GOLDER

REPORT

Giant Mine Remediation Project

Climate Change

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Executive Summary

Climate change provides the opportunity to assess current and future risk in terms of the design parameters regarding mine closure to assist decision-making. This climate change assessment supports the surface water design basis report. Golder has developed a standardized approach for completing climate change assessments which is in line with the best guidance practices being developed by the Mining Association of Canada (MAC). The approach provides a description of the current climate baseline and how those values are projected to change under future climate conditions, grounded in the best available climate observations and climate projections.

A description of the current climate over the past 48 years (1971 – 2018) is provided based on observed measurements from Yellowknife A climate station, approximately 5 kilometres away from Giant Mine. The climate station observations have been infilled with reanalysis data (based on satellite and ground observations) to achieve the data completeness required for the analysis and adjusted to account for siting and wind undercatch impacts on observations. These observations are used as a climate baseline which provides context for the current climate and how it is changing. The future climate is described using the projections from Global Climate Models (GCMs) included as part of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). There is uncertainty with the projections, however, this uncertainty is captured by using multiple projections from multiple models and scenarios (multi-model ensemble), as recommended by the IPCC (IPCC 2013). The future projections are provided in terms of percentiles, allowing for different levels of acceptable risk.

With the potential for the future distribution and amount of precipitation to change, it is important to understand how these changes will affect the design basis. This report establishes a connection between various climate indices, the current climate baseline, and the future projected climate. A summary of the key climate indices for the current conditions compared to the projected future climate conditions is provided below (Table 1), with additional climate indices available in the report. The projected increase under future climate conditions is provided in the Table in brackets, where appropriate, for the 50th percentile of the multi-model ensemble. Projecting forward to the future climate conditions of the 2050s (2041 – 2070) and the 2080s (2071 – 2100) sees a continual increase in the 50th percentile of the multi-model ensemble.

Table 1: Comparison of Key Climate Indices

Climate Index	ECCC data 1963-1993	Current Climate Baseline Conditions 1971 -2018	Future Climate Conditions[a]	
			2050s	2080s
1:100 Year Return, 24 hours Duration Event (mm)	79.0	80.7[b]	—	—
1:100 Year Return, 1-Day Duration Event (mm)	—	71.4	78.2 (9.5%)	88.5 (23.9%)
Probable Maximum Precipitation (PMP) 1-Day Duration (mm)	—	267.0	292.4 (9.5%)	304.4 (14.0%)

Notes:

(a) The future projection is provided followed by the increase measured from the modelled climate baseline, where appropriate, for the 50th percentile of the multi-model ensemble.

(b) Converted from 1-day to 24-hour duration using 1.13 ratio (WMO, 2009).

The current local and regional data related to the current and projected climate change scenarios were compared to the results of the Climate Change Review completed for the Freeze Design by AECOM and Newmans Geotechnique (2018). The Climate Change Review focused on projected changes to annual and seasonal temperature summarized in the Table 2. In general, the trends are consistent between the previous report and the current assessment in this report. However, the values differ slightly, and that can be attributed to differing methodologies used, including the current climate baseline, number of climate models, and different time horizons.

Table 2: Comparison of the Climate Change Review's results to Golder's Climate Change Assessment

Change in Air Temperature (°C)	RCP Scenario	AECOM and Newmans Geotechnique 2018			Golder 2019 Assessment
		Global IPCC Projection Scenarios[a]	Canadian Climate Centre for Modelling and Analysis (CCCma)[c]	Scenarios Network for Alaska and Arctic Planning (SNAP)[d]	Climate Change Assessment[e]
Annual Mean	2.6	1.0 (0.3 – 1.7)	—	6.2	**3.6 (1.4 – 8.3)**
	4.5	1.8 (1.1 – 2.6)			
	8.5	3.7 (2.6 – 4.8)			
Winter Mean	2.6	—	3.0 (1.8 – 4.1)	8.4	**5.2 (1.3 – 11.5)**
	4.5		5.8 (4.1 – 7.4)		
	8.5		12 (9.4 – 14.4)		
Summer Mean	2.6	—	1.5 (0.9 – 2.1)	3.9	**2.7 (0.5 – 6.7)**
	4.5		2.6 (1.7 – 3.4)		
	8.5		5.4 (4.0 – 6.8)		

Notes:

(a) Used a climate baseline of 1986-2005 for 2081-2100. Mean presented with the 5th and 95th percentiles in brackets.

(b) Used a climate baseline of 1986-2005 for 2081-2100. Mean presented with the 25th and 75th percentiles in brackets.

(c) Climate baseline and percentiles not provided, only mean presented.

(d) Used a climate baseline of 1971-2018 for a multi-model ensemble during the 2080s. The 50th percentile is presented with the 5th and 95th percentiles in brackets.

This assessment is based on the current available climate science. The nature of the work undertaken is stochastic with substantial inherent uncertainly around any given data points. The uncertainty associated with any projection increases with the duration of the projected period and is subject to future developments; therefore, this work should be updated as new climate science is developed and after the release of the latest Assessment Report (AR) by the IPCC.

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1.0 INTRODUCTION

Climate change has the potential to change future precipitation, evapotranspiration, and temperature regimes, and has been identified for consideration during the design of the Giant Mine Remediation Project (GMRP) closure plan. To incorporate assumptions related to climate change and to describe any limitations on the impact of climate change model projections of the surface water design, a detailed climate dataset was developed to support the design basis work. This climate change report identifies potential future changes that can be incorporated into hydrological modeling, thermal modeling, engineering design and sensitivity analysis. The report will summarize current local and regional data related to the current and projected climate change scenarios and compare this summary with the results of the previous Climate Change Review completed for the Freeze Design (AECOM and Newmans Geotechnique 2018). The report will focus on mean temperature and total precipitation, along with statements on extreme events.

Golder has developed an approach for completing a climate change assessment based on recent best guidance found in literature and is consistent with the guidance being developed by the Mining Association of Canada (MAC) and based on best guidance accepted by the Intergovernmental Panel on Climate Change (IPCC). The approach applied to the Giant Mine site, located outside Yellowknife, Northwest Territories, aims to provide a description of the current climate conditions in the region of the site of interest and projections of how the climate is likely to change under future climate conditions.

Future climate projections are important for understanding how climate is projected to change from the climate baseline. Global Climate Models (GCMs) have been developed by various governments and included in the IPCC's Fifth Assessment Report (AR5). The future climate projections come from publicly available statistically downscaled future climate projections from these GCMs on a daily scale. Recognizing the inherent uncertainty with projections, the results in this report are based on multiple projections from multiple models and scenarios, as recommended by the IPCC (IPCC 2013). Therefore, the future projections are provided in terms of percentiles calculated over the range of projections. The development of a climate change assessment dataset provides the basis for continuous improvement at Giant Mine.

The report provides the following sections to support the climate change assessment and provides a starting point for discussion of climate change vulnerability and risk for Giant Mine:

- A review of the methodology used to characterize the current climate and future climate conditions in the Giant Mine area. Detailed descriptions of the data sources and approaches used for both the climate baseline and the future climate projections are provided in Appendix A.
- A discussion of the baseline climate conditions and future projections for temperature and precipitation (including extreme indices). Emphasis is placed on the probable maximum precipitation (PMP), changes in rainfall statistics for various return periods, and temperature.
- A comparison of the current local and regional data related to the current and projected climate change scenarios to the results of the Climate Change Review completed for the Freeze Design (AECOM and Newmans Geotechnique 2018).
- A brief discussion on how the future climate change projections should be used.

2.0 DATA SOURCES AND APPROACHES FOR CLIMATE CHANGE PROJECTIONS

Golder has developed a standardized approach for completing a climate change assessment, which has been applied to Giant Mine. Fundamental to this approach is understanding what the current climate conditions in the region of the site of interest are and understanding how they are projected to change under future climate conditions. To support the Design Basis Report, the discussion of climate vulnerability is focused on changes in temperature (which may impact freeze design), as well as precipitation and rainfall events, namely probable maximum precipitation, rainfall statistics with different return periods and durations, and extreme rainfall and snowmelt statistics and evapotranspiration. The following sections provide high level overviews of the methodologies followed to develop the current climate and future projected climate datasets used in this report. More detailed information on each methodology is provided in Appendix A: Detailed Methodology.

2.1 Current Climate Methodology

The climate baseline is based on observations from Yellowknife A climate station (Climate ID 2204101 and 2204100) given its proximity (approximately 5.71 - 5.73 km from the mine site) and the availability of observations. In addition, this station has been used for previous studies completed for Giant Mine. The baseline is established using publicly available climate station data. A review for data completeness indicates that infilling with reanalysis data is necessary to meet the data completeness requirements. Reanalysis data from Version 2 of the National Aeronautics and Space Administration's (NASA's) Modern-Era Retrospective analysis for Research and Applications (MERRA-2) is used to represent current climate or to infill the missing data from observations. Before infilling, the reanalysis data is compared and correlated to Yellowknife A climate station. The Adjusted and Homogenized Canadian Climate Data (AHCCD) is used to apply adjustments to the infilled station observations to account for non-climatic shifts in data, mainly due to the relocation of stations and wind undercatch corrections (ECCC 2017).

The current climate temperature and precipitation is used to calculate the annual and monthly current climate normals, along with 27 extreme indices focused on temperature and precipitation identified by the World Meteorological Organisation (WMO) (WMO 2009). Trends are established for the annual and monthly climate, as well as climate extremes, to help provide a description of the current climate conditions. The trends are calculated using an accepted methodology, further described in Appendix A, that is based on the most recent best guidance found in literature and recommended by the IPCC. The trends are used to assess climate changes predicted from long-term climate observations. This information forms the daily current climate baseline.

Using the daily current climate baseline precipitation, the PMP (theoretical highest possible precipitation) is calculated according to Hershfield Method (WMO 2009). A second method (the moisture maximization method) relies on observations that are not available under current climate conditions.

Using the same daily current climate baseline precipitation, rainfall statistics are calculated for various durations (1-day through 120-day) and return periods (1 in 2 years, 1 in 10 years, 1 in 100 years, 1 in 200 years, 1 in 500 years, 1 in 1,000 years and 1 in 2,000 years). Probable Maximum Precipitation (PMP) is calculated for 1-day and 3-day durations. The Intensity-Duration-Frequency (IDF) curves for the current climate are calculated by adjusting a statistical distribution to the daily annual maximum series (AMS). The Gumbel distribution is adopted in this study and the parameters are estimated using the method of moments (Hogg et al. 1989), following the approach adopted by ECCC. The evapotranspiration potential is estimated by two methods: the Hargreaves equation that uses daily minimum and maximum temperature and solar radiation (based on the latitude) as inputs; and the Thornthwaite equation that uses the daily mean temperature as input. The snowmelt model developed by Environment and

Climate Change Canada is used to calculate the daily snowmelt, which is estimated using degree-day equation proposed by Pysklywec et al. (1968).

In addition to the statistics described above, selected climate statistics (rainfall, snow, and snowpack) are calculated for five two-week periods to capture the transition from winter to spring (March 19th to May 31st). The five periods cover the following time periods:

- March 19th to March 31st (Spring Period 1);
- April 1st to April 15th (Spring Period 2);
- April 16th to April 30th (Spring Period 3);
- May 1st to May 15th (Spring Period 4); and
- May 16th to May 31st (Spring Period 5).

2.2 Future Climate Methodology

Future climate projections are important for understanding how climate is projected to change from the climate baseline. The IPCC is generally considered to be the definitive source of information related to past and future climate change as well as climate science. As an international body, the IPCC provides a common source of information relating to emission scenarios, provides third party reviews of models, and recommends approaches to document future climate projections. Periodically, the IPCC issues assessment reports summarizing the most current state of climate science. The Fifth Assessment Report (AR5) (IPCC 2013) represents the most current complete synthesis of information regarding climate change. The future climate projections come from publicly available statistically downscaled future climate projections based on AR5, on a daily scale.

Future climate is typically projected using GCMs that involve the mathematical representation of global land, sea and atmosphere interactions over a long period of time. These GCMs have been developed by various government agencies, but they share a number of common elements described by the IPCC. The IPCC does not run the models but acts as a clearinghouse for the distribution and sharing of the model forecasts. Future climate projection data are available from about 30 GCMs and four representative concentration pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) in AR5. The pathways are named after the radiative forcing projected to occur by 2100. These RCPs are described more fully by van Vuuren et al. (2011) in their paper “The representative concentration pathways: an overview” and have been summarized in Table 3 in Appendix A.

The data used in this report is obtained from the climate portal ClimateData.ca provided by Environment and Climate Change Canada (ECCC). This portal allows users to access, visualize, and analyze climate data, information, and tools to support adaptation planning. It provides access to high-resolution climate data at annual, monthly or daily model outputs across Canada. This report focuses on analysis using the statistically downscaled daily data using the Bias Correction/Construction Analogues with Quantile mapping reordering version 2 (BCCAQv2) model. The IPCC identified four representative concentration pathways; however, this report focuses on the three RCPs (RCP 2.6, RCP 4.5, and RCP 8.5) currently available from ClimateData.ca for the BCCAQv2 model.

The statistically downscaled models provide daily Canada-wide climate scenarios, at a gridded resolution of 300 arc-seconds (or roughly 10 km) for the simulated period of 1950-2100 (ClimateData.ca 2019). The climate variables available from this dataset include minimum temperature, maximum temperature and precipitation. The selection of this data for this project is based on the available temporal and spatial resolution of the data. The availability of daily downscaled data allows for better characterization of the climate extremes, especially for precipitation. The availability of high spatial resolution (10 km instead of hundreds of km in GCMs) provides better representation for site-specific studies like this project.

Future climate extremes are projected using the same 27 WMO extreme indices as in the current climate, using the temperature and precipitation projections from the available downscaled ClimateData.ca dataset. The future climate extremes are described in terms of an “anomaly” or change from the baseline. As each model has a unique baseline, the calculations are first completed for each model and then statistics are provided to describe the range of projections over the multi-model ensemble.

Since no one model or climate scenario can be viewed as completely accurate, the IPCC recommends that climate change assessments use as many models and climate scenarios as possible, or a “multi-model ensemble”. For this reason, the multi-model ensemble approach is used to delineate the probable range of results and better capture the actual outcome (an inherent unknown).

Before beginning the future climate projections, the 72 potential members of the multi-model ensemble are reviewed to observe whether the general temperature and precipitation ranges reasonably matched the observed ranges of climate for the region. In particular, monthly averages were used to capture the known seasonality of the region.

The model projections can be summarized for magnitude of change from the climate regime baseline for different time horizons. The time horizons applied to this study include the following:

- 1971 to 2018 (baseline);
- 2041 to 2070 (2050s); and
- 2071 to 2100 (2080s).

In order to understand how the precipitation and precipitation events are projected to change for Giant Mine, more detailed information is needed on how the distribution of precipitation is projected to change. This can be inferred by examining the projected changes in the PMP, rainfall statistics, and combined extreme rainfall and snowmelt events, consistent with the current climate.

The future projected changes in PMP is calculated using the moisture maximization method and the Hershfield method (not used under current climate conditions). Comparing the modelled future climate to modelled baseline produces changes in relative humidity, so it can be used to estimate percent change in PMP depths between baseline and future conditions. Ensemble statistics in terms of percentiles are calculated across the results from both methods. The monthly evapotranspiration potential and the daily rain and snowmelt projected changes were calculated using the same methodology as for the current climate, but applied to all ensemble members and presented using percentiles across the ensemble.

Like the current climate period, additional climate statistics are provided to capture the winter to spring transition with the five additional two-week periods. Climate statistics are provided for rainfall, snow, and snowpack.

3.0 CURRENT CLIMATE

The following sections outline the data sources considered to develop the daily current climate dataset and the analysis of the dataset using the methodology outlined in Section 2.0. First, a general description of the current climate is provided in Sections 3.1 through 3.3. Second, more detailed descriptions related to the precipitation are provided in Sections 3.4 through 3.6. Results are summarized as part of the conclusions in Section 6.0.

3.1 Existing Conditions

The current climate dataset was developed based on publicly available observations from Yellowknife A climate station (Climate ID 2204101 and 2204100) and, where needed, infilling from reanalysis data.

3.1.1 Station Summary

As noted above that the current climate conditions are defined using climate normal, which are long-term (usually 30-year) averages of observed climate data. It should be noted that Yellowknife A station was moved in 2013, by approximately 30 m. To include the most recent observations and create a long-term observation record, the two stations were combined into one continuous time series of observations. Table 3 describes the selected climate station, Yellowknife A, with daily summaries from ECCC for both locations.

Table 3: Yellowknife A Climate Station Properties

Station Name	Station ID	Latitude and Longitude	Elevation (masl)	Distance from Giant Mine (km)	Years Available	Notes
Yellowknife A (Old Station)	2204100	62.46278N, 144.44000W	205.70	5.73	1942 - 2013	Data available during part of the desired normal period.
Yellowknife A (New Station)	2204100*	62.46306N, 144.44000W	205.70	5.71	2013 - 2019	Data available during part of the desired normal period.
Yellowknife A – IDF Dataset	2204100	62.46306N, 144.44000W	205.70	5.73	1963 - 1996	Sub-daily IDF data

Note: Yellowknife A station was moved in 2013 approximately 30 metres from the original location, however, a new station ID was not assigned.

3.1.2 Infilling Missing Data

To make the climate data temporally representative in the current climate analysis methodology, the data availability must be above certain levels. For the level of detail required for this project, the data availability must be above 90%. For example, the monthly precipitation is deemed to be representative of that month only when over 90% of the daily precipitation data is available and valid.

Overall, the observations from Yellowknife A station had a very good data availability during the baseline period from 1971 through 1992, 1994 through 2012, and 2014 through 2018. However, the observations of both the temperature and precipitation for the years 1993 and 2013 are not available above the data completeness criteria of 90% for each year. Accordingly, the data was infilled using NASA's MERRA-2 reanalysis data. The hourly precipitation and temperature data at the nearest grid cell centroid, which is approximately 5.3 km away from station towards northeast, were used for this analysis.

Infilling the missing data is a two-step process. The first step is to perform a correlation analysis for the concurrent period between the non-missing observations and MERRA-2 data. The MERRA-2 reanalysis data is available starting in 1981 so the concurrent period is focused on the period from 1981 through 2018. If the correlation is reasonable with a squared Pearson correlation coefficient (R^2) above 0.8, the linear relationship will be used to scale the reanalysis data before infilling the missing data in the second step. If the correlation does not have R^2 above 0.8, then the data must be considered more qualitatively due to the uncertainty in the bias correction.

The correlations for both the temperature and precipitation during the 38-year concurrent period between the observed data at Yellowknife A station and MERRA-2 data are reasonable, as shown in Table 4, with the potential exception of daily precipitation. Ideally, the R^2 value would be above 0.8 for a good correlation, however, the correlation is below 0.8. The scatter plots of the mean daily temperature and precipitation are shown in Figure 1. From Figure 1, it appears that data outliers of high precipitation events are having a strong influence on the R^2 value. The missing data was infilled using the MERRA-2 data and the linear relationship as shown in Table 4. For precipitation, the intercept of the linear relationship was forced to zero to avoid precipitation occurrence during the missing days. To remain consistent, the intercepts of the linear relationships for temperature were also forced to zero.

Table 4: Correlation between Yellowknife A station and MERRA-2 Data during 1981-2018

Climate Variable	Percentage Infilled[(a)]	Daily R^2	Infilling Equation
Daily Maximum Temperature	0.915%	0.993	Infilled=0.856 x MERRA-2
Daily Minimum Temperature	0.915%	0.979	Infilled=0.859 x MERRA-2
Daily Mean Temperature	0.915%	0.988	Infilled=0.844 x MERRA-2
Daily Precipitation	0.915%	0.567	Infilled=0.661 x MERRA-2

Note:
(a) Observations from Yellowknife A station are available from 1981 through to 2018. MERRA-2 is available from 1981.

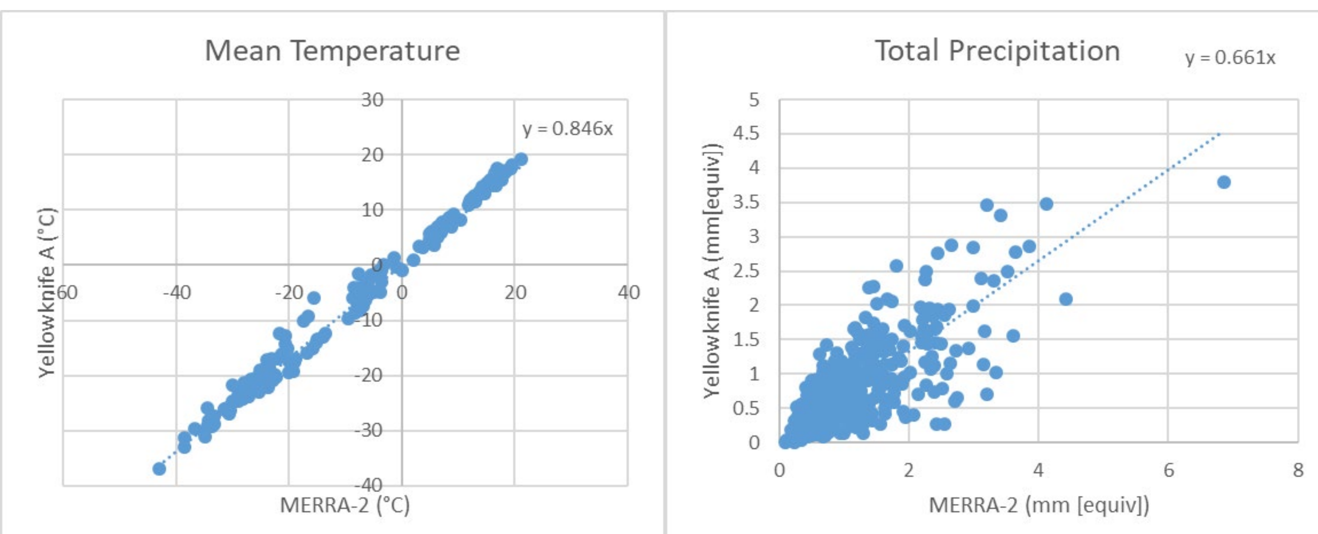

Figure 1: Scatter Plots of Daily Mean Temperatures and Total Precipitation Between Yellowknife A station and MERRA-2 Data

3.1.3 Adjusted and Homogenized Canadian Climate Data (AHCCD)

As mentioned in Section 2.1, the AHCCD daily dataset accounts for non-climatic shifts in data, mainly due to the relocation of stations and wind undercatch correction (ECCC 2017). The AHCCD daily dataset for Yellowknife A station was used to apply adjustments to the infilled station observations to create the Yellowknife A Adjusted dataset that was used for the remaining climate analyses.

The AHCCD daily dataset included the daily minimum, maximum and mean temperatures and total precipitation. Overall, the AHCCD daily dataset had very good availability from 1971 through to 2013. The daily minimum, maximum and mean temperatures met the data completeness of 90% during all years within the baseline period (1971 – 2018). Where temperature data was missing from the AHCCD daily dataset, the values from Yellowknife A Infilled were used. The daily total precipitation for the period between 2013 and 2018 was not available. For this reason, an adjustment exercise was completed using the infilled station observations to extend the precipitation dataset to 2018 to include the most recent observations. Appendix A provides a more detailed description of how the adjustment exercise was calculated using the AHCCD daily dataset for total precipitation.

Once the adjustment was completed to the daily total precipitation dataset, a sensitivity analysis was conducted comparing the three datasets (Yellowknife A Infilled, AHCCD daily, and Yellowknife A Adjusted datasets) to verify that the adjustments are consistent with the infilled dataset. The analysis confirmed that Yellowknife A Adjusted dataset was representative of the current climate. As shown in Figure 2 and Figure 4, the annual averaged monthly and annual mean temperature generally shows a high agreement in trends between all three datasets. However, the annual mean temperature shows two high temperature events in the AHCCD daily dataset, that do not appear in the other two.

In Figure 3 and Figure 5, there is a high agreement in trends, however, a shift upwards can be seen for both the monthly and annual averaged monthly total precipitation by the AHCCD daily and Yellowknife A Adjusted datasets compared to the Yellowknife A Infilled. This can be attributed to the adjustments made in the AHCCD data to account for the non-climatic shifts in data.

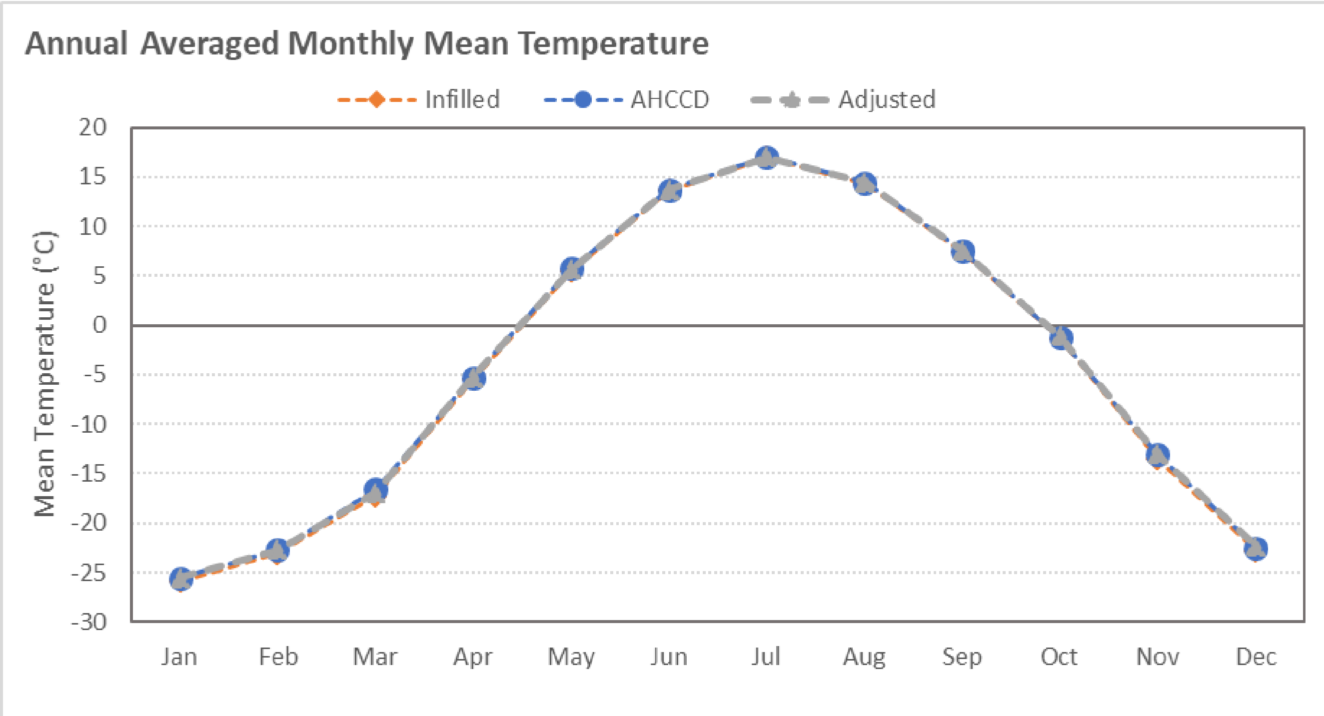

Figure 2: Annual Averaged Monthly Mean Temperature for the three datasets; Yellowknife A Infilled, AHCCD daily, and Yellowknife A Adjusted for the period between 1971 to 2018.

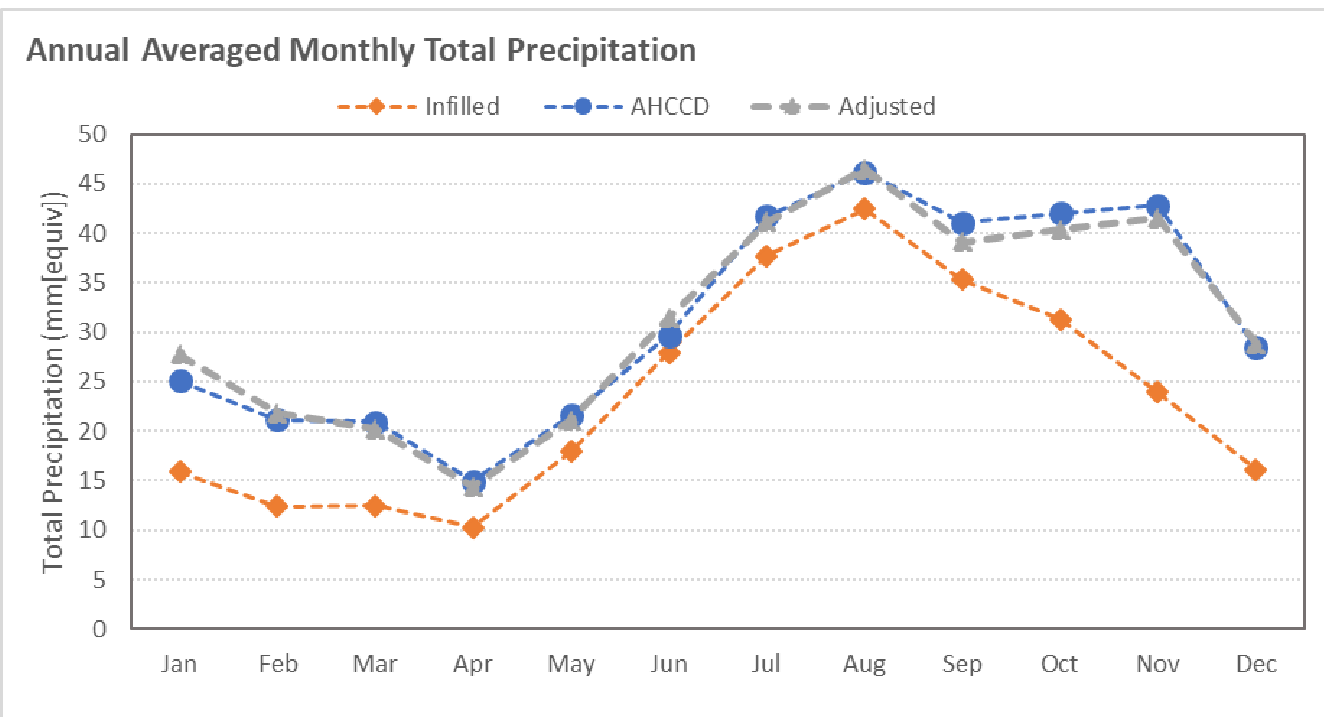

Figure 3: Annual Averaged Monthly Total Precipitation for the three datasets; Yellowknife A Infilled, AHCCD daily, and Yellowknife A Adjusted for the period between 1971 to 2018

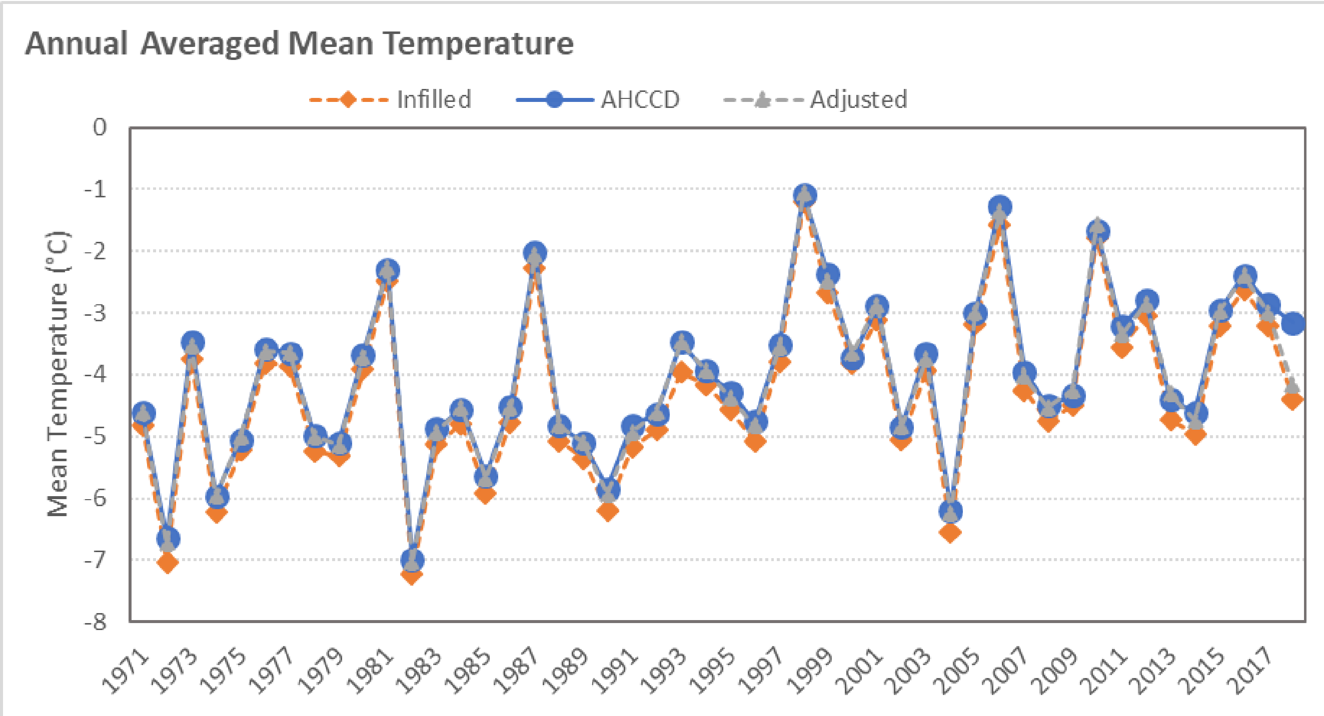

Figure 4: Annual Averaged Mean Temperature for the three datasets; Yellowknife A Infilled, AHCCD daily, and Yellowknife A Adjusted

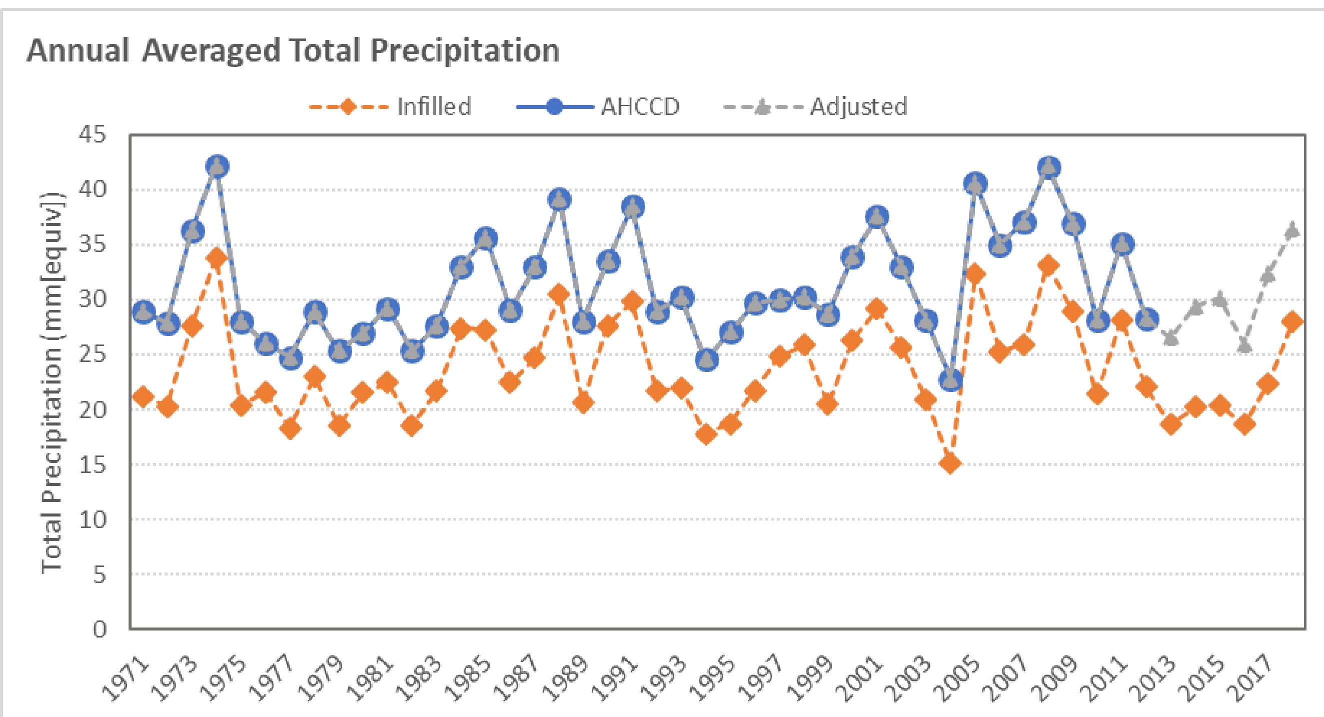

Figure 5: Annual Averaged Total Precipitation for the three datasets; Yellowknife A Infilled, AHCCD daily, and Yellowknife A Adjusted

3.2 Current Climate Normals and Trends

The current climate normals and trends were calculated using the Yellowknife A Adjusted data (Yellowknife A Adjusted) for the period from 1971 through 2018. Both annual and monthly normals and trends were calculated for the mean temperature, as well as total precipitation. The analysis resulted in three pieces of information for each climate parameter as follows:

- climate normal;
- climate trend; and
- statistical significance of the trend.

The analysis only assessed the statistical significance at the 90th, 95th, 99th and 99.9th percentile levels. A trend that is assessed to be zero is classified as no apparent trend. A trend that is not assessed to be statistically significant at the 90th percentile is classified as being "not significant." A trend is assessed to be statistically significant at the 95th percentile; there is a less than 5% chance that the observed trend does not exist if the statistical test conditions are met. The normals and trends are presented in Table 5 for the selected period.

Table 5: Current Climate Normals and Trends - Yellowknife A Adjusted (1971 - 2018)

Climate Indices	Normals	Decadal Trend	Statistical Significance
Average Annual Temperature [°C]	-4.0	+0.4	significant at the 99th percentile
Average January Temperature [°C]	-25.5	+1.0	significant at the 99th percentile
Average February Temperature [°C]	-22.7	+0.6	not statistically significant
Average March Temperature [°C]	-16.9	+0.4	not statistically significant
Average April Temperature [°C]	-5.3	-0.1	not statistically significant
Average May Temperature [°C]	5.6	+0.1	not statistically significant
Average June Temperature [°C]	13.7	+0.2	significant at the 90th percentile
Average July Temperature [°C]	17.0	+0.3	not statistically significant
Average August Temperature [°C]	14.4	+0.2	not statistically significant
Average September Temperature [°C]	7.5	+0.4	not statistically significant
Average October Temperature [°C]	1.1	+0.2	not statistically significant
Average November Temperature [°C]	-13.1	+0.4	not statistically significant
Average December Temperature [°C]	-22.4	+1.1	significant at the 95th percentile
Total Precipitation [mm (equiv.)]	374.1	+7.8	not statistically significant
January Total Precipitation [mm (equiv.)]	27.8	+4.4	significant at the 99th percentile
February Total Precipitation [mm (equiv.)]	21.8	+0.8	not statistically significant
March Total Precipitation [mm (equiv.)]	20.2	-0.2	not statistically significant
April Total Precipitation [mm (equiv.)]	14.4	-0.6	not statistically significant
May Total Precipitation [mm (equiv.)]	21.1	-1.5	not statistically significant
June Total Precipitation [mm (equiv.)]	31.4	+1.5	not statistically significant
July Total Precipitation [mm (equiv.)]	41.2	+1.0	not statistically significant
August Total Precipitation [mm (equiv.)]	46.5	+0.5	not statistically significant
September Total Precipitation [mm (equiv.)]	39.1	+1.1	not statistically significant

Table 5: Current Climate Normals and Trends - Yellowknife A Adjusted (1971 - 2018)

Climate Indices	Normals	Decadal Trend	Statistical Significance
October Total Precipitation [mm (equiv.)]	40.4	-3.5	significant at the 95th percentile
November Total Precipitation [mm (equiv.)]	41.5	-0.5	not statistically significant
December Total Precipitation [mm (equiv.)]	28.8	+0.8	not statistically significant

The analysis of the current climate observations shows that annual and monthly temperatures are increasing, with the annual, January, June, and December increasing temperature trends statistically significant above the 90th percentile. The remaining temperature trends are not statistically significant above the 90th percentile. The analysis also shows that it is likely that total precipitation is increasing both annually and for selected months. The only statistically significant trends are shown in January (at the 99th percentile) and October (at the 95th percentile) with an increase in precipitation. However, there are decreasing trends observed in March, April, May, October, and November, but only October is statistically significant above the 95th percentile.

Figure 6 describes the historical data and trends for the period from 1971 through 2018. The graph shows the variation in year to year observations, along with the climate normal (i.e., the average of the 48 years of observations, and the trend derived from the current climate data. In Figure 6, there is an increasing trend in average annual temperature at a rate of 0.4°C (equivalent) per decade (°C [equiv.]/decade). The trend was identified as being statistically significant at the 99th percentile. Figure 7 to Figure 11 show similar data for the remaining climate indices identified as statistically significant.

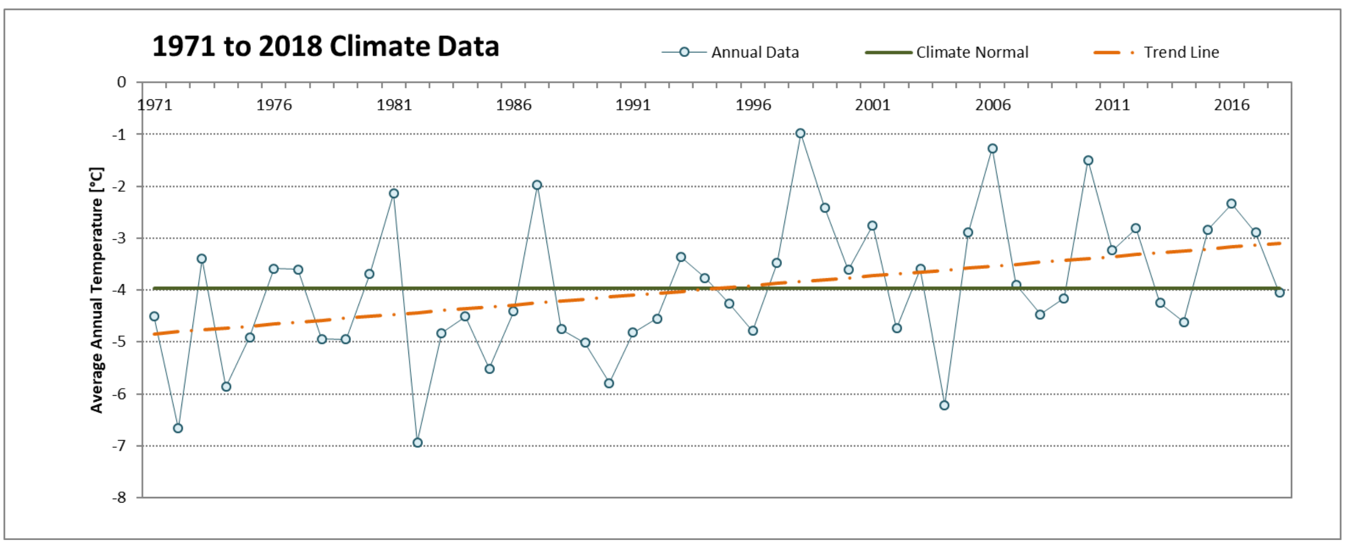

Figure 6: Current Climate Average Annual Temperature Analysis for Yellowknife A Adjusted — Annual

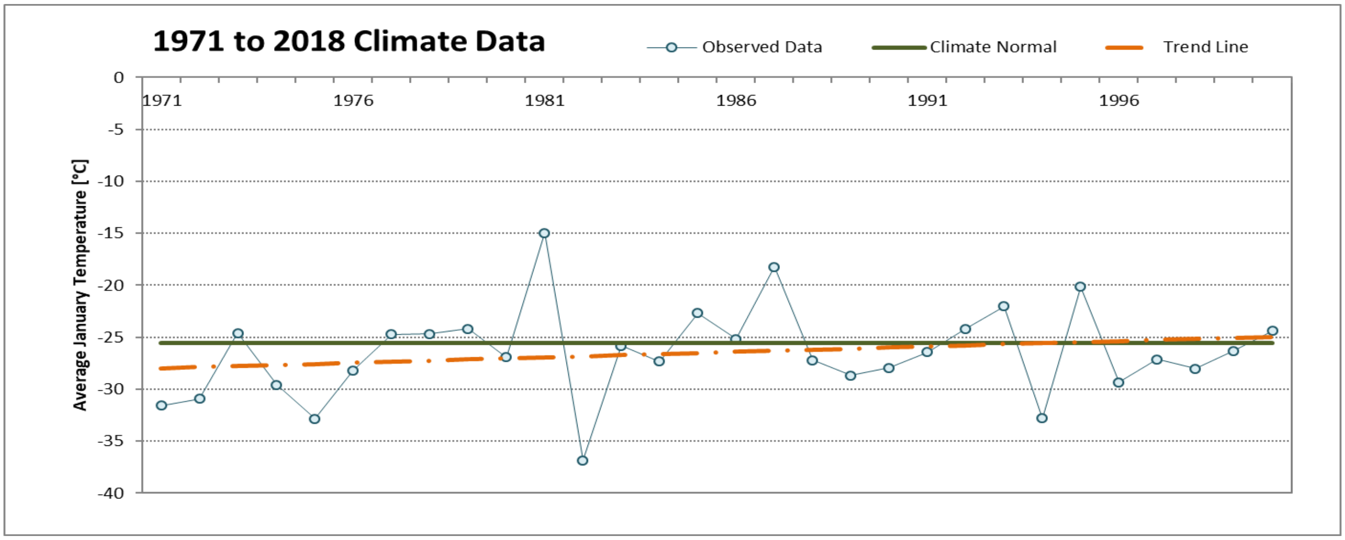

Figure 7: Current Climate Average Monthly Temperature Analysis for Yellowknife A Adjusted — January

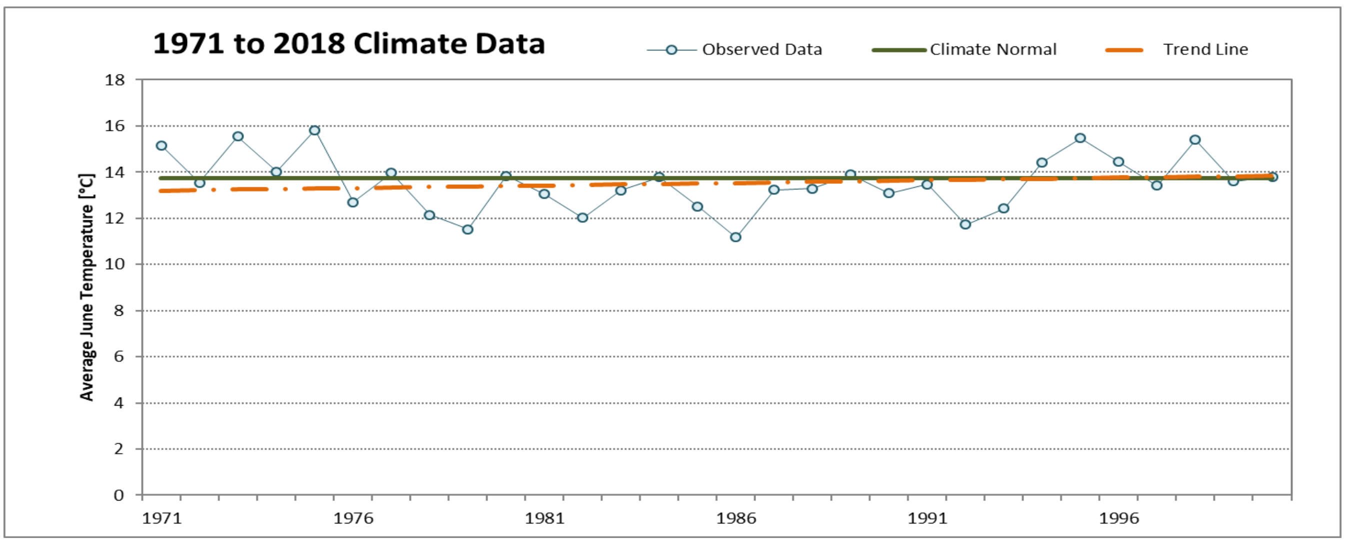

Figure 8: Current Climate Average Monthly Temperature Analysis for Yellowknife A Adjusted — June

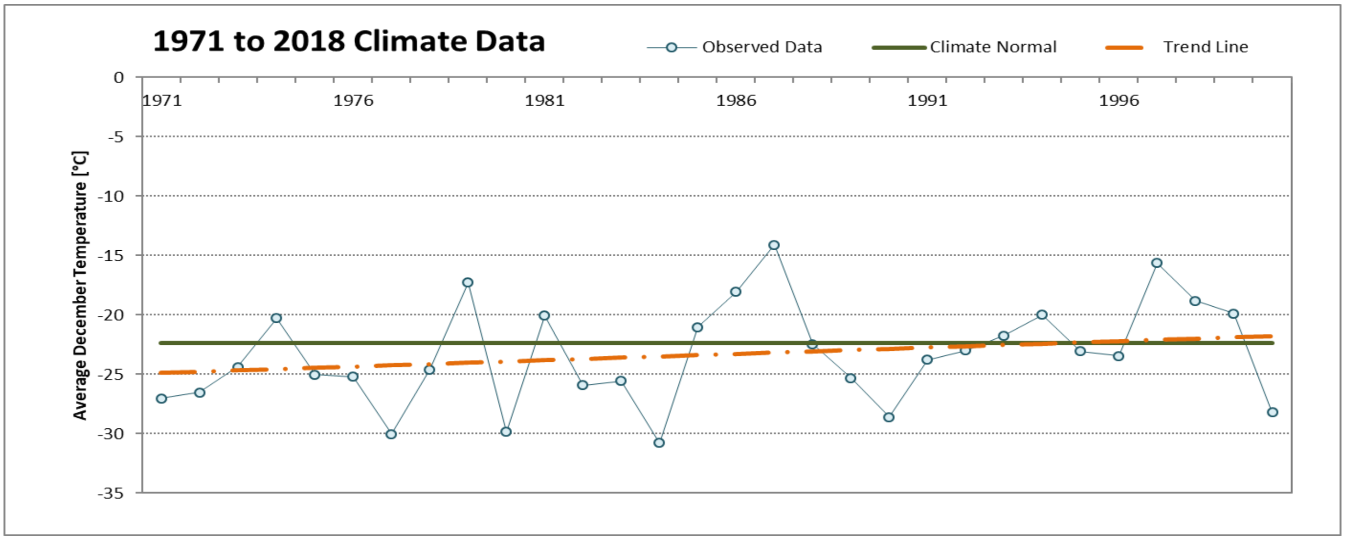

Figure 9: Current Climate Average Monthly Temperature Analysis for Yellowknife A Adjusted — December

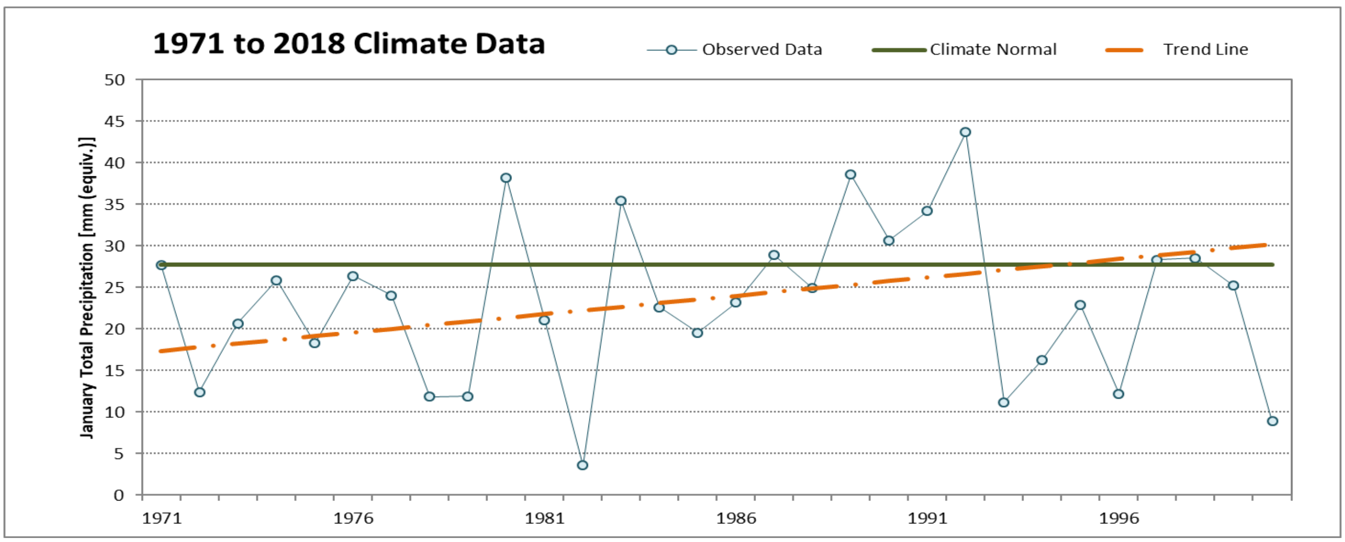

Figure 10: Current Climate Monthly Total Precipitation Analysis for Yellowknife A Adjusted — January

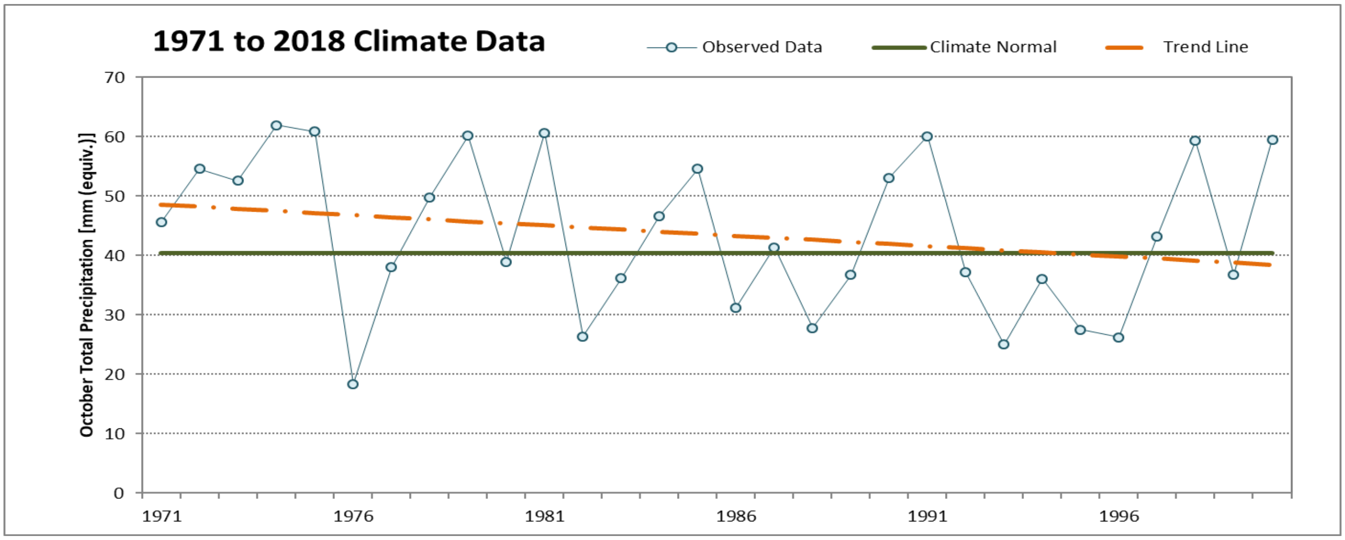

Figure 11: Current Climate Monthly Total Precipitation Analysis for Yellowknife A Adjusted — October

In general, for the period from 1971 through 2018, the current climate normals and trends indicate a current climate that has become warmer and likely wetter over time. However, the total precipitation trends were not found to be statistically significant above the 90th percentile, with the exception of the January and October total precipitation. It should be noted that trend analysis is subject to the data quality and data availability, and caution should be exercised when using the trends.

These trends are consistent with current climate trends available through the Canadian Centre for Climate Services (CCCS), ClimateData.ca, and the latest ECCC report 'Canada's Changing Climate Report' (Government of Canada 2019; ClimateData.ca 2019; Bush and Lemmen 2019). The CCCS offers a climate data viewer that displays historical climate data including the adjusted historical climate data. For the period between 1943 to 2017, an increasing trend in mean temperature for Yellowknife A climate station is available for the adjusted historical climate data. There are no trends available from CCCS for precipitation for the adjusted historical climate data. The ClimateData.ca portal shows that the annual average temperature in Yellowknife has increased from -5.3°C (between 1951 to 1980) to -4.2°C (between 1981 to 2010) (ClimateData.ca 2019). The Bush and Lemmen (2019) report does not include trends specifically for Yellowknife; however, an increasing trend in both mean annual temperature and precipitation have been estimated for northern Canada as a whole. The annual mean temperature between 1948 and 2016 increased by 2.3°C for northern Canada (Bush and Lemmen 2019).

3.3 Current Climate Extremes and Trends

The current climate extremes were calculated for the period of 1971-2018 using the 27 indices recommended by WMO's Expert Team on Climate Change Detection and Indices (ETCCDI; ETCCDI 2017), as described in Appendix A. Based on WMO direction when calculating extreme indices, months with more than 3 days of missing records, or any year with over 15 days of missing records, should be set to zero. As described in Section 3.1, the dataset was complete with no missing periods due to the infilling of the data. As described in Appendix A, for the current climate extremes, two analyses are completed. In the first, the minimum, maximum, mean and median values for each of the 27 indices are calculated over the entire period. In the second, the normals and trends are calculated based on the annual values of each of the indices. The results of these analyses are shown in Table 6.

The minimum, maximum, mean and median were calculated for the indices described in Table 2 in Appendix A and are presented in Table 6. In general, the number of very heavy precipitation days (R20) (i.e., daily precipitation greater than 20 mm) was approximately 1 day per year, ranging from 0 to 4 days during the period of 1971-2018. For at least one day in almost every year examined, the daily precipitation could be above 15 mm. Maximum one-day (RX1day) and five-day (Rx5day) precipitation events were 27.5 mm and 41.6 mm on average, respectively. The precipitation during the extremely wet days (R99p) (i.e., the annual total precipitation when daily precipitation is greater than the 99th percentile) could be up to a maximum of 101.8 mm. The number of consecutive dry days (CDD) ranged from 16 days to 45 days per year, with an average of 27.7 days. The maximum daily temperature (TXx) is above 25.5°C every year, with the highest recorded maximum daily temperature of 32.5°C during the period of interest.

Table 6: Current Climate Extremes - Yellowknife A Adjusted (1971 - 2018)

ID	Indicator Name	Units	Minimum	Maximum	Mean	Median
CDD	Consecutive dry days	Days	16.0	45.0	27.7	27.0
CSDI	Cold spell duration indicator	Days	0.0	24.0	4.8	0.0
CWD	Consecutive wet days	Days	2.0	8.0	4.9	4.5
DTR	Diurnal temperature range	ºC	7.6	9.1	8.3	8.3
FD0	Frost days	Days	184.0	245.0	218.6	219.0
GSL	Growing season Length	Days	108.0	168.0	135.8	137.0
ID0	Ice days	Days	151.0	197.0	173.3	172.5
PRCPTOT	Annual total wet-day precipitation	mm	230.9	465.5	328.3	311.2
R10	Number of heavy precipitation days	Days	2.0	12.0	6.3	6.0
R20	Number of very heavy precipitation days	Days	0.0	4.0	1.0	1.0
R95p	Very wet days	mm	14.6	199.9	73.1	72.6
R99p	Extremely wet days	mm	0.0	101.8	25.0	23.5
R15MM	Number of days above 15 mm	Days	0.0	7.0	2.2	2.0
RX1day	Max 1-day precipitation amount	mm	14.5	84.6	27.5	23.4
Rx5day	Max 5-day precipitation amount	mm	21.8	114.6	41.6	39.5
SDII	Simple daily intensity index	mm/day	3.4	5.9	4.3	4.2
SU25	Summer days	Days	1.0	24.0	10.0	9.5
TN10p	Cool nights	% of Days	1.3	21.9	10.3	10.2
TN90p	Warm nights	% of Days	2.9	23.0	10.2	9.7
TNn	Minimum of daily minimum temperature	ºC	-48.2	-35.2	-43.1	-43.3
TNx	Maximum of daily minimum temperature	ºC	14.1	21.8	18.1	18.3
TR20	Tropical nights	Days	0.0	2.0	0.1	0.0
TX10p	Cool days	% of Days	2.5	19.3	10.2	9.0
TX90p	Warm days	% of Days	2.7	20.1	10.2	9.7
TXn	Minimum of daily maximum temperature	ºC	-41.7	-27.4	-36.5	-36.6
TXx	Maximum of daily maximum temperature	ºC	25.5	32.5	28.8	28.8
WSDI	Warm spell duration indicator	Days	0.0	23.0	4.6	3.0

The normals and trends over the period from 1971 to 2018 were calculated for the climate extremes using the same methodology outlined in Appendix A. For each of the 27 indices, the climate normal, climate trend, and statistical significance of the trend were calculated. The analysis only assessed the statistical significance at the 90th, 95th, 99th and 99.9th percentile levels. The normals and trends are presented in Table 7.

Table 7: Current Climate Extremes Normals and Trends - Yellowknife A Adjusted (1971 - 2018)

Climate Indices	Units	Normals	Decadal Trend	Statistical Significance
Consecutive dry days	Days	27.7	+0.7	not statistically significant
Cold spell duration indicator	Days	4.8	0.0	no apparent trend
Consecutive wet days	Days	4.9	+0.3	significant at the 99th percentile
Diurnal temperature range	ºC	8.3	0.0	no apparent trend
Frost days	Days	218.6	+0.5	not statistically significant
Growing season length	Days	135.8	-2.6	not statistically significant
Ice days	Days	173.3	-0.7	not statistically significant
Annual total wet-day precipitation	mm	328.3	+11.5	significant at the 95th percentile
Number of heavy precipitation days	Days	6.3	+0.4	significant at the 90th percentile
Number of very heavy precipitation days	Days	1.0	0.0	no apparent trend
Very wet days	mm	73.1	+6.0	not statistically significant
Extremely wet days	mm	25.0	0.0	no apparent trend
Number of days above 15 mm	Days	2.2	0.0	no apparent trend
Max 1-day precipitation amount	mm	27.5	+1.0	not statistically significant
Max 5-day precipitation amount	mm	41.6	0.0	not statistically significant
Simple daily intensity index	mm/day	4.3	+0.1	not statistically significant
Summer days	Days	10.0	+1.1	significant at the 90th percentile
Cool nights	% of Days	10.3	-1.4	significant at the 95th percentile
Warm nights	% of Days	10.2	+0.9	significant at the 95th percentile
Min Tmin	ºC	-43.1	+0.9	significant at the 99.9th percentile
Max Tmin	ºC	18.1	+0.1	not statistically significant
Tropical nights	Days	0.1	0.0	no apparent trend
Cool days	% of Days	10.2	-1.8	significant at the 99.9th percentile
Warm days	% of Days	10.2	+0.7	not statistically significant
Min Tmax	ºC	-36.5	+1.1	significant at the 99.9th percentile
Max Tmax	ºC	28.8	+0.2	not statistically significant
Warm spell duration indicator	Days	4.6	0.0	no apparent trend

Similar to Figure 6, Figure 12 describes the historical data and trends for the period from 1971 through 2018. The graph shows the variation in year to year observations, along with the climate normal (i.e., the average of the 48 years of observations, and the trend derived from the current climate data. In the Figure shown, there was an increase in the number consecutive wet days at a rate of 0.4 days per decade (days/decade). The trend was identified as being statistically significant at the 99.9th percentile. Figure 13 through Figure 21 show similar data for the remaining extreme climate indices identified as statistically significant.

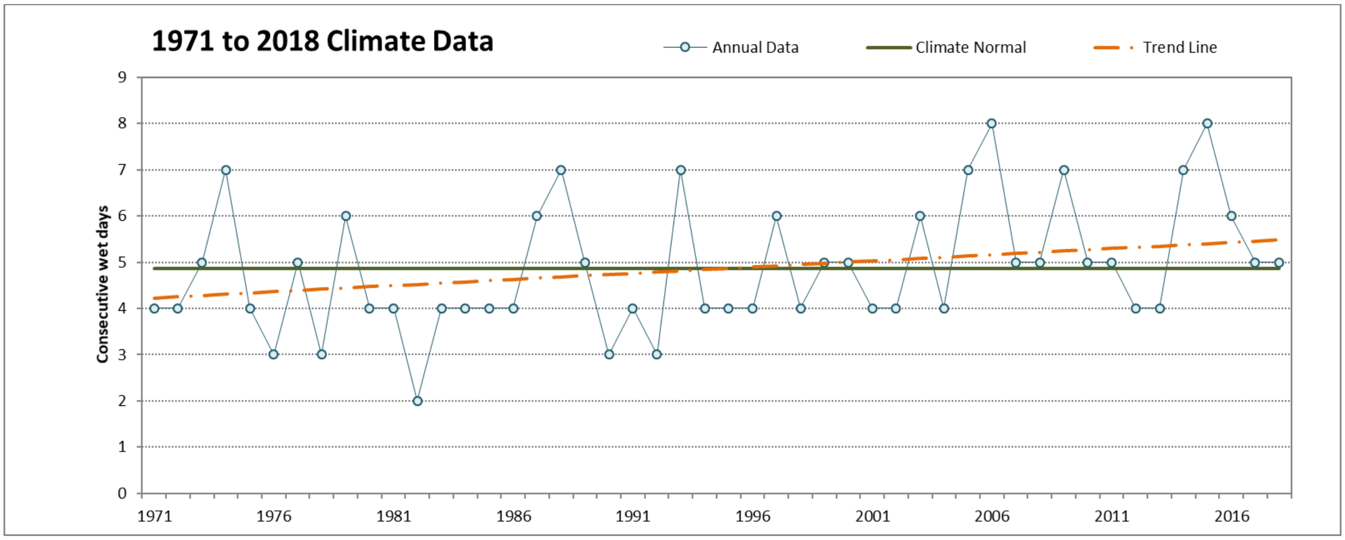

Figure 12: Current Climate Extremes Analysis for Yellowknife A Adjusted — Consecutive Wet Days

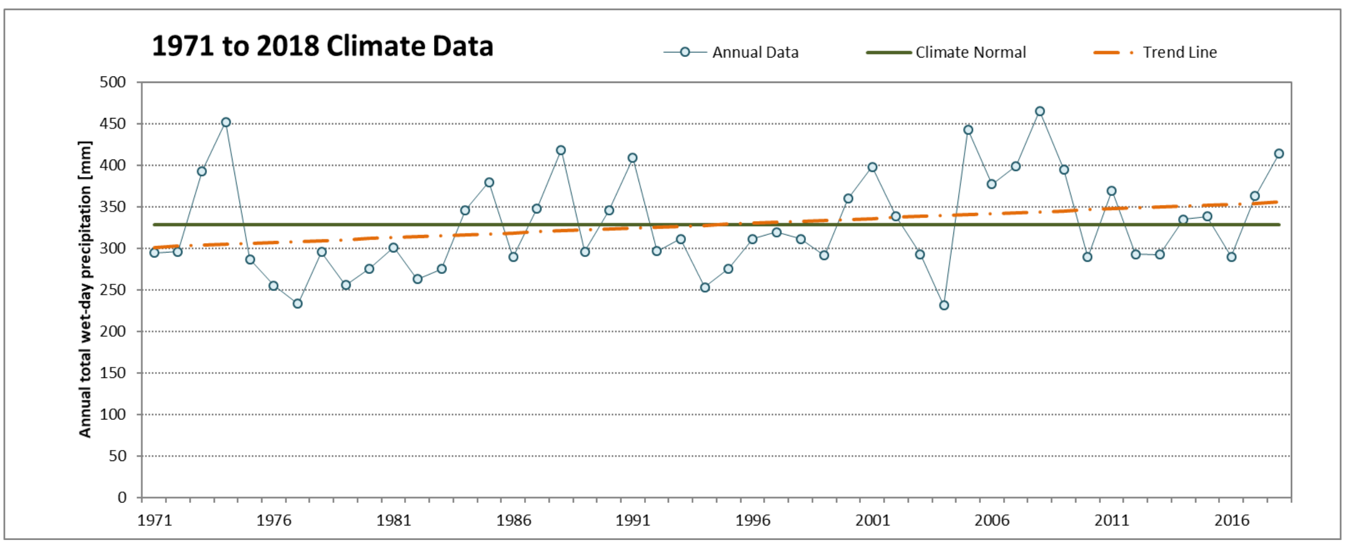

Figure 13: Current Climate Extremes Analysis for Yellowknife A Adjusted — Annual Total Wet-Day Precipitation

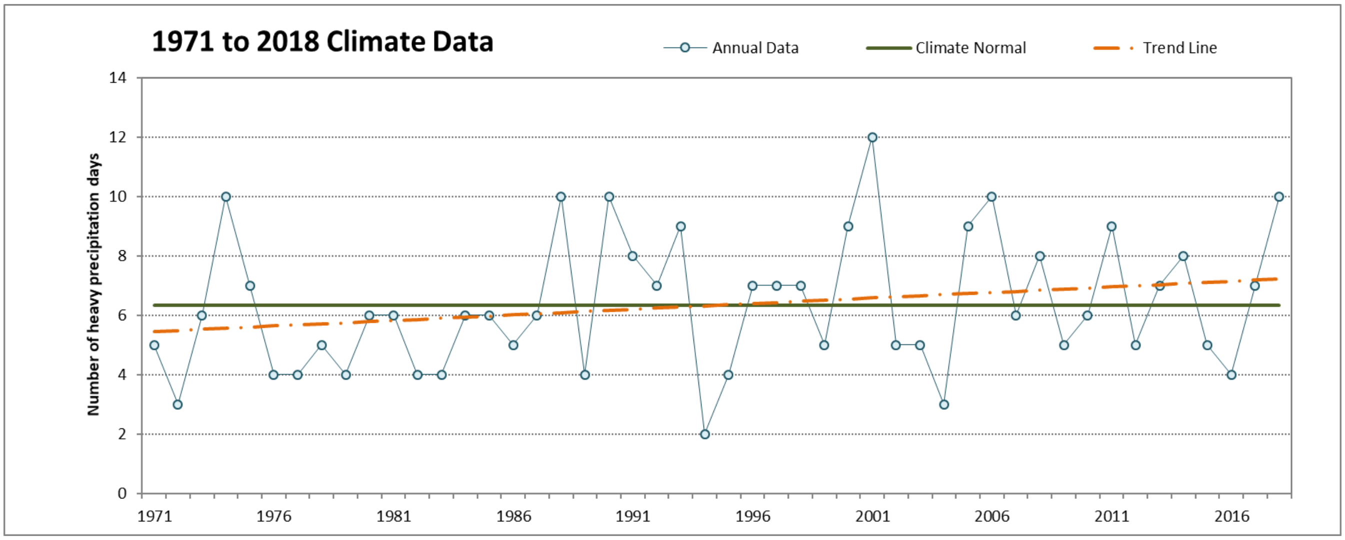

Figure 14: Current Climate Extremes Analysis for Yellowknife A Adjusted — Number of Heavy Precipitation Days

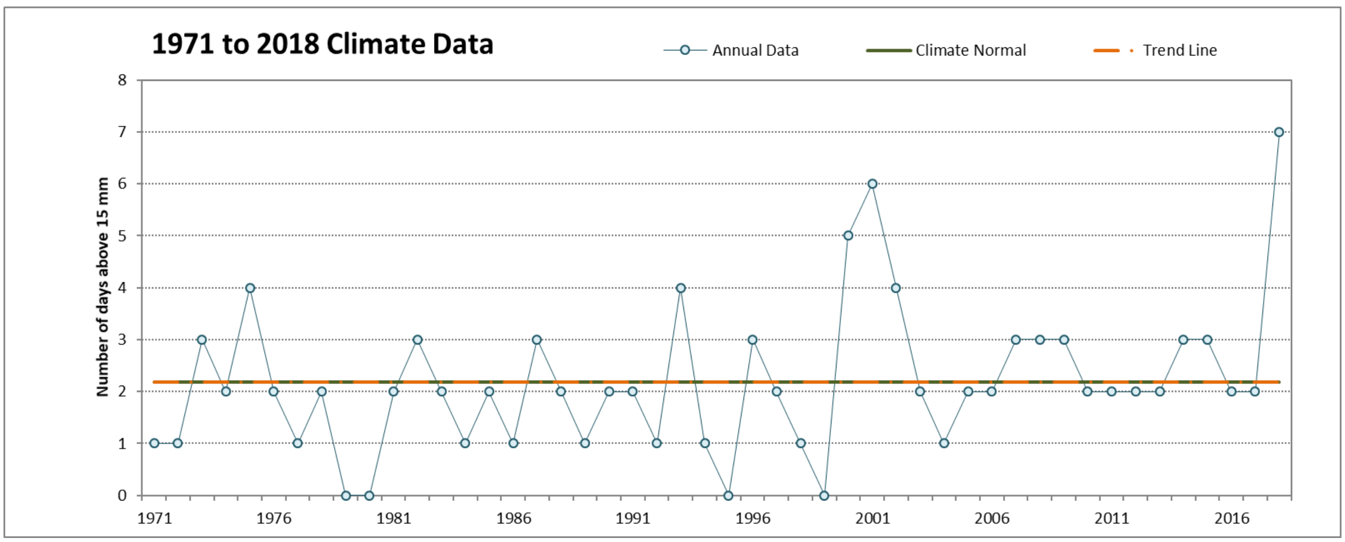

Figure 15: Current Climate Extremes Analysis for Yellowknife A Adjusted — Number of days above 15mm

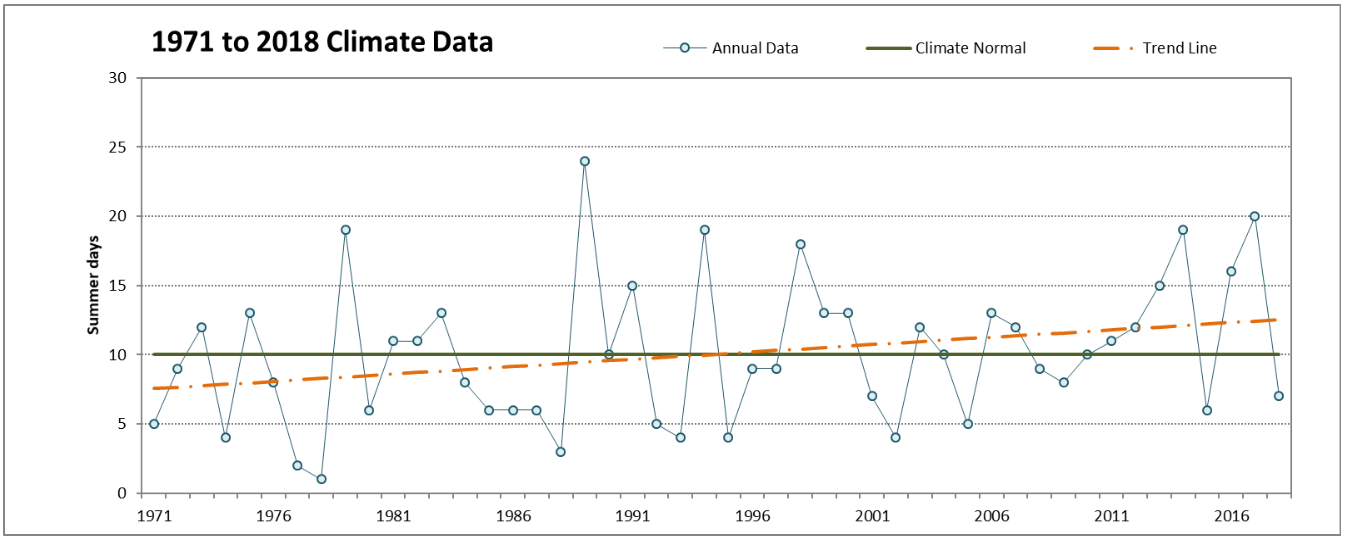

Figure 16: Current Climate Extremes Analysis for Yellowknife A Adjusted — Summer days

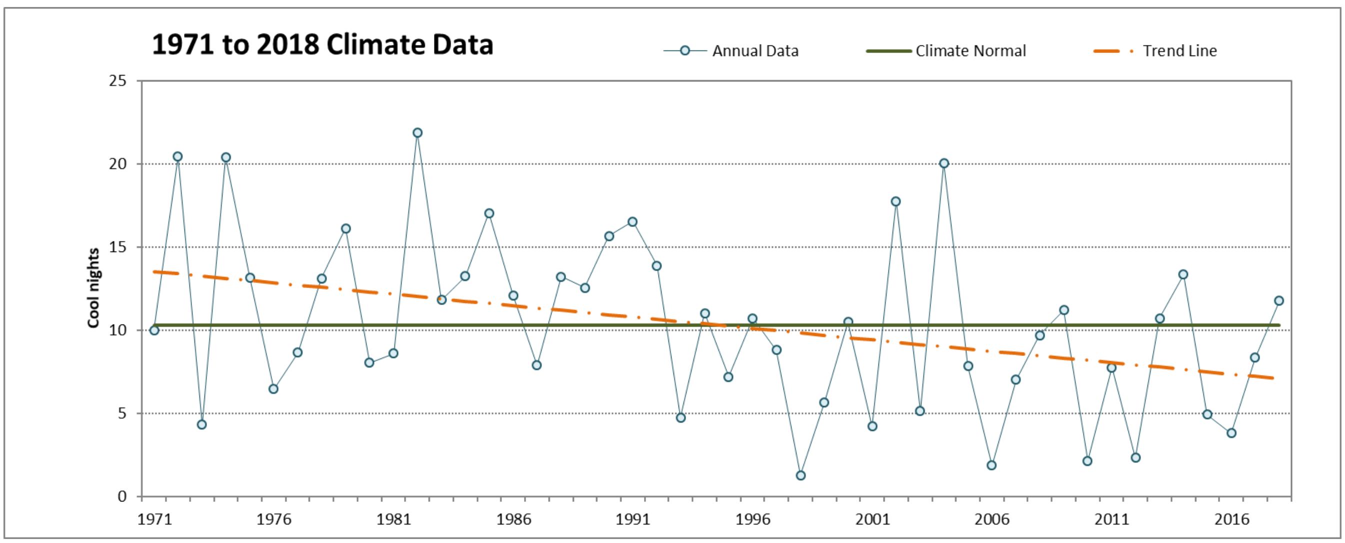

Figure 17: Current Climate Extremes Analysis for Yellowknife A Adjusted — Cool Nights

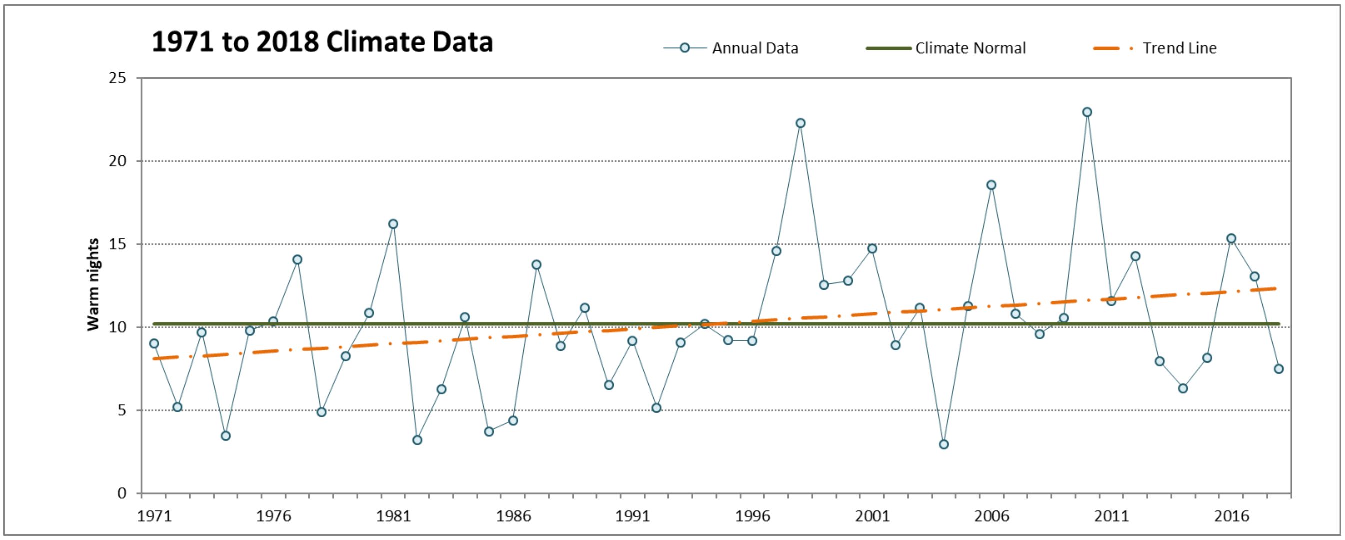

Figure 18: Current Climate Extremes Analysis for Yellowknife A Adjusted — Warm Nights

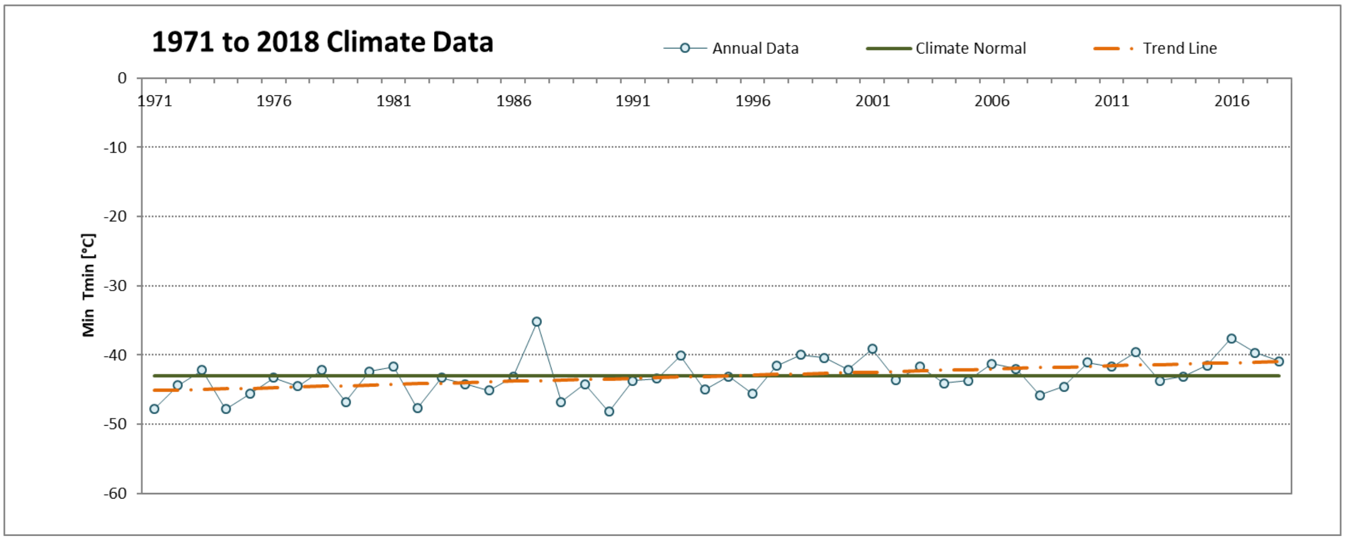

Figure 19: Current Climate Extremes Analysis for Yellowknife A Adjusted — Min Tmin

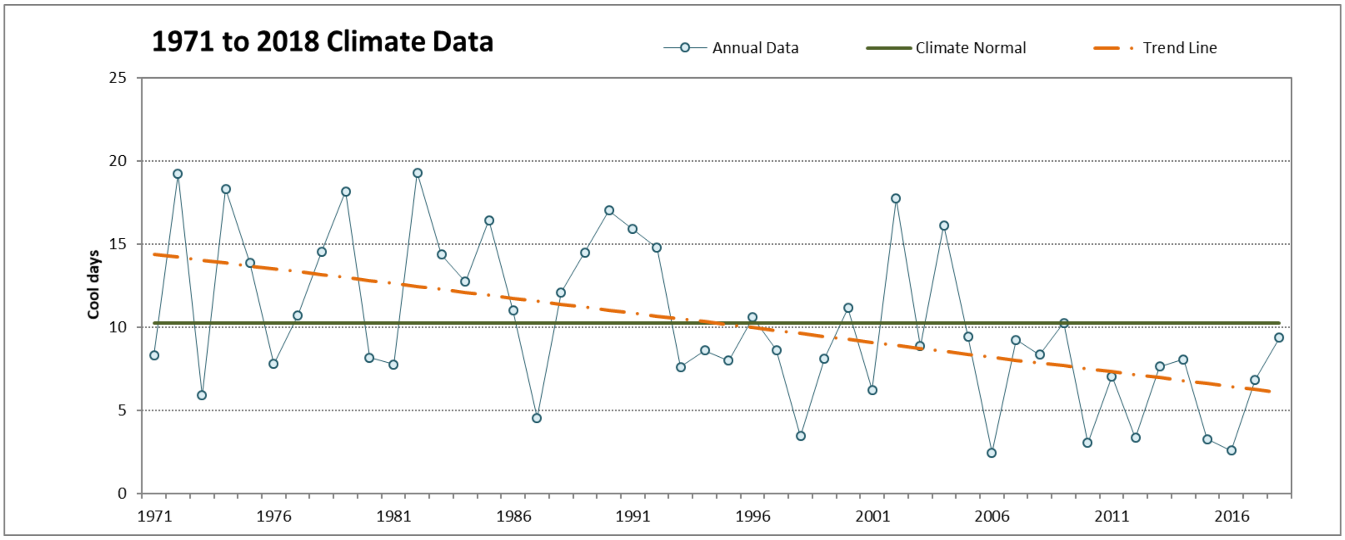

Figure 20: Current Climate Extremes Analysis for Yellowknife A Adjusted — Cool Days

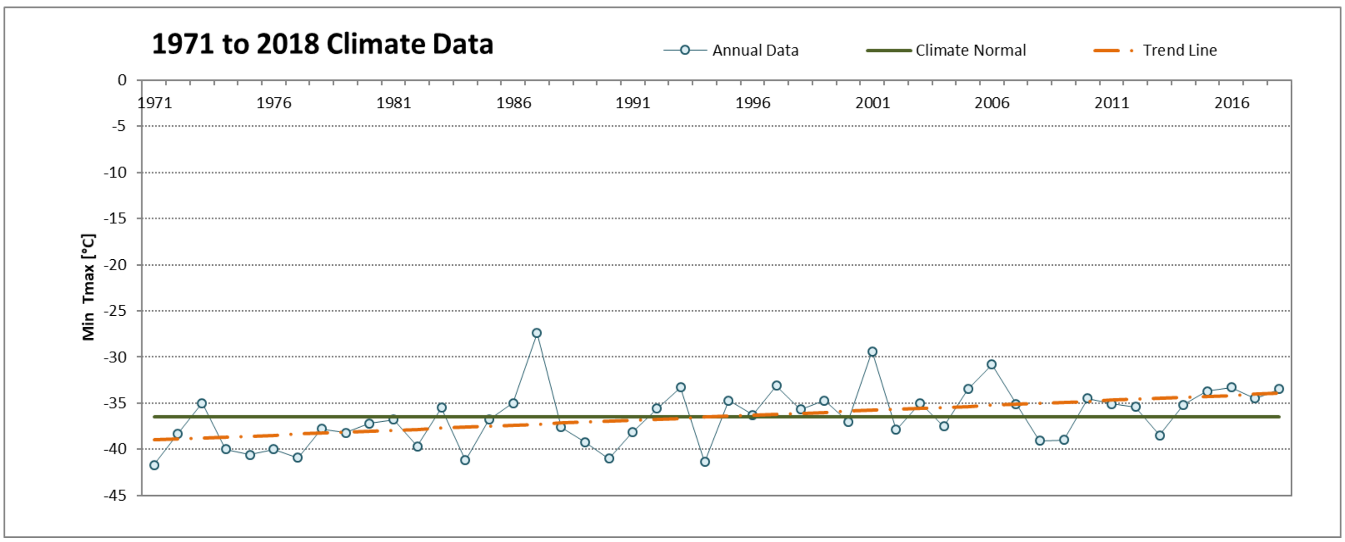

Figure 21: Current Climate Extremes Analysis for Yellowknife A Adjusted — Min Tmax

In general, the climate extremes agree with the current climate normals and trends presented in Section 3.2, with warming trends in the temperature indices and trends in six indices statistically significant above the 90th percentile). Decreasing trends are observed for cool days and nights and increasing trends in minimum temperatures and minimum maximum temperatures. Increases observed in consecutive wet days (statistically significant at the 99th percentile), the annual total wet-day precipitation (statistically significant at the 95th percentile), number of heavy precipitation days (statistically significant at the 90th percentile), and maximum 1-day precipitation (not statistically significant) suggest increasing precipitation trends.

3.4 Current Probable Maximum Precipitation

The 1-day and 3-day PMP was estimated for Giant Mine using the Yellowknife A Adjusted data and the Hershfield statistical method (WMO 2009). This method uses annual maximum rainfall events (in this case, measured events in the infilled dataset) to estimate a value for the PMP event based on statistics of the measured dataset. The resulting 1-day and 3-day PMP estimates are 267 and 308 mm, respectively, as summarized in Table 8. 1-day PMP was estimated previously as 328 mm for the site using daily rainfall data from Yellowknife A regional climate station for the period of 1942 to 2012 (Golder 2017). The same method and primary data source were used in this report; however, the baseline periods and infilling methods are different, leading to different estimates of PMP. In Golder (2017), estimates of PMP from existing studies were compiled, showing a range of 203 mm to 356 mm. Therefore the 1-day PMP estimate provided here is within the range of existing studies. The more conservative estimate of PMP between Golder (2017) and this report should be used for design purposes.

Table 8: Current PMPs for Daily Event at the Yellowknife A Adjusted Data

Design Storm Event	Golder Estimate (mm)
1-Day Storm PMP	267
3-Days Storm PMP	308

3.5 Current Rainfall Statistics (IDF)

The current rainfall statistics for various durations (1-day through 120-day) and return periods (1 in 2 years, 1 in 10 years, 1 in 100 years, 1 in 200 years, 1 in 500 years, 1 in 1,000 years and 1 in 2,000 years) were calculated using the current climate dataset. Daily rainfall can be calculated for two different periods: 24-hour rainfall and 1-day rainfall. The 24-hour rainfall is calculated as the maximum rainfall during a moving block of 24 hours, while the 1-day rainfall is calculated as the maximum rainfall during the period from midnight of one day to midnight of the next. Due to the differences in the method of calculation, there are typically differences in the values, with the 24-hour rainfall often being higher (moving block allows for greater capture of storms). WMO recommends an adjustment factor of 1.13 to be applied to daily IDF values for obtaining 24-hourly IDF values (WMO 2009). In the following sections, the analysis is focused on the 1-day rainfall, as the Yellowknife A Adjusted data is limited to a daily resolution.

3.5.1 Daily Precipitation

Annual maximum daily rainfall values are calculated for each year based on the daily precipitation from Yellowknife A Adjusted. Daily rainfall statistics (namely return period daily rainfall values) were derived by fitting the annual maximum series (AMS) to a Gumbel distribution with the method of moments. Annual maximum results are presented in Table 9. No significant trend can be observed in the daily annual maximum series. The daily rainfall statistics (as well as values for 24-hour rainfall estimated by multiplying daily values by the 1.13 factor; WMO 2009) are listed in Table 10. Data from the ECCC Engineering Dataset (ECCC 2019) from Yellowknife A station is also included in Table 10 for comparison purposes. The ECCC data is available for 24-hours duration from 1963-1996 and the 100-years return period, 24-hours duration storm is calculated at 79 mm while Golder's estimate is slightly higher at 80.7 mm.

Table 9: 1-Day AMS (mm) Using Yellowknife A Adjusted Data

Year	Peak Annual Rainfall Depth (mm)	Year	Peak Annual Rainfall Depth (mm)
	1-Day		1-Day
1971	18.4	1995	14.6
1972	19.0	1996	27.9
1973	84.6	1997	25.0
1974	22.4	1998	15.5
1975	33.1	1999	14.6
1976	23.7	2000	31.3
1977	16.7	2001	25.0
1978	20.7	2002	40.2
1979	14.6	2003	25.2
1980	14.5	2004	18.7
1981	16.7	2005	24.4
1982	30.4	2006	16.9
1983	18.5	2007	58.7
1984	23.2	2008	39.8
1985	45.0	2009	37.7
1986	35.0	2010	18.5
1987	16.1	2011	17.5
1988	67.5	2012	26.2
1989	20.3	2013	20.0
1990	40.1	2014	26.8
1991	32.6	2015	22.7
1992	23.0	2016	23.9
1993	23.2	2017	32.8
1994	17.9	2018	39.4

Table 10: Rainfall Statistics (in mm) Using the Yellowknife A Adjusted Data Compared to Results Environment and Climate Change Canada (ECCC)

Return Period (Years)	24-hour IDF (mm)		Daily IDF (mm)
	Yellowknife A (2204100) Station[(a)]	Yellowknife A Adjusted[(b)]	Yellowknife A Adjusted
2	26.4	28.5	25.2
10	49.8	51.7	45.8
100	79.0	80.7	71.4
200	87.6	89.3	79.0
500	99.0	100.6	89.0
1000	107.6	109.2	96.6
2000	116.3	117.7	104.2

Notes:

(a) Taken from Environment Canada based on the period from 1963 – 1996 (ECCC 2019)

(b) Converted from 1-day to 24-hour duration using 1.13 ratio (WMO 2009)

Golder relied on the Gumbel distribution with the method of moments, to estimate different return periods of rainfall, as explained in Appendix A. To evaluate the validity of this approach, one method is to verify the number of exceedances in the AMS series. The peak annual rainfall depth during a *n*-year return period event should be equalled or exceeded once in a *n*-year period on average (Hogg and Carr 1985). The 2, 10, and 100-year return period peak daily rainfall depths (Table 10) have been equalled or exceeded 19, 3 and 1 times, respectively, in 48 years of baseline (Table 9). As each return period daily peak rainfall has been exceeded at least once during the appropriate time period (i.e., 2, 10 and 100 years), the statistical analyses are valid and the extrapolation to higher return periods such as 2000-year return period is reliable.

3.5.2 Multi-day Precipitation

The Yellowknife A Adjusted data was used to estimate precipitation depths for events with durations between 1 day and 120 days. The results are shown in Table 11. Generally, results suggest that for rainfall above a 10-day duration, the rainfall depth increases linearly with the number of days.

Table 11: Rainfall Statistics (in mm) Using Yellowknife A Adjusted

Return Period (Years)	Precipitation Depth (mm)													
	1-day	2-day	3-day	4-day	5-day	6-day	7-day	10-day	20-day	30-day	50-day	75-day	90-day	120-day
2	25.2	31.0	34.3	36.7	38.7	40.7	42.4	47.5	64.1	78.6	104.9	135.9	153.1	188.3
10	45.8	53.9	57.2	62.0	64.5	67.1	69.0	76.4	96.0	117.5	150.8	189.5	209.3	250.5
100	71.4	82.5	85.9	93.7	96.5	100.1	102.2	112.4	135.7	166.1	208.0	256.3	279.4	328.2
200	79.0	90.9	94.4	103.1	106.0	109.9	112.1	123.1	147.5	180.4	225.0	276.1	300.1	351.2
500	89.0	102.1	105.6	115.4	118.6	122.8	125.1	137.1	163.0	199.4	247.4	302.2	327.5	381.5
1000	96.6	110.6	114.0	124.8	128.0	132.5	134.9	147.7	174.8	213.7	264.3	322.0	348.2	404.4
2000	104.2	119.0	122.5	134.1	137.5	142.3	144.7	158.4	186.5	228.0	281.2	341.7	368.9	427.4

3.6 Current Evapotranspiration Potential

Average current monthly potential evapotranspiration was estimated for the Yellowknife Infilled dataset using the Hargreaves and Thornthwaite methods. The results are shown in Table 12. The Hargreaves method is projecting approximately 40% higher annual evapotranspiration potential than the Thornthwaite method.

Table 12: Potential Evaporation at Yellowknife using Thornthwaite and Hargreaves Methods (mm)

Month	Potential Evapotranspiration (mm)	
	Thornthwaite Method	Hargreaves Method
Jan	0.0	0.8
Feb	0.0	2.6
Mar	0.0	12.6
Apr	0.6	51.8
May	55.8	108.6
Jun	127.6	139.2
Jul	149.6	150.2
Aug	110.8	121.9
Sep	50.4	69.8
Oct	2.3	29.4
Nov	0.0	7.3
Dec	0.0	1.4
Annual	497.0	695.7

3.7 Current Extreme Rainfall and Snowmelt Statistics Estimates

Combined extreme rainfall and snowmelt events for multiple durations and return periods consistent with rainfall statistics was calculated. Using the Yellowknife A Adjusted daily data, the multiple day daily snowmelt plus rainfall statistics were calculated for various return periods. All the snowmelt plus rainfall statistics in Table 13 were derived by fitting the daily melt estimates and precipitation data from October to June using the Gumbel distribution. In contrast with the rainfall events, the snowmelt plus rainfall are less intense for 1-day duration, and higher for all other durations. The 1-day 100-year event presents a snowmelt of 39.9 mm, while the rainfall for the same event is 71.4 mm; the 10-day 100-year snowmelt is 202.1 mm, while the rainfall is projected at 112.4 mm. Similar behavior can be observed through the other durations and return periods. Annual snowpack statistics are shown in Table 14. Snowpack varies from 161.5 mm for the 2-year return period and increases up to 348.8 mm for the 2000-year return period.

Table 13: Snowmelt plus Rainfall Statistics for Yellowknife A (mm)

Return Period (Years)	Snowmelt Plus Rainfall (mm)													
	1-day	2-day	3-day	4-day	5-day	6-day	7-day	10-day	20-day	30-day	50-day	75-day	90-day	120-day
2	22.3	38.0	51.5	63.3	74.5	85.0	91.8	111.8	144.9	163.1	184.1	205.7	210.6	211.8
10	30.1	47.5	66.4	83.4	99.7	114.7	125.8	152.0	190.0	210.9	235.1	264.0	270.0	271.2
100	39.9	59.4	85.0	108.5	131.2	151.7	168.1	202.1	246.4	270.4	298.8	336.8	344.2	345.4
200	42.8	62.9	90.5	115.9	140.6	162.7	180.7	216.9	263.1	288.1	317.6	358.4	366.1	367.3
500	46.6	67.6	97.7	125.7	152.8	177.2	197.2	236.5	285.1	311.3	342.5	386.8	395.1	396.3
1000	49.5	71.1	103.2	133.1	162.1	188.1	209.7	251.3	301.8	328.9	361.3	408.3	417.0	418.2
2000	52.4	74.6	108.7	140.5	171.4	199.0	222.2	266.1	318.4	346.5	380.0	429.8	438.9	440.1

Table 14: Annual Maximum Snowpack Statistics for Current Climate Baseline (mm equivalent)

Return Period (Years)	Snowpack (mm equivalent)
2	161.5
5	190.9
10	210.3
20	228.9
50	253.0
100	271.1
200	289.1
500	312.9
1000	330.8
2000	348.8

3.8 Current Precipitation Over the Spring Transition Period

Precipitation statistics from the previous sections have been re-evaluated here to capture the seasonal transition from winter to summer months. Total precipitation has been separated into rainfall and snowfall, and calculation of IDF, snowpack, and snowmelt statistics for a set of spring periods to illustrate this transition. The spring periods correspond to:

- March 19th to March 31st (Spring Period 1);
- April 1st to April 15th (Spring Period 2);
- April 16th to April 30th (Spring Period 3);
- May 1st to May 15th (Spring Period 4); and
- May 16th to May 31st (Spring Period 5).

3.8.1 Current Climate Normals and Trends for Rain and Snow

The precipitation normals and trends presented in Section 3.2 are shown here for both rainfall and snowfall. Annual total rain and snow amounts correspond to 197.3 mm [equiv.] and 176.8 mm [equiv.]. Both rain and snow are shown to have an increasing trend of 3.3 mm [equiv.]/year and 3.8 mm [equiv.]/year respectively, however both are shown to be not statistically significant. On average, from November to March there is virtually no rainfall as during this time precipitation typically falls as snow. Conversely, from May to September there is very little snowfall as higher temperatures cause precipitation to fall as rain. The only statistically significant trends identified are decreasing October rainfall at -1.8 mm [equiv.]/decade (90th percentile) and increasing January snowfall at 4.4 mm [equiv.]/decade (99th percentile).

Rainfall during spring period 1 and 2 (mid March to mid April) have small amounts of precipitation and show no trend for the current climate baseline. Rainfall amounts increase from spring periods 3 to 5 (mid April to end of May), with the only statistically significant trend showing a decrease in period 3 rainfall at a rate of 0.2 mm/decade. Snowfall amounts are shown to decrease in spring periods 1 through 3 (mid March to end of April), after which there is no snowfall in periods 4 and 5. In the case of snowfall, no statistically significant trends were found for the spring transition period.

Table 15: Current Climate Normals and Trends for Rainfall and Snowfall - Yellowknife A Adjusted (1971 - 2018)

Climate Indices	Normals	Decadal Trend	Statistical Significance
Total Rainfall [mm (equiv.)]	197.3	+3.3	not statistically significant
January Total Rainfall [mm (equiv.)]	0.0	0.0	no trend
February Total Rainfall [mm (equiv.)]	0.0	0.0	no trend
March Total Rainfall [mm (equiv.)]	0.2	0.0	no trend
April Total Rainfall [mm (equiv.)]	4.0	-0.1	not statistically significant
May Total Rainfall [mm (equiv.)]	18.3	-1.2	not statistically significant
June Total Rainfall [mm (equiv.)]	31.4	+1.5	not statistically significant
July Total Rainfall [mm (equiv.)]	41.2	+1.0	not statistically significant
August Total Rainfall [mm (equiv.)]	46.5	+0.5	not statistically significant
September Total Rainfall [mm (equiv.)]	37.7	+1.4	not statistically significant
October Total Rainfall [mm (equiv.)]	17.9	-1.8	significant at the 90th percentile
November Total Rainfall [mm (equiv.)]	0.2	0.0	no trend
December Total Rainfall [mm (equiv.)]	0.0	0.0	no trend
Spring Period 1 Total Rainfall [mm (equiv.)]	0.2	0.0	no trend
Spring Period 2 Total Rainfall [mm (equiv.)]	1.1	0.0	no trend
Spring Period 3 Total Rainfall [mm (equiv.)]	2.9	-0.2	significant at the 95th percentile
Spring Period 4 Total Rainfall [mm (equiv.)]	6.9	-0.5	not statistically significant
Spring Period 5 Total Rainfall [mm (equiv.)]	11.4	+0.2	not statistically significant
Total Snowfall [mm (equiv.)]	176.8	+3.8	not statistically significant
January Total Snowfall [mm (equiv.)]	27.8	+4.4	significant at the 99th percentile
February Total Snowfall [mm (equiv.)]	21.8	+0.8	not statistically significant
March Total Snowfall [mm (equiv.)]	20.0	-0.3	not statistically significant
April Total Snowfall [mm (equiv.)]	10.4	-0.3	not statistically significant

Table 15: Current Climate Normals and Trends for Rainfall and Snowfall - Yellowknife A Adjusted (1971 - 2018)

Climate Indices	Normals	Decadal Trend	Statistical Significance
May Total Snowfall [mm (equiv.)]	2.8	0.0	no trend
June Total Snowfall [mm (equiv.)]	0.0	0.0	no trend
July Total Snowfall [mm (equiv.)]	0.0	0.0	no trend
August Total Snowfall [mm (equiv.)]	0.0	0.0	no trend
September Total Snowfall [mm (equiv.)]	1.4	0.0	no trend
October Total Snowfall [mm (equiv.)]	22.5	-1.5	not statistically significant
November Total Snowfall [mm (equiv.)]	41.3	-0.3	not statistically significant
December Total Snowfall [mm (equiv.)]	28.8	+0.8	not statistically significant
Spring Period 1 Total Snowfall [mm (equiv.)]	7.9	+0.1	not statistically significant
Spring Period 2 Total Snowfall [mm (equiv.)]	8.2	-0.3	not statistically significant
Spring Period 3 Total Snowfall [mm (equiv.)]	2.2	-0.1	not statistically significant
Spring Period 4 Total Snowfall [mm (equiv.)]	2.1	0.0	no trend
Spring Period 5 Total Snowfall [mm (equiv.)]	2.1	0.0	no trend

3.8.2 Current Spring Precipitation Statistics (IDF)

Rainfall statistics for the spring transition period are obtained using the same approach as in Section 3.5.1, however the 1-day annual maximums are developed using only the spring period of March 19th to May 31st. The 1-day rainfall amounts for the 2- to 2000-year return period events range from 9.3 mm to 34.8 mm. These values are much less than those obtained for all seasons in Section 3.5.1 (25.2 mm and 104.2 mm for the 2- and 2000-year events, respectively). This can be expected, as the months of March to May contain the lowest precipitation amounts in the year, based on the climate normals for the site provided in Section 3.2.

Table 16: Spring IDF Statistics for the Current Climate Baseline

Return Period (Years)	1-Day Spring Precipitation (mm)
2	9.3
5	13.3
10	16.0
20	18.5
50	21.8
100	24.2
200	26.7
500	29.9
1000	32.4
2000	34.8

3.8.3 Current Snowpack Over the Spring Transition Period

The same analysis for annual snowpack (Section 3.7) was performed separately for each spring transition period (Table 17). Spring transition periods 1 to 3 (early to mid spring) show values similar to the annual statistics, with slightly lower amounts of snowpack for the low return periods and higher amounts for the higher return periods. Spring transition period 4 (early May) is most frequently lower than the annual snowpack amount, with the potential for the highest amounts of snowpack at 423.9 mm for the 2000-year return period event. The large range in snowpack for period 4 is likely due to variation in the timing of the spring melt. If most of the melt occurs in period 5, period 4 will have the longest time for accumulation compared to the earlier periods, while if the melt occurs in period 4 there will be much less snowpack. Finally, spring period 5 (late May) has the lowest amounts of snowpack as melting begins to occur, however the 2000-year event is still greater than the 2-year event for spring transition period 1 to 4.

Table 17: Annual Maximum Snowpack Statistics for each Spring Transition Period (mm equivalent)

Return Period (Years)	Spring Transition Period				
	1	2	3	4	5
2	144.8	148.9	141.1	79.2	11.8
5	177.1	182.7	175.0	134.6	33.7
10	198.5	205.1	197.5	171.3	48.2
20	219.0	226.5	219.0	206.5	62.2
50	245.6	254.2	246.9	252.1	80.2
100	265.5	275.0	267.8	286.2	93.7
200	285.3	295.8	288.6	320.2	107.2
500	311.5	323.1	316.1	365.1	124.9
1000	331.2	343.8	336.8	399.0	138.3
2000	351.0	364.4	357.6	432.9	151.7

4.0 FUTURE CLIMATE

The following sections build on the current climate descriptions by providing the projected changes under future climate conditions for two future time horizons (2050s and 2080s). Sections 4.1 and 4.2 provide a description of future projected conditions for temperature and precipitation. Sections 4.3 through 4.5 provide the projected changes in the detailed precipitation analysis. In all sections, projections are provided in terms of percentiles measured over the 72-member multi-model ensemble. The focus of the results is on 50th percentile. Results are summarized as part of the conclusions in Section 6.0.

4.1 Future Temperature and Precipitation

This section provides the projected future mean temperature and precipitation for the Giant Mine area. The future climate projections are benchmarked against a modelled baseline and put in context of the results from Section 3.2.

4.1.1 Annual Projections

Comparisons of the future climate projections for the Giant Mine area for the 2050s and 2080s projection periods are shown as a scatter plot in Figure 22. The plots illustrate the projected change in temperature (vertical axis) and precipitation (horizontal axis) from the current climate baseline (1971 through 2018 normal period) for each of the models, and the four relative concentration pathways considered in the IPCC's AR5 (IPCC 2013). For reference, the current climate is shown as a solid circle where the axes intersect. The model projections are in the upper right half of the plots, suggesting a future climate that will likely be warmer and wetter. There is a larger spread of future projected precipitations, with a majority of model runs projecting a wetter future climate. These projections agree with the current climate temperatures presented in Section 3.2, which shows a warming current climate. The projections are reasonably consistent with a current climate that is showing possibly wetter trends. Precipitation projections typically have larger uncertainty than temperature projections due to the challenge of capturing precipitation in the climate models (temperature is well understood).

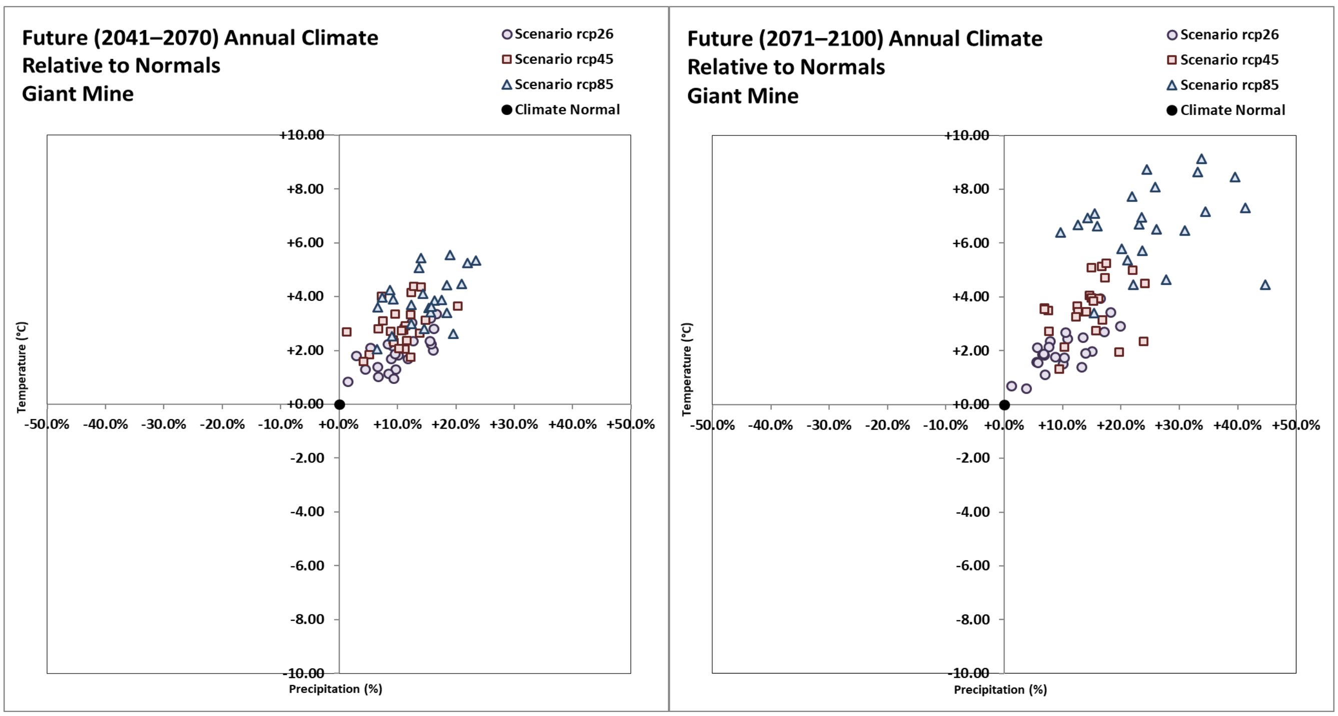

Figure 22: Scatter Plots Showing the Annual Temperature and Precipitation Projections for the 2050s and the 2080s for the Giant Mine Area

4.1.2 Monthly Projections

The following figures summarize the magnitude of model-projected changes during the 2050s and the 2080s from the modelled climate baseline. Figure 23 and Figure 24 depict the projected anomalies in monthly mean temperatures in the Giant Mine area for the 2050s and 2080s, respectively. The Figure also shows a dashed line, which represents the mean of all the modelled projections. The dotted line in the figures represents the spread between the 5th percentile and the 95th percentile of the ensemble. The figures show projected increases in temperature for a majority of the months, with increased temperatures and larger spread in the 2080s ensemble in the winter, and shows a good agreement in the summer and fall months.

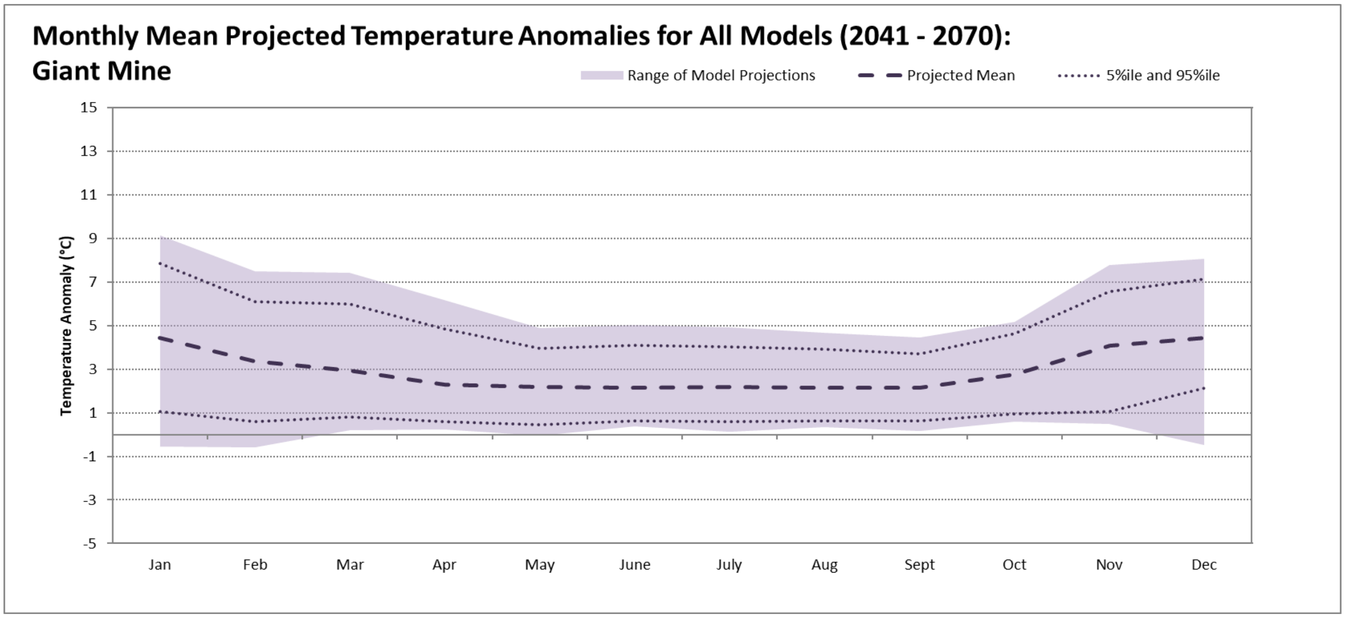

Figure 23: Monthly Projected Temperature Anomalies for the Giant Mine Area (2050s)

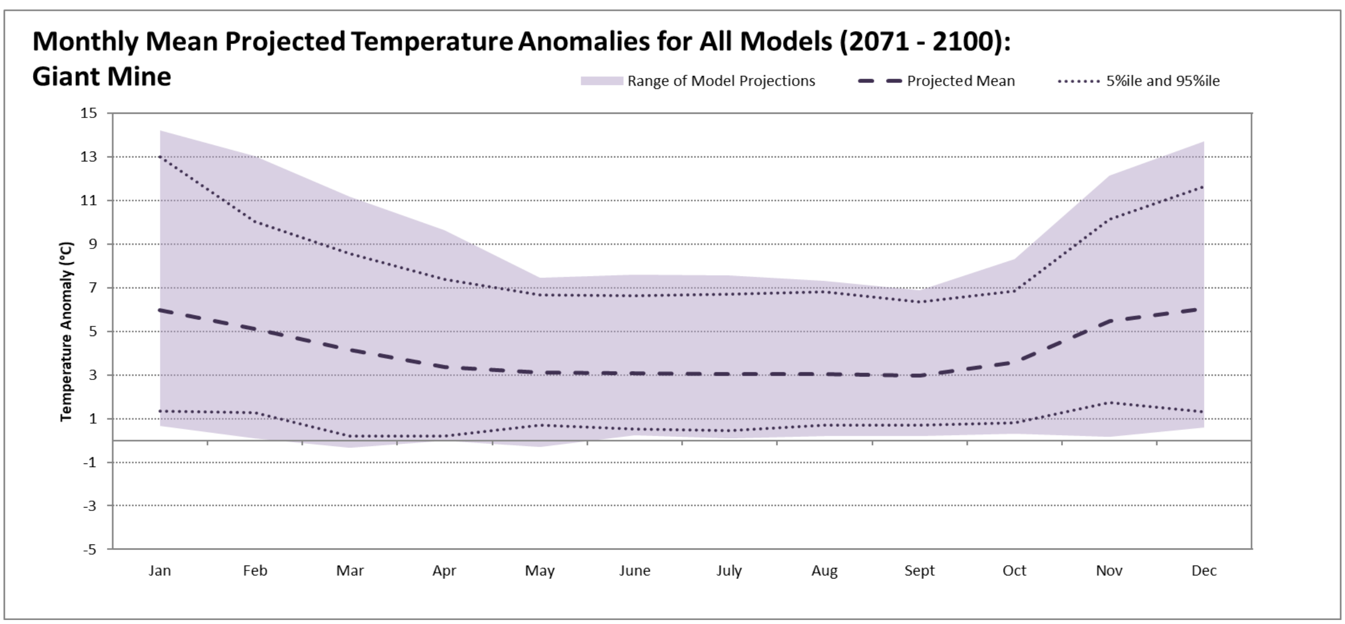

Figure 24: Monthly Projected Temperature Anomalies for the Giant Mine Area (2080s)

Figure 25 and Figure 26 present the monthly projected precipitation anomalies for the Giant Mine area for the 2050s and 2080s, respectively. There is less agreement seen during the 2080s, with the largest spread seen through the spring and summer months (April through August). On a month to month basis, the projected mean (purple dashed line) indicates a slight projected increase throughout the year.

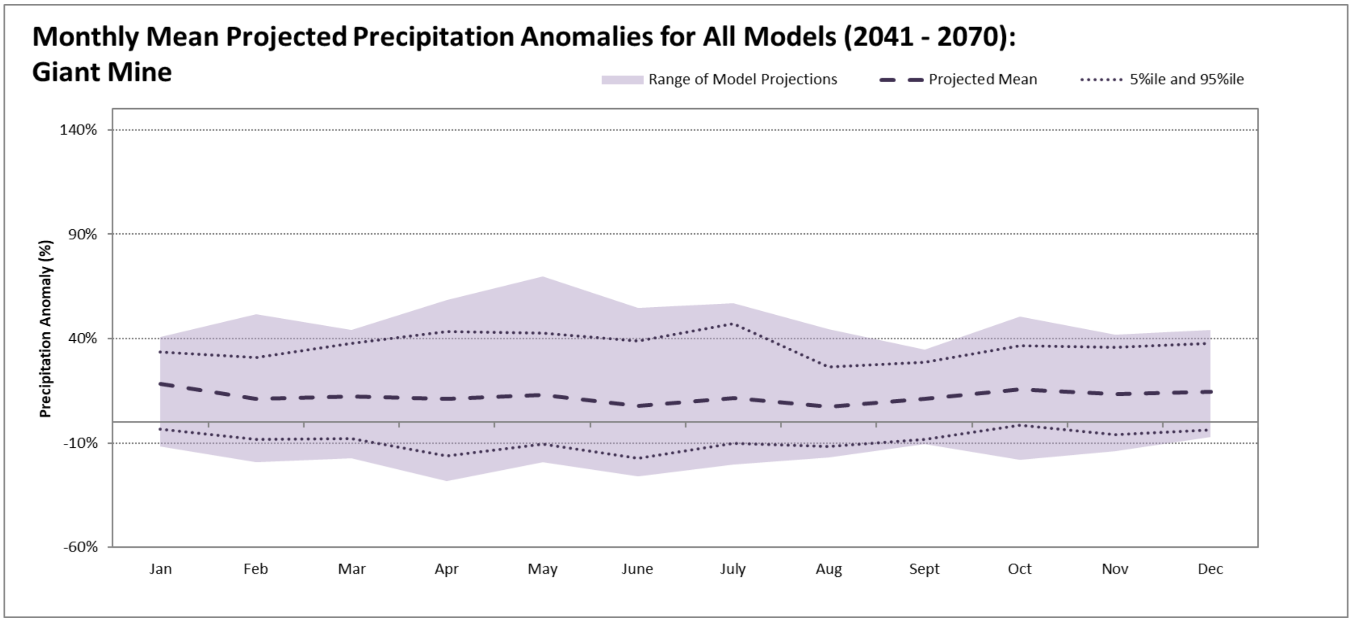

Figure 25: Monthly Projected Precipitation Anomalies for Giant Mine Area (2050s)

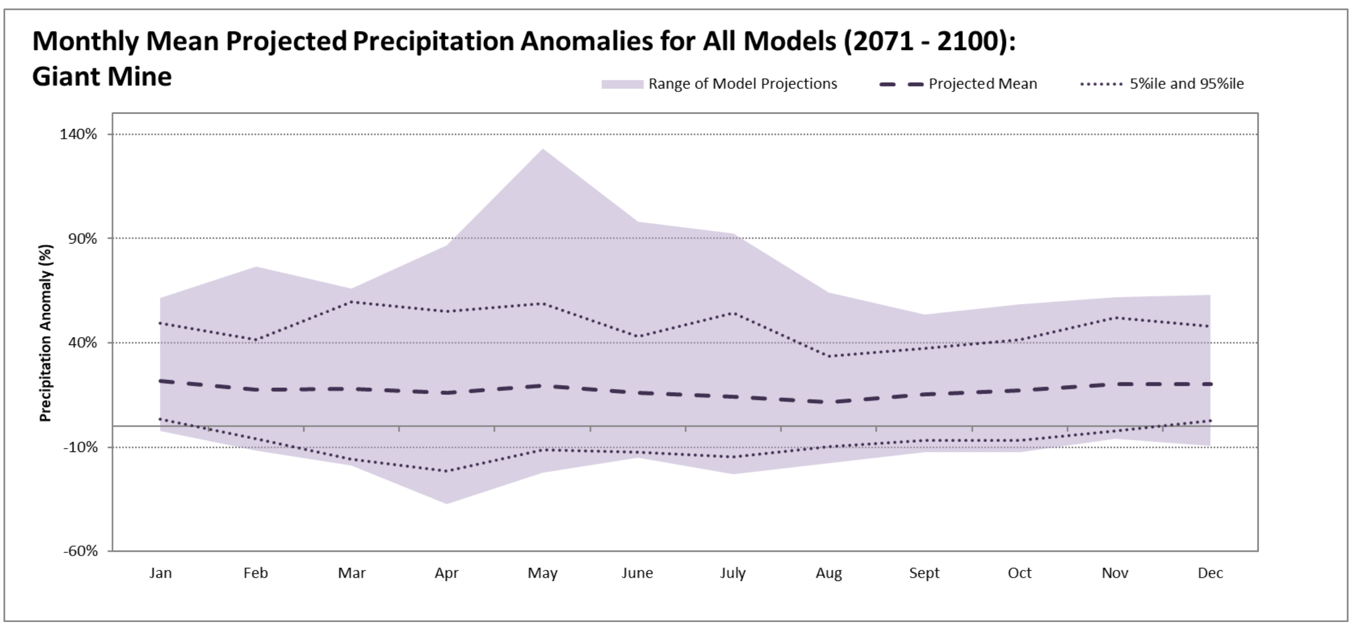

Figure 26: Monthly Projected Precipitation Anomalies for Giant Mine Area (2080s)

Overall, there is less variability and uncertainty (measured as the agreement within the ensemble or range of projected anomalies) during the 2050s. However, variability increases for both the precipitation and temperature anomalies during the 2080s.

4.1.3 Summary of Annual and Monthly Projections

The projected future changes in the 2050s and 2080s from the baseline period (1971 through 2018) in monthly and annual temperatures are summarized in Table 18 and Table 19. In the 2050s, at the 50th percentile, the annual temperature is projected to increase by 2.8°C, with the biggest monthly increase of 4.4°C in January, and smallest monthly increase of 1.9°C in June. In the 2080s, at the 50th percentile, the annual temperature is projected to increase by 3.6°C, with the biggest monthly increase of 5.9°C in December, and smallest monthly increase of 2.6°C in July and September.

Table 18: Projected Changes in Monthly and Annual Temperature in the 2050s (°C)

Month	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	-0.5	1.1	2.0	**4.4**	6.1	7.0	7.9	8.9	9.1	4.4	2.1
February	-0.6	0.6	1.2	**3.1**	4.9	5.5	6.1	7.1	7.5	3.4	1.8
March	0.2	0.8	1.3	**2.8**	3.6	5.0	6.0	6.8	7.4	2.9	1.5
April	0.2	0.6	0.8	**2.1**	2.8	4.1	4.9	5.4	6.2	2.3	1.3
May	0.0	0.4	0.9	**2.1**	3.0	3.4	3.9	4.5	4.9	2.2	1.1
June	0.4	0.6	0.8	**1.9**	2.9	3.6	4.1	4.7	5.0	2.1	1.1
July	0.1	0.6	0.8	**2.1**	2.9	3.8	4.0	4.6	4.9	2.2	1.1
August	0.4	0.6	1.0	**2.0**	2.7	3.6	3.9	4.3	4.7	2.1	1.0
September	0.2	0.6	1.0	**2.0**	2.9	3.5	3.7	4.4	4.5	2.1	1.0
October	0.6	0.9	1.3	**2.6**	3.4	4.4	4.6	5.0	5.2	2.8	1.1
November	0.5	1.0	1.9	**4.2**	5.1	6.3	6.5	7.4	7.8	4.1	1.7
December	-0.5	2.1	2.6	**4.3**	5.9	6.5	7.1	7.8	8.1	4.4	1.7
Annual	0.8	1.2	1.6	**2.8**	3.7	4.4	5.1	5.5	5.6	2.9	1.1

Table 19: Projected Changes in Monthly and Annual Temperature in the 2080s (°C)

Month	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	0.7	1.3	1.8	**5.3**	7.7	11.4	13.0	14.0	14.2	6.0	3.5
February	0.1	1.3	1.6	**4.4**	7.0	9.7	10.0	12.4	13.0	5.1	3.0
March	-0.3	0.2	1.3	**4.0**	5.9	7.8	8.6	10.4	11.2	4.1	2.6
April	0.0	0.2	0.6	**3.2**	4.6	6.6	7.4	8.3	9.6	3.4	2.3
May	-0.3	0.7	1.0	**2.8**	4.1	6.0	6.7	7.4	7.4	3.1	1.9
June	0.2	0.5	0.9	**2.7**	4.1	5.9	6.6	7.2	7.6	3.1	1.9
July	0.1	0.4	1.1	**2.6**	4.3	6.2	6.7	7.3	7.6	3.0	1.9
August	0.2	0.7	1.0	**2.8**	3.9	6.1	6.8	7.1	7.3	3.1	1.9
September	0.2	0.7	0.9	**2.6**	3.9	5.7	6.3	6.7	6.9	3.0	1.8
October	0.3	0.8	1.7	**3.2**	4.6	6.5	6.8	7.6	8.3	3.6	1.9
November	0.1	1.7	2.1	**5.3**	8.2	9.1	10.2	11.1	12.2	5.5	2.8
December	0.6	1.3	2.2	**5.9**	8.4	10.8	11.6	13.4	13.7	6.0	3.3
Annual	0.6	1.4	1.6	**3.6**	5.7	7.2	8.3	8.9	9.1	4.1	2.2

The projected future changes in the 2050s and 2080s from the baseline period (1971 through 2018) in monthly and annual precipitation are summarized in Table 20 and Table 21. The annual precipitation in the 2050s is projected to increase by 11% from the baseline, at the 50th percentile. The projected highest monthly increases in the 2050s would occur in the fall and winter while small changes are expected in the summer. The 2080s annual precipitation is projected to increase by 15% from the baseline, with the largest increases occurring in the fall and winter.

Table 20: Projected Changes in Monthly and Annual Precipitation in the 2050s (%)

Month	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	-12%	-3%	1%	**20%**	26%	32%	33%	38%	41%	18%	11%
February	-19%	-8%	-5%	**11%**	21%	27%	31%	44%	52%	11%	14%
March	-17%	-8%	-5%	**12%**	25%	31%	38%	43%	44%	12%	15%
April	-28%	-16%	-14%	**9%**	27%	38%	43%	55%	58%	11%	19%
May	-19%	-11%	-6%	**11%**	24%	39%	43%	54%	70%	13%	17%
June	-26%	-17%	-12%	**5%**	15%	33%	39%	54%	55%	8%	18%
July	-20%	-10%	-7%	**9%**	20%	37%	47%	56%	57%	11%	17%
August	-17%	-12%	-10%	**8%**	18%	23%	27%	38%	45%	8%	13%
September	-10%	-8%	-4%	**11%**	21%	26%	29%	35%	35%	11%	12%
October	-18%	-2%	1%	**14%**	23%	34%	37%	48%	51%	16%	13%
November	-14%	-6%	-3%	**14%**	22%	32%	36%	42%	42%	13%	14%
December	-7%	-4%	-1%	**13%**	24%	35%	38%	42%	44%	15%	13%
Annual	1%	4%	6%	**11%**	15%	18%	20%	22%	23%	12%	5%

Table 21: Projected Changes in Monthly and Annual Precipitation in the 2080s (%)

Month	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	-2%	3%	8%	**19%**	29%	40%	49%	56%	61%	22%	14%
February	-12%	-6%	-4%	**17%**	27%	38%	41%	69%	76%	17%	17%
March	-19%	-16%	-6%	**15%**	30%	38%	60%	65%	66%	18%	20%
April	-37%	-21%	-12%	**14%**	32%	41%	55%	74%	87%	16%	23%
May	-22%	-11%	-8%	**12%**	31%	45%	59%	131%	133%	19%	27%
June	-15%	-13%	-4%	**13%**	24%	38%	43%	92%	98%	16%	21%
July	-23%	-15%	-9%	**14%**	22%	32%	54%	92%	92%	14%	22%
August	-17%	-10%	-8%	**11%**	20%	30%	34%	49%	64%	12%	15%
September	-12%	-7%	0%	**16%**	24%	33%	38%	50%	54%	15%	14%
October	-13%	-7%	-1%	**16%**	28%	40%	41%	53%	58%	17%	16%
November	-6%	-2%	-1%	**16%**	29%	45%	52%	59%	62%	20%	17%
December	-9%	3%	3%	**18%**	29%	43%	48%	62%	63%	20%	15%
Annual	1%	6%	7%	**15%**	22%	28%	34%	42%	45%	17%	9%

The projections are consistent with the future climate trends available through CCCS, ClimateData.ca, and the latest ECCC report ‘Canada’s Changing Climate Report’ (Government of Canada 2019; ClimateData.ca 2019; Bush and Lemmen 2019). Under a high emissions scenario (RCP 8.5), the projected 20-year average change in mean temperature for Yellowknife between 2041 to 2060 is 3.4°C and that increases to 7.2°C for the period between 2081 to 2100. Under a high emissions scenario (RCP 8.5), the projected 20-year average change in total precipitation for Yellowknife between 2041 to 2060 is 12.5% and increases to 26.5% for the period between 2081 to 2100 (Government of Canada 2019).

Under a high emissions scenario (RCP 8.5), the ClimateData.ca portal projects that the annual average temperature in Yellowknife will be -2.3°C for the 2021 to 2050 period, 0.4°C for the 2051 to 2080 period, and 2.2°C for the end of the century (ClimateData.ca 2019). Also, average annual precipitation is projected to increase by 11% for the 2021 to 2050 period, 19% for the 2051 to 2080 period, and by 24% for the end of the century (ClimateData.ca 2019).

The Bush and Lemmen (2019) report does not include trends specifically for Yellowknife, however, projections indicate an increase in both mean annual temperature and precipitation with northern Canada expected to experience larger increases (Bush and Lemmen 2019). Under a low emissions scenario (RCP 2.6) temperature is projected to increase by 1.8°C and by more than 6°C under a high emissions scenario (RCP 8.5) by the end of the century. Annual mean precipitation is projected to increase by 7% under a low emissions scenario (RCP 2.6) and by 24% under a high emissions scenario (RCP 8.5) by the end of the century (Bush and Lemmen 2019).

4.2 Future Climate Extremes

The projected future changes in climate extremes in the 2050s and 2080s, in terms of anomalies (differences) from the baseline period (1971-2018) are provided in Table 22 and Table 23. These ensemble statistics were calculated based on the 72-member multi-model ensemble.

Using the median or 50th percentile provides an indication of middle of the projected changes from the multi-model ensemble. The difference between the median and mean provides an indication for how the projections are distributed within the range of projects. For example, if the mean is below the median, the majority of the ensemble members are projecting lower values than the median, with a few higher projections from a small number of ensemble members.

The future projected monthly climate described in Section 4.1.2 indicates the future climate for both the 2050s and the 2080s is likely to become warmer and wetter. This is in agreement with the current climate temperature trends in Section 3.2. From the median (50th percentile) values for the 2050s and 2080s, the projected future climate extremes are indicating a future that is likely to be warmer and wetter on an annual basis. Temperature is projected to increase, resulting in increased warm days and warm nights, reduced cool days and nights, as well as reduced ice and frost days. Cold spell durations are projected to be reduced while warm spell durations are projected to increase. Along with the increases in temperature, the growing season also shows an increase in both periods.

The number of consecutive wet days shows a slight increase in both the 2050s and 2080s, and the annual amount of total wet-day precipitation is increasing at the 50th percentile, which may indicate wetter conditions. However, increasing trends in both periods for the number of very heavy precipitation days, and the amount of precipitation on very wet and extremely wet days, indicates a consistent trend with the current climate period. With the potential for future distribution and amount of precipitation to change, it is important to understand future projected rainfall statistics and probable maximum precipitation events from a design and operation standpoint. These will be discussed in the following sections.

Table 22: Projected Changes from Baseline (1971 - 2018) in WMO Extreme Indices for the 2050s (2041 - 2070)

WMO Index	Percentile										
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
Consecutive dry days [days]	-5.9	-4.4	-3.9	**-1.7**	-0.4	1.9	2.9	3.5	3.6	-1.4	2.3
Cold spell duration indicator [days]	-9.8	-9.0	-8.4	**-6.1**	-4.6	-3.8	-3.2	-1.8	-1.6	-6.0	1.8
Consecutive wet days [days]	-0.4	-0.2	-0.1	**0.2**	0.5	0.8	0.9	1.1	1.3	0.3	0.3
Diurnal temperature range [°C]	-1.5	-0.8	-0.7	**-0.3**	-0.2	-0.1	0.0	0.0	0.1	-0.4	0.3
Frost days [days]	-33.9	-29.8	-27.3	**-17.8**	-13.5	-9.0	-7.3	-6.0	-5.6	-18.4	7.1
Growing season length [days]	0.9	4.0	6.3	**15.4**	20.8	27.0	29.6	34.5	38.5	15.7	7.9
Ice days [days]	-39.8	-25.8	-22.2	**-13.5**	-8.3	-6.2	-4.2	-2.6	-2.0	-14.1	7.4
Annual total wet-day precipitation [mm]	3.8	13.1	17.2	**35.9**	46.5	53.9	62.1	68.0	68.9	35.9	14.9
Number of heavy precipitation days [days]	-0.1	0.2	0.3	**0.9**	1.3	1.5	1.7	1.9	2.2	0.9	0.5
Number of very heavy precipitation days [days]	-0.2	-0.1	0.0	**0.2**	0.4	0.5	0.6	0.6	0.7	0.2	0.2
Very wet days [mm]	-2.1	3.6	6.8	**17.4**	23.8	28.0	32.6	35.0	36.0	17.0	8.9
Extremely wet days [mm]	-5.5	-1.2	0.3	**6.5**	11.0	13.7	15.6	17.7	19.9	6.8	5.4
Number of days above 15 mm [days]	-0.3	0.0	0.1	**0.4**	0.6	0.8	0.9	1.1	1.1	0.4	0.3
Max 1-day precipitation amount [mm]	-2.8	-0.7	-0.6	**2.2**	2.8	4.5	5.5	7.0	7.4	1.9	2.0
Max 5-day precipitation amount [mm]	-4.0	-0.2	1.1	**3.5**	4.8	8.3	9.9	11.0	12.2	3.7	3.0
Simple daily intensity index [mm/day]	0.0	0.0	0.1	**0.2**	0.3	0.3	0.3	0.4	0.4	0.2	0.1
Summer days [days]	-0.1	2.2	3.7	**10.8**	15.6	21.5	24.2	33.8	39.4	12.1	7.8
Cool nights [% of days]	-10.3	-9.6	-9.5	**-8.0**	-6.5	-5.4	-4.5	-3.9	-3.6	-7.6	1.6
Warm nights [% of days]	3.1	5.2	7.0	**15.2**	21.6	28.0	30.9	35.7	36.7	16.2	8.2
Min Tmin [°C]	0.9	1.7	2.0	**4.4**	5.7	6.9	7.9	9.4	10.5	4.5	2.0
Max Tmin [°C]	0.1	0.7	1.0	**2.0**	2.8	3.4	3.9	4.3	4.3	2.2	1.0
Tropical nights [days]	0.0	0.0	0.1	**0.5**	1.4	2.2	2.8	3.9	4.4	0.9	1.0
Cool days [% of days]	-9.7	-9.4	-9.1	**-7.3**	-5.8	-4.2	-3.5	-2.9	-2.5	-6.9	1.8
Warm days [% of days]	1.9	3.8	4.6	**10.3**	15.0	20.2	24.8	26.9	28.1	11.6	6.4
Min Tmax [°C]	0.1	1.8	2.4	**4.5**	6.3	7.7	8.3	9.5	9.7	4.9	2.1
Max Tmax [°C]	-0.1	0.7	0.9	**2.2**	3.1	3.7	4.1	5.0	5.1	2.2	1.1
Warm spell duration indicator [days]	4.1	8.7	11.1	**23.9**	40.2	56.7	70.0	74.0	75.9	29.8	18.3

Table 23: Projected Changes from Baseline (1971 - 2018) in WMO Extreme Indices for the 2080s (2071 - 2100)

WMO Index	Percentile										
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
Consecutive dry days [days]	-7.7	-5.8	-4.9	**-2.0**	0.1	1.7	3.2	5.8	7.4	-1.8	2.9
Cold spell duration indicator [days]	-10.0	-9.5	-8.6	**-6.2**	-5.2	-3.7	-3.0	-0.9	-0.3	-6.2	2.0
Consecutive wet days [days]	-0.5	-0.3	-0.1	**0.4**	0.5	0.8	1.1	1.6	1.7	0.4	0.4
Diurnal temperature range [°C]	-1.9	-1.3	-1.0	**-0.4**	-0.2	-0.1	0.0	0.1	0.1	-0.5	0.4
Frost days [days]	-52.4	-48.0	-44.2	**-22.4**	-14.1	-10.4	-7.5	-3.0	-0.7	-25.0	13.3
Growing season Length [days]	-3.2	4.4	7.1	**18.8**	33.1	41.3	46.5	53.0	55.3	22.1	13.9
Ice days [days]	-63.5	-39.7	-38.8	**-17.0**	-8.5	-6.1	-3.9	-1.8	-1.3	-20.1	13.5
Annual total wet-day precipitation [mm]	5.9	17.9	21.1	**46.5**	65.7	88.8	106.0	129.3	132.9	51.0	28.0
Number of heavy precipitation days [days]	-0.1	0.2	0.5	**1.2**	2.0	2.6	3.1	4.3	5.1	1.4	1.0
Number of very heavy precipitation days [days]	-0.2	0.0	0.0	**0.4**	0.5	0.7	0.9	1.0	1.1	0.4	0.3
Very wet days [mm]	0.4	5.9	7.7	**22.6**	38.0	44.4	48.7	76.0	89.0	26.4	16.6
Extremely wet days [mm]	-2.3	-0.1	2.4	**11.6**	15.0	21.0	26.5	34.0	34.1	11.3	8.1
Number of days above 15 [days]	-0.2	0.0	0.1	**0.6**	0.9	1.1	1.3	1.8	2.1	0.6	0.4
Max 1-day precipitation amount [mm]	-1.4	-0.6	-0.2	**3.5**	4.7	5.8	7.3	11.0	11.9	3.2	2.6
Max 5-day precipitation amount [mm]	-2.3	0.3	1.3	**6.3**	7.8	9.8	11.9	16.5	18.0	5.7	3.8
Simple daily intensity index [mm/day]	0.0	0.0	0.1	**0.3**	0.4	0.5	0.6	0.8	0.9	0.3	0.2
Summer days [days]	-1.8	2.4	4.7	**13.3**	25.5	42.5	45.6	56.1	62.5	18.8	14.7
Cool nights [% of days]	-10.4	-10.2	-10.1	**-8.9**	-6.9	-5.6	-5.1	-2.8	-2.8	-8.2	1.9
Warm nights [% of days]	2.8	4.3	6.9	**21.4**	35.8	49.2	56.1	61.5	65.3	24.4	16.3
Min Tmin [°C]	1.4	1.9	2.2	**5.5**	9.3	12.5	13.9	15.6	16.3	6.5	3.9
Max Tmin [°C]	0.5	0.8	1.0	**2.9**	4.0	5.8	6.5	6.9	6.9	3.0	1.8
Tropical nights [days]	0.0	0.1	0.1	**1.0**	2.9	10.8	16.3	19.6	24.0	3.2	5.2
Cool days [% of days]	-10.4	-10.2	-10.0	**-8.2**	-6.1	-4.9	-4.2	-1.7	-1.3	-7.7	2.2
Warm days [% of days]	1.1	3.1	5.2	**14.6**	26.7	39.4	47.4	51.6	53.3	18.7	13.7
Min Tmax [°C]	0.7	2.0	2.4	**6.1**	9.3	12.5	14.5	15.5	15.9	6.7	4.0
Max Tmax [°C]	-0.5	0.6	1.1	**2.7**	4.4	6.1	6.6	8.4	8.5	3.1	2.0
Warm spell duration indicator [days]	2.6	6.9	12.2	**37.9**	72.3	124.5	157.6	174.8	188.7	53.6	47.1

The extreme trends are consistent with projections by ClimateData.ca and the Bush and Lemmen 2019 report. Both sources project increases in growing degree days, wet days, and maximum and minimum temperatures, and decreases in frost and ice days across all scenarios (ClimateData.ca 2019; Bush and Lemmen 2019).

4.3 Future Changes in Probable Maximum Precipitation

The projected changes in future 1-day PMP values are shown in Table 24. Each method was applied to the multi-model ensemble, with the statistics calculated across the results of both methods. The 50th percentile results suggest increases in the 1-day PMP of 9.5% for the 2050s and 14.0% for the 2080s. The results agree with the expectation that as temperature increases under future climate conditions, precipitation is expected to increase as more vapor becomes available in the atmosphere (Kunkel et al. 2013), resulting in a rise in the projected PMP. The range of results (from -49.1% to +99.7% in 2050s and -29.5% and +69.7% in 2080s) suggest that significant flexibility may be required in the future for systems designed for the PMP event.

Table 24: Future Percent Changes in 1- and 3-Day PMP in 2050s and 2080s from Baseline Period of 1971-2018

Ensemble Indices	1-Day PMP		3-Day PMP	
	2050s	2080s	2050s	2080s
Minimum	-49.1%	-29.5%	-34.3%	-36.5%
5%	-25.2%	-16.3%	-22.0%	-17.4%
10%	-18.6%	-10.8%	-16.6%	-8.9%
50%	9.5%	14.0%	12.1%	17.1%
75%	19.2%	30.8%	22.3%	35.7%
90%	29.3%	45.0%	32.2%	47.5%
95%	35.1%	56.1%	39.8%	58.3%
99%	62.7%	61.4%	70.8%	67.9%
Maximum	99.7%	69.7%	100.4%	70.1%
Mean	8.9%	16.2%	11.3%	19.2%
Standard Deviation	20.1%	20.8%	20.5%	22.6%

4.4 Future Changes in Rainfall Statistics

The percent changes in IDF conditions (relative to the modelled baseline) were estimated for different durations of extreme rainfall events. Selected results for the 50th percentile are summarized in Table 25 and Table 26, with the remaining percentiles for all the duration periods are presented in Appendix B: Additional Future Climate Rainfall Statistics.

The projected changes in the 50th percentile 1-day IDF curves (7.8% to 12.2% in the 2050s and 18.6% to 23.9% in the 2080s; see Table 25 and Table 26) are in line with the projected changes in the 50th percentile 1-day PMP (9.5% in the 2050s and 14% in the 2080s; see Table 24). Also, the increasing of the 50th percentile both for 1-day PMP (see Table 24) and 1-day IDF values (Table 25 and Table 26), indicates that large rainfall events are expected to increase in projected climate. Generally, the longer durations show a smaller percentage increase (compared to the shorter durations) for both the 2050 and 2080 horizons.

Table 25: Summary of the 50th Percentile (median) of Projected Percent Changes in Rainfall in the 2050s

Duration	Return Period (years)						
	2	10	100	200	500	1000	2000
1-Day	12.2%	10.8%	9.5%	8.7%	8.2%	7.9%	7.8%
2-Day	12.1%	11.3%	11.2%	11.0%	11.0%	11.1%	10.8%
3-Day	11.2%	12.8%	13.8%	13.8%	14.0%	14.2%	14.4%
4-Day	12.2%	11.9%	11.7%	12.1%	12.6%	12.7%	12.8%
5-Day	12.3%	12.5%	11.7%	11.2%	10.7%	10.4%	10.0%
6-Day	12.1%	12.7%	11.3%	10.6%	10.1%	9.8%	9.5%
7-Day	11.4%	11.6%	9.8%	9.4%	9.3%	9.3%	9.4%
10-Day	12.2%	11.9%	10.1%	9.9%	9.6%	9.7%	9.4%
20-Day	11.6%	10.4%	8.7%	8.4%	8.3%	8.1%	8.0%
30-Day	12.3%	11.0%	11.0%	10.8%	10.8%	10.1%	9.8%
50-Day	12.2%	13.0%	10.7%	10.3%	10.3%	10.2%	9.9%
75-Day	12.4%	12.0%	12.0%	12.2%	12.1%	11.9%	11.7%
90-Day	12.8%	12.4%	12.9%	12.8%	13.1%	13.0%	12.6%
120-Day	13.3%	13.4%	15.2%	15.4%	15.7%	15.8%	15.9%

Table 26: Summary of the 50th Percentile of Projected Percent Changes in Rainfall in the 2080s

Duration	Return Period (years)						
	2	10	100	200	500	1000	2000
1-Day	18.6%	21.8%	23.9%	23.4%	22.9%	23.0%	23.1%
2-Day	22.1%	27.6%	27.6%	27.7%	28.3%	28.7%	28.7%
3-Day	20.4%	27.7%	29.1%	28.7%	28.5%	28.6%	29.0%
4-Day	19.8%	26.4%	26.9%	26.5%	26.0%	26.3%	26.4%
5-Day	19.9%	24.3%	23.3%	23.7%	24.1%	24.2%	24.3%
6-Day	18.9%	22.8%	22.2%	22.4%	22.6%	22.6%	22.7%
7-Day	18.9%	22.3%	22.0%	21.9%	22.0%	22.2%	22.2%
10-Day	19.4%	21.1%	22.8%	23.2%	23.7%	23.7%	23.8%
20-Day	18.1%	18.6%	19.4%	19.6%	19.7%	19.7%	20.0%
30-Day	18.1%	18.7%	17.1%	16.4%	16.3%	16.3%	16.4%
50-Day	16.8%	15.8%	17.2%	17.5%	17.3%	17.0%	17.3%
75-Day	17.1%	17.9%	18.5%	18.6%	18.8%	18.8%	18.7%
90-Day	16.9%	17.5%	18.1%	18.6%	18.6%	18.4%	18.0%
120-Day	17.2%	18.9%	20.9%	20.8%	20.7%	21.0%	21.4%

4.5 Future Changes in Evapotranspiration Potential

The projected changes of monthly and annual evapotranspiration under baseline conditions (1971-2018) are shown in Table 27. At the 50th percentile, the annual potential evapotranspiration is projected to increase by 9% for the 2050s and 11.1% for the 2080s. The percentage change in the winter months is significant in perceptual amount, however, are low in absolute terms and have low influence in the annual total amount as shown in Table 28.

Table 27: Monthly and Annual Percent Change in Potential Evapotranspiration between the Baseline Period and Future Periods using Hargreaves Formula

Month	50th Percentile Change in Potential Evapotranspiration (%)	
	2050s	2080s
January	100.5%	125.3%
February	58.1%	95.6%
March	34.1%	51.7%
April	14.8%	23.5%
May	10.3%	12.8%
June	6.3%	7.9%
July	5.2%	6.9%
August	6.1%	7.8%
September	7.5%	9.7%
October	11.7%	14.9%
November	38.3%	49.2%
December	83.4%	116.8%
Annual	**9.0%**	**11.1%**

Table 28: Monthly and Annual Historical and Future Projected Potential Evapotranspiration (mm) using Hargreaves Formula

Month	Historical Baseline (GCMs)	50th Percentile Projected	
		2050	2080
January	0.7	1.4	1.6
February	2.4	3.8	4.7
March	11.6	15.5	17.6
April	49.9	57.3	61.7
May	107.2	118.2	120.9
June	143.8	152.9	155.2
July	158.3	166.6	169.2
August	129.8	137.7	139.9
September	73.4	78.9	80.5
October	31.3	34.9	35.9
November	7.9	10.9	11.8
December	1.4	2.5	2.9
Annual	**717.4**	**782.0**	**797.0**

4.6 Future Changes in Extreme Rainfall and Snowmelt Events

The changes of rainfall and snowmelt in the 2050s and 2080s the 50th percentile (compared to the baseline period) are shown in Table 29 and Table 30. The results generally suggest an increase in rainfall plus snowmelt in the future. In general, the projected changes in the future are lower than the changes projected for the rainfall from the IDF-curves (see Table 25 and Table 26), which is caused by lower accumulation of snow on the ground and lower snowmelt as consequence. The projected increase for 1-day, 100-years return period for the 2050s is 0.5%, while the projected increase for the 2080s is 9.6%.

Table 29: Summary of the 50th Percentile of Projected Percent Changes (%) in Rainfall plus Snowmelt in the 2050s

Return Period (Years)	Snowmelt Plus Rainfall (mm)													
	1-day	2-day	3-day	4-day	5-day	6-day	7-day	10-day	20-day	30-day	50-day	75-day	90-day	120-day
2	6.5%	5.6%	6.4%	4.8%	4.0%	2.2%	2.0%	1.2%	1.7%	0.6%	1.4%	3.8%	5.2%	5.8%
10	3.2%	4.7%	4.2%	3.1%	3.2%	2.5%	1.0%	2.4%	3.3%	2.9%	3.8%	5.9%	7.3%	7.4%
100	0.5%	5.6%	3.5%	3.0%	2.5%	1.2%	0.4%	2.3%	2.3%	5.6%	5.2%	6.0%	7.3%	7.6%
200	0.7%	4.8%	3.3%	2.8%	2.9%	1.5%	0.2%	2.1%	3.0%	6.0%	5.4%	6.3%	7.3%	7.4%
500	0.2%	4.3%	3.2%	2.7%	3.4%	1.6%	0.0%	2.3%	3.3%	6.3%	5.8%	6.6%	7.9%	7.4%
1000	-0.2%	3.9%	3.1%	2.8%	3.3%	1.6%	0.2%	2.2%	3.5%	6.7%	6.0%	6.8%	8.3%	7.4%
2000	-0.5%	3.4%	3.0%	2.8%	3.1%	1.7%	0.1%	2.3%	3.5%	7.0%	6.3%	6.9%	8.6%	7.5%

Table 30: Summary of the 50th Percentile of Projected Changes (%) in Rainfall plus Snowmelt in the 2080s

Return Period (Years)	Snowmelt Plus Rainfall (mm)													
	1-day	2-day	3-day	4-day	5-day	6-day	7-day	10-day	20-day	30-day	50-day	75-day	90-day	120-day
2	9.2%	8.1%	7.2%	5.6%	4.9%	4.5%	3.9%	3.7%	2.5%	0.6%	3.5%	4.4%	5.9%	6.9%
10	10.2%	8.4%	6.7%	6.3%	5.9%	5.7%	5.3%	3.9%	3.7%	3.2%	4.7%	7.3%	8.4%	9.0%
100	9.6%	8.9%	6.5%	5.6%	5.8%	4.5%	4.3%	3.7%	4.2%	6.0%	7.7%	9.7%	9.8%	10.1%
200	10.0%	8.9%	6.6%	5.7%	5.8%	4.9%	4.1%	3.3%	4.9%	6.3%	8.1%	9.7%	9.7%	10.4%
500	10.5%	8.7%	6.5%	6.0%	6.2%	4.9%	4.1%	3.6%	5.0%	6.4%	8.8%	9.8%	10.0%	10.7%
1000	10.6%	8.4%	6.1%	6.4%	6.4%	5.0%	4.3%	3.8%	5.4%	7.4%	9.5%	10.4%	10.3%	10.7%
2000	10.9%	8.2%	5.8%	6.8%	6.7%	5.4%	4.4%	4.0%	5.8%	7.7%	9.7%	10.9%	10.5%	10.9%

Projected changes in the 1-day annual maximum snowpack for the 2050s and 2080s are shown in Table 31 and Table 32. In the 2050s, the percentage changes are increasing with the return period, ranging from 1% for the 2-year event, and 5% for the 2000-year event at the 50th percentile. The range in projections and standard deviation also increase with return period. This suggests that the largest changes and highest uncertainty in snowpack will be for extreme events. In the 2080s, the percentage changes show decreases in snowpack for all return periods ranging from -48% to -11% at the 50th percentile. This indicates that snowpack will be greatly reduced by the end of the century, likely due to increased temperatures leading to more melting and less snowfall. The variation across return periods is similar to the 2050s with the exception of 30% increase shown for the maximum percentage change of the 2-year event. This percentage change of 30% is an outlier in the multi-model ensemble, as the 17% change at the 99th percentile for the 2-year event is considerably lower.

Table 31: Projected Changes in Annual Maximum Snowpack for the 2050s (%)

Return Period (Years)	Percentile										
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-13%	-11%	-8%	**1%**	6%	9%	13%	17%	19%	1%	7%
5	-11%	-9%	-7%	**3%**	6%	11%	14%	20%	23%	2%	7%
10	-11%	-9%	-6%	**3%**	7%	12%	15%	22%	25%	3%	7%
25	-12%	-9%	-6%	**4%**	8%	12%	17%	23%	26%	4%	8%
50	-12%	-9%	-7%	**5%**	10%	13%	19%	25%	27%	4%	9%
100	-13%	-10%	-8%	**5%**	11%	14%	20%	26%	28%	5%	9%
200	-14%	-10%	-8%	**5%**	11%	16%	21%	27%	29%	5%	9%
500	-15%	-11%	-9%	**5%**	12%	17%	22%	28%	30%	5%	10%
1000	-16%	-11%	-9%	**5%**	13%	18%	23%	29%	31%	5%	10%
2000	-16%	-12%	-9%	**5%**	14%	18%	24%	30%	31%	6%	11%

Table 32: Projected Changes in Annual Maximum Snowpack for the 2080s (%)

Return Period (Years)	Percentile										
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-43%	-14%	-12%	**1%**	6%	11%	13%	18%	19%	0%	10%
5	-40%	-10%	-8%	**1%**	7%	13%	15%	22%	29%	2%	9%
10	-39%	-9%	-7%	**3%**	8%	14%	16%	24%	35%	3%	10%
25	-38%	-9%	-6%	**4%**	9%	15%	18%	27%	40%	3%	10%
50	-37%	-9%	-7%	**5%**	11%	15%	20%	30%	45%	4%	11%
100	-36%	-10%	-7%	**5%**	12%	16%	20%	33%	48%	5%	12%
200	-36%	-10%	-7%	**6%**	13%	18%	21%	34%	51%	5%	12%
500	-35%	-11%	-8%	**7%**	14%	20%	22%	36%	55%	6%	13%
1000	-35%	-11%	-8%	**7%**	14%	20%	23%	38%	57%	6%	13%
2000	-34%	-12%	-8%	**7%**	15%	22%	25%	39%	59%	6%	14%

4.7 Future Changes in Precipitation Over the Spring Transition

Precipitation projections shown in Section 4.1.2 have been re-evaluated here to capture the seasonal transition from winter to summer months. As this requires packaging the available daily projections into smaller groups, outliers within each group may have a larger influence, changing both the distributions and the uncertainty compared to longer time periods (e.g., weeks compared to months). This has been done through the separation of precipitation into rainfall and snowfall, and calculation of IDF, snowpack, and snowmelt statistics for a set of spring periods to illustrate this transition. The spring periods correspond to the analysis conduced in Section 3.8 as follows:

- March 19th to March 31st (Spring Period 1);
- April 1st to April 15th (Spring Period 2);
- April 16th to April 30th (Spring Period 3);
- May 1st to May 15th (Spring Period 4); and
- May 16th to May 31st (Spring Period 5).

4.7.1 Future Changes in Rain and Snow During the Spring Transition

The projected future changes in rainfall amounts for the 2050s and 2080s from the baseline period (1971 through 2018) are shown in Table 33 and Table 34. Projected changes in rain and snow are shown for only for months that have rain and snow amounts greater than 0.

For the 2050s, the annual percentage changes in rainfall have a range of 4% to 36%, with a change of 18% for the 50th percentile. The total monthly values have a larger range from -100% to 1421% across all projections and a range of -24% to 96% for the 50th percentile. The largest increase occurs during the month of November. The reason for this may be due to a combination of increased temperatures which cause snowfall to become rain, as well as increased total precipitation for the month shown previously in Figure 25 and Figure 26. During the spring transition period there is a high degree of variability for projected changes in rainfall for the 2050s, with an increase of 119% for the early spring (period 1) and decreased rainfall for all other spring periods ranging from -51% to -100%.

For the 2080s, the range in annual percentage changes are from -2% to 79% with a change of 23% for the 50th percentile. Monthly percentage changes in rainfall range from -100% to 6685% (see discussion below on high percentage changes) with the greatest change of 167% for the month of February at the 50th percentile. During the spring, an overall decrease in rainfall is projected, ranging from -29% to -95% at the 50th percentile. Compared to the 2050s, there is a larger range in projections for annual and monthly rainfall amounts with greater projected changes at the 50th percentile. However, in the spring transition periods there is less rainfall in the early and late spring periods, and more rainfall in the mid spring periods for the 2080s. This may indicate a shift in the rainfall patterns from the mid to end of century.

For both the 2050s and 2080s very high percentage changes in total monthly rainfall are projected for November through April. This is because there are typically very low amounts of rainfall during these months due to lower temperatures causing precipitation to fall as snow (see Section 3.8.1). Therefore, the large percentage changes are caused by relatively small absolute changes in rainfall. For example, the maximum percentage change in rainfall for the month of March in the 2080s is 6685%. Given that the current climate normal for rainfall is 0.2 mm in the month of March (Table 15), this translates to an absolute increase of 13.7 mm. In some months or spring periods there are cases where the percentage change is the same for all percentiles. This is due to only one ensemble member being present that has values for rainfall or snowfall in a given month or spring period. For this same reason, the standard deviation cannot be calculated for certain months and spring periods. It should also be noted that the monthly projected changes cannot simply be compared to the projected changes for the spring periods (e.g., comparing April to Period 2 and 3). The modelled baseline from which the projections are measured for the months and the period are different not only in absolute value but also in the number and distribution of datapoints considered, making any comparison difficult. For example, the modelled baseline in April is comparable to the modelled baseline of Period 2, but an order of magnitude lower than the modelled baseline for Period 3. As the percent change is measured relative to the baseline, this can lead to differing trends that may be resolved when the absolute amounts are considered.

Table 33: Projected Changes in Rainfall for Monthly, Annual, and Spring Transition Periods in the 2050s (%).

Period	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	—	—	—	—	—	—	—	—	—	—	—
February	-100%	-100%	-99%	-24%	101%	138%	183%	242%	256%	11%	115%
March [(a)]	-99%	-78%	-62%	71%	249%	691%	913%	1404%	1421%	190%	341%
April [(a)]	-33%	-14%	-2%	46%	74%	96%	126%	180%	214%	49%	46%
May	-16%	-7%	-2%	17%	36%	49%	55%	70%	76%	21%	20%
June	-26%	-17%	-12%	5%	15%	33%	39%	54%	55%	8%	18%
July	-20%	-10%	-7%	9%	20%	37%	47%	56%	57%	11%	17%
August	-17%	-12%	-10%	8%	18%	23%	27%	38%	45%	8%	13%
September	-11%	-6%	-1%	14%	23%	30%	33%	36%	38%	14%	12%
October	-2%	21%	31%	62%	84%	100%	107%	128%	131%	63%	30%
November [(a)]	-33%	-14%	-5%	96%	209%	348%	518%	688%	746%	145%	168%
December	—	—	—	—	—	—	—	—	—	—	—
Annual	4%	8%	10%	18%	24%	27%	33%	35%	36%	19%	8%
Period 1	119%	119%	119%	119%	119%	119%	119%	119%	119%	119%	—[(b)]
Period 2	-100%	-97%	-92%	-56%	-19%	34%	82%	179%	216%	-38%	60%
Period 3	-100%	-100%	-100%	-100%	-33%	7%	20%	31%	33%	-56%	77%
Period 4	-63%	-55%	-51%	-28%	-4%	24%	37%	49%	53%	-21%	29%
Period 5	-100%	-100%	-100%	-84%	2%	146%	195%	389%	500%	-23%	122%

Note:

(a) Indicates months with potential for high percentage changes due to change in small absolute values.

(b) No standard deviation as only one value is available.

Table 34: Projected Changes in Rainfall for Monthly, Annual, and Spring Transition Periods in the 2080s (%).

Period	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	—	—	—	—	—	—	—	—	—	—	—
February [(a)]	-100%	-100%	-100%	167%	536%	692%	802%	892%	914%	271%	328%
March [(a)]	-70%	-62%	-50%	111%	341%	810%	1339%	3739%	6685%	363%	897%
April [(a)]	-29%	-13%	5%	79%	119%	190%	221%	263%	287%	83%	71%
May	-26%	-10%	-3%	26%	47%	59%	84%	157%	176%	31%	34%
June	-15%	-13%	-4%	13%	24%	38%	43%	92%	98%	16%	21%
July	-23%	-15%	-9%	14%	22%	32%	54%	92%	92%	14%	22%
August	-17%	-10%	-8%	11%	20%	30%	34%	49%	64%	12%	15%
September	-10%	-5%	1%	19%	27%	37%	43%	53%	58%	18%	15%
October	-10%	17%	25%	75%	108%	138%	149%	168%	170%	79%	42%
November [(a)]	-43%	6%	23%	127%	305%	547%	869%	1967%	3299%	274%	447%
December	—	—	—	—	—	—	—	—	—	—	—
Annual	-2%	6%	8%	23%	33%	49%	55%	64%	79%	25%	16%
Period 1	-52%	-52%	-52%	-52%	-52%	-52%	-52%	-52%	-52%	-52%	—[(b)]
Period 2	-92%	-89%	-85%	-51%	-16%	25%	38%	119%	167%	-37%	48%
Period 3	-100%	-93%	-86%	-30%	6%	27%	34%	40%	41%	-30%	100%
Period 4	-83%	-69%	-58%	-29%	-4%	30%	47%	51%	55%	-21%	33%
Period 5	-100%	-100%	-100%	-95%	-43%	36%	92%	270%	355%	-55%	83%

Note:

(a) Indicates months with potential for high percentage changes due to change in small absolute values.

(b) No standard deviation as only one value was available.

The projected future changes in snowfall amounts for the 2050s and 2080s from the baseline period (1971 through 2018) are shown in Table 35 and Table 36. The months of June to August are not included, as precipitation only falls as rain during these months. For the 2050s, annual snowfall is projected to increase by 2%, with the largest increase for the month of January at 20%, both at the 50th percentile. This is likely due to increased precipitation amounts with climate change, while temperatures are low enough for precipitation to fall as snow. Decreasing snowfall is found for the months of April to October, with the largest decrease occurring in September at -43%. During the spring transition periods, changes in snowfall are smallest for the early spring periods, while there is an 18% increase in snow for period 3 (April 16th to April 30th). Spring periods 4 and 5 are typically rainfall therefore the percentage changes will result in relatively minor absolute changes in snowfall.

In the 2080s, the projected change in snowfall remains at 2% annually, however the increase in January snowfall from the baseline is slightly lower than the 2050s at 19%, while the months of February and March show changes of 16% and 13%, compared to 11% and 9% in the 2050s. This indicates a small shift in precipitation patterns during the winter months with greater snowfall in February and March. During the spring transition, more snowfall is projected for period 3 compared to the 2050s with a 79% increase from current climate.

Table 35: Projected Changes in Snowfall for Monthly, Annual, and Spring Transition Periods in the 2050s (%).

Period	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	-12%	-3%	1%	20%	26%	31%	33%	38%	41%	18%	11%
February	-20%	-8%	-6%	11%	20%	28%	31%	44%	52%	11%	14%
March	-17%	-9%	-5%	9%	22%	29%	34%	42%	43%	11%	14%
April	-33%	-32%	-27%	-4%	15%	22%	32%	41%	46%	-3%	21%
May[(a)]	-79%	-65%	-61%	-27%	-6%	13%	28%	92%	129%	-22%	34%
June	—	—	—	—	—	—	—	—	—	—	—
July	—	—	—	—	—	—	—	—	—	—	—
August	—	—	—	—	—	—	—	—	—	—	—
September[(a)]	-100%	-100%	-95%	-43%	3%	59%	102%	135%	151%	-28%	63%
October[(a)]	-81%	-67%	-62%	-37%	-23%	-7%	-3%	3%	8%	-36%	20%
November	-31%	-19%	-12%	1%	11%	21%	25%	31%	32%	3%	14%
December	-7%	-4%	-1%	13%	24%	35%	37%	42%	44%	14%	13%
Annual	-9%	-6%	-5%	2%	5%	9%	11%	13%	15%	2%	5%
Period 1	-76%	-69%	-61%	-8%	35%	75%	89%	100%	103%	3%	76%
Period 2	-44%	-31%	-27%	1%	12%	26%	33%	42%	46%	-1%	21%
Period 3	18%	18%	18%	18%	18%	18%	18%	18%	18%	18%	—[(b)]
Period 4	-100%	-100%	-98%	-32%	-3%	105%	128%	213%	235%	-22%	77%
Period 5	-20%	-19%	-18%	-10%	-5%	-2%	-1%	0%	0%	-10%	14%

Note:

(a) Indicates months with potential for high percentage changes due to change in small absolute values.

(b) No standard deviation as only one value was available.

Table 36: Projected Changes in Snowfall for Monthly, Annual, and Spring Transition Periods in the 2080s (%)

Period	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
January	-2%	3%	8%	19%	29%	39%	46%	54%	61%	21%	13%
February	-12%	-6%	-4%	16%	26%	38%	41%	69%	76%	17%	17%
March	-23%	-18%	-9%	13%	25%	34%	45%	57%	58%	14%	18%
April	-65%	-47%	-41%	-12%	5%	23%	29%	47%	58%	-10%	24%
May[(a)]	-100%	-80%	-74%	-35%	-5%	20%	34%	80%	94%	-30%	39%
June	—	—	—	—	—	—	—	—	—	—	—
July	—	—	—	—	—	—	—	—	—	—	—
August	—	—	—	—	—	—	—	—	—	—	—
September[(a)]	-100%	-93%	-85%	-35%	-5%	41%	115%	185%	191%	-21%	66%
October[(a)]	-96%	-85%	-80%	-49%	-30%	-13%	8%	15%	16%	-46%	27%
November	-54%	-34%	-20%	-2%	9%	15%	19%	33%	34%	-1%	16%
December	-10%	2%	3%	16%	27%	42%	47%	62%	63%	19%	15%
Annual	-14%	-9%	-6%	2%	6%	10%	12%	16%	19%	2%	7%
Period 1	-59%	-9%	0%	0%	63%	90%	111%	174%	190%	28%	57%
Period 2	-63%	-35%	-25%	-3%	10%	22%	31%	44%	50%	-3%	20%
Period 3	79%	79%	79%	79%	79%	79%	79%	79%	79%	79%	—[(b)]
Period 4	-100%	-96%	-93%	-50%	-20%	63%	104%	297%	470%	-27%	89%
Period 5	121%	121%	121%	121%	121%	121%	121%	121%	121%	121%	—[(b)]

Note:

(a) Indicates months with potential for high percentage changes due to change in small absolute values.

(b) No standard deviation as only one value was available.

4.7.2 Future Changes in Spring Precipitation Statistics (IDF)

Projected changes in extreme precipitation statistics of 1-day duration were calculated separately for the spring period. The 1-day spring IDF curves for the 2050s and 2080s from the baseline period (1971 through 2018) are shown in Table 37 and Table 38. The range of projected changes is 4.0% to 13.3% in the 2050s and 19.5% to 22.4% in the 2080s. In both time periods there are projected increases in spring precipitation across return periods, with largest percentage changes for more frequent events. This indicates that the spring transition period will become wetter overall with moderate increase in extreme events.

Table 37: Projected Changes in Spring IDF Statistics for the 2050s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	25%	50%	75%	90%	95%	Maximum	Std. Dev.
2	-9.8%	-4.6%	-1.9%	6.9%	**13.3%**	25.3%	32.6%	35.4%	43.9%	12.8%
5	-18.5%	-12.4%	-9.4%	-1.7%	**10.1%**	20.5%	36.5%	46.0%	57.2%	18.0%
10	-24.1%	-14.9%	-12.3%	-3.7%	**9.3%**	22.6%	39.7%	51.8%	66.5%	20.6%
25	-27.5%	-17.3%	-13.9%	-5.6%	**7.8%**	24.3%	39.4%	56.0%	72.7%	22.4%
50	-30.3%	-20.1%	-15.4%	-7.1%	**6.5%**	23.2%	40.2%	60.0%	78.5%	24.1%
100	-31.7%	-21.6%	-16.2%	-7.9%	**5.8%**	22.4%	41.3%	62.2%	81.7%	25.1%
200	-32.8%	-22.8%	-17.1%	-8.5%	**5.4%**	21.8%	42.3%	63.9%	84.3%	25.9%
500	-34.0%	-24.0%	-18.1%	-9.1%	**4.7%**	21.1%	43.2%	65.8%	87.1%	26.7%
1000	-34.6%	-24.7%	-18.7%	-9.5%	**4.3%**	20.9%	43.8%	66.9%	88.8%	27.2%
2000	-35.2%	-25.4%	-19.2%	-9.9%	**4.0%**	21.2%	44.4%	67.9%	90.3%	27.6%

Table 38: Projected Changes in Spring IDF Statistics for the 2080s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	25%	50%	75%	90%	95%	Maximum	Std. Dev.
2	-11.4%	-5.0%	-0.1%	11.7%	**22.4%**	37.1%	48.8%	59.3%	71.0%	18.8%
5	-23.0%	-12.2%	-10.1%	4.2%	**23.4%**	35.9%	55.6%	63.8%	106.5%	25.0%
10	-26.9%	-15.6%	-13.9%	2.1%	**24.1%**	36.3%	57.7%	66.0%	131.2%	28.3%
25	-29.4%	-18.0%	-15.5%	0.8%	**23.3%**	37.5%	58.0%	68.1%	147.2%	30.5%
50	-31.6%	-20.2%	-17.3%	-0.7%	**21.7%**	36.3%	59.3%	71.4%	161.5%	32.6%
100	-32.8%	-21.4%	-18.2%	-2.0%	**20.9%**	36.9%	60.1%	73.4%	169.5%	33.8%
200	-33.8%	-22.3%	-18.8%	-3.0%	**20.6%**	37.7%	60.8%	74.9%	175.7%	34.7%
500	-34.8%	-23.2%	-19.5%	-4.0%	**20.5%**	38.8%	61.3%	76.6%	182.3%	35.7%
1000	-35.4%	-23.7%	-20.0%	-4.6%	**19.9%**	38.3%	61.6%	77.6%	186.3%	36.3%
2000	-35.9%	-24.2%	-20.4%	-5.1%	**19.5%**	38.6%	61.9%	78.5%	189.7%	36.8%

4.7.3 Future Changes in Snowpack Over the Spring Transition Period

The projected changes in snowpack during the spring transition periods highlight the effect of climate change on spring melt. The percentage changes for the 2050s for each spring period are shown in Table 39 through Table 43. Spring periods 1 to 3 (mid March to end of April) show the greatest percentage changes in snowpack. During these periods the changes are increasing with return period and a larger range in the changes is shown moving from the earlier to later periods. At the 50th percentile the percentage changes in snowpack range from 2% to 7%, 0% to 8%, and -10% to 13% for spring periods 1 through 3 at the 50th percentile. Spring periods 4 and 5 (early to late May) show decreasing snowpack for all return periods ranging from -31% to -6% (early May) and -76% to -41% (late May). The largest decreases are for more frequent events (lower return period). These results suggest that in spring more snowpack is to be expected in a shorter period of time, with greater extreme events

In the 2080s the same patterns are found across return periods and the spring transition periods as the 2050s, however the magnitude of the changes in snowpack are different. For spring periods 1 to 3 (mid March to end of April) the range in percentage changes across return periods are greater. In spring periods 4 and 5 (early to late May) there is a larger projected decrease in snowpack. For all periods the range in projections from the multi-model ensemble is larger, indicating a higher degree of uncertainty for snowpack projections in the 2080s versus the 2050s.

Table 39: Projected Changes in Snowpack During Spring Period 1 (March 19th to 31st) in the 2050s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-16%	-12%	-7%	**2%**	6%	10%	13%	19%	19%	2%	7%
5	-11%	-9%	-7%	**4%**	8%	11%	15%	23%	25%	3%	7%
10	-11%	-8%	-6%	**5%**	9%	12%	16%	25%	28%	4%	8%
25	-12%	-8%	-6%	**5%**	9%	14%	18%	26%	30%	4%	9%
50	-13%	-8%	-8%	**6%**	10%	16%	20%	29%	32%	5%	9%
100	-14%	-10%	-8%	**6%**	11%	17%	22%	31%	34%	5%	10%
200	-15%	-11%	-8%	**6%**	12%	18%	23%	32%	35%	6%	11%
500	-15%	-11%	-9%	**6%**	13%	19%	24%	34%	37%	6%	11%
1000	-16%	-11%	-10%	**7%**	14%	20%	25%	35%	38%	6%	12%
2000	-16%	-12%	-10%	**7%**	15%	21%	26%	36%	39%	7%	12%

Table 40: Projected Changes in Snowpack During the Spring Period 2 (April 1st to 15th) in the 2050s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-31%	-16%	-10%	**0%**	5%	10%	13%	16%	16%	0%	9%
5	-19%	-10%	-7%	**3%**	7%	11%	15%	22%	23%	3%	8%
10	-13%	-9%	-6%	**4%**	9%	14%	18%	25%	27%	4%	8%
25	-11%	-8%	-6%	**5%**	11%	15%	22%	28%	29%	5%	9%
50	-13%	-8%	-6%	**6%**	13%	21%	24%	31%	32%	7%	10%
100	-14%	-8%	-6%	**7%**	15%	23%	26%	33%	34%	8%	11%
200	-15%	-9%	-7%	**7%**	16%	26%	29%	35%	36%	8%	12%
500	-17%	-10%	-6%	**7%**	18%	27%	32%	38%	39%	9%	13%
1000	-18%	-11%	-6%	**8%**	18%	28%	34%	40%	41%	10%	13%
2000	-18%	-12%	-6%	**8%**	19%	29%	35%	43%	43%	10%	14%

Table 41: Projected Changes in Snowpack During the Spring Period 3 (April 16th to 30th) in the 2050s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-49%	-32%	-26%	**-10%**	-2%	4%	6%	8%	10%	-11%	12%
5	-31%	-18%	-15%	**-1%**	4%	7%	11%	14%	16%	-2%	9%
10	-23%	-12%	-10%	**2%**	7%	9%	17%	19%	21%	2%	9%
25	-18%	-10%	-8%	**6%**	10%	14%	21%	24%	25%	4%	9%
50	-16%	-9%	-6%	**7%**	13%	19%	25%	29%	31%	7%	10%
100	-17%	-8%	-5%	**8%**	15%	22%	28%	31%	35%	9%	10%
200	-17%	-7%	-4%	**9%**	16%	25%	31%	34%	39%	10%	11%
500	-18%	-6%	-3%	**11%**	19%	28%	33%	38%	42%	12%	12%
1000	-19%	-5%	-2%	**12%**	21%	30%	35%	41%	44%	13%	12%
2000	-19%	-4%	-2%	**13%**	22%	32%	36%	43%	46%	14%	13%

Table 42: Projected Changes in Snowpack During the Spring Period 4 (May 1st to 15th) in the 2050s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-91%	-76%	-61%	**-31%**	-15%	-10%	-7%	6%	10%	-33%	22%
5	-67%	-58%	-46%	**-16%**	-7%	0%	1%	11%	11%	-19%	18%
10	-62%	-54%	-41%	**-12%**	-3%	3%	6%	13%	16%	-16%	18%
25	-58%	-52%	-38%	**-10%**	0%	5%	10%	15%	19%	-14%	18%
50	-56%	-50%	-35%	**-9%**	2%	6%	13%	16%	21%	-12%	18%
100	-55%	-48%	-34%	**-8%**	2%	7%	14%	17%	23%	-11%	18%
200	-54%	-47%	-33%	**-7%**	3%	9%	15%	18%	24%	-10%	18%
500	-53%	-47%	-33%	**-7%**	3%	10%	16%	20%	25%	-9%	18%
1000	-53%	-46%	-32%	**-7%**	3%	10%	16%	20%	25%	-9%	18%
2000	-52%	-46%	-32%	**-6%**	3%	11%	16%	21%	26%	-8%	18%

Table 43: Projected Changes in Snowpack During the Spring Period 5 (May 16th to 31st) in the 2050s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-100%	-100%	-100%	**-76%**	-57%	-5%	21%	57%	58%	-64%	40%
5	-100%	-100%	-98%	**-50%**	-25%	-2%	12%	27%	34%	-48%	36%
10	-100%	-100%	-98%	**-47%**	-21%	0%	11%	26%	33%	-46%	36%
25	-100%	-100%	-98%	**-46%**	-18%	3%	10%	25%	33%	-45%	37%
50	-100%	-100%	-98%	**-44%**	-16%	3%	10%	26%	32%	-45%	37%
100	-100%	-100%	-98%	**-43%**	-15%	5%	10%	27%	32%	-44%	37%
200	-100%	-100%	-98%	**-42%**	-15%	6%	10%	27%	32%	-44%	37%
500	-100%	-100%	-98%	**-42%**	-14%	6%	10%	27%	32%	-44%	37%
1000	-100%	-100%	-98%	**-42%**	-14%	7%	10%	27%	32%	-44%	37%
2000	-100%	-100%	-98%	**-41%**	-14%	7%	10%	27%	32%	-43%	37%

Table 44: Projected Changes in Snowpack During the Spring Period 1 of (March 19th to 31st) in the 2080s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-64%	-16%	-12%	**2%**	7%	14%	14%	20%	21%	0%	12%
5	-52%	-10%	-7%	**2%**	8%	13%	17%	26%	35%	3%	11%
10	-46%	-6%	-6%	**3%**	9%	15%	19%	29%	42%	4%	11%
25	-41%	-6%	-4%	**4%**	10%	17%	21%	31%	48%	5%	11%
50	-36%	-7%	-5%	**6%**	11%	18%	23%	34%	55%	6%	12%
100	-33%	-7%	-5%	**7%**	13%	21%	25%	36%	59%	7%	12%
200	-31%	-7%	-6%	**8%**	14%	23%	26%	38%	63%	8%	13%
500	-28%	-8%	-7%	**8%**	15%	24%	28%	40%	67%	8%	13%
1000	-26%	-8%	-7%	**8%**	15%	24%	30%	42%	69%	9%	14%
2000	-24%	-8%	-7%	**9%**	16%	26%	31%	44%	72%	9%	14%

Table 45: Projected Changes in Snowpack During the Spring Period 2 (April 1st to 15th) in the 2080s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-85%	-28%	-22%	**-1%**	6%	11%	13%	15%	15%	-4%	15%
5	-73%	-14%	-9%	**1%**	8%	12%	16%	25%	32%	1%	13%
10	-66%	-9%	-5%	**5%**	10%	15%	19%	30%	41%	4%	12%
25	-61%	-8%	-3%	**6%**	13%	18%	21%	34%	49%	6%	13%
50	-56%	-8%	-3%	**8%**	15%	23%	25%	38%	57%	8%	13%
100	-53%	-8%	-4%	**9%**	17%	26%	29%	41%	61%	10%	14%
200	-50%	-8%	-4%	**11%**	18%	29%	32%	46%	66%	11%	15%
500	-47%	-8%	-5%	**12%**	21%	32%	35%	51%	71%	12%	16%
1000	-45%	-8%	-5%	**13%**	22%	34%	37%	55%	74%	13%	17%
2000	-43%	-8%	-5%	**14%**	23%	36%	39%	59%	77%	14%	18%

Table 46: Projected Changes in Snowpack During the Spring Period 3 (April 16th to 30th) in the 2080s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-94%	-63%	-50%	**-17%**	-3%	5%	11%	12%	13%	-20%	22%
5	-85%	-38%	-27%	**-5%**	4%	9%	10%	13%	17%	-7%	17%
10	-81%	-27%	-18%	**1%**	8%	13%	14%	20%	20%	-2%	15%
25	-78%	-19%	-13%	**4%**	11%	17%	22%	26%	27%	2%	15%
50	-75%	-16%	-8%	**8%**	16%	24%	28%	35%	37%	6%	16%
100	-73%	-15%	-8%	**10%**	19%	25%	32%	41%	44%	9%	17%
200	-71%	-13%	-7%	**12%**	20%	30%	36%	45%	50%	11%	17%
500	-70%	-13%	-7%	**14%**	23%	33%	40%	50%	57%	13%	18%
1000	-69%	-13%	-5%	**15%**	26%	37%	43%	54%	62%	15%	19%
2000	-68%	-12%	-5%	**16%**	27%	40%	45%	57%	66%	16%	20%

Table 47: Projected Changes in Snowpack During the Spring Period 4 (May 1st to 15th) in the 2080s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-100%	-93%	-90%	**-48%**	-16%	-2%	4%	17%	30%	-46%	33%
5	-100%	-80%	-73%	**-27%**	-8%	3%	9%	18%	18%	-30%	28%
10	-100%	-77%	-68%	**-21%**	-6%	5%	12%	17%	20%	-26%	28%
25	-100%	-76%	-66%	**-18%**	-2%	6%	14%	17%	21%	-24%	27%
50	-100%	-75%	-63%	**-16%**	-2%	7%	16%	19%	22%	-22%	27%
100	-100%	-74%	-62%	**-15%**	-1%	7%	17%	20%	22%	-21%	27%
200	-100%	-73%	-61%	**-13%**	0%	8%	18%	21%	23%	-20%	27%
500	-100%	-73%	-60%	**-12%**	0%	8%	18%	22%	23%	-19%	27%
1000	-100%	-72%	-60%	**-11%**	0%	8%	18%	23%	23%	-18%	27%
2000	-100%	-72%	-59%	**-11%**	1%	8%	19%	23%	23%	-18%	27%

Table 48: Projected Changes in Snowpack During the Spring Period 5 (May 16th to 31st) in the 2080s (%)

Return Period (Years)	Percentile									
	Minimum	5%	10%	50%	75%	90%	95%	99%	Maximum	Mean	Std. Dev.
2	-100%	-100%	-100%	**-84%**	-67%	-32%	-8%	7%	21%	-75%	29%
5	-100%	-100%	-100%	**-62%**	-37%	-16%	-3%	9%	11%	-61%	32%
10	-100%	-100%	-100%	**-60%**	-32%	-16%	-3%	12%	16%	-60%	33%
25	-100%	-100%	-100%	**-59%**	-29%	-15%	-3%	14%	19%	-59%	34%
50	-100%	-100%	-100%	**-58%**	-28%	-15%	-3%	15%	21%	-58%	34%
100	-100%	-100%	-100%	**-58%**	-27%	-14%	-3%	16%	21%	-58%	34%
200	-100%	-100%	-100%	**-58%**	-27%	-14%	-2%	16%	22%	-58%	34%
500	-100%	-100%	-100%	**-58%**	-26%	-14%	-2%	16%	23%	-58%	34%
1000	-100%	-100%	-100%	**-58%**	-26%	-14%	-2%	17%	23%	-57%	34%
2000	-100%	-100%	-100%	**-58%**	-26%	-14%	-2%	17%	23%	-57%	34%

5.0 COMPARISON TO PREVIOUS STUDY

The previous Climate Change Review completed for the Freeze Design by AECOM and Newmans Geotechnique (2018) (Appendix C: Design Basis Report), was completed to support the advanced design of freeze areas AR1 and AR2, which included a review of the current climate change documentation and its impacts to the project. The study reviewed findings from both the Developer's Assessment Report (DAR) (INAC and GNWT 2010) and the Freeze Program Design Basis Report (DBR) (SRK 2016), and compared results to the latest climate projection scenarios from the IPCC, Canadian Climate Centre for Climate Modelling and Analysis (CCCma), and the Scenarios Network for Alaska and Arctic Planning (SNAP).

Table 49 presents the results of both the DAR and DBR reports. The DAR references the IPCC's Third and Fourth Assessment Reports (AR3 and AR4) (IPCC 2001; IPCC 2007). The annual mean change in air temperature around Yellowknife was projected to be 3°C based on IPCC's AR3. This value was later revised once IPCC's AR4 was released, to a projected increase by 3.3°C. The difference between the projected air temperatures was found to still be within the error bands of inputs to the thermal modelling, therefore further detailed thermal modelling was not necessary. A simplified thermal model was developed to include temperature increases in the "current", "best estimate" and "worst estimate" scenarios using climate projections in AR4. The DBR was based on IPCC's AR4, and formed a design basis for the advanced design of the ground freezing program, applying a maximum change in mean annual air temperature of 6.1°C to all freeze pipe layout variants based on historical modelling files (SRK 2016). The review did not include the specific emission scenarios, number of models or time periods used for either the DAR or DBR.

Table 49: Results from previous studies including the DAR and DBR

Change in Air Temperature (°C)	Developer's Assessment Report (DAR)[a]	Freeze Program Design Basis Report (DBR)[b]
Winter Temperature	5.4 - 9.6	—
Summer Temperature	1.2 - 2.1	—
Annual Temperature	-4.5 (Current Climate) -1.2 (ΔT = 3.3) - 1.35 (ΔT = 5.85)	6.1

Notes:

(a) Change in air temperature from the best estimate to the worst-case scenarios.

(b) Maximum change in air temperature considered to occur over 100 to 200 years.

The updated report by AECOM and Newmans Geotechnique (2018) used the most up to date AR5 scenarios and provided the projected annual global mean temperatures using a baseline between 1986 to 2005 for each RCP scenario (RCP 2.6, 4.5, 6.0, 8.5) during two time horizons (2016 to 2035 and 2081 to 2100). The study projected a change in mean annual air temperature between 2.6°C to 4.8°C by 2100.

The report included detailed temperature projections for the Northwest Territories taken from the CCCma (2015) report 'Climate data and scenarios for Canada: Synthesis of recent observations and modelling results'. The projected surface air temperature for each RCP scenario (RCP 2.6, 4.5, 6.0, 8.5) during two time horizons (2016 to 2035 and 2081 to 2100) was included. The increase in temperature during the winter months was anticipated to be approximately double that of the summer months to conservatively represent Yellowknife.

Lastly, the study referenced a tool developed by SNAP that provides model outputs that form the basis for AR5 for RCP 2.6, 4.5 and 8.5 scenarios, from five GCMs. The tool includes temperature and precipitation projections for Yellowknife and found that monthly mean temperature is projected to increase by 8.4°C in the winter and 3.9°C in the summer, with an overall increase in the mean temperature by 6.2°C over a 90 year period.

Table 50 provides a summary of the results found in both the AECOM and Newmans Geotechnique (2018) report and this assessment. Future climate projections presented in Section 4.0 of this assessment have been found to be consistent with the trends presented in the AECOM and Newmans Geotechnique (2018) study. However, values differ slightly because of differing methodologies used, including the current climate baseline, number of climate models, and different time horizons.

As outlined in the Future Climate Methodology (Section 2.2), this assessment is based on the most up to date climate science research from AR5 and was expanded to include precipitation. Following general best practice, a multi-model ensemble approach was used to reduce uncertainty and bias associated with individual climate models.

This assessment used RCP scenarios 2.6, 4.5, and 8.5, consistent with recommendations made by the IPCC (IPCC 2013). The previous report used all RCP scenarios (including RCP 6.0), however, the comparison in Table 50 only focuses on RCP 2.5, 4.5 and 8.5 to be consistent. The climate baseline used in this assessment was extended to include the most recent years of observations (1971 to 2018), while the climate baseline in the previous report used a less current baseline (1986 to 2005). This assessment provides future projections on both a monthly, seasonal and annual basis for two time horizons 2050s (2041 – 2070) and the 2080s (2071 – 2100). The comparison focuses on projections for the end of the century since these time horizons were the most similar between the assessments. In this assessment, all values under future climate conditions were provided for a range of percentiles, allowing for different levels of acceptable risk.

As shown in Table 50, the annual temperature in the 2080s at the 50th percentile is projected to increase by 3.5°C. The mean changes in air temperature during the winter and summer months were found to be 5.1°C and 2.5°C, respectively. These trends are consistent with those presented in the previous report, as winter seasons are expected to experience a larger increase than in the summer months.

The results from this assessment can be used to help inform the Giant Mine freeze design and provide more detailed information for both temperature and precipitation on a monthly, seasonal and annual basis, based on the most up to date climate science. Further investigation may be considered for the freeze design to incorporate the updated climate values and trends and confirm if these values still fall within the error bands of inputs to the thermal modelling (not provided in previous study).

Table 50: Comparison of the Climate Change Review's results to Golder's Climate Change Assessment

Change in Air Temperature (°C)	RCP Scenario	AECOM and Newmans Geotechnique (2018)			Golder's Assessment
		Global IPCC Projection Scenarios[(a)]	Canadian Climate Centre for Modelling and Analysis (CCCma)[(b)]	Scenarios Network for Alaska and Arctic Planning (SNAP)[(c)]	Climate Change Assessment[(d)]
Annual Mean	2.6	1.0 (0.3 – 1.7)	—	6.2	**3.6 (1.4 – 8.3)**
	4.5	1.8 (1.1 – 2.6)			
	8.5	3.7 (2.6 – 4.8)			
Winter Mean	2.6	—	3.0 (1.8 – 4.1)	8.4	**5.2 (1.3 – 11.5)**
	4.5		5.8 (4.1 – 7.4)		
	8.5		12 (9.4 – 14.4)		
Summer Mean	2.6	—	1.5 (0.9 – 2.1)	3.9	**2.7 (0.5 – 6.7)**
	4.5		2.6 (1.7 – 3.4)		
	8.5		5.4 (4.0 – 6.8)		

Notes:

(a) Used a climate baseline of 1986-2005 for 2081-2100. Mean presented with the 5th and 95th percentiles in brackets.

(b) Used a climate baseline of 1986-2005 for 2081-2100. Mean presented with the 25th and 75th percentiles in brackets.

(c) Climate baseline and percentiles not provided, only mean presented.

(d) Used a climate baseline of 1971 – 2018 for a multi-model ensemble during the 2080s. The 50th percentile is presented with the 5th and 95th percentiles in brackets.

6.0 CONCLUSIONS

Based on Golder's experience in climate change projections, the proposed approaches as described in this assessment, are considered best guidance for the industry. The results are summarized and compared to the findings presented in the previous Climate Change Review by AECOM and Newmans Geotechnique (2018) study.

The mean annual rainfall is about 374.1 mm, and the mean annual temperature is about -4.0°C at the Yellowknife A station during the 48-year baseline period (1971-2018) based on the Yellowknife A Adjusted data. During this period, warming trends for different time periods (e.g., annual and monthly) were detected at statistically significant levels for the months of January, June, and December. Statistically significant trends for total precipitation are in October and January. The current climate extreme indices are consistent with the current climate trends, showing warming trends and likely wetter conditions.

The current 1-day probable maximum precipitation (PMP) value was estimated near 267 mm/day based on the rainfall data from the Yellowknife A Adjusted data. The rainfall depth was estimated at 71.4 mm for the 1-day duration and 100-year return period. The potential annual evapotranspiration was estimated as 695.7 mm using the Hargreaves method and 497.0 mm using the Thornthwaite method.

The observed trends in the baseline period are consistent with the future climate projections. The annual temperatures are projected to increase by 2.8°C, and 3.6°C, in 2050s and 2080s, respectively, at the 50th percentile. Annual projections of precipitation at the 50th percentile are projected to increase by 11% and 15%, in both the 2050s and 2080s, with increases in precipitation observed during all months.

Similarly, the future climate extreme projections are consistent with the current climate and the future climate temperature trends. From the median (50th percentile) values for the 2050s and 2080s, the projected future climate extremes are indicating a future that is likely to be warmer and wetter on an annual basis. Temperature is projected to increase, resulting in increased warm nights and reduced ice and frost days. Precipitation is also projected to increase, resulting in increased annual total wet-day precipitation, very wet and extremely wet days. The potential shift in maximum 5-day precipitation amount, from a decreasing trend observed in the current climate to an increasing trend in the future climate, may indicate a change in the temporal distribution of rainfall events and implies an increase in frequency of short duration high intensity events. The AECOM and Newmans Geotechnique (2018) study referenced assessments that used different methodologies but came to similar conclusions and trends for projected future changes in annual mean temperature, especially when comparing between the seasonal variation.

The 1-day PMP values are projected to increase between approximately 9.5% and 14.0% in the 2050s and in the 2080s, respectively, at 50th percentile. The 100-year, 1-day rainfall events are projected to increase by 9.5%, over current rainfall depths by 2050s and 23.9% by the 2080s at the 50th percentile. Estimates for future potential evapotranspiration using the Hargreaves method, using the 50th percentile temperature anomalies, suggests an 9.0% increase in annual potential evapotranspiration by the 2050s and an 11.1% increase in annual potential evapotranspiration by the 2080s.

Current climate normals for the spring transition period show the change in precipitation from rain to snow as temperatures increase from early to late spring. The trends in rain and snow were found to be mostly not significant except for decreasing rain in October and increasing snow in January. Snowpack was found to have the largest potential for extreme events in early May due to more time for accumulation if temperatures remain low enough to prevent snowmelt. Future projections for the spring transition period show that rainfall amounts are expected to increase in the early spring, while a decrease is expected for the remaining four periods. Projected snowfall amounts are expected to increase in the early to mid spring and decrease in May. Snowpack projections show increases in early spring and large decreases in the late spring. Overall, the spring transition is expected to have less rainfall with more snow in the beginning of the spring period and less towards the late spring.

7.0 USING THE RESULTS

This assessment is based on the current available climate science. The nature of the work undertaken is stochastic with substantial inherent uncertainly around any given data points, as described in Section 3.2 and 4.1. The uncertainty associated with any projections or forecasts is increased with the duration of the projected period and is subject to future developments, therefore, this work should be updated as new climate science is developed and after the release of the latest AR by the IPCC.

To acknowledge this uncertainty, rather than provide one projection the future projections have been described using percentiles. The projections at the 50th percentile represent the ensemble median projections representing good agreement across GCMs. The projections at the 5th and 95th percentile represent more extreme low and high projections across the multi-model ensemble. When considering the impact of future projected climate on current design parameters, the level of acceptable risk can be selected by using the desired percentile. Selection of future projections for climate change risk assessment should be based on the balance between the extra investment and consequential risks.

Therefore, it is recommended that the results in this report be used as follows:

- For the ensemble mean projections, the projections at 50th percentile, should be selected as the starting point, which Giant Mine should consider in regard to risk assessment and undertaking planning and engineering design applications of infrastructure in the future.
- Consideration should be given to the “project life & future level of service requirements” and selection of the appropriate planning horizon for each infrastructure component (i.e., 2050s and 2080s).
- For critical infrastructure, selection of future projections at a more conservative percentile should be considered. For example, for critical infrastructure, whose failure is considered unacceptable, a 95th percentile could be considered over the typical 50th percentile if a projected increase is considered more conservative for a given climate variable.
- If a risk is identified for an infrastructure component for the area, then a more refined analysis should be performed to further define the risks using the projections at different percentiles.
- When considering action to address an identified potential risk, consideration should be given to selection of future projections at different percentiles through a cost-benefit analysis.

8.0 LIMITATIONS

The nature of the work undertaken is stochastic with substantial inherent uncertainly around any given data points. The reader acknowledges that the uncertainty associated with any projections or forecasts is increased with the duration of the projected period and is subject to future developments or intervening acts which may manifest in the interim period.

The information in this report was prepared using published data and information, technical journals, articles as well as professional judgment and experience. No sampling or fieldwork was conducted in the course of this work.

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APPENDIX A

Detailed Methodology

1.0 DETAILED CLIMATE CHANGE METHODOLOGY

This methodology appendix is a summary of the approach that will be applied to Giant Mine and documents the most recent best guidance found in literature. This standardized approach for completing a climate change assessment is developed based on recommended best guidance accepted by the Intergovernmental Panel on Climate Change (IPCC) and other scientific bodies as referenced in the sections below. This approach combines information about the current climate conditions and publicly available projections of how the climate may change under future climate conditions, to describe a range of projections on how the current climate may change in the future at the site of interest.

The following sections provides the detailed methodology followed to develop a current climate baseline (Section 2.0) and future climate projections (Section 3.0) for the Giant Mine.

2.0 CURRENT CLIMATE BASELINE DEVELOPMENT

Understanding the current climate and current climate trends is important when evaluating current design parameters and establishing future projected changes due to climate change. Where available, the climate baseline is grounded in observations from local observation stations. Publicly available observations from Yellowknife A climate station will be used to establish the baseline infilled with reanalysis data (to meet data completeness requirements). Before infilling, the reanalysis data will be compared and correlated to the available regional climate station.

If available, the Adjusted and Homogenized Canadian Climate Data (AHCCD) will be used to apply adjustments to the station observations (infilled if necessary) to account for non-climatic shifts in data, mainly due to the relocation of stations and wind undercatch correction (ECCC 2017). Wind undercatch describes the effects of wind on rain gages that can cause underestimation of rainfall which contributes to inconsistencies in the rainfall dataset (Guo, Urbonas & Stewart 2001). After the station observations have been reviewed for data completeness, infilling, and any available adjustments, the current climate normal and trends will be calculated along with current climate extremes and trends, probable maximum precipitation, rainfall statistics, and potential evapotranspiration.

2.1 Data Sources for Current Climate

The current climate is based on available long term daily meteorological observations from Yellowknife A climate station near Giant Mine. Observations from Yellowknife A station was obtained from ClimateData.ca (ClimateData.ca 2019). For Giant Mine, the selected current climate baseline period is from 1971 through 2018 (48 years). The current climate baseline period was extended the current climate normal period of 1981 through 2010 to capture a large precipitation event prior to 1981 and to include the most recent years of observations (WMO 2017). Meeting the monthly data availability is often a challenge over the desired, long observation period. The data availability is necessary to properly capture the different cycles impacting the observations (e.g., diurnal, seasonal) and avoid potential biases in the analysis of the observations (e.g., consistently missing observations during the nighttime or winter). When available climate observations are representative of a site but fail to meet the required data completeness, reanalysis data from the National Aeronautics and Space Administration's (NASA's) Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) will be used to represent current climate or to infill the missing data. MERRA-2 is a NASA's atmospheric reanalysis using the Goddard Earth Observing System Model, along with its atmospheric data assimilation system that simulates temperature and precipitation on an hourly basis (NASA 2019).

Infilling the missing data is a two-step process: the first step is to perform a correlation analysis for the concurrent period between the non-missing observations and MERRA-2 data and the second step is to scale the reanalysis data using a linear relationship based on the correlation.

Environment and Climate Change Canada (ECCC) has provided the AHCCD dataset that has adjusted measurements to account for non-climatic measurement issues (i.e., wind undercatch) and have combined observations from nearby stations to create longer time series that are useful for trend studies (Mekis & Vincent 2011). The AHCCD dataset includes daily observations for minimum, maximum and mean temperatures and total precipitation. The AHCCD dataset does not always include the most recent observations and as a result, a trending analysis will be used to adjust the AHCCD dataset to match the infilled observations to account for any missing observations/years. This adjustment will use monthly factors using the difference between the two datasets for the concurrent period. A sensitivity analysis will then be conducted comparing the datasets to verify that the adjustments are consistent with the infilled dataset. The adjusted observations will be used for the remaining current and future climate analysis and will be referred to as the Yellowknife A Adjusted dataset.

2.2 Quantifying Current Climate Normals and Trends

The current climate temperature and precipitation will be used to calculate the annual, monthly, and spring transition current climate normals and trends using the definitions provided in Table 1.

Table 1: Definition of Current Climate Indices

Climate Indices	Definition	Units
Total Precipitation	Calculated as the sum of all the observed total precipitation during the selected annual period. Each annual value is averaged over the period of the climate normal.	mm
Monthly Precipitation	Calculated as the sum of all the observed total precipitation during the selected month. Each annual value is averaged over the period of the climate normal.	mm
Average Annual Temperature	Calculated as the average of all the observed daily mean temperatures during the selected annual period. Each annual value is averaged over the period of the climate normal.	°C
Monthly Temperature	Calculated as the average of all the observed mean temperatures during the selected month. Each annual value is averaged over the period of the climate normal.	°C

The reviewed data will be used to calculate selected climate normals and trends (Table 1), using a methodology developed by the Finnish Meteorological Institute (Salmi et al. 2002) to assess climate changes predicted from long-term climate observations. Both annual and seasonal climate normals and trends will be calculated for the mean temperature and total precipitation. The climate normal will be calculated as the average of a given climate parameter over the selected period, and the climate trend will be calculated as the average change in the climate parameter per decade (i.e., the decadal trend or change). Potential trends in temperature and precipitation will be evaluated by fitting a model to the data using the Sen's nonparametric model. The statistical significance of the observed trends will be determined using the Mann-Kendall test. The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series with no seasonal cycle. The analysis uses a two-tail test to determine statistical significance at the 90th, 95th, 99th and 99.9th percentile levels.

2.3 Quantifying Current Climate Extremes and Trends

In addition to the annual and monthly current climate indices discussed above, climate extremes will be calculated. The climate extremes are defined by the World Meteorological Organization's (WMO's) Expert Team on Climate Change Detection and Indices (ETCCDI; WMO 2009) who recommend 27 indices (ClimDEX) as a means of summarizing daily temperature and precipitation statistics, focusing primarily on aspects of climate extremes. They have been developed to allow comparison of climate conditions on an international basis. The detailed definitions for these 27 indices, quality control procedures and calculation software are provided by ETCCDI (2017). In addition to the normals and trends (calculated using the methodology described in Section 1.0), the minimum, maximum, mean and median for each of the 27 indices will be calculated using the annual values provided for each index during the selected baseline range (1971 through 2018). Table 2 provides a summary of these indices and their definitions.

Table 2: List of WMO Recommended 27 Extreme Indices

ID	Indicator Name	Definitions [(a)]	Units
CDD	Consecutive dry days	Maximum number of consecutive days with daily precipitation amount less than 1 mm (RR<1 mm)	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when daily minimum temperatures are less than the 10th percentile (TN<10th percentile)	Days
CWD	Consecutive wet days	Maximum number of consecutive days with daily precipitation amount greater than or equal to 1 mm (RR>=1 mm)	Days
DTR	Diurnal temperature range	Monthly mean difference between the daily minimum temperature (TX) and the daily maximum temperature (TN)	ºC
FD0	Frost days	Annual count when the daily minimum temperature is less than 0°C (TN<0ºC)	Days
GSL	Growing season length	Annual (1st Jan to 31st Dec in the northern hemisphere, 1st July to 30th June in the southern hemisphere) count between first span of at least 6 days with ground temperatures greater than 5°C (TG>5ºC) and first span after July 1 (January 1 in the southern hemisphere) of 6 days with ground temperatures less than 5°C (TG<5ºC)	Days
ID0	Ice days	Annual count when the daily maximum temperature is less than 0° (TX<0ºC)	Days
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation (PRCP) in wet days where the daily precipitation is greater than or equal to 1 mm (RR>=1 mm)	mm
R10	Number of heavy precipitation days	Annual count of days when precipitation is greater than or equal to 10 mm) (PRCP>=10 mm)	Days
R20	Number of very heavy precipitation days	Annual count of days when precipitation is greater than or equal to 20 mm (PRCP>=20 mm)	Days
R95p	Very wet days	Annual total precipitation (PRCP) when the daily precipitation is greater than the 95th percentile (RR>95th percentile)	mm
R99p	Extremely wet days	Annual total precipitation (PRCP) when the daily precipitation is greater than the 99th percentile (RR>99th percentile)	mm
Rnn	Number of days above nn mm	Annual count of days when precipitation when precipitation is greater than or equal to a user defined threshold (PRCP> = "nn" mm, "nn" is user defined threshold)	Days

Table 2: List of WMO Recommended 27 Extreme Indices

ID	Indicator Name	Definitions [(a)]	Units
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0 mm) in the year	mm/day
SU25	Summer days	Annual count when the daily maximum temperature is greater than 25°C (TX>25ºC)	Days
TN10p	Cool nights	Percentage of days when the daily minimum temperature is less than the 10th percentile (TN<10th percentile	% of Days
TN90p	Warm nights	Percentage of days when the daily minimum temperature is greater than the 90th percentile (TN>90th percentile	% of Days
TNn	Min Tmin	Daily minimum value of daily minimum temp	ºC
TNx	Max Tmin	Daily maximum value of daily minimum temp	ºC
TR20	Tropical nights	Annual count when the daily minimum temperature is greater than 20°C (TN>20ºC)	Days
TX10p	Cool days	Percentage of days when the daily maximum temperature is less than the 10th percentile (TX<10th percentile)	% of Days
TX90p	Warm days	Percentage of days when the daily maximum temperature is greater than the 90th percentile (TX>90th percentile)	% of Days
TXn	Min Tmax	Daily minimum value of daily maximum temp	ºC
TXx	Max Tmax	Daily maximum value of daily maximum temp	ºC
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when the daily maximum temperature is greater than the 90th percentile (TX>90th percentile)	Days

Note:

(a) The abbreviations for the variables used in the definitions are as follows: SH is southern hemisphere; RR is the daily precipitation amount (mm); TX is the maximum temperature (°C); TN is the minimum temperature (°C); TG is the ground temperature (°C); and PRCP is the precipitation amount (mm); RR – daily precipitation amount (mm).

2.4 Quantifying Current Probable Maximum Precipitation

Probable Maximum Precipitation (PMP) is defined as “*the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends”* (WMO 2009). The PMP is a theoretical value that represents the greatest amount of rain possible in a given area as opposed to a design storm that represents the greatest amount of rain observed in a given area. The WMO acknowledges that there is significant uncertainty regarding PMP calculations and recommends that a comparison of reported values is conduced.

There are two widely accepted approaches (meteorological and statistical) to estimate the PMP. The meteorological approach maximizes the moisture content or precipitable water of rainfall storm events while the statistical approach utilizes the historical annual maximum rainfall events to estimate the PMP. The precipitable water of rainfall storm events was not available for this location so only the statistical approach is used to estimate the current value.

The statistical approach following the Hershfield Method (WMO 2009) is as follows:

$$PMP = X_n + KS_n$$ **Equation 2**

Where X_n and S_n are the mean and standard deviation (respectively) of the annual maximum 1-day precipitation, and K is a frequency factor that is a function of X_n and rainfall intervals. In computing PMP with Equation (2), various adjustments are made, including:

- adjustment of X_n and S_n for the maximum observed events;
- adjustment of X_n and S_n for sample size;
- adjustment for fixed observational time intervals; and
- adjustment for the area.

The 1-day PMP storm will be estimated using daily current climate baseline precipitation data on a daily time step using the Hershfield Method.

2.5 Quantifying Current Rainfall Statistics

Extreme rainfall events for multiple durations and return periods are calculated according the methodology presented in the following sections.

2.5.1 Daily Precipitation

The peak 1-day duration rainfall events will be estimated for each year of the current climate baseline period. The method of moments was used to estimate parameters for the Gumbel Distribution (the approach used by ECCC to describe the annual return period precipitation depths for the 1-day rainfall duration), and the analysis will include the results for various return periods (2, 5, 10, 20, 50, 100, 200, 500, 1000, and 2000-years).

2.5.2 Multi-Day Precipitation

Multi-day precipitation depths will be estimated by deriving multi-day running totals for precipitation (using 1, 2, 3, 4, 5, 10, 20, 30, 50, 75, 90, and 120-day durations) and then applying the method described in Section 2.5.1 for the annual maximum and Gumbel distribution.

2.6 Quantifying Current Climate during the Spring Transition Period

Consideration of climate change impacts during spring melt conditions are important, as this time of the year can be critical for generating extreme runoff amounts. The transition from winter to spring can result in combined rainfall and snowmelt on frozen ground. This has the potential to create large amounts of excess precipitation which does not infiltrate and contributes directly to runoff. To examine climate change impacts during the spring transition, statistics for temperature, rain, snow, and snowpack have been calculated separately for five periods in the spring months corresponding to:

- Period 1 – March 19th to 31st
- Period 2 – April 1st to 15th
- Period 3 – April 16th to 30th
- Period 4 – May 1st to 15th
- Period 5 – May 16th to 31st

Daily precipitation amounts are first separated into rain and snow based on daily temperatures. For temperatures of 0 and below, precipitation is assumed to fall as snow, while for temperatures greater than zero precipitation is assumed to fall as rain. Spring IDF statistics have been calculated using daily precipitation amounts across the spring transition period (Period 1 through Period 5) following the same calculation procedure as for the current daily rainfall statistics in Appendix Section 2.5.1.

2.7 Quantifying Current Potential Evapotranspiration

Evaporation and transpiration can occur simultaneously. The principal weather parameters affecting evapotranspiration are air temperature, extraterrestrial radiation, humidity and wind speed, with air temperature typically being the dominant independent variable. As only the observed minimum temperature, maximum temperature and total precipitation are available from the daily current climate dataset (no infilled observations of radiation, humidity, and wind speed are produced), two air temperature-based formulas (the Hargreaves equation; Food and Agriculture Organization [FAO] 2006 and the Thornthwaite Equation; EC 1983) will be used. The two methods have different focus (humidity for Hargreaves and heat index for Thornthwaite) and data is not available to suggest which is more appropriate here; thus, both methods will be used to provide a range for current potential evaporation.

2.7.1 Hargreaves Equation

The Hargreaves equation was developed in 1982 as an alternative to the more complicated energy-balance approach of the Penman-Monteith equation (developed in 1948). The Penman-Monteith method required significant amounts of climate data including incoming solar radiation, wind speed, and humidity, which is often not available; by contrast, the Hargreaves equation requires only the daily minimum, maximum, and mean temperatures. The Hargreaves equation builds into a more complete model by making assumptions about the solar radiation (based on latitude), accounting for humidity (based on the difference between daily minimum and maximum temperatures), and assuming that the effect of wind is not significant. The FAO has noted that for potential evapotranspiration (ET_o):

> *"Temperatures methods remain empirical and require local calibration in order to achieve satisfactory results. A possible exception is the 1985 Hargreaves' method which has shown reasonable ET_o results with a global validity" (FAO 2006).*

The Hargreaves estimate of daily potential evapotranspiration is arrived at by the following formula:

$$E = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a \qquad \textbf{Equation 3}$$

where T_{mean} is the average temperature, T_{max} and T_{min} are daily maximum and minimum temperatures, and R_a is the extraterrestrial radiation. The R_a is calculated as:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [w_s sin(\varphi) sin(\delta) + cos(\varphi) cos(\delta) sin(w_s)] \qquad \textbf{Equation 4}$$

where G_{sc} is the solar constant: 0.0820 MJ/m^2/min;
d_r is the inverse relative distance Earth-Sun: $d_r = 1 + 0.033cos\left(\frac{2\pi}{365}J\right)$;
w_s is the sunset hour angle: $w_s = arccos[-tan(\varphi)tan(\delta)]$;
φ is the latitude of the site in radians;
δ is the solar declination in radians: $\delta = 0.409sin\left(\frac{2\pi}{365}J - 1.39\right)$; and
J is the Julian day.

2.7.2 Thornthwaite Equation

The Thornthwaite equation was developed in 1955 as a way to estimate potential evapotranspiration (PE) using only mean daily temperature (EC 1983). It is commonly used by Environment Canada for estimating values for water budgets in Canada. The method includes assumptions about day length, but does not account for humidity, radiation, or wind speed. Rather, the method includes an estimate for an annual Heat Index (I) for a location based on the monthly temperatures for the entire year. The complete method for water budgets (including soil water holding and evaporation) focuses the evapotranspiration results on evapotranspiration from the soil. The vegetation is accounted for through soil water holding capacity. According to Environment Canada:

> *"This equation does not directly account for the significant short-term controls on evapotranspiration rates that are exerted by humidity, wind, radiation, or plant physiology. However, Calder et al. (1983) have found that sophisticated meteorological PE models that incorporate some of these factors do not necessarily result in improved soil moisture predictions. The Thornthwaite model includes a seasonal variation of PE that was found to be necessary for good model performance by Calder et al. (1983)."* (EC 1983).

The Thornthwaite estimate of daily potential evapotranspiration is arrived by the formula:

$$E(mm/day) = Adj \times 0.533\left(\frac{10T}{I}\right)^{A} \qquad \textbf{Equation 5}$$

where Adj. is the daylight adjustment factor (unitless);
T is the daily mean temperature;
I is the Thornthwaite heat index (from 12 monthly temperatures): $I = \sum_{i=1}^{12}(\frac{T}{5})^{1.514}$
A is the Thornthwaite Factor: $A = 6.75 \times 10^{-7} \times I^{-3} - 7.71 \times 10^{-5} \times I^{2} + 1.79 \times 10^{-2} \times I + 0.49$

2.8 Quantifying Extreme Rainfall and Snowmelt Statistics

The calculation of extreme combined rainfall and snowmelt statistics follows the methodology adopted by ECCC (Louie and Hogg 1980) to estimate runoff from snowmelt. The methodology first separates rainfall and snowmelt using mean daily temperature and uses a degree-day method to model the processes of snow accumulation and melt. The following steps are used in the procedure:

1) The snowpack accumulation is estimated based on the daily mean temperature and the total rainfall. If temperature is >0ºC, precipitation falls as rain and no snowpack is accumulated; if temperature is <0ºC, precipitation falls as snow and is accumulated to the snowpack.
2) The snowmelt amount (SM) is estimated based on the model presented in Equation 6 (Pysklywec et al. 1968) and is depleted from the snowpack.

$$SM = 1.008\,(1.8 \cdot Ta + 4.4)\ \frac{mm}{day} \qquad \textbf{Equation 6}$$

   Where T_a is the mean daily air temperature in ºC.
3) For combined rainfall and snowmelt, the calculated snowmelt is added to the rainfall amount, if any (rain + snowmelt).
4) The process is repeated for all days in the data series are calculated.

5) Finally, the daily maximums of rain, snow, snowfall, snowmelt, combined rainfall and snowmelt, and snowpack for each year are calculated and the Gumbel statistical distribution is fitted to estimate the required return periods.

Please note that the combined extreme rainfall and snowmelt events were only considered from October to June each year. This assumption is valid given there is no snow accumulation for the summer months (from July to September) based on the observed climate normals.

2.9 Quantifying Current Climate during the Spring Transition Period

Consideration of climate change impacts during spring melt conditions are important, as this time of the year can be critical for generating extreme runoff amounts. The transition from winter to spring can result in combined rainfall and snowmelt on frozen ground. This has the potential to create large amounts of excess precipitation which does not infiltrate and contributes directly to runoff. To examine climate change impacts during the spring transition, statistics for rain, snow, and snowpack have been calculated separately for five periods in the spring months corresponding to:

- Period 1 – March 19th to 31st
- Period 2 – April 1st to 15th
- Period 3 – April 16th to 30th
- Period 4 – May 1st to 15th
- Period 5 – May 16th to 31st

Daily precipitation amounts are first separated into rain and snow based on daily temperatures. For temperatures of 0°C and below, precipitation is assumed to fall as snow, while for temperatures greater than 0°C precipitation is assumed to fall as rain. Spring IDF statistics have been calculated using daily precipitation amounts across the spring transition period (Period 1 through Period 5) following the same calculation procedure as for the future rainfall statistics in Appendix Section 2.5.1.

3.0 FUTURE CLIMATE BASELINE DEVELOPMENT

Future climate projections are important for understanding how climate is projected to change from the climate baseline. The future climate projections come from publicly available statistical downscaled future climate projections on a daily scale. Recognizing the inherent uncertainty with projections, multiple projections from multiple models and scenarios will be included in the analysis. Therefore, the future projections will be provided in terms of percentiles.

3.1 Data Sources for Future Climate

In 1988, the IPCC was formed by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to review international climate change data. The IPCC is generally considered to be the definitive source of information related to past and future climate change as well as climate science. As an international body, the IPCC provides a common source of information relating to emission scenarios, provides third party reviews of models, and recommends approaches to document future climate projections. Periodically, the IPCC issues assessment reports summarizing the most current state of climate science. The Fifth Assessment Report (AR5) (IPCC 2013) represents the most current complete synthesis of information regarding climate change.

3.2 Global Climate Change Projections

Future climate is typically projected using global circulation models (GCMs) that involve the mathematical representation of global land, sea and atmosphere interactions over a long period of time. These GCMs have been developed by various government agencies, but they share a number of common elements described by the IPCC. The IPCC does not run the models but acts as a clearinghouse for the distribution and sharing of the model forecasts.

Future climate projection data are available from about 30 GCMs and four representative concentration pathways (RCP 2.6, RCP 4.5, RCP6.0 and RCP 8.5) in AR5. The model projections can be summarized for magnitude of change from the climate regime baseline for different time horizons. Based on conversations with Giant Mine, the time horizons applied to this study include the following:

- 1971 to 2018 (baseline);
- 2041 to 2070 (2050s); and
- 2071 to 2100 (2080s).

Global climate models require extensive inputs to characterize the physical processes and social development paths that could alter climate in the future. In order to represent the wide range of the inputs possible to global climate models, the IPCC has established a series of RCPs that help define the future levels of radiative forcing terms. The IPCC identified four scenarios, namely, RCP 2.6, RCP 4.5, RCP6.0, and RCP 8.5. The pathways are named after the radiative forcing projected to occur by 2100. These four RCPs have been described more fully by van Vuuren et al (2011) in their paper "The representative concentration pathways: an overview" and have been summarized in Table 3. The IPCC identified four representative concentration pathways, however, this report focuses on the three RCPs (RCP2.6, RCP4.5, and RCP8.5) currently available from ClimateData.ca (ClimateData.ca 2019).

Table 3: Characterization of Representative Concentration Pathways

Name	Radiative Forcing in 2100	Characterization
RCP8.5	8.5 W/m²	Increasing greenhouse gas emissions over time, with no stabilization, representative of scenarios leading to high greenhouse gas concentration levels; and comparable to the SRES A2/A1FI scenarios.
RCP6.0	6.0 W/m2	Without additional efforts to constraint emissions (baseline scenarios); and comparable to SRES B2 scenario.
RCP4.5	4.5 W/m²	Total radiative forcing is stabilized shortly after 2100, without overshoot. This is achieved through a reduction in greenhouse gases over time through climate policy; and comparable to SRES B1 scenario.
RCP2.6	2.6 W/m²	"Peak and decline" scenario where the radiative forcing first reaches 3.1 W/m² by mid century and returns to 2.6 W/m² by 2100. This is achieved through a substantial reduction in greenhouse gases over time through stringent climate policy.

Note: Summarized from van Vuuren et al 2011; W/m² = watt per square metre.

3.2.1 Regional Climate Change Projections

The ClimateData.ca portal provides statistically downscaled daily Canada-wide climate scenarios, at a gridded resolution of 300 arc-seconds (or roughly 10 km) for the simulated period of 1950-2100 (ClimateData.ca 2019). The climate variables available from ClimateData.ca data include minimum temperature, maximum temperature and precipitation. The selection of data for this project is based on the available temporal and spatial resolution of the data. The availability of daily downscaled data allows for better characterization of the climate extremes, especially for precipitation. The availability of high spatial resolution (10 km instead of hundreds of km in GCMs) provides better representation for site-specific studies like this project.

GCM projections are downscaled to a finer resolution using the Bias Correction/Constructed Analogues with Quantile mapping reordering version 2 (BCCAQv2) developed by the Pacific Climate Impacts Consortium (PCIC) (ClimateData.ca 2019). This downscaling method is a statistical algorithm that disaggregate the GCM outputs to a finer spatial and temporal resolution, in other words they take the gridded data and calculate values that reflect the local conditions that cannot be simulated by the GCM. The Bias Correction/Constructed Analogues with Quantile mapping reordering interpolates spatially to a finer scale on a daily basis. More detailed description and model performance can be found in (Werner and Cannon 2016).

These downscaled outputs are based on GCM projections from the Coupled Model Intercomparison Project Phase 5 (Taylor et al. 2012) and historical daily gridded data from Canada (Mckenney et al. 2011; Hopkinson et al. 2011) and are available for a subset of 12 GCMs. These 12 GCMs are selected to provide the widest spread in projected future climate for smaller subsets of the full ensemble following Cannon (2015).

For each downscaling method, there are a total of 72 future projections; with the combination of three RCPs with 24 GCMs. With two downscaling approaches, a total of 72 simulations / projections are available on a daily basis from 1950 to 2100.

Since no one model or climate scenario can be viewed as completely accurate, the IPCC recommends that climate change assessments use as many models and climate scenarios as possible, or a “multi-model ensemble”. For this reason, the multi-model ensemble approach was used to delineate the probable range of results and better capture the actual outcome (an inherent unknown). Best practices recommend using all plausible futures for greenhouse gases that includes to best- and worst-case scenarios (RCP 2.6, 4.5, 6.0, and 8.5) when considering long timescales to address uncertainty. In addition, a multi-model ensemble is also recommended since the mean of an ensemble is generally closer to the observed values for past climate than any given individual model or scenario (Charron 2016).

Before beginning the future climate projections, the 72 potential members of the multi-model ensemble were reviewed to observe whether the general temperature and precipitation ranges reasonably matched the observed ranges of climate for the region. In particular, monthly averages were used to capture the known seasonality of the region. From this evaluation, all scenarios from the ensemble demonstrated typical behaviour within the current climate normal for the region and within the monthly averages.

The downscaled data has a daily temporal resolution (GCMs typically have monthly temporal resolution) which will allow for the characterization of future climate extremes. In addition, the improved horizontal resolution of 10 km in the downscaled data could better improve the representation of the Project, given the complex terrain in the Project Area.

3.2.2 Uncertainty of Climate Change Downscaling Methods

The spatial and temporal resolution mismatch between GCMs outputs and the data requirements of climate change risk assessment is a major obstacle. It is therefore necessary to perform some post-processing to minimize the mismatch. Consequently, dynamic downscaling (regional climate models, RCMs) and statistical downscaling (SD) have been developed to meet these requirements (Chen et al. 2011). The main challenge for RCMs is the computing cost, therefore, the dynamic downscaling is only limited for selected regions and scenarios, and mainly at the research stage. SD techniques have been developed to overcome these challenges, and typically fall into four categories: transfer function, weather typing, weather generators and climate change factor (MWH 2015). Transfer function approaches establish statistical linear or nonlinear relationships between observed local climate variables and GCM outputs. Weather typing relates a group of local climate variables to different classes of atmospheric circulation. Weather generators perturb its parameters based on empirical distributions and relative changes projected by GCMs. The climate change factor adjusts the baseline conditions by adding the differences or multiplying the ratios between future and current climates as simulated by the RCMs or GCMs. Each approach has pros and cons. In its Fourth Assessment Report, the IPCC (2007) supported the conclusions on statistical downscaling methodologies and dynamical downscaling with RCMs. Both methodologies produce comparable results in simulating current climate and should thus be considered complementary approaches for downscaling regional climate (Canadian Standards Association 2010).

For the future projected daily temperature and precipitation, the publicly available statistically downscaled projections from PCIC described in Section 3.2.1 will be used. Where additional downscaling steps are needed to capture the local rainfall variation in the future (Section 3.4 and 3.5), the ensemble approach will be used across the two different downscaling methodologies to help quantify the uncertainty.

3.3 Projecting Future Climate Extremes

Future climate extremes are projected using the 27 WMO extreme indices described in Section 2.3 using the temperature and precipitation projections from the available downscaled ClimateData.ca data. The future climate extremes are described in terms of an “anomaly” or change from the baseline. As each model has a unique baseline, the calculations are first completed for each model and then statistics are provided to describe the range of projections over the multi-model ensemble.

The 27 WMO indices are calculated for each of the 72 multi-model ensemble members for each year of the baseline (1971 through 2018) and each year of the two desired future periods (2050s and 2080s). This creates the unique baseline and future projections for each model that will be used as a basis to calculate the anomaly. Before calculating the anomaly, for each ensemble member, each index is averaged over all the annual values contained in each period considered (baseline and two future periods) creating three values for each index for each model (i.e., mean value for the baseline, the 2050s and the 2080s). Finally, the anomalies are calculated as the difference between each future period and the baseline for each index (e.g., mean 2050s less mean baseline and mean 2080s less mean baseline) and each ensemble member. This provides on anomaly per index per ensemble member for each future period. This information is summarized using statistics to describe the range in projected anomalies across the ensemble members (min, max, mean, median and percentiles).

3.4 Projecting Future Changes in PMPs

Consistent with all future projections, the ensemble approach will be used. Both the meteorological and statistical PMP approaches from Section 2.4 will be used to project the future PMP. The moisture maximization approach can be estimated by:

$$PMP = P_s \times \frac{W_{max}}{W_{storm}} = P_s \times r \qquad \textbf{Equation 7}$$

Where P_s is the observed precipitation of a large storm, W_{max} is the maximum precipitable water at the same time of year in the same location, W_{storm} is the precipitable water of the observed storm, and r is the moisture maximization ratio. Precipitable water is the amount of water from condensation of all water vapour in an atmospheric column. The future moisture content is projected using readily available data from the ensemble GCMs as a proxy. Ideally, the precipitable water can be calculated for each combination of GCMs and RCPs for every day by:

$$W_{i,j,k} = \frac{1}{g}\int_{p_s}^{p_t} Q(p)dp \qquad \textbf{Equation 8}$$

where *i*, *j* and *k* represents the combination of the i[th] RCP, j[th] GCM and k[th] day, *g* is gravitational acceleration, p_s and p_t are the pressures at the surface and top levels of atmosphere column, and *Q(p)* is the specific humidity at pressure level *p*, can be calculated as:

$$Q(p) = \frac{r_v}{1 + r_v} \approx r_v = \frac{0.622e}{p - e} \qquad \textbf{Equation 9}$$

where r_v is the saturation water vapor mixing ratio and *e* is the saturation vapor pressure which can be calculated by Clausius-Clapeyron equation:

$$e = 6.112exp\left(\frac{17.67T_{dew}}{T_{dew} + 243.5}\right) \qquad \textbf{Equation 10}$$

$$p = \rho RT \qquad \textbf{Equation 11}$$

where T_{dew} is the dew point temperature, *T* is the mean temperature, ρ is the air density and *R* is gas specific constant.

However, the ClimateData.ca dataset has only daily precipitation, minimum and maximum temperatures at one level, but not the moisture content at multiple levels. Accordingly, the daily minimum temperature will be used as a proxy for the dew point temperature, and surface specific humidity as a proxy for the precipitable water:

$$W_{i,j,k} \sim Q(p_s) \qquad \textbf{Equation 12}$$

The maximum precipitable water using Equations (8) ~ (12) can be calculated for the observational period and future period. The future PMP (PMPF) for the i[th] RCP and j[th] GCM is projected to be:

$$PMPF_{i,j} = \frac{Wf_{i,j}}{Wb_{i,j}} PMP \qquad \textbf{Equation 13}$$

where W_f and W_b are the maximum precipitable water in the future period and baseline period, respectively. Current research (Rouhani 2016) indicates that using the 100-year precipitable water instead of the maximum precipitable water yields more robust results.

Using Equation (14), the future PMP can be projected for all combinations of RCPs and GCMs.

The second approach follows the Hershfield method, the PMP is calculated for the baseline period and future period by:

$$PMP_{i,j}^{l} = X_n(i,j) + K(i,j)S_n(i,j) \qquad \textbf{Equation 14}$$

Where *i* and *j* represent one combination of ith RCP and jth GCM, and l represents the periods. The projected percentage change is calculated as the difference between the future modelled period and modelled baseline period.

The projected change, in terms of percentage (%) change, from each method will be calculated for each model, resulting in an ensemble of percentage differences. Percentiles will be calculated over the ensemble of projected changes including both methods, which will result in one set of projected changes.

3.5 Projecting Future Rainfall Statistics

Data downscaling of coarse regional climate projections available from the GCMs to a local scale with a fine degree of resolution in both space and time is essential in the development of the future IDF statistics. It may not be readily apparent why an additional downscaling step is necessary while the statistically downscaled daily precipitation is available from the ClimateData.ca dataset. Although the ClimateData.ca dataset is statistically downscaled, properly accounting for the local rainfall distributions is essential to capture extreme rainfall events that are critical to the construction of the IDF statistics. Therefore, an additional downscaling step is necessary. In addition to the uncertainties inherited from the GCMs and RCPs, the downscaling approaches also create uncertainties as well.

To capture all these uncertainties, two statistical downscaling approaches driven by all combinations of GCMs and RCPs to project not only the future IDF statistics, but the uncertainties and IDF statistics at different percentiles will be used. The two proposed downscaling approaches are Equidistance Quantile Matching (EQM Srivistav et al. 2014) method, and (2) Ratio Method (RM).

However, it is noted that, as indicated by Canadian Standards Association (2010), "*In an effort to derive quantitative future short-duration rainfall estimates to better suit the needs of design, water resource and storm water management practitioners, a number of various statistical downscaling and analysis techniques have been developed. However, there is no standard or accepted research methodology to determine how future sub-daily extreme rainfall could change in intensity and frequency at point locations or over a small area in the future climate*".

The EQM has two components: (1) spatial downscaling relating concurrent GCM daily simulation and historical observations at a station of interest using quantile-mapping functions; and (2) temporal downscaling relating the GCM daily simulation for the observational period to future GCM projection using quantile-mapping functions. The quantile-mapping functions are based on Gumbel distribution which is fitted with annual maximum series. A flow chart of the EQM is shown in Figure 2.

RM does not directly input the observed rainfall data into the GCM projections but uses the ClimateData.ca dataset to produce the IDF statistics during the historical observation period and future period. The ratio of the future period to the historical period is then applied to the existing IDF statistics to project the future IDF curves. A flow chart is shown in Figure 3.

Using both methods would allow us to take advantage of both the model climate data and observational data, which allow a better estimate of the uncertainty.

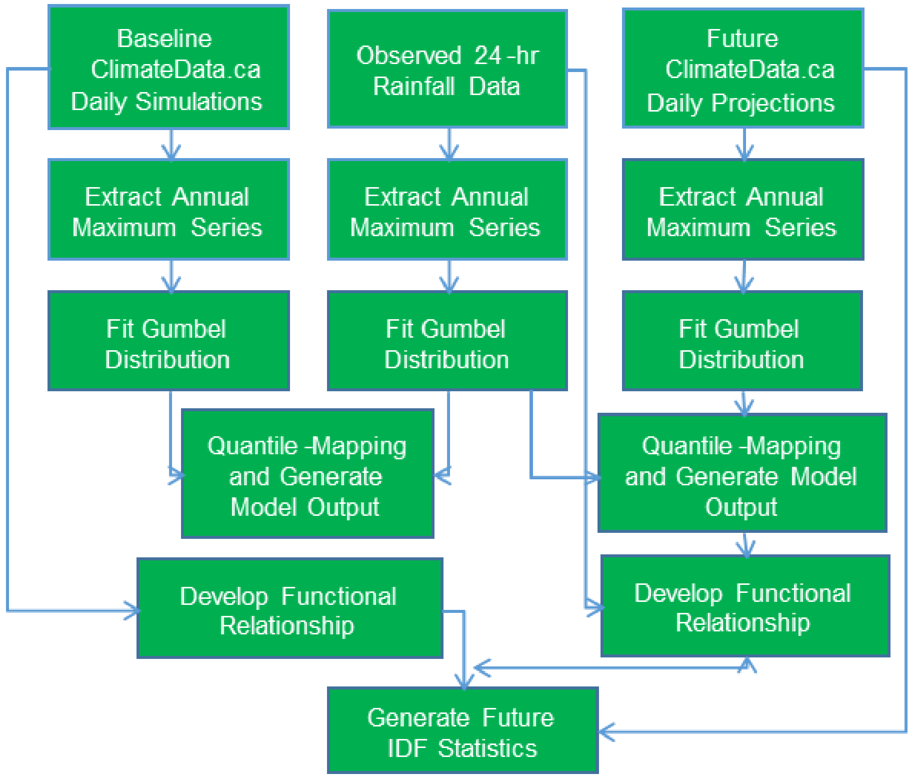

Figure 1: Flow Chart of EQM Method

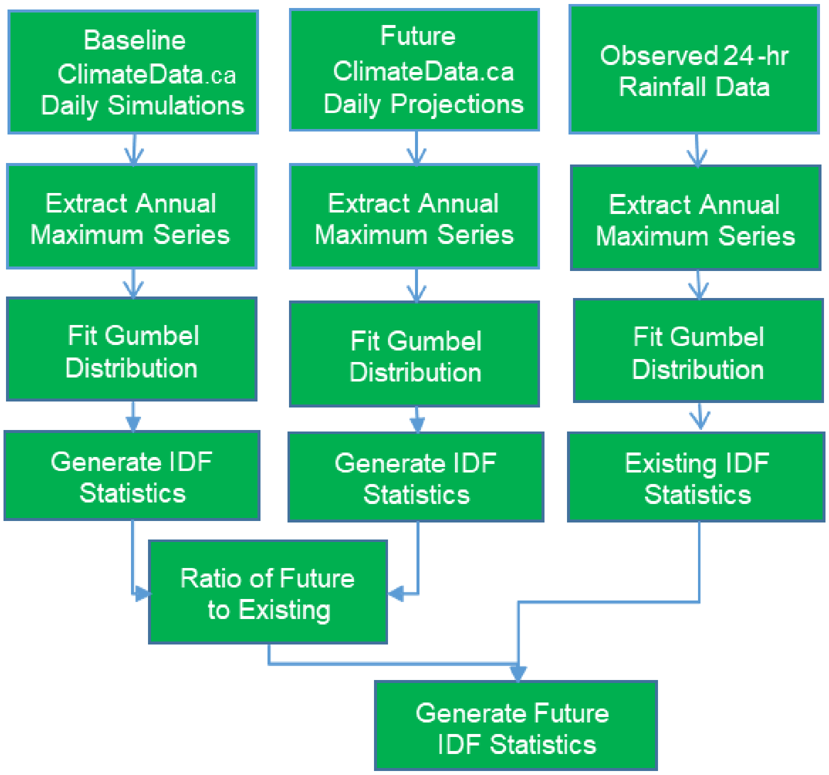

Figure 2: Flow Chart of the RM Method

3.5.1 Daily precipitation

Consistent with all future projections, the ensemble approach will be used. 1-day rainfall amounts for return periods of 2, 5, 10, 50, 100, 200, 500, 1000 and 2000 years in the future periods at different percentiles will be presented. The same methodology used in Section 2.5.1 will be used.

3.5.2 Multi-day precipitation

Consistent with all future projections, the ensemble approach will be used. 1-day, 2-day, 3-day, 4-day, 5-day, 10-day, 20-day, 30-day, 50-day, 75-day, 90-day and 120-day consecutive rainfall amounts for return periods of 2, 5, 10, 50, 100, 200, 500, 1000 and 2000 years in the future periods at different percentiles will be presented. The same methodology used in Section 2.5.2 will be used.

3.6 Projecting Extreme Rainfall and Snowmelt Statistics

The combined daily rainfall and snowmelt was calculated for all the combinations of RCPs and GCMs using the approach discussed in Section 2.8 for the baseline (1971-2018) and future periods (2050s and 2080s) using the GCMs daily precipitation and temperature data. The changes in rainfall and snowmelt events at various return periods were then described.

3.7 Projecting Future Climate During the Spring Transition Period

Consideration of climate change impacts during spring melt conditions are important, as this time of the year can be critical for generating extreme runoff amounts. The transition from winter to spring can result in combined rainfall and snowmelt on frozen ground. This has the potential to create large amounts of excess precipitation which does not infiltrate and contributes directly to runoff. To examine climate change impacts during the spring transition, statistics for rain, snow, and snowpack have been calculated separately for five periods in the spring months corresponding to:

- Period 1 – March 19th to 31st
- Period 2 – April 1st to 15th
- Period 3 – April 16th to 30th
- Period 4 – May 1st to 15th
- Period 5 – May 16th to 31st

Daily precipitation amounts are first separated into rain and snow based on daily temperatures. For temperatures of 0°C and below, precipitation is assumed to fall as snow, while for temperatures greater than 0°C precipitation is assumed to fall as rain. Spring IDF statistics have been calculated using daily precipitation amounts across the spring transition period (Period 1 through Period 5) following the same calculation procedure as for the future rainfall statistics in Appendix Section 2.9.

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APPENDIX B

Additional Future Climate Rainfall Statistics

1.0 ADDITIONAL FUTURE CLIMATE RAINFALL STATISTICS

This appendix contains more information on the future climate projections that have been presented in the main body of report. As described in Section 6, due to inherent uncertainty with projections, the climate projections presented in the main body of report for the 50th percentile represent the ensemble median projections.

The results presented in this Appendix present all percentiles from 5th to 99th. In addition to the probability exceedance levels data on minimum, maximum, mean and standard deviation of the ensemble are also provided. Using the median or 50th percentile provides an indication of middle of the projected changes from the multi-model ensemble. The difference between median and mean provides an indication for how the range of projections are distributed. For example, if the mean is below the median, the majority of the ensemble members are projecting lower values than the median, with a few higher projections from a small number of ensemble members. This information could be used as part of a more detailed risk or cost benefit assessment.

1.1 Projection to 2050s

Table 1: Summary of the Projected Changes (%) in 1-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-21.0%	-28.4%	-31.5%	-33.7%	-35.8%	-38.8%	-41.2%	-43.9%	-45.5%	-47.0%
5%	-5.8%	-11.7%	-15.0%	-16.5%	-18.4%	-20.3%	-21.8%	-23.5%	-24.6%	-25.5%
10%	-0.9%	-6.4%	-8.5%	-10.2%	-12.5%	-14.3%	-15.8%	-17.0%	-17.3%	-17.5%
50%	12.2%	11.8%	10.8%	10.5%	9.7%	9.5%	8.7%	8.2%	7.9%	7.8%
75%	23.5%	23.2%	24.1%	26.0%	27.2%	27.8%	27.7%	27.5%	27.7%	27.9%
90%	31.8%	37.5%	40.3%	42.2%	47.1%	50.3%	52.0%	53.1%	54.4%	55.5%
95%	43.6%	59.4%	61.6%	67.2%	71.6%	71.7%	72.0%	74.1%	75.0%	75.2%
99%	78.3%	94.7%	104.9%	113.2%	124.4%	130.9%	136.3%	142.1%	145.7%	148.9%
Maximum	108.4%	151.9%	169.7%	182.4%	194.8%	202.0%	207.9%	214.3%	218.3%	221.8%
Mean	15.0%	15.2%	15.3%	15.4%	15.4%	15.5%	15.5%	15.6%	15.6%	15.6%
Standard deviation	18.1%	23.1%	26.0%	28.3%	30.6%	31.9%	33.1%	34.4%	35.2%	35.9%

Table 2: Summary of the Projected Changes (%) in 2-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-16.4%	-26.9%	-31.1%	-34.2%	-37.1%	-38.8%	-40.3%	-41.8%	-42.7%	-43.6%
5%	-2.4%	-9.8%	-13.9%	-17.7%	-20.1%	-21.2%	-22.1%	-23.9%	-25.3%	-26.5%
10%	-0.5%	-7.1%	-10.2%	-12.8%	-15.8%	-17.4%	-18.7%	-20.2%	-21.1%	-21.8%
50%	12.1%	11.0%	11.3%	11.3%	11.2%	11.2%	11.0%	11.0%	11.1%	10.8%
75%	25.2%	25.9%	27.3%	29.3%	30.8%	31.5%	32.6%	33.7%	34.5%	35.3%
90%	37.9%	44.3%	46.3%	49.1%	51.8%	53.4%	54.7%	56.2%	57.3%	58.2%
95%	55.6%	73.8%	77.2%	79.9%	83.6%	83.9%	84.0%	83.9%	84.0%	84.3%
99%	84.9%	104.6%	124.8%	139.6%	154.0%	162.5%	169.9%	178.0%	183.2%	187.7%
Maximum	106.3%	172.9%	200.1%	219.5%	238.2%	249.1%	258.1%	267.7%	273.8%	279.1%
Mean	17.2%	17.7%	18.0%	18.3%	18.5%	18.7%	18.8%	18.9%	19.0%	19.1%
Standard deviation	19.9%	26.9%	30.6%	33.5%	36.3%	38.0%	39.4%	41.0%	42.0%	42.8%

Table 3: Summary of the Projected Changes (%) in 3-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-16.0%	-25.3%	-29.3%	-32.1%	-34.9%	-36.6%	-37.9%	-39.4%	-40.3%	-41.2%
5%	-2.0%	-8.0%	-11.5%	-13.9%	-16.4%	-18.3%	-19.3%	-20.2%	-20.8%	-21.4%
10%	1.4%	-4.2%	-7.2%	-10.5%	-13.0%	-14.2%	-15.3%	-16.3%	-16.9%	-17.4%
50%	11.2%	13.3%	12.8%	13.2%	13.5%	13.8%	13.8%	14.0%	14.2%	14.4%
75%	21.8%	28.0%	27.5%	29.3%	31.3%	32.5%	33.9%	35.5%	35.9%	36.2%
90%	36.7%	48.8%	47.5%	50.1%	53.1%	54.6%	56.2%	58.8%	59.6%	60.6%
95%	55.7%	61.4%	68.7%	78.5%	79.4%	79.6%	81.5%	84.0%	85.7%	87.3%
99%	71.8%	101.2%	115.3%	130.0%	145.2%	154.2%	161.7%	169.9%	175.2%	180.0%
Maximum	82.5%	122.0%	143.7%	159.4%	174.7%	183.8%	191.3%	199.4%	204.6%	209.1%
Mean	16.2%	17.8%	18.5%	19.0%	19.6%	19.9%	20.2%	20.5%	20.7%	20.9%
Standard deviation	16.9%	23.5%	27.2%	30.1%	33.0%	34.8%	36.3%	37.9%	38.9%	39.8%

Table 4: Summary of the Projected Changes (%) in 4-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-15.6%	-23.9%	-27.3%	-29.8%	-32.3%	-33.7%	-34.9%	-36.2%	-37.0%	-37.7%
5%	-0.5%	-6.7%	-10.4%	-13.0%	-15.7%	-17.4%	-18.7%	-20.3%	-21.2%	-22.0%
10%	1.6%	-3.7%	-7.2%	-9.9%	-12.6%	-14.3%	-15.8%	-16.9%	-17.7%	-18.2%
50%	12.2%	12.7%	11.9%	12.1%	11.8%	11.7%	12.1%	12.6%	12.7%	12.8%
75%	22.5%	25.9%	28.1%	29.4%	29.9%	31.3%	31.6%	32.7%	33.8%	34.3%
90%	33.5%	40.6%	45.1%	47.7%	49.4%	51.1%	52.5%	54.1%	55.0%	56.0%
95%	48.1%	53.9%	67.5%	70.0%	72.0%	73.2%	74.2%	75.0%	75.4%	75.7%
99%	68.9%	91.3%	103.2%	116.7%	130.3%	138.4%	145.1%	152.8%	157.9%	162.2%
Maximum	80.2%	103.1%	122.2%	136.0%	149.5%	157.4%	163.9%	171.1%	175.5%	179.5%
Mean	15.8%	16.7%	17.2%	17.5%	17.9%	18.1%	18.3%	18.5%	18.6%	18.7%
Standard deviation	15.7%	21.2%	24.5%	27.1%	29.8%	31.4%	32.8%	34.3%	35.2%	36.1%

Table 5: Summary of the Projected Changes (%) in 5-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-12.4%	-21.1%	-24.9%	-27.5%	-30.2%	-31.8%	-33.1%	-34.5%	-35.4%	-36.2%
5%	-2.2%	-5.1%	-10.2%	-13.9%	-16.9%	-18.2%	-19.7%	-21.4%	-22.5%	-23.5%
10%	2.8%	-2.8%	-6.1%	-8.3%	-10.8%	-12.2%	-13.3%	-14.5%	-15.5%	-16.3%
50%	12.3%	11.9%	12.5%	12.1%	12.2%	11.7%	11.2%	10.7%	10.4%	10.0%
75%	22.5%	24.2%	26.0%	26.4%	27.7%	28.6%	29.3%	29.0%	29.6%	30.2%
90%	32.6%	43.4%	46.0%	47.4%	50.8%	52.6%	54.1%	55.8%	56.9%	57.9%
95%	46.3%	57.5%	64.6%	67.3%	71.1%	73.5%	75.6%	77.9%	78.8%	79.2%
99%	66.7%	86.4%	99.5%	111.0%	124.9%	132.7%	139.1%	146.2%	150.7%	154.6%
Maximum	73.1%	94.7%	110.0%	121.2%	132.6%	140.2%	146.4%	153.3%	157.6%	161.4%
Mean	16.1%	16.8%	17.2%	17.5%	17.8%	18.0%	18.2%	18.3%	18.4%	18.5%
Standard deviation	15.3%	20.2%	23.3%	25.7%	28.3%	29.8%	31.1%	32.5%	33.5%	34.3%

Table 6: Summary of the Projected Changes (%) in 6-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-12.7%	-19.5%	-22.5%	-24.6%	-26.7%	-28.0%	-29.0%	-30.1%	-31.4%	-33.0%
5%	-1.8%	-6.8%	-10.7%	-14.6%	-16.9%	-18.1%	-19.0%	-20.0%	-20.6%	-21.2%
10%	1.9%	-2.5%	-5.2%	-7.4%	-10.1%	-11.5%	-12.8%	-14.2%	-15.0%	-15.8%
50%	12.1%	13.3%	12.7%	11.8%	12.0%	11.3%	10.6%	10.1%	9.8%	9.5%
75%	22.2%	22.2%	23.0%	25.2%	27.2%	27.6%	27.9%	28.2%	28.3%	28.3%
90%	32.7%	41.8%	43.7%	46.6%	49.7%	51.6%	52.8%	53.6%	55.1%	56.8%
95%	45.5%	57.2%	63.1%	66.8%	70.0%	72.8%	75.2%	77.7%	79.3%	80.6%
99%	63.6%	77.0%	86.1%	93.4%	104.3%	111.3%	117.3%	123.9%	128.1%	131.8%
Maximum	66.2%	94.2%	108.9%	119.5%	130.0%	136.2%	141.3%	146.9%	150.5%	153.5%
Mean	15.6%	16.1%	16.3%	16.5%	16.7%	16.8%	17.0%	17.1%	17.2%	17.2%
Standard deviation	14.7%	19.3%	22.2%	24.5%	26.8%	28.3%	29.5%	30.8%	31.7%	32.5%

Table 7: Summary of the Projected Changes (%) in 7-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-15.5%	-21.7%	-24.3%	-26.3%	-28.2%	-29.3%	-30.2%	-31.2%	-33.1%	-34.7%
5%	0.1%	-6.4%	-10.5%	-13.4%	-17.0%	-19.4%	-20.8%	-22.8%	-24.2%	-25.4%
10%	2.8%	-2.8%	-6.7%	-9.4%	-12.4%	-13.8%	-14.7%	-15.7%	-16.4%	-17.0%
50%	11.4%	11.9%	11.6%	10.7%	10.1%	9.8%	9.4%	9.3%	9.3%	9.4%
75%	19.8%	21.7%	24.3%	25.6%	25.5%	25.8%	26.3%	27.0%	27.6%	27.9%
90%	32.2%	41.8%	46.6%	47.7%	51.2%	52.8%	53.6%	54.9%	56.0%	57.0%
95%	47.9%	58.3%	65.3%	67.0%	72.7%	75.6%	76.5%	77.8%	79.1%	80.2%
99%	64.3%	72.3%	83.6%	92.2%	101.3%	107.9%	113.5%	119.7%	123.8%	127.4%
Maximum	65.9%	85.3%	97.4%	106.2%	114.9%	120.0%	124.2%	128.8%	131.8%	134.3%
Mean	15.5%	15.7%	15.8%	15.9%	16.0%	16.1%	16.2%	16.3%	16.3%	16.4%
Standard deviation	14.9%	19.5%	22.3%	24.6%	26.9%	28.3%	29.5%	30.8%	31.7%	32.4%

Table 8: Summary of the Projected Changes (%) in 10-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-11.2%	-18.0%	-20.9%	-23.1%	-25.3%	-26.5%	-28.7%	-31.6%	-33.4%	-35.0%
5%	1.0%	-4.7%	-8.1%	-10.5%	-12.8%	-14.1%	-15.6%	-17.1%	-18.1%	-19.0%
10%	1.7%	-2.4%	-4.6%	-6.4%	-8.4%	-10.0%	-11.1%	-12.4%	-13.2%	-14.1%
50%	12.2%	11.5%	11.9%	11.4%	10.7%	10.1%	9.9%	9.6%	9.7%	9.4%
75%	20.9%	21.1%	23.8%	24.0%	26.7%	27.1%	27.3%	27.5%	28.1%	28.7%
90%	31.1%	37.0%	40.1%	43.8%	48.4%	49.5%	51.0%	51.1%	50.6%	50.7%
95%	39.1%	50.8%	55.6%	57.6%	62.9%	66.0%	68.4%	70.4%	71.7%	72.9%
99%	61.3%	60.3%	66.6%	75.9%	85.9%	88.6%	90.8%	93.6%	95.3%	96.8%
Maximum	70.0%	78.6%	82.3%	85.0%	87.8%	95.4%	101.9%	109.2%	113.8%	117.9%
Mean	15.1%	14.9%	14.9%	14.9%	14.9%	15.0%	15.0%	15.0%	15.0%	15.0%
Standard deviation	13.4%	16.6%	18.9%	20.8%	22.9%	24.2%	25.2%	26.5%	27.2%	27.9%

Table 9: Summary of the Projected Changes (%) in 20-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-3.6%	-11.4%	-14.8%	-17.2%	-19.6%	-21.3%	-22.7%	-24.2%	-25.2%	-26.1%
5%	0.1%	-2.5%	-4.9%	-7.4%	-10.2%	-11.8%	-13.2%	-14.9%	-16.0%	-17.0%
10%	2.5%	-0.2%	-2.8%	-5.3%	-8.0%	-9.1%	-10.2%	-11.5%	-12.4%	-13.2%
50%	11.6%	10.7%	10.4%	10.2%	8.9%	8.7%	8.4%	8.3%	8.1%	8.0%
75%	18.8%	20.1%	21.0%	21.3%	22.2%	22.7%	23.2%	23.7%	24.2%	24.8%
90%	29.6%	30.9%	34.2%	35.3%	38.3%	38.4%	38.6%	39.3%	40.3%	41.6%
95%	34.3%	40.8%	43.2%	45.0%	47.2%	48.9%	51.1%	53.4%	54.7%	56.1%
99%	51.6%	57.5%	69.6%	80.1%	87.4%	90.2%	93.0%	96.0%	98.0%	99.7%
Maximum	79.0%	83.4%	85.4%	87.0%	95.0%	103.0%	109.8%	117.4%	122.3%	126.6%
Mean	14.2%	13.9%	13.8%	13.8%	13.7%	13.7%	13.7%	13.7%	13.7%	13.7%
Standard deviation	11.8%	14.5%	16.5%	18.2%	20.1%	21.3%	22.3%	23.4%	24.1%	24.8%

Table 10: Summary of the Projected Changes (%) in 30-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-1.6%	-12.1%	-17.0%	-20.7%	-24.6%	-27.0%	-29.0%	-31.2%	-32.7%	-33.9%
5%	1.0%	-0.6%	-4.6%	-7.8%	-10.9%	-12.7%	-14.2%	-15.9%	-17.0%	-18.0%
10%	3.7%	0.9%	-1.7%	-4.0%	-6.7%	-7.9%	-8.9%	-10.3%	-11.4%	-12.5%
50%	12.3%	12.1%	11.0%	11.0%	11.0%	11.0%	10.8%	10.8%	10.1%	9.8%
75%	19.5%	20.4%	21.3%	22.6%	24.0%	24.7%	25.1%	25.7%	26.2%	26.8%
90%	28.6%	30.4%	33.3%	33.4%	33.3%	33.1%	32.8%	34.3%	35.2%	36.1%
95%	39.5%	39.8%	45.3%	46.9%	48.6%	51.7%	54.6%	57.9%	59.0%	59.9%
99%	45.5%	54.1%	58.6%	63.7%	68.8%	72.0%	74.7%	78.6%	80.4%	81.7%
Maximum	74.1%	76.1%	77.1%	77.8%	78.5%	79.0%	79.3%	79.8%	82.2%	85.1%
Mean	14.9%	14.3%	14.0%	13.9%	13.7%	13.6%	13.5%	13.4%	13.4%	13.3%
Standard deviation	11.3%	13.5%	15.3%	16.9%	18.7%	19.8%	20.7%	21.8%	22.5%	23.2%

Table 11: Summary of the Projected Changes (%) in 50-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-2.3%	-7.1%	-11.3%	-14.6%	-18.1%	-20.2%	-22.0%	-24.0%	-25.4%	-26.6%
5%	1.1%	-0.7%	-5.2%	-7.3%	-10.0%	-11.0%	-12.3%	-14.1%	-15.6%	-16.4%
10%	3.8%	0.5%	-1.4%	-3.2%	-5.5%	-6.8%	-7.9%	-9.1%	-9.8%	-10.2%
50%	12.2%	12.1%	13.0%	12.4%	11.4%	10.7%	10.3%	10.3%	10.2%	9.9%
75%	19.7%	20.6%	21.1%	22.2%	21.6%	22.3%	22.6%	23.4%	24.0%	24.4%
90%	29.5%	31.5%	33.6%	36.0%	38.2%	39.7%	39.9%	39.9%	39.9%	40.0%
95%	35.5%	39.4%	41.3%	42.7%	46.1%	47.3%	49.1%	52.0%	53.9%	55.6%
99%	46.7%	52.5%	56.6%	59.9%	63.8%	66.8%	69.4%	72.3%	74.3%	75.6%
Maximum	60.1%	64.8%	67.1%	68.8%	70.6%	71.8%	72.8%	73.8%	74.6%	76.0%
Mean	14.6%	14.3%	14.1%	14.0%	13.9%	13.9%	13.8%	13.8%	13.8%	13.7%
Standard deviation	10.7%	12.8%	14.5%	15.9%	17.5%	18.5%	19.4%	20.4%	21.0%	21.6%

Table 12: Summary of the Projected Changes (%) in 75-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-5.8%	-6.5%	-8.6%	-11.9%	-15.5%	-19.0%	-21.9%	-25.3%	-27.5%	-29.4%
5%	1.3%	-0.2%	-2.2%	-4.4%	-6.8%	-7.5%	-8.4%	-10.2%	-11.6%	-12.9%
10%	4.1%	2.5%	0.7%	-0.7%	-2.6%	-3.6%	-4.4%	-5.1%	-5.9%	-6.5%
50%	12.4%	12.2%	12.0%	11.8%	11.8%	12.0%	12.2%	12.1%	11.9%	11.7%
75%	19.9%	20.3%	21.5%	21.7%	22.8%	23.2%	24.2%	24.2%	24.6%	24.8%
90%	27.1%	30.3%	31.6%	33.9%	36.0%	37.9%	39.6%	40.8%	41.1%	41.3%
95%	33.9%	36.1%	36.4%	40.0%	41.2%	41.2%	41.7%	43.5%	45.2%	46.9%
99%	42.8%	44.1%	47.7%	51.1%	54.8%	57.0%	58.0%	59.2%	60.8%	62.4%
Maximum	54.8%	55.9%	56.5%	57.0%	57.5%	57.8%	59.9%	62.3%	63.9%	65.2%
Mean	14.4%	14.3%	14.3%	14.3%	14.3%	14.3%	14.4%	14.4%	14.4%	14.4%
Standard deviation	10.0%	11.3%	12.5%	13.6%	14.9%	15.8%	16.6%	17.4%	18.0%	18.6%

Table 13: Summary of the Projected Changes (%) in 90-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-3.7%	-5.5%	-10.2%	-13.6%	-17.1%	-19.7%	-22.5%	-25.8%	-27.9%	-29.8%
5%	0.7%	-0.1%	-1.8%	-3.6%	-6.1%	-7.2%	-8.0%	-9.6%	-10.6%	-11.4%
10%	3.9%	1.9%	0.2%	-1.1%	-2.5%	-3.2%	-4.2%	-5.6%	-6.5%	-7.3%
50%	12.8%	12.4%	12.4%	12.8%	12.9%	12.9%	12.8%	13.1%	13.0%	12.6%
75%	19.8%	20.1%	21.6%	22.0%	22.9%	23.3%	24.0%	24.7%	24.9%	25.1%
90%	28.0%	28.6%	31.4%	30.8%	32.2%	33.4%	33.9%	34.7%	35.7%	36.6%
95%	33.5%	34.7%	34.8%	36.1%	38.3%	38.7%	39.8%	41.5%	42.6%	43.6%
99%	38.9%	41.7%	43.3%	44.2%	45.1%	47.5%	49.9%	52.6%	54.3%	55.9%
Maximum	47.0%	46.1%	48.5%	51.6%	54.9%	57.0%	58.8%	60.8%	62.1%	63.3%
Mean	14.4%	14.2%	14.1%	14.0%	13.9%	13.9%	13.8%	13.8%	13.8%	13.7%
Standard deviation	9.6%	10.5%	11.5%	12.5%	13.7%	14.5%	15.2%	16.1%	16.6%	17.1%

Table 14: Summary of the Projected Changes (%) in 120-Day Rainfall in 2050s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	0.3%	-3.8%	-8.0%	-11.1%	-14.4%	-16.3%	-18.0%	-19.9%	-21.0%	-22.1%
5%	2.4%	1.5%	-0.3%	-2.5%	-4.8%	-6.3%	-7.5%	-8.8%	-9.7%	-10.6%
10%	5.2%	4.1%	2.0%	1.4%	-0.4%	-2.1%	-3.2%	-4.6%	-5.7%	-6.6%
50%	13.3%	13.5%	13.4%	14.5%	14.9%	15.2%	15.4%	15.7%	15.8%	15.9%
75%	20.6%	22.5%	22.2%	23.4%	23.7%	25.3%	25.7%	26.2%	26.6%	27.2%
90%	29.3%	30.1%	31.6%	33.3%	35.4%	37.3%	37.7%	38.4%	38.4%	38.5%
95%	32.8%	34.2%	36.9%	37.2%	39.6%	41.6%	42.7%	44.8%	45.6%	46.5%
99%	39.8%	42.6%	45.5%	47.4%	49.4%	50.6%	52.1%	54.7%	56.4%	57.9%
Maximum	42.6%	44.4%	46.0%	48.5%	51.2%	52.9%	54.3%	56.0%	57.1%	58.1%
Mean	15.2%	15.3%	15.4%	15.5%	15.6%	15.7%	15.7%	15.8%	15.8%	15.9%
Standard deviation	9.2%	10.1%	11.2%	12.3%	13.5%	14.4%	15.1%	16.0%	16.6%	17.2%

1.2 Projection to 2080s

Table 15: Summary of the Projected Changes (%) in 1-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-15.1%	-15.2%	-17.5%	-19.2%	-21.0%	-22.4%	-23.6%	-24.8%	-26.0%	-27.2%
5%	-2.5%	-5.6%	-7.8%	-10.3%	-12.3%	-13.6%	-14.9%	-15.8%	-16.4%	-16.8%
10%	-0.9%	-2.2%	-3.7%	-4.6%	-6.6%	-8.1%	-9.2%	-9.9%	-10.4%	-10.9%
50%	18.6%	20.5%	21.8%	24.0%	24.7%	23.9%	23.4%	22.9%	23.0%	23.1%
75%	37.8%	42.1%	44.5%	47.2%	47.6%	47.3%	47.7%	47.6%	47.9%	48.6%
90%	54.5%	58.7%	62.6%	64.7%	66.7%	68.6%	71.0%	73.0%	74.1%	75.1%
95%	65.4%	82.9%	91.0%	95.1%	96.2%	95.5%	95.0%	94.5%	95.7%	96.8%
99%	110.1%	123.8%	138.1%	146.7%	151.3%	154.5%	157.1%	159.9%	161.7%	163.2%
Maximum	159.4%	161.1%	161.8%	168.2%	181.9%	190.0%	196.6%	203.7%	208.2%	212.1%
Mean	24.7%	27.0%	28.0%	28.7%	29.4%	29.8%	30.1%	30.5%	30.7%	30.9%
Standard deviation	25.6%	29.2%	31.4%	33.3%	35.1%	36.3%	37.3%	38.3%	39.0%	39.6%

Table 16: Summary of the Projected Changes (%) in 2-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-11.5%	-21.2%	-26.7%	-30.5%	-34.3%	-36.5%	-38.3%	-40.3%	-41.5%	-42.6%
5%	-2.4%	-7.5%	-10.3%	-13.6%	-17.1%	-19.0%	-20.4%	-21.7%	-22.6%	-23.3%
10%	2.4%	-2.3%	-5.4%	-8.3%	-9.9%	-11.2%	-12.1%	-12.9%	-13.2%	-13.4%
50%	22.1%	25.8%	27.6%	28.0%	27.3%	27.6%	27.7%	28.3%	28.7%	28.7%
75%	37.5%	41.2%	46.2%	47.2%	49.3%	52.1%	52.7%	53.9%	53.8%	54.5%
90%	62.4%	71.2%	77.5%	79.2%	77.6%	79.2%	82.0%	85.8%	88.2%	89.4%
95%	80.4%	86.2%	93.3%	96.8%	104.3%	111.0%	116.4%	120.3%	122.8%	124.9%
99%	98.4%	143.3%	163.7%	178.2%	192.2%	200.4%	207.1%	214.3%	218.9%	222.8%
Maximum	225.2%	238.2%	243.5%	247.3%	251.0%	253.1%	254.9%	256.8%	257.9%	259.0%
Mean	27.7%	30.8%	32.1%	33.0%	33.9%	34.5%	34.9%	35.4%	35.7%	36.0%
Standard deviation	28.7%	33.8%	36.8%	39.2%	41.7%	43.2%	44.5%	45.8%	46.7%	47.5%

Table 17: Summary of the Projected Changes (%) in 3-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-13.6%	-17.2%	-22.6%	-26.5%	-30.3%	-32.5%	-34.4%	-36.4%	-37.7%	-38.8%
5%	-2.7%	-8.8%	-10.9%	-12.1%	-14.6%	-16.1%	-17.4%	-18.8%	-19.7%	-20.5%
10%	3.6%	-1.7%	-5.2%	-6.9%	-7.6%	-8.4%	-9.9%	-11.6%	-12.0%	-12.3%
50%	20.4%	25.8%	27.7%	28.7%	28.8%	29.1%	28.7%	28.5%	28.6%	29.0%
75%	35.8%	39.9%	45.5%	48.7%	54.3%	56.8%	58.6%	60.5%	61.1%	61.5%
90%	55.6%	66.3%	71.5%	75.0%	78.5%	80.5%	82.4%	85.1%	86.9%	88.0%
95%	72.3%	85.4%	96.7%	99.4%	108.4%	114.7%	118.6%	122.6%	125.1%	127.9%
99%	94.6%	123.3%	142.3%	156.0%	170.8%	180.2%	188.0%	193.2%	195.5%	197.6%
Maximum	198.9%	212.4%	218.1%	222.3%	226.3%	228.7%	230.7%	238.7%	245.3%	251.1%
Mean	25.6%	29.4%	31.1%	32.3%	33.5%	34.2%	34.8%	35.4%	35.8%	36.1%
Standard deviation	25.9%	31.2%	34.5%	37.1%	39.8%	41.5%	42.8%	44.4%	45.4%	46.2%

Table 18: Summary of the Projected Changes (%) in 4-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-13.2%	-15.8%	-21.1%	-24.9%	-28.7%	-30.9%	-32.7%	-34.7%	-35.9%	-37.0%
5%	-1.9%	-7.1%	-9.8%	-12.4%	-15.2%	-16.9%	-18.3%	-19.6%	-20.3%	-21.0%
10%	3.5%	-1.0%	-5.2%	-6.8%	-7.5%	-7.8%	-8.2%	-9.7%	-10.7%	-11.5%
50%	19.8%	24.4%	26.4%	27.3%	26.9%	26.9%	26.5%	26.0%	26.3%	26.4%
75%	33.1%	39.4%	43.2%	46.3%	50.6%	52.4%	53.7%	54.8%	56.1%	57.0%
90%	49.7%	65.1%	66.9%	68.9%	76.6%	78.1%	80.2%	80.8%	81.2%	81.3%
95%	72.9%	84.0%	89.8%	93.6%	98.8%	101.3%	103.4%	105.8%	107.3%	108.8%
99%	92.0%	111.8%	133.0%	142.8%	147.9%	150.8%	153.3%	155.9%	157.6%	159.0%
Maximum	159.7%	161.3%	161.9%	172.3%	190.6%	201.3%	210.2%	219.8%	225.9%	231.2%
Mean	25.0%	28.1%	29.4%	30.4%	31.4%	32.0%	32.5%	33.0%	33.3%	33.6%
Standard deviation	23.5%	28.3%	31.4%	34.0%	36.6%	38.3%	39.7%	41.2%	42.1%	43.0%

Table 19: Summary of the Projected Changes (%) in 5-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-9.5%	-14.4%	-16.9%	-20.6%	-25.0%	-27.6%	-29.8%	-32.1%	-33.6%	-34.9%
5%	0.9%	-6.1%	-8.6%	-11.1%	-12.2%	-13.3%	-14.7%	-16.3%	-17.1%	-17.4%
10%	4.0%	1.0%	-0.7%	-3.0%	-5.4%	-6.4%	-7.8%	-9.4%	-10.4%	-11.1%
50%	19.9%	24.6%	24.3%	23.3%	23.5%	23.3%	23.7%	24.1%	24.2%	24.3%
75%	35.4%	40.9%	43.6%	45.8%	51.1%	54.1%	54.5%	55.0%	55.7%	56.3%
90%	50.8%	62.1%	64.7%	69.4%	75.6%	77.1%	79.4%	81.7%	83.1%	84.4%
95%	69.5%	74.7%	83.6%	88.2%	93.5%	95.4%	97.1%	98.9%	100.4%	103.1%
99%	90.8%	120.4%	134.7%	138.4%	142.1%	144.3%	146.1%	148.0%	149.3%	150.4%
Maximum	143.8%	148.1%	158.2%	177.1%	195.7%	206.7%	215.9%	225.8%	232.1%	237.6%
Mean	25.0%	28.0%	29.3%	30.3%	31.3%	31.9%	32.4%	32.9%	33.2%	33.5%
Standard deviation	22.3%	27.0%	30.2%	32.7%	35.4%	37.0%	38.4%	39.9%	40.9%	41.8%

Table 20: Summary of the Projected Changes (%) in 6-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-9.8%	-14.3%	-19.3%	-23.7%	-28.1%	-30.7%	-32.8%	-35.1%	-36.6%	-37.8%
5%	-0.3%	-7.3%	-9.0%	-10.9%	-12.7%	-14.3%	-15.0%	-16.1%	-17.0%	-17.8%
10%	3.1%	0.9%	-3.5%	-5.6%	-7.0%	-8.5%	-8.8%	-9.4%	-10.2%	-11.0%
50%	18.9%	22.0%	22.8%	22.8%	22.2%	22.2%	22.4%	22.6%	22.6%	22.7%
75%	32.6%	38.1%	41.5%	41.2%	42.8%	45.8%	48.7%	51.6%	52.4%	52.5%
90%	51.3%	58.2%	61.1%	63.8%	68.1%	71.3%	73.4%	75.4%	76.9%	78.2%
95%	69.5%	69.2%	82.0%	83.8%	91.9%	97.1%	102.6%	105.1%	107.6%	109.5%
99%	97.8%	123.8%	142.2%	147.1%	151.9%	154.8%	157.1%	159.7%	161.4%	162.8%
Maximum	141.8%	149.7%	154.3%	172.4%	190.3%	200.9%	209.6%	219.2%	225.2%	230.5%
Mean	24.1%	26.5%	27.5%	28.3%	29.1%	29.5%	29.9%	30.3%	30.6%	30.8%
Standard deviation	22.5%	26.9%	29.9%	32.2%	34.7%	36.3%	37.6%	39.0%	39.9%	40.8%

Table 21: Summary of the Projected Changes (%) in 7-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-11.4%	-17.2%	-23.1%	-27.4%	-31.6%	-34.1%	-36.2%	-38.4%	-39.9%	-41.1%
5%	-2.2%	-7.8%	-10.6%	-11.6%	-12.7%	-14.4%	-15.4%	-16.8%	-17.3%	-17.7%
10%	2.4%	-0.7%	-3.8%	-5.6%	-7.3%	-8.4%	-9.6%	-11.0%	-12.0%	-12.8%
50%	18.9%	22.2%	22.3%	23.4%	22.0%	22.0%	21.9%	22.0%	22.2%	22.2%
75%	33.3%	37.5%	40.3%	41.2%	44.7%	46.0%	46.9%	47.8%	49.4%	50.2%
90%	52.9%	57.1%	58.3%	63.1%	66.1%	67.9%	70.4%	71.8%	73.1%	74.9%
95%	69.1%	78.6%	87.0%	85.9%	88.5%	90.7%	92.4%	96.1%	98.6%	100.6%
99%	96.4%	120.6%	138.4%	142.5%	146.6%	149.0%	151.0%	153.4%	155.5%	157.3%
Maximum	148.4%	157.8%	163.7%	183.4%	202.9%	214.4%	224.0%	234.4%	241.0%	246.8%
Mean	24.1%	26.3%	27.3%	28.0%	28.7%	29.1%	29.5%	29.9%	30.1%	30.3%
Standard deviation	22.9%	27.1%	30.0%	32.3%	34.8%	36.4%	37.7%	39.1%	40.0%	40.9%

Table 22: Summary of the Projected Changes (%) in 10-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-6.5%	-8.3%	-13.9%	-18.1%	-22.2%	-24.6%	-26.7%	-28.9%	-30.3%	-31.6%
5%	1.8%	-3.9%	-7.0%	-9.5%	-12.3%	-13.9%	-15.1%	-16.5%	-17.4%	-18.1%
10%	4.2%	-0.6%	-1.8%	-4.6%	-5.7%	-5.9%	-6.1%	-6.8%	-7.4%	-7.8%
50%	19.4%	21.1%	21.1%	21.7%	22.3%	22.8%	23.2%	23.7%	23.7%	23.8%
75%	34.1%	38.4%	40.8%	42.5%	45.3%	47.0%	47.7%	48.9%	50.3%	51.5%
90%	51.3%	58.6%	63.6%	68.3%	72.9%	73.8%	74.6%	76.8%	77.3%	78.9%
95%	68.8%	74.9%	77.9%	80.2%	82.6%	83.9%	85.3%	87.4%	88.2%	89.1%
99%	100.2%	119.9%	120.6%	125.7%	131.7%	135.2%	138.2%	141.4%	143.5%	145.3%
Maximum	133.8%	165.1%	196.3%	219.3%	242.1%	255.7%	267.0%	279.4%	287.3%	294.1%
Mean	25.1%	27.1%	28.0%	28.7%	29.4%	29.8%	30.1%	30.5%	30.8%	31.0%
Standard deviation	22.0%	26.6%	29.6%	32.0%	34.6%	36.1%	37.5%	39.0%	39.9%	40.8%

Table 23: Summary of the Projected Changes (%) in 20-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-7.6%	-9.7%	-14.4%	-18.1%	-21.9%	-24.3%	-26.2%	-28.4%	-29.9%	-31.1%
5%	2.3%	-3.2%	-5.9%	-8.7%	-10.8%	-12.6%	-13.0%	-14.1%	-15.7%	-17.1%
10%	4.1%	0.4%	-2.7%	-4.5%	-6.8%	-8.7%	-10.0%	-11.3%	-12.2%	-13.0%
50%	18.1%	18.5%	18.6%	18.6%	18.9%	19.4%	19.6%	19.7%	19.7%	20.0%
75%	28.3%	31.9%	32.0%	32.7%	33.8%	34.6%	36.1%	37.7%	38.8%	39.6%
90%	44.9%	50.2%	53.3%	56.0%	60.0%	62.0%	63.7%	65.6%	66.8%	66.9%
95%	55.0%	64.9%	69.8%	73.4%	76.8%	78.8%	80.8%	83.0%	84.4%	85.4%
99%	83.6%	101.7%	107.1%	110.1%	117.9%	122.9%	127.0%	131.7%	134.7%	137.7%
Maximum	109.5%	118.2%	145.1%	167.5%	190.4%	204.5%	216.4%	229.6%	238.2%	245.7%
Mean	21.8%	22.8%	23.3%	23.7%	24.2%	24.4%	24.6%	24.9%	25.1%	25.2%
Standard deviation	18.1%	21.8%	24.5%	26.8%	29.3%	30.9%	32.3%	33.8%	34.9%	35.8%

Table 24: Summary of the Projected Changes (%) in 30-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-7.4%	-9.4%	-15.3%	-19.3%	-23.1%	-25.2%	-26.9%	-28.7%	-29.9%	-30.8%
5%	0.2%	-2.5%	-5.8%	-7.7%	-8.9%	-10.2%	-11.9%	-13.8%	-15.1%	-16.0%
10%	5.3%	2.2%	-1.6%	-4.2%	-6.6%	-8.1%	-8.6%	-9.5%	-9.9%	-10.5%
50%	18.1%	18.1%	18.7%	18.2%	17.1%	17.1%	16.4%	16.3%	16.3%	16.4%
75%	30.6%	29.7%	30.6%	32.7%	34.2%	33.9%	35.4%	37.0%	37.0%	37.4%
90%	46.4%	53.5%	56.0%	58.8%	60.6%	61.6%	63.0%	64.5%	65.5%	66.3%
95%	59.0%	69.9%	66.3%	68.4%	73.6%	76.8%	79.5%	82.6%	84.1%	85.0%
99%	80.4%	99.1%	107.9%	118.4%	129.8%	136.8%	142.7%	149.3%	153.6%	157.4%
Maximum	103.6%	141.7%	179.3%	208.0%	237.6%	255.7%	271.1%	288.2%	299.3%	309.1%
Mean	22.2%	22.8%	23.1%	23.3%	23.6%	23.8%	23.9%	24.1%	24.2%	24.3%
Standard deviation	18.3%	22.9%	26.2%	29.0%	32.0%	33.9%	35.6%	37.4%	38.7%	39.8%

Table 25: Summary of the Projected Changes (%) in 50-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-4.1%	-11.5%	-15.1%	-17.9%	-20.8%	-22.6%	-24.1%	-25.8%	-27.0%	-27.9%
5%	1.3%	-3.3%	-5.9%	-7.7%	-9.2%	-10.3%	-11.6%	-13.4%	-14.0%	-14.5%
10%	3.7%	3.1%	2.1%	0.7%	-2.1%	-3.9%	-5.4%	-6.9%	-7.7%	-8.6%
50%	16.8%	16.7%	15.8%	15.9%	17.0%	17.2%	17.5%	17.3%	17.0%	17.3%
75%	28.4%	27.9%	28.1%	29.5%	30.4%	31.3%	32.4%	33.2%	33.4%	33.8%
90%	44.8%	48.0%	48.5%	49.2%	49.9%	50.4%	51.2%	52.4%	53.5%	54.6%
95%	49.7%	58.4%	62.9%	66.3%	69.3%	70.6%	71.8%	73.2%	74.2%	75.0%
99%	66.1%	100.6%	114.2%	125.0%	138.6%	147.0%	154.2%	162.3%	167.6%	172.3%
Maximum	108.0%	131.0%	168.2%	197.0%	227.2%	245.9%	261.8%	279.8%	291.5%	301.9%
Mean	21.0%	21.5%	21.8%	22.1%	22.3%	22.5%	22.6%	22.8%	22.9%	23.0%
Standard deviation	16.8%	21.0%	24.1%	26.8%	29.9%	31.8%	33.5%	35.4%	36.7%	37.8%

Table 26: Summary of the Projected Changes (%) in 75-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-3.6%	-10.2%	-13.5%	-16.1%	-18.9%	-20.6%	-22.1%	-23.7%	-24.8%	-25.8%
5%	-0.2%	-0.8%	-2.9%	-3.4%	-5.8%	-6.6%	-7.3%	-8.1%	-8.6%	-9.2%
10%	4.3%	2.3%	1.5%	-0.2%	-1.3%	-2.2%	-2.8%	-3.6%	-4.4%	-5.0%
50%	17.1%	17.8%	17.9%	18.1%	18.4%	18.5%	18.6%	18.8%	18.8%	18.7%
75%	28.0%	29.1%	28.6%	29.3%	32.2%	32.8%	33.8%	33.4%	34.1%	34.9%
90%	42.7%	47.0%	51.3%	52.3%	51.7%	51.4%	52.3%	52.9%	53.2%	53.5%
95%	49.3%	58.2%	55.6%	59.6%	64.1%	67.0%	68.2%	68.6%	69.6%	71.0%
99%	69.0%	107.7%	125.0%	139.1%	156.3%	167.0%	176.3%	186.8%	193.7%	199.8%
Maximum	110.2%	148.8%	191.5%	225.1%	260.7%	282.9%	302.1%	323.8%	338.0%	350.7%
Mean	20.7%	22.1%	22.8%	23.4%	24.0%	24.3%	24.7%	25.0%	25.3%	25.5%
Standard deviation	17.1%	21.6%	25.2%	28.3%	31.8%	34.0%	36.0%	38.3%	39.8%	41.2%

Table 27: Summary of the Projected Changes (%) in 90-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-4.0%	-7.6%	-11.0%	-13.8%	-16.7%	-18.5%	-20.1%	-21.8%	-23.0%	-24.0%
5%	-0.1%	-0.2%	-0.9%	-1.0%	-3.0%	-3.9%	-4.6%	-5.4%	-6.6%	-7.2%
10%	4.3%	4.3%	2.5%	1.2%	0.5%	-0.4%	-1.1%	-2.4%	-3.1%	-3.5%
50%	16.9%	17.4%	17.5%	17.2%	18.6%	18.1%	18.6%	18.6%	18.4%	18.0%
75%	29.3%	29.4%	30.3%	30.6%	30.8%	31.0%	32.0%	32.8%	33.0%	33.4%
90%	39.8%	42.9%	45.9%	48.8%	51.0%	50.7%	50.9%	51.7%	52.2%	52.6%
95%	51.0%	58.2%	58.5%	59.9%	63.9%	66.5%	68.5%	70.3%	71.5%	72.5%
99%	71.1%	106.4%	124.0%	140.0%	157.0%	167.6%	176.7%	187.1%	193.8%	199.9%
Maximum	105.4%	158.3%	204.0%	240.0%	278.2%	302.0%	322.5%	345.8%	361.1%	374.7%
Mean	20.9%	22.2%	22.8%	23.3%	23.9%	24.2%	24.5%	24.9%	25.1%	25.3%
Standard deviation	17.2%	21.8%	25.5%	28.7%	32.3%	34.7%	36.7%	39.1%	40.7%	42.1%

Table 28: Summary of the Projected Changes (%) in 120-Day Rainfall in 2080s

Statistical Indices	Return Period (yrs)									
	2	5	10	20	50	100	200	500	1000	2000
Minimum	-3.8%	-5.3%	-8.4%	-10.8%	-13.5%	-15.1%	-16.5%	-18.2%	-19.2%	-20.2%
5%	1.6%	2.4%	1.6%	0.4%	-0.3%	-0.9%	-2.3%	-3.4%	-4.0%	-4.8%
10%	5.8%	5.1%	4.5%	4.1%	3.0%	2.1%	1.9%	0.6%	-0.6%	-1.5%
50%	17.2%	18.4%	18.9%	19.1%	20.2%	20.9%	20.8%	20.7%	21.0%	21.4%
75%	31.0%	31.3%	30.5%	31.2%	33.0%	32.5%	33.1%	33.6%	34.1%	34.7%
90%	41.5%	44.8%	46.4%	49.2%	51.2%	52.9%	54.9%	57.2%	58.7%	60.0%
95%	54.2%	57.1%	60.8%	64.3%	65.0%	65.8%	66.4%	68.2%	69.9%	71.5%
99%	77.1%	118.2%	143.4%	163.4%	184.9%	198.4%	210.1%	223.5%	232.3%	240.1%
Maximum	110.2%	185.3%	240.6%	284.4%	331.3%	360.9%	386.5%	415.7%	435.0%	452.2%
Mean	21.9%	24.1%	25.3%	26.2%	27.1%	27.7%	28.3%	28.9%	29.3%	29.6%
Standard deviation	17.3%	23.6%	28.3%	32.5%	37.1%	40.1%	42.7%	45.8%	47.8%	49.6%

APPENDIX C

Design Basis Report

AECOM
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Technical Memorandum

To	Jennifer Singbeil (PSPC)	Page	1
CC	Rudy Schmidtke (AECOM), Barry Fedorak (AECOM), Tauhid-Brian Thomas (INAC)		
Subject	**Climate Change Review – FINAL Rev 0.**		
From	Michael Gregg (AECOM), Lori Newman (NGI)		
Date	July 26, 2018	Project Number	60556818

Purpose

AECOM is conducting the advanced design of freeze areas AR1 and AR2. To support the design work, a review of current climate change documentation and its impacts to the project has been done.

This technical memorandum summarizes:

- Background of the climate change data as it has been used in the project-to-date.
- Current climate change data.
- Preliminary analysis and recommendations for integration of current climate change data for use in the advanced design of ground freezing.

Background

Climate change is an important risk for consideration in the design of the ground freezing systems at Giant Mine. The design utilizes thermosyphons, which are active when exposed to arctic climatic conditions where the air temperature is colder than the temperature of the ground being frozen. In order to predict ground freezing success or the possibility of climate related warming in the future, a projection of future air temperature must be considered.

Both the Developer's Assessment Report (DAR) and the Freeze Program Design Basis Report (DBR) describe how climate change has been used in ground freezing design work to date, but there are differences between the two reports and the need for some additional analyses was identified and completed. Climate change predictions specific to the Northwest Territories have, in recent years, also been revised to reflect a greater understanding of how the Arctic regions will be more significantly affected by climate change than what global averages suggest.

<u>Developer's Assessment Report (DAR)</u>
The Giant Mine Remediation Project Developer's Assessment Report (INAC & GNWT, 2010) presented the environmental assessment for the project. It addressed the effects of the implementation of the remediation plan and the on-going management during long-term operation and maintenance phase.

Section 6.2.8.2 of the DAR summarized the modelling scenarios presented earlier by SRK (2006b) where ground thawing was evaluated by deactivating all thermosyphons simultaneously and exposing the chamber models to a “best estimate” of climate warming from the IPCC Third Assessment Report in 2001. The IPCC 2001 report had predicted a best estimate 3°C increase in mean annual air temperatures around Yellowknife.

In 2007, the IPCC issued the Fourth Assessment Report. This report revised the “best estimate” change in mean annual air temperature to be +3.3°C. It was concluded in the DAR that the difference in predicted temperature change (3°C to 3.3°C) was well within the error bands of any inputs to the thermal modelling so additional detailed modelling was not necessary. Instead, a simplified model was developed to further assess the thermal behaviour of Chamber 12. Chamber 12 was selected as the SRK (2006b) report had showed it to be the most sensitive to thawing due to its location in a prominent bedrock outcrop. The climate change predictions and observations in the DAR for the simplified model were increased to include “current”, “best estimate” (ΔT +3.3°C) and “worst estimate” (ΔT +5.85°C) scenarios using climate predictions as set out in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007). Table 6.2.8 of the DAR presented the IPCC projected temperature increases as shown in Table 1.

Table 1: Simplified Model of Thawing and Thermosyphon Performance Projected Temperature Increases used in the DAR (IPCC 2007).

	Current Climate	IPCC 2007 Best Estimate	IPCC 2007 Worst Case
Winter Temperature Increase (°C)	-	5.4	9.6
Summer Temperature Increase (°C)	-	1.2	2.1
Mean Annual Air Temperature (°C)	-4.5	-1.2 **(ΔT = 3.3)**	1.35 **(ΔT = 5.85)**

The conclusion drawn from the simplified model for Chamber 12 was that the IPCC 2007 worst case predictions of climate warming would shorten the thaw times originally predicted in the SRK modelling by approximately 15% but that the design presented in the DAR would still work. The effects of climate warming both increase the heat flux to the ground and reduce the performance of thermosyphons. The DAR stated that under the worst case climate warming, the rate of heat removal by a thermosyphon would drop to about one third of the current rate. The conclusion was that once the active freeze pipes were converted to thermosyphons, the planned number of 60 thermosyphons would still be adequate to keep Chamber 12 at -8°C even for the IPCC (2007) worst case scenario.

<u>Freeze Program Design Basis Report (DBR)</u>
The Giant Mine Freeze Program – Design Basis Report (SRK, 2016) brought together all work-to-date on the ground freezing program for Giant Mine, and formed a design basis for the advanced design. The DBR used a maximum ΔT = 6.1°C in mean annual air temperature applied to all of the freeze pipe layout variants and reflected the upper range <u>global</u> average temperature increase from the multi-century “stabilization scenarios” as published in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2004). Note that it has been assumed that the IPCC 2004 reference is a typo, and was intended to be IPCC, 2007 in reference to the Fourth Assessment Report.

The DBR refers to a maximum mean global temperature increase of 6.1°C, but based on dissection of historical modelling files, it appears that the length of time over which this maximum change was considered to occur over varied between 100 to 200 years. Experiential modelling has shown that the time period over which the increase is applied does not affect the chamber performance, as long as the maximum value is reached within the modelled time frame and equilibrium conditions are able to establish. The top figure in the Appendix drawing NGI-017-910-FEM-01 shows a representative sinusoidal function for the climatic condition used in the DBR models. For this particular function, the maximum $\Delta T = 6.1°C$ is reached after 150 years (year 2160). Also note that the maximum increase in temperature has been applied equally to both the winter and summer warming trends.

Climate Projection Scenarios from the International Panel on Climate Change

To date, all climate change projections used in the freeze modelling have been based on information from the Third and Fourth Assessment Reports by the IPCC. In 2014, the IPCC released the Fifth Assessment Report (AR) using four different Representative Concentration Pathways (RCPs) to depict a range of possible future concentrations of atmospheric greenhouse gases (GHG), air pollutants and land use scenarios. The scenarios reflect various levels of effort being put into mitigating against the development and control of greenhouse gases moving forward.

The four RCP scenarios of the Fifth Assessment Report have been extrapolated out to year 2100; and use the naming convention RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. The names compare projected radiative forcing values (W/m^2) relative to pre-industrial (i.e.,1750 AD) values. For example, the worst case or "very high RCP 8.5" scenario means that in the year 2100, the solar energy absorbed by each square meter of Earth will be, on average, 8.5 W/m^2 greater than it was in the year 1750. Additional descriptions of the four RCPs are as follows:

- RCP 2.6 – a stringent mitigation scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures.
- RCP 4.5 – an intermediate mitigation scenario
- RCP 6.0 – an intermediate mitigation scenario
- RCP 8.5 – a very high future GHG emissions scenario

It is interesting to note that baseline scenarios, which do not include any mitigation efforts to constrain emissions, result in pathways that fall between RCP 6.0 and RCP 8.5. Therefore using a RCP 8.5 projected temperature increase would be considered conservative and the worst case scenario.

The values presented in Table 2 are projected annual global mean values and are all are referenced back to 1986-2005. The range of values listed indicate the 5th and 95th percentile values computed by the various models used by the IPCC. For example, by 2100 for the RCP 8.5 scenario, the change in mean annual air temperatures (relative to 1986-2005) will *likely* be between 2.6°C to 4.8°C. The likelihood of regional variations in temperatures is also discussed and it is concluded that climate warming will be greater over land masses than over oceans, and that the Arctic region will continue to warm faster than the global rate.

Table 2: Annual Mean, and Projected Ranges of Global Surface Air Temperature Temperatures taken from the IPCC 5th Assessment Synthesis Report (Table 2.1)

Scenario	2016-2035 Mean (range) (°C)	2081-2100 Mean (range) (°C)
RCP 2.6	0.5 (0.3 – 0.7)	1.0 (0.3 – 1.7)
RCP 4.5	0.5 (0.3 – 0.7)	1.8 (1.1 – 2.6)
RCP 6.0	0.5 (0.3 – 0.7)	2.2 (1.4 – 3.1)
RCP 8.5	0.5 (0.3 – 0.7)	***3.7 (2.6 - 4.8)***

*Note that the ranges presented represent 5th and 95th percentile values provided by the predictive models

More detailed temperature projections specific to Canadian regions can be obtained through the Canadian Centre for Climate Modelling and Analysis (CCCma). This climate modelling is conducted in support of the IPCC. The CCCma provides temperature projections for individual provinces/territories and differentiates the warming trends by season.

The CCCma issued a report in 2016 titled 'Climate data and scenarios for Canada: Synthesis of recent observations and modelling results'. The range of projected surface air temperatures from this report are summarized in Table 3. Summer is the average of June - August. Winter is the average of December - February. Note that the CCCma ranges presented are for the 25th and 75th percentiles, whereas the IPCC data range presented in Table 2 represents the 5th and 95th percentiles.

Table 3: CCCma Air Temperature Increase Projections for Northwest Territories

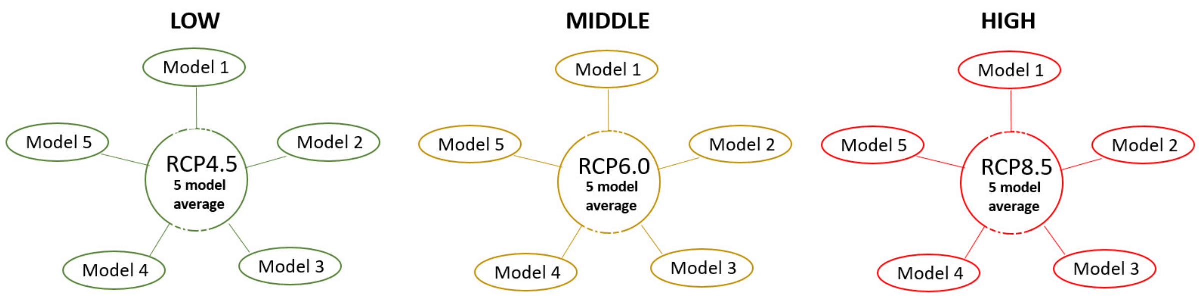
Scenario	2016-2035 Mean (range) (°C)	2081-2100 Mean (range) (°C)
Winter (Dec – Feb)		
RCP2.6	2.0 (1.3 – 2.7)	3.0 (1.8 – 4.1)
RCP4.5	1.9 (1.2 – 2.7)	5.8 (4.1 – 7.4)
RCP8.5	2.4 (1.7 – 3.1)	***12 (9.4 – 14.4)***
Summer (Jun – Aug)		
RCP2.6	1.2 (0.7 – 1.6)	1.5 (0.9 – 2.1)
RCP4.5	1.2 (0.8 – 1.5)	2.6 (1.7 – 3.4)
RCP8.5	1.3 (0.9 – 1.6)	***5.4 (4.0 – 6.8)***

*Note that the ranges presented represent the 25th and 75th percentile values provided by the predictive models

Note that the increase in temperature during the winter months is anticipated to be approximately double that of the summer months. Representing Yellowknife with the full NWT dataset would be considered to be on the conservative side, since both the IPCC and CCCma anticipate that the greater temperature rises will occur further north.

Government of Northwest Territories Climate Change

The Government of the Northwest Territories website regarding climate change (www.nwtclimatechange.ca), states that the rate of warming in the Northwest Territories is four to five times faster than the global rate. The website also provides a link to an outlook tool developed by SNAP (Scenarios Network for Alaska + Arctic Planning), which is part of the International Arctic Research Center at the University of Alaska Fairbanks. The tool allows the user to explore temperature and precipitation projections for communities across Alaska and Canada. The SNAP predicted climate change at Yellowknife for each representative concentration pathway (RCP) scenario is derived from the mean of the most appropriate five General Circulation Models (GCMs) applied to each RCP. This concept is illustrated below.



The following descriptions of these RCP scenarios are taken directly from the SNAP descriptions:

- Low (RCP4.5) – This pathway assumes emissions peak around the year 2040 and radiative forcing (energy absorbed by the earth, W/m^2) stabilizes shortly after 2100.
- Medium (RCP6.0) – This pathway assumes a range of technologies and strategies for reducing greenhouse gas emissions are developed, and emissions peak around 2080 then decline. Total radiative forcing stabilizes shortly after 2100.
- High (RCP8.5) – This potential future has greenhouse gas emissions increasing through the 21st century. SNAP uses this as its "high" or worst-case scenario.

More specifically, the SNAP tool projections currently available for the RCP scenarios for Yellowknife, NWT, use model output that form the basis for the IPCC's Fifth Assessment Report 2014. It presents the data on a monthly basis which allows for the user to differentiate between summer and winter warming trends, similar to the CCCma data.

An example of a SNAP generated monthly mean temperature graph for Yellowknife, NWT is presented as the middle, left-side figure in the Appendix drawing NGI-017-910-FEM-01. The coloured bars represent the average (mean) monthly values for several decades. Further reducing this data for only two decades (2010-2019 and 2090-2099) results in the figure shown on the middle right. The bottom figure on the drawing is the resulting mean annual sinusoidal function that uses the future temperature trends, generated over 90 years. The function shows greater warming is projected during winter (ΔT = 8.4°C) than during summer (ΔT = 3.9°C) with an overall increase in the mean temperature of 6.2°C. This is a key variance from all previous model assumption which distributed the mean global air temperature rise evenly between summer and winter months. In other words, looking forward, there will be less winter cooling opportunity if winter temperatures rise more than summer temperatures.

Climate Change and Previous Modelling Review Summary

There have been several approaches used to evaluate the impact of climate warming on the Giant Mine freeze design. Below are the climate review summary points:

- The original design submitted in 2006 (SRK 2006b) considered complete deactivation of all thermosyphons while including an increase to the global mean air temperature of 3°C.
- The DAR report considered both a +3.3°C and +5.85°C global warming trend and applied these ranges to a simplified model for Chamber 12 as this was identified as being the chamber most susceptible to thawing due to its proximity to a bedrock outcrop. It was determined that the number of thermosyphons being evaluated was sufficient to offset climate change for the conditions and assumptions being considered.

- For all the variants studied in the DBR, a global climate change warming rate of approximately +3°C/100 years, up to a maximum of +6.1°C, was applied to the models. However, the models were only solved until containment criteria was achieved which was significantly less than 100 years.
- The DBR did include a study on climate sensitivity using Chambers 11 and B208 for various combinations of cold years/warm years, but again, the focus was on the resulting time difference required to achieve containment given these annual temperature combinations.
- The conceptual thermosyphon layout (Supporting Document F) of the DBR evaluated the maximum thermosyphon spacing required to maintain the DBR documented long-term freeze criteria under an applied climate change of +6.1°C relative to the current MAAT. Each 2D model was run for 100 years under this consistently warmer climatic condition.
- The DBR results with respect to long-term climate change did not incorporate differential seasonal warming rates.

Finally, the DBR states that the objective for a global warming climate scenario of +6.1°C applied to the Yellowknife mean annual air temperature is for all outside edges of the chambers and stopes are to be maintained at −5°C or less. This long-term design criteria is currently in the process of being re-interpreted and will be presented at the May 2018 IPRP meetings.

Additional Analyses

1. The need for additional understanding of climate warming risk through modelling arose as part of the current climate review process. The DBR climate sensitivity models of hot/cold year combinations were applied to Chamber 11 and B208 until containment was achieved but Chamber 12 is a likely worst case to evaluate warming impact. While long-term 2D climate warming models were developed as part of the DBR Supporting Document F, the models did not simulate gradual warming over time and instead applied the +6.1°C increase to the seasonal MAAT function consistently over a 100 year modelled period. As such, a 2D analysis of Chamber 12 in particular should be developed to gain an understanding of the warming process under gradual warming up to the maximum increase (i.e., +6.1°C). A 3D analysis of Chamber 12 applying a gradual warming trend would also be beneficial for comparison purposes as 3D modelling was not attempted as part of the DBR and a revised climate warming pattern specific to Yellowknife should be considered in a separate 3D analysis. These three additional analyses were completed with the results provided in the attached appendix. For all analyses, a perimeter pipe spacing of 4m was used for Chamber 12.

1. Appendix NGI-017-910-FEM-02 shows the following images relating to a new 2D - Chamber 12 analysis with gradual warming:
    - The sinusoidal climate function applied equally to both summer and winter warming of +6.1°C and applied gradually over 150 years. Note that whether the warming is applied over 50, 100 or 150 years is inconsequential to the results as long as the entire warming magnitude is accounted for within the modelled period.
    - The data point locations for Chamber 12 marking 10 m above the chamber, at the corner of the chamber and 10 m under the chamber.
    - Temperature versus time graphs for the three data point locations.
    - Temperature contours colder than -5°C after 150 years of warming.

    The results indicate that for a 2D modelling scenario, the climate change of +6.1°C applied gradually results in the bedrock warming above -5°C within 10 m of the chamber near the ground surface after initial cooling is complete. The edge of the chamber does not appear to warm above -5°C with prolonged exposure to warming trends.

2. In order to better understand the impact of seasonally variable climate change ranges, two 3D analyses were developed for Chamber 12. One model applied a 6.1°C increase to both summer

and winter over a 90 year interval, and the other model applied the seasonally variable SNAP generated values as outlined earlier, applied over 90 years. The time period of 90 years was used as the SNAP model only predicts temperature trends to the year 2100.

Appendix NGI-017-910-FEM-03 shows the following images relating to the +6.1°C climate change projection for a 3D model.

- The sinusoidal climate function applied equally to both summer and winter warming of 6.1°C over 90 years.
- The data point locations for Chamber 12 marking 10 m above the chamber, at the corner of the chamber and 10 m under the chamber.
- Temperature versus time graphs for the three data point locations.
- Temperature contours colder than -5°C after 90 years of warming.

The temperature trends and contour results indicate that the climate change rate of +6.1°C/90 years will result in the bedrock warming above -5°C within 10 m of the chamber near the ground surface. After 90 years, when the maximum climate warming has been fully applied within the model, the edge of the chamber (DP#2) appears to have warmed to approximately -5°C. This result differs from those presented by the 2D model (NGI-017-910-FEM-02) due to the nature of modelling thermosyphons in either 2D or 3D space with a 3D analysis representing the three dimensional nature of heat flow between neighbouring thermosyphons more appropriately.

Appendix NGI-017-910-FEM-04 shows the following images for a 3D analysis using the SNAP tool projected climate change projections applicable to Yellowknife.

- The sinusoidal climate function showing temperature warming of +8.4°C during the winter and +3.9°C during the summer over 90 years.
- The data point locations for Chamber 12 marking 10 m above the chamber, at the corner of the chamber and 10 m under the chamber.
- Temperature versus time graphs for the three data point locations.
- Temperature contours colder than -5°C after 90 years of warming.

The results indicate that site specific projected warming trends, especially greater warming during winter months results in a portion of the arsenic chamber thawing after 90 years. After 85 years, the edge of the chamber appears to warm above -5°C.

It is anticipated that excessive climate warming can be mitigated with additional near surface thermosyphons for shallow chambers but this will need to be investigated during advanced design.

Conclusions and Recommendations

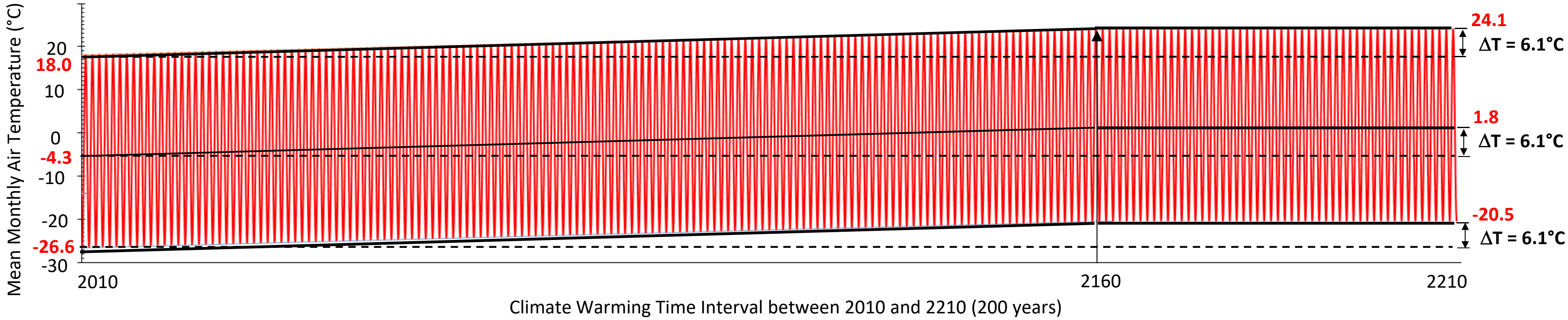
The impact of Yellowknife site specific climate warming trending with variable summer and winter offsets (i.e., greater warming of the MAAT during winter than during summer) has not been evaluated previously for the Giant Mine freeze program. Climate change models have been revised in recent years to better reflect climate change in northern climates. It appears from the preliminary modelling presented in this memo that considering a greater warming increase during winter months is necessary, especially given the current design using passive thermosyphons, which only function during cold weather.

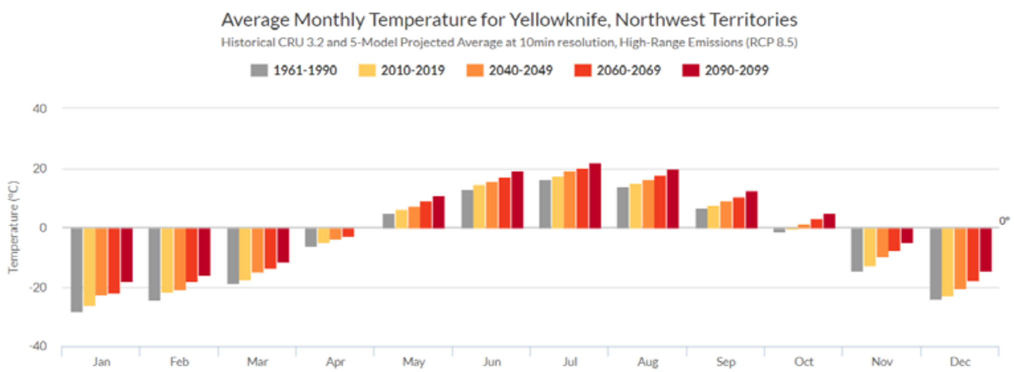
For the advanced design of the Giant Mine freeze program, it is recommended that:

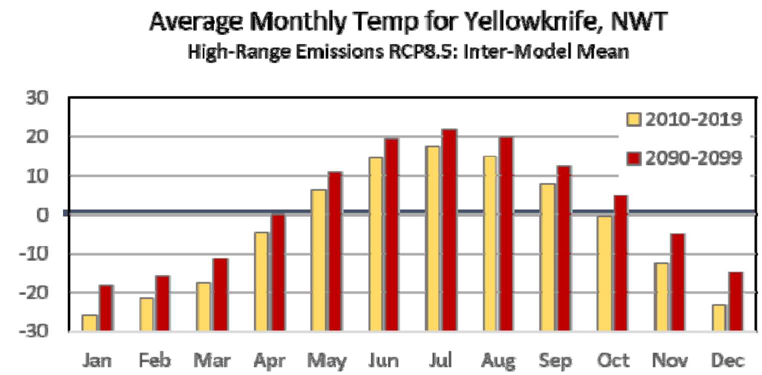
- Seasonal variation be included in any future design modelling

- Modelling be completed to 100 years, or the maximum available date as it relates to the climate change prediction models, to confirm containment for the full duration of the simulation and to clearly show the effect of climate change.
- The most current maximum projections for RCP 8.5 (or future equivalent) be used for all analyses. This projection is deemed conservative.

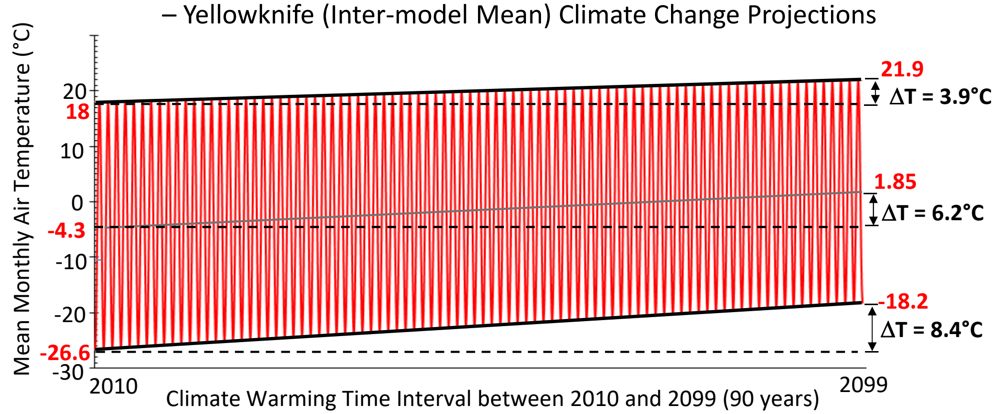
Design Basis Report (DBR) Mean Annual Air Temperature Sine Function – Global Climate Change Projections







Mean Annual Air Temperature Sine Function – Yellowknife (Inter-model Mean) Climate Change Projections



NOTES:

1. The mean annual air temperatures of -4.3°C for 2010 is from Table 4.1 of the DBR SD D: Thermal Modelling Guidelines.
2. The average monthly data specific to Yellowknife, NWT was produced using the Scenarios Network for Alaska & Arctic Planning (SNAP) tool developed by the International Arctic Research Centre (IARC) at the University of Alaska Fairbanks. This tool is accessible from the Government Northwest Territories (GNWT) website - http://www.enr.gov.nt.ca/en/services/climate-change.

REV	DATE	DESCRIPTION
A	03/12/2017	ISSUED FOR INFORMATION

DESIGNED BY	
DRAWN BY	LN
CHECKED BY	GN
APPROVED BY	
DATE	03.12.2017

NEWMANS GEOTECHNIQUE

AECOM

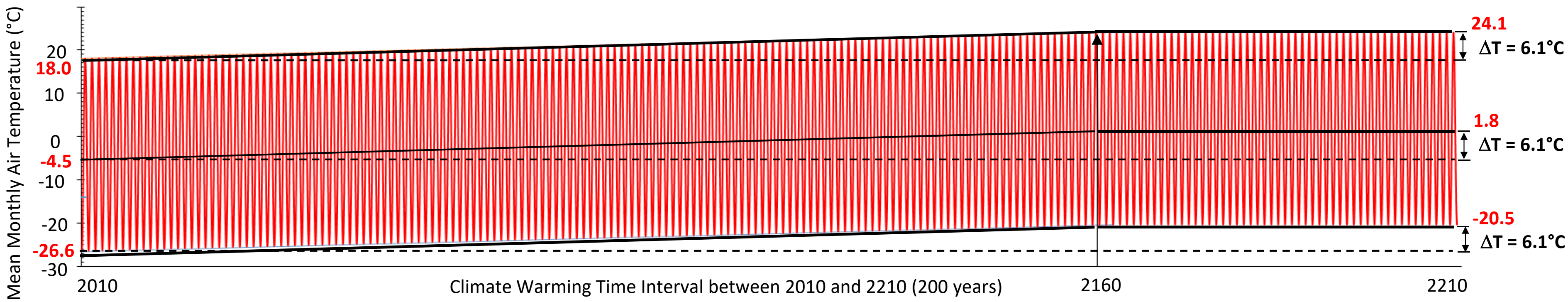
Public Services and Procurement Canada

AECOM Ref. 60556818

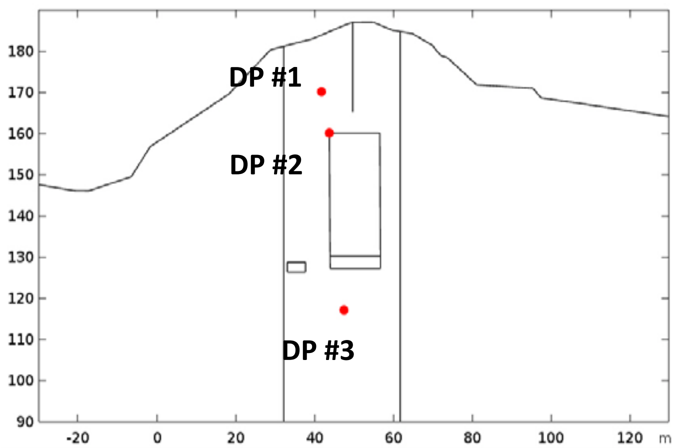
GIANT MINE ADVANCED DESIGN TA-17
CLIMATE CHANGE REVIEW
HISTORICAL AND CURRENT MODELLING INPUT FUNCTIONS

CONTRACT NO	
DRAWING FILENAME	
DRAWING NO	NGI-017-910-FEM-01
SHEET NO	
REV	0

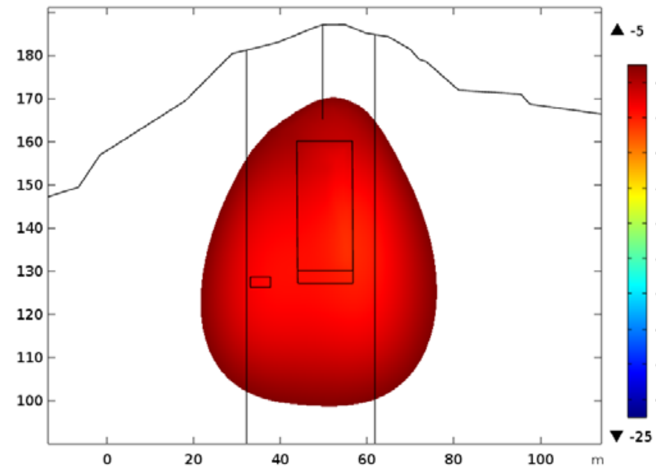
Design Basis Report (DBR) Mean Annual Air Temperature (MAAT) Function



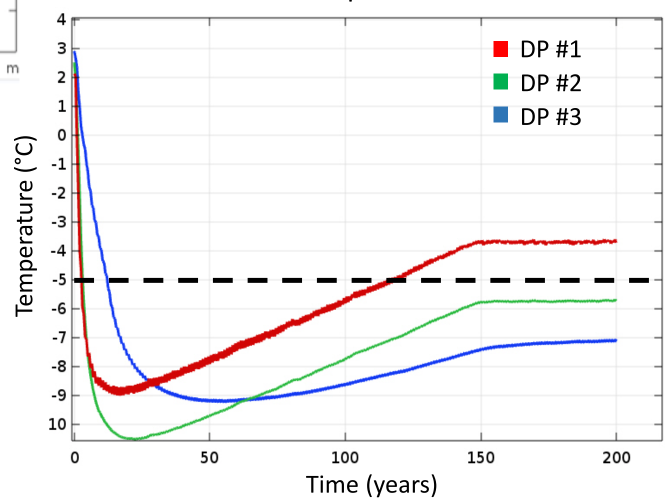
Data point graphing locations for 2D - Chamber 12



Colder than -5°C Contours after 150 yrs during summer



Temp vs time



NOTES:

1. Whether the warming is applied over 50, 100 or 150 years is inconsequential to the results as long as the entire warming magnitude is accounted for in the modelled period.
2. Perimeter pipe spacing used for this model is 4m.

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			DRAWN BY	LN
			CHECKED BY	GN
			APPROVED BY	
			DATE	03.12.2017

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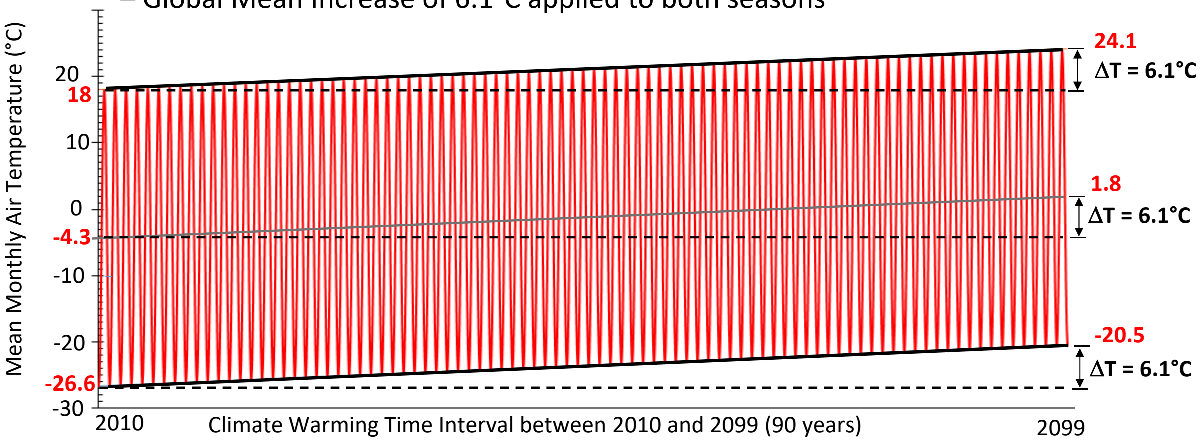
Public Services and Procurement Canada

AECOM Ref. 60556818

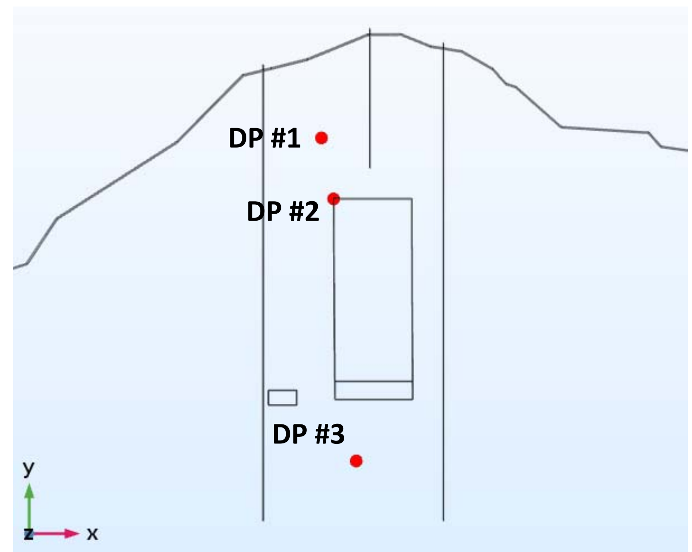
GIANT MINE ADVANCED DESIGN TA-17
CLIMATE CHANGE REVIEW
Chamber 12 – 2D long term DBR global climate change

CONTRACT NO	
DRAWING FILENAME	
DRAWING NO	NGI-017-910-FEM-02
SHEET NO	
REV	0

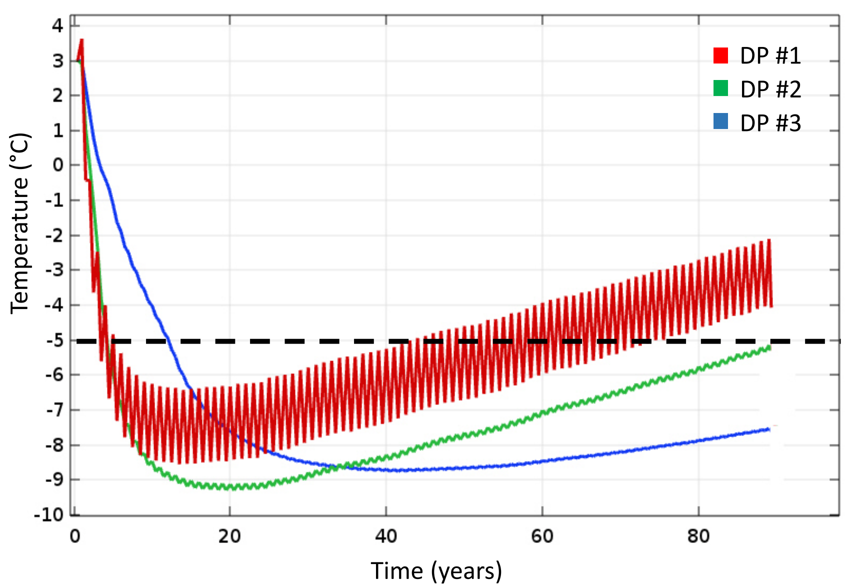
Annual Air Temperature Sine Function
– Global Mean Increase of 6.1°C applied to both seasons



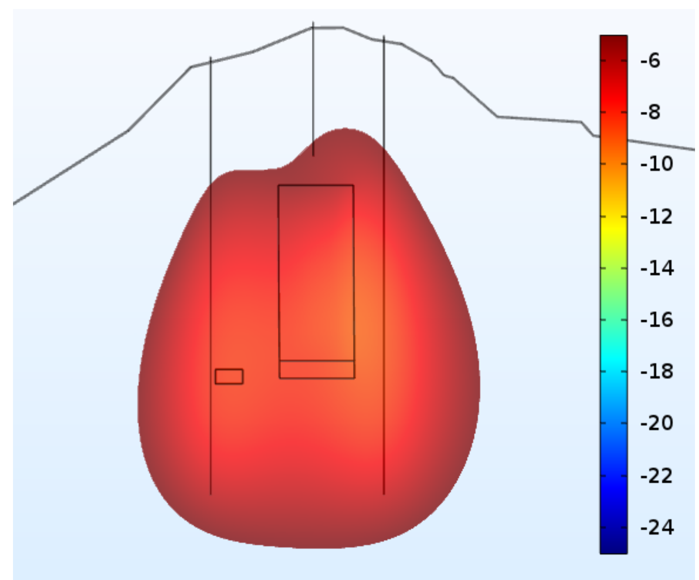
Data point graphing locations for 3D - Chamber 12



Temp vs time



Colder than -5°C Contours after 90 yrs during summer



NOTES:

1. Perimeter pipe spacing used for this model is 4m.

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DESIGNED BY
DRAWN BY LN
CHECKED BY GN
APPROVED BY
DATE 03.12.2017

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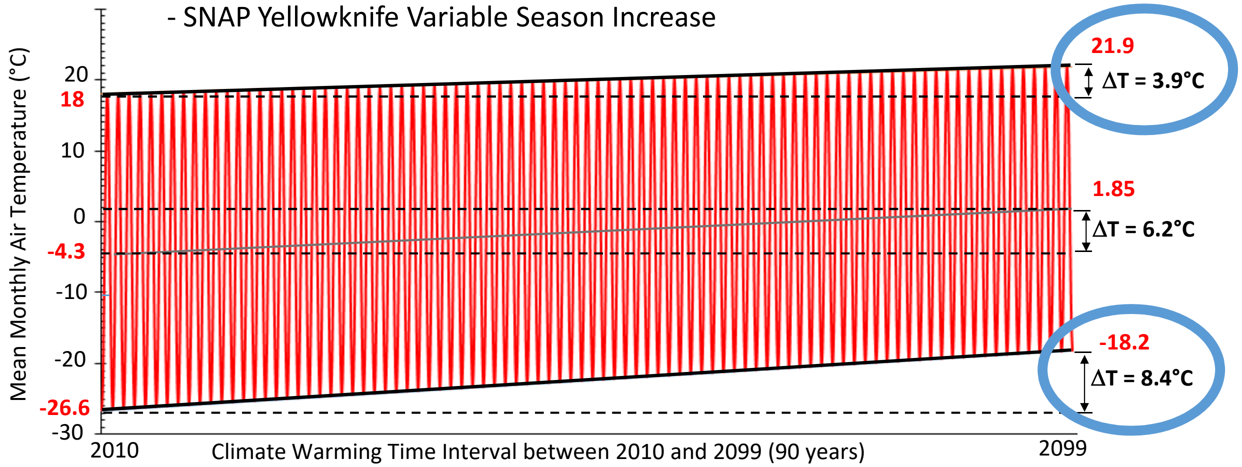
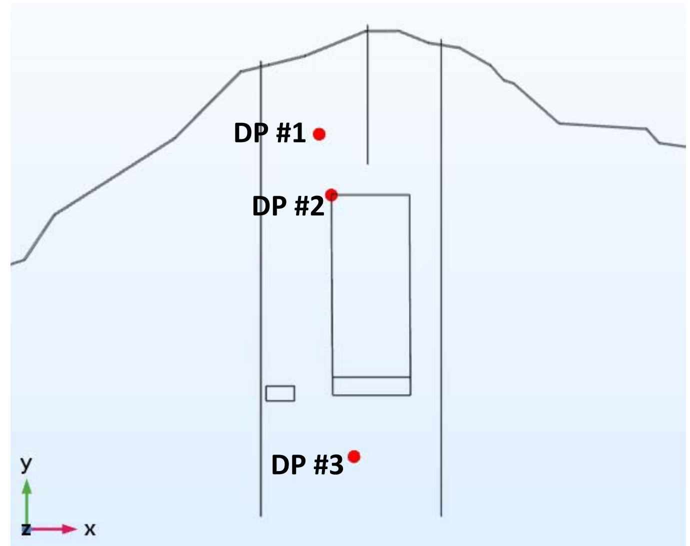
GIANT MINE ADVANCED DESIGN TA-17
CLIMATE CHANGE REVIEW
Chamber 12 – 3D long-term global climate change

CONTRACT NO
DRAWING FILENAME
DRAWING NO NGI-017-910-FEM-03
SHEET NO
REV 0

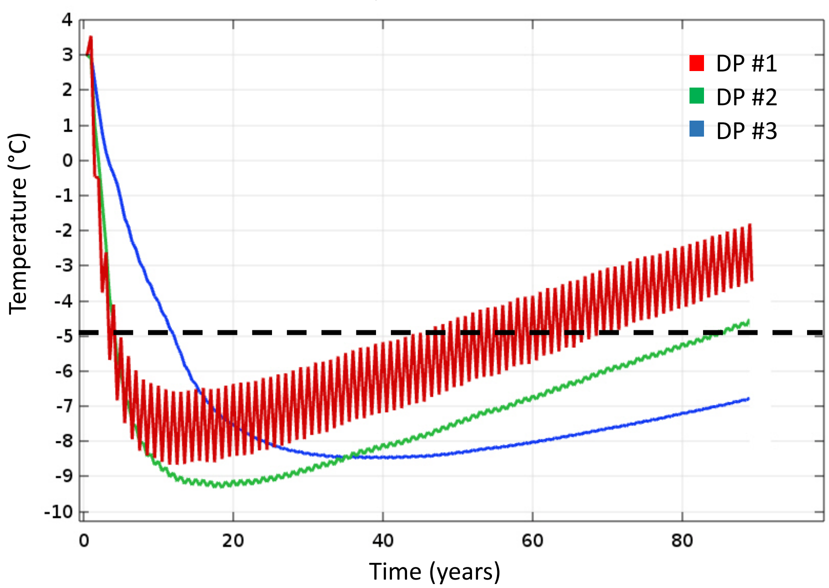
Annual Air Temperature Sine Function -
- SNAP Yellowknife Variable Season Increase



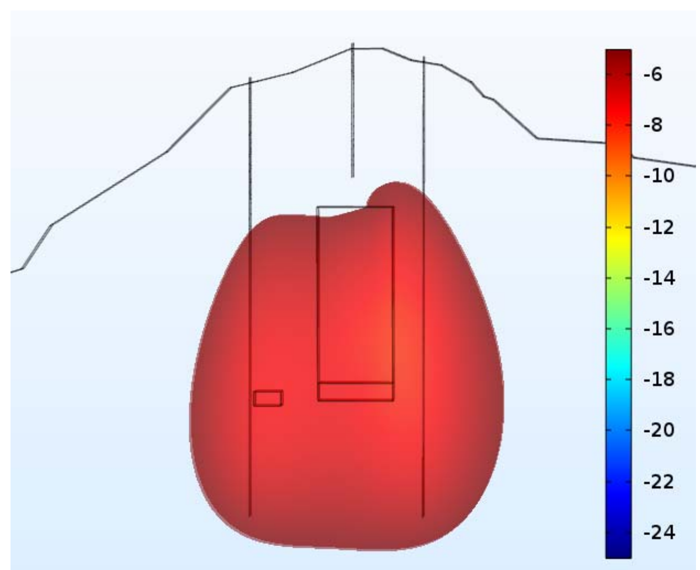
Data point graphing locations for 3D - Chamber 12



Temp vs time



Colder than -5°C Contours after 90 yrs during summer



NOTES:

1. Perimeter pipe spacing used for this model is 4m.

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A	03/12/2017	ISSUED FOR INFORMATION	DESIGNED BY: DRAWN BY: LN CHECKED BY: GN APPROVED BY: DATE: 03.12.2017	NEWMANS GEOTECHNIQUE AECOM	Public Services and Procurement Canada AECOM Ref. 60556818	GIANT MINE ADVANCED DESIGN TA-17 CLIMATE CHANGE REVIEW Chamber 12 – 3D Long-term Yellowknife, NWT climate change	CONTRACT NO: DRAWING FILENAME: DRAWING NO: NGI-017-910-FEM-04 SHEET NO: REV: 0

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