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CLIMATE CHANGE ASSESSMENT FOR THE NEAR SURFACE DISPOSAL FACILITY PROJECT

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	M. Klukas Environmental Assess Analyst	Date

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CANADIAN NUCLEAR LABORATORIES

Technical Supporting Document

Climate Change Assessment for the Near Surface Disposal Facility Project

Revision 1

Submitted to:
Martin Klukas
Canadian Nuclear Laboratories Ltd.
Chalk River Laboratories
286 Plant Road, Building 457
Chalk River, ON
K0J 1J0

REPORT

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Golder Associates

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AECL	Atomic Energy Canada Limited
AOGCM	atmospheric ocean general circulation model
CCCSN	Canadian Climate Change Scenarios Network
CCDS	Canadian Climate Data and Scenarios
CEAA, 2012	*Canadian Environmental Assessment Act, 2012*
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
CRL	Chalk River Laboratories
ECCC	Environment and Climate Change Canada
EMIC	Earth Model of Intermediate Complexity
FPTCCCEA	Federal Provincial Territorial Committee on Climate Change and Environmental Assessment
GCM	General Circulation Model
IPCC	Intergovernmental Panel on Climate Change
NSDF	Near Surface Disposal Facility
QA/QC	Quality Assurance and Quality Control
RCP	Representative Concentration Pathway
TSD	Technical Supporting Document
UNEP	United Nations Environment Program
WMO	World Meteorological Organization

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1.0 INTRODUCTION

Canadian Nuclear Laboratories (CNL) is proposing to construct the Near Surface Disposal Facility (NSDF) Project for the long-term management of large quantities of low level radioactive waste from legacy waste, current operations, and decommissioning projects at Chalk River Laboratories (CRL) and its other business locations. The NSDF Project will provide a safe, permanent solution for the disposal of radioactive waste and other acceptable waste streams at CRL and replace the current CNL practice of placing the waste in temporary storage. A key element of the regulatory approvals process is the completion of an environmental assessment under the *Canadian Environmental Assessment Act, 2012 (CEAA 2012)* (Government of Canada 2012).

This technical supporting document (TSD) provides an assessment of a changing climate to support the Environmental Impact Statement for the NSDF Project. The assessment will follow the guidance provided by the Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment (FPTCCCEA), which has prepared a general guidance document for practitioners to use when incorporating climate change issues into environmental assessments (FPTCCCEA 2003). This TSD provides a quantitative assessment of the current climate analysis and future climate projections up to the year 2100. A qualitative assessment of climate change projections past 2100, through to the year 3000, is also provided.

1.1 Background and Approach

To understand how the climate has been changing, and may change in the future, climate trends were analysed by:

- describing the current climate using available long-term (30 years) data;
- documenting how the climate has changed over the past 30 years in the region where the NSDF Project footprint is located (i.e., NSDF Project region); and
- discussing the range of future climate projections (2041 through 2070 and 2071 through 2100).

To describe the current climate, the most representative climate station was selected. The current climate and current climate trends for the selected climate station were documented. The current climate conditions were defined using climate normals, which are long-term (usually 30 years) averages of observed climate data. Current climate conditions are used to document how the climate has changed over the 30-year period in the area by identifying apparent trends and assessing whether these apparent trends are statistically significant.

The projected ranges of future climate conditions were described using the outputs from General Circulation Models (GCMs) accepted by the Intergovernmental Panel on Climate Change (IPCC) for various representative concentration pathways (RCPs) defining the radiative forcing in 2100. The publicly available GCM projections and multiple RCPs are accessed for the area providing an indication of the range of possible future climate conditions.

1.2 Current Climate Analysis Methodology

The current climate is based on available long-term daily meteorological observations from a climate station near the NSDF Project footprint. The climate station selection was based upon specific recommendations from Environment Canada's Canadian Climate Change Scenarios Network (CCCSN), now called Canadian Climate Data and Scenarios (CCDS) interface. The CCCSN is a previous version of the Government of Canada's interface for distributing global climate change scenarios and adaptation research, and provides useful guidance for selecting a climate station to represent an area of interest and how climate data should be used when calculating trends. The criteria used to select applicable climate stations were based on the following CCCSN selection factors (CCCSN 2009):

- the length of record (minimum 30 years of data);
- availability of a continuous record; and
- proximity to the area of interest.

In addition to the CCCSN criteria, the following selection factors were also considered to identify the station that best represents the NSDF Project footprint, meteorologically:

- age of observations compared to the currently accepted normal period;
- latitude;
- elevation of station; and
- geographic siting.

The available climate data from each station must be compared to, and pass, the selection criteria outlined above. Data from most climate stations is constrained by low numbers of observations or a limited life span for the station (data quantity), and varying data quality. Available daily meteorological data from selected climate stations was collected for a representative 30-year period, defined as the climate normal, which corresponds as closely as possible to 1981 through to 2010. The daily climate observations for mean temperature and total precipitation were reviewed to identify the completeness of the record, including data checks on the ranges of the data and percentage of missing data.

The reviewed data was used to calculate selected climate normals and trends, 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 were calculated for the mean temperature and total precipitation. The climate normal was calculated as the average of a given climate parameter over the selected period, and the climate trend was calculated as the average change in the climate parameter per decade (i.e., the decadal trend or change). Potential trends in temperature and precipitation were evaluated by fitting a model to the data using the Sen’s nonparametric model. The statistical significance of the observed trends was 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 90^{th}, 95^{th}, 99^{th} and 99.9^{th} percentile levels.

1.3 Future Climate Analysis Methodology

The projected future climate was described using the outputs from GCMs accepted by the IPCC for various Representative Concentration Pathways (described in Section 3.1.2 Climate Scenarios). The mean temperature and total precipitation outputs from the GCMs are available through the CCDS data download interface (Government of Canada 2015) and have been validated against observations and the interpretation of their results peer reviewed by the IPCC and others. The model projections were selected for the desired future projection period (i.e., 2041 through 2070 or 2071 through 2100). In the case of climate models, projections are not made at a location, but for a series of grid cells in the scale of hundreds of kilometres in size. Using the gridded model projections downloaded from the interface, the NSDF Project coordinates were used to extract the appropriate grid cell for all model projections and RCPs available under the IPCC Fifth Assessment Report (referred to as AR5; IPCC 2013), for a set of 90 unique modelling projections. This ensemble approach was used to delineate the probable range of results and to better capture the actual outcome (an inherent unknown).

In keeping with accepted climate practices, the description of future climate is presented in the context of change from the current climate period. The projected change for each model is calculated by comparison to the selected model baseline (30-year average from 1981 through 2100) and then normalized using the observed current climate normal (1981 through 2010).

Once all the future climate projections for each model are normalized, the future climate projections were analyzed for the annual, seasonal (dry and wet) and monthly periods. The analysis is summarized graphically, looking at both the mean of all model projections for a desired period, as well as the full range of projections for the same period.

1.4 Quality Assurance, Quality Control

Quality assurance and quality control (QA/QC) procedures were developed to produce technically and legally defensible results. These procedures were applied so that the data collected are of known, acceptable, and defensible quality and that proper office procedures (e.g., database management, general computer file management, document control, report reviewing procedures) were followed.

The data relied upon for the climate change assessment comes from Environment Canada and established Government of Canada clearinghouses, and has already been through a QA/QC process at the source where the data were extracted.

A spreadsheet control procedure was implemented to control calculations such that they are accurate, checked and reproducible. The procedure followed a four-step process.

- **Step 1:** Completion of calculation/spreadsheet by originator including reference to the source of all data used.
- **Step 2:** Checking of calculation/spreadsheet by an appropriate reviewer other than originator, and sign-off by the reviewer on a calculation control summary sheet and/or the electronic calculation workbook.
- **Step 3:** If revisions are required, the new calculation/spreadsheet will be recorded on the summary sheet and the old calculation will be marked as superseded.
- **Step 4:** Technical review of calculation/spreadsheet by an appropriate reviewer other than originator, and sign-off by the reviewer on a calculation control summary sheet and/or the electronic calculation workbook.

1.5 Climate and Meteorological Data Utilized By Other Disciplines

Other disciplines areas use climate and/or meteorology data in their characterization of baseline conditions, as well as the prediction and assessment of effects. Because each discipline has a different purpose for using climate or meteorology data, the station selected, the type of data used and the way in which it is used, can vary among the disciplines.

Table 1 provides a summary of how climate and meteorology data is used directly by other disciplines in their assessments.

Table 1: Comparison of Climate and Meteorological Data used by Discipline

Discipline	Type of Meteorology/ Climate Data Used	Rationale for the Consideration of Meteorology/Climate Data	Application and Use of Meteorology/Climate Data
Air Quality	■ The Ministry of the Environment and Climate Change provided a site-specific meteorology data set using the on-site CNL meteorological station at CRL and Petawawa Awos 2, Pembroke and Ottawa Airport ECCC meteorological stations. Upper air data was taken from Maniwaki station. ■ Climate normals were taken from the Chalk River AECL and Sheenboro ECCC meteorological stations.	Within the air quality assessment, an air dispersion model will be used to predict changes to air quality. The meteorological data used in the model will be based on five years' worth of mesoscale meteorological data.	Meteorology from the two climate normal stations will be considered when validating the dispersion model's meteorological dataset.
Surface Water	■ The meteorological data was collected from the Chalk River AECL station. If insufficient data was available at the Chalk River AECL station, then data from Petawawa AWOS 2 was used. ■ Climate normals were taken from the Chalk River AECL station. ■ Data used was limited to air temperature and precipitation.	■ Monthly mean air temperature can be used to estimate water temperature in shallow lakes and streams (e.g., Perch Lake and Perch Creek) in the absence of monitoring data. ■ Precipitation records and predictions can be used to determine wet, average, and dry flow conditions on the site and predict runoff amount and rates. ■ Changes in air temperature and precipitation can also be used to assess the site conditions for climate change scenarios.	■ Monthly air temperature data and normals will be used to estimate water temperature at the site. ■ Precipitation records will be used to conform low flow conditions at the site. ■ Precipitation records will be used to access anticipated changes in runoff volumes and rates.

CRL = Chalk River Laboratories; ECCC = Environmental and Climate Change Canada; AECL = Atomic Energy of Canada Limited.

2.0 EXISTING CONDITIONS

2.1 Station Selection

Nine climate stations were found to be within 25 kilometres (km) of the NSDF Project. The stations were evaluated using the CCCSN guidance. Of the nine stations, eight were excluded based on a shorter record length and lower data availability (Table 2).

Table 2: Available Climate Stations within 25 km of the Near Surface Disposal Facility Project Centroid

Station Name	Climate ID	Latitude and Longitude	Distance to NSDF Project Centroid (km)	Full Years Available	Notes
Chalk River Atomic Energy of Canada Limited (AECL)	6101335	46°03'00"N, 77°22'00"W	3.46	1961 – 2016	Consistent data record from 1981 through 2006. Shorter normal period (less than 30 years) but few missing data points.
Petawawa Nat Forestry	6106400	45°59'00"N, 77°26'00"W	7.47	1970 – 1999	Data record too short compared to other stations
Petawawa Awos 2	6106396	45°57'00"N, 77°19'00"W	13.24	2009 – 2015	Data record too short compared to other stations
Petawawa A	6106398	45°57'00"N, 77°19'00"W	13.24	1970 – 2007	Missing data from 1994 to 1998 that could skew trends
Sheenboro	7038080	45°58'00"N, 77°15'00"W	15.7	1949 – 2013	Missing August 1997 through March 1998, which may skew trends
Perch Lake Main IHD	6106378	46°04'00"N, 77°38'00"W	18.07	—	Partial data available for 1967
Petawawa Hoffman	610FC98	45°53'00"N, 77°15'00"W	22.37	1994 – 2015	Data record too short compared to other stations
Pembroke Climate	6106367	45°51'37"N, 77°15'08"W	24.42	2011 – 2015	Data record too short compared to other stations
Rolphton	6107182	45°58'00"N, 77°15'00"W	24.46	1991 – 2000	Data record too short compared to other stations

km = kilometres

Available daily meteorological data from the Chalk River Atomic Energy of Canada Limited (AECL) station were collected for the period from 1981 through to 2006, closely matching the current climate normal of 1981 through to 2010. While more recent observations which capture the warming trend of the past few years were not available from Chalk River AECL climate station, the observations are similar to those from Petawawa Hoffman climate station, which does have more recent observations. For the period from 1981 through 2006, less than 1 percent (%) of the data is missing from Chalk River AECL station for mean temperature and total precipitation. For the individual years, less than 2% of data is missing for the temperature and precipitation with the exception of 1986. Notably, 1986 is missing approximately 10% of the data, as no observations were made during October for temperature and no observations were made during parts of August and all of October for precipitation.

Therefore, the climate assessment completed for the NSDF Project used data from the Chalk River AECL climate station (Station ID 610FC98) to describe current climate conditions, climate variability and long-term trends. Chalk River AECL climate station is the station closest to the NSDF Project with the longest continuous and most complete dataset available that falls near the desired normals period (1981 through 2010). The station is approximately 3 km east-southeast of the NSDF Project centroid, within the regional study area, at a similar latitude and elevation.

2.2 Current Climate with Current Climate Trends and Extremes

The climate normals and current climate trends were calculated for Chalk River AECL station. Both annual and seasonal 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 determined to be statistically significant at the 90th percentile is classified as being "not significant." A trend is determined 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 trends are presented in Table 3, while the graphical representations of the trends are provided in Appendix A (Historical Climate Analysis).

Table 3: Climate Normals and Trends – Chalk River Atomic Energy of Canada Limited Station (1981 – 2006)

Climate Indices	Normals	Decadal Trend	Statistical Significance
Total Precipitation [mm (equiv.)]	852.0	+9.6	not statistically significant
Spring Total Precipitation [mm (equiv.)]	201.1	-12.0	not statistically significant
Summer Total Precipitation [mm (equiv.)]	251.1	+21.7	significant at the 95th percentile
Fall Total Precipitation [mm (equiv.)]	243.9	+9.9	not statistically significant
Winter Total Precipitation [mm (equiv.)]	155.9	-0.4	not statistically significant
Total Snowfall [cm]	181.5	-3.2	not statistically significant
Total Rainfall [mm]	675.5	+31.1	not statistically significant
End of Winter (March 21) Snowpack [cm]	—	—	not statistically significant, not enough observations
Number of Period of More Than 10 Days With No Rain [#]	1.7	+0.0	no apparent trend
Length of Dry Spells [days]	14.1	+0.0	no apparent trend
Number of Days With >20 mm Rainfall [#]	6.3	+1.3	significant at the 95th percentile
Number of Days With >15 cm Snowfall [#]	1.1	+0.0	no apparent trend
Average Annual Temperature [°C]	5.7	+0.4	significant at the 90th percentile

Table 3: Climate Normals and Trends – Chalk River Atomic Energy of Canada Limited Station (1981 – 2006)

Climate Indices	Normals	Decadal Trend	Statistical Significance
Average Spring Temperature [°C]	5.0	+0.0	no apparent trend
Average Summer Temperature [°C]	19.0	+0.4	significant at the 95th percentile
Average Fall Temperature [°C]	7.5	+0.7	significant at the 95th percentile
Average Winter Temperature [°C]	-9.3	+0.7	not statistically significant
Number of Period of More Than 3 Days With Tmax >30°C [#]	1.5	+0.0	no apparent trend
Length of Heat Waves [days]	4.4	+0.0	no apparent trend
Maximum Daily Temperature [°C]	33.8	+0.6	not statistically significant
Number of Days with Freeze-Thaw Cycle [#]	42.5	+1.3	not statistically significant
Number of Period of More Than 3 Days With Tmin <-15°C [#]	6.2	-1.0	significant at the 90th percentile
Length of Cold Spells [days]	11.0	-2.0	not statistically significant

°C = degrees Celsius; mm = millimetres; cm = centimetres.

The analysis of Chalk River AECL climate station data shows that temperatures are increasing, with the exception of spring. The annual, summer and fall temperatures are statistically significant above the 90th percentile. The total annual precipitation climate indices show an increasing trend that is not statistically significant above the 90th percentile. The total seasonal precipitation shows increasing trends except for winter and spring, which show a decreasing trend. Only the summer precipitation seasonal trends are significant above the 90th percentile. Of the 23 trends examined, only six trends were statistically significant above the 90th percentile: increasing trend in the summer total precipitation, increasing trend in the number of days with more than 20 mm of rainfall, increasing trend in the average annual temperature, increasing trend in the average summer temperature, increasing trend in the average fall temperatures, and a decreasing trend in the number of days with a minimum temperatures less than minus 15°C.

In general, the current climate normals and trends indicate a current climate that has likely become warmer and wetter over time. However, the majority of trends were not found to be statistically significant above the 90th percentile.

3.0 FUTURE CLIMATE CONDITIONS UNTIL 2100

In 1988, the IPCC was formed by the World Meteorological Organisation (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 summarising 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.

3.1 Approach for Describing Future Climate

Climate modeling involves 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 (IPCC 2013). 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 for the NSDF Project (i.e., for the appropriate GCM grid square) were extracted from the CCDS interface (CCDS 2015) for all available GCMs (30) and the three representative concentration pathways (RCP 2.6, RCP 4.5 and RCP 8.5 – detailed in Section 3.1.2 Climate Scenarios) in AR5, providing a set of 90 unique modelling projections. The model projections were summarized for magnitude of change from the climate regime baseline for the following two-time horizons:

- 2041 to 2070 (denoted as Mid Term); and
- 2071 to 2100 (denoted as Far Term).

The Mid Term represents the second half of the operation phase (2041 through 2070) and the Far Term represents the beginning of the post-closure phase (2070 through 2100). While the two-year construction phase (2020 through 2022) occurs during the Near Term (2011 through 2040), it is too short for any measurable change to either the climate normals (e.g., means) or extreme weather events (e.g., storms) and has a very low potential for being affected by climate change impacts, as any projected changes in climate are very likely to be within the variability currently experienced in the weather in the NSDF Project region. Projected changes in climate are more easily measured over longer periods, for example the 30-year periods between the Mid Term and Far Term. Over shorter periods, the projected change in climate is difficult to distinguish, as a statistically significant trend, outside of the day to day, seasonal and year to year (interannual) variability experienced in weather. For this reason, climate change impacts during the three-year construction phase would be difficult to project outside of the variability in weather being experienced under current climate, as outlined in Table 3 in Section 2.2 (Current Climate with Current Climate Trends and Extremes) and Appendix A (Historical Climate Analysis).

In order to graphically represent the individual model output in a comparable and meaningful way, the data must have a consistent baseline. For each model, the change in temperature and precipitation was calculated relative to the respective modelled baseline values, which are unique to each model. This change was then imposed onto the historic climate baseline for the NSDF Project.

Given the large grid size of a GCM projection, as described below, the data are representative of area averages and are not necessarily representative of a specific location contained within the grid box. Murdock and Spittlehouse (2011) recommend that analyses involving GCM projections be based on descriptions of future climate that have been presented in the context of change from the accepted baseline period (i.e., the model baseline period for this study was taken as 1981 through 2010). Since the models may have an absolute bias, the predicted future climate is compared to the predicted baseline using the same model. Also, because the models are most effective at describing projections of change, projected changes from a modeled baseline are typically described as a deviation from baseline, either in degrees Celsius (°C) for temperature, or percent (%) for precipitation. The resulting change from the modelled baseline can then be used to project the future climate conditions in the context of the actual current climate for the NSDF Project.

The current climate was analyzed for the period from 1981 through 2006, a normal encompassed by the selected model baseline of 1981 through 2010. The CCDS interface provides model projections for the historical period from 1900 through 2005, as well as the future projections from 2006 through 2100, and the appropriate years from the AR5 dataset were selected to match the desired current and future climate time periods. Climate projections, in the form of a deviation from the current climate baseline, were calculated for the two desired future periods most relevant to the NSDF Project.

3.1.1 General Circulation Models

Climate simulations produced by these general circulation models vary because each model uses a different combination of algorithms to describe and couple the earth's atmospheric, oceanic and terrestrial processes. The GCMs used in this analysis have been validated against observations, and the interpretation of their results has been peer-reviewed by the IPCC and others. Rather than selecting a single model, the climate change projections from all available models from AR5 (i.e., 90 unique sets of modeling results) obtained using the CCDS interface were included in the analysis. This ensemble approach was used to delineate the probable range of results and better capture the actual outcome (an inherent unknown).

In the case of climate models, projections are not made at a location, but for a series of grid cells in the scale of hundreds of kilometres in size. The CCDS interface provides gridded global GCM projections. For this assessment, the climate projections for the grid square encompassing the NSDF Project centroid were extracted from the gridded AR5 model projections provided by CCDS.

3.1.2 Climate Scenarios

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 of the atmosphere. The IPCC identified four scenarios but this report focuses on the three RCPs currently available from CCDS, namely, RCP 2.6, RCP 4.5 and RCP 8.5. The pathways are named after the radiative forcing projected to occur by 2100. These three 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 4.

Table 4: Characterization of Representative Concentration Pathways

Name	Radiative Forcing in 2100	Characterization
RCP 8.5	8.5 W/m²	Increasing greenhouse gas emissions over time, with no stabilization, representative of scenarios leading to high greenhouse gas concentration levels.
RCP 4.5	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.
RCP 2.6	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/m^2 = watt per square metre.

3.1.3 Long-term Effects of Climate Change

Long-term effects of climate change on these factors (beyond 2100) are highly dependent on the emissions scenarios (RCPs) being considered, and are not provided by the CCDS interface. As a result, the period beyond 2100 will be discussed in Section 4.0 (Future Climate Conditions Post 2100), in a qualitative manner based on publicly available, peer-reviewed literature.

3.1.4 Understanding Climate Projections and Their Limitations

General circulation models have inherent limitations that are important to bear in mind when evaluating variability and the rate of climate change, (i.e., when comparing future projections to historical observations). These limitations are dependent on the research institution's approach to overcoming model uncertainty. 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. For this reason, the multi-model ensemble approach described in Section 3.1.1 (General Circulation Models) was used to account for these uncertainties and limitations.

3.1.4.1 Spatial and Temporal Scales

Due to limitations on computing power, the GCM outputs are limited to grid cells of 1 to 2.5° (approximately 110 to 275 km) and a small number of vertical layers in both the atmosphere and the ocean. These grid cells represent a mathematically defined "*region*" rather than a specific geographic location and are different for many models. Although the appropriate grid cells were selected to represent the NSDF Project region, the spatial scale of the grid cells are much larger than that of most weather processes experienced locally, such as convective thunderstorms. In addition, local changes in topography cannot be represented at this scale.

Temporally, the GCM simulations are run at monthly time scales, with only monthly average temperature and precipitation are available as outputs from CCDS.

3.1.4.2 Unpredictable Events

Climate model simulations represent average conditions and typically do not consider the influence of inherently unpredictable stochastic or episodic events (e.g., volcanic eruptions, earthquakes, tsunamis). In other words, events of a certain magnitude tend to occur at a certain frequency; however, their actual magnitude and timing is unknown and currently not predictable within a specific GCM's outputs.

3.1.4.3 Changes to Collective Understanding of the Processes

The earth's system processes and feedbacks are very complex, and therefore, have to be approximated in GCM model simulations. In these instances, mathematical parameterizations of these processes are required to reduce the computational burden within the simulations. Each of these independent processes that drive climate change can be assigned a rank based on the current level of scientific understanding. The contribution of aerosols in the GCMs is an example of this uncertainty. Through the various assessment reports from the IPCC (First Assessment Report in 1990 through the Fifth Assessment Report in 2013) the level of scientific understanding of aerosols has improved, due to the large amount of research conducted by the scientific community during that period. As the scientific community improves its understanding of the climate system through research, the representation of the climate system within the GCMs may also improve.

3.2 Annual Projections

Comparisons of the future climate projections for the NSDF Project region for the Mid-Term and the Far Term projection periods are shown as scatter plots on Figure 1. The plots illustrate the projected change in temperature (vertical axis) and precipitation (horizontal axis) from the Chalk River AECL climate baseline (1981 through to 2006 normal period) for each of the models, and for three of the relative concentration pathways considered in AR5 (IPCC 2013). The scatter plots shown in Figure 1 also illustrate the change in climate that would occur if the observed historical changes continue forward into the future (i.e., the black diamond on the scatter plot graphs). For reference, the current climate is shown as a solid circle where the axes intersect. The current climate trend shown in the figure is based on the Chalk River AECL climate station data. The model projections are generally located in the upper right quadrant of the plots, suggesting a future climate that will likely be warmer and wetter. These projections are similar to the observed current climate trends at Chalk River AECL climate station (Table 3). The potential implications of these projections are discussed in the Environmental Impact Statement for the NSDF Project (Section 10.4 Climate Change).

Figure 1: Scatter Plots Showing the Mid Term and Far Term Annual Projections for the Near Surface Disposal Facility Project Region

The range of annual temperature projections for the NSDF Project covering the Mid Term period is shown on a "cloud graph" presented on Figure 2. In the figure, the shaded cloud represents the range of climate projections over the 30-year projection period for each of the models and emission scenarios available. To provide context, the 26-years of observations used to describe the current climate (1981 through 2006) from Chalk River AECL climate station, and the resulting climate normals, are provided on the plot to give an indication whether the models are projecting a future climate that is similar to what is being observed, or a future climate that is different than recent observations. The future Mid Term temperature projections for the NSDF Project region, indicated in Figure 2 as the shaded cloud, are generally warmer than the current climate observations, with the projected absolute minimum below the current climate normal.

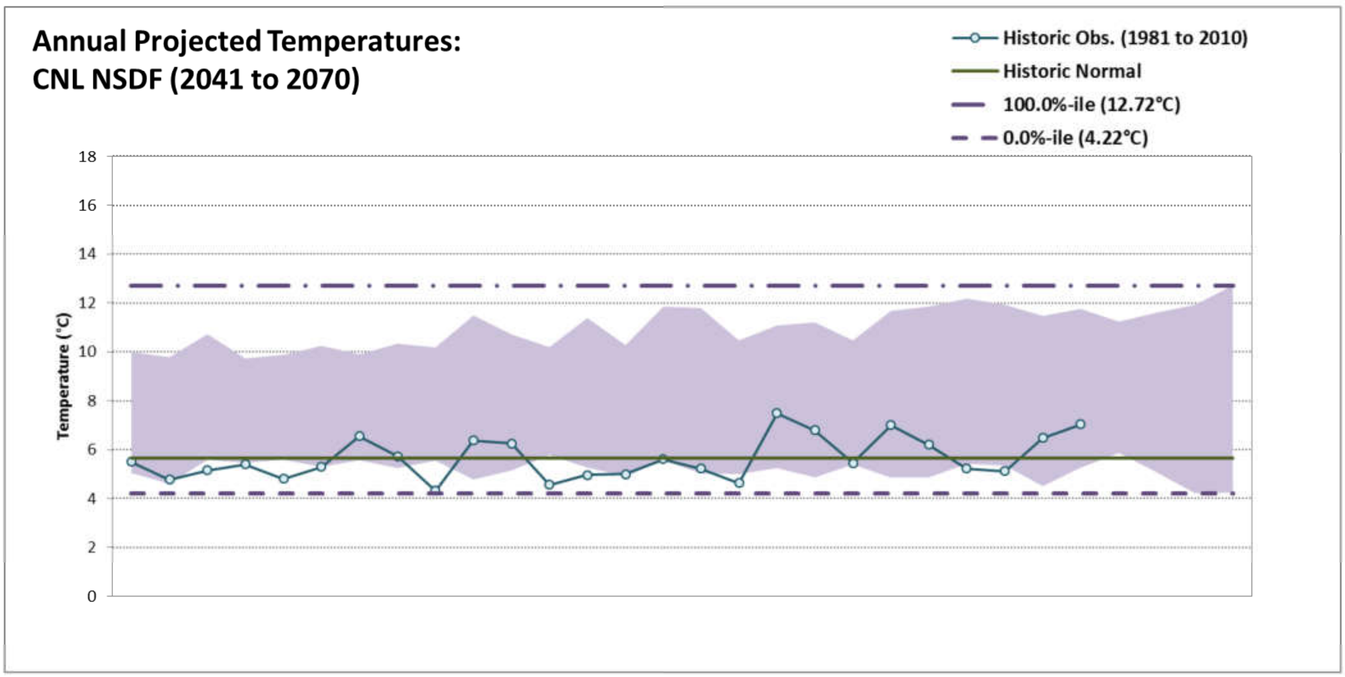

Figure 2: Mean Annual Projected Temperatures for the Near Surface Disposal Facility Project region (Mid Term Period)

The range of annual projected temperatures for the NSDF Project region for the Far Term shows an increase in the absolute maximum relative to the projections for the Mid Term period and a lower absolute minimum projection indicating a larger variation in the projections as shown in Figure 3. The absolute minimum projection is below the range of the current climate normal for the period (1981 through to 2006 shown over the period from 1981 through to 2010) and, generally, the projected temperature normal (estimate as the mean of the projected temperature range) is above all current climate values and the current climate normal.

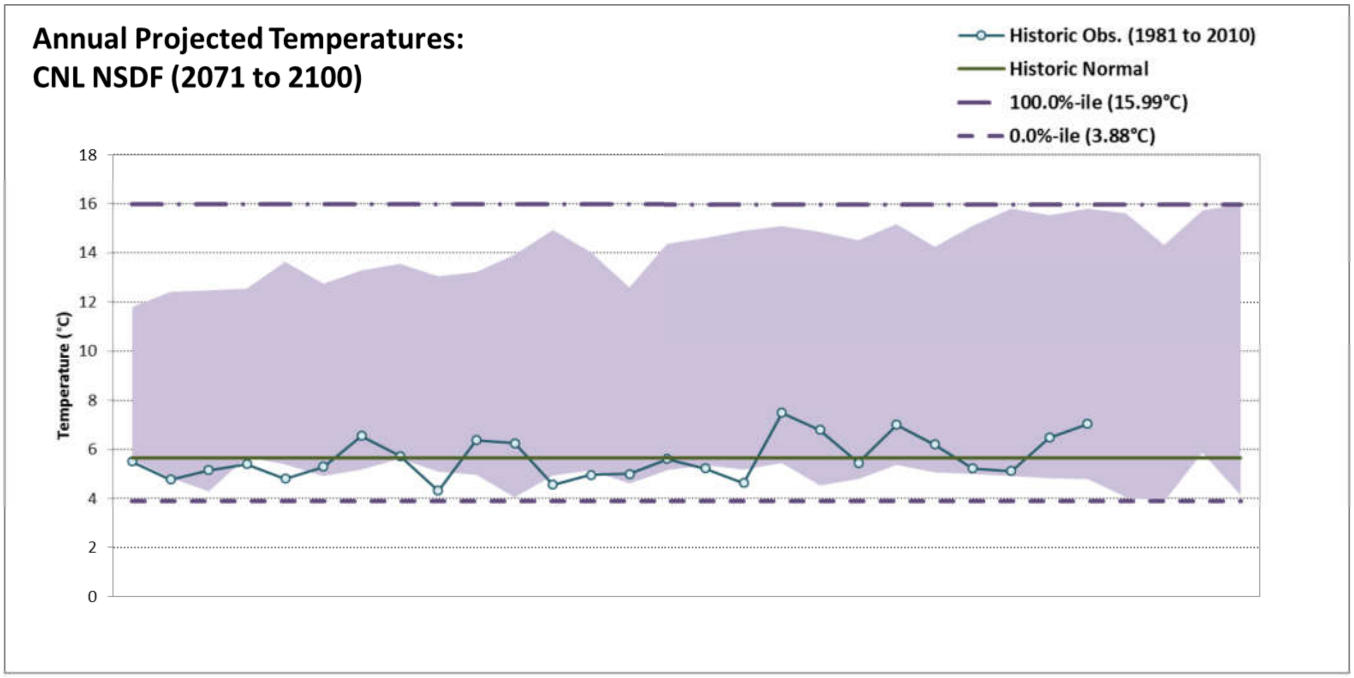

Figure 3: Annual Projected Temperatures for the Near Surface Disposal Facility Project region (Far Term Period)

The projected annual precipitation for the Mid Term period for the NSDF Project, compared to current climate observations indicates that the future annual precipitation rates will be consistent with historical observations shown on Figures 4 and 5. Almost all of the current climate observations of annual precipitation fall within the "cloud." The large spike seen in the graph helps to illustrate the importance of considering a multi-model ensemble and the 30-year normal period, which helps to reduce the influence of single year and model projections.

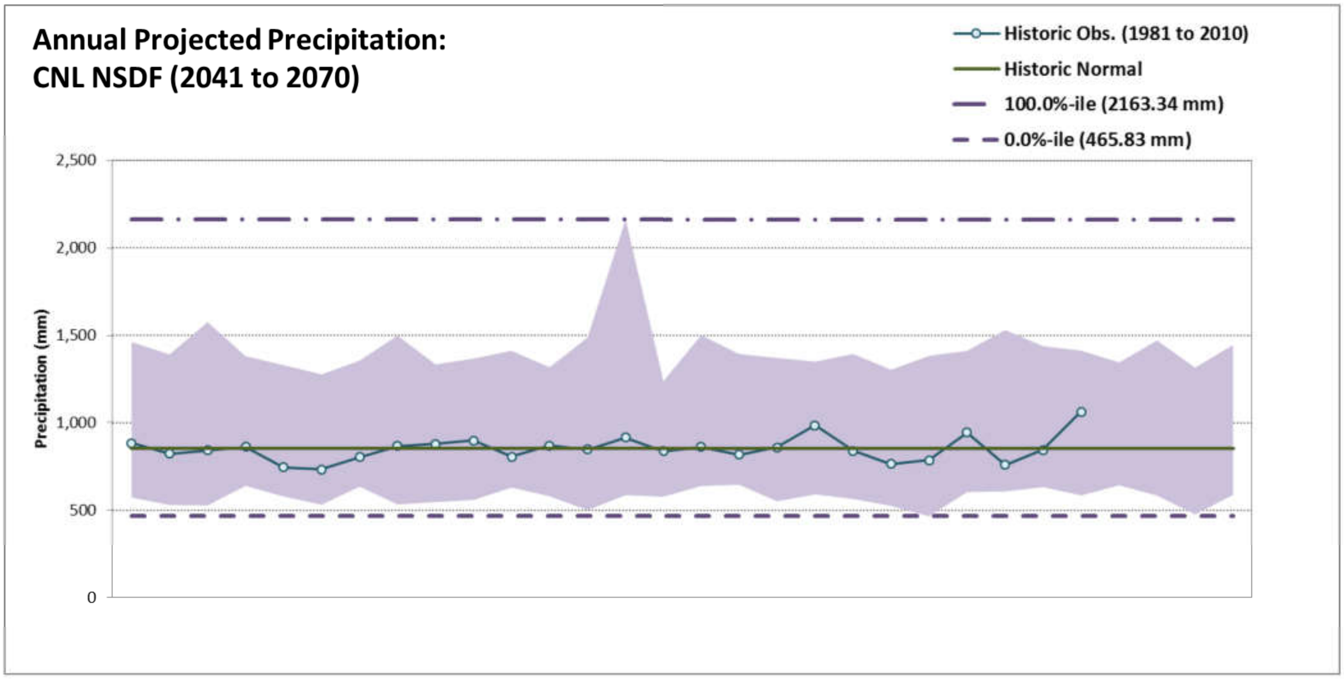

Figure 4: Annual Projected Precipitation for the Near Surface Disposal Facility Project Area (Mid Term Period)

The projections of annual precipitation for the Far Term period show a slight increase in precipitation range relative to the Mid Term; however, the range of future projections still covers the range of historical observed precipitation as shown on Figure 5. Unlike Figure 4, the large spike is not present in the Far Term projections.

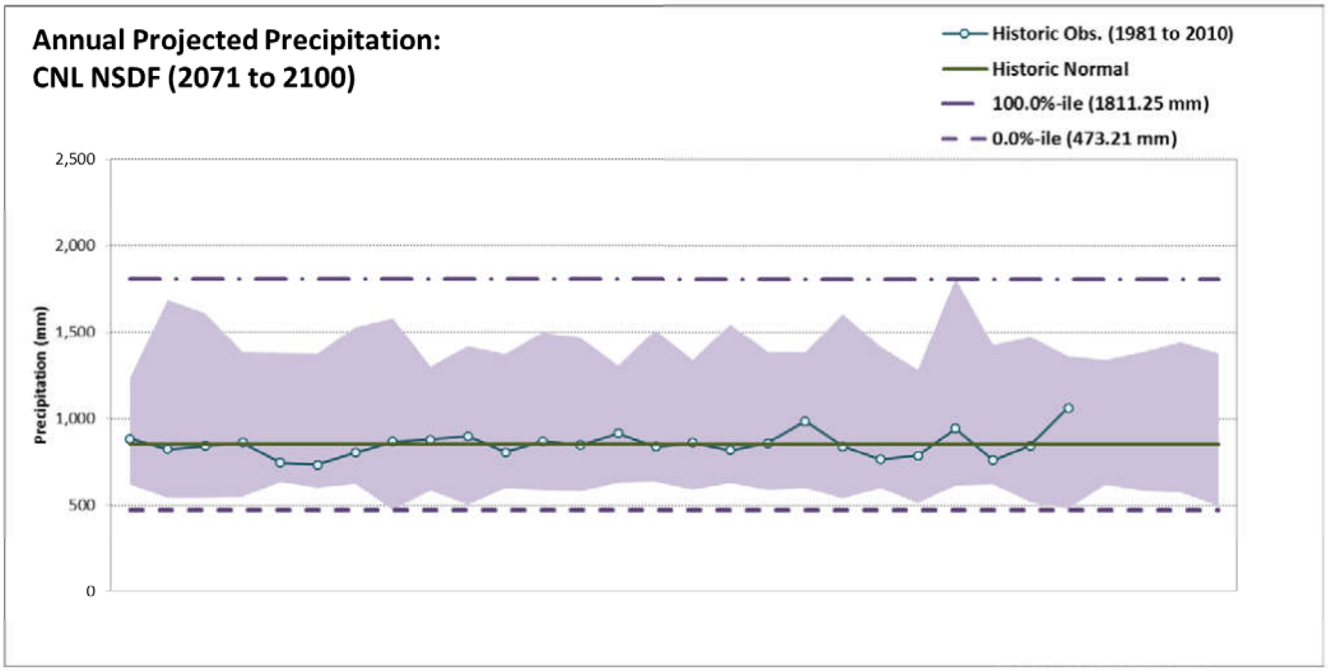

Figure 5: Annual Projected Precipitation for the Near Surface Disposal Facility Project region (Far Term Period)

3.3 Monthly Projections

Figures 6, 7, 8 and 9 and Tables 5 and 6 summarize the magnitude of monthly projected change during the Mid Term and Far Term from the model baseline. Figures 6 and 7 present the monthly range of projected temperatures for the NSDF Project (purple shaded area), for the Mid Term and Far Term. The figures also show a dashed line, which represents the mean of all the modelled projections. The solid line in Figures 6 and 7 represents the monthly observed climate normal based on data from 1981 through to 2006, with the teal shaded area showing the range of current climate observations. The figures show a noticeable increase between the currently observed and projected monthly mean temperatures (up to approximately 3°C in fall).

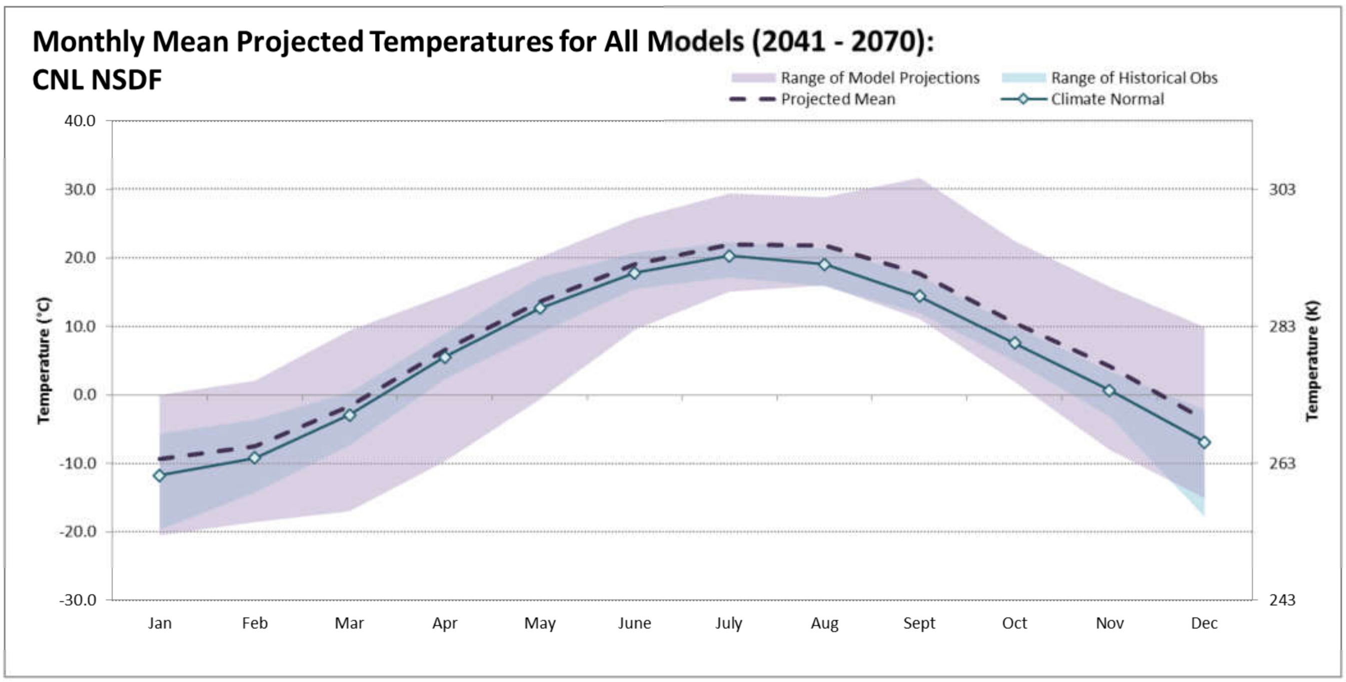

Figure 6: Monthly Projected Temperatures for Near Surface Disposal Facility Project region for the Mid Term

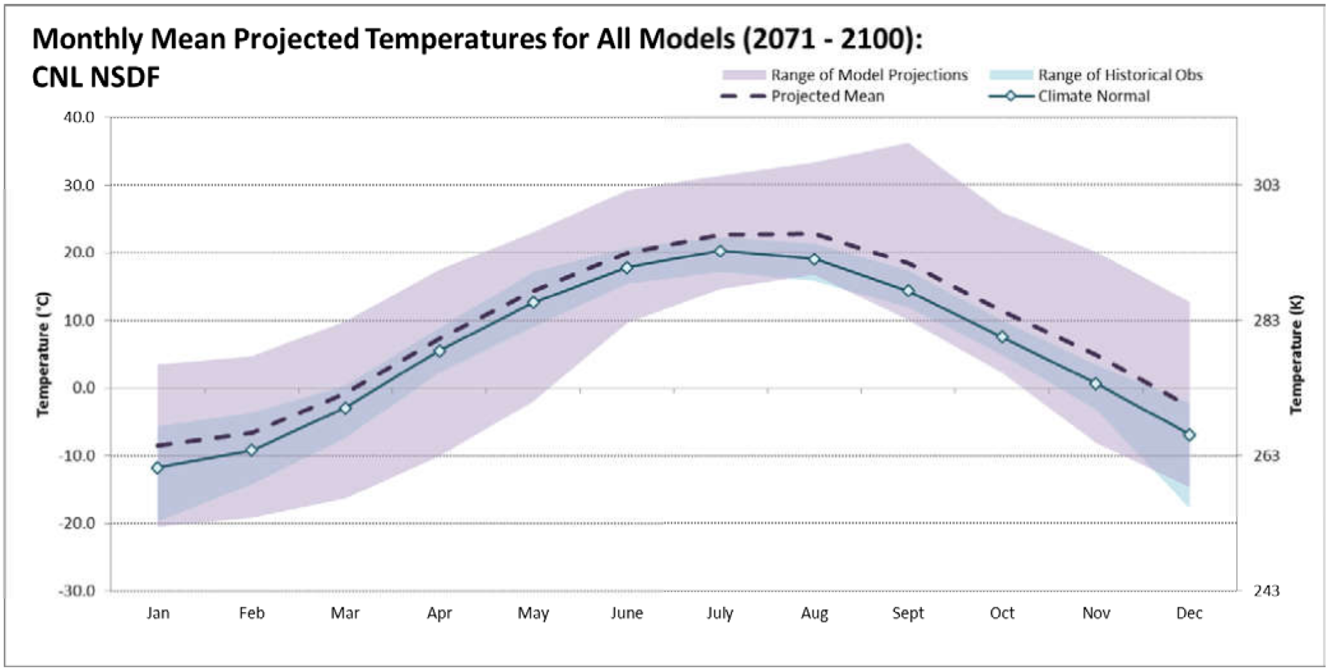

Figure 7: Monthly Projected Temperatures for Near Surface Disposal Facility Project region for the Far Term

Figures 8 and 9 present the monthly projected precipitation for the NSDF Project region, for the Mid Term and Far Term. In both figures, there is a noticeable difference between the current normal and the projected mean from October through to January (late fall and early winter). There appears to be a large range in model projections occurring during a similar period. On average, the projected future conditions appear to be similar to the current climate, with a larger range in projections than the variability experienced in the observed record.

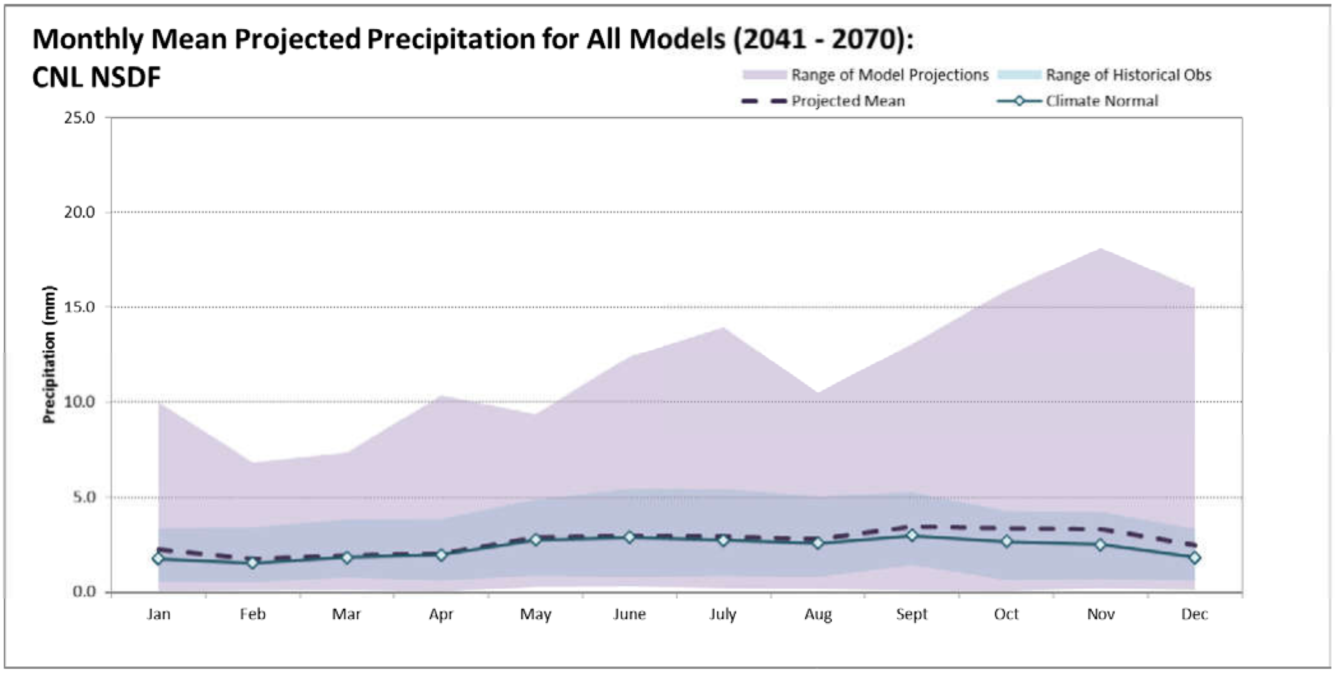

Figure 8: Monthly Projected Precipitation for Near Surface Disposal Facility Project region for the Mid Term

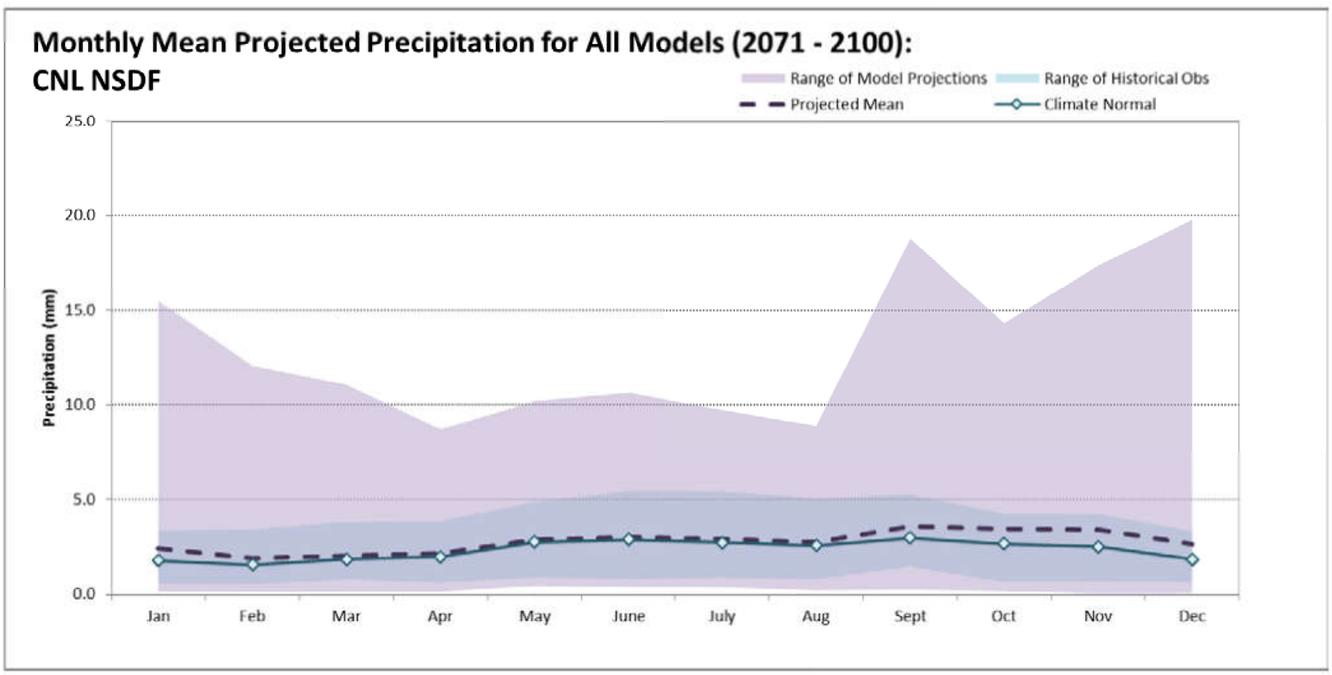

Figure 9: Monthly Projected Precipitation for Near Surface Disposal Facility Project region for the Far Term

The difference between the current climate normal and the projected mean for the Mid Term and the Far Term is shown in Tables 5 and 6. Overall, the model projected means are greater than the observed climate normal for temperature and precipitation. The largest differences in temperature and precipitation occur during the fall and early winter (September through December). November shows the largest temperature and precipitation increase in both the Mid Term and Far Term.

Table 5: Model Projected Mean and Climate Normal for Near Surface Disposal Facility Project Region for the Mid Term (2041 – 2070)

Month	Temperature [°C]			Precipitation [mm]		
	Climate Normal	Projected Mean	Difference	Climate Normal	Projected Mean	Difference
January	-11.77	-9.32	2.44	1.78	2.24	0.46
February	-9.18	-7.48	1.71	1.55	1.78	0.22
March	-2.91	-1.65	1.26	1.83	1.96	0.13
April	5.49	6.52	1.03	1.98	2.02	0.04
May	12.63	13.56	0.93	2.75	2.87	0.12
June	17.78	19.11	1.33	2.89	2.97	0.08
July	20.27	21.94	1.67	2.74	2.90	0.17
August	19.05	21.84	2.78	2.57	2.77	0.20
September	14.35	17.65	3.30	2.98	3.46	0.48
October	7.57	10.54	2.97	2.66	3.36	0.69
November	0.67	4.15	3.48	2.51	3.30	0.79
December	-6.91	-3.63	3.28	1.85	2.49	0.64

Note: Summations of the precipitation data over all months may show minor variations (<5%) when compared to the annual value based on the same data. This is due to the weighted averaging introduced by parcelling the data into months, which vary in length, rather than considering the whole annual period.

Table 6: Model Projected Mean and Climate Normal for Near Surface Disposal Facility Project Region for the Far Term (2071 – 2100)

Month	Temperature [°C]			Precipitation [mm]		
	Climate Normal	Projected Mean	Difference	Climate Normal	Projected Mean	Difference
January	-11.77	-8.54	3.23	1.78	2.42	0.64
February	-9.18	-6.61	2.58	1.55	1.92	0.36
March	-2.91	-0.82	2.08	1.83	2.01	0.17
April	5.49	7.24	1.76	1.98	2.14	0.17
May	12.63	14.33	1.70	2.75	2.88	0.14
June	17.78	19.89	2.11	2.89	3.01	0.12
July	20.27	22.72	2.46	2.74	2.92	0.19
August	19.05	22.76	3.71	2.57	2.76	0.19
September	14.35	18.51	4.16	2.98	3.56	0.59
October	7.57	11.35	3.79	2.66	3.45	0.79
November	0.67	4.96	4.29	2.51	3.40	0.89
December	-6.91	-2.84	4.07	1.85	2.66	0.81

Note: Summations of the precipitation data over all months may show minor variations (<5%) when compared to the annual value based on the same data. This is due to the weighted averaging introduced by parcelling the data into months, which vary in length, rather than considering the whole annual period.

The monthly projections indicate a future that is likely warmer and wetter than currently observed, on a month-to-month basis. The change in temperature normals between the currently observed and projected monthly periods is more pronounced than the monthly projected changes in precipitation, which are hard to observe in the figures as they are much smaller (only visible in the tables). The projected changes in monthly temperature appear reasonably uniform in the figures, while the fall and early winter shows the largest change in the mean precipitation.

3.4 Summary of Future Climate Conditions Until 2100

To summarize, the future climate in the NSDF Project region is projected to be likely warmer and slightly wetter, consistent with the observed current climate trends (1981 through 2006) at the Chalk River AECL climate station. The projected temperatures will continue to increase for both the Mid Term and Far Term periods. The projected changes in precipitation also show an increase for both the Mid Term and Far Term. Tables 7 and 8 summarize the projected means and current climate normals for the Mid Term and Far Term for the annual and seasonal periods.

Table 7: Model Projected Mean and Climate Normal for Near Surface Disposal Facility Project for the Mid Term (2041 – 2070)

Period	Temperature [°C]			Precipitation [mm]		
	Climate Normal	Projected Mean	Difference	Climate Normal	Projected Mean	Difference
Annual	5.7	7.8	2.2	852.0	924.1	72.0
Spring	5.0	6.1	1.1	201.1	208.7	7.5
Summer	19.0	21.0	1.9	251.1	263.7	12.7
Fall	7.5	10.8	3.3	243.9	294.7	50.9
Winter	-9.3	-6.8	2.5	155.9	192.6	36.6

°C = degrees Celsius; mm = millimetres.

Table 8: Model Projected Mean and Climate Normal for Near Surface Disposal Facility Project for the Far Term (2071 – 2100)

Period	Temperature [°C]			Precipitation [mm]		
	Climate Normal	Projected Mean	Difference	Climate Normal	Projected Mean	Difference
Annual	5.7	8.6	3.0	852.0	940.6	88.6
Spring	5.0	6.9	1.8	201.1	214.2	13.1
Summer	19.0	21.8	2.8	251.1	265.2	14.1
Fall	7.5	11.6	4.1	243.9	302.6	58.8
Winter	-9.3	-6.0	3.3	155.9	207.0	51.0

°C = degrees Celsius; mm = millimetres.

4.0 FUTURE CLIMATE CONDITIONS POST 2100

Due primarily to computational limitations in early climate modelling and the uncertainty further discussed in Section 3.1 (Approach for Describing Future Climate), most climate model projections extend only to the year 2100. However, the warming effects and radiative forcing resulting from atmospheric greenhouse gases extends long after emissions have ceased and beyond the atmospheric lifetime of the gas (Lenton et al. 2006). Therefore, while a large portion of warming resulting from anthropogenic carbon dioxide (CO_2) will happen on the century timescale, warming can continue well beyond 2100 and into the next millennia. CO_2 is significantly more abundant than other greenhouse gases and aerosols, and has the largest impact, compared to other species, on the radiative forcing used to drive the climate models.

The projected future climate beyond 2100 was described in a qualitative manner using publicly available, peer-reviewed literature, including AR5.

4.1 Past Climate Cycles

The earth is currently in an interglaciation period, meaning that it is between ice ages. It is estimated that the current period, called the Holocene, began approximately 11,700 years ago (Clark et al. 2016). The most recent glacial period peaked approximately 21,000 years ago (Clark et al. 2016). The transition from the previous glacial period to the current Holocene represented a change in atmospheric CO_2 concentrations of approximately 80 ppm and a global average rise in temperature of 4°C. Records suggest that previous interglaciation periods have lasted anywhere from 10,000 to 20,000 years (Berger et al. 2003).

4.2 Climate Projections from 2100 Through 3000

The projected ranges of future climate conditions were described using the results accepted by the IPCC for various representative concentration pathways (RCPs). Meinshausen et al. (2011) extended four RCP scenarios (RCP 2.6, 4.5, 6.0 and 8.5) until 2300 in support of AR5 using Earth Models of Intermediate Complexity (EMICs). The results of the EMIC extensions were consistent until 2300 with atmospheric-ocean general circulation models (AOGCM) used in AR5. Zickfield et al. (2013) used the extensions to estimate temperature changes up until the year 3000, assuming that the CO_2 concentration and forcing was held constant at year 2300 levels for all four RCP scenarios. In order to remain consistent with Section 3.0 (Future Climate Conditions until 2100), only RCP2.6, 4.5 and 8.0 are described further, covering the full range of projections.

The RCPs are named after the radiative forcing projected to occur by 2100. For example, RCP 4.5 represents a scenario where the radiative forcing is stabilized shortly after 2100 at 4.5 W/m². These three RCPs have been described more fully by van Vuuren et al. (2011) in their paper “The representative concentration pathways: an overview” and in Section 3.1.2 (Climate Scenarios).

As shown on Figure 10, presented in Zickfield et al. (2013), in scenarios RCP4.5 and RCP8.5, rapid warming occurs until the radiative forcing is stabilized (assumed to be 2300), with predicted increases of 2.2°C and 7.0°C respectively, relative to the 1986 to 2005 reference period used in AR5 (this reference period is encompassed by the current climate normal used in Sections 2.0 (Existing Conditions) and 3.0 (Future Climate Conditions until 2100). After the forcing is stabilized warming slows but continues through the year 3000, with additional warming estimated at 0.3°C and 0.8°C for RCP4.5 and RCP8.5 respectively from 2300 to 3000. Under the RCP2.6 scenario, temperatures peak around 2070 and decreases until 2300 after which it slowly starts to increase again. Overall, for the period from 2281 through to 3000, relative to the 1986 through 2005 reference period, the temperatures are projected to rise by 0.6°C to 7.8°C across all four scenarios.

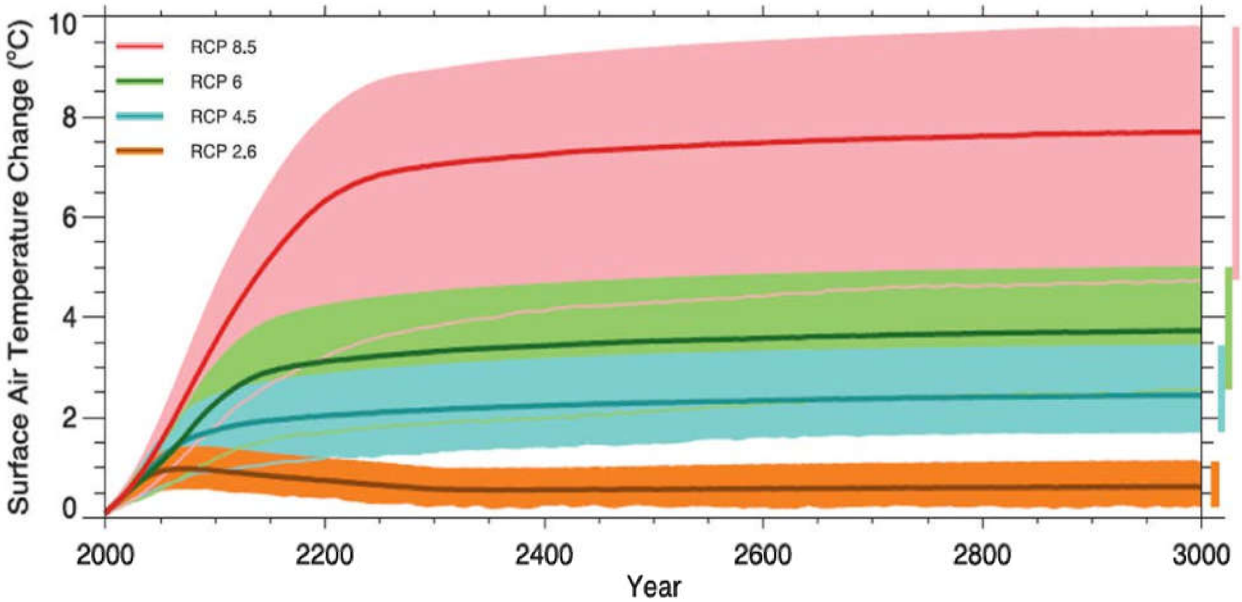

Figure 10: Time Evolution of Surface Air Temperature Change (from 1985 to 2005 reference period) for the Constant Composition Simulation for All Four RCP Scenarios (Zickfield et al. 2013)

Results showed that if anthropogenic emissions are ceased abruptly it would require centuries before temperatures would begin to decrease. If emissions stopped in 2300, temperatures would only decrease by about 1 to 2 degrees by year 3000 and ocean expansion would still be increasing. Under the scenarios currently presented in the literature, only an abrupt net removal of CO_2 from the atmosphere would result in a decrease in temperatures by year 3000 for RCP scenarios 4.5 and higher, beyond current technological capabilities (Cao and Caldeira 2010; IPCC 2013, Plattner et al. 2008; Zickfield et al. 2013).

It is generally accepted that with increased temperature, mean sea levels and global precipitation will also increase. It has been estimated that global precipitation will increase by 1-3% per degree Celsius increase in temperature (IPCC 2013). However, the distribution of precipitation will vary spatially, with increases in some regions and decreases in others. Given the increase in precipitation and uncertainty in distribution, it is likely that there will be an increase in the variation or range of precipitation projected for the period up until 2100 (Section 3.0 Future Climate Conditions until 2100).

No peer-reviewed literature discussions were found on extreme events (e.g., storms). In AR5, there is a lot of uncertainty surrounding extreme events for the period up until 2100. It is likely that this uncertainty will continue into the period post 2100, especially with the uncertainty on how the global radiative forcing will develop over the period up until 2100.

4.3 Future Glaciation Cycles

The global warming projected until the year 3000 (0.6 to 7.8°C over 1,000 years) represents a much higher warming rate than the rate seen at the end of the last glacial period, which was a change of approximately 4°C over an estimated 8,000 years. This corresponds to a higher rate of increase in atmospheric CO_2 concentrations than in previous periods (Clark et al. 2016, Berger et al. 2003). CO_2 concentrations and glaciation models coupled together predict a relatively long interglacial period of 55,000 years (Berger et al. 2003) as compared to previous periods of 10,000-20,000 years due to higher atmospheric CO_2 concentrations. The next significant glacial event is not projected to occur before 60,000 after present (Berger et al. 2003).

4.4 Summary of Future Climate Conditions Post 2100

Under the RCP scenarios described in IPCC's fifth assessment report, global temperatures are predicted to rise between 0.6°C and 7.8°C by the year 3000. The majority of the warming will occur before 2300 with warming rates slowing after stabilization of radiative forcing. Warmer temperatures are only projected to be reversible under abrupt CO_2 removal scenarios which are currently beyond technological abilities. Projections of precipitation changes for the period from 2100 to 3000 were often not provided in the peer-reviewed literature. However, as outlined in AR5, changes in precipitation are anticipated with an estimate increase in global precipitation of 1% to 3% per degree Celsius of increased temperature over the period from 2100 to 3000. However, with distribution of the precipitation varying spatially, there will be increases in some areas while precipitation decreases in others. With this uncertainty in the distribution or precipitation, it is likely that precipitation after 2100 will show a greater variation or range from the projections up until 2100. A summary of the mean temperature and total precipitation future projections are provided in the Table 9. Absolute changes in temperature and precipitation for the NSDF Project are not provided for the Long Term as quantitative analysis of the climate projections was not undertaken (e.g., the methodology followed in Section 3.0 Future Climate Conditions until 2100). Sufficient information was not readily available to perform a quantitative analysis; however, long-term projections of increased precipitation, and warming at higher latitudes are likely to continue past the 21st century.

Table 9: Projected Climate for the Mid Term, Far Term and Long Term

Period and Variable	Temperature		Precipitation	
	Value	Units	Value	Units
Current Climate Normal (1981 - 2006)	5.7	°C	852.0	mm
Mid Term Projected Change (2041 - 2070)[a]	2.2	°C	72.0	mm
Far Term Projected Change (2071 - 2100)[a]	3.0	°C	88.6	mm
Long Term Projected Changes (2281 - 3000)[b]	0.6 to 7.8[2]	°C	1 to 3[2]	%/°C

a) Please note that projected changes represent changes above the current climate (1981 – 2006) for the NSDF Project region.
b) Please note that these projected changes represent the changes above the reference period of 1986 – 2005 and are global values. NSDF Project-specific information is not available at this time.
°C = degrees Celsius; mm = millimetres;%/°C = percent/degree Celsius.

There is still much uncertainty around future extreme events, as outlined in AR5. While no discussions were found in peer-reviewed literature of extreme events beyond 2100, given the uncertainty around the temperature and precipitation projections past 2100, it is likely that the uncertainty in future extreme events will continue. Further discussion of extreme events is provided in Section 5.0 (Project-Specific Climate Factors and Extreme Events).

High CO_2 concentrations and warming temperatures will likely delay the end of the current interglacial period until 60,000 years after present, based on the increased interglacial period. Therefore, a glaciation cycle is not likely before the year 3000.

5.0 PROJECT-SPECIFIC CLIMATE FACTORS AND EXTREME EVENTS

Based on the historical climate parameters and climate data analyzed up to 2100, climate factors have been developed to further analyse the potential climate infrastructure interactions for the NSDF Project region. The climate factors include changes to rainfall, temperature and extreme events (e.g., storms). These factors are further subdivided into specific event type factors that describe long term changes such as increasing temperatures or extreme events such as increased storms with intense precipitation. Where information is available from Section 4.0 (Future Climate Conditions Post 2100), the climate factor trends will be extended out to the year 3000. Climate factor trends for the NSDF Project are described in Table 10.

The future trends of the climate factors were analysed using the climate model projections in Section 3.0 (Future Climate Conditions until 2100). If climate projections were not available from Section 3.0, literature values were referenced to discuss the projected change in climate. Increase in intensity and frequency of rainfall and precipitation, including snowfall, is expected for the region (Coulibaly and Shi 2005; IPCC 2013; Kunkel et al. 1999; Stone et al. 2000). The amount of increase is dependent on the increase in temperature resulting from the CO_2 emission scenario (IPCC 2013). Extreme weather events, such as storms and flooding risks, are expected to increase however, the natural variability of storm events and the uncertainty in the modeled scenarios make accurate quantitative projections of frequency and intensity of extreme events difficult to predict (Colombo et al. 2007; IPCC 2013).

Table 10: Climate Factor Trends for the Near Surface Disposal Facility Project Region

Climate Factor Description		Trend	Comments on Future Trends
Rain	Drought	Decreasing	■ Drought was not evaluated under Sections 3.0 (Future Climate Conditions until 2100) or 4.0 (Future Climate Conditions Post 2100). Section 3.0, the future climate for the NSDF Project region shows both increased temperature and precipitation. The future trend in drought will depend on how the projected increases in temperature and precipitation interact locally in the NSDF Project region. ■ In the near and mid-term, droughts are expected to decrease in the NSDF Project region as the area becomes wetter with increased precipitation (Easterling et al. 2000). Long term projections predict that wet areas will continue to become wetter and drier areas will become drier (IPCC 2013). In Canada, higher evaporation rates associated with warmer summers will increase the tendency towards drier conditions, with large variability between the emission scenarios (Warren and Lemmen 2014).

Table 10: Climate Factor Trends for the Near Surface Disposal Facility Project Region

Climate Factor Description		Trend	Comments on Future Trends
Rain (cont'd)	Amount of rain	Increasing	■ In Section 3.0, precipitation is projected to increase for the NSDF Project region up to 2100. Precipitation is projected to increase with temperature past 2100, as shown in Section 4.0, at a global level. ■ In the near and mid-term precipitation is expected to increase, with the largest precipitation increase occurring in spring and winter (Stone et al. 2000). Long term projections predict global increases in precipitation past 2100 with increasing temperature (IPCC 2013) however, no regional projections past 2100 are available in the literature.
	Frequency of heavy rainfall events	Increasing	■ The distribution of precipitation was not projected in Section 3.0; however, precipitation is projected to increase in the NSDF Project region up to 2100. Precipitation is projected to increase with temperature past 2100, as shown in Section 4.0, at a global level. ■ In the near and mid-term intense rainfall frequency is expected to increase in Ontario (Coulibaly and Shi 2005; IPCC 2013; Kunkel et al. 1999; Warren and Lemmen 2014) but there are still relatively large uncertainties associated with projections of extreme precipitation. In particular, a 1-in-20-year storm would become a 1-in-10-year storm by mid-century for mid to high latitudes under higher emission scenarios (Warren and Lemmen 2014). Long term projections predict continued increases however, no regional projections past 2100 are available in the literature.
	Amount of rainfall per event	Increasing	■ The distribution of precipitation was not projected in Section 3.0 (Future Climate Conditions until 2100); however, precipitation is projected to increase in the NSDF Project region up to 2100. Precipitation is projected to increase with temperature past 2100, as shown in Section 4.0 (Future Climate Conditions Post 2100), at a global level. ■ In the near and mid-term rainfall intensity is expected to increase in Ontario (Coulibaly and Shi 2005; IPCC 2013; Kunkel et al. 1999). Long term projections predict continued increases however, no regional projections past 2100 are available in the literature.
	Amount of snow	Increasing	■ The distribution of precipitation between snow and rain was not projected in Section 3.0; however total precipitation is projected to increase in the NSDF Project region up to 2100. Total precipitation is projected to increase with temperature past 2100, as shown in Section 4.0, at a global level. ■ In the near and mid-term precipitation including snowfall is expected to increase, with the largest precipitation increase occurring in winter (Stone et al., 2000). However, coupled with increased temperatures, it is unclear whether the distribution of precipitation between snow and rain will change in the NSDF Project region. Long term projections predict global increases in precipitation past 2100 with increasing temperature (IPCC 2013) however, no regional projections past 2100 are available in the literature.

Table 10: Climate Factor Trends for the Near Surface Disposal Facility Project Region

Climate Factor Description		Trend	Comments on Future Trends
Rain (cont'd)	Frequency of heavy snowfall events	Increasing	■ The distribution of precipitation between snow and rain was not projected in Section 3.0; however, total precipitation is projected to increase in the NSDF Project region up to 2100. Total precipitation is projected to increase with temperature past 2100, as shown in Section 4.0, at a global level. ■ An increase in snowfall and intensity in the northern latitudes is predicted in the near and mid-term (Colombo et al. 2007; IPCC 2013; Zhang et al. 2001).
	Amount of snowfall per event	Increasing	■ The distribution of precipitation between snow and rain was not projected in Section 3.0 (Future Climate Conditions until 2100); however, total precipitation is projected to increase in the NSDF Project region up to 2100. Total precipitation is projected to increase with temperature past 2100, as shown in Section 4.0 (Future Climate Conditions Post 2100), at a global level. ■ An increase in snowfall and intensity in the northern latitudes is predicted in the near and mid-term (Colombo et al. 2007; IPCC 2013; Zhang et al. 2000).
Temperature	Mean temperature	Increasing	■ Mean temperature is projected to increase in the NSDF Project region up to 2100 (Section 3.0), with global temperatures projected to increase post 2100 (Section 4.0). ■ In the near, mid and long term mean temperature is expected to increase for the NSDF Project region (IPCC 2013). In Canada at the mid-latitudes the greatest increase in temperature occurs during the summer (Warren and Lemmen 2014). Warmings of 1.5 to 2.5°C are projected in the summer under the low emission scenario (Warren and Lemmen 2014). Global long-term trends predict increasing temperature past 2100 (Lenton et al. 2006; Meinhausen et al. 2011)
	High temperatures	Increasing	■ Extreme temperatures were not evaluated under Section 3.0 or 4.0. However, mean temperature is projected to increase in the region up to 2100 (Section 3.0), with global temperatures projected to increase post 2100 (Section 4.0). It is likely that with this increase in temperature, the number of extreme warm days would also increase. ■ In the near, mid and long term mean temperature is expected to increase for the region (IPCC 2013) and the NSDF Project region. Increases in the number of warm days and nights are also projected, with the number of extreme hot days projected to increase (Warren and Lemmen 2014). Global long-term trends predict increasing temperature past 2100 (Lenton et al. 2006; Meinhausen et al. 2011)

Table 10: Climate Factor Trends for the Near Surface Disposal Facility Project Region

Climate Factor Description		Trend	Comments on Future Trends
Temperature (cont'd)	Heat waves	Increasing	■ Heat waves were not evaluated under Sections 3.0 (Future Climate Conditions until 2100) or 4.0 (Future Climate Conditions Post 2100). However, with projected increases in temperature it is likely that the number of extreme warm days would increase. ■ In the near and mid-term it is projected that the frequency and intensity of heat waves will increase (IPCC 2013; Warren and Lemmen 2014). Projections beyond the 21st century are not available however it is likely that these trends will continue beyond the 21st century.
	Annual changes effecting snow deposition and rate of melt (freeze-thaw cycles)	Decreasing	■ Annual changes in the freeze-thaw cycle were not evaluated under Sections 3.0 or 4.0. However, with the projected increases in temperature it is likely that the number of freeze cycles would decrease. ■ Wide-spread decreases in the duration of snow cover are projected across the Northern Hemisphere (Warren and Lemmen 2014). Near and mid-term projections of snow deposition predict a decrease in snow cover extent is predicted (IPCC 2013). Long term projections predict continued decreases however, no regional projections past 2100 are available in the literature.
Other Events	Increase in extreme events (e.g., storms)	Increasing	■ Changes in extreme events were not evaluated under Sections 3.0 or 4.0. ■ Near and mid-term projections of occurrence of extreme events predict a shift to more intense storms and an increase in frequency of extreme weather phenomena, such as tornados. There are no regional predictions of extreme weather events in the long term. Climate change is likely to affect flood risks by increasing the frequency of extreme events as well as influencing the storm type, depth-duration-are curves, and storm efficiency (AMEC 2011; Jakob et al. 2009)

NSDF = Near Surface Disposal Facility; °C = degrees Celsius.

6.0 LIMITATIONS

6.1 Standard of Care

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The Client and Approved Users acknowledge that the nature of the work undertaken is stochastic with substantial inherent uncertainly around any given data points. The latter also acknowledge 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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GOLDER ASSOCIATES LTD.

Janya Kelly, PhD
Climate Change Specialist

Sean Capstick, P.Eng.
Principal, Senior Climate Change Specialist

JK/SC/jlb

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APPENDIX A

Historical Climate Analysis

HISTORICAL CLIMATE TRENDS

Historical changes in climate have been described as the trend in the observed data from Chalk River Atomic Energy of Canada Limited (AECL) climate station (ID 6101335) between 1981 and 2006 (Environment Canada 2016). There is approximately less than 1% of the data missing from this station for this period, with less than 2% of data missing for the majority of individual years during the selected period. Notably, 1986 is missing approximately 10% of the data, as no observations were made during October for temperature and no observations were made during parts of August and all of October for precipitation. This is the data used to define the climate normal, which represents the expected climate near the station.

As presented, the historical trend is the slope of a regression line fit to the historical data. In addition to having a slope, each regression line has a level of statistical significance. The statistical significance of a trend line indicates whether a trend is robust or not. Typically, trends that are not statistically significant are ignored because it is not possible to know whether it is an upward or downward trend. The level of statistical significance is expressed as a degree of confidence in percentiles. Usually, a trend that has a statistical significance of less than the 90th percentile is not considered to be a statistically significant trend.

Figure 1 describes the historical data and trends. The graph shows the variation in year to year observations, along with the climate normal (i.e., the average of the 26 years of observations, and the trend derived from the observed data. In the figure shown, there was an upward trend in average annual temperature at a rate of 0.4 Celsius degrees per decade (°C/decade). The trend was identified as being not statistically significant above the 90th percentile.

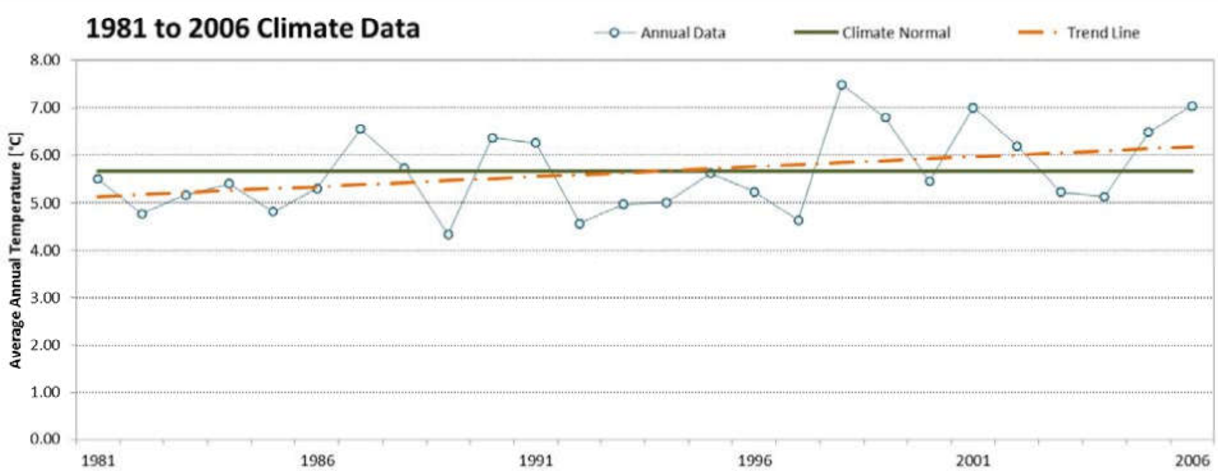

Figure 1: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Annual

Figures 2 to 22 show similar data for the remaining climate factors discussed in Table 3 of the NSDF Project Climate Change Assessment TSD (Climate Normals and Trends – Chalk River Atomic Energy of Canada Limited Station [1981-2006]). Table 3 of the TSD provides a listing of the statistical significance of these climate factors.

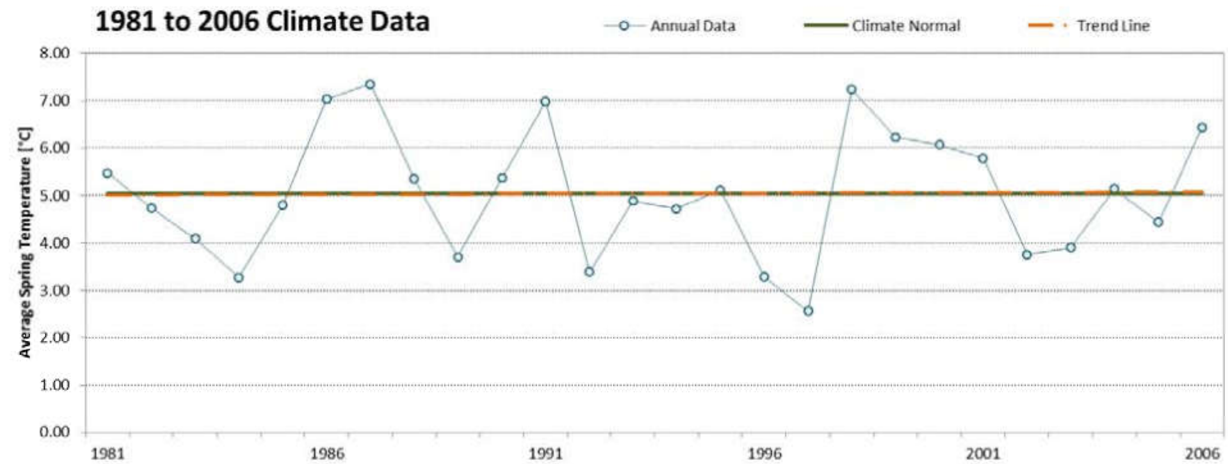

Figure 2: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited– Spring

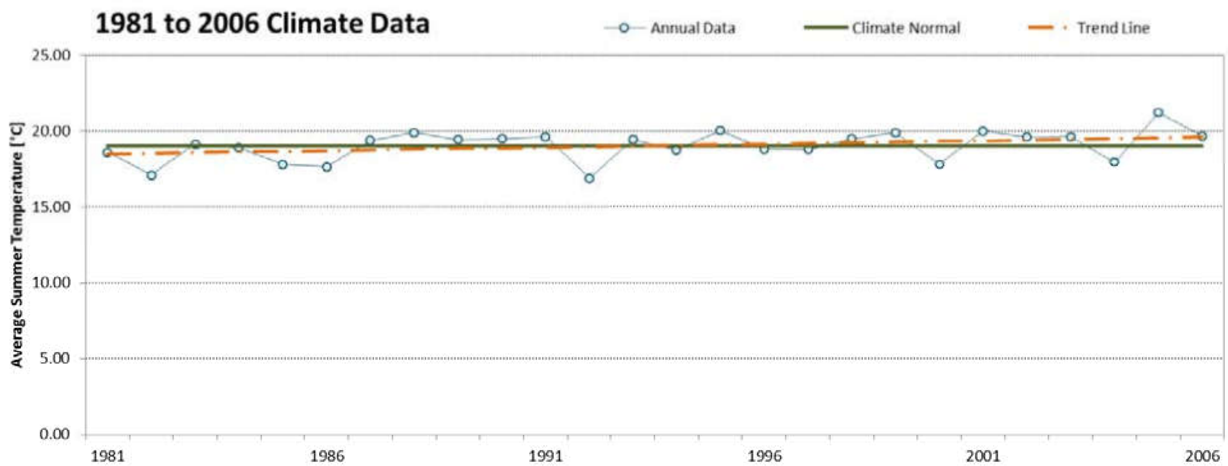

Figure 3: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Summer

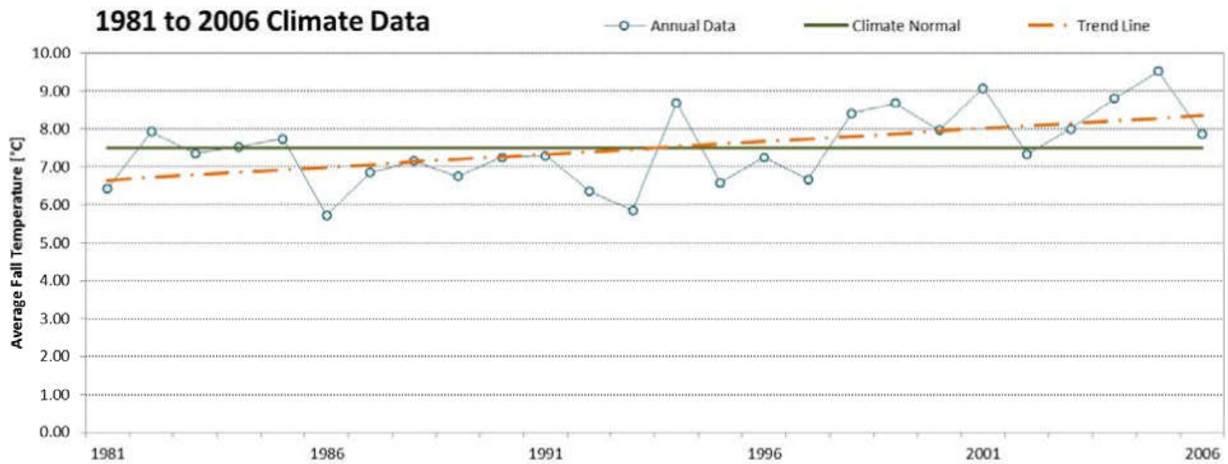

Figure 4: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Fall

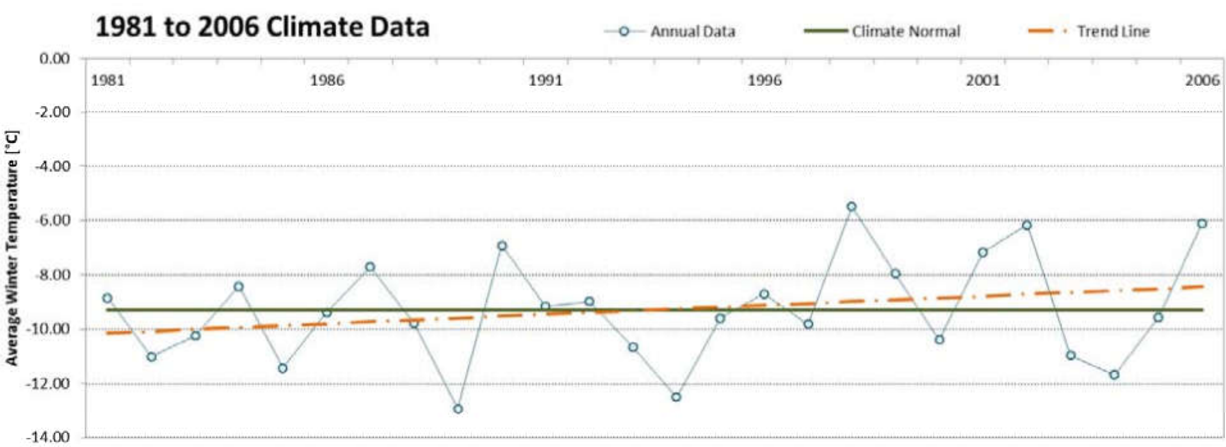

Figure 5: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Winter

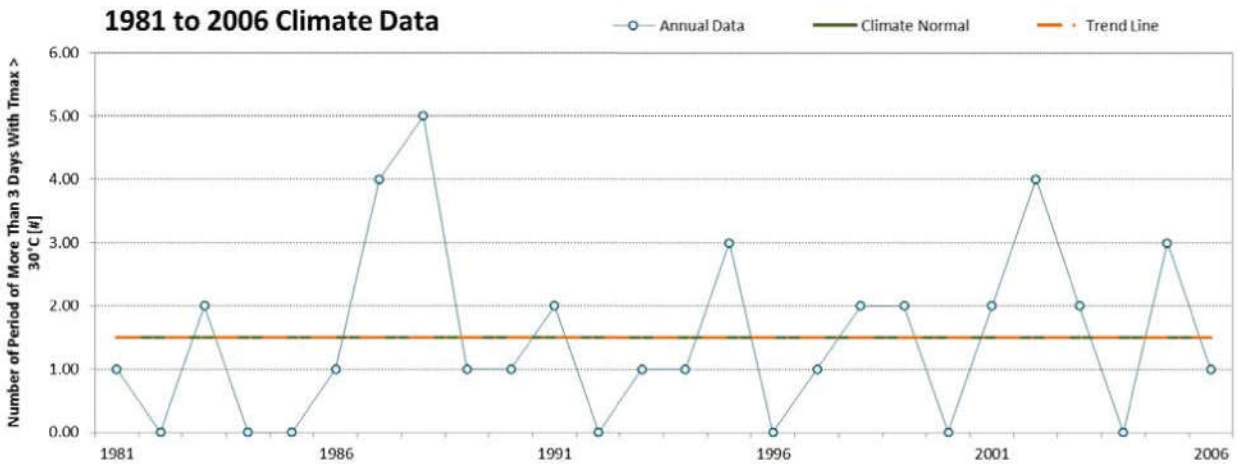

Figure 6: *Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Number of Periods of More Than 3 Days with Maximum Temperature Above 30°C (Heat Waves)*

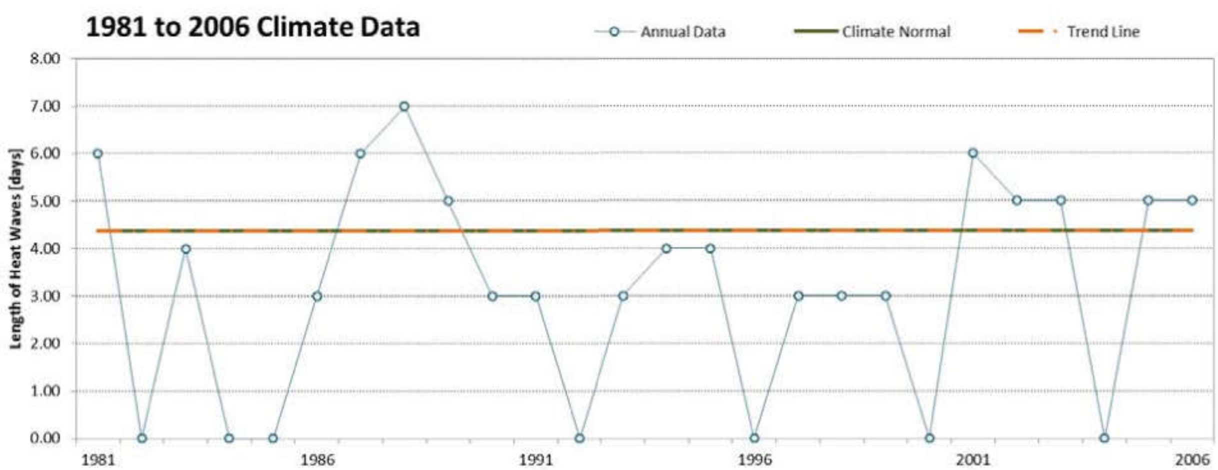

Figure 7: *Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Length of Heat Waves*

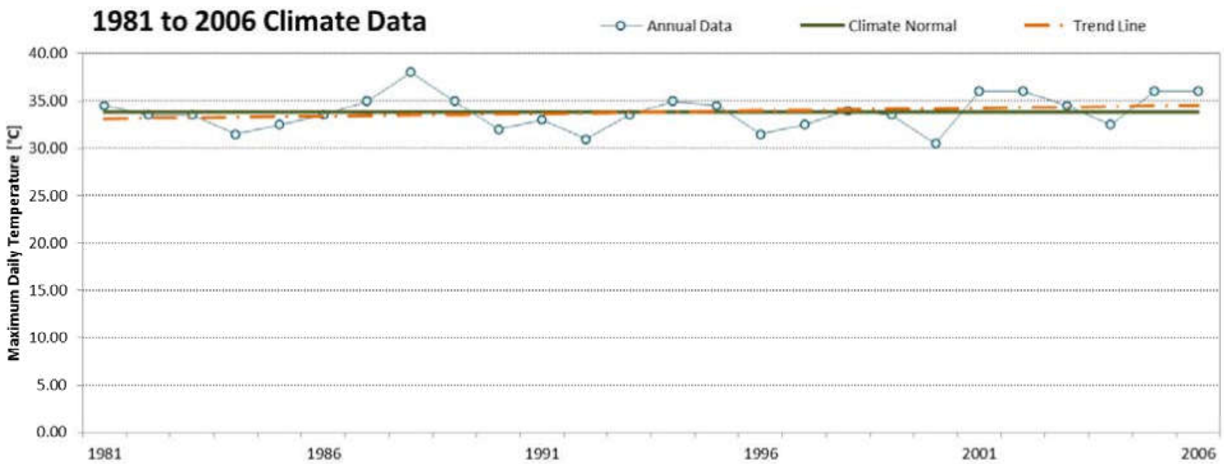

Figure 8: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Maximum Daily Temperature

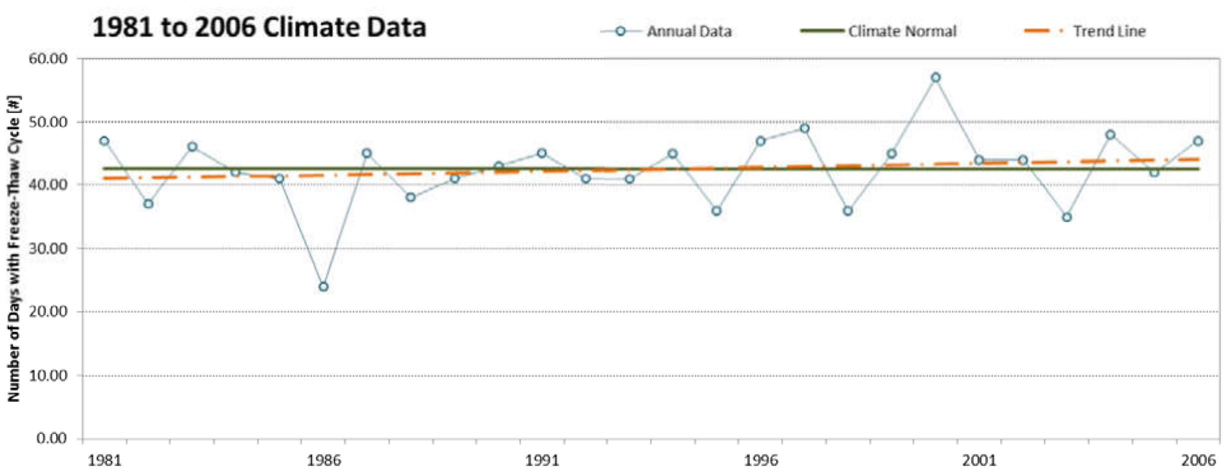

Figure 9: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Number of Days with a Freeze--Thaw Cycle

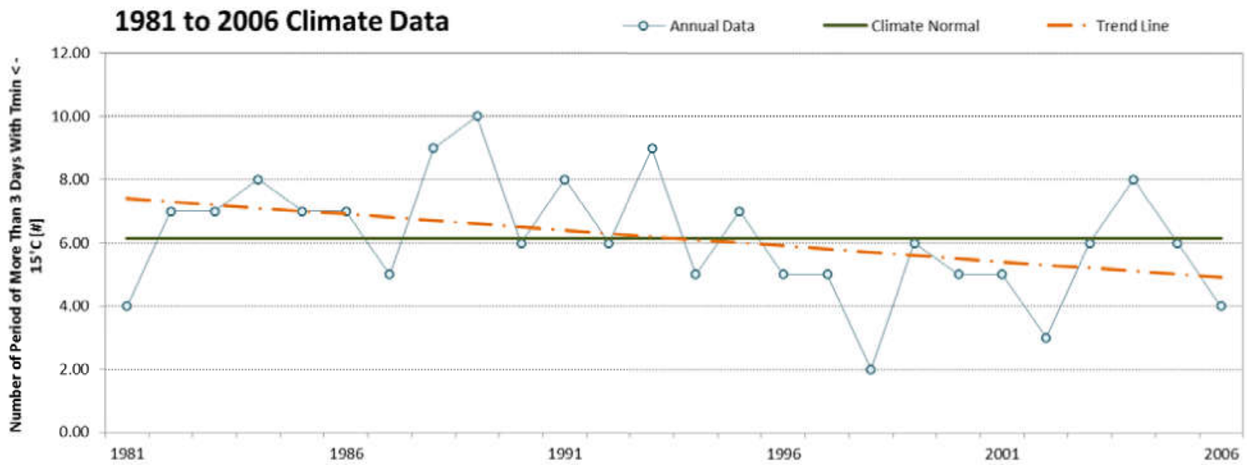

Figure 10: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Number of Periods of More Than 3 Days with Minimum Temperature Below --15°C (Cold Spells)

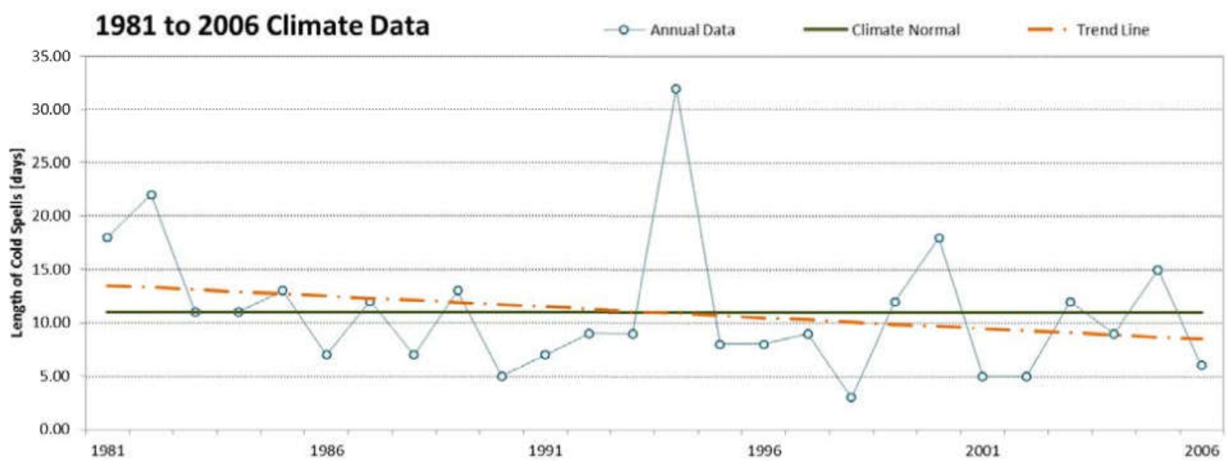

Figure 11: Historical Temperature Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Length of Cold Spells

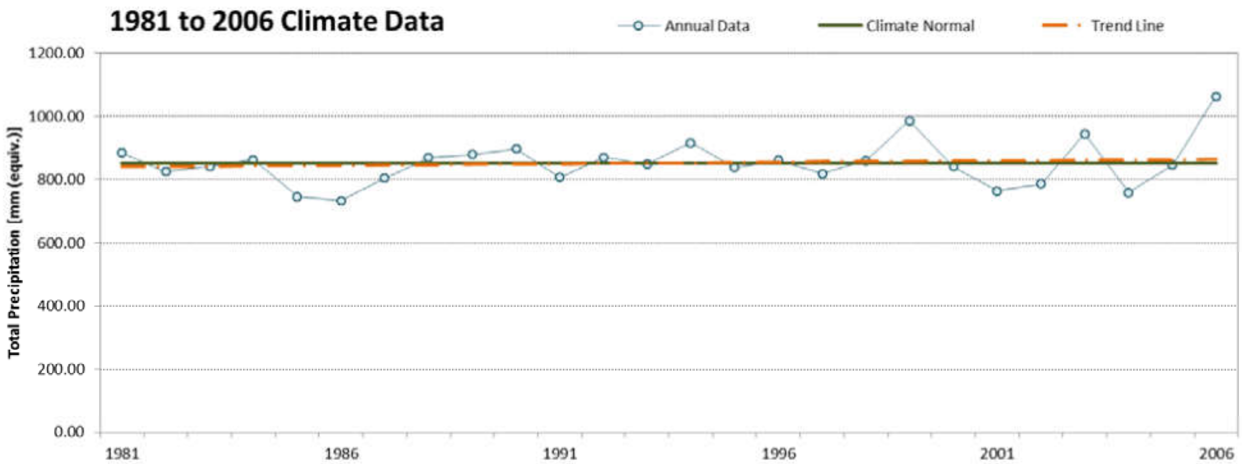

Figure 12: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Annual

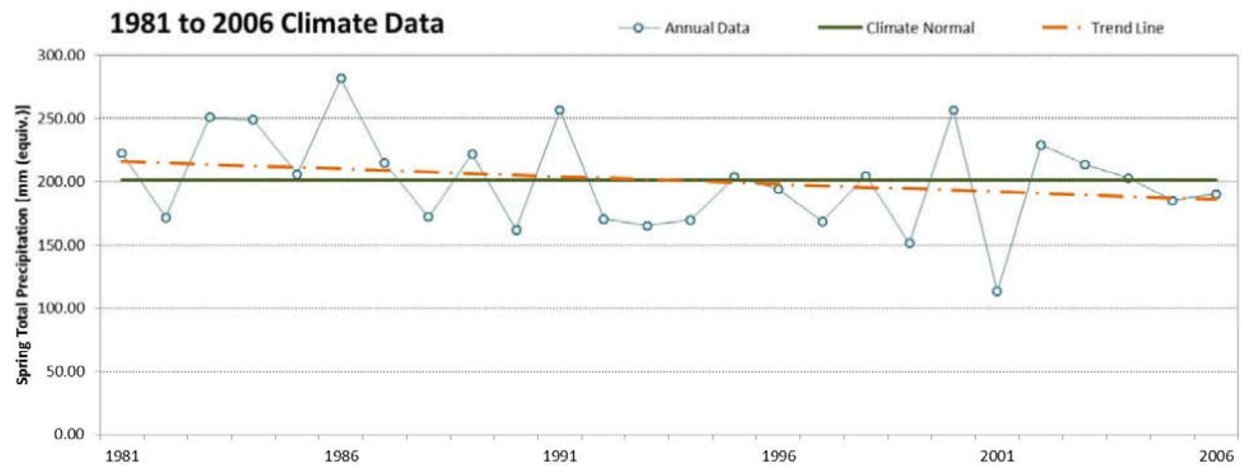

Figure 13: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Spring

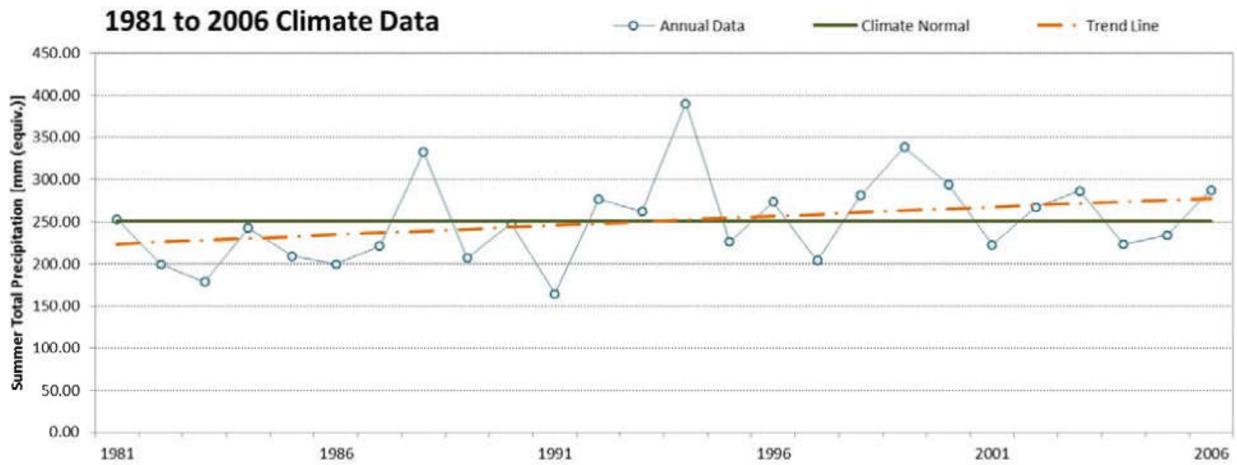

Figure 14: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Summer

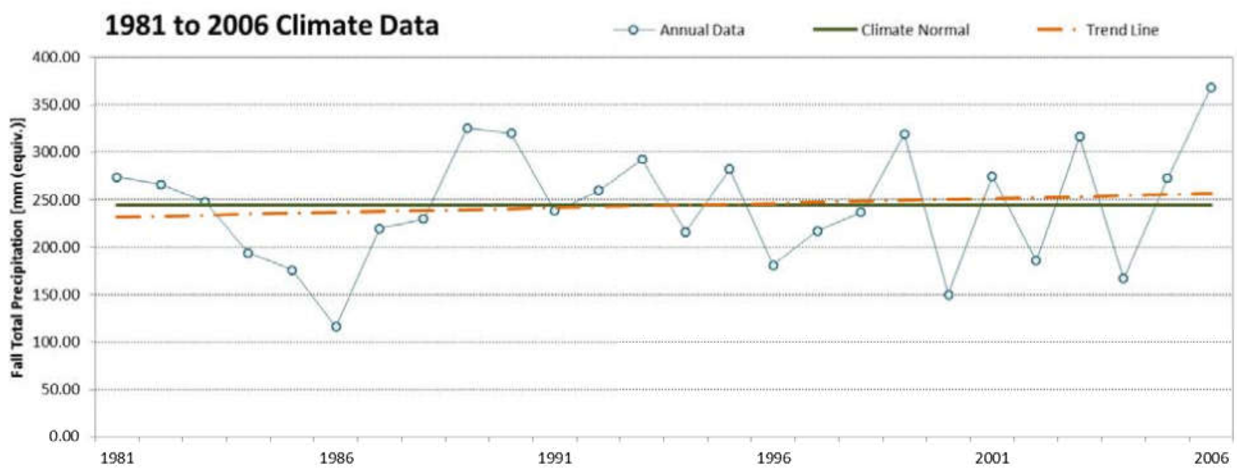

Figure 15: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Fall

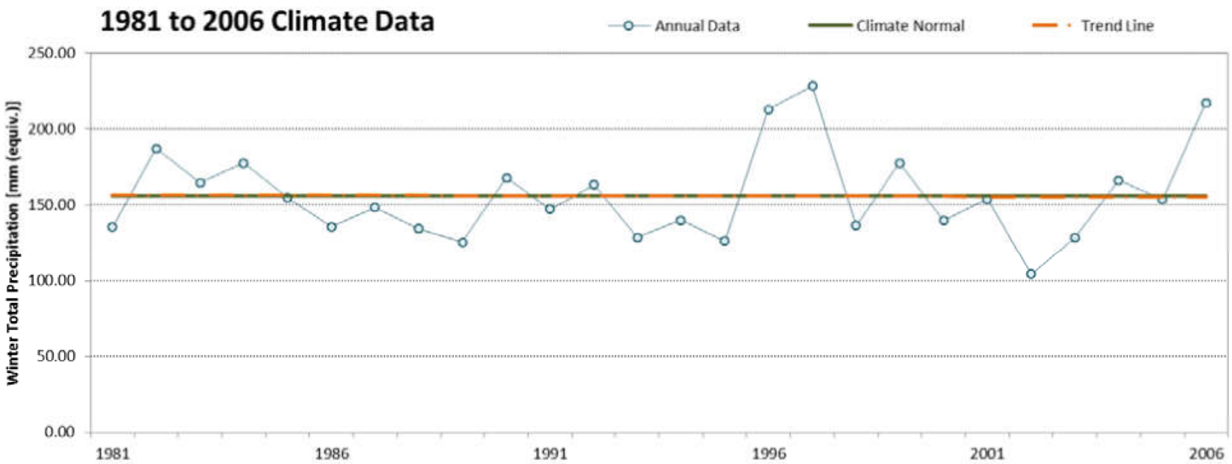

Figure 16: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Winter

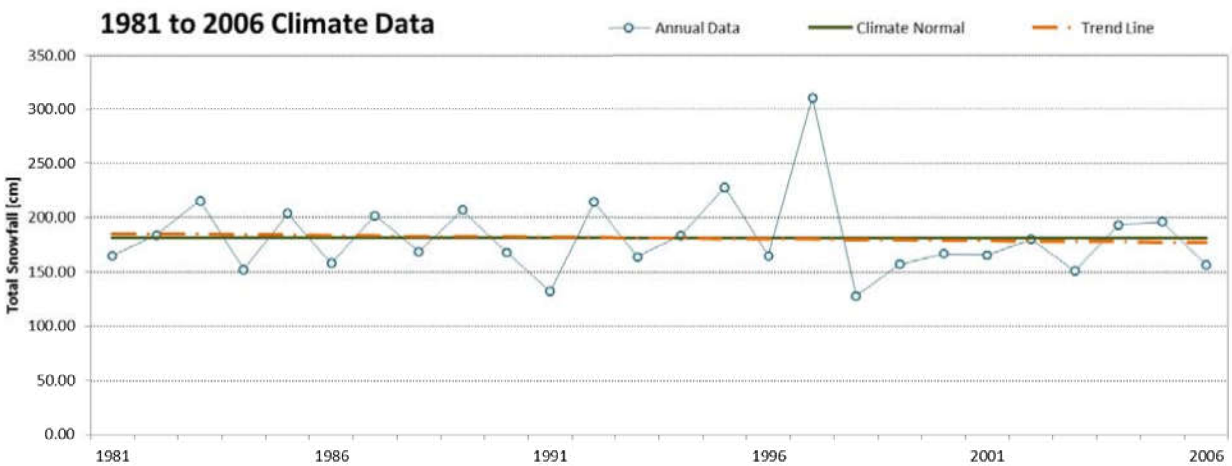

Figure 17: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Total Snowfall

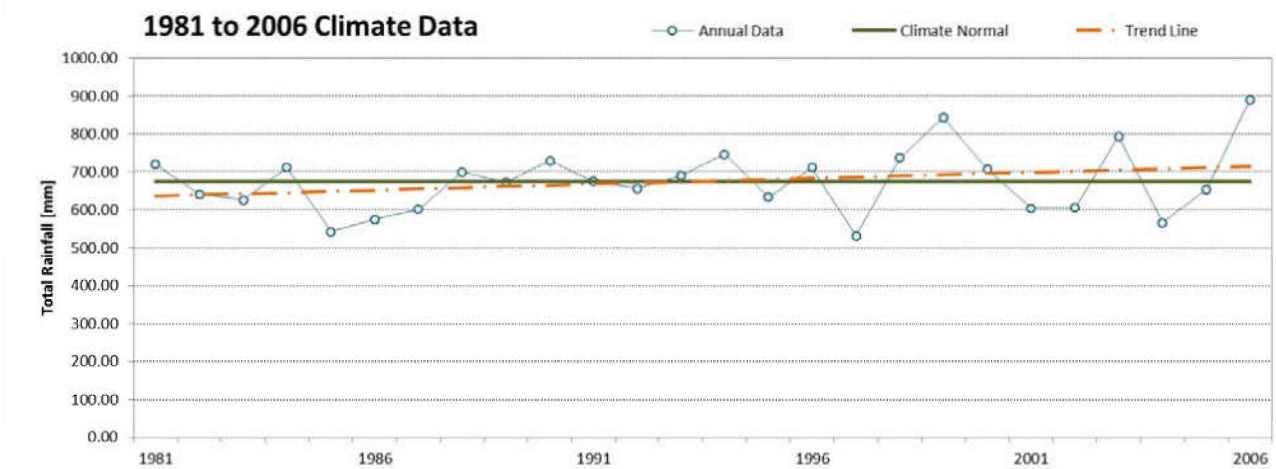

Figure 18: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Total Rainfall

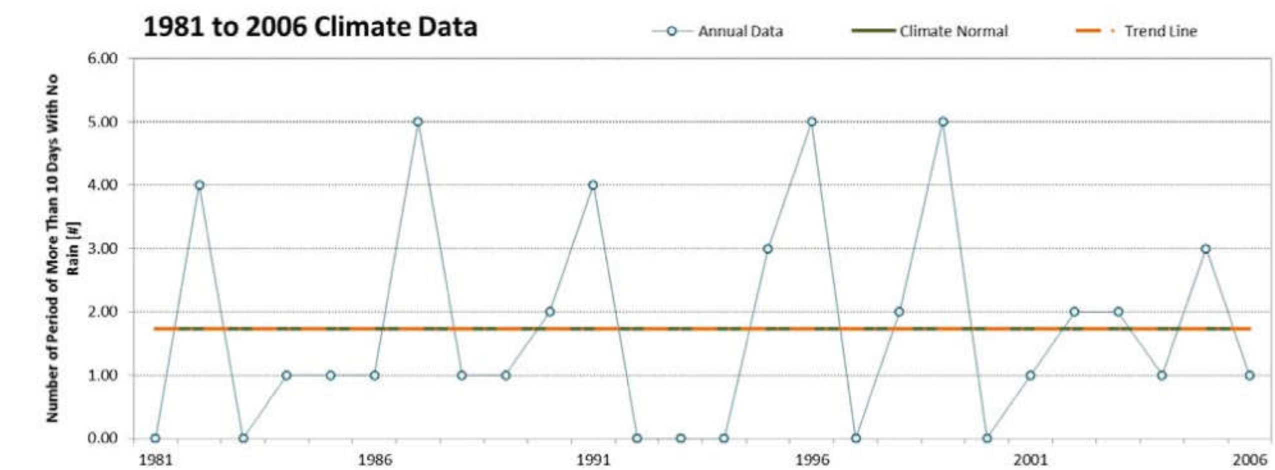

Figure 19: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Number of Periods of More Than 10 days With No Rain (Dry Spells)

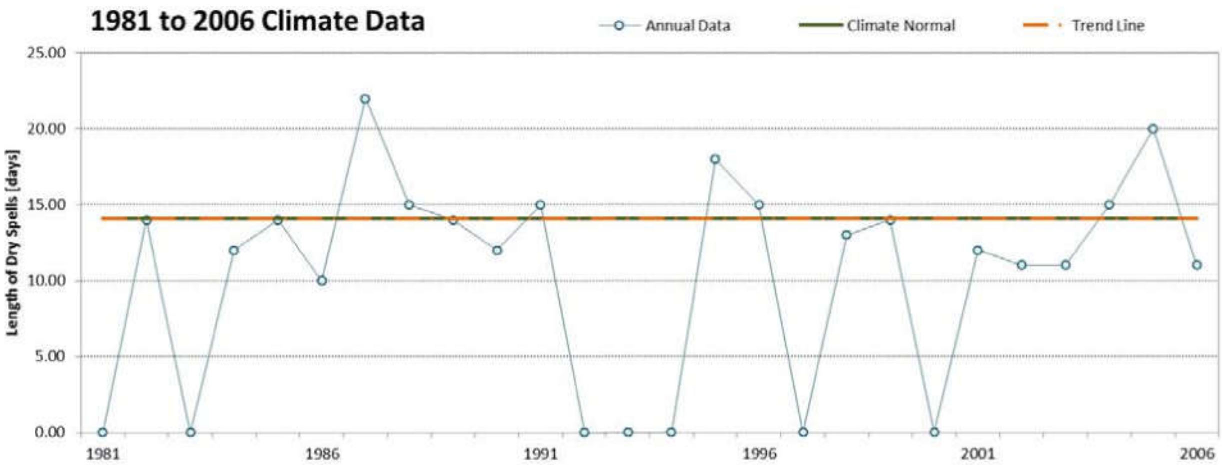

Figure 20: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Length of Dry Spells

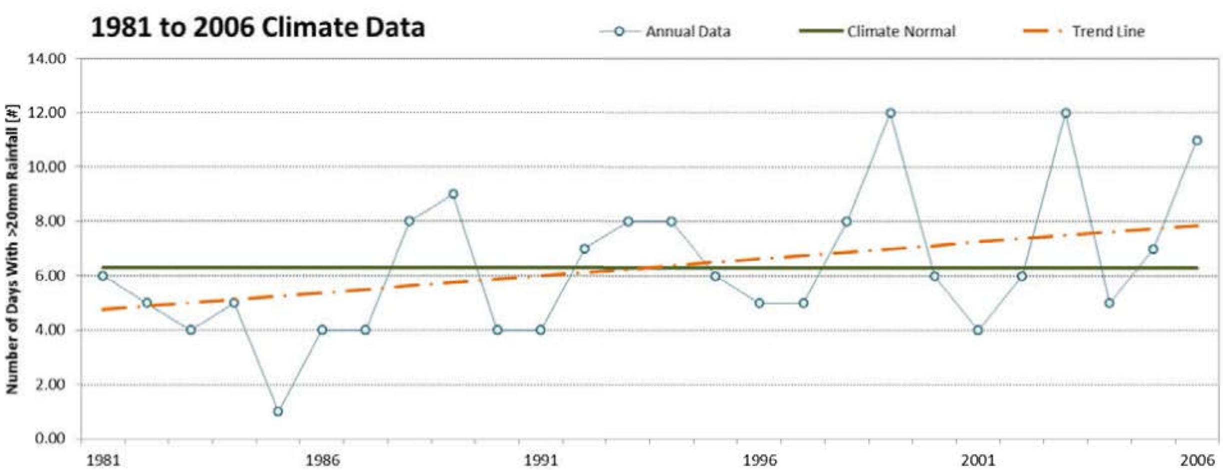

Figure 21: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Number of Days with More Than 20 mm of Rainfall

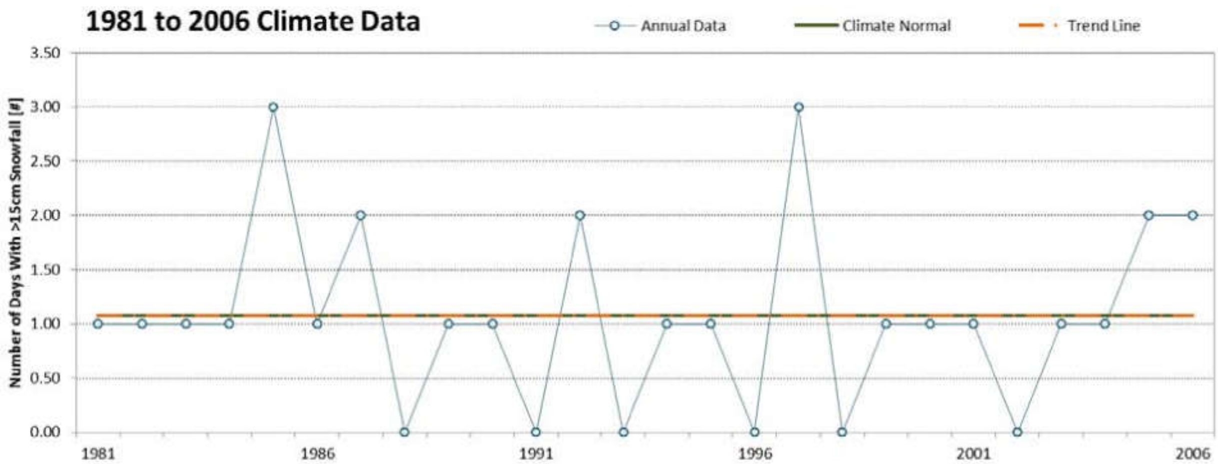

Figure 22: Historical Precipitation Analysis for Chalk River Atomic Energy of Canada Limited Climate Station – Number of Days with More Than 15 cm of Snowfall

DEFINITION OF CLIMATE INDICES

Table A1 defines how each of the climate indices was calculated.

Table A1: Definitions of Climate Indices

Climate Indices	Definition
Total Precipitation	Calculated as the sum of all the observed precipitation during the selected annual period. Each annual value is averaged over the 30 years of the climate normal.
Seasonal Precipitation (Spring, Summer, Fall, Winter)	Calculated as the sum of all the observed precipitation during the selected season. Each annual value is averaged over the 30 years of the climate normal.
Total Snowfall	Calculated as the sum of all the observed snowfall during the selected annual period. Each annual value is averaged over the 30 years of the climate normal.
Total Rainfall	Calculated as the sum of all the observed rainfall during the selected annual period. Each annual value is averaged over the 30 years of the climate normal.
End of Winter (March 21) Snowpack	Calculated as the observed snowpack on March 21 during the selected annual period. Each annual value is averaged over the 30 years of the climate normal.
Number of Annual Dry Spells	A dry spell is defined as a period of more than ten contiguous days with no rain. This climate index counts the number of dry spells during each annual period. Each annual value is averaged over the 30 years of the climate normal.
Length of Dry Spells	Calculated as the maximum length of all dry spells during the selected annual period and then averages over the 30 years of the climate normal.
Number of Days With >20 mm Rainfall	Calculated as the number of days with more than 20 mm rainfall during the selected annual period and then averaged over the 30 years of the climate normal.
Number of Days With >15 cm Snowfall	Calculated as the number of days with more than 15 cm snowfall during the selected annual period and then averaged over the 30 years of the climate normal.
Average Annual Temperature	Calculated as the average of all the observed temperatures during the selected annual period. Each annual value is averaged over the 30 years of the climate normal.

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Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
1931 Robertson Road
Ottawa, Ontario, K2H 5B7
Canada
T: +1 (613) 592 9600