiplied by a factor of 1.04 and snowfall was multiplied by a factor of 0.78. The resulting long-term characteristics at the project site are given in Table 7.1-10. Average annual precipitation at the project site is estimated to be 510 mm, of which rainfall accounts for 72% of the total (369 mm) and the remaining 28% consists of snowfall (SWE; 141 mm). Monthly rainfall, snowfall and total precipitation values derived for Minago for the period of 1950 to 2008 are also provided in Appendix 7.1.

Table 7.1-10 Derived Long-Term Precipitation Characteristics at Minago (1950-2008)

Month	Precipitation (mm) [1, 2]		
	Rainfall	**Snowfall**	**Total Precipitation**
Jan	0.2 (0.3)	20.1 (20.5)	20.2 (20.8)
Feb	0.2 (0.4)	17.5 (17.2)	17.8 (17.5)
Mar	1.6 (2.1)	20.9 (19.0)	22.4 (21.1)
Apr	11.0 (11.2)	15.8 (16.1)	26.8 (27.3)
May	38.6 (37.2)	4.2 (3.5)	42.8 (40.7)
Jun	74.2 (78.5)	0.2 (0.2)	74.4 (78.8)
Jul	78.3 (75.4)	0.0 (0.0)	78.3 (75.4)
Aug	69.6 (71.0)	0.0 (0.0)	69.6 (71.0)
Sep	64.6 (65.0)	1.1 (0.9)	65.8 (65.9)
Oct	27.5 (29.8)	11.5 (12.1)	39.0 (41.9)
Nov	2.9 (2.9)	25.3 (23.5)	28.2 (26.4)
Dec	0.2 (0.3)	24.8 (25.1)	25.0 (25.4)
Annual	369 (375)	141 (139)	510.2 (514)

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).
2. The values in parentheses are the mean values for the period from 1968 to 2008.

7.1.3.2.2 Extreme Precipitation Events

The complete adjusted precipitation record at The Pas for the period of 1950 to 2007 was used in a frequency analysis to derive estimated extreme return period events at the Minago project site. The results of the analysis are presented below.

Annual and Monthly Precipitation

Table 7.1-11 presents the estimated annual rainfall, snowfall and total precipitation amounts at the Minago Project for dry and wet precipitation events with return periods from 5 to 1000 years. Similarly, Table 7.1-12 provides the dry and wet monthly total precipitation amounts with return periods from 5 to 1000 years. Extreme rainfall, snowfall and total precipitation are derived independently of one another. Therefore the sum of rainfall and snowfall would not equal total precipitation for a same return period in Table 7.1-11.

Table 7.1-11 Estimated Wet and Dry Extreme Annual Precipitations for the Minago Project Site

Return Period (Years)		Rainfall (mm) [1]	Snowfall (mm) [1]	Total Precipitation (mm) [1]
Wet	1000	596	289	739
	500	582	278	724
	200	562	262	703
	100	544	248	686
	50	525	233	666
	20	496	212	637
	10	470	193	610
	5	437	173	577
Mean [2]		369	141	510
Dry	5	303	109	446
	10	266	94	410
	20	234	82	380
	50	198	69	346
	100	173	60	323
	200	151	53	301
	500	122	44	275
	1000	102	38	257

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).
2. The mean is roughly equivalent to the 2-year return period event.

Long Duration Rainfall Events

Rainfall intensity-duration-frequency (IDF) curves were determined for long-duration events ranging from 1 to 60 days using daily rainfall values derived for Minago based on the data collected at The Pas from 1950 to 2007. The resulting curves are presented in Table 7.1-13. The 30-day events are higher than any of the monthly events in Table 7.1-12 for the same return period. The estimation of 30-day events considers rainfall amounts that may overlap two consecutive months.

Short Duration Rainfall Events

Adjusted hourly rainfall data collected at The Pas from 1972 to 2007 were used to derive estimated project site rainfall IDF curves for events ranging from 1 to 24 hours. The resulting curves are presented in Table 7.1-14.

Table 7.1-12 Estimated Wet and Dry Extreme Monthly Precipitations for the Minago Project Site

Return Period (Years)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet [1]	1000	60	70	112	119	183	276	277	266	221	199	92	70
	500	57	64	101	108	168	252	256	245	205	176	87	67
	200	53	56	86	94	147	220	229	218	184	148	79	62
	100	49	50	75	84	132	197	208	196	167	128	73	58
	50	45	44	64	73	116	174	186	175	151	110	66	53
	20	37	36	51	60	95	145	156	146	128	87	57	47
	10	35	30	42	50	79	123	133	124	110	71	49	41
	5	29	25	32	39	62	100	108	100	90	55	40	35
Mean [2]		20	18	22	27	43	74	78	70	66	39	28	25
Dry [1]	5	11	10	11	13	21	44	44	36	38	19	16	16
	10	7.8	9.3	7.3	8.0	15	35	34	25	31	13	12	11
	20	5.4	8.9	5.1	4.9	12	29	28	17	26	8.4	8.6	7.2
	50	3.0	8.7	3.1	1.9	7.9	24	21	10	22	4.3	5.6	4.6
	100	1.5	8.7	1.9	0.1	6.0	21	17	5.9	20	1.9	3.9	3.5
	200	0.3	8.7	1.0	0.0	4.4	18	14	2.4	18	0.0	2.5	2.8
	500	0.0	8.7	0.0	0.0	2.8	16	11	0.0	17	0.0	0.9	2.2
	1000	0.0	8.6	0.0	0.0	1.8	14	9.3	0.0	16	0.0	0.0	2.0

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).
2. The mean is equivalent to the 2-year return period event.

Table 7.1-13 Long-Duration Extreme Rainfall Estimates for Minago

Return period	Rainfall Depth (mm) for Various Durations [1]					
(Year)	1-day	3-day	5-day	10-day	30-day	60-day
2	40	57	65	80	132	193
5	53	76	86	106	168	245
10	62	87	99	122	189	276
20	71	97	110	135	208	304
50	82	108	123	151	231	336
100	90	116	133	161	248	358
200	98	123	142	171	263	378
500	110	131	154	182	284	402
1000	128	136	162	190	298	419

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).

Table 7.1-14 Short-Duration Extreme Rainfall Estimates for Minago

Return period	Rainfall Depth (mm) for Various Durations [1]				
(Year)	1-hr	2-hr	6-hr	12-hr	24-hr
2	16	20	29	36	49
5	23	28	40	52	67
10	28	35	49	64	79
20	33	42	59	77	89
50	40	52	73	87	102
100	45	60	85	98	111
200	51	70	99	110	120
500	60	84	121	126	132
1000	67	96	139	140	141

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008c)).

As indicated in Table 7.1-14, the 24-hour events are roughly 20% higher than the 1-day events. Unlike the 1-day events, the 24-hour events consider recorded rainfall maxima that overlap 2 calendar days. An increase of 13% is typically assumed in the absence of supporting data (Watt et al., 1989), and therefore the estimates of 24-hour events in Table 7.1-14 may be conservative.

Probably Maximum Precipitation

Estimates of Probably Maximum Precipitation (PMP) for the Minago project site were derived using the Hershfield statistical approach (Hershfield, 1977). In this approach, extreme rainfall is expressed as:

$$X_T = U_x + K_{MT} * Std_x$$

where X_T is the extreme rainfall amount for a given return period T, U_x is the mean of the annual maximum series, K_{MT} is a frequency factor associated with a given duration, and Std_x is the standard deviation of the annual maximum series. For a 24-hr duration event,

$K_{M24} = 19 * (10)^{-0.000965*U24}$, resulting in a 24-hour PMP at Minago of 447 mm.

This estimate is considered applicable on a regional scale; however, significant spatial variability can be present in extreme precipitation events, particularly for small watersheds. Hopkinson (1999) developed PMP estimates for watersheds smaller than or equal to 1 km^2. Based on historical storms in the Canadian prairie region and the analysis of the maximum persisting dew point, Hopkinson (1999) estimated a 24-hour point PMP of 606 mm at the Flin Flon station. This estimate is considered applicable to smaller watersheds (<= 1 km^2) in the vicinity of the Minago Project since the mean annual rainfalls are similar between the study area and Flin Flon.

7.1.3.3 Evaporation

No evaporation record is available for the proposed Minago Project site. However, May to October pan and lake evaporation estimates are available at the Norway House, Grand Rapids and Pasquia Project stations. The evaporation records at these stations are summarized in Table 7.1-15.

Pan and lake evaporation follows a monthly distribution that is roughly similar for both variables. Lake evaporation is on average equal to 77% of pan evaporation.

The distribution of evaporation on a monthly basis is similar at all three regional stations. The total amount of evaporation is relatively equivalent at Grand Rapids (581 mm) and Norway House (549 mm), while it is lower at Norway House (354 mm).

It is assumed that the amount of evaporation at Minago would be similar to that Pasquia Project, since both locations are inland as opposed to located near large waterbodies, which is the case for the Grand Rapids and Norway House stations. However, based on the derived air temperature record presented in Table 7.1-8, it is anticipated that evaporation also occurs in April at the Minago Project. In this report, the additional evaporation in April was assumed to be similar to that for the month of October.

Table 7.1-15 Pan and Lake Evaporation Estimates at Regional Stations

Station	Data [1]	May	June	July	August	Septembe r	October	May to October Total
Norway House (1971 to 2000)	Mean Lake Evaporation	66	77	81	74	44	12	354
	% of Annual	19%	22%	23%	21%	12%	3%	
	Mean Pan Evaporation	84	101	107	96	59	17	464
	% of Annual	18%	22%	23%	21%	13%	4%	
	# Years	6	29	27	17	24	20	
Grand Rapids (1966 to 1978)	Mean Lake Evaporation	112	127	139	120	67	15	581
	% of Annual	19%	22%	24%	21%	12%	3%	
	Mean Pan Evaporation	134	165	181	155	87	20	742
	% of Annual	18%	22%	24%	21%	12%	3%	
	# Years	1	5	8	10	10	5	
Pasquia Project (1969 to 1985)	Mean Lake Evaporation	128	122	123	94	61	21	549
	% of Annual	23%	22%	22%	17%	11%	4%	
	Mean Pan Evaporation	170	159	157	124	81	28	720
	% of Annual	24%	22%	22%	17%	11%	4%	
	# Years	5	8	8	6	8	3	

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008c)).

Table 7.1-16 provides the derived long-term lake evaporation estimates at Minago. The estimates were derived assuming that:

- The monthly distribution of evaporation would be equal to the average distribution from the three regional stations; and
- The average total evaporation would be approximately 549 mm from May to October (Pasquia Project) plus an additional amount in April equal to that for the month of October, for an estimated total mean annual evaporation at the Minago Project of 566 mm.

Table 7.1-16 Long-term Lake Evaporation Estimates at Minago

Station	Data [1]	April	May	June	July	August	September	October	Total
Minago	Mean Monthly Evaporation (mm)	17.6	112	121	127	107	64.1	17.6	566
	% of Annual	3%	20%	21%	22%	19%	11%	3%	100.0%

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008c)).

7.1.3.4 Wind

Table 7.1-17 presents the distribution of the wind among the 8 major directions at the Norway House, The Pas and Thompson stations for the period from 1968 to 2008. The distribution at The Pas and Thompson is relatively similar to that shown for these two stations in Table 7.1-6 for the period of 2007 to 2008.

Based on the wind data presented in Tables 7.1-6 and 7.1-17, the wind distribution at Minago appears to differ from that at the regional stations. Moreover, the recorded mean wind speed at Minago appears to be higher than that at the regional stations. It should be noted however that the project site period of record is too short to draw definitive conclusions with respect to differences in wind characteristics between Minago and the regional stations. Assessment of wind characteristics at Minago is therefore limited to the estimation of extreme wind speeds based on hourly wind data recorded at the The Pas station from 1953 to 2008. The extreme hourly wind speeds for the Minago Project are provided in Table 7.1-18.

7.1.3.5 Sublimation and Snow Redistribution

The amount of water released from the snow pack during the spring thaw will depend on the amount of snow accumulated, redistributed, and/or sublimated over the winter period. Sublimation is the process by which ice and snow change directly to water vapor without passing through the liquid stage. Sublimation can occur directly from snowpack surfaces or during blowing snow events with overall rates dependent upon humidity and wind speed (Essery et al., 1999; Déry and Yau, 2002). Snow redistribution refers to snow erosion from, and deposition to, the snowpack due to wind.

Table 7.1-17 Regional Wind Characteristics from 1968 to 2008

Wind Direction	Norway House [1]			The Pas [1]			Thompson [1]		
	Mean Speed (km/hr)	Probability of Occurrence Excluding Calm (%)	Probability of Occurrence Including Calm (%)	Mean Speed (km/hr)	Probability of Occurrence Excluding Calm (%)	Probability of Occurrence Including Calm (%)	Mean Speed (km/hr)	Probability of Occurrence Excluding Calm (%)	Probability of Occurrence Including Calm (%)
N	13.6	13%	11%	14.4	14%	13%	13.9	13%	11%
NE	13.7	12%	10%	11.5	7%	6%	14.6	13%	12%
E	12.7	11%	9%	12.2	10%	9%	11.8	13%	11%
SE	11.5	8%	7%	15.3	20%	18%	10.5	8%	7%
S	15.1	14%	12%	13.2	12%	11%	12.2	10%	9%
SW	14.4	15%	13%	11.7	5%	4%	12.3	8%	7%
W	12.9	11%	10%	17.1	17%	16%	12.8	20%	17%
NW	14.1	16%	13%	19.3	15%	14%	14.2	15%	13%
Calm [2]	-	-	15%	-	-	9%	-	-	12%
All	13.5	100%	100%	14.3	100.0%	100.0%	12.8	100%	100%

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008c)).
2. Calm refers to wind below the detection limit of the instruments (*i.e.,* the wind speed is assumed to be zero).

Sublimation and snow redistribution can have a significant impact on snow pack depths and melt in northern environments, where humidity can be low and the land subject to high winds (Marsh et al., 1994; Pomeroy et al., 1997). The assessment of these two processes at Minago is based on the snowfall amounts and on snow survey observations, as discussed below.

Snow survey observations with more than 10 years of record for conditions in March of each year are available at nine (9) regional stations (Table 7.1-2). Table 7.1-19 presents the snow depth, snow water equivalent, and density characteristics at these stations.

The average snow depth and water equivalent at the regional stations listed in Table 7.1-2 are 480 mm and 81 mm, respectively, with observations ranging from 140 to 920 mm for snow depth and from 25 to 170 mm for snow water equivalent (Table 7.1-19). Snow density is the ratio of snow water equivalent to snow depth, and ranges from 0.07 to 0.47 mm/mm at the regional stations, with an average of 0.17 for all stations (Table 7.1-19).

Table 7.1-20 compares the snow water equivalent observed in March at the snow survey stations to the cumulated snowfall recorded at the corresponding nearest regional climate station between November and the March survey date. Snowfalls in September and October are not included, since recorded air temperatures suggest that any snow that fell during these months would have likely melted and therefore not contributed to the snow pack observed in March. All observations of snow water equivalent in Table 7.1-20 are lower than their corresponding accumulated snowfall, which indicates that snow erosion and sublimation of the snow pack exceeded snow

Table 7.1-18 Estimated Extreme Hourly Wind Speeds (km/h) at Minago

Wind Direction	Return Period							
	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	200 Year	500 Year
Annual Period (January to December) [1]								
N	46	51	53	56	58	60	62	63
NE	31	36	39	43	45	48	50	53
E	35	38	40	42	43	44	45	46
SE	46	50	52	54	55	57	58	60
S	40	44	47	50	52	54	56	59
SW	36	43	48	55	62	68	75	85
W	51	60	68	78	87	97	108	124
NW	56	62	66	71	75	78	82	87
Open Water Period (May to October) [1]								
N	44	50	52	55	57	58	60	61
NE	31	36	39	43	46	48	51	54
E	33	37	39	41	43	45	46	48
SE	43	47	50	53	55	58	60	64
S	38	42	45	48	50	52	54	56
SW	35	40	43	48	51	53	56	60
W	48	57	62	69	75	80	85	91
NW	52	58	60	64	66	67	69	71

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008c)).

Table 7.1-19 Summary of Snow Characteristics at Regional Stations

Station [1]	Observations in March	Snow Depth (mm)			Snow Water Equivalent (mm)			Density (mm/mm)		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Crossing Bay	20	250	480	770	33	79	107	0.08	0.17	0.24
Flin Flon	24	190	500	790	25	77	147	0.07	0.15	0.21
Norway House	14	410	550	700	46	101	152	0.11	0.18	0.24
Overflowing River	24	160	420	780	30	66	117	0.11	0.16	0.26
Pasquia Hills	22	140	450	820	27	73	160	0.09	0.16	0.22
Red Earth Lake	21	190	410	780	30	65	103	0.09	0.16	0.22
The Pas	35	150	470	920	38	92	170	0.12	0.20	0.47
Thicket Portage	14	390	560	730	56	113	170	0.13	0.20	0.25
Westray	24	230	440	880	30	67	145	0.10	0.15	0.22

1. Data source: Golder Associates, 2009 (Secondary source: EC (2007)).

deposition. The average annual loss from snow redistribution and sublimation is approximately 39%.

Loss due to snow redistribution and sublimation is dependent on local geography and conditions. A large portion of the Minago Project area would consist of open terrain with low lying vegetation. According to Essery et al. (1999), losses to sublimation for open tundra areas can reach up to 47% of the snow pack, and losses due to snow redistribution can account for an additional 18 to 22% for lakes and open tundra. However, the proposed project area is also partially covered with forest, and snow redistribution only constitutes a loss when snow leaves the watershed. Therefore, the total snow losses at Minago were presumed to be less than the values reported by Essery et al. (1999), and an estimate of 39% was assumed to be representative of losses for the Minago project area (Golder Associates, 2009).

Table 7.1-20 Snow Lost to Sublimation and Redistribution at Regional Station

Snow Survey Station	Snow Survey Station - Period of Record	Nearest Climate Station	Climate Station Snowfall - Period of Record	Average SWE (mm) [1]	Accumulated Snowfall (mm) [2]	Losses (%)
Crossing Bay	1966 to 1985	The Pas	1947 to 2008	79	136	42
Flin Flon	1962 to 1985	Flin Flon	1980 to 2008	73	92	20
Norway House	1962 to 1971 and 1974 to 1977	Norway House	1971 to 2008	91	143	36
Overflowing River	1962 to 1985	The Pas	1947 to 2008	66	138	52
Pasquia Hills	1962 to 1985	The Pas	1947 to 2008	73	138	47
Red Earth Lake	1965 to 1985	The Pas	1947 to 2008	65	137	53
The Pas	1962 to 1997	The Pas	1947 to 2008	92	130	30
Thicket Portage	1962 to 1977	Thompson	1968 to 2008	104	122	15
Westray	1962 to 1985	The Pas	1947 to 2008	67	138	51

1. Data source: Golder Associates, 2009 (Secondary source: EC (2007)).
2. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).

7.1.4 Climate Change relevant to Minago

In 2007, the Intergovernmental Panel on Climate Change (IPCC), a scientific body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP), released its Fourth Assessment Report on Climate Change. The report comprises three documents, each produced by a separate working group as follows: I - The Physical Science Basis; II - Impacts, Adaptation and Vulnerability; and III - Mitigation of Climate Change. The assessment was conducted by the world's leading climate change experts and scientists, and represents the current state-of-knowledge on a global basis.

The following sections provide a summary of the information from Volume I – The Physical Science Basis as it pertains to Canadian northern latitudes and the Minago Project site. The information and descriptions presented are excerpted, paraphrased, or indirectly derived from the report. Where appropriate, chapter numbers are provided for reference.

7.1.4.1 Summary of Climate Projections for Minago

Mean annual temperatures in the northwestern part of North America are expected to rise by about 4.5^{O}C in the 100 years leading up to 2100 (i.e., increase from mean of 1980 to 1999 period to mean of simulated 2080 to 2099 period). This increase represents the median of the values projected by a series of 21 models for an average emissions scenario. The mean projected increase for a high emissions scenario is about 5.2^{O}C while the mean increase for a lower emissions scenario is about 3.1^{O}C (Golder Associates, 2009).

Mean annual precipitation for the same region and time period is projected to rise by about 21%. Of the 21 models for average emissions, the maximum and minimum projections for precipitation are increases of 32% and 6%, respectively (Golder Associates, 2009).

Following are detailed projections, including seasonal variations, and a discussion on observed climate changes.

7.1.4.2 Observed Changes

Observed changes in temperature, precipitation, snow cover, lake and river ice, and frozen ground are summarized as applicable to the Minago site. The descriptions focus on observations related to the Northern Hemisphere, North America, northern Canada, and the Artic.

Temperature (IPCC 2007 Report, Section 3.2; Trenberth et al., 2007):

- Global mean surface temperatures have risen by 0.74^{O}C over the last 100 years. The trend is not linear and is not always increasing. The rate of warming over the last 50 years is almost double that over the last 100 years (0.13^{O}C per decade vs. 0.07^{O}C per decade). The rate of warming over the last 25 years has been 0.18^{O}C per decade.
- Eleven of the last 12 years (1995 to 2006) rank among the 12 warmest years on record since 1850.
- Average arctic temperatures increased at almost twice the global average rate in the past 100 years. Arctic temperatures have a high decadal variability. A slightly longer warm period, almost as warm as the present, was also observed from the late 1920s to the early 1950s, but appears to have had a different spatial distribution than the recent warming.
- The length of the frost-free season has increased in most mid- and high-latitude regions. In the northern hemisphere, this is mostly manifested in an earlier start to spring.

- Changes in global and regional temperatures are influenced by changes in the large-scale atmospheric circulation. There are substantial multi-decadal variations in the Pacific sector with extended periods of weakened as well as strengthened circulation.

Precipitation and Surface Hydrology (IPCC 2007 Report, Sect. 3.3; Trenberth et al., 2007):

Temperature changes are one of the more obvious and easily measured changes in climate; however, these changes also drive changes in atmospheric moisture, precipitation, and circulation. Further, increases in temperature result in increased moisture-holding capacity of the atmosphere at a rate of about 7% per ^{O}C. All these factors combined lead to changes to the overall hydrologic cycle.

- *Global precipitation over land:* An analysis of global land precipitation anomalies from 1900 to 2005 indicates an increase in precipitation until the 1950s (relative to 1981-2000 base period) followed by a decline until the early 1990s and then a recovery since then. The linear trend is minimal and statistically insignificant.
- *Regional precipitation trends:* For most of North America, and especially over high-latitude regions in Canada, annual precipitation has increased over the 105-year period from 1900 to 2005.
- *Changes in snowfall:* Statistically significant increases in snowfall have been documented for most of Canada, particularly in the northern regions, up until at least 1995 when the analysis ended (Stone et al., 2002 in IPCC, 2007).
- *Evapotranspiration:* Global land evapotranspiration has been found to closely follow variations in land precipitation due its dependence on moisture supply. As precipitation has generally increased in northern latitudes over the past 100 years, presumably so has evapotranspiration. Not only does evapotranspiration depend on moisture supply, but also on energy available and surface wind. In other areas of the world, increased cloud cover, aerosols, and air pollution may contribute to reduced evapotranspiration rates.

Snow Cover (IPCC 2007 Report, Section 4.2; Lemke et al., 2007):

- Based on satellite data, in the Northern Hemisphere, snow cover in November, December and January has decreased over the 1966 to 2005 period. Decreases were observed in every other month, as well as a stepwise drop of 5% in the annual mean in the late 1980’s. The decrease in snow cover in February and March has resulted in a shift in the date of snowmelt start by about eight days since the mid-1960s.

River and Lake Ice (IPCC 2007 Report, Section 4.3; Lemke et al., 2007):

- Freeze-up and breakup dates for river and lake ice exhibit considerable spatial variability (with some regions showing trends of opposite signs). When data for the Northern Hemisphere is averaged over the past 150 years, freeze-up date has occurred later at a rate of 5.8 days per century, and the breakup date has occurred earlier at a rate of 6.5 days per century.

7.1.4.3 Projected Changes

7.1.4.3.1 Climate Models

Increasingly reliable regional climate change projections are now available for many regions of the world due to advances in modelling and understanding of the physical processes of the climate system. Atmosphere-Ocean General Circulation Models (AOGCMs) remain the foundation for projections while downscaling techniques now provide valuable additional detail. AOGCMs cannot provide information at scales finer than their computational grid (typically on the order of 200 km) and processes at the unresolved scales are important. Providing information at finer scales can be achieved through using high resolution dynamical models or empirical statistical downscaling. Downscaled climate change projections tailored to specific needs are only now starting to become available (IPCC 2007 Report, Section 11.1; Christensen et al., 2007).

The regional climate change projections are based on four potential sources: AOGCM simulations; downscaling of AOGCM-simulated data using technique to enhance regional detail; physical understanding of the processes governing regional responses; and recent historical climate change. The following general statements have been reported with respect to North America and/or the Arctic, and are relevant to the Minago region:

- The annual mean warming is very likely to exceed the global mean warming;
- Seasonally, warming is likely to be largest in winter and smallest in summer;
- Minimum winter temperatures are likely to increase more than the average;
- Annual mean precipitation is very likely to increase in Canada;
- The relative precipitation increase is very likely to be largest in winter and smallest in summer; and
- Maximum snow depth (snowfall) is likely to increase.

7.1.4.3.2 Projections for North America and Arctic Region

Climate projections are presented in the IPCC 2007 Report (Chapter 11; Christensen et al., 2007) for 30 sub-regions around the globe. The Minago project site (54^{O} 05'; 99^{O} 12') is within the "East Canada, Greenland and Iceland" (CGI) sub-region of North America.

Table 7.1-21 summarizes the regional average temperature projections from a set of 21 global models for the A1B emissions scenario. The A1B scenario represents a "middle-of-the-road" estimate of future emissions, with more extreme conditions characterized by scenarios B1 and A2. The ratio of global mean surface temperatures (projected changes for 2080 to 2099 based on 1980 to 1999 base case) are 0.69:1:1.17 for B1:A1B:A2 scenarios. Regional temperatures are shown to closely follow the global ratios.

The values shown in Table 7.1-21 represent the change between the mean values for the 2080 to 2099 simulated period as compared to the 1980 to 1999 base case (A1B Scenario). In effect, they represent the projected changes over a 100-year period ending in 2100. Table 7.1-22 presents similar information for changes in precipitation for the A1B Scenario.

For a more extreme case (A2), temperature changes can be estimated by factoring the A1B results by 1.17. Similarly, for reduced emissions, temperature changes for the B1 scenario can be estimated by factoring the A1B results by 0.69.

Table 7.1-21 Projected Regional Temperature Increase (^{O}C) for A1B Scenario

Period	Minimum	25th Percentile	Median (50th Percentile)	75th Percentile	Maximum
Winter (Dec-Feb)	3.3	5.2	5.9	7.2	8.5
Spring (Mar-May)	2.4	3.2	3.8	4.6	7.2
Summer (Jun-Aug)	1.5	2.1	2.8	3.7	5.6
Fall (Sep-Nov)	2.7	3.4	4.0	5.7	7.3
Annual	2.8	3.5	4.3	5.0	7.1

Source: Golder Associates, 2009 (Secondary source : IPCC 2007 Report, Section 11.1; Christensen et al., 2007).

Note: Projections for CGI sub-region of North America; projections represent difference in mean temperature of 2080 to 2099 period compared to 1980 to 1999 base case.

7.1.4.3.3 Projections for Minago

The changes in temperature and precipitation discussed above are applicable to the Minago site. The absolute projected temperatures and precipitation for Minago are summarized in Table 7.1-23.

Table 7.1-22 Projected Regional Precipitation Increase (%) for A1B Scenario

Period	Minimum	25^{th} Percentile	Median (50^{th} Percentile)	75^{th} Percentile	Maximum
Winter (Dec-Feb)	6	15	26	32	42
Spring (Mar-May)	4	13	17	20	34
Summer (Jun-Aug)	0	8	11	12	19
Fall (Sep-Nov)	7	14	16	22	37
Annual	8	12	15	20	31

Source: Golder Associates, 2009 (Secondary source : IPCC 2007 Report, Section 11.1; Christensen et al., 2007).

Notes: Projections for CGI sub-region of North America; projections represent difference in annual precipitation of 2080 to 2099 period compared to 1980 to 1999 base case.

Table 7.1-23 Projected Mean Temperature and Precipitation at Minago for the 2088 to 2099 Period

Annual Temperature / Precipitation	Derived Mean for 1980 to 1999 Period[a]	Median Projected Change[b]	Projected Mean for 2080 to 2099 Period
Temperature	0.1 ^{O}C	4.3 ^{O}C	4.4 ^{O}C
Precipitation	504 mm	15%	580 mm

Notes: Source: Golder Associates, 2009

(a) refer to Section 7.1.3;

(b) IPCC 2007 regional projections for CGI sub-region of North America for A1B emissions scenario (Christensen et al., 2007).

7.1.5 Effects Assessment Methodology

For the climate effects assessment, the following five climate VECCs have been selected:

- air temperature;
- precipitation;
- snowpack depth and snow water equivalent;
- wind velocity and direction; and
- relative humidity.

The rationale for this selection and baseline data are summarized in Table 7.1-24.

Any project effects on climate will be at a micro-climatic scale. The effects that will occur have been characterized according to the effects attributes defined in Table 7.1-25.

Table 7.1-24 Selected Climate VECCs

Parameter	Rationale for Selection	Linkage to Regulatory Drivers	Baseline Data for Environmental Assessment
Air temperature	• Influences type of precipitation, evaporation and snowmelt rate. • Influences dispersion of air emissions.	• Identified in EBS Workplan	• Field data • Regional data
Precipitation (snowfall and rainfall: mean daily, monthly, and annual; peak and drought)	• Controlling input to site hydrology and water balance. • Required for water management facilities design. • Influences surface erosion. • Influences natural hazards (landslides, avalanches, floods).	• Identified in EBS Workplan	• Field data • Regional data
Snowpack depth and snow water equivalent	• Influences runoff. • Can influence operability of mine operations, growing season, wildlife migration, and avalanche risk.	• Identified in EBS Workplan	• Field data • Regional data
Wind velocity and wind direction	• Can influence evaporation and controls snow drifting. • Affects dispersion of dust and air emissions.	• Identified in EBS Workplan	• Field data • Regional data
Relative humidity	• Affects evaporation and site hydrology.	• Identified in EBS Workplan	• Field data

Table 7.1-25 Effect Attributes for Climate

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

7.1.5.1 Project Effects

Effects of the project on climate will be limited to the effects of vegetation clearing and project-related structures on localized wind exposure, speed and direction; deposition of precipitation; solar radiation; snowmelt rate and snow water equivalent etc., and the effects of the project site and access road snow plowing and compaction of snowpack. These effects will commence early in the construction phase and continue with the same intensity to the end of decommissioning. At closure, effects associated with project site structures will cease; however, localized effects due to site clearing will persist until vegetation will have been re-established on reclaimed areas.

The project will have very little effect on air temperature, precipitation, wind direction and velocity, solar radiation and relative humidity, because the controlling forces on these parameters are regional to global in scale. Any effects would be neutral, low magnitude, site-specific, short-term and of moderate frequency (seasonal). Most effects are reversible, though some (e.g., associated with access road clearing and operation) are functionally irreversible. The likelihood of effects occurring as predicted is high.

The project will have localized effects on snowpack depth, snow water equivalent and snowmelt rate. Road plowing, compaction of snow by mine machinery, and the deposition of windblown dust will result in localized increases and decreases in snow accumulation and melt rate. These effects can be characterized as both positive and adverse in terms of linkages to other VECCs. Compacted snow will have a lower snowpack depth, but a higher snow water equivalent than uncompacted snow. Changes in snowmelt rate are discussed in Section 7.4: Surface Water Hydrology.

In summary, the effects of the project on snowpack depth, snow water equivalent and snowmelt rate will be positive to adverse, of low magnitude (while measurable on a site-specific scale, it will not affect average snowpack depth, snow water equivalent or melt rate in affected stream basins), site-specific, short-term, and of moderate frequency (seasonal). Most effects are reversible, though some (e.g., associated with access road operation) are functionally irreversible. The likelihood of effects occurring as predicted is high.

7.1.5.2 Residual Project Effects and Significance

As noted above, any effects of the project on climate parameters will be very localized and well within the range of natural variability for these occurrences. Based on the criteria defined in Table 7.1-25, predicted effects of the project on climate parameters are considered to be not significant.

7.1.5.3 Cumulative Effects

Residual project effects are very localized and there are no additional activities in the foreseeable future, which would contribute to cumulative effects on climate on a local or regional scale.

Therefore, there will be no significant adverse cumulative or residual cumulative effects in the project area. The likelihood of occurrence of effects as predicted is high.

7.1.5.4 Mitigation Measures

There will be no significant effects of the project on climate parameters; therefore, no mitigation measures are proposed.

7.1.5.5 Monitoring and Follow-up

Data collection at the climate station will continue during the construction, operation, and decommissioning of the mine. The climate station will likely be moved to a suitable site, to obtain wind speeds and directions that are more generally representative of the project site. Possible new locations are at the mine portal and processing area, or at the TWRMF. The accuracy and quality of field climate data will improve as the period of record increases in duration.

A dedicated snow course monitoring program will be installed, with monthly or weekly measurement of snowpack depth and snow water equivalent, to improve site-specific data on winter precipitation and to refine site water balances. Follow-up and monitoring programs are summarized in Table 7.1-26.

Table 7.1-26 Monitoring Programs for Climate

Program	Program Objectives	General Methods	Reporting	Implementation
Follow-up and Monitoring Programs				
Climate station data collection	• Confirm the accuracy of the climate characterization. • Detect climatic trends and continue data baseline.	• Automated data collection with periodic downloads as required	• Internal • Data could be shared with Manitoba or other interested parties, if desired.	Proponent
Snow course installation	• Measure snowpack depth and snow water equivalent at projec site. • Refine estimates of winter precipitation and snowpack contributions to site hydrology (Section 7.4).	• Manual data collection on monthly or periodic basis for snowpack depth and snow water equivalent	• Internal	Proponent

7.1.5.6 Summary of Effects

Effects of project and cumulative effects on climate are summarized in Table 7.1-27.

Table 7.1-27 Summary of Effects on Climate

Potential Effect	Level of Effect						Effect Rating	
	Direction	**Magnitude**	**Extent**	**Duration/ Frequency**	**Reversibility**	**Likelihood**	**Project Effect**	**Cumulative Effect**
Construction, Operations and Decommissioning								
Localized increases in snowpack depth, water content and melt rate	Positive to adverse	Low	Site-specific	Short term, seasonal	Reversible to irreversible (ongoing access road use)	High	Not significant	Not significant
Localized changes in wind speed and direction, precipitation deposition, and solar radiation due to site clearing and project structures	Neutral	Low	Site-specific	Short term, seasonal	Reversible to irreversible (ongoing access road use)	High	Not significant	Not significant
Closure								
Ongoing localized effects of clearing and snow plowing on wind, solar radiation and snowpack	Positive to adverse	Moderate	Site-specific	Short term, seasonal	Irreversible	High	Not significant	Not significant