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SHELL CANADA ENERGY

Appendix 4: Climate Change

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REPORT

Golder Associates

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1.0 INTRODUCTION

1.1 Background

Shell Canada Energy (Shell) submitted the Applications and supporting Environmental Impact Assessment (EIA) for the Jackpine Mine Expansion (JME) and Pierre River Mine (PRM) Project in December 2007. As part of the regulatory process for the PRM Application, the PRM Joint Review Panel (JRP) requested additional Information in October 2012. The reassessment of the effect of changes in water level in the Athabasca River and availability of water caused by climate change for PRM - using the most up-to-date data to identify potential trends using outputs from climate change scenarios - is one component of the information requested by the JRP, (i.e., PRM Supplemental Information Request [SIR] 26).

A number of hydrologic issues associated with forecasted climate change were raised during past reviews of EIAs of oil sands mine developments. The issues included the potential effects of climate change on flows in the Athabasca River, particularly the winter low flows, as well as the effects on flows in the tributaries within the Oil Sands Region that discharge into the Athabasca River. To address the issue of potential effects of climate change on flows, climate change analysis was included in the EIAs for the JME and PRM Project. The analysis included analyzing past records for trends and developing scenarios based on forecasted changes by General Circulation Models (GCMs).

The two main assessment methods for evaluating the potential effects of future climate conditions on rivers flows are: (1) extrapolation of historic trends observed in hydrologic responses of local watersheds; and (2) using the future changes of monthly precipitation and monthly air temperature forecasted by GCM as part of inputs to hydrologic models set up for the local watersheds. Several assumptions are implicit in each approach that may or may not be fully validated based on current knowledge, and result in weaknesses in both approaches. As discussed in the EIA, Volume 3, Appendix 3-4, estimates based on extrapolation of historic trends are subject to uncertainties resulting from, for example, the lengths of the data records used for establishing the trends, multi-year to multi-decadal oscillations in climate regimes, and uncertainties in partitioning the effects of climate variability from those of climate change. The modelling approach is subject to uncertainties in model calibration, the wide range of forecasts produced by a large number of GCM, and uncertainties in downscaling GCM forecasts to local watersheds.

To address the recent regulatory and stakeholder concerns raised during the public hearing of the JME Project regulatory application, the potential effects of climate change on the Athabasca River flows were further assessed using outputs from projected climate change scenarios based on GCM. Forecasts of future climate conditions were analyzed using a calibrated and validated hydrologic model, (i.e., the Hydrological Simulation Program-Fortran [HSPF] model) developed for the Athabasca River basin and its tributaries. The modelling approach consisted of selecting one scenario that, on an annual basis, would be considered as an average of the range of possible forecasts (referred to as the scenario representing future ‘median conditions’) and four possible forecasts that would represent the future extreme forecasts (wetter/drier and warmer/cooler conditions) relative to the ‘median conditions’. In essence, the approach is a sensitivity analysis of selected future changes in climate parameters, such as air temperature, precipitation and potential evapotranspiration, on flows in the Athabasca River and its tributary streams. The 2041 to 2070 period was selected to quantify the potential hydrologic effects of future climate forecasts because this period corresponds to when all mine-disturbed areas are expected to have been reclaimed. Characterizing climate change depends not only on future conditions but also on the baseline climate to which the predictions are compared. The 1961 to 1990 period was used as the climate baseline period to estimate the incremental changes in temperature and precipitation predicted by the GCM.

This report presents an assessment of the effects of potential climate change scenarios on the Athabasca River flows and flows of tributaries to the Athabasca River located within the PRM Local Study Area (LSA), and in water quality.

An assessment of the effects of climate change on the air quality assessment, the hydrogeological assessment, fish and fish habitat, and the terrestrial and human health assessments is provided in Attachment F. A description of the GCM used for the updated climate change analysis is also provided.

1.2 Athabasca River Basin Characteristics

The Athabasca River starts in the Rocky Mountains near Mount Columbia (elevation 3,747 masl) and flows northeast for 1,300 km before flowing through the Peace-Athabasca Delta until it empties into Lake Athabasca (elevation 208 masl) (RAMP 2013a). Flows from the basin eventually make their way to the Arctic Ocean. The river drains an area of approximately 138,000 km^2. The river flows past the urban centres of Jasper, Hinton, Whitecourt, Athabasca and Fort McMurray before emptying into Lake Athabasca. The Athabasca River basin includes the McLeod, Pembina and Clearwater rivers.

As a major river system, the Athabasca River is influenced by a variety of climate, terrain and landscape characteristics found within its basin (RAMP 2013b). The seasonality of climatic conditions is a major influence affecting river flow conditions. The climate includes cold winters, when most of the seasonal precipitation falls as snow. Cold winters are typically followed by warm summers, when snow and glacial melt waters from the river's headwaters combine with runoff from localized snowmelt and rainfall events throughout the basin. As the river flows toward Lake Athabasca, water is contributed to the river from individual sub-basins.

The Athabasca River basin encompasses the following ecoregions (natural regions) (Mitchell, P. and E. Prepas. 1990):

- Rocky Mountain (Alpine, Subalpine, Mountain);
- Boreal Foothills;
- Boreal Mixed Wood (dry and wet);
- Boreal Uplands;
- Boreal Lowlands; and
- Canadian Shield (Athabasca Plains).

The surficial geology of a basin is one of the main factors in the hydrologic response of the basin. The surficial geology characteristics considered for modelling the Athabasca River basin are shown in Attachment A, Figure A-1. The Athabasca River basin was sub-divided into nine land types based on the following major surficial geology classifications:

- well drained sand and rapidly drained sand;
- well drained till and rapidly drained till;

- well drained clay loam;
- organic soil;
- poorly drained sand (lowland glaciolacustrine);
- poorly drained till (lowland glaciofluvial);
- poorly drained clay loam (lowland glacial);
- impervious/fractured rock; and
- impervious/glacier sometimes.

The head watersheds of the Athabasca River basin are covered by glaciers. Glaciated areas could be modelled as an impervious land type with discharges from the glaciated areas when temperatures rise above 0°C. A major portion of the upper areas of the Athabasca River basin is also classified as impervious. However, most of these areas are fractured, thus increasing the travel time of runoff compared to strictly impervious areas.

The characteristics of the vegetation cover in a basin also play an important role in the basin's hydrologic response through interception of precipitation, evapotranspiration of intercepted precipitation and water stored in the soil layer, and shading of solar radiation (which affects snow melt rate). The sub-basins in the Athabasca River basin were not explicitly divided into vegetation types; however, the characteristics were considered in the specification of parameters controlling interception, evapotranspiration and shading.

2.0 ASSESSMENT METHODS

2.1 Modelling Approach

To evaluate the potential effects of climate change on the Athabasca River flow requires an understanding of how the climate variables have been changing and might change in the future. General Circulation Models were used to forecast future climate change scenarios in the Athabasca River basin. The continuous (dynamic) Hydrologic Simulation Program Fortran (HSPF) model developed by the United States Environmental Protection Agency (U.S. EPA) was calibrated and validated for the Athabasca River basin, based on the recorded climate and flow data in the basin up to 2006 as part of the Lower Athabasca River Regional Planning Study completed by Golder Associates Ltd. for Alberta Environment and Sustainable Resource Development (ESRD) (Golder 2009). As part of the current climate change effect analysis work completed for PRM, the baseline climate data was extended by five years to 2011, and HSPF model validation statistics and comparison were revaluated based on a longer period of baseline data records.

The recorded climate data series were then adjusted using the forecasted monthly climate changes from the GCM and were used as inputs to the HSPF model for estimating future Athabasca River flow data. Flow statistics (mean annual flow, mean open-water flow, mean ice-cover flow, flood peak flows, and 10-year 7-day low flow or 7Q10) were derived from the simulated flow series and compared with the baseline statistics that did not include the potential effects of climate change.

The general modelling approach used for implementing the HSPF model to the Athabasca River basin required the following elements:

- Compile available model input data, including data on climate, soil, vegetation, and flow data from gauged watersheds for calibration and validation purposes.
- Assess changes in land use patterns in gauged watersheds during the period of available climate and flow data.
- Select one period (5 to 10 years) of climate and flow data that is relatively free of trends and without land use changes for calibration purposes, and another similar period (5 to 10 years) for validation purposes. The calibration and validation periods should ideally include both hydrologically wet and dry years.
- Discretize basin into sub-basins that are physiographically different, have different geologic characteristics, experience different climate regimes, and have flow data at convenient locations (outlet of sub-basin).
- Select climate stations whose data would be representative of the climatic regime within each gauged watershed selected for calibration and validation purposes.
- Calibrate model for each gauged watershed using statistics such as annual yield, monthly yield, winter flows and flood flows. Compare observed and simulated hydrographs visually.
- Validate model for each gauged watershed using input from selected period and comparing observed and simulated data for the same period. Adjust calibration parameters if necessary.
- Use model calibration parameters for each gauged watershed to represent model parameters for each sub-basin encompassing the gauged watershed(s) used for calibration purposes.
- Run the model for the entire basin using available climate data at climate stations in the basin and compare with flows recorded at several hydrometric stations on the main stem of the Athabasca River from Jasper to Fort McMurray.
- Run the model for the entire basin using the baseline (1961 to 2011) climate data for the basin, and compare with flows recorded at several hydrometric stations on the main stem of the Athabasca River over the same time period (i.e., 1961 to 2011). Summarize key hydrologic variables (annual and monthly water yield particularly) at these locations and compare with those using the climate station data.
- Derive five future climate change scenarios from GCM to represent the possible range of climate regimes for future 30-year time periods. Run the selected and calibrated hydrologic model for the Athabasca River basin with the five climate change scenarios.
- Summarize key hydrologic variables (annual and monthly water yield particularly) at Fort McMurray hydrometric station. Compare with those from using the baseline data.
- Summarize seasonal changes in mean flows at Fort McMurray hydrometric station compared with that from using the baseline data.

2.1.1 Hydrology Model Setup

The HSPF model used for the Athabasca River flow estimation simulates stream flows as the sum of three components: surface flow, interflow and groundwater. The relative magnitude of each component depends on land use, soils and vegetation cover. The model user can specify specific parameters for various land use types to represent the physical processes in a basin.

The Athabasca River basin was sub-divided into 75 sub-basins for representing the basin in the HSPF model, based on the drainage network and the locations of the Water Survey Canada (WSC) stations on gauged sub-basins selected for calibration and validation of the model. The 75 sub-basins were further sub-divided based on surficial geology. The locations of the hydrometric stations for the selected gauged sub-basins are shown in Attachment B, Figure B-1.

2.1.2 Model Data Input

Data used to run the HSPF model were the following:

- Temperature and precipitation data for the calibration and validation of the model were from climate stations closest (specific selection based on availability of concurrent climate and flow data) to the gauged sub-basins. Climate stations in the basin are shown in Attachment C, Figure C-1. To account for the spatial variability of precipitation, precipitation data from different stations were assigned to the different Hydrologic Regions encompassed by the Athabasca River basin. The Hydrologic Regions of Alberta were developed by Golder (2006) as part of a project for ESRD. Hydrologic regions of the Lower Athabasca River basin are shown in Attachment B, Figure B-1. The Hydrologic Regions represent areas within which the climate, geology and hydrologic responses are more or less homogeneous, but different from the adjacent Hydrologic Region. The Hydrologic Regions provide a rational basis for assigning climate stations to the sub-basins of the Athabasca River basin. The climate stations selected for precipitation and temperature data for the sub-basins within the Hydrologic Regions encompassing the Athabasca River basin are listed in Table 2.1-1.

- Wind speed and dew point temperature data were from the Edmonton International Airport station, Edson station or Fort McMurray station depending on the Hydrologic Region (Table 2.1-1), while solar radiation data were from the Edmonton Stony Plain station and Aurora climate station. The solar radiation data at the Edmonton Stony Plain Station were assumed to be representative of the Hydrologic Region above Fort McMurray and the Aurora climate station were assumed to be representative of the Hydrologic Region below McMurray because solar radiation tends to be generally less spatially variable than most other climatic variables.

- Evapotranspiration and lake evaporation data were derived using the Morton Model (Morton et al. 1985), with air temperature, dew point temperature, precipitation and solar radiation used as input data.

- Channel cross-sections used in generating depth-area-volume-flow tables were estimated from data used by WSC to develop rating curves at the hydrometric gauging stations.

- Recorded stream flows at several hydrometric stations in the basin were used for model calibration and validation.

- Simulation of HSPF model was completed based on input climate data from 1962 to 2001.

Table 2.1-1 Climate Stations Selected for Sub-Basins Within Hydrologic Regions of Athabasca River Basin

Hydrologic Region	Climate Station(s) Selected for Precipitation and Temperature Data for Sub-Basins within Hydrologic Region	Climate Station(s) Selected for Wind Speed and Dew Point Temperature Data for Sub-Basins within Hydrologic Region
3 and 4	Jasper and Jasper Warden	Edson
5 and 10.1 (south of Athabasca River)	Edson	Edson
8.1 (south of Athabasca River)	Campsie	Edmonton International Airport
8.2 and10.2 (north of Athabasca River)	Slave Lake	Edmonton International Airport for wind speed Edson for dew point temperature
2C	Lac La Biche	Fort McMurray
9A	Fort McMurray	Fort McMurray

2.1.3 Model Calibration and Validation

The general assessment methods used to calibrate and validate the HSPF model for the Athabasca River basin were as follows:

- Select the climate station(s) to represent each hydrologic region and adjust temperature and precipitation data for elevation if the climate station is at an elevation different from most of the sub-basin elevations.
- Select gauged sub-basins that are dominated by one surficial geology type and fix the model parameters for this surficial geology type. Then repeat the process for the other surficial geology types. The purpose of this assessment method was to establish "Basin-wide model parameters" that can be transferred to other sub-basins in the basin that have similar surficial geology. The effects of land cover or vegetation types were indirectly considered in the modelling through calibration of the parameters that simulate their influences. The vegetation types were considered through the following HSPF model parameters: FOREST (fraction of the pervious land segment that is covered by forest), CEPSC (interception storage capacity) and LZETP (lower zone evapotranspiration parameter).
- Select one gauged sub-basin with a given hydrologic region for calibration and another nearby gauged sub-basin for validation.
- The model calibration parameters for each gauged watershed can be used for all sub-basins (gauged and ungauged) in the basin, which are similar in topographic, climatic, soil and vegetation characteristics.

The sub-basins used for calibration and validation, as well as location, drainage area, land type and other information on the sub-basins are shown in Table 2.1-2.

At least three years of meteorological and hydrologic data were used to calibrate the HSPF model. Calibration began with an initial estimate of the model parameters based on the lower and upper limits of each model parameter as described in the HSPF manual. Then, the simulated monthly and annual runoff volumes were compared to the observed volumes at hydrologic gauging stations. Appropriate parameters were adjusted until the simulated monthly and annual volumes were acceptably close to the observed values.

Table 2.1-2 Characteristics of Sub-Basins Used for Model Calibration and Validation

Hydrologic Region	Station Number	Sub-Basin Name	Calibration or Validation	Latitude [degminsec]	Longitude [degminsec]	Gross Drainage Area [km^2]	Percent Land Type	Percent of Hydrologic Region Contributing to Station	Record Length	On Main Stem?	Calibration/ Validation Period	
											Start Year	End Year
3	07AA002	Athabasca River Near Jasper	Validation	525436	1180325	3,880	26% Well Drained Till, 54% Impervious, 20% Glacier	3% to 100%	1913 to 2010	Yes	1971	2010
	07AA001	Miette River Near Jasper	Calibration	525150	1180621	629	31% Well Drained Till, 49% Impervious, 20% Glacier	3% to 100%	1914 to 2011	No	1995	2006
	07AA007	Sunwapta River at Athabasca Glacier	Calibration	521258	1171355	29	100% Glacier	3% to 100%	1948 to 2011	No	1994	1996
4	07AD002	Athabasca River at Hinton	Validation	532523	1173414	9,780	26% Well Drained Till,2% Well Drained Sand,64% Impervious,8% Glacier	3% to 70%, 4% to 30%	1961 to 2011	Yes	1962	2011
	07BA003	Lovett River Near the Mouth	Calibration	525950	1163920	103	100% Well and Rapidly Drained Till	4% to 100%	1975 to 2011	No	1982	1991
5	07AE001	Athabasca River Near Windfall	Validation	541225	1160345	19,600	49% Well Drained Till, 6% Well Drained Sand, 1% Poorly Drained Sand, 37% Impervious, 7% Glacier	3% to 38%, 4% to 26%, 5% to 36%	1960 to 2011	Yes	1962	2011
	07AF907	Erith River Below Hanlan Creek	Calibration	531408	1163355	595	60% Well Drained Till, 40% Well Drained Clay Loam	5% to 100%	1984 to 1990	No	1984	1990
8	07BE001	Athabasca River at Athabasca	Validation	544320	1131710	74,600	62% Well Drained Till, 12% Well Drained Sand, 5% Well Drained Loam, 3% Poorly Drained Sand, 1% Poorly Drained Loam, 10% Impervious, 2% Glacier, 5% Organic	10% to 23%, 8% to 29%, 5% to 17%, 4% to 9%, 3% to 9%, 2E-8%, 2C-4%	1913 to 2011	Yes	1962	2011
	07BK007	Driftwood River near the Mouth	Calibration	551519	1141354	2,100	56% Well Drained Till, 41% Well Drained Sand, 3% Organic	8-100%	1968 to 2010	No	1987	1998
9A	07DA001	Athabasca River Below Fort McMurray	Validation	564650	1112400	133,000	43% Well Drained Till, 8% Well Drained Sand, 3% Well Drained Loam, 1% Poorly Drained Till, 2% Poorly Drained Sand, 1% Poorly Drained Loam, 6% Impervious, 1% Glacier, 13% Organic, 23% from Clearwater basin	8% to 45%, 10% to 20%, 5% to 15%, 4% to 4%, 3% to 4%, 2E-3%, 2C-4%, 9A-5%	1957 to 2011	Yes	1961	2011
	07CD001	Clearwater River at Draper	Not Applicable	564107	1111515	30,800	Calibrated separately (see section 2.1.3 text for details)	8% to 10%, 9A-90% + SK Province	1930 to 2010	No	1961	2010
	07DB005	Mackay River Above Dunkirk River	Calibration	564535	1123650	1,010	100% Organic	8% to 100%	1983 to 1991	No	1983	1990

Once streamflow volumes were calibrated, flow hydrographs were calibrated using both interflow and channel routing parameters. The shapes of event hydrographs, and to some extent the peak flows, were calibrated by changing the interflow parameters and the appropriate stage-storage-discharge relationships. A combination of manual and automatic (using a model independent parameter estimation tool - PEST) calibration were used to derive the model's calibration parameters. The calibration parameters for each of the nine land types are provided in Attachment D, Tables D-1 to D-5. Values in parentheses in Table D-1 identify instances when slight changes were made in the parameters of similar land types but located in different parts of the basin. The sub-basins used for calibration and validation are listed in Table 2.1-2, and hydrometric stations are shown in Attachment B, Figure B-1.

The specific model calibration assessment method for the Athabasca River basin is summarized below:

- Model parameters for the Well/Rapidly Drained Till land type were calibrated using the recorded stream flows at Lovett River near the Mouth (Environment Canada Hydrometric Station 07BA003; Attachment B, Figure B-1). The entire Lovett River sub-basin is covered with the Well/Rapidly Drained Till land type. The precipitation data used were from the Lovett Lookout station and missing winter precipitation data were filled using data from the Edson climate station (Attachment C, Figure C-1).

- Model parameters for the Well Drained Clay Loam land type were calibrated using the recorded stream flows at Erith River below Hanlan Creek (Environment Canada Hydrometric Station 07AF907; Attachment B, Figure B-1). The surficial geology of the Erith River sub-basin is approximately 60% Well/Rapidly Drained Till and 40% Well Drained Clay Loam. During the calibration process, the model parameters for the Well/Rapidly Drained Till land type as determined during the calibration on the Lovett River sub-basin were transferred to the Erith River sub-basin. The precipitation data used were from the Lovett Lookout station and missing winter precipitation data were filled using data from the Edson climate station (Attachment C, Figure C-1).

- Model parameters for the Organic land type were calibrated using the recorded stream flows at Mackay River above Dunkirk River (Environment Canada Hydrometric Station 07DB005; Attachment B, Figure B-1). The entire Mackay River above Dunkirk River watershed was assumed to be covered by the Organic land type. The precipitation data used were from Livock Lookout station and the missing winter precipitation data were filled using data from the Fort McMurray Airport climate station (Attachment C, Figure C-1).

- Model parameters for the Glacier land type were calibrated using the recorded stream flows at Sunwapta River at Athabasca Glacier (Environment Canada Hydrometric Station 07AA007; Attachment B, Figure B-1). The entire Sunwapta River sub-basin was assumed to be covered by glaciers. The precipitation data used were from Jasper and Jasper Warden climate stations (Attachment C, Figure C-1).

- Model parameters for the Impervious/Fractured Rock land type were calibrated using the recorded stream flows at Miette River near Jasper (Environment Canada Hydrometric Station 07AA001; Attachment B, Figure B-1). The surficial geology of the Miette River sub-basin is approximately 31% Well/Rapidly Drained Till, 20% Glacier, and 49% Impervious/Fractured Rock. During the calibration process, the model parameters for the Well/Rapidly Drained Till and Glacier land types were transferred from those obtained during the calibration of the Lovett River and Sunwapta River sub-basins, respectively. The precipitation data used were from Jasper and Jasper Warden climate stations (Attachment C, Figure C-1).

- Model parameters for the Well/Rapidly Drained Sand land type were calibrated using the recorded stream flows at Driftwood River near the Mouth (Environment Canada Hydrometric Station 07BK007; Attachment B, Figure B-1). The surficial geology of the Driftwood River sub-basin is approximately 56% Well/Rapidly Drained Till, 3% Organic, and 41% Well/Rapidly Drained Sand. During the calibration process, the model parameters for the Well/Rapidly Drained Till and Organic land types were transferred from those obtained during the calibration of the Lovett River and Mackay River above Dunkirk River sub-basins, respectively. The precipitation data used were from the Slave Lake climate station (Attachment C, Figure C-1).
- Model parameters for the Poorly Drained Till (Lowland Glaciofluvial), Poorly Drained Sand (Lowland Glaciolacustrine), and Poorly Drained Clay Loam (Lowland Glacial) land types were obtained from the *Regional Surface Water Hydrology Study for Re-Calibration of HSPF Model* (Golder 2003).

The sub-basins used for validation are listed in Table 2.1-2. The validation of the calibrated HSPF model was based on a comparison of observed and simulated flows at gauging stations on the main stem of the Athabasca River (Attachment B, Figure B-1), namely, Athabasca River near Jasper (Environment Canada Hydrometric Station 07AA002), Athabasca River at Hinton (Environment Canada Hydrometric Station 07AD002), Athabasca River near Windfall (Environment Canada Hydrometric Station 07AE001), Athabasca River at Athabasca (Environment Canada Hydrometric Station 07BE001), Athabasca River below McMurray (Environment Canada Hydrometric Station 07DA001), and Clearwater River at Draper (Environment Canada Hydrometric Station 07CD001). Model parameters for the Clearwater River at Draper were calibrated and validated separately because most of the sub-basin lies within the province of Saskatchewan and the land type information was not available. The portion of the Clearwater River sub-basin with missing surficial geology data were assumed to be covered by rapidly drained sand (i.e., extending the surficial geology data available on the province of Alberta side of the border), and the calibration/validation was done using recorded stream flow data.

The accuracy of the model calibration and validation was evaluated by comparing the following measured and simulated flow parameters:

- mean annual flow;
- mean open water (March to October) flow;
- mean monthly flow (12 months); and
- 2-, 10- and 25-year peak flood flows.

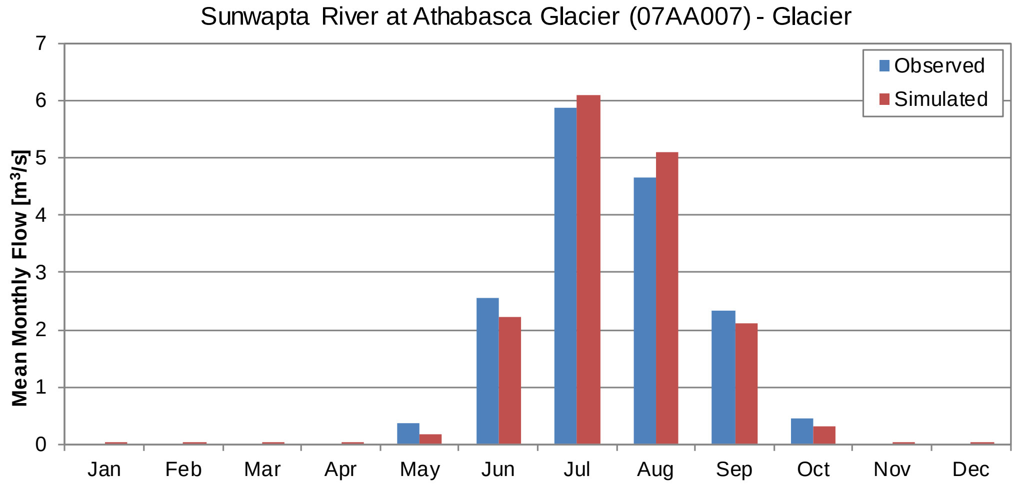
2.1.3.1 Model Calibration and Validation Statistics

Comparisons of simulated and observed flows statistics and mean monthly plots on the six gauged sub-basins used for calibration, each dominated by one particular land type, are shown in Figure 2.1-1. Flows statistics and mean monthly plots for the six sub-basins used for validation of the calibrated HSPF model are compared in Figure 2.1-2.

Figure 2.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins

Figure 2.1-1a Simulated and Recorded Flow Statistics for Sunwapta River at Athabasca Glacier (Station 07AA007) - Calibration (Glacier) (1994-1996)

Statistic	Calibration		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	-	-	-
Mean Open-Water Flow [(a)]	2.71	2.67	-1
2-Year Peak Flow	10.4	11.4	10
10-Year Peak Flow	10.9	15.4	41
25-Year Peak Flow	11.2	16.9	52
Mean Monthly Flows			
Month	**Observed [m³/s]**	**Simulated [m³/s]**	**Difference [%]**
January	-	0.00	-
February	-	0.00	-
March	-	0.00	-
April	-	0.00	-
May	0.36	0.18	-49
June	2.56	2.23	-13
July	5.9	6.09	4
August	4.66	5.09	9
September	2.34	2.10	-10
October	0.46	0.31	-33
November	-	0.03	-
December	-	0.01	-



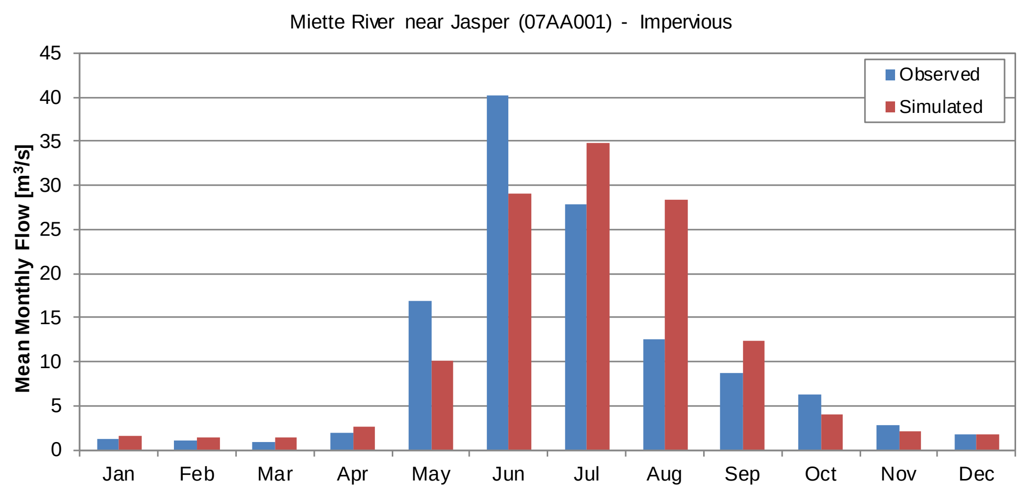
[(a)] Open water season is from May to October.

\- = Recorded data are not available.

Figure 2.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (continued)

Figure 2.1-1b Simulated and Recorded Flow Statistics for Miette River near Jasper (Station 07AA001) - Calibration (Impervious/Fractured Rock) (1995-2006)

Statistic	Calibration		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	10.2	10.8	6
Mean Open-Water Flow[(a)]	16.4	17.4	6
2-Year Peak Flow	67.0	62.7	-6
10-Year Peak Flow	92.1	91.2	-1
25-Year Peak Flow	104	104	0
Mean Monthly Flows			
Month	**Observed [m³/s]**	**Simulated [m³/s]**	**Difference [%]**
January	1.21	1.54	27
February	1.01	1.42	40
March	0.92	1.34	45
April	1.97	2.63	34
May	16.9	10.16	-40
June	40.1	29.1	-28
July	27.9	34.9	25
August	12.6	28.3	125
September	8.80	12.44	41
October	6.32	3.98	-37
November	2.85	2.13	-25
December	1.69	1.73	2

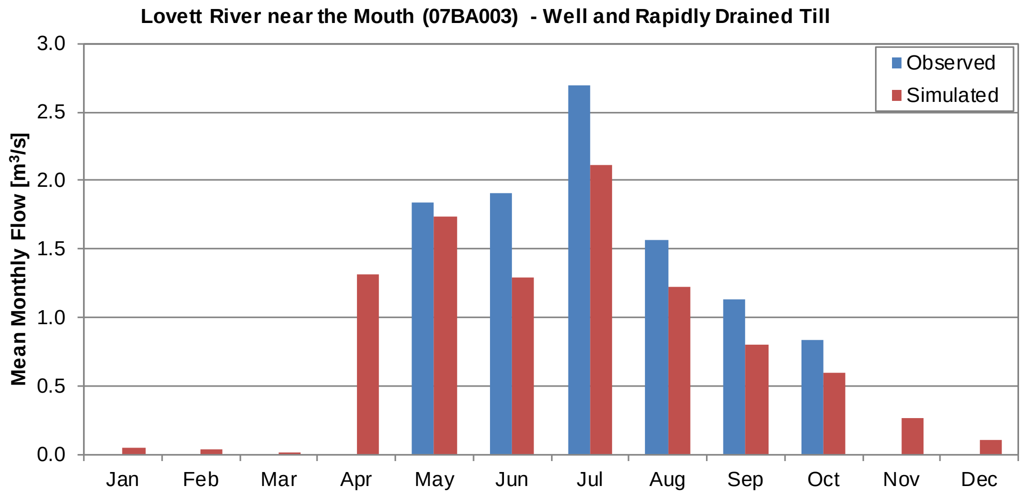


(a) Open water season is from May to October.

Figure 2.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (continued)

Figure 2.1-1c Simulated and Recorded Flow Statistics for Lovett River near the Mouth (Station 07BA003) - Calibration (Well and Rapidly Drained Till) (1982-1991)

Statistic	Calibration: Recorded [m³/s]	Calibration: Simulated [m³/s]	Difference [%]
Mean Annual Flow	-	-	-
Mean Open-Water Flow[(a)]	1.7	1.29	-22
2-Year Peak Flow	12.0	9.15	-24
10-Year Peak Flow	33.0	31.5	-5
25-Year Peak Flow	44.9	53.3	19
Mean Monthly Flows			
Month	**Observed [m³/s]**	**Simulated [m³/s]**	**Difference [%]**
January	-	0.05	-
February	-	0.03	-
March	-	0.02	-
April	-	1.32	-
May	1.83	1.73	-6
June	1.90	1.29	-32
July	2.7	2.11	-22
August	1.57	1.23	-22
September	1.13	0.80	-29
October	0.83	0.60	-28
November	-	0.26	-
December	-	0.10	-



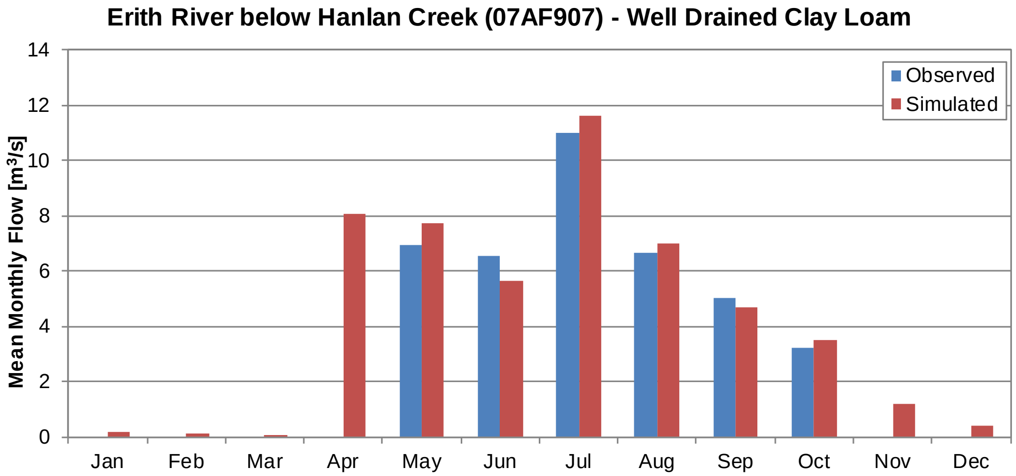
[(a)] Open water season is from May to October.

\- = Recorded data are not available.

Figure 2.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (continued)

Figure 2.1-1d Simulated and Recorded Flow statistics for Erith River below Hanlan Creek (Station 07AF907) - Calibration (Well Drained Clay Loam) (1984-1990)

Statistic	Calibration		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	-	-	-
Mean Open-Water Flow[a]	6.6	6.70	2
2-Year Peak Flow	48.7	70.9	46
10-Year Peak Flow	199	276	39
25-Year Peak Flow	444	457	3
Mean Monthly Flows			
Month	**Observed [m³/s]**	**Simulated [m³/s]**	**Difference [%]**
January	-	0.20	-
February	-	0.12	-
March	-	0.08	-
April	-	8.09	-
May	6.97	7.72	11
June	6.53	5.67	-13
July	11.0	11.64	6
August	6.67	7.02	5
September	5.04	4.68	-7
October	3.22	3.48	8
November	-	1.22	-
December	-	0.43	-



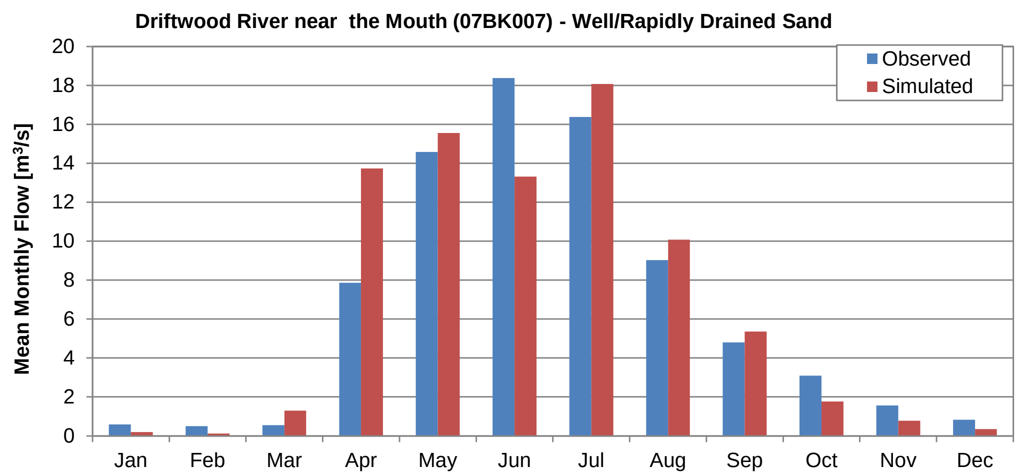
[a] Open water season is from May to October.

- = Recorded data are not available.

Figure 2.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (continued)

Figure 2.1-1e Simulated and Recorded Flow statistics for Driftwood River Near the Mouth (Station 07BK007) (1987-1998) - Calibration (Well/ Rapidly Drained Sand)

Statistic	Calibration Recorded [m³/s]	Calibration Simulated [m³/s]	Difference [%]
Mean Annual Flow	6.51	6.72	3
Mean Open-Water Flow[(a)]	10.6	11.1	5
2-Year Peak Flow	55.7	43.9	-21
10-Year Peak Flow	154	162	5
25-Year Peak Flow	231	284	23
Mean Monthly Flows			
Month	**Observed [m³/s]**	**Simulated [m³/s]**	**Difference [%]**
January	0.59	0.20	-66
February	0.50	0.13	-75
March	0.56	1.30	134
April	7.87	13.73	75
May	14.58	15.56	7
June	18.37	13.31	-28
July	16.38	18.07	10
August	9.02	10.08	12
September	4.81	5.35	11
October	3.09	1.76	-43
November	1.56	0.77	-50
December	0.83	0.35	-57

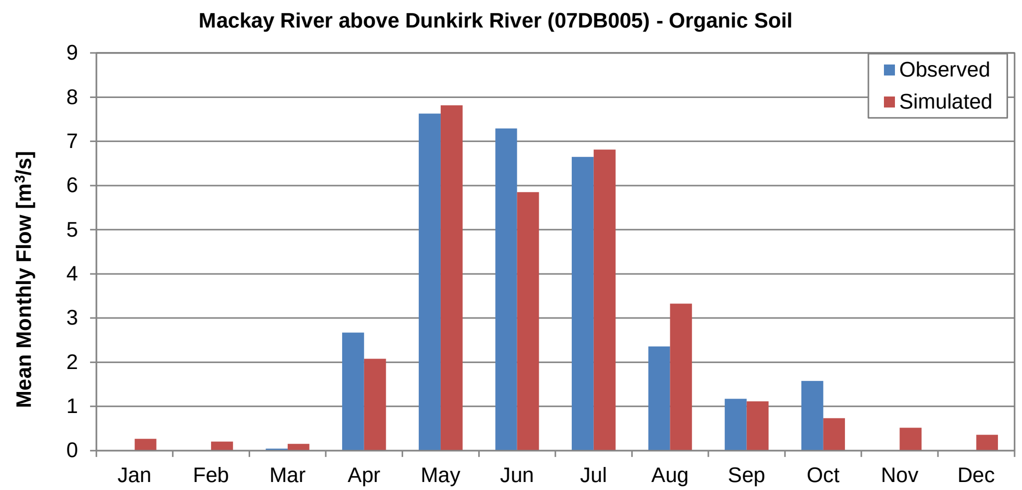


(a) Open water season is from May to October.

Figure 2.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (continued)

Figure 2.1-1f Simulated and Recorded Flow Statistics for Mackay River above Dunkirk River (Station 07DB005) - Calibration (Organic Soil) (1983-1990)

Statistic	Calibration		Difference [%]
	Recorded [m^3/s]	Simulated [m^3/s]	
Mean Annual Flow	-	-	-
Mean Open-Water Flow[(a)]	3.7	3.48	-5
2-Year Peak Flow	19.9	21.8	9
10-Year Peak Flow	41.4	41.4	0
25-Year Peak Flow	50.1	51.0	2
Mean Monthly Flows			
Month	**Observed [m^3/s]**	**Simulated [m^3/s]**	**Difference [%]**
January	-	0.26	-
February	-	0.20	-
March	0.04	0.15	273
April	2.67	2.08	-22
May	7.63	7.81	2
June	7.29	5.85	-20
July	6.6	6.81	2
August	2.36	3.32	41
September	1.17	1.12	-5
October	1.58	0.73	-54
November	-	0.52	-
December	-	0.36	-



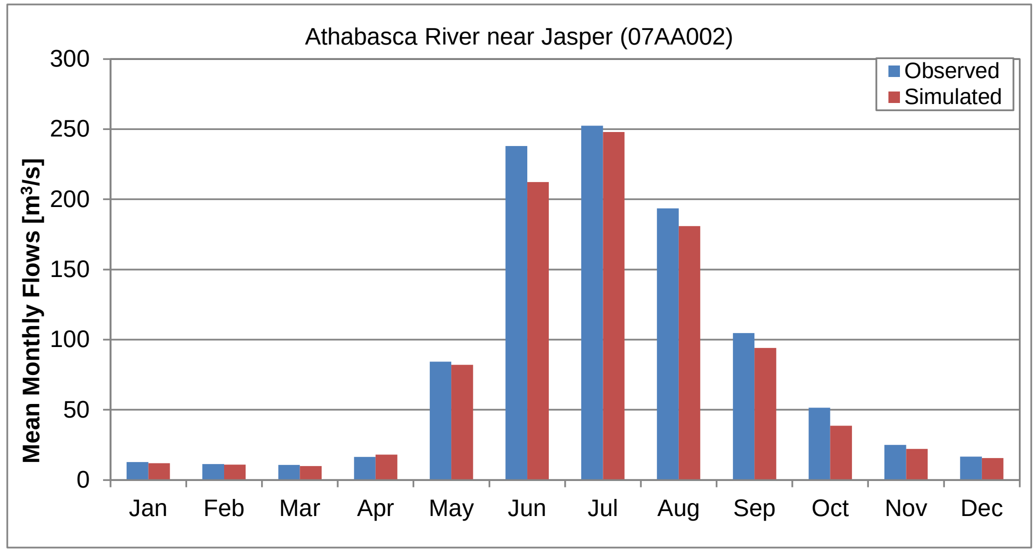
(a) Open water season is from May to October.

- = Recorded data are not available.

Figure 2.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins

Figure 2.1-2a Simulated and Recorded Flow Statistics for Athabasca River Near Jasper (Station 07AA002)

Statistic	Validation (1971 to 2010) Recorded [m^3/s]	Validation (1971 to 2010) Simulated [m^3/s]	Difference [%]
Mean Annual Flow	84.8	78.7	-7
Mean Open-Water Flow[(a)]	134	125	-7
2-Year Peak Flow	396	349	-12
10-Year Peak Flow	566	409	-28
25-Year Peak Flow	666	424	-36
Mean Monthly Flows			
January	12.8	12.0	-6
February	11.3	11.0	-3
March	10.8	10.0	-8
April	16.5	18.1	10
May	84.2	82.2	-2
June	238	212	-11
July	252	248	-2
August	194	181	-7
September	105	94.0	-10
October	51.5	38.6	-25
November	25.1	22.1	-12
December	16.8	15.6	-7

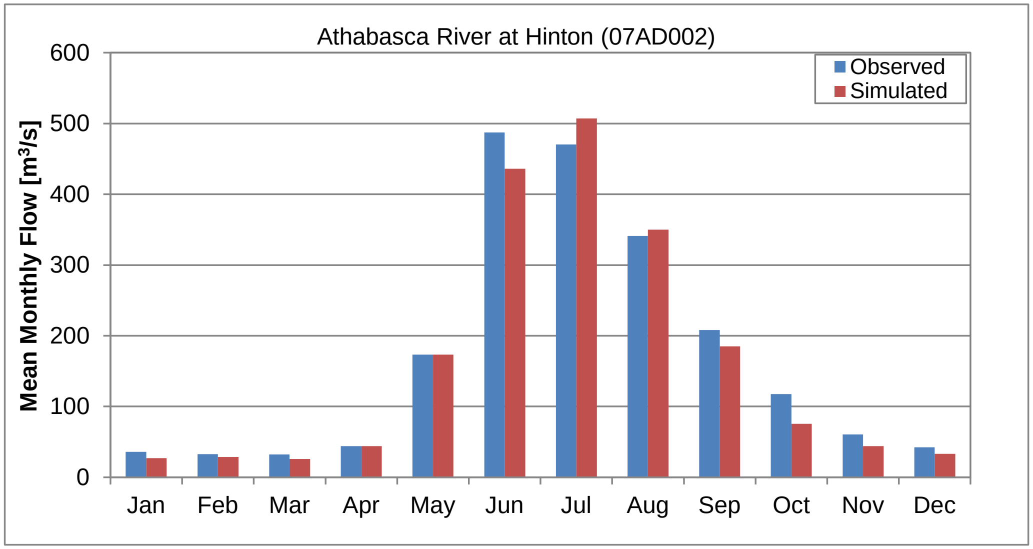


(a) Open water season is from May to October.

Figure 2.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (continued)

Figure 2.1-2b Simulated and Recorded Flow Statistics for Athabasca River at Hinton (Station 07AD002)

Statistic	Validation (1962 to 2011)		Difference [%]
	Recorded [m^3/s]	Simulated [m^3/s]	
Mean Annual Flow	171	161	-6
Mean Open-Water Flow[(a)]	263	253	-4
2-Year Peak Flow	784	1,088	39
10-Year Peak Flow	1,041	1,394	34
25-Year Peak Flow	1,157	1,438	24
Mean Monthly Flows			
January	36.1	26.9	-26
February	32.6	28.8	-12
March	32.5	25.8	-20
April	44.1	43.9	-1
May	174	173	0
June	488	436	-11
July	470	507	8
August	341	350	3
September	208	185	-11
October	118	75.5	-36
November	60.7	44.1	-27
December	42.5	33.0	-22

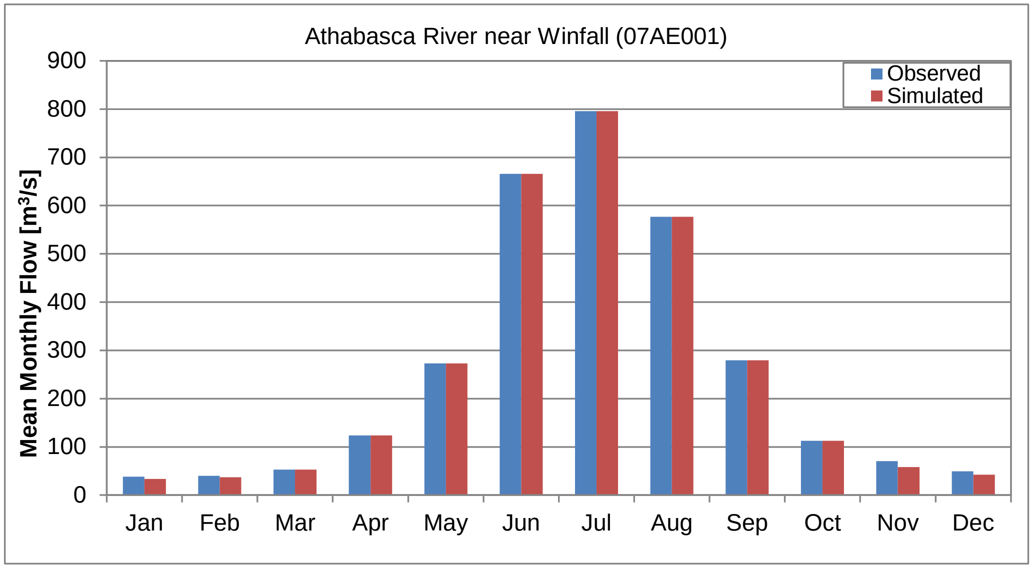


(a) Open water season is from May to October.

Figure 2.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (continued)

Figure 2.1-2c Simulated and Recorded Flow Statistics for Athabasca River Near Windfall (Station 07AE001)

Statistic	Validation (1962 to 2011)		Difference [%]
	Recorded [m^3/s]	Simulated [m^3/s]	
Mean Annual Flow	257	254	-1
Mean Open-Water Flow[(a)]	404	404	0
2-Year Peak Flow	1,054	1,436	36
10-Year Peak Flow	1,675	2,211	32
25-Year Peak Flow	2,048	2,542	24
Mean Monthly Flows			
January	38.1	33.7	-12
February	40.3	37.4	-7
March	53.2	53.2	0.0
April	124	124	0.0
May	273	273	0.0
June	666	666	0.0
July	795	795	0.0
August	577	577	0.0
September	280	280	0.0
October	112	112.5	0.0
November	70.3	58.5	-17
December	49.7	42.4	-15

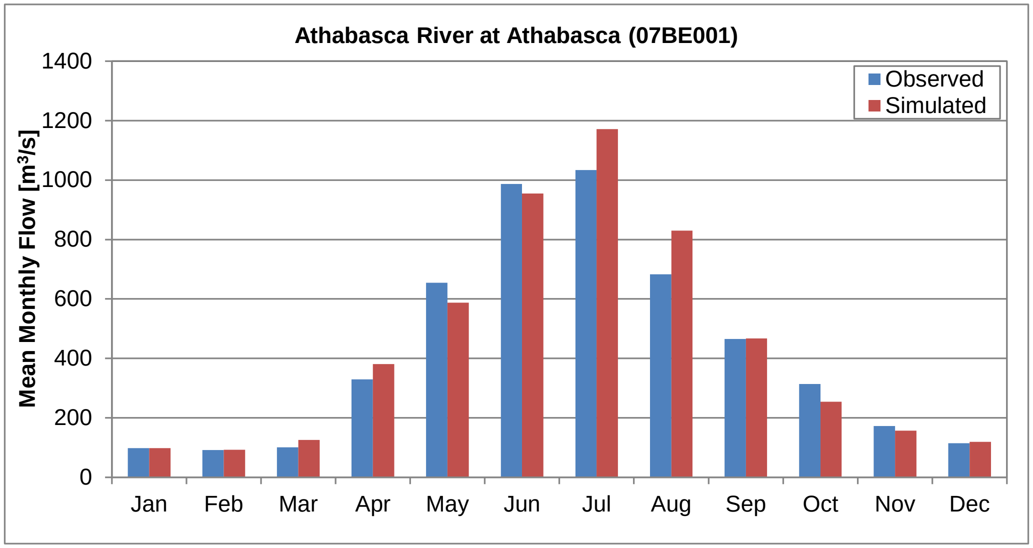


(a) Open water season is from May to October.

Figure 2.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (continued)

Figure 2.1-2d Simulated and Recorded Flow Statistics for Athabasca River at Athabasca (Station 07BE001)

Statistic	Validation (1962 to 2011)		Difference [%]
	Recorded [m^3/s]	Simulated [m^3/s]	
Mean Annual Flow	420	436	4
Mean Open-Water Flow[(a)]	638	663	4
2-Year Peak Flow	1,879	1,754	-7
10-Year Peak Flow	3,249	2,726	-16
25-Year Peak Flow	4,066	3,180	-22
Mean Monthly Flows			
January	98	98	1
February	92	93	1
March	101	126	25
April	330	381	15
May	654	587	-10
June	987	955	-3
July	1,034	1,171	13
August	683	830	21
September	466	467	0
October	314	254	-19
November	172	157	-9
December	115	119	4

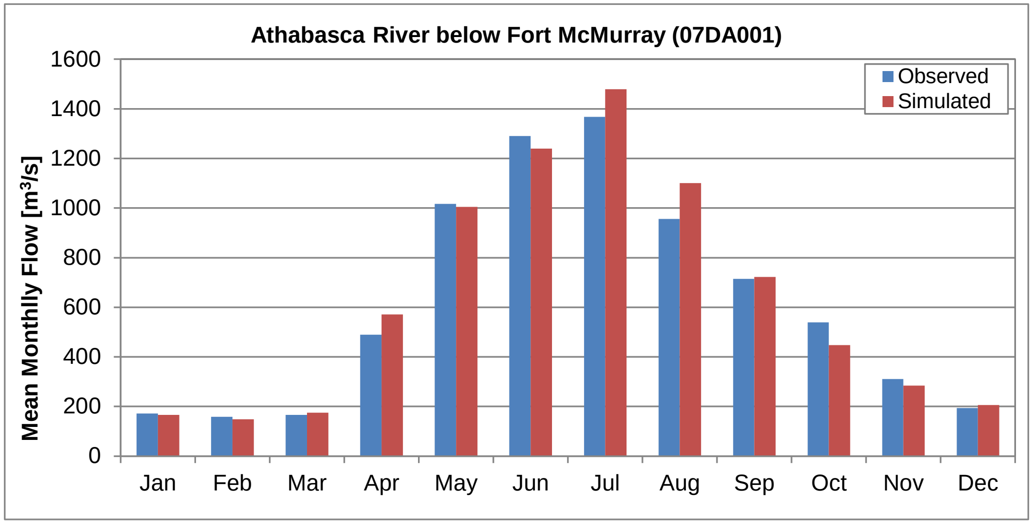


(a) Open water season is from May to October.

Figure 2.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (continued)

Figure 2.1-2e Recorded and Simulated Flow statistics for Athabasca River Below Fort McMurray (Station 07DA001)

Statistic	Validation (1961 to 2011)		Difference [%]
	Recorded [m^3/s]	Simulated [m^3/s]	
Mean Annual Flow	615	629	2
Mean Open-Water Flow[(a)]	911	938	3
2-Year Peak Flow	2,302	2,043	-11
10-Year Peak Flow	3,681	3,142	-15
25-Year Peak Flow	4,414	3,677	-17
Mean Monthly Flows			
January	172	167	-3
February	158	149	-6
March	166	175	5
April	489	571	17
May	1,017	1,004	-1
June	1,291	1,240	-4
July	1,368	1,479	8
August	956	1,101	15
September	714	722	1
October	539	448	-17
November	310	284	-8
December	194	206	6

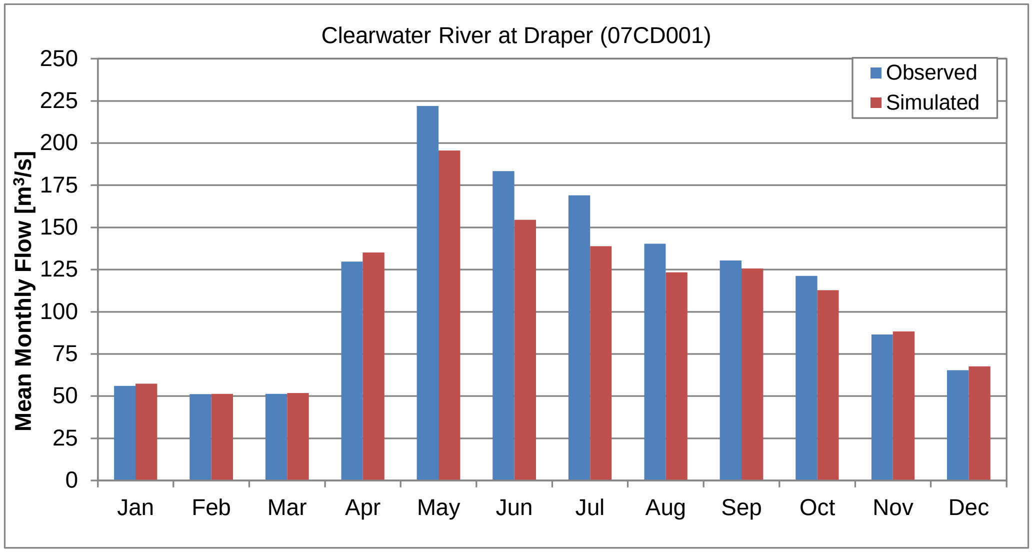


(a) Open water season is from May to October.

Figure 2.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (continued)

Figure 2.1-2f Recorded and Simulated Flow Statistics for Clearwater River at Draper (Station 07CD001)

Statistic	Validation (1961 to 2010) Recorded [m^3/s]	Validation (1961 to 2010) Simulated [m^3/s]	Difference [%]
Mean Annual Flow	117	109	-7
Mean Open-Water Flow[(a)]	157	141	-10
2-Year Peak Flow	365	334	-8
10-Year Peak Flow	583	764	31
25-Year Peak Flow	678	1,007	49
Mean Monthly Flows			
January	56.0	57.3	2
February	51.2	51.4	0
March	51.3	52	1
April	130	135	4
May	222	196	-12
June	183	155	-16
July	169	139	-18
August	140	123	-12
September	130	126	-4
October	121	113	-7
November	87	88	2
December	65	68	3



(a) Open water season is from May to October.

The outcome of the calibration and validation of the HSPF model was deemed to be good to reasonable to poor based on the following criteria:

- Good:
  - observed mean annual flow or mean open-water flow replicated to less than 10%; and
  - mean monthly flows replicated to within 20%, except for winter (very low flow) months when a difference of less than 40% was deemed to be good.
- Reasonable:
  - observed mean annual flow or mean open-water flow replicated to less than 15%; and
  - mean monthly flows replicated to within 40%, except for winter (very low flow) months when a difference of less than 60% was deemed to be reasonable.
- Poor:
  - difference between observed and simulated mean annual flows is more than 15%; and
  - difference between observed and simulated mean monthly flows is greater than 40%, and greater than 60% for winter (very low flow) months.

The calibration on mean annual and/or mean open-water flows is generally good for five calibration sub-basins and poor on the Lovett River sub-basin. For mean monthly flows, the calibration is generally reasonable, although there are some significant differences between observed and simulated values for some winter months, which is not unexpected, and generally for the Miette River sub-basin.

The reasons for some of the significant variances between observed and simulated statistics can be explained as follows. For the calibration of these sub-basins, climate data are not generally available within the sub-basin itself; instead, the data are transferred from other locations. For example, the calibration on the Driftwood River sub-basin is based on climate data recorded at Slave Lake Station (more than 40 km from the centre of the sub-basin). The drainage areas of the calibration sub-basins are relatively small, and, therefore, are more likely to be subject to uncertainties due to the spatial variability in precipitation than larger basins. The timing and magnitude of actual within-basin precipitation can be different from the recorded data at the climate station used for calibration. Redistribution of snow on the landscape can have a significant influence on the rate and timing of snow melt and the soil water regime, and hence watershed yield. These processes are difficult to model, primarily because of a general lack of the required data, except perhaps in research basins. Hence, it is difficult to get good calibration for small sub-basins that are more prone to be affected by localized precipitation.

In addition, climate stations tend to be located at relatively low elevations compared to the runoff-producing areas in the upper Athabasca River basin. Extrapolating the station data to high elevation sub-basins can be problematic. For example, precipitation data at the Jasper climate station, which is located at an elevation of about 1,050 masl, was used for simulation of runoff from the Miette River sub-basin. The summer and winter precipitation was adjusted using an orographic adjustment factor. More than 70% of the Miette River sub-basin is at an elevation greater than 2,000 masl, with a maximum elevation up to 2,500 masl. It is possible that extrapolation of the orographic adjustment factor to the very high elevations in this sub-basin may have resulted in some errors in the simulated runoff values. In practice, there should be a cap on the application of the orographic adjustment with elevation since rainfall amounts tend to decrease past certain elevations.

The calibration shows differences between observed and simulated values for winter flows in the small sub-basins because (1) there are uncertainties in low winter flow values and (2) small differences in magnitude usually manifest themselves as large percentage changes because the differences are divided by small winter flow values.

Other factors that may have affected the calibration of the model are spatial variability in frozen soil conditions, spatial variability in vegetation cover, land use changes over time, water withdrawals and returns. Adjustments for these factors can be made within the model for specific studies on stand-alone sub-basins; however, given that the model is being implemented for the entire Athabasca River basin with the focus on the natural flows in the lower reaches of the Athabasca River basin, these adjustments are not considered necessary at this stage.

Further attempts at refining the calibration of the model did not result in significant improvements in model performance. Also, given that the performance of the model at the validation nodes on the main stem of the Athabasca River is considered good, the HSPF model is considered calibrated with parameters as given in Attachment D, Tables D-1 to D-5 for the Athabasca River basin.

The calibrated model reproduced the measured discharges at the validation nodes on the main stem of the Athabasca River well to reasonably well, giving confidence in the use of the model for assessing the hydrologic effects of potential future climate changes (Figure 2.1-2). The validation nodes capture sub-basins with different land types (in different percentages within each sub-basin as shown in Table 2.1-2) and different climate regimes. The combination of a range of land types and climate regimes at the validation nodes is likely a more rigorous test of the performance of the calibrated model. However, it may be argued that at these nodes the drainage areas are much larger than those of the small sub-basins and differences in responses between small sub-basins tend to be “masked” out, thus improving the model performance at the validation stage. Notwithstanding the foregoing, it is concluded that the calibrated HSPF model has been validated and is appropriate for assessing the effects of climate change on the flow in the Athabasca River basin.

2.2 Baseline Climate Conditions and Future Climate Scenarios

To address the potential effects of climate change on flows in the Athabasca River basin, the calibrated and validated HSPF model for the basin was used to simulate the hydrologic effects of forecasted future climate scenarios. An analysis of the effects of climate change depends not only on future conditions but also on the baseline climate to which the predictions are compared. The baseline climate data input to the HSPF model for baseline flow simulations were obtained from the records at six index climate stations within the Athabasca River basin. The baseline climate data used for climate change scenarios (changes in future climate variables) were based on the recommendation of the Intergovernmental Panel on Climate Change (IPCC). The IPCC recommends that 1961 to 1990 be adopted as the climatological baseline period in impact assessments (IPCC 2013).

The Canadian Climate Change Scenarios Network (CCCSN) allows users to download GCM outputs. The average climate changes in climate variables were downloaded from CCCSN (CCCSN 2013) at the locations of index stations in the Athabasca River basin for the 24 available combinations of GCM and associated emission scenarios (the combinations referred to as GCM-scenarios) recommended by the IPCC (IPCC 2007). The forecast of climate change relative to the 1961 to 1990 baseline period represents the forecasted total climate change between the modelled baseline period (1961 to 1990) as represented by its 30-year average and the modelled future period (i.e., 2041 to 2070, called the 2050s) as represented by its 30-year average.

Scatterplots of mean temperature and precipitation changes for seasonal and annual averages from 24 GCM scenarios at each index climate station for the Athabasca River basin were prepared (Attachment E) to select representative GCM scenarios associated with extreme changes forecasted for the basin. The forecasted climate changes at the index climate stations for the 2041 to 2070 period relative to the 1961 to 1990 baseline period for annual and seasonal averages are shown in Attachment E, Figures E-1 to E-30. Five selected representative GCM and scenarios for the Athabasca River basin are shown in Table 2.2-1.

Table 2.2-1 Selected Climate Change Models and Scenarios for Athabasca River Basin

Modelling Centre	Country	Climate Change Model	Emissions Scenario	Scenario Run	Climate Condition
Bjerknes Centre for Climate Research (BCCR)	Norway	BCM2.0	SR-B1	Run 1	Cool and dry
Canadian Centre for Climate Modelling and Analysis (CCCma)	Canada	CGCM3T47	SR-B1	Mean	Median
Météo-France/Centre National de Recherches Meteorologiques (CNRM)	France	CNRMCM3	SR-A2	Run 1	Warm and dry
Institute for Numerical Mathematics (INM)	Russia	INMCM3.0	SR-A2	Run 1	Cool and wet
Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2 hires	SR-A1B	Run 1	Warm and wet

The five selected scenarios represent climate conditions that were cooler and drier (BCM2.0 SR-B1), cooler and wetter (INMCM3.0 SR-A2), warmer and wetter (MIROC3.2 hires SR-A1B), and warmer and drier (CNRMCM3 SR-A2) than median conditions (CGCM3T47 RS-B1). These five scenarios bound the range of reasonably possible future climate regimes from several GCM scenarios for temperature and precipitation. The changes in climate variables forecasted by the selected GCM scenarios and the baseline climate data recorded at index climate stations within the Athabasca River basin provide the future climate scenarios for the 2050s.

3.0 RESULTS OF ASSESSMENT OF EFFECTS OF CLIMATE CHANGE ON THE LOWER ATHABASCA RIVER BASIN

The effects of climate change on river flows in the Athabasca River basin will affect water uses and water management in the basin. Changes in future climate regimes and their effects on flows in the basin were provided.

3.1 Baseline Climate for Model Simulations

The HSPF model is a continuous simulation model that requires daily temperature and precipitation values as inputs. The baseline input daily series for HSPF were obtained from the records at climate stations within the Athabasca River basin. The daily series of temperature and precipitation were compiled for six index climate stations (Attachment C, Figure C-1) in the Athabasca River basin. The criteria used to select the index stations were: range of climate variables recorded by the station (e.g., precipitation, temperature, wind speed), length of recorded data (preferably from 1960 to the present and at least covering the baseline period of 1961 to 1990), reliable/good quality data with low number of missing data, and spatial distribution to cover most of the Hydrologic Regions in the Athabasca River basin. The index climate stations selected are:

- Jasper and Jasper Warden, covering sub-basins in Hydrologic Regions 3 and 4;

- Edson, covering sub-basins in Hydrologic Regions 5 and 10 South;
- Campsie, covering sub-basins in Hydrologic Region 8 South;
- Slave Lake, covering sub-basins in Hydrologic Regions 10 North and 8 North;
- Lac La Biche, covering sub-basins in Hydrologic Region 2C; and
- Fort McMurray, covering sub-basins in Hydrologic Region 9A.

These stations provide good coverage of the Athabasca River basin. Missing data at the index stations were filled in by developing a relationship between monthly precipitation data from nearby climate stations to the index station within the same Hydrologic Region.

3.2 Estimating Changes in Future Temperature and Precipitation

The GCM provide the changes in the average monthly temperature and precipitation values compared to the baseline (1961 to 1990) average values. The changes in forecasted mean temperature and precipitation compared to baseline values for the index stations in the Athabasca River basin are shown in Attachment E, Tables E-1 to E-30 for Jasper, Edson, Campsie, Slave Lake, Lac La Biche and Fort McMurray climate stations, respectively. The changes in precipitation are expressed as the percentage of the difference between future value and baseline value relative to the baseline value, and the changes in temperature are shown as the difference between the future value and the baseline value. The changes in mean annual precipitation and mean annual temperature, respectively, relative to the baseline values are shown in Figures 3.2-1 and 3.2-2.

The average changes in mean annual precipitation in the basin vary from -6.5% at Lac La Biche station to +27% at the Fort McMurray and Lac La Biche stations as shown in Attachment E, Table E-1 to E-30. The range of the changes in precipitation is much wider on a monthly basis, varying from -30% at Edson station to +92% at Fort McMurray and Lac La Biche stations. The general trend appears to be increased precipitation relative to the baseline period, but with greater variability in the monthly changes. The average increases in mean annual temperature varies from 0.78°C at Edson, Campsie and Slave Lake stations to 4.66°C at the Fort McMurray station as shown in Attachment E, Tables E-1 to E-30. The range of the changes in temperature depends on the season under consideration; increases are generally higher for the winter months than for the summer months.

Figure 3.2-1 Percent Changes in Average Annual Precipitation for the 2050s at Index Climate Stations

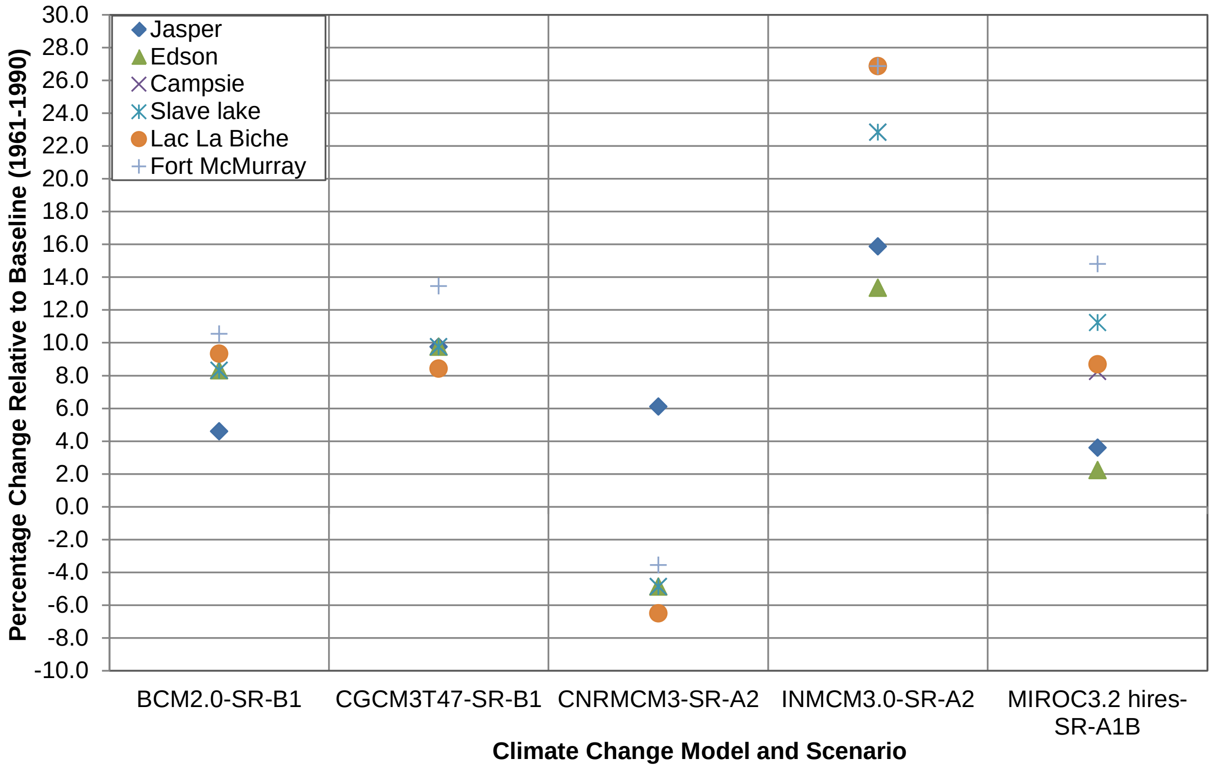
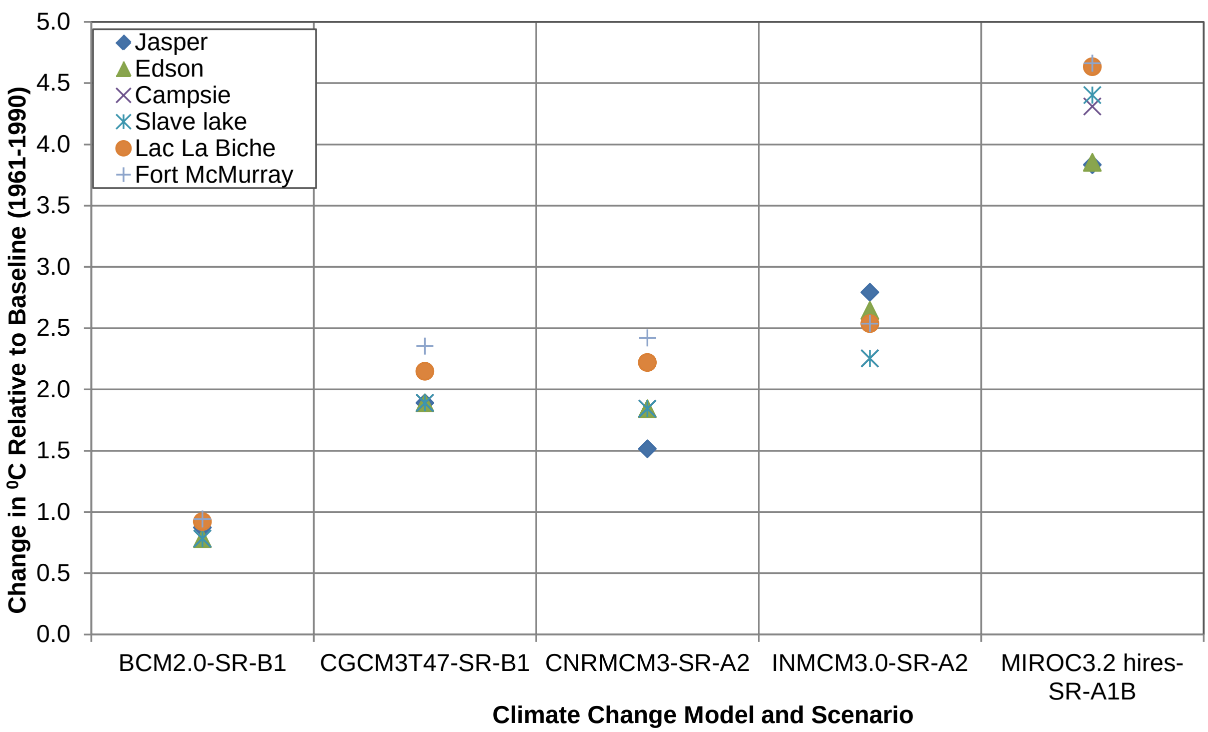


Figure 3.2-2 Changes in Average Annual Temperature for the 2050s at Index Climate Stations



3.3 Future Daily Climate Scenarios

The daily series of temperature and precipitation data for the future climate scenarios were generated by adjusting the daily baseline climate data recorded at index climate stations as described in Section 3.1 by the differences in the temperature and precipitation forecasted by the selected GCM scenarios as described in Section 3.2.

3.3.1 Effects of Climate Change on Flows in the Lower Athabasca River Basin

The HSPF model calibrated for the Athabasca River basin was run with the baseline climate data (Section 3.1) and the adjusted future climate data (Section 3.3). Summaries of a comparison of flow statistics (mean annual flow, mean open-water and ice-cover flows, 2-yr, 10-yr, 25 and 100-yr flood flows, 7Q10 – low flow and mean monthly flows) for the five selected climate change scenarios are presented in Table 3.3-1 for the Athabasca River flow below Fort McMurray Station. The forecasted changes in mean monthly flows are presented graphically in Figure 3.3-1.

General conclusions from the comparison of flow statistics presented in Table 3.3-1 are summarized as follows:

- For the cool and wet climate conditions represented by INMCM3.0 (Run 1)-SR-A2 climate change scenario, the flow statistics for Athabasca River at the station below Fort McMurray will increase relative to baseline values except in the case of the August mean monthly flow for which a decrease of about 4% is predicted. The mean annual and mean open water season flows will increase by about 17% and 14%, respectively. The mean ice-cover flow will increase by about 38%, and the largest increase in the mean monthly flow will be about 76% in March.
- For the cool and dry, and median climate conditions represented by BCM2.0 (Run 1)-SR-B1 and CGCM3T47 (Mean)-SR-B1, respectively, some flow statistics will decrease relative to baseline values, while others will increase. The decrease in mean annual and mean open water season flows will be less than 6%. The mean ice-cover flow will however increase. The largest decrease in the mean monthly flows will be about 22% in August.
- For the warm and dry climate condition represented by CNRMCM3 (Run 1)-SR-B1 climate change scenario, all the flow statistics will decrease. The mean annual and mean open water season flows will decrease by about 24% and 26%, respectively. The mean ice-cover flow will decrease by about 10%, and the largest decrease in the mean monthly flow will be about 41% in August.
- Most of the flow statistics forecasted by the MIROC3.2 hires (Run 1)-SR-A1B scenario, representing the warm and wet climate condition, will be relative to baseline values. The mean annual and mean open water season flows will decrease by about 19% and 28%, respectively. However the mean ice-cover flow will increase. The mean monthly flows will decrease for most months except February, March and April. The largest decrease in the mean monthly flows will be about 53% in the month of August.

Table 3.3-1 Hydrologic Effects of Forecasted Climate Change on Athabasca River Flows

	Forecasted Percentage Change in Flows at Athabasca River below Fort McMurray WSC 07DA001 Compared to Baseline Flows (1961-1990)					
	Baseline Flows (1961-1990)	BCM2.0 (Run 1) - SR-B1	CGCM3T47 (Mean) - SR-B1	CNRMCM3 (Run 1) - SR-A2	INMCM3.0 (Run 1) - SR-A2	MIROC3.2 hires (Run 1) - SR-A1B
	[m^3/s]	Change [%]	Change [%]	Change [%]	Change [%]	Change [%]
Mean Annual Flow	718	-0.1	-2.9	-24.1	16.9	-19.2
Mean Open-Water Flow	1,073	-2.2	-5.7	-26.1	13.9	-27.5
Mean Ice-Cover Flow	216	14.8	16.9	-9.8	38.2	39.9
2-Year Peak Flow	2,331	-0.2	-4.2	-25.1	28.4	-28.0
10-Year Peak Flow	3,454	8.3	1.0	-22.2	43.7	-21.4
25-Year Peak Flow	4,006	10.3	3.6	-21.0	50.4	-19.4
100-Year Peak Flow	4,820	11.9	7.3	-19.3	59.7	-17.2
7Q10-Low Flow	116	-0.9	-4.5	-23.9	16.7	-11.8
Mean Monthly Flows						
Jan	181	8.5	1.6	-14.9	19.6	-1.9
Feb	160	7.9	8.8	-13.1	31.9	20.4
Mar	181	15.8	44.4	-4.1	75.5	124
Apr	599	18.4	20.8	-7.3	35.6	44.2
May	1,139	-4.4	-1.9	-22.5	12.5	-4.2
Jun	1,362	-2.9	8.7	-13.2	36.4	-20.7
Jul	1,701	-0.7	-8.0	-30.8	17.3	-49.6
Aug	1,313	-14.2	-22.1	-41.3	-4.4	-52.8
Sep	869	-2.9	-14.3	-33.2	0.2	-29.5
Oct	520	14.0	-2.9	-15.8	10.3	-2.0
Nov	324	13.7	0.6	-15.4	15.7	-1.9
Dec	228	12.6	2.0	-15.7	18.9	-2.4

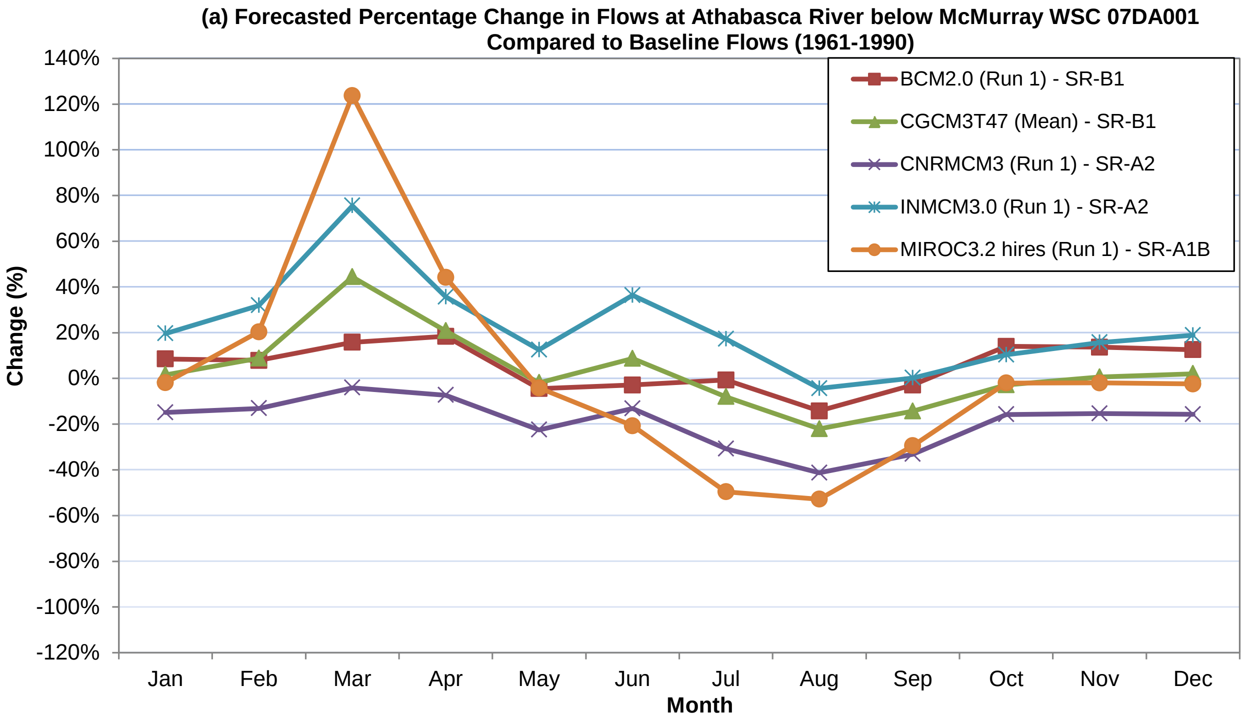
Note: Baseline Flow data (1961-1990) at Athabasca River below Fort McMurray Hydrometric Station (WSC 07DA001) are simulated from baseline climate data.

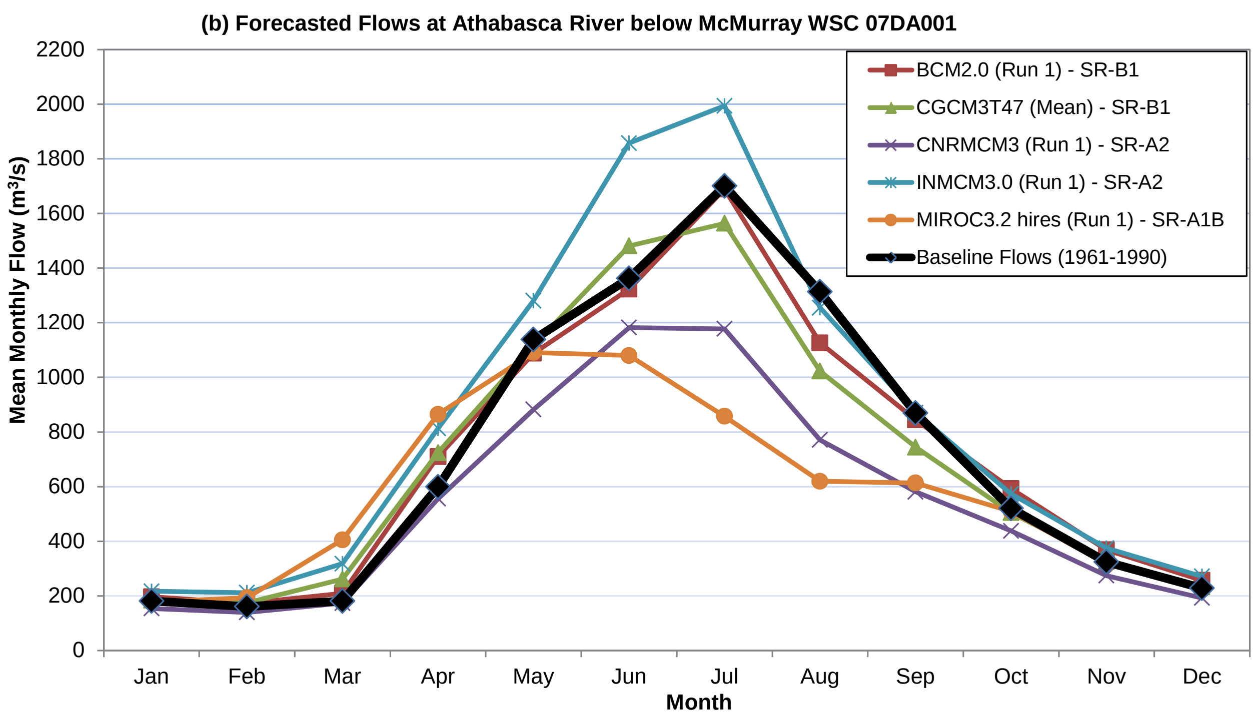
Table 3.3-1 Hydrologic Effects of Forecasted Climate Change on Athabasca River Flows (continued)

	Forecasted Flows at Athabasca River below Fort McMurray WSC 07DA001					
	Baseline Flows (1961-1990)	BCM2.0 (Run 1) - SR-B1	CGCM3T47 (Mean) - SR-B1	CNRMCM3 (Run 1) - SR-A2	INMCM3.0 (Run 1) - SR-A2	MIROC3.2 hires (Run 1) - SR-A1B
	[m^3/s]	[m^3/s]	[m^3/s]	[m^3/s]	[m^3/s]	[m^3/s]
Mean Annual Flow	718	718	697	545	840	581
Mean Open-Water Flow	1,073	1,050	1,012	793	1,222	778
Mean Ice-Cover Flow	216	248	252	195	298	302
2-Year Peak Flow	2,331	2,327	2,234	1,745	2,993	1,680
10-Year Peak Flow	3,454	3,740	3,488	2,687	4,964	2,713
25-Year Peak Flow	4,006	4,419	4,149	3,166	6,027	3,228
100-Year Peak Flow	4,820	5,393	5,171	3,887	7,696	3,989
7Q10-Low Flow	116	115	111	88.6	136	103
Mean Monthly Flows						
Jan	181	197	184	154	217	178
Feb	160	173	175	139	212	193
Mar	181	210	261	174	318	405
Apr	599	710	724	555	813	865
May	1,139	1,088	1,117	882	1,281	1,091
Jun	1,362	1,323	1,481	1,182	1,858	1,080
Jul	1,701	1,689	1,564	1,178	1,994	857
Aug	1,313	1,126	1,023	771	1,255	619
Sep	869	844	745	581	871	613
Oct	520	593	505	438	573	509
Nov	324	368	326	274	375	317
Dec	228	257	233	192	271	223

Note: Baseline Flow data (1961-1990) at Athabasca River below Fort McMurray Hydrometric Station (WSC 07DA001) are simulated from baseline climate data.

Figure 3.3-1 Forecasted Effects of Climate Change on Mean Monthly Flows





The forecasted percentage changes in the Athabasca River mean seasonal flows at station below Fort McMurray compared to baseline flows (1961 to 1990) due to potential climate change by the 2050s are summarized in Table 3.3-2.

Table 3.3-2 Forecasted Percentage Changes in Athabasca River Mean Seasonal Flows at Fort McMurray Compared to Baseline Flows (1961-1990) by the 2050s

Period	Cool-Dry Conditions [BCM2.0 (Run 1) – SR-B1] [%]	Median conditions [CGCM3T47 (Mean) - SR-B1] [%]	Warm –Dry Conditions [CNRMCM3 (Run 1) - SR-A2] [%]	Cool-Wet Conditions [INMCM3.0 (Run 1) - SR-A2] [%]	Warm-Wet Conditions [MIROC3.2 hires (Run 1) - SR-A1B] [%]
Annual	-0.1	-2.9	-24.1	16.9	-19.2
Winter	10.0	3.7	-14.8	22.6	3.8
Spring	4.5	9.4	-16.1	25.6	22.8
Summer	-5.5	-7.2	-28.6	16.5	-41.8
Fall	5.5	-8.0	-24.4	6.2	-15.8

3.3.2 Potential Climate Changes and Water Withdrawals on Athabasca River Flows

The development of the Water Management Framework for the Athabasca River below Fort McMurray (AENV and DFO 2007) is based on historical flows for the river from 1958 to 2004. If flows were to decrease in the future because of climate change, the Water Management Framework restrictions would be invoked more often. Expected percentages of flow reductions due to potential climate change, as given in Table 3.3-2, and a summary of water withdrawals from the lower reach of the Athabasca River provided in October 2013, PRM JRP SIR Appendix 2, Table 3.3-5, were used to assess the level of uncertainty in predicting changes in seasonal flow parameters.

The predicted changes in Athabasca River flows and water levels, respectively, as a result of the total allowable water withdrawals under the Water Management Framework restrictions including the effects of reduced Athabasca River flows due to climate change for 2013 Base Case, 2013 PRM Application Case and 2013 Planned Development Case (PDC) are shown in Tables 3.3-3 and 3.3-4. The results indicate that under climate change scenarios that reduce Athabasca River flows (e.g., CNRMCM3 (Run 1) - SR-A2), more frequent restrictions on water withdrawals would be imposed. Consequently, the percent reductions in seasonal flows due to water withdrawal are less relative to those reductions without the effects of climate change or climate change scenarios that increase flows in Athabasca River (INMCM3.0 (Run 1) - SR-A2INMCM3.0 (Run 1).

Table 3.3-3 Change to Athabasca River Flows in Reach 4 Considering Climate Change Effects in the 2050s

Model Scenario	Season	Baseline Flow (1961 to 1990)	Flows - with Climate Change (no-Water Withdrawal)		Climate Change plus Water Withdrawal					
					2013 Base Case		2013 PRM Application Case		2013 Planned Development Case	
		Stream Flow Discharge	Stream Flow Discharge	Change due to Climate Change Only	Stream Flow Discharge	Change From Baseline Flow	Stream Flow Discharge	Change From Baseline Flow	Stream Flow Discharge	Change From Baseline Flow
		[m^3/s]	[m^3/s]	[%]	[m^3/s]	[%]	[m^3/s]	[%]	[m^3/s]	[%]
MIROC3.2 hires (Run 1) - SR-A1B	winter	196	204	3.8	181	-7.9	177	-9.7	174	-11.2
	spring	602	740	22.8	717	19.0	713	18.3	706	17.2
	summer	1,463	852	-41.8	829	-43.4	825	-43.6	817	-44.1
	fall	617	520	-15.7	497	-19.5	493	-20.2	485	-21.4
CNRMCM3 (Run 1) - SR-A2	winter	196	167	-14.8	145	-26.1	144	-27.0	142	-27.6
	spring	602	502	-16.6	479	-20.4	476	-20.9	472	-21.7
	summer	1,463	1,045	-28.6	1,022	-30.2	1,018	-30.4	1,010	-31.0
	fall	617	467	-24.3	444	-28.1	440	-28.8	433	-29.9
INMCM3.0 (Run 1) - SR-A2INMCM3.0 (Run 1)	winter	196	241	23.0	218	10.9	214	8.8	208	6.0
	spring	602	756	25.6	734	21.8	729	21.1	723	20.0
	summer	1,463	1,705	16.5	1,682	14.9	1,678	14.7	1,670	14.1
	fall	617	656	6.3	633	2.5	629	1.8	621	0.6
BCM2.0 (Run 1) - SR-B1]	winter	196	216	10.2	193	-1.7	189	-3.7	185	-5.6
	spring	602	629	4.5	607	0.7	603	0.0	597	-0.8
	summer	1,463	1,383	-5.5	1,360	-7.1	1,356	-7.3	1,348	-7.9
	fall	617	651	5.5	629	1.8	624	1.1	617	-0.1
CGCM3T47 (Mean) - SR-B1	winter	196	204	4.1	181	-8.0	177	-9.8	174	-11.3
	spring	602	659	9.5	636	5.6	632	4.9	626	4.0
	summer	1,463	1,358	-7.2	1,335	-8.8	1,331	-9.0	1,324	-9.6
	fall	617	568	-7.9	545	-11.7	541	-12.4	533	-13.6

Table 3.3-4 Change to Athabasca River Water Level in Reach 4 Considering Climate Change Effects in 2050s

Model Scenario	Season	Baseline Water Level (1961 to 1990)	Water Level – with Climate Change (no-Water Withdrawal)		Climate Change Plus Water Withdrawal					
					2013 Base Case		2013 PRM Application Case		2013 Planned Development Case	
		Stream Flow Discharge	Water Level	Change due to Climate Change Only	Water Level	Change From Baseline Water Level	Water Level	Change From Baseline Water Level	Water Level	Change From Baseline Water Level
		[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
MIROC3.2 hires (Run 1) - SR-A1B	winter	225.98	225.99	0.01	225.95	-0.03	225.94	-0.03	225.94	-0.04
	spring	226.68	226.91	0.23	226.87	0.19	226.86	0.18	226.85	0.17
	summer	227.96	227.08	-0.88	227.05	-0.91	227.04	-0.92	227.03	-0.93
	fall	226.71	226.54	-0.17	226.50	-0.20	226.50	-0.21	226.49	-0.22
CNRMCM3 (Run 1) - SR-A2	winter	225.98	225.92	-0.06	225.88	-0.09	225.88	-0.10	225.88	-0.10
	spring	226.68	226.51	-0.17	226.47	-0.21	226.47	-0.21	226.46	-0.22
	summer	227.96	227.38	-0.58	227.34	-0.62	227.34	-0.63	227.33	-0.64
	fall	226.71	226.45	-0.26	226.41	-0.29	226.41	-0.30	226.40	-0.31
INMCM3.0 (Run 1) - SR-A2INMCM3.0 (Run 1)	winter	225.98	226.06	0.08	226.01	0.04	226.01	0.03	226.00	0.02
	spring	226.68	226.93	0.25	226.90	0.21	226.89	0.21	226.88	0.20
	summer	227.96	228.27	0.31	228.24	0.28	228.23	0.27	228.23	0.26
	fall	226.71	226.77	0.06	226.73	0.03	226.73	0.02	226.71	0.01
BCM2.0 (Run 1) - SR-B1]	winter	225.98	226.01	0.03	225.97	-0.01	225.96	-0.01	225.96	-0.02
	spring	226.68	226.73	0.05	226.69	0.01	226.68	0.00	226.67	-0.01
	summer	227.96	227.86	-0.10	227.82	-0.14	227.82	-0.14	227.81	-0.15
	fall	226.71	226.76	0.05	226.73	0.02	226.72	0.01	226.71	0.00
CGCM3T47 (Mean) - SR-B1	winter	225.98	225.99	0.01	225.95	-0.03	225.94	-0.03	225.93	-0.04
	spring	226.68	226.78	0.10	226.74	0.06	226.73	0.05	226.72	0.04
	summer	227.96	227.82	-0.14	227.79	-0.17	227.78	-0.18	227.77	-0.19
	fall	226.71	226.62	-0.09	226.59	-0.12	226.58	-0.13	226.57	-0.14

3.3.3 Sensitivity of Flows in the Athabasca River Tributary Streams to Potential Changes in Climate Parameters

This section presents the results of using the modelling approach to assess the potential effects of forecasted climate changes on flows in the tributaries to the Athabasca River located within the PRM LSA. One of the main reasons for using this approach is that the reclaimed landscape after mining can have hydrologic responses that are very different from those of undisturbed natural watersheds and these responses can only be estimated with some confidence using a calibrated hydrologic model. The changes in mean annual temperature and mean annual precipitation forecasted by 24 GCM and associated scenarios (A2, B1 and A1B) for an area encompassing the Oil Sands Region are shown in Figure 3.3-2. The selected GCM scenarios that encompass the range of the climate forecasts for changes in mean annual temperature and precipitation are also shown in Figure 3.3-2. The monthly and seasonal changes in temperature and precipitation were then determined for each of the five selected GCM scenarios. The results (annual and seasonal) are provided in Table 3.3-5. The monthly changes in temperature and precipitation were used to estimate the changes in potential evapotranspiration and lake evaporation using Morton's complementary model for evaporation (Morton et al. 1985). Dew point temperatures were adjusted based on observed air temperature and dew point relationship prior to using the Morton's model.

The results in Table 3.3-5 suggest that mean annual air temperature in the Fort McMurray region is forecast to increase by between 0.9 and 4.7°C, with the median increase being about 2.4°C. This forecast is close to the 3.06°C (EIA, Volume 3, Appendix 3-4, Table 39) predicted by extrapolating the trend in observed air temperature data at Fort McMurray climate station. The change in mean annual precipitation is forecasted to range from a decrease of 3.6% to an increase of about 26.9%, with the median change being an increase of about 13.5%. The results in Table 39 in the EIA, Volume 3, Appendix 3-4 indicate that the trend in mean annual precipitation based on observed data are a decrease of about 5.5%. The results of the comparison suggest that the GCM forecasts roughly encompass the predictions based on trends in observed data.

Figure 3.3-2 Changes in Temperature and Precipitation Forecasted by General Circulation Models

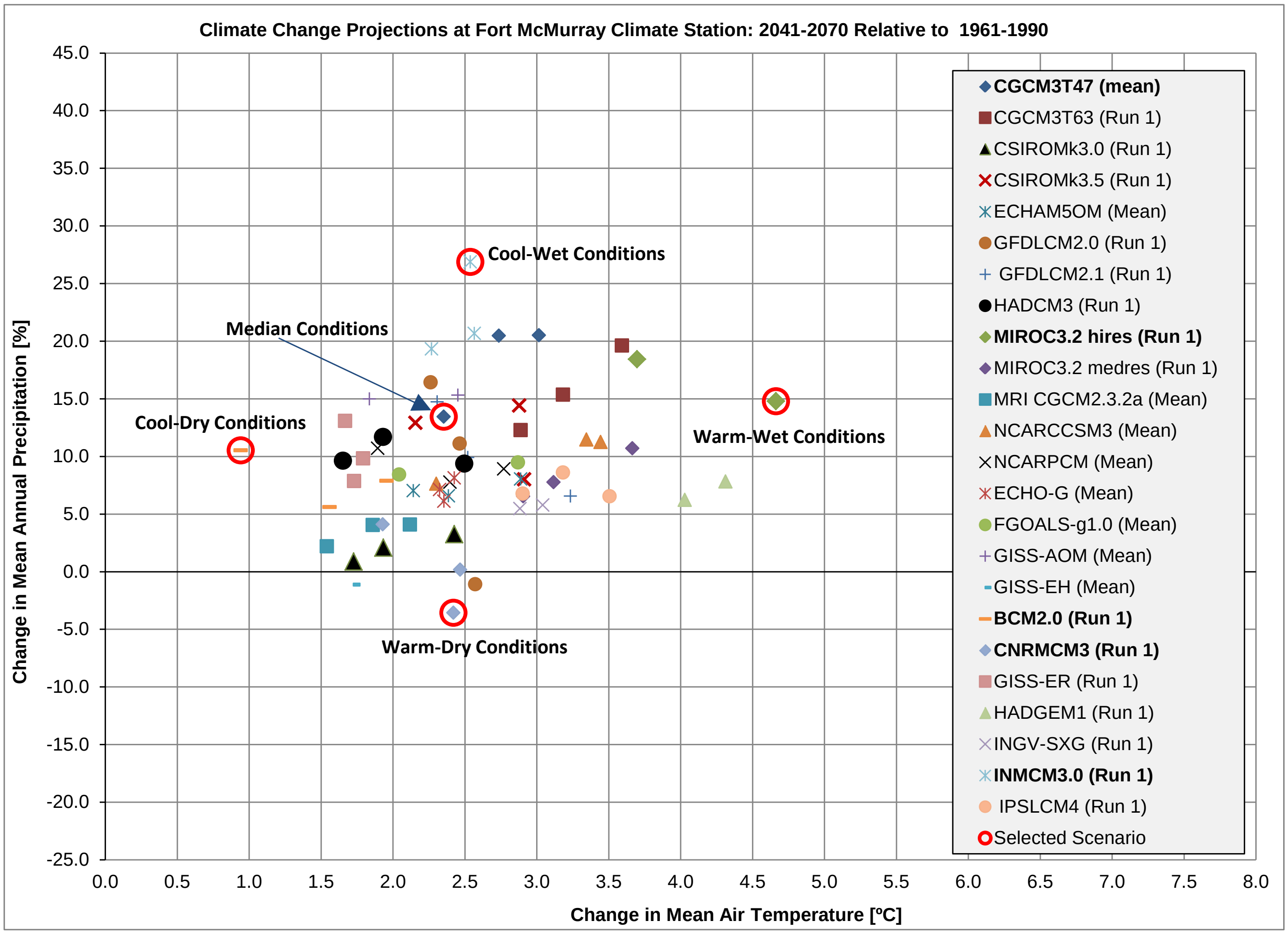


Table 3.3-5 Forecasted Air Temperature, Precipitation, Evapotranspiration and Evaporation Changes in 30 Year Average (2041-2070) from Baseline (1961-1990) for Sensitivity Analysis

Climate Change Scenario	Warm-Wet Scenario [MIROC3.2 hires (Run 1) - SR-A1B Model]					Warm-Dry Scenario [CNRMCM3 (Run 1) - SR-A2 Model]				
Period	Change in Air Temperature	Change in Precipitation		Change in Potential Evapotranspiration	Change in Lake Evaporation	Change in Air Temperature	Change in Precipitation		Change in Potential Evapotranspiration	Change in Lake Evaporation
	[°C]	[mm]	[%]	[mm]	[mm]	[°C]	[mm]	[%]	[mm]	[mm]
Annual	4.7	68.8	14.8	148	73.1	2.4	-16.7	-3.6	64.0	38.7
Winter	6.1	8.5	14.2	6.8	1.7	3.5	-2.1	-3.5	1.0	0.1
Spring	5.3	21.7	26.9	64.9	29.9	1.5	-2.0	-2.5	18.7	8.0
Summer	3.5	-2.4	-1.1	57.1	33.5	2.9	-14.8	-6.9	36.6	26.0
Fall	3.8	26.6	24.3	19.0	8.1	1.8	7.8	7.1	7.7	4.6

Climate Change Scenario	Cool-Wet Scenario [INMCM3.0 (Run 1) - SR-A2 Model]					Cool-Dry Scenario [BCM2.0 (Run 1) - SR-B1 Model]				
Period	Change in Air Temperature	Change in Precipitation		Change in Potential Evapotranspiration	Change in Lake Evaporation	Change in Air Temperature	Change in Precipitation		Change in Potential Evapotranspiration	Change in Lake Evaporation
	[°C]	[mm]	[%]	[mm]	[mm]	[°C]	[mm]	[%]	[mm]	[mm]
Annual	2.5	125	26.9	71.9	37.3	0.9	48.8	10.5	25.6	11.7
Winter	2.9	10.0	16.8	2.6	0.6	1.0	-1.7	-2.8	0.0	0.6
Spring	2.5	32.8	40.6	28.5	14.5	0.8	6.2	7.7	8.1	4.6
Summer	1.8	79.0	36.8	25.7	16.4	0.6	20.4	9.5	12.5	4.9
Fall	2.9	10.7	9.8	15.1	5.9	1.4	35.4	32.3	5.4	1.6

Climate Change Scenario	Median Scenario [CGCM3T47 (Mean) - SR-B1 Model]				
Period	Change in Air Temperature	Change in Precipitation		Change in Potential Evapotranspiration	Change in Lake Evaporation
	[°C]	[mm]	[%]	[mm]	[mm]
Annual	2.4	62.7	13.5	57.2	28.9
Winter	4.2	10.7	17.9	2.9	0.7
Spring	1.6	13.5	16.7	17.9	10.5
Summer	1.5	29.0	13.5	26.2	13.6
Fall	2.1	9.0	8.2	10.2	4.1

3.3.3.1 Effects of Forecasted Climate Scenarios on the Flows in the South Redclay Lake – 2013 PRM Application Case

The effects of forecasted climate scenarios on the hydrology of South Redclay Lake were assessed at the lake's outlet channel. The total drainage area is about 506 km^2, which includes 5.82 km^2 of the lake's surface area.

The effects of forecasted climate scenarios were investigated using the HSPF model. The results presented in Table 3.3-6 are summarized as follows:

- The mean annual flow from the watershed that includes significant reclaimed areas is predicted to increase by about 21% under future median climate forecasts.
- The mean summer flow is predicted to increase by about 14% under future median climate forecasts.
- The mean winter flow is predicted to increase by 139% under future median climate forecasts.
- The effect on the 10-year 7-day low flow (7Q10) is not significant because the flow statistics is essentially zero.
- The 1:10 year and 1:100 year flow peaks are predicted to increase by about 6% and 2%, respectively, under future median climate forecasts.
- Warmer and wetter than median conditions would increase all flow statistics, except the summer flow.
- Warmer and drier conditions tend to decrease all flow statistics investigated except winter flows, while cooler and wetter, and cooler and drier conditions tend to increase all flow statistics.

3.3.3.2 Effects of Forecasted Climate Conditions on Flows in the Eymundson Creek – 2013 PRM Application Case

Eymundson Creek has a drainage area of about 345 km^2 near its mouth, which includes 17.4 km^2 of lakes and pond surface area.

The effects of forecasted climate scenarios were investigated using the HSPF model. The results of the sensitivity analysis are presented in Table 3.3-7 and are summarized as follows:

- The mean annual flow is predicted to increase by about 20% under future median climate forecasts. For warmer and drier climate forecast scenarios, the mean annual flow is predicted to decrease by about 23%. For cooler and wetter scenarios, the mean annual flow is predicted to increase by up to 73%.
- The mean summer flow is predicted to increase by about 21% under future median climate forecasts.
- The mean winter flow is predicted to increase by about 16% under future median climate forecasts.
- The effect on the 10-year 7-day low flow (7Q10) is not significant for most climate forecast scenarios since the flow statistics is essentially zero. The exception is for cooler and wetter climate forecast scenarios for which the 7Q10 increases from zero under baseline conditions to 24 L/s.
- The 1:10 year and 1:100 year flow peaks are predicted to increase by about 16% and 32%, respectively, under future median climate forecasts. Warmer and wetter than median conditions would increase all flow statistics, except the 7Q10 flow.

- Warmer and drier conditions tend to decrease all flow statistics investigated, while cooler and wetter and cooler and drier conditions tend to increase most of the flow statistics.

3.3.3.3 Effects of Forecasted Climate Conditions on Flows in the Pierre River – 2013 PRM Application Case

The Pierre River has a drainage area of about 113 km^2 at its mouth. The basin is well vegetated and consists of about 87% upland areas (ground slopes greater than 0.5%), 13% lowland areas (ground slopes less than 0.5%), and extensive muskeg terrain.

The results of the sensitivity analysis for the five forecasted climate scenarios are presented in Table 3.3-8 and are summarized as follows:

- The mean annual flow is predicted to increase by about 19% under future median climate forecasts.
- The mean summer flow is predicted to increase by about 12% under future median climate forecasts.
- The mean winter flow is predicted to increase significantly (by about 196%) under future median climate forecasts.
- The effect on the 10-year 7-day low flow (7Q10) is not significant for most climate forecast scenarios since the flow statistics is essentially zero.
- Similar to results predicted for other watersheds in the PRM LSA, warmer and wetter than median conditions would increase most of the flow statistics. Warmer and drier conditions tend to decrease most of the flow statistics investigated, while cooler conditions tend to increase most of the flow statistics.

Table 3.3-6 Effects of Future Climate Scenarios (2041 to 2070) on South Redclay Lake Flows in the Far Future – 2013 PRM Application Case

Scenario	Change in Annual Parameter	Description	Discharge						Change to Discharge					
			Mean Winter [m³/s]	Mean Summer [m³/s]	Mean Annual [m³/s]	10-Year peak [m³/s]	100-Year peak [m³/s]	7Q10 [L/s]	Mean Winter [%]	Mean Summer [%]	Mean Annual [%]	10-year Peak [%]	100-year Peak [%]	7Q10 [L/s]
Baseline 1961 to 1990	none	Baseline Condition	0.104	1.33	0.819	13.7	27.0	0.0	none	none	none	none	none	none
CGCM3T47 (MEAN)-SR-B1	T +2.3; P +59 mm, +13.2%; PET +59 mm	Future Median Conditions	0.249	1.52	0.992	14.5	27.5	0.0	139	14	21	6	2	0
MIROC3.2 hires (RUN 1)-SR-A1B	T +4.7; P +56 mm,+12.5%; PET +153 mm	Warmer and Wetter	0.645	1.29	1.02	18.0	37.5	0.0	520	-3	25	31	39	0
CNRMCM3 (RUN 1)-SR-A2	T +2.4; P -10 mm, -2.1%; PET +79 mm	Warmer and Drier	0.186	1.09	0.716	11.4	22.9	0.0	79	-18	-13	-17	-15	0
INMCM3.0 (RUN 1)-SR-A2	T +2.5; P +143 mm, +31.9%; PET +79 mm	Cooler and Wetter	0.229	2.09	1.32	19.5	42.6	0.0	120	57	61	42	58	0
BCM2.0 (RUN 1)-SR-B1	T +0.9; P +55 mm, +12.3%; PET +24 mm	Cooler and Drier	0.213	1.71	1.09	15.8	29.5	0.0	105	29	33	15	9	0

Note: P = Precipitation; PET = Potential Evapotranspiration; T = Air Temperature.

Table 3.3-7 Effects of Future Climate Scenarios (2041 to 2070) on Eymundson Creek Flows in the Far Future – 2013 PRM Application Case

Scenario	Change in Annual Parameter	Description	Discharge						Change to Discharge					
			Mean Winter [m³/s]	Mean Summer [m³/s]	Mean Annual [m³/s]	10-Year peak [m³/s]	100-Year peak [m³/s]	7Q10 [L/s]	Mean Winter [%]	Mean Summer [%]	Mean Annual [%]	10-year Peak [%]	100-year Peak [%]	7Q10 [L/s]
Baseline 1961 to 1990	None	Baseline Condition	0.226	0.948	0.647	6.38	11.5	0.0	none	none	none	none	none	none
CGCM3T47 (MEAN)-SR-B1	T +2.3; P +59 mm, +13.2%; PET +59 mm	Future Median Conditions	0.262	1.15	0.779	7.43	15.2	0.0	16	21	20	16	32	0
MIROC3.2 hires (RUN 1)-SR-A1B	T +4.7; P +56 mm,+12.5%; PET +153 mm	Warmer and Wetter	0.397	1.00	0.751	8.18	14.6	0.0	76	5	16	28	27	0
CNRMCM3 (RUN 1)-SR-A2	T +2.4; P -10 mm, -2.1%; PET +79 mm	Warmer and Drier	0.202	0.711	0.499	5.56	10.6	0.0	-11	-25	-23	-13	-8	0
INMCM3.0 (RUN 1)-SR-A2	T +2.5; P +143 mm, +31.9%; PET +79 mm	Cooler and Wetter	0.288	1.71	1.12	10.1	18.3	24	27	80	73	58	59	24
BCM2.0 (RUN 1)-SR-B1	T +0.9; P +55 mm, +12.3%; PET +24 mm	Cooler and Drier	0.320	1.25	0.860	8.03	12.5	0.0	42	32	33	26	9	0

Notes: P = Precipitation; PET = Potential Evapotranspiration; T = Air Temperature.

Table 3.3-8 Effects of Future Climate Scenarios (2041 to 2070) on Pierre River Flows in the Far Future – 2013 PRM Application Case

Scenario	Change in Annual Parameter	Description	Discharge						Change to Discharge					
			Mean Winter [m³/s]	Mean Summer [m³/s]	Mean Annual [m³/s]	10-Year peak [m³/s]	100-Year peak [m³/s]	7Q10 [L/s]	Mean Winter [%]	Mean Summer [%]	Mean Annual [%]	10-year Peak [%]	100-year Peak [%]	7Q10 [L/s]
Baseline 1961 to 1990	none	Baseline Condition	0.024	0.451	0.274	7.15	16.5	0.0	none	none	none	none	none	none
CGCM3T47 (MEAN)-SR-B1	T +2.3; P +59 mm, +13.2%; PET +59 mm	Future Median Conditions	0.071	0.505	0.326	7.15	14.5	0.0	196	12	19	0	-12	0
MIROC3.2 hires (RUN 1)-SR-A1B	T +4.7; P +56 mm,+12.5%; PET +153 mm	Warmer and Wetter	0.200	0.415	0.326	8.54	17.6	0.0	733	-8	19	19	7	0
CNRMCM3 (RUN 1)-SR-A2	T +2.4; P -10 mm, -2.1%; PET +79 mm	Warmer and Drier	0.053	0.364	0.235	5.68	11.6	0.0	121	-19	-14	-21	-30	0
INMCM3.0 (RUN 1)-SR-A2	T +2.5; P +143 mm, +31.9%; PET +79 mm	Cooler and Wetter	0.071	0.708	0.444	11.1	25.5	0.0	196	57	62	55	55	0
BCM2.0 (RUN 1)-SR-B1	T +0.9; P +55 mm, +12.3%; PET +24 mm	Cooler and Drier	0.057	0.557	0.350	7.87	16.0	0.0	138	24	28	10	-3	0

Notes: P = Precipitation; PET = Potential Evapotranspiration; T = Air Temperature.

3.3.4 Summary

The results of simulations of five forecasted climate conditions (median and extremes of wet/dry and cool/warm conditions) on the Athabasca River, South Redclay Lake, Pierre River and Eymundson Creek support the following conclusions:

- Under predicted future climate change scenarios, more frequent restrictions on water withdrawals would be imposed, consequently, the percentage reductions in seasonal flows due to water withdrawal are less compared to those without the effects of climate change.
- Under future median conditions, winter low flows tend to increase significantly, while changes in the mean annual flows ranges from 19% for Pierre River to 21% for South Redclay Lake. The predicted mean summer flows are expected to increase by 12% for Pierre River and by about 16% for Eymundson Creek.
- Warmer and drier conditions tend to decrease most of the flow statistics, while warmer and wetter conditions tend to increase most of the flow statistics.
- The effects on the 10-year 7-day low flow (7Q10) from the predominantly reclaimed area are not significant because these flows statistics are essentially zero at most nodes.

The additional effect of median forecasted climate conditions on 100-year flood flows is about 2% for South Redclay Lake outlet channel and about 32% for Eymundson Creek flows. The flow changes are considered to be a negligible to low effect to the sustainability of the channels and waterbodies in the reclaimed landscape.

4.0 WATER QUALITY ASSESSMENT

This section presents the assessment of climate change effects on surface water quality in the PRM LSA and RSA. Climate change effects for the 2013 PRM Application Case and 2013 PDC were predicted at the Big Creek node in the LSA and at the nodes downstream of Redclay Creek and at Embarras in the Athabasca River. The Big Creek node was chosen to represent LSA effects because it will be affected by both the PRM and Frontier Mine projects. The Athabasca River nodes capture the effects of cumulative oil sands developments under each assessment case.

4.1 Modelling Analysis

4.1.1 Assessment Methods

Water quality was modelled for small streams and the Athabasca River. The assessment methods were consistent with those described in the EIA, Volume 4B, Appendix 4-2, with the exception of different inputs that were used to represent climate change scenarios. Five climate change scenarios were considered for the hydrological analysis, as presented in Section 2.2. Water quality modelling was performed by taking into account the derived changes in hydrological regime and consequent river flows. As with the EIA scenario modelling, the water quality models were built upon the hydrologic models, so that inputs were consistent between components.

Water quality modelling was performed in two steps:

- The HSPF model was applied to simulate water quality in Big Creek when considering the effects of the PRM and Frontier Mine projects under various hydrological conditions.

- The Athabasca River Model (ARM) was applied to simulate water quality in the Athabasca River when considering the estimated loadings from small streams and cumulative oil sands developments under various hydrological conditions.

For simulating water quality in small streams, the changes in air temperature, precipitation and evapotranspiration were the same as those assumed for hydrology predictions in Section 2.1.2. Wind and solar radiation were also included as meteorological variables and were presented in Section 2.1.2. Predicted wind and solar radiation data corresponding to precipitation results from climate change models were used for assessing the effects on water quality.

The changes in stream flow for the Athabasca River, which was based on statistical analysis, was used to generate a time series of daily flows under each climate change scenario. The time series were used in the Athabasca River Model to predict water quality in the Athabasca River under each scenario. The water quality of the Athabasca River was assessed at two nodes; the first node is located downstream of Redclay Creek and the second is located at Embarras.

Modelling for both systems was completed under the Far Future snapshot for both the 2013 PRM Application Case and 2013 PDC. The 2013 PRM Application Case included the PRM along with existing and approved developments, and serves to examine the incremental effect of the PRM on water quality. The 2013 PDC includes the projects listed in Appendix 3.1.

The climate change assessment focused on five representative constituents comprised of acute and chronic toxicity, labile and refractory naphthenic acids and total dissolved solids. These were highlighted as key indicators in the EIA, Volume 4A, Section 6.5.3 and are indicative of behavior of degradable and non-degradable constituents.

4.1.2 Results

For each scenario, the probability of non-attainment of each constituent concentration (i.e., the likelihood that concentrations will remain below a given value) was analyzed at each assessment node. The results for the 2013 PRM Application Case and 2013 PDC are presented in Attachment G, Figure G-1 to Figure G-5, and results for the 2013 PDC are presented in Attachment G, Figure G-6 to Figure G-10. The probability of non-attainment in the EIA 2013 PRM Application Case and 2013 PDC is included in the figures for comparison.

In the 2013 PRM Application Case, the climate change effects on water quality are predicted to be negligible in comparison to those estimated for the EIA at Big Creek. However, in the 2013 PDC at Big Creek, the model predicted more variation by climate scenario. Unlike the Athabasca River results, presented below, the wetter scenarios are predicted to result in higher concentrations in the LSA because the mine-related waters will release higher loads to the small streams under wet scenarios. However, predicted water quality changes for these scenarios represent the combined effect of changes to precipitation, evaporation and residence time. Under dry scenarios, the reduction of the water volume as a result of evaporation from waterbodies with long residence times increases concentrations of non-degradable constituents, such as refractory naphthenic acids and total dissolved solids. Residence time increases under some climate change scenarios, resulting in additional decay and consequently reduced concentrations of non-conservative constituents such as labile naphthenic acids and acute and chronic toxicity. This effect is observed in the predicted concentrations for the MIROC3.2 2013 PDC scenario at Big Creek. Thus, the results of climate change in the LSA are predicted to be mixed, with some constituent concentrations increasing slightly and others decreasing.

Unlike the small streams, effects to water quality in the Athabasca River as a result of climate change will be primarily driven by changes upstream of the Oil Sands Region, where the majority of instream flow originates. In both nodes of the Athabasca River, all scenarios except CNRMCM3 are predicted to result in lower constituent concentrations compared to the EIA. This scenario is predicted to have slightly higher concentrations because of lower flow rates from upstream sources. The total range of concentrations by scenario varies by constituent, with refractory naphthenic acids and total dissolved solids showing very little variation, while labile naphthenic acids and toxicity are predicted to vary by up to 50% by scenario. Under all scenarios, concentrations of these constituents are predicted to remain below applicable thresholds in the Athabasca River.

The literature review in the EIA, Volume 3, Appendix 3-4, indicated a low potential for effects on water temperature and dissolved oxygen in rivers and lakes as a result of changes in air temperature from climate change. It concluded that water temperature and oxygen solubility under the combined effects of the PRM and potential climate changes were likely to be negligible in the Athabasca River. This conclusion remains unchanged by the present analysis.

4.1.3 Summary

Potential effects to water quality as a result of climate change were assessed by modelling the same five climate scenarios as presented in Section 2.2. Modelling was completed for Big Creek in the LSA and downstream of Redclay Creek and at Embarras in the Athabasca River. The model results indicated that wetter scenarios may lead to slight increases in constituent concentrations in the LSA because of the additional load released from reclaimed mines, whereas dryer scenarios would lead to higher concentrations in the Athabasca River as a result of lower flows from sources upstream of the Oil Sands Region. Under all scenarios, concentrations of these constituents are predicted to remain below applicable thresholds in the Athabasca River, so EIA conclusions would remain unchanged under these scenarios.

5.0 REFERENCES

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6.0 ABBREVIATIONS

°C	temperature in degrees Celsius
%	percent
7Q10	lowest 7-day consecutive flow that occurs, on average, once every 10 years
CCCSN	Canadian Climate Change Scenarios Network
EIA	Environmental Impact Assessment
ESRD	Alberta Environment and Sustainable Resource Development
GCM	General Circulation Model
HSPF	Hydrological Simulation Program-Fortran
IPCC	Intergovernmental Panel on Climate Change
JME	Jackpine Mine Expansion
km	kilometres
km^2	square kilometres
L/s	litres per second
LSA	Local Study Area
m	metres
m^3/s	cubic metres per second
masl	metres above sea level
mm	millimetres
PDC	Planned Development Case
PRM	Pierre River Mine
U.S. EPA	United States Environmental Protection Agency
WSC	Water Survey Canada
yr	year

ATTACHMENT A

Athabasca River Basin Surficial Geology

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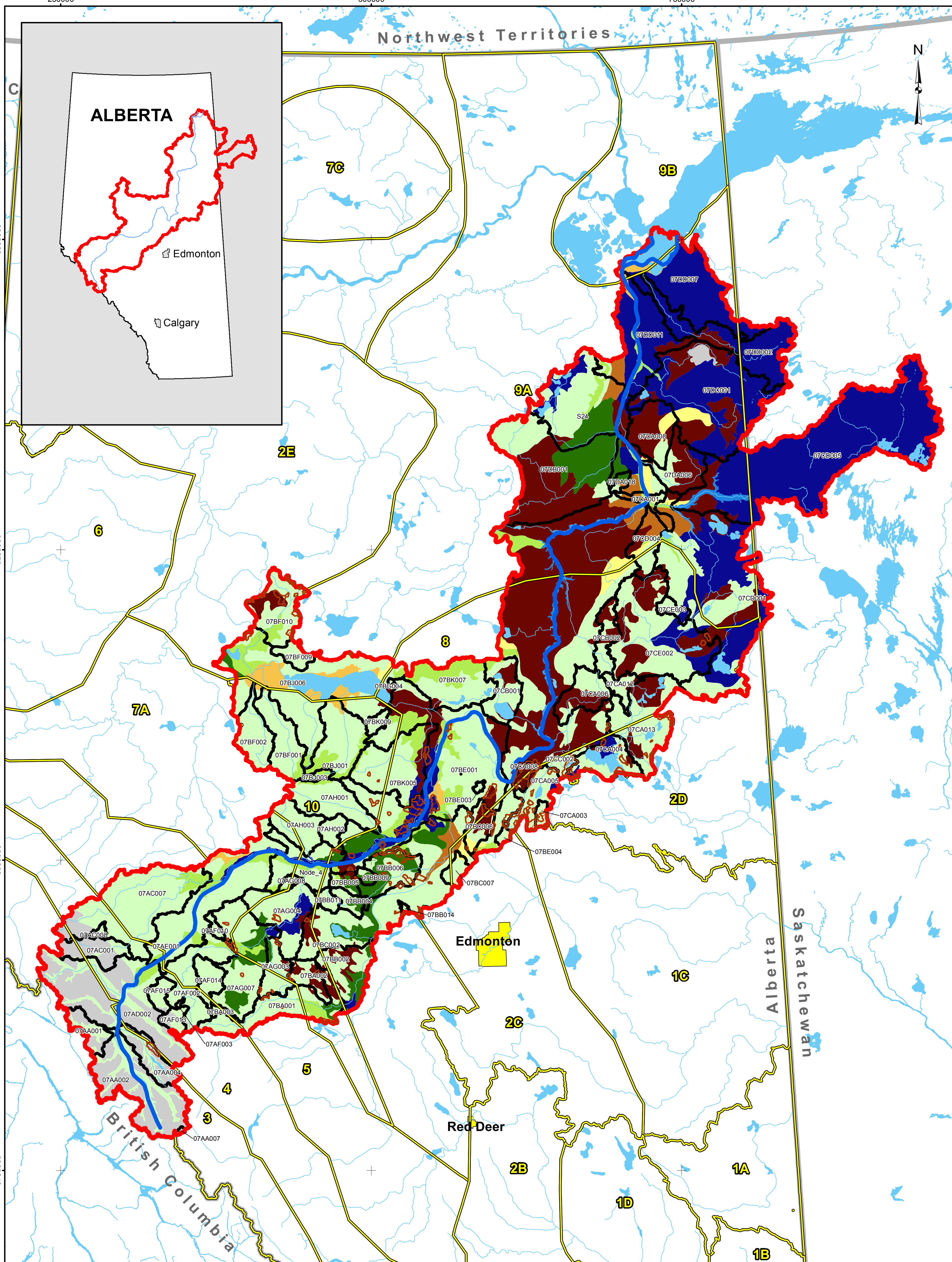

LEGEND

- ATHABASCA RIVER
- WATERCOURSE
- HYDROLOGIC REGION
- NON-CONTRIBUTING AREA
- STUDY AREA
- SUB-BASIN
- CITY
- WATERBODY

SOIL TYPE

- IMPERVIOUS
- ORGANIC
- POORLY DRAINED CLAY LOAM
- POORLY DRAINED SAND
- POORLY DRAINED TILL
- RAPIDLY DRAINED SAND
- RAPIDLY DRAINED TILL
- WELL DRAINED CLAY LOAM
- WELL DRAINED SAND
- WELL DRAINED TILL

100 0 100

SCALE 1:3,000,000 KILOMETRES

REFERENCE

CITY AND HYDROLOGY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. SUB-BASIN AREAS OBTAINED FROM PFRA. GROSS DRAINAGE AREAS JOINED TO SELECTED ALBERTA ENVIRONMENT HYDROMETRIC STATIONS AND PREVIOUS GOLDER PROJECTS. HYDROMETRIC STATIONS AND HYDROLOGIC REGIONS OBTAINED FROM ALBERTA ENVIRONMENT. SURFICIAL GEOLOGY OBTAINED FROM GOVERNMENT OF CANADA / AGRICULTURE AND AGRI-FOOD CANADA(GC/AAFC) .
PROJECTION: ALBERTA 10TM FALSE EASTING 500,000 AT 115 ° W. DATUM: NAD 83

PROJECT
Shell Canada Limited

PIERRE RIVER MINE CLIMATE MODEL UPDATE FOR ATHABASCA RIVER BASIN

TITLE

SURFICIAL GEOLOGY ATHABASCA RIVER BASIN

Golder Associates

PROJECT NO. 13-1346-0001			FILE No.	
DESIGN	DS	26 Aug. 2013	SCALE AS SHOWN	REV. 0
GIS	SS	06. Sep. 2013	FIGURE: A-1	
CHECK	DS	10 Sep. 2013		
REVIEW	WES	10 Sep. 2013		

ATTACHMENT B

Hydrometric Stations in the Athabasca River Basin

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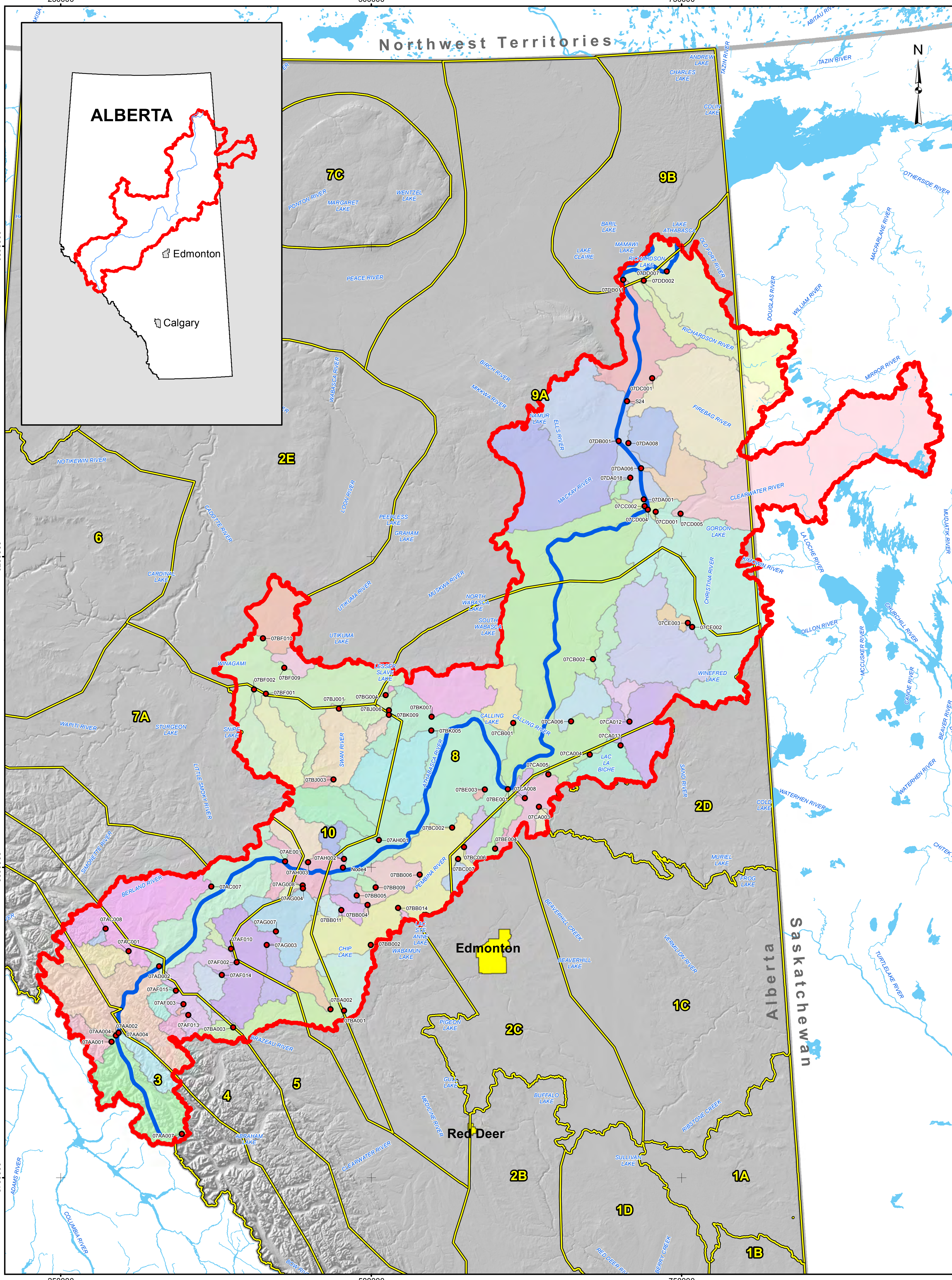

LEGEND

- HYDROMETRIC STATION
- ATHABASCA RIVER
- WATERCOURSE
- HYDROLOGIC REGION
- STUDY AREA
- CITY
- WATERBODY

100 0 100

SCALE 1:3,000,000 KILOMETRES

REFERENCE

CITY DATA OBTAINED FROM NATURAL RESOURCES CANADA. HYDROLOGY DATA OBTAINED FROM IHS ENERGY INC. SUB-BASIN AREAS OBTAINED FROM PFRA GROSS DRAINAGE AREAS JOINED TO SELECTED ALBERTA ENVIRONMENT HYDROMETRIC STATIONS AND PREVIOUS GOLDER PROJECTS. HYDROMETRIC STATIONS, HYDROLOGIC REGIONS, AND SUB-BASIN DATA OBTAINED FROM ALBERTA ENVIRONMENT. SURFICIAL GEOLOGY OBTAINED FROM GOVERNMENT OF CANADA / AGRICULTURE AND AGRI-FOOD CANADA(GC/AAFC) .
PROJECTION: ALBERTA 10TM FALSE EASTING 500,000 AT 115 ° W. DATUM: NAD 83

PROJECT

Shell Canada Limited

PIERRE RIVER MINE CLIMATE MODEL UPDATE FOR ATHABASCA RIVER BASIN

TITLE

HYDROMETRIC STATIONS IN THE ATHABASCA RIVER BASIN

Golder Associates

PROJECT NO. 12-1337-0003		
DESIGN	DS	24 May 2013
GIS	SS	06 Sep. 2013
CHECK	DS	10 Sep. 2013
REVIEW	WES	10 Sep. 2013

FILE No.

SCALE AS SHOWN

REV. 0

FIGURE: B-1

ATTACHMENT C

Climate Stations in the Athabasca River Basin

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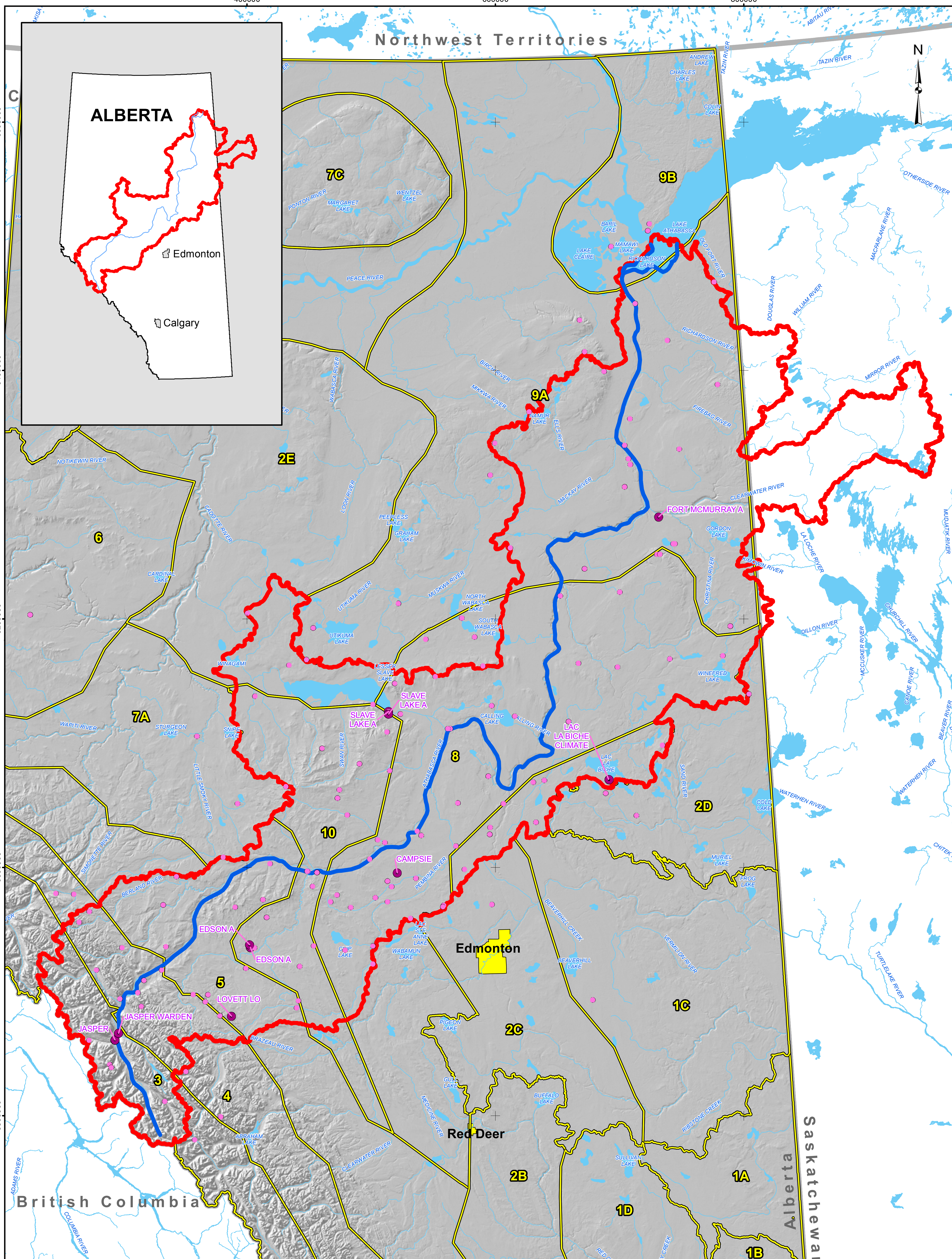

LEGEND

- CLIMATE STATION SELECTED FOR SUB-BASIN FOR CALIBRATION AND VALIDATAION OF THE MODEL
- CLIMATE STATION
- ATHABASCA RIVER
- WATERCOURSE
- HYDROLOGIC REGION
- STUDY AREA
- CITY
- WATERBODY

100 0 100

SCALE 1:3,000,000 KILOMETRES

REFERENCE

CITY DATA OBTAINED FROM NATURAL RESOURCES CANADA. HYDROLOGY DATA OBTAINED FROM IHS ENERGY INC. SUB-BASIN AREAS OBTAINED FROM PFRA GROSS DRAINAGE AREAS JOINED TO SELECTED ALBERTA ENVIRONMENT HYDROMETRIC STATIONS AND PREVIOUS GOLDER PROJECTS. HYDROMETRIC STATIONS, HYDROLOGIC REGIONS, AND SUB-BASIN DATA OBTAINED FROM ALBERTA ENVIRONMENT. SURFICIAL GEOLOGY OBTAINED FROM GOVERNMENT OF CANADA / AGRICULTURE AND AGRI-FOOD CANADA(GC/AAFC) .
PROJECTION: ALBERTA 10TM FALSE EASTING 500,000 AT 115 ° W. DATUM: NAD 83

PROJECT

Shell Canada Limited

PIERRE RIVER MINE CLIMATE MODEL UPDATE FOR ATHABASCA RIVER BASIN

TITLE

CLIMATE STATIONS IN THE ATHABASCA RIVER BASIN

Golder Associates

PROJECT NO. 13-1346-0001			FILE No.	
DESIGN	DS	26 Aug. 2013	SCALE AS SHOWN	REV. 0
GIS	SS	09 Sep. 2013		
CHECK	DS	10 Sep. 2013	**FIGURE: C-1**	
REVIEW	WES	10 Sep. 2013		

ATTACHMENT D

Calibrated Hydrologic Simulation Program-Fortran Model Parameters for Athabasca River Basin

Table D-1 Calibrated HSPF Model Parameters for the Athabasca River Basin – Pervious Land Parameters

Water Parameter	Meaning	Units	WELL DRAINED TILL	WELL DRAINED SAND	WELL DRAINED CLAY LOAM	POORLY DRAINED TILL (LOWLAND GLACIOFLUVIAL)	POORLY DRAINED SAND (LOWLAND GLACIOLACUSTRINE)	POORLY DRAINED CLAY LOAM (LOWLAND GLACIAL)	ORGANIC	IMPERVIOUS (FRACTURED ROCK TREATED AS PERVIOUS)
FOREST	The fraction of the pervious land segment which is covered by forest	none	0.8	0.5	0.8	0.8	0.8	0.8	0.8	0.2
LZSN	The lower zone nominal storage	inch	0.3	2	3.3	0.05	0.3	0.4	0.9	13.26
INFILT	An index to the infiltration capacity of the soil	inch/hr	0.008	0.5	0.0173	0.05	0.008	0.01	0.5	0.02 (0.04)
KVARY	Parameter which affects the behavior of groundwater recession flow, enabling it to be non-exponential in its decay with time	1/inch	0.03	5	1.18	0	0	0	2.847	0.8
AGWRC	The basic groundwater recession rate if KVARY is zero and there is no inflow to groundwater	1/day	0.993 (0.983)	0.8	0.938	0.87	0.87	0.87	0.992	0.997
PETMAX	The air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series	degree Fahrenheit	40	40	40	40	40	40	40	40
PETMIN	The temperature below which E-T will be zero regardless of the value in the input time series	degree Fahrenheit	35	35	35	35	35	35	35	35
INFEXP	Exponent in the infiltration equation	none	2	2	2	2	2	2	2	2
INFILD	Ratio between the maximum and mean infiltration capacities	none	2	2	2	2	2	2	2	2
DEEPFR	Fraction of groundwater inflow which will enter deep (inactive) groundwater	none	0	0	0	0.11	0	0	0	0
BASETP	Fraction of remaining potential E-T which can be satisfied from baseflow (groundwater outflow), if enough is available.	none	0.005	0.005	0.005	0.3	0.2	0.2	0.005	0.005
AGWETP	Fraction of remaining potential E-T which can be satisfied from active groundwater storage if enough is available	none	0.01	0.01	0.01	0.4	0.01	0.01	0.01	0.01
CEPSC	Interception storage capacity	inch	see monthly interception table	see monthly interception table	see monthly interception table	see monthly interception table	0.1	0.10	see monthly table	see monthly table
UZSN	Upper zone nominal storage	inch	0.1 (0.2)	0.05	0.3	0.5	0.5	0.5	0.703	0.6
NSUR	Manning's n for the overland flow plane	Second/(meter$^{1/3}$)	0.25	0.25	0.25	0.35	0.35	0.35	0.25	0.25
INTFW	Interflow inflow parameter	none	3.3	4.83	1	25	8	10	8.42	3.3
IRC	Interflow recession parameter	1/day	0.94	0.798	0.534	0.92	0.925	0.925	0.944	0.2
LZETP	Lower zone E-T parameter	none	see monthly table	see monthly table	see monthly table	see monthly table	0.5	0.5	see monthly table	see monthly table

Table D-2 Calibrated HSPF Model Parameters for the Athabasca River Basin – Pervious Land Parameters – Monthly Interception

	WELL DRAINED TILL	WELL DRAINED SAND	WELL DRAINED CLAY LOAM	POORLY DRAINED TILL (LOWLAND GLACIOFLUVIAL)	POORLY DRAINED SAND (LOWLAND GLACIOLACUSTRINE)	POORLY DRAINED CLAY LOAM (LOWLAND GLACIAL)	ORGANIC	IMPERVIOUS (FRACTURED ROCK TREATED AS PERVIOUS)
Unit	inch	inch	inch	inch	inch	inch	inch	inch
Jan	0.5	0.5	0.5	1	Not Applicable	Not Applicable	1	1
Feb	0.5	0.5	0.5	1	Not Applicable	Not Applicable	1	1
Mar	0.1	0.1	0.1	1.2	Not Applicable	Not Applicable	1.2	1.2
Apr	0.1	0.1	0.1	0.4	Not Applicable	Not Applicable	0.4	0.4
May	0.05	0.05	0.05	0.05	Not Applicable	Not Applicable	0.05	0.05
Jun	0.1	0.1	0.1	0.1	Not Applicable	Not Applicable	0.1	0.1
Jul	0.05	0.05	0.05	0.05	Not Applicable	Not Applicable	0.05	0.05
Aug	0.35	0.35	0.35	0.35	Not Applicable	Not Applicable	0.35	0.35
Sep	0.4	0.4	0.4	0.4	Not Applicable	Not Applicable	0.4	0.4
Oct	0.4	0.4	0.4	0.4	Not Applicable	Not Applicable	0.4	0.4
Nov	0.4	0.4	0.4	0.4	Not Applicable	Not Applicable	0.4	0.4
Dec	0.4	0.4	0.4	0.4	Not Applicable	Not Applicable	0.4	0.4

Table D-3 Calibrated HSPF Model Parameters for the Athabasca River Basin – Pervious Land Parameters – Monthly Lower Zone Evapotranspiration

	WELL DRAINED TILL	WELL DRAINED SAND	WELL DRAINED CLAY LOAM	POORLY DRAINED TILL (LOWLAND GLACIOFLUVIAL)	POORLY DRAINED SAND (LOWLAND GLACIOLACUSTRINE)	POORLY DRAINED CLAY LOAM (LOWLAND GLACIAL)	ORGANIC	IMPERVIOUS (FRACTURED ROCK TREATED AS PERVIOUS)
Unit	inch	inch	inch	inch	inch	inch	inch	inch
Jan	0.3	0.3	0.3	0.01	Not Applicable	Not Applicable	0.3	0.3
Feb	0.5	0.5	0.5	0.01	Not Applicable	Not Applicable	0.5	0.5
Mar	0.6	0.6	0.6	0.01	Not Applicable	Not Applicable	0.6	0.6
Apr	0.8	0.8	0.8	0.1	Not Applicable	Not Applicable	0.8	0.8
May	0.2	0.2	0.2	0.1	Not Applicable	Not Applicable	0.2	0.1
Jun	0.2	0.2	0.2	0.1	Not Applicable	Not Applicable	0.2	0.1
Jul	0.2	0.2	0.2	0.1	Not Applicable	Not Applicable	0.2	0.2
Aug	0.4	0.4	0.4	0.1	Not Applicable	Not Applicable	0.4	0.4
Sep	0.5	0.5	0.5	0.1	Not Applicable	Not Applicable	0.5	0.5
Oct	0.5	0.5	0.5	0.1	Not Applicable	Not Applicable	0.5	0.2
Nov	0.5	0.5	0.5	0.1	Not Applicable	Not Applicable	0.5	0.2
Dec	0.6	0.6	0.6	0.01	Not Applicable	Not Applicable	0.6	0.2

Table D-4 Calibrated HSPF Model Parameters for the Athabasca River Basin – Pervious Land Parameters – Impervious Land Parameters

Water Parameter	Meaning	Units	GLACIER
NSUR	Manning's n for the overland flow plane	none	1
RETSC	The retention (interception) storage capacity of the surface.	inch	0
PETMAX	The air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series.	degree Fahrenheit	48
PETMIN	The temperature below which E-T will be zero regardless of the value in the input time series.	degree Fahrenheit	40
RETS	The initial retention storage.	inch	0.001
SURS	The initial surface (overland flow) storage.	inch	0.001

Table D-5 Calibrated HSPF Model Parameters for the Athabasca River Basin – Pervious Land Parameters – Snow Parameters

Snow Parameter	Description	Units	WELL DRAINED TILL	WELL DRAINED SAND	WELL DRAINED CLAY LOAM	POORLY DRAINED TILL (LOWLAND GLACIOFLUVIAL)	POORLY DRAINED SAND (LOWLAND GLACIOLACUSTRINE)	POORLY DRAINED CLAY LOAM (LOWLAND GLACIAL)	ORGANIC	IMPERVIOUS (TREATED AS PERVIOUS)	GLACIER (IMPERVIOUS)
LAT	Latitude	Degree	54.3 (57.5)	54.3 (57.5)	54.3 (57.5)	54.3 (57.5)	54.3 (57.5)	54.3 (57.5)	54.3 (57.5)	54.3 (57.5)	54.3
SHADE	Fraction of the land which is shaded from solar radiation by trees	none	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.66
SNOWCF	Factor by which the input precipitation data will be multiplied	none	1	1	1	1	1	1	1	1	1
COVIND	Maximum snowpack (water equivalent) at which the entire land will be covered with snow	none	10	5	5	5	5	5	5	3	8.8
KMELT	Constant degree-day factor for the temperature index snowmelt method	inch/day.F	0	0	0	0	0	0	0	0	0
TBASE	Reference temperature for the temperature index method	degree Fahrenheit	32	32	32	32	32	32	32	32	32
RDCSN	Density of cold, new snow relative to water	none	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
TSNOW	Air temperature below which precipitation will be snow	degree Fahrenheit	40	40	40	40	40	40	37	40	30.2
SNOEVP	Parameter which adapts the snow evaporation (sublimation) equation to field conditions	none	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.25	0.0003
CCFACT	Parameter which adapts the snow condensation/convection melt equation to field conditions.	none	0.1 (0.2)	0.1	0.1	0.1	0.1	0.1	0.1	0.1 (0.2)	0.677
MWATER	Maximum water content of the snow pack, in depth of water per depth of water	none	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.25	0.005
MGMELT	Maximum rate of snowmelt by ground heat, in depth of water per day	inch/day	0.02	0.02	0.02	0.02	0.02	0.02	0	0.02	0
PACK-ICE	Quantity of ice in the pack (water equivalent)	inch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1000

ATTACHMENT E

Climate Change Forecasts at Index Climate Stations

Table E-1 Changes in Forecasted Mean Precipitation and Temperature Compared to Baseline Values at Jasper Climate Station

Climate Change Models	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
	Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values [%]																
BCM2.0 (Run 1) - SR-B1	6.7	2.5	7.5	8.9	4.4	-9.3	-6.8	-10.1	-5.2	18.2	20.4	20.4	9.4	6.8	-8.7	11.7	4.6
CGCM3T47 (Mean) - SR-B1	16.1	11.3	9.3	11.3	24.3	10.7	-0.8	-1.6	2.8	13.3	16.7	19.8	16.0	16.5	3.1	10.8	9.8
CNRMCM3 (Run 1) - SR-A2	0.6	13.3	15.7	14.6	9.2	5.7	-13.1	-15.6	1.1	22.2	25.3	10.5	8.0	12.9	-6.4	17.2	6.1
INMCM3.0 (Run 1) - SR-A2	7.1	24.0	12.6	38.7	31.0	12.1	2.5	-6.8	-17.0	4.7	37.8	38.4	23.3	25.6	4.3	11.8	15.9
MIROC3.2 hires (Run 1) - SR-A1B	7.3	5.6	14.9	18.2	29.7	-5.0	-25.7	-18.6	6.1	13.9	18.0	14.3	9.6	21.9	-16.2	12.7	3.6
Average	**7.6**	**11.3**	**12.0**	**18.3**	**19.7**	**2.8**	**-8.8**	**-10.5**	**-2.4**	**14.5**	**23.6**	**20.7**	**13.3**	**16.7**	**-4.8**	**12.8**	**8.0**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values [°C]																
BCM2.0 (Run 1) - SR-B1	1.61	-0.47	0.09	0.85	0.31	0.18	1.62	1.33	1.03	0.53	1.74	1.65	0.93	0.42	1.04	1.10	0.87
CGCM3T47 (Mean) - SR-B1	2.77	2.82	1.67	1.04	1.15	1.65	1.89	1.66	2.09	1.73	2.06	2.13	2.57	1.29	1.73	1.96	1.89
CNRMCM3 (Run 1) - SR-A2	1.61	-0.53	0.20	0.29	1.45	2.40	2.91	2.84	1.99	1.45	1.04	2.53	1.20	0.65	2.72	1.49	1.51
INMCM3.0 (Run 1) - SR-A2	4.23	4.99	4.25	2.59	1.30	1.21	1.73	2.03	2.67	3.08	2.55	2.86	4.03	2.71	1.66	2.77	2.79
MIROC3.2 hires (Run 1) - SR-A1B	3.35	4.18	3.63	2.82	5.29	4.01	4.22	4.11	4.06	2.74	2.73	4.86	4.13	3.91	4.11	3.17	3.83
Average	**2.71**	**2.20**	**1.97**	**1.52**	**1.90**	**1.89**	**2.47**	**2.39**	**2.37**	**1.91**	**2.02**	**2.81**	**2.57**	**1.80**	**2.25**	**2.10**	**2.18**

Table E-2 Changes in Forecasted Mean Monthly Precipitation and Temperature Compared to Baseline Values at Edson Climate Station

Climate Change Models	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
	Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values [%]																
BCM2.0 (Run 1) - SR-B1	10.6	-6.2	-4.5	13.9	-1.1	13.0	12.6	2.8	13.9	34.3	-8.0	11.3	5.2	1.2	9.8	14.4	8.3
CGCM3T47 (Mean) - SR-B1	16.1	11.3	9.3	11.3	24.3	10.7	-0.8	-1.6	2.8	13.3	16.7	19.8	16.0	16.5	3.1	10.8	9.8
CNRMCM3 (Run 1) - SR-A2	1.1	-16.6	-2.1	14.8	-7.6	-11.7	-2.1	-4.0	12.5	-1.6	-13.5	-28.1	-15.9	-1.7	-6.5	3.2	-4.9
INMCM3.0 (Run 1) - SR-A2	3.9	8.4	4.1	62.9	45.9	13.8	-3.2	-11.0	-7.5	7.7	32.3	39.7	17.1	35.6	1.5	12.1	13.4
MIROC3.2 hires (Run 1) - SR-A1B	9.7	5.2	12.6	22.7	26.2	0.0	-29.6	-18.4	-0.5	17.5	17.0	13.6	9.9	21.6	-15.8	10.5	2.2
Average	**8.3**	**0.4**	**3.9**	**25.1**	**17.5**	**5.2**	**-4.6**	**-6.4**	**4.2**	**14.2**	**8.9**	**11.3**	**6.5**	**14.6**	**-1.6**	**10.2**	**5.8**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values [°C]																
BCM2.0 (Run 1) - SR-B1	1.74	-1.06	0.27	0.66	0.75	0.60	0.99	0.94	0.96	0.50	2.35	0.66	0.45	0.56	0.84	1.27	0.78
CGCM3T47 (Mean) - SR-B1	2.77	2.82	1.67	1.04	1.15	1.65	1.89	1.66	2.09	1.73	2.06	2.13	2.57	1.29	1.73	1.96	1.89
CNRMCM3 (Run 1) - SR-A2	2.74	0.28	0.82	0.89	2.08	2.15	2.62	2.47	1.65	1.44	1.26	3.70	2.24	1.26	2.42	1.45	1.84
INMCM3.0 (Run 1) - SR-A2	3.39	4.30	3.45	2.47	1.56	1.52	2.05	2.18	2.89	3.06	2.57	2.30	3.33	2.49	1.92	2.84	2.64
MIROC3.2 hires (Run 1) - SR-A1B	3.37	4.29	3.97	3.41	4.49	4.19	4.24	4.04	4.07	2.81	2.66	4.68	4.11	3.96	4.16	3.18	3.85
Average	**2.80**	**2.13**	**2.04**	**1.69**	**2.01**	**2.02**	**2.36**	**2.26**	**2.33**	**1.91**	**2.18**	**2.69**	**2.54**	**1.91**	**2.21**	**2.14**	**2.20**

Table E-3 Changes in Forecasted Mean Monthly Precipitation and Temperature Compared to Baseline Values at Campsie Climate Station

Climate Change Models	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
	Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values [%]																
BCM2.0 (Run 1) - SR-B1	10.6	-6.2	-4.5	13.9	-1.1	13.0	12.6	2.8	13.9	34.3	-8.0	11.3	5.2	1.2	9.8	14.4	8.3
CGCM3T47 (Mean) - SR-B1	16.1	11.3	9.3	11.3	24.3	10.7	-0.8	-1.6	2.8	13.3	16.7	19.8	16.0	16.5	3.1	10.8	9.8
CNRMCM3 (Run 1) - SR-A2	1.1	-16.6	-2.1	14.8	-7.6	-11.7	-2.1	-4.0	12.5	-1.6	-13.5	-28.1	-15.9	-1.7	-6.5	3.2	-4.9
INMCM3.0 (Run 1) - SR-A2	10.5	24.1	-6.5	20.6	72.5	44.7	22.6	18.9	10.4	4.4	26.3	23.0	19.4	28.0	28.6	13.0	22.8
MIROC3.2 hires (Run 1) - SR-A1B	6.5	10.3	11.9	54.8	23.1	-3.1	-22.2	-12.9	3.5	19.3	28.5	14.2	10.5	29.2	-12.3	16.3	8.2
Average	**9.0**	**4.6**	**1.6**	**23.1**	**22.2**	**10.7**	**2.0**	**0.6**	**8.6**	**13.9**	**10.0**	**8.0**	**7.0**	**14.6**	**4.5**	**11.5**	**8.8**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values [°C]																
BCM2.0 (Run 1) - SR-B1	1.74	-1.06	0.27	0.66	0.75	0.60	0.99	0.94	0.96	0.50	2.35	0.66	0.45	0.56	0.84	1.27	0.78
CGCM3T47 (Mean) - SR-B1	2.77	2.82	1.67	1.04	1.15	1.65	1.89	1.66	2.09	1.73	2.06	2.13	2.57	1.29	1.73	1.96	1.89
CNRMCM3 (Run 1) - SR-A2	2.74	0.28	0.82	0.89	2.08	2.15	2.62	2.47	1.65	1.44	1.26	3.70	2.24	1.26	2.42	1.45	1.84
INMCM3.0 (Run 1) - SR-A2	2.78	2.65	2.56	2.41	1.45	1.42	1.79	1.93	2.86	3.24	2.46	1.49	2.31	2.14	1.71	2.85	2.25
MIROC3.2 hires (Run 1) - SR-A1B	3.90	5.53	6.33	4.89	4.05	3.57	3.77	3.83	3.96	3.03	3.26	5.59	5.01	5.09	3.72	3.42	4.31
Average	**2.79**	**2.04**	**2.33**	**1.98**	**1.90**	**1.88**	**2.21**	**2.17**	**2.30**	**1.99**	**2.28**	**2.71**	**2.52**	**2.07**	**2.08**	**2.19**	**2.21**

Table E-4 Changes in Forecasted Mean Monthly Precipitation and Temperature Compared to Baseline Values at Slave Lake Climate Station

Climate Change Models	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
	Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values [%]																
BCM2.0 (Run 1) - SR-B1	10.6	-6.2	-4.5	13.9	-1.1	13.0	12.6	2.8	13.9	34.3	-8.0	11.3	5.2	1.2	9.8	14.4	8.3
CGCM3T47 (Mean) - SR-B1	16.1	11.3	9.3	11.3	24.3	10.7	-0.8	-1.6	2.8	13.3	16.7	19.8	16.0	16.5	3.1	10.8	9.8
CNRMCM3 (Run 1) - SR-A2	1.1	-16.6	-2.1	14.8	-7.6	-11.7	-2.1	-4.0	12.5	-1.6	-13.5	-28.1	-15.9	-1.7	-6.5	3.2	-4.9
INMCM3.0 (Run 1) - SR-A2	10.5	24.1	-6.5	20.6	72.5	44.7	22.6	18.9	10.4	4.4	26.3	23.0	19.4	28.0	28.6	13.0	22.8
MIROC3.2 hires (Run 1) - SR-A1B	9.0	5.4	8.7	49.6	30.5	-8.7	-8.9	2.4	18.9	11.2	20.5	11.7	8.9	29.5	-5.6	16.9	11.2
Average	**9.5**	**3.6**	**1.0**	**22.0**	**23.7**	**9.6**	**4.7**	**3.7**	**11.7**	**12.3**	**8.4**	**7.5**	**6.7**	**14.7**	**5.9**	**11.7**	**9.4**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values [°C]																
BCM2.0 (Run 1) - SR-B1	1.74	-1.06	0.27	0.66	0.75	0.60	0.99	0.94	0.96	0.50	2.35	0.66	0.45	0.56	0.84	1.27	0.78
CGCM3T47 (Mean) - SR-B1	2.77	2.82	1.67	1.04	1.15	1.65	1.89	1.66	2.09	1.73	2.06	2.13	2.57	1.29	1.73	1.96	1.89
CNRMCM3 (Run 1) - SR-A2	2.74	0.28	0.82	0.89	2.08	2.15	2.62	2.47	1.65	1.44	1.26	3.70	2.24	1.26	2.42	1.45	1.84
INMCM3.0 (Run 1) - SR-A2	2.78	2.65	2.56	2.41	1.45	1.42	1.79	1.93	2.86	3.24	2.46	1.49	2.31	2.14	1.71	2.85	2.25
MIROC3.2 hires (Run 1) - SR-A1B	4.26	5.76	6.14	5.04	4.09	3.58	3.76	3.71	3.78	3.13	3.62	5.94	5.32	5.09	3.68	3.51	4.40
Average	**2.86**	**2.09**	**2.29**	**2.01**	**1.90**	**1.88**	**2.21**	**2.14**	**2.27**	**2.01**	**2.35**	**2.78**	**2.58**	**2.07**	**2.08**	**2.21**	**2.23**

Table E-5 Changes in Forecasted Mean Monthly Precipitation and Temperature Compared to Baseline Values at Lac La Biche Climate Station

Climate Change Models	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
	Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values [%]																
BCM2.0 (Run 1) - SR-B1	15.6	-13.3	-13.3	6.0	-0.2	13.9	14.3	4.2	18.6	35.6	-7.7	18.7	6.1	-0.2	11.1	17.8	9.3
CGCM3T47 (Mean) - SR-B1	13.6	8.6	9.5	7.7	24.3	8.4	3.2	-5.7	-1.6	14.2	14.0	19.8	14.2	16.1	2.7	8.6	8.4
CNRMCM3 (Run 1) - SR-A2	-14.4	-19.1	-6.3	15.2	-8.8	-8.4	-7.2	-8.7	10.8	-5.3	-22.6	-27.4	-20.8	-2.4	-8.0	0.7	-6.5
INMCM3.0 (Run 1) - SR-A2	1.4	33.4	-6.3	40.0	92.4	63.7	26.4	25.1	7.0	3.9	20.4	17.2	16.8	40.6	36.8	9.8	26.9
MIROC3.2 hires (Run 1) - SR-A1B	5.1	18.4	4.4	67.4	29.3	-15.5	-7.4	-7.1	2.3	9.8	22.1	8.4	10.1	33.6	-10.7	11.0	8.7
Average	**4.3**	**5.6**	**-2.4**	**27.3**	**27.4**	**12.4**	**5.9**	**1.6**	**7.4**	**11.6**	**5.2**	**7.3**	**5.3**	**17.5**	**6.4**	**9.6**	**9.4**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values [°C]																
BCM2.0 (Run 1) - SR-B1	1.93	-0.53	0.52	1.02	0.71	0.63	0.63	0.78	0.87	0.50	2.68	1.29	0.90	0.75	0.68	1.35	0.92
CGCM3T47 (Mean) - SR-B1	3.33	3.57	2.22	1.28	1.26	1.53	1.88	1.81	2.27	1.79	2.09	2.75	3.21	1.59	1.74	2.05	2.15
CNRMCM3 (Run 1) - SR-A2	2.98	0.89	1.14	1.05	2.34	2.58	3.02	3.02	2.03	1.67	1.49	4.41	2.76	1.51	2.87	1.73	2.22
INMCM3.0 (Run 1) - SR-A2	3.66	3.02	2.84	2.68	1.93	1.80	1.84	1.89	2.75	3.15	2.82	2.06	2.92	2.48	1.84	2.90	2.54
MIROC3.2 hires (Run 1) - SR-A1B	4.22	6.07	7.16	5.39	4.21	3.71	3.90	3.82	3.98	3.21	3.75	6.14	5.48	5.59	3.81	3.65	4.63
Average	**3.22**	**2.60**	**2.78**	**2.28**	**2.09**	**2.05**	**2.25**	**2.26**	**2.38**	**2.06**	**2.57**	**3.33**	**3.05**	**2.38**	**2.19**	**2.34**	**2.49**

Table E-6 Changes in Forecasted Mean Monthly Precipitation and Temperature Compared to Baseline Values at Fort McMurray Climate Station

Climate Change Models	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
	Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values [%]																
BCM2.0 (Run 1) - SR-B1	1.8	-6.6	-14.0	11.4	11.4	15.9	11.7	-1.4	46.4	33.2	3.5	-4.2	-2.8	7.7	9.5	32.3	10.5
CGCM3T47 (Mean) - SR-B1	18.2	14.0	20.4	14.5	16.0	13.7	11.4	16.1	3.1	11.9	9.9	21.1	17.9	16.7	13.5	8.2	13.5
CNRMCM3 (Run 1) - SR-A2	3.9	-10.6	5.1	17.9	-11.1	-4.4	-6.1	-11.3	4.4	11.2	7.7	-3.5	-3.5	-2.5	-6.9	7.1	-3.6
INMCM3.0 (Run 1) - SR-A2	1.4	33.4	-6.3	40.0	92.4	63.7	26.4	25.1	7.0	3.9	20.4	17.2	16.8	40.6	36.8	9.8	26.9
MIROC3.2 hires (Run 1) - SR-A1B	14.1	21.0	5.8	58.7	19.9	-6.6	-3.6	7.0	45.3	10.3	20.1	9.4	14.2	26.9	-1.1	24.3	14.8
Average	**7.9**	**10.2**	**2.2**	**28.5**	**25.7**	**16.5**	**8.0**	**7.1**	**21.2**	**14.1**	**12.3**	**8.0**	**8.5**	**17.9**	**10.4**	**16.3**	**12.4**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values [°C]																
BCM2.0 (Run 1) - SR-B1	1.89	0.21	1.24	0.73	0.53	0.38	0.67	0.63	0.79	0.43	2.85	0.96	1.02	0.83	0.56	1.36	0.94
CGCM3T47 (Mean) - SR-B1	4.64	4.31	2.48	1.34	1.11	1.12	1.91	1.51	2.21	1.70	2.28	3.60	4.18	1.64	1.52	2.07	2.35
CNRMCM3 (Run 1) - SR-A2	3.99	1.55	1.16	0.80	2.47	2.81	2.98	2.80	1.71	1.74	2.08	4.95	3.50	1.48	2.86	1.84	2.42
INMCM3.0 (Run 1) - SR-A2	3.66	3.02	2.84	2.68	1.93	1.80	1.84	1.89	2.75	3.15	2.82	2.06	2.92	2.48	1.84	2.90	2.54
MIROC3.2 hires (Run 1) - SR-A1B	4.82	6.56	5.99	5.38	4.48	3.81	3.50	3.24	3.71	3.28	4.28	6.89	6.09	5.29	3.52	3.75	4.66
Average	**3.80**	**3.13**	**2.74**	**2.19**	**2.10**	**1.98**	**2.18**	**2.01**	**2.23**	**2.06**	**2.86**	**3.69**	**3.54**	**2.34**	**2.06**	**2.38**	**2.58**

Figure E-1 Climate Change Forecasts at Jasper Climate Station for 2041-2070 Based on 1961-1990 Base – Annual Average

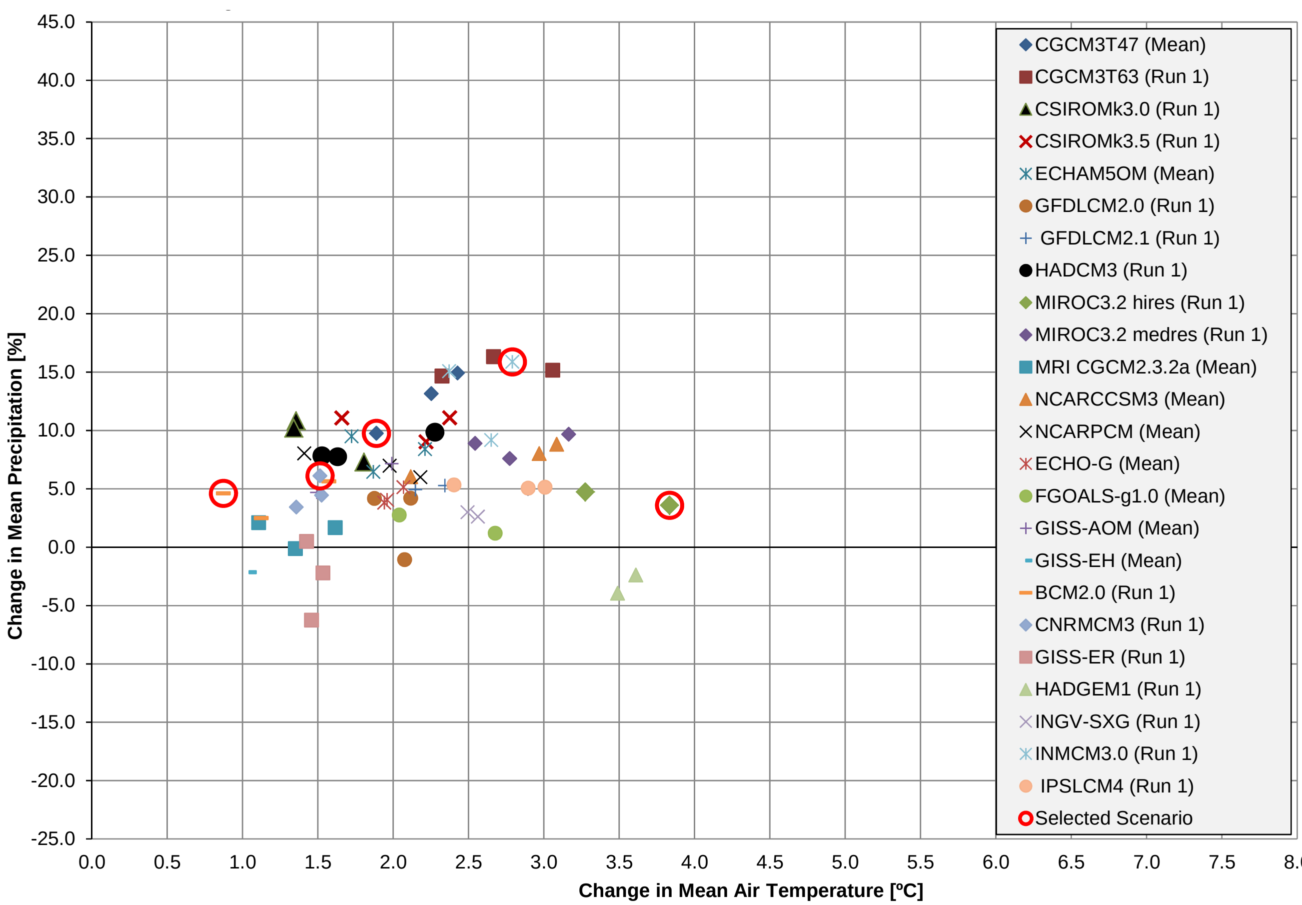

Figure E-2 Climate Change Forecasts at Jasper Climate Station for 2041-2070 Based on 1961-1990 Base – Spring Season Average (March to May)

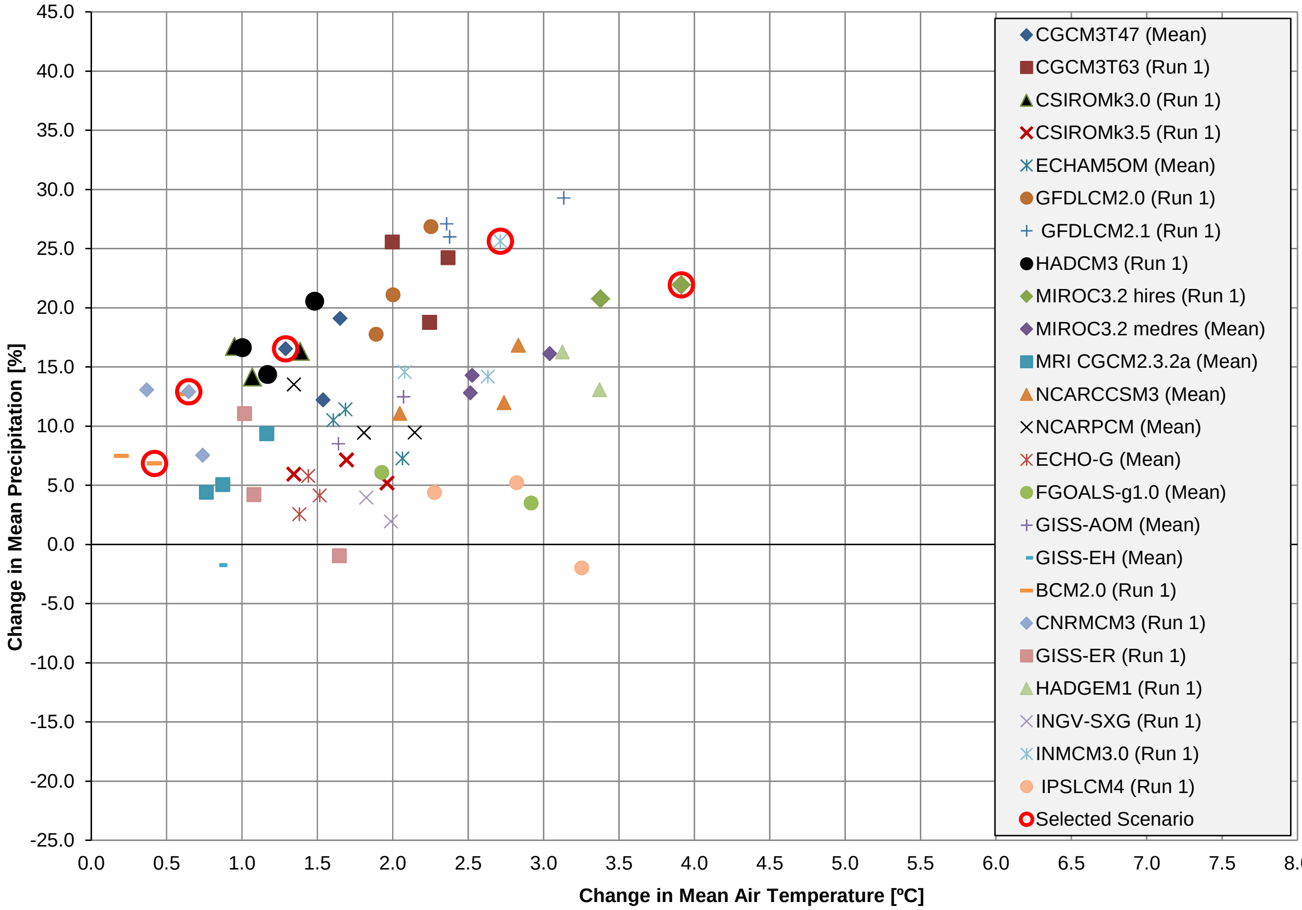

Figure E-3 Climate Change Forecasts at Jasper Climate Station for 2041-2070 Based on 1961-1990 Base – Summer Season Average (June to August)

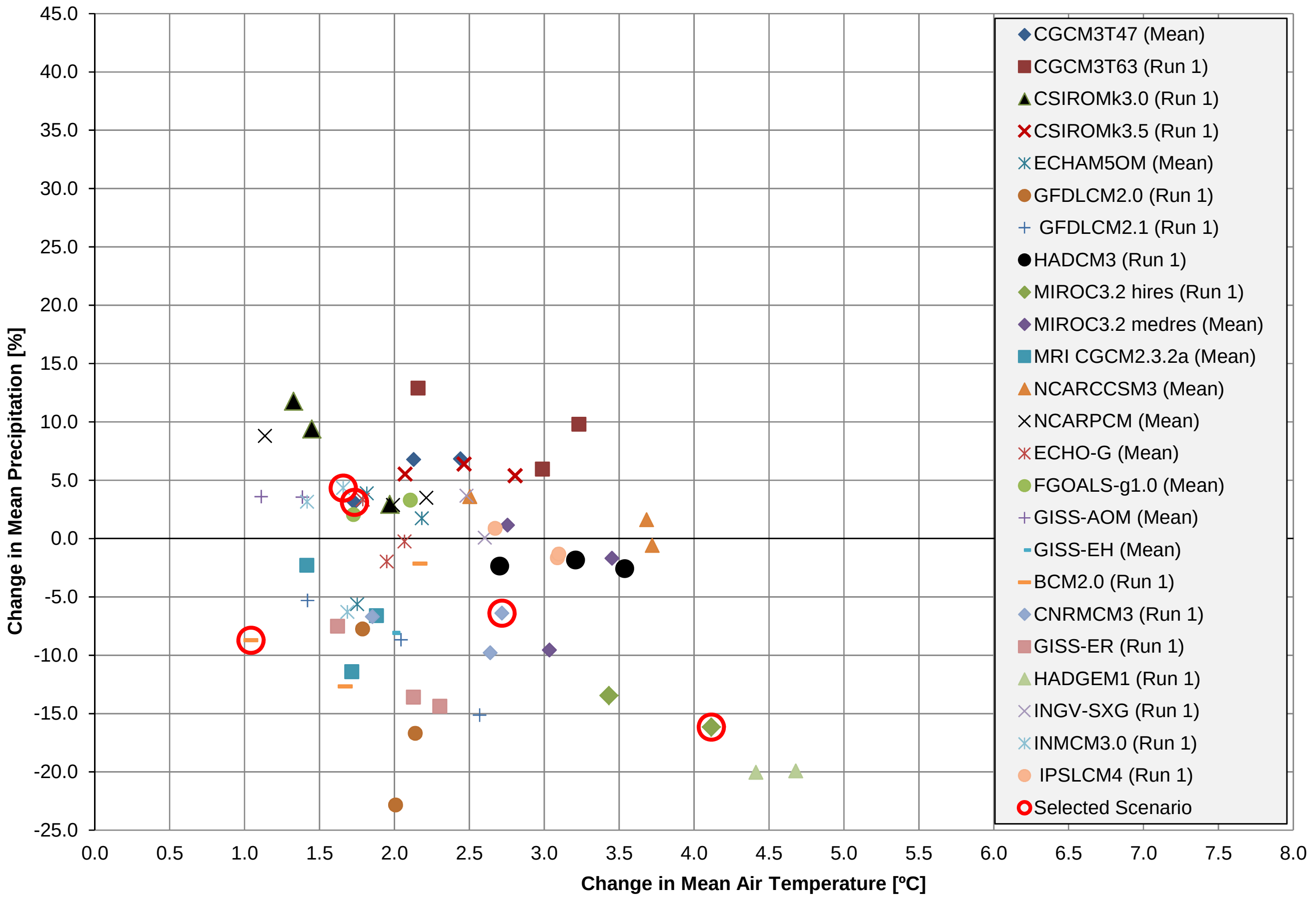

Figure E-4 Climate Change Forecasts at Jasper Climate Station for 2041-2070 Based on 1961-1990 Base – Autumn Season Average (September to November)

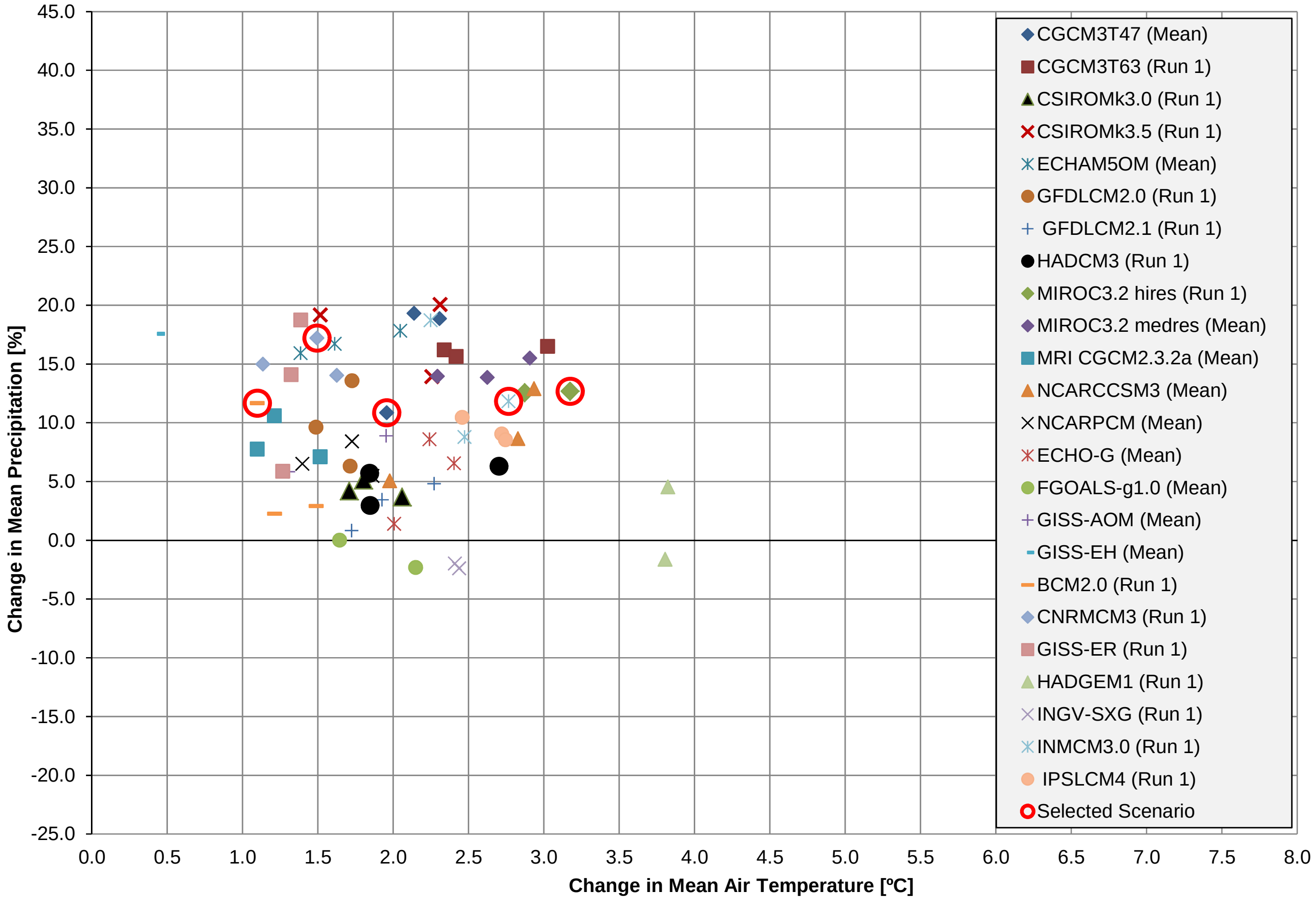

Figure E-5 Climate Change Forecasts at Jasper Climate Station for 2041-2070 Based on 1961-1990 Base – Winter Season Average (December to February)

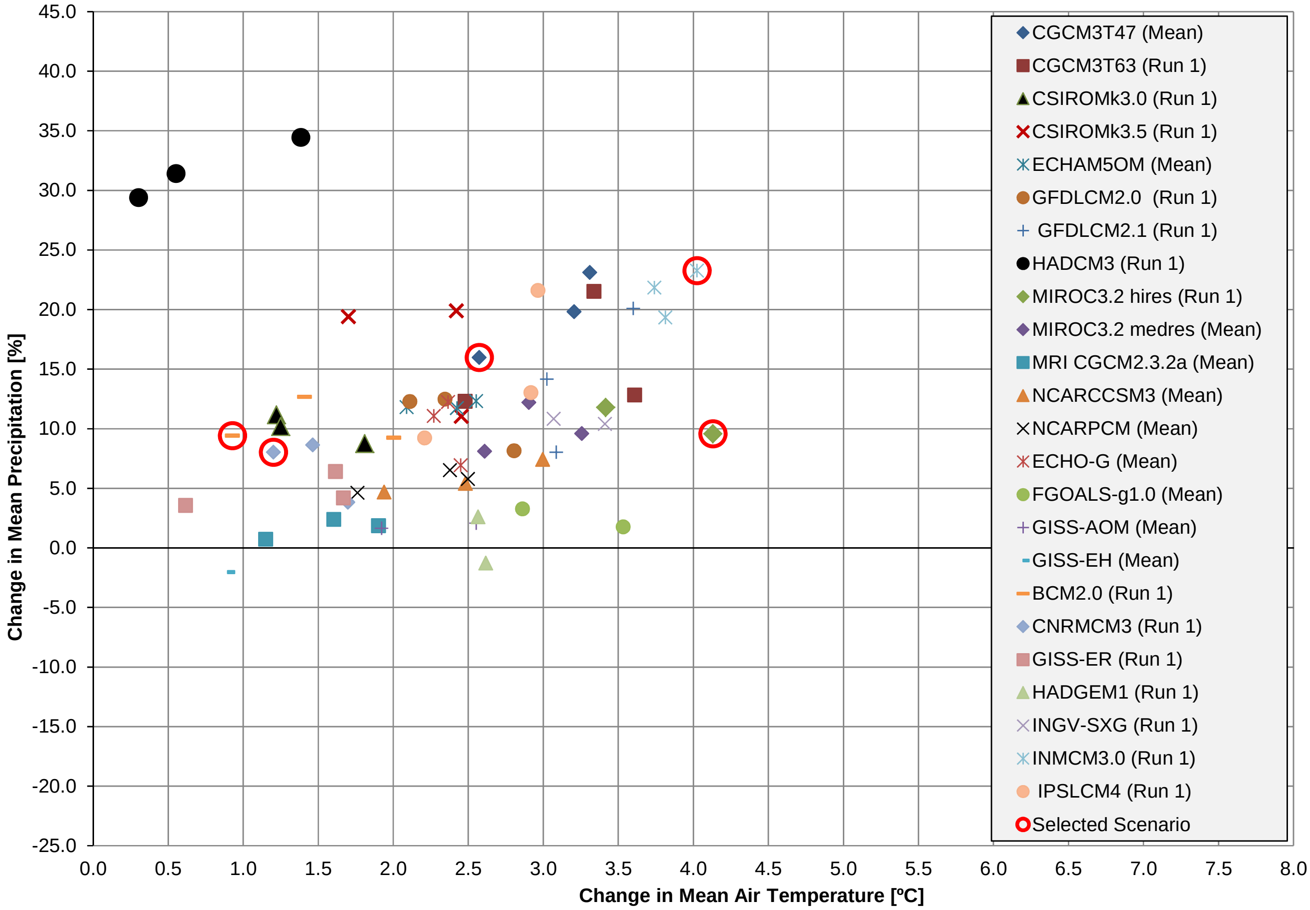

Figure E-6 Climate Change Forecasts at Edson Climate Station for 2041-2070 Based on 1961-1990 Base – Annual Average

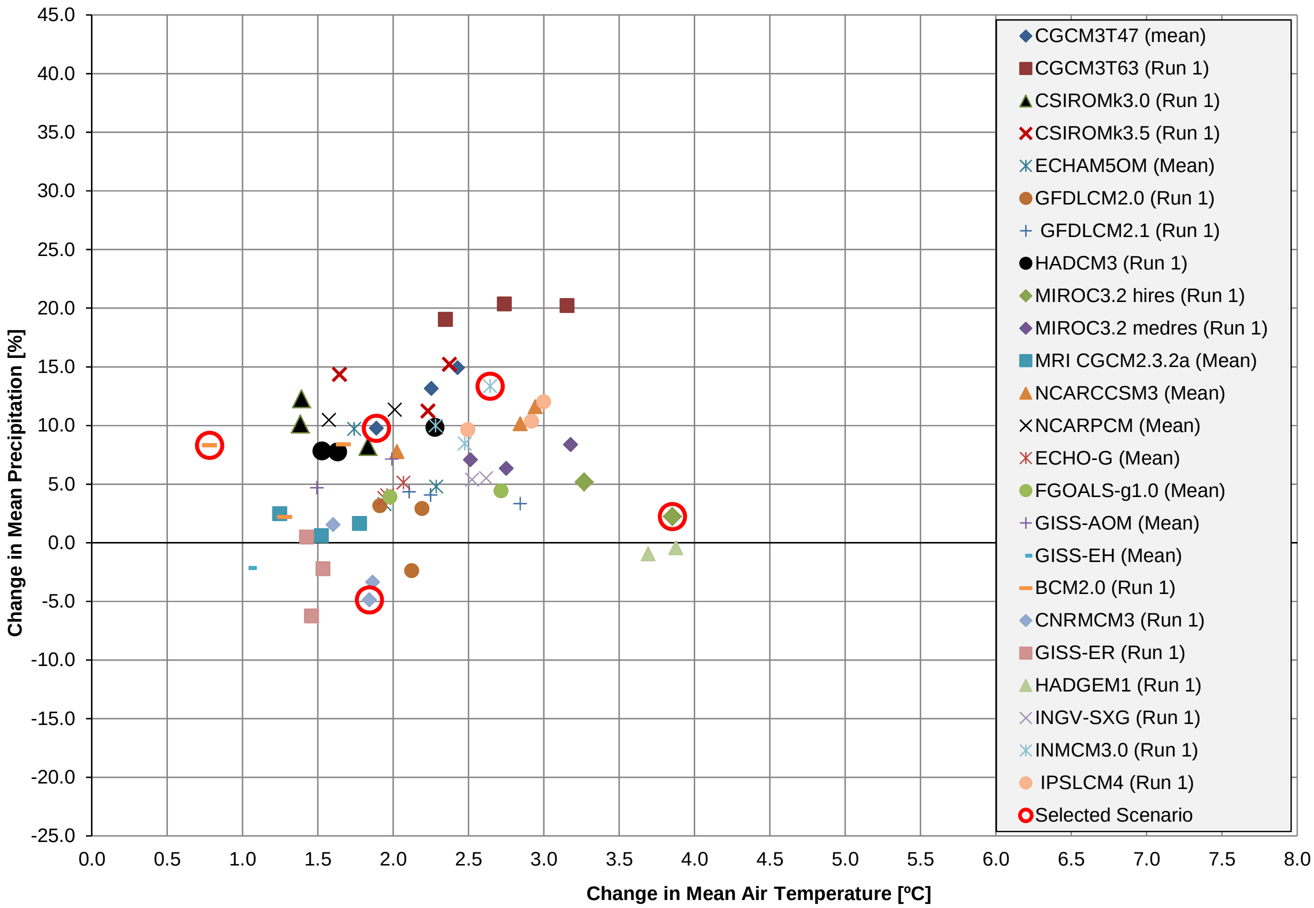

Figure E-7 Climate Change Forecasts at Edson Climate Station for 2041-2070 Based on 1961-1990 Base – Spring Season Average (March to May)

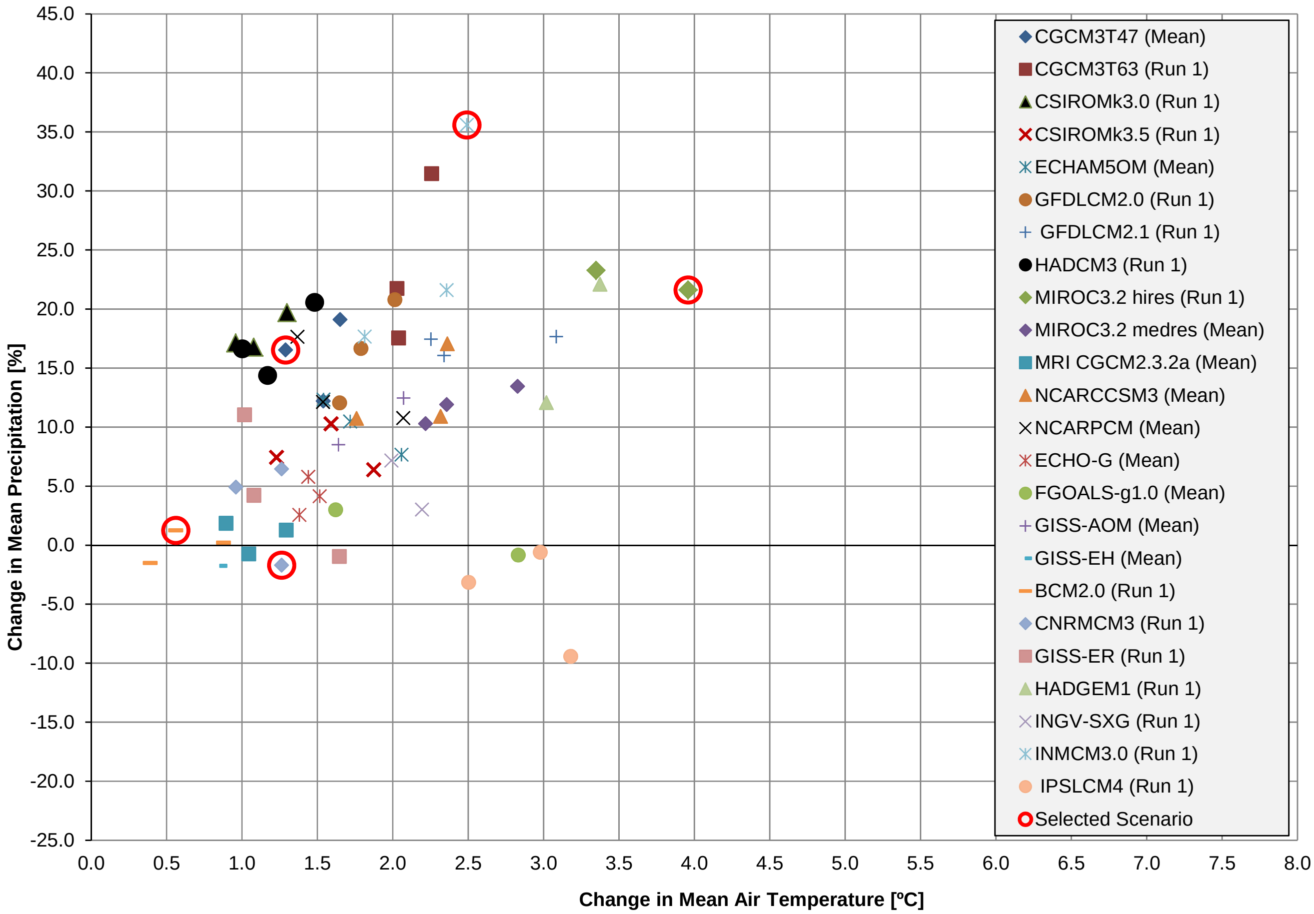

Figure E-8 Climate Change Forecasts at Edson Climate Station for 2041-2070 Based on 1961-1990 Base – Summer Season Average (June to August)

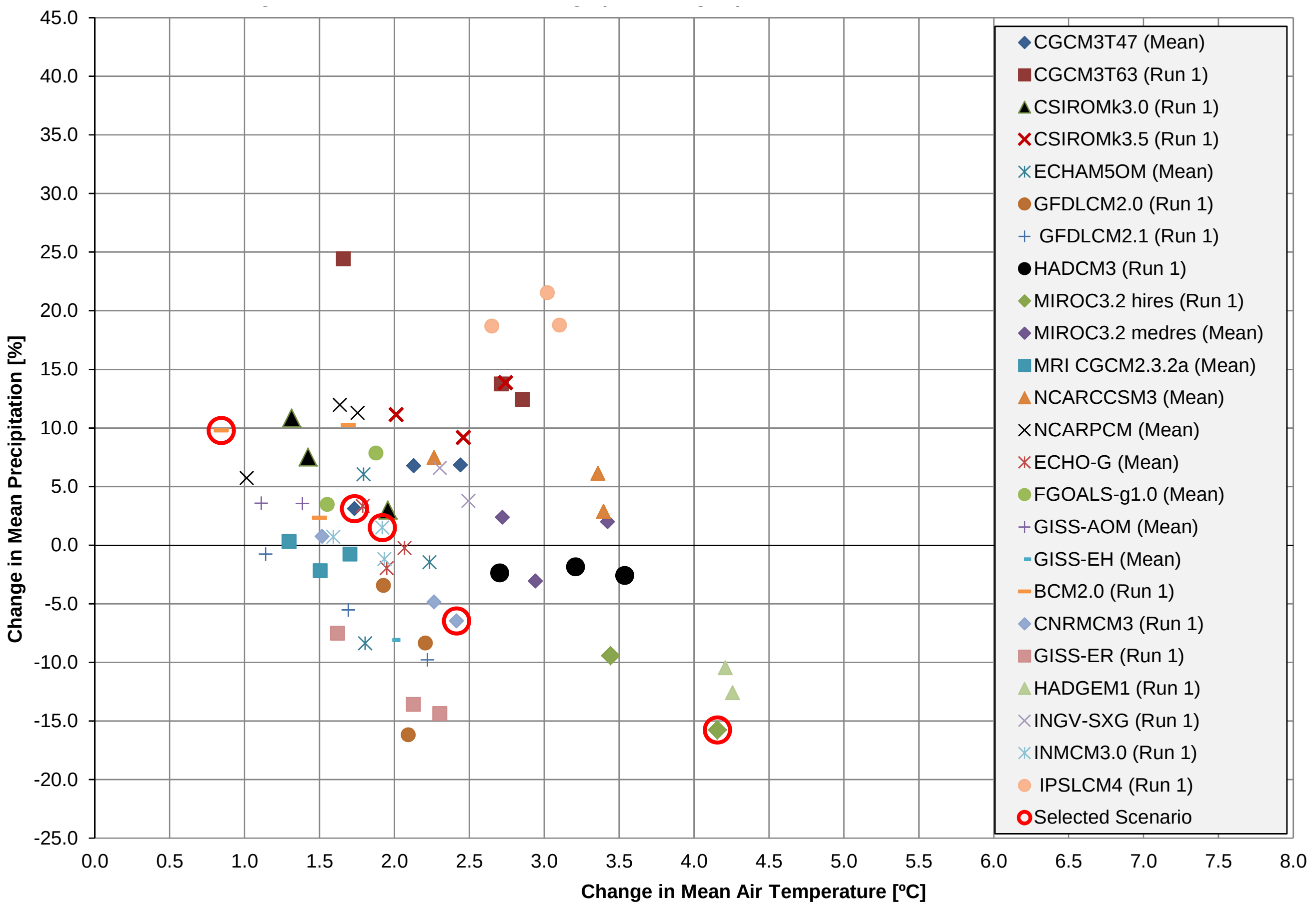

Figure E-9 Climate Change Forecasts at Edson Climate Station for 2041-2070 Based on 1961-1990 Base – Autumn Season Average (September to November)

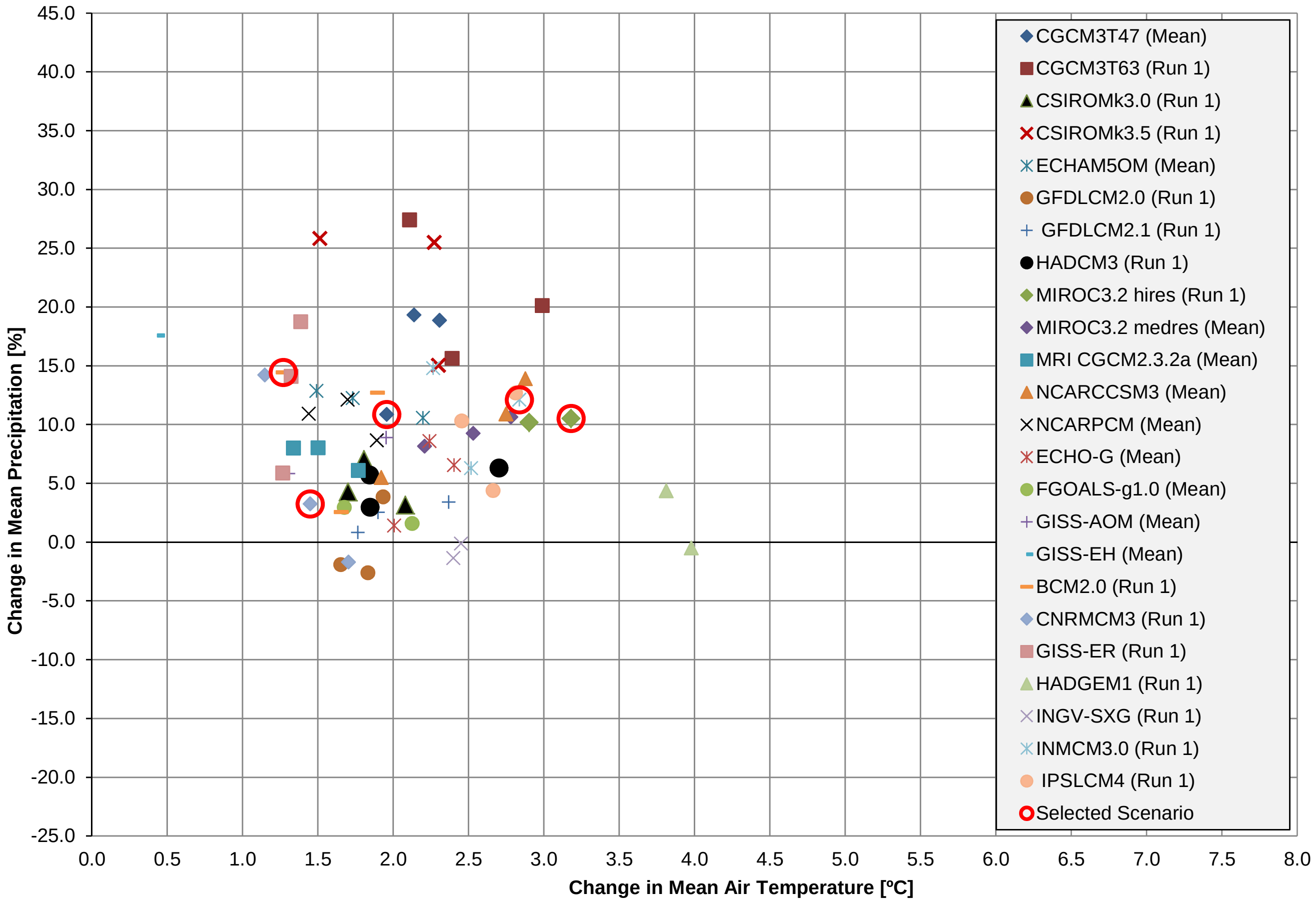

Figure E-10 Climate Change Forecasts at Edson Climate Station for 2041-2070 Based on 1961-1990 Base – Winter Season Average (December to February)

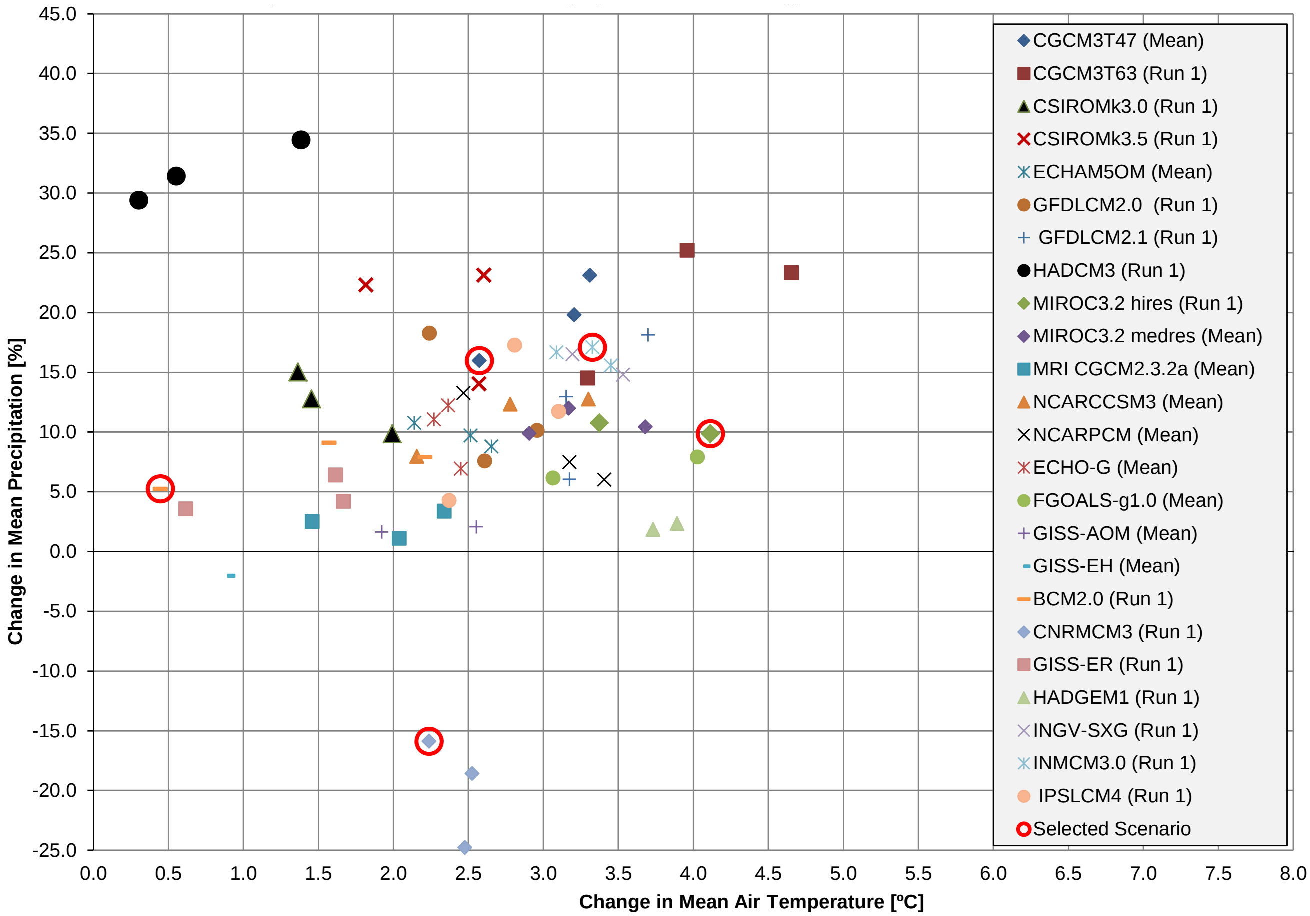

Figure E-11 Climate Change Forecasts at Campsie Climate Station for 2041-2070 Based on 1961-1990 Base – Annual Average

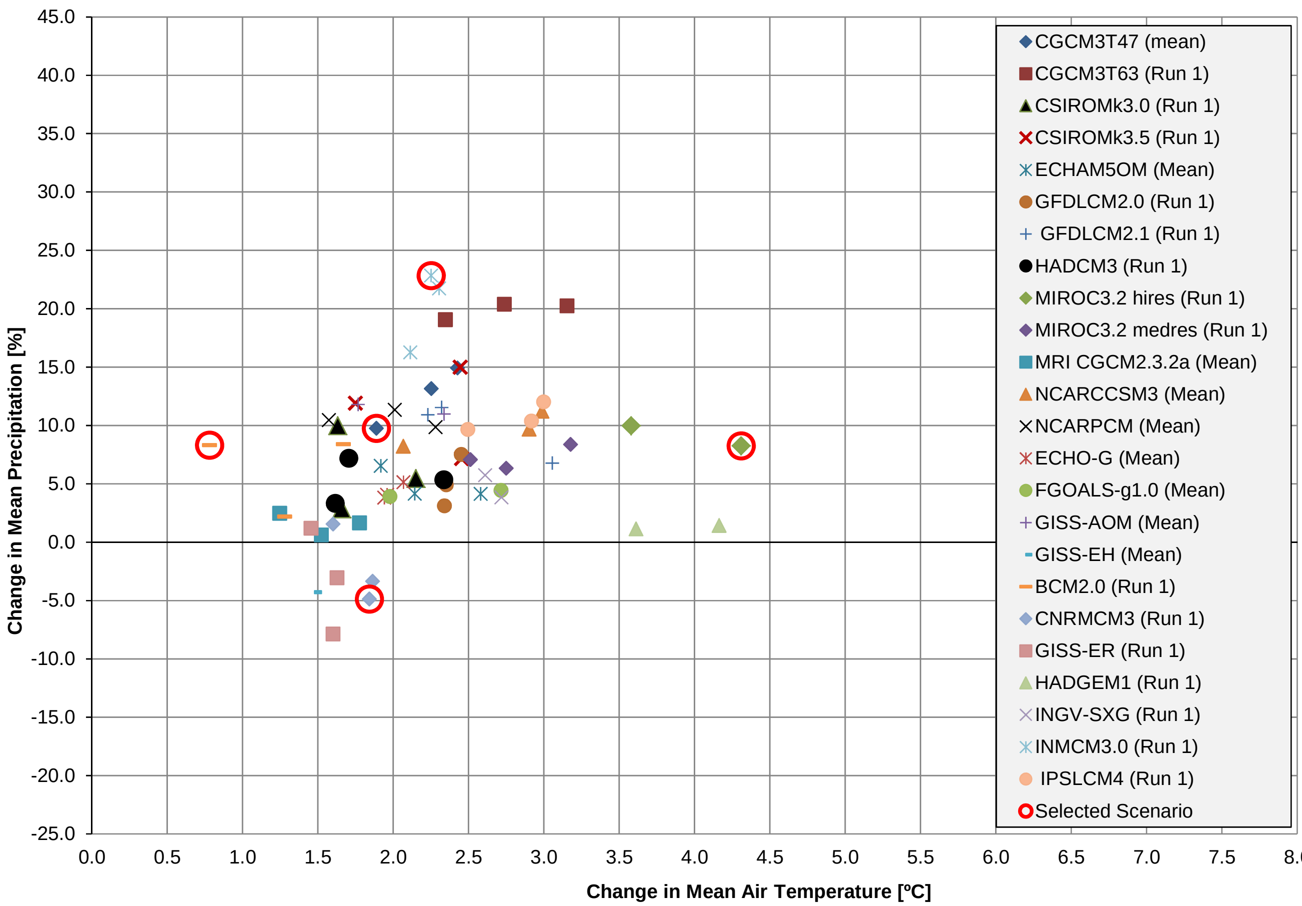

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Figure E-12 Climate Change Forecasts at Campsie Climate Station for 2041-2070 Based on 1961-1990 Base – Spring Season Average (March to May)

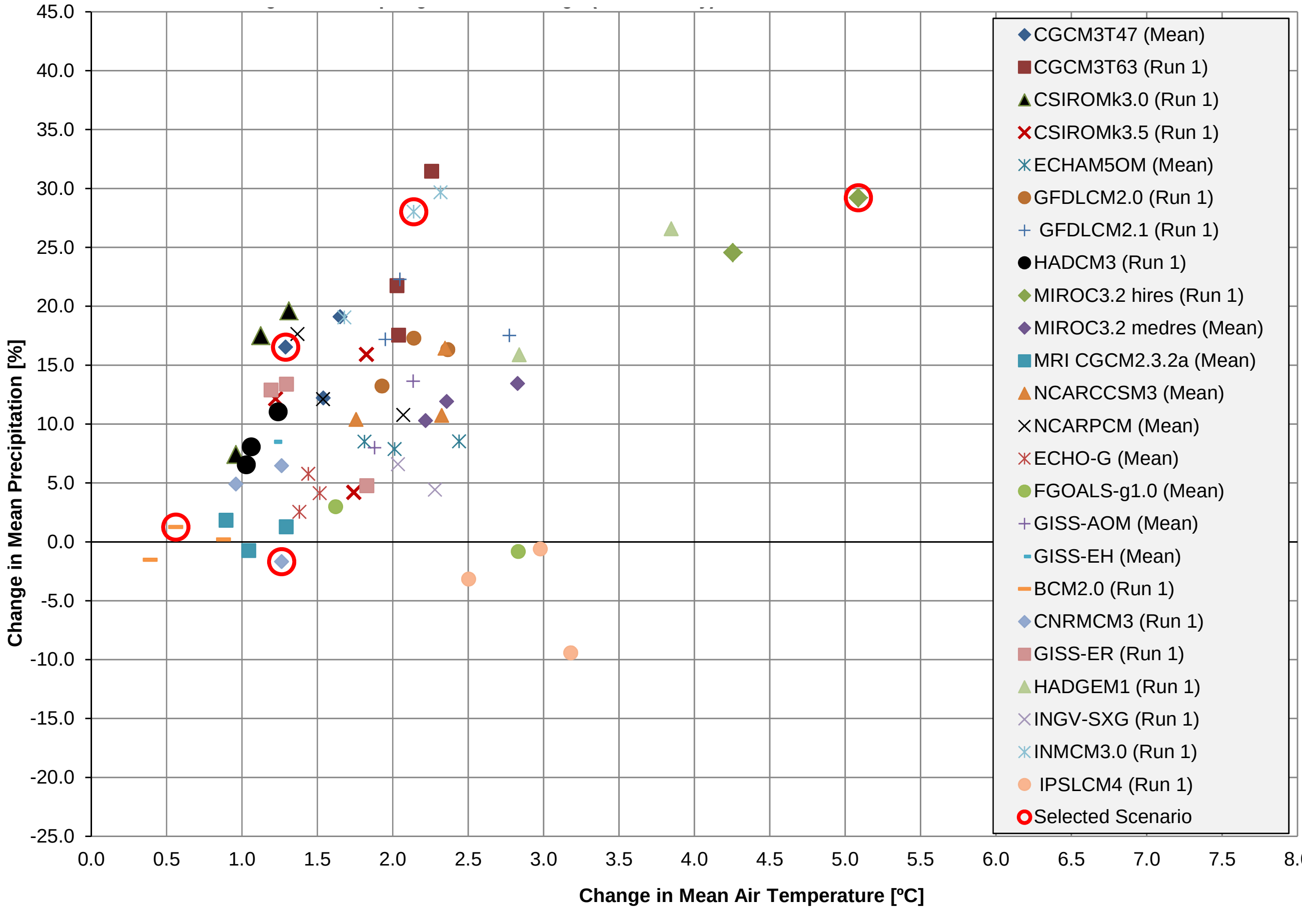


Figure E-13 Climate Change Forecasts at Campsie Climate Station for 2041-2070 Based on 1961-1990 Base – Summer Season Average (June to August)

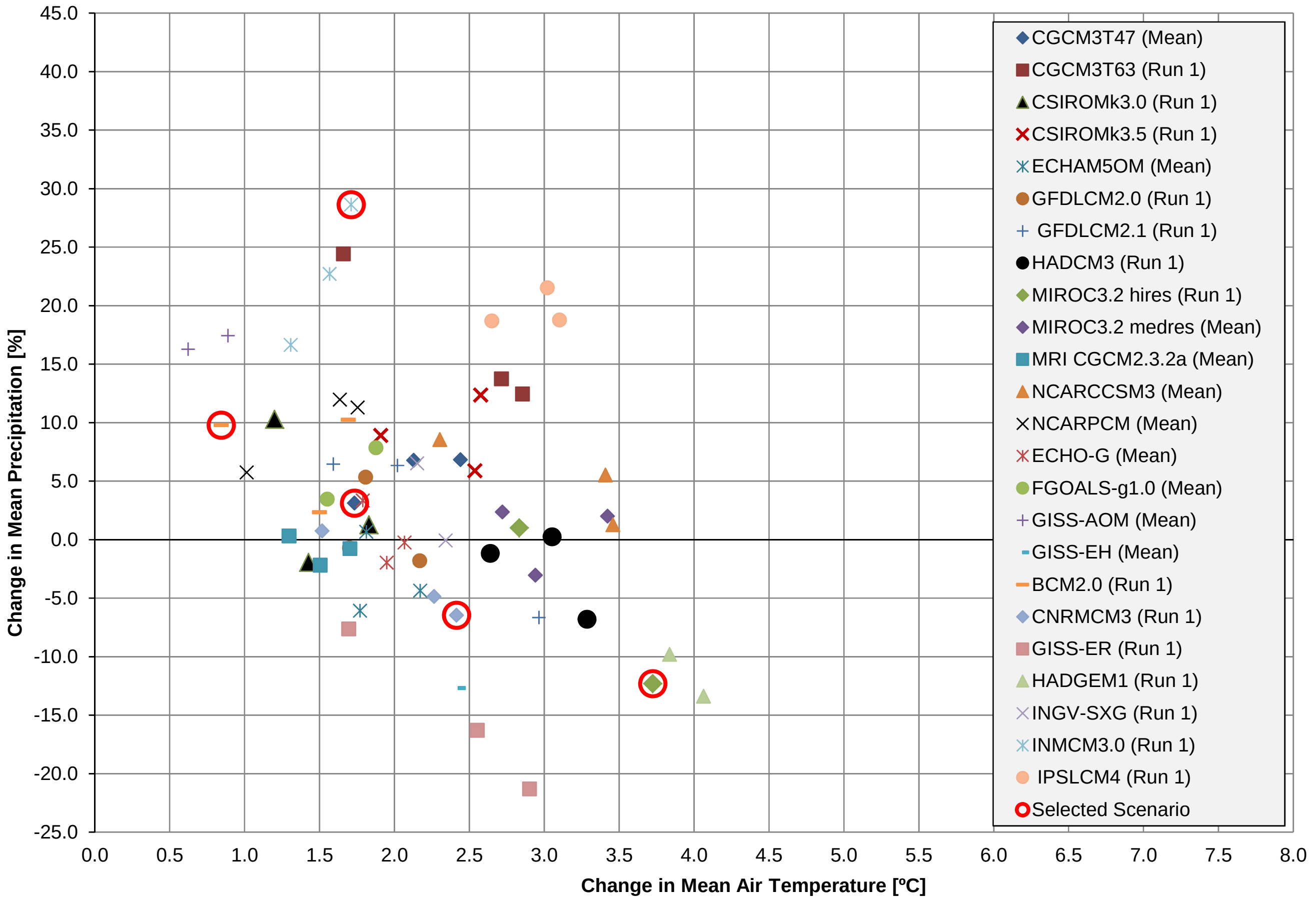


Figure E-14 Climate Change Forecasts at Campsie Climate Station for 2041-2070 Based on 1961-1990 Base – Autumn Season Average (September to November)

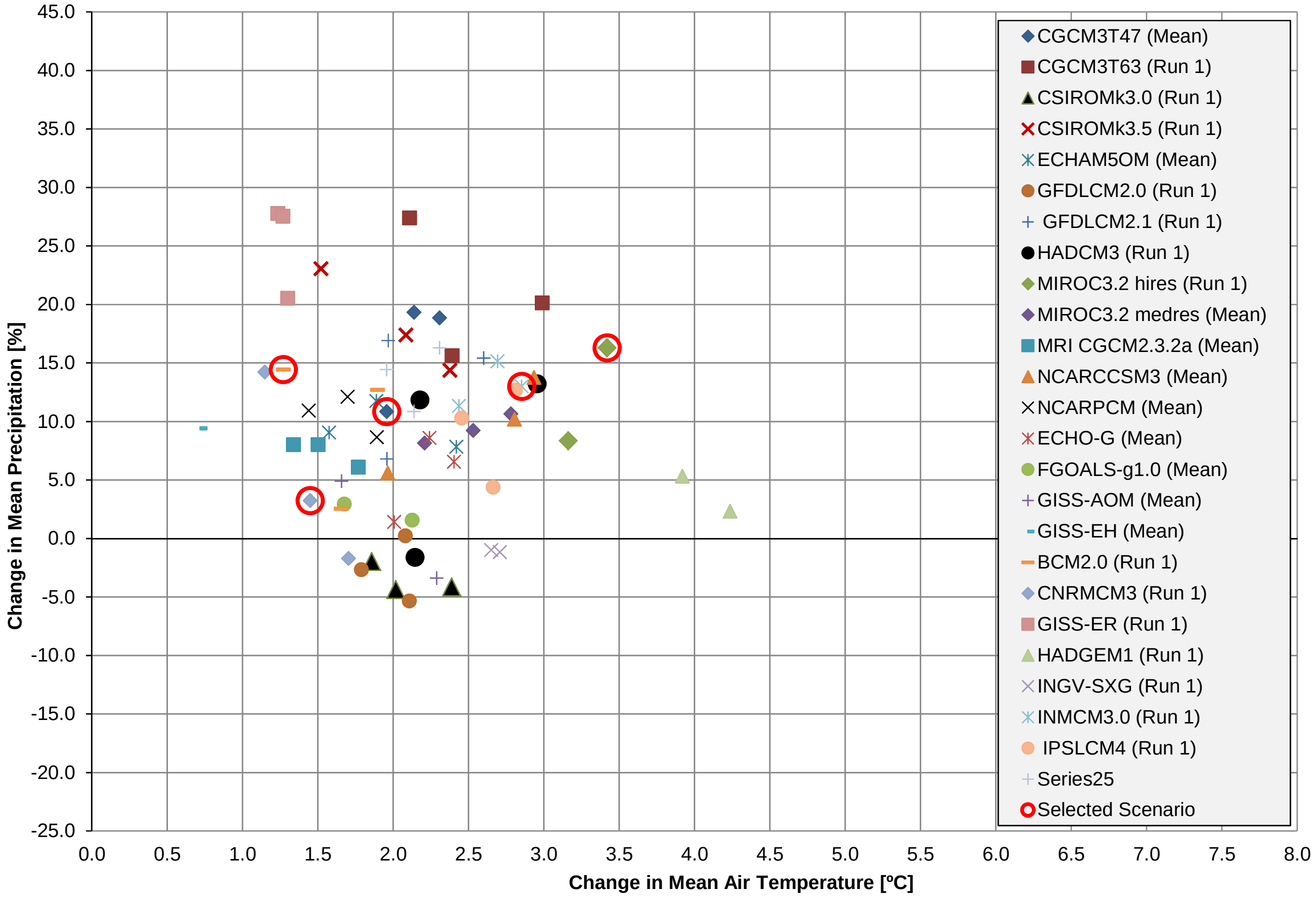


Figure E-15 Climate Change Forecasts at Campsie Climate Station for 2041-2070 Based on 1961-1990 Base – Winter Season Average (December to February)

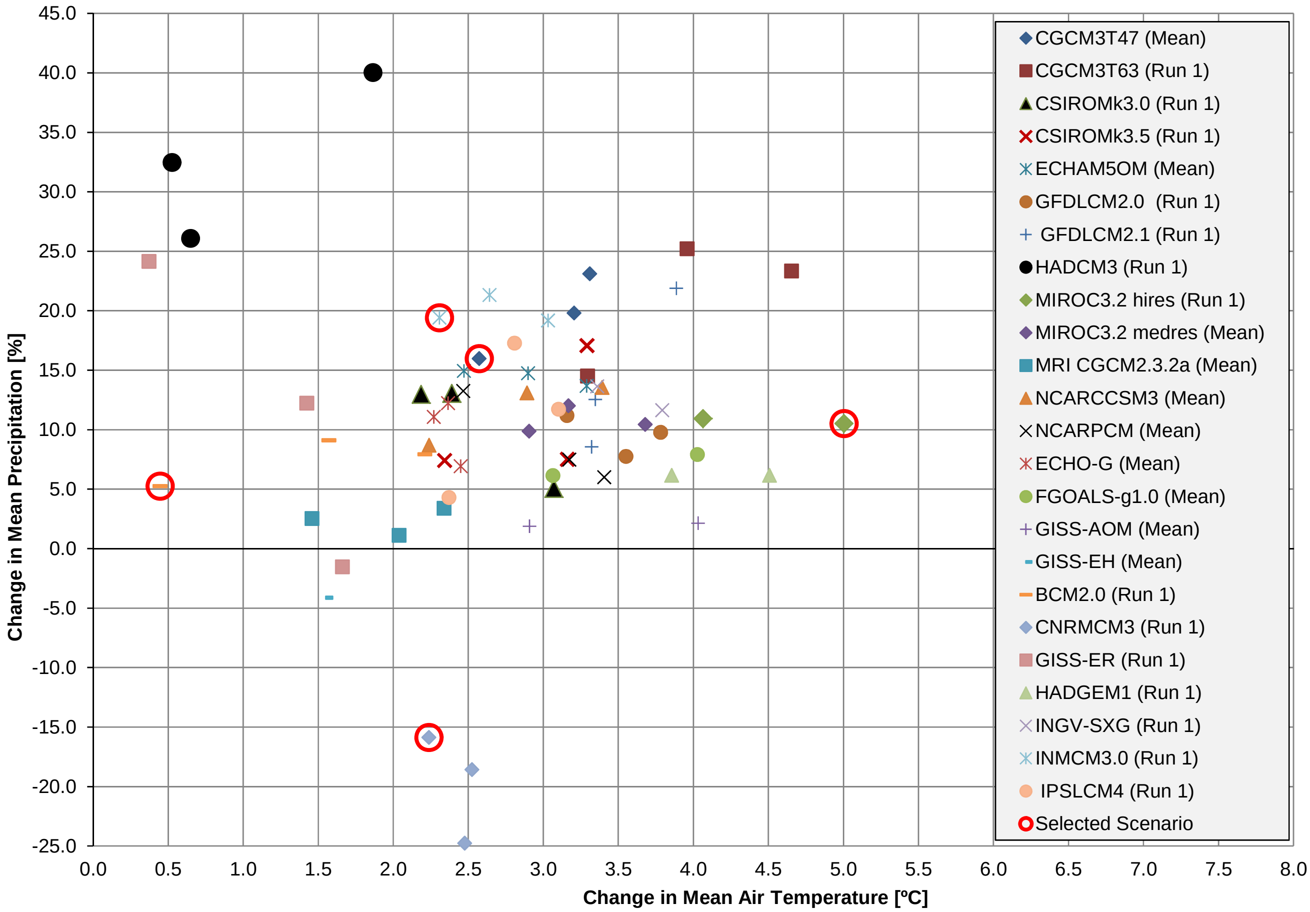


Figure E-16 Climate Change Forecasts at Slave Lake Climate Station for 2041-2070 Based on 1961-1990 Base – Annual Average

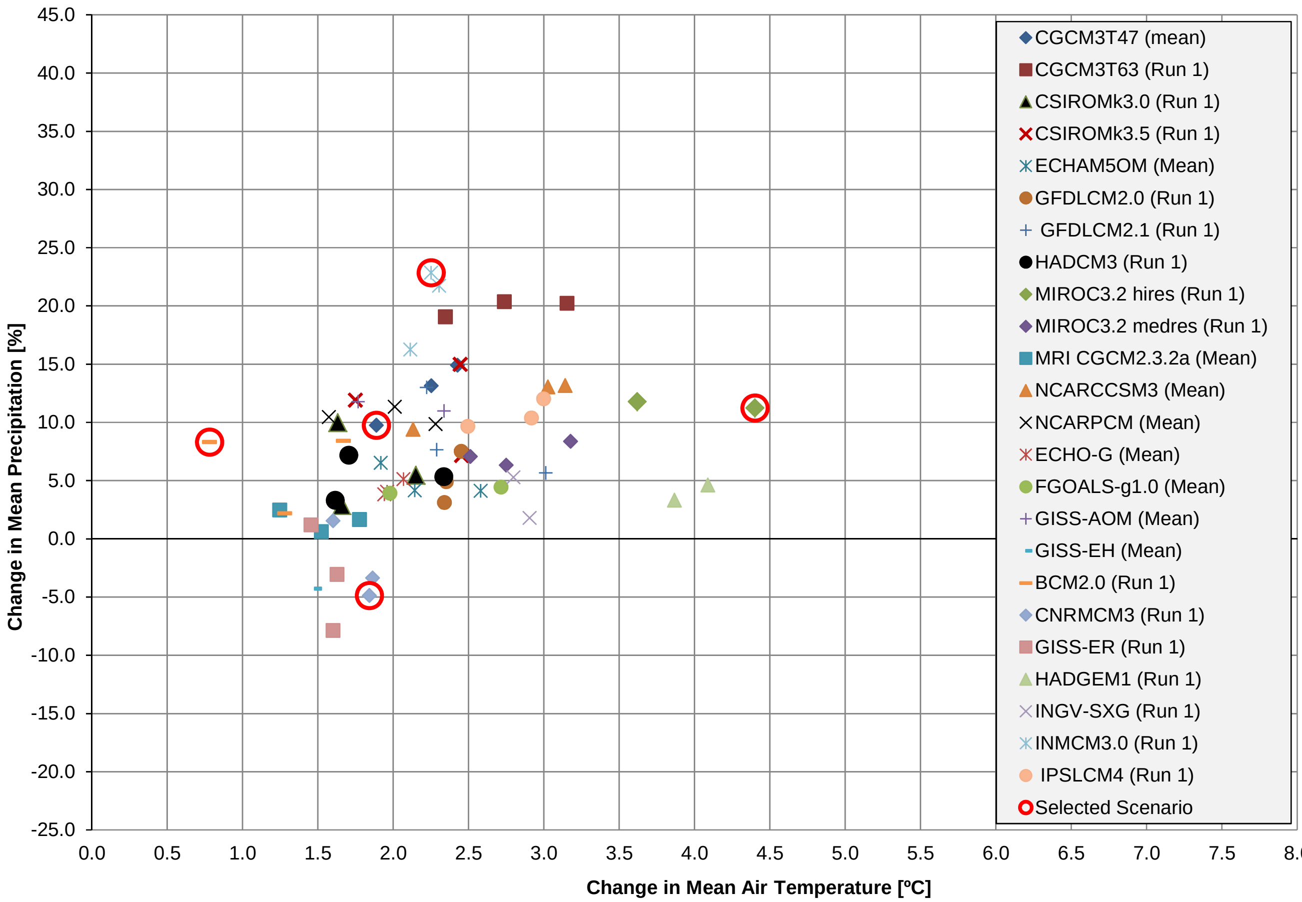


Figure E-17 Climate Change Forecasts at Slave Lake Climate Station for 2041-2070 Based on 1961-1990 Base – Spring Season Average (March to May)

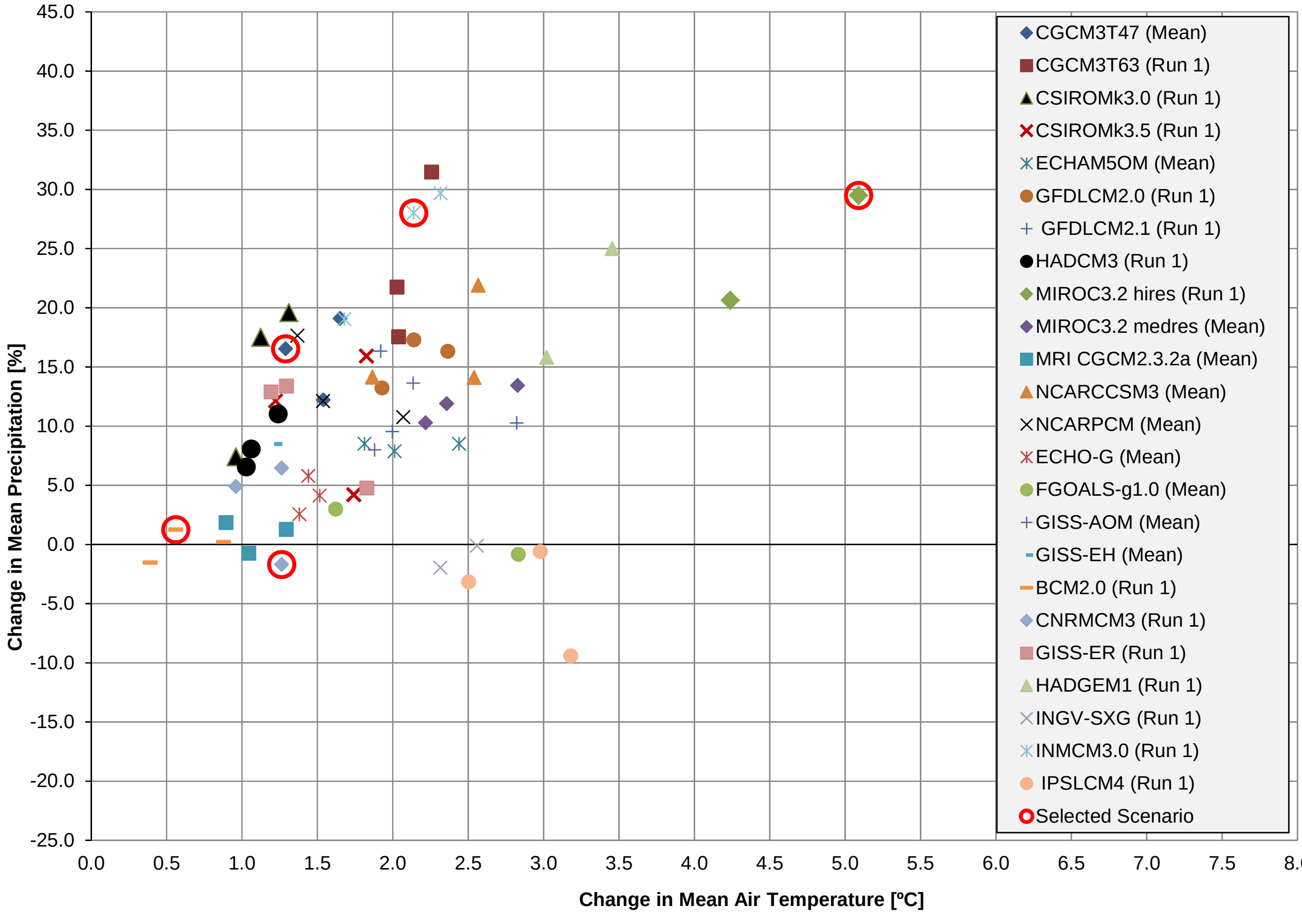


Figure E-18 Climate Change Forecasts at Slave Lake Climate Station for 2041-2070 Based on 1961-1990 Base – Summer Season Average (June to August)

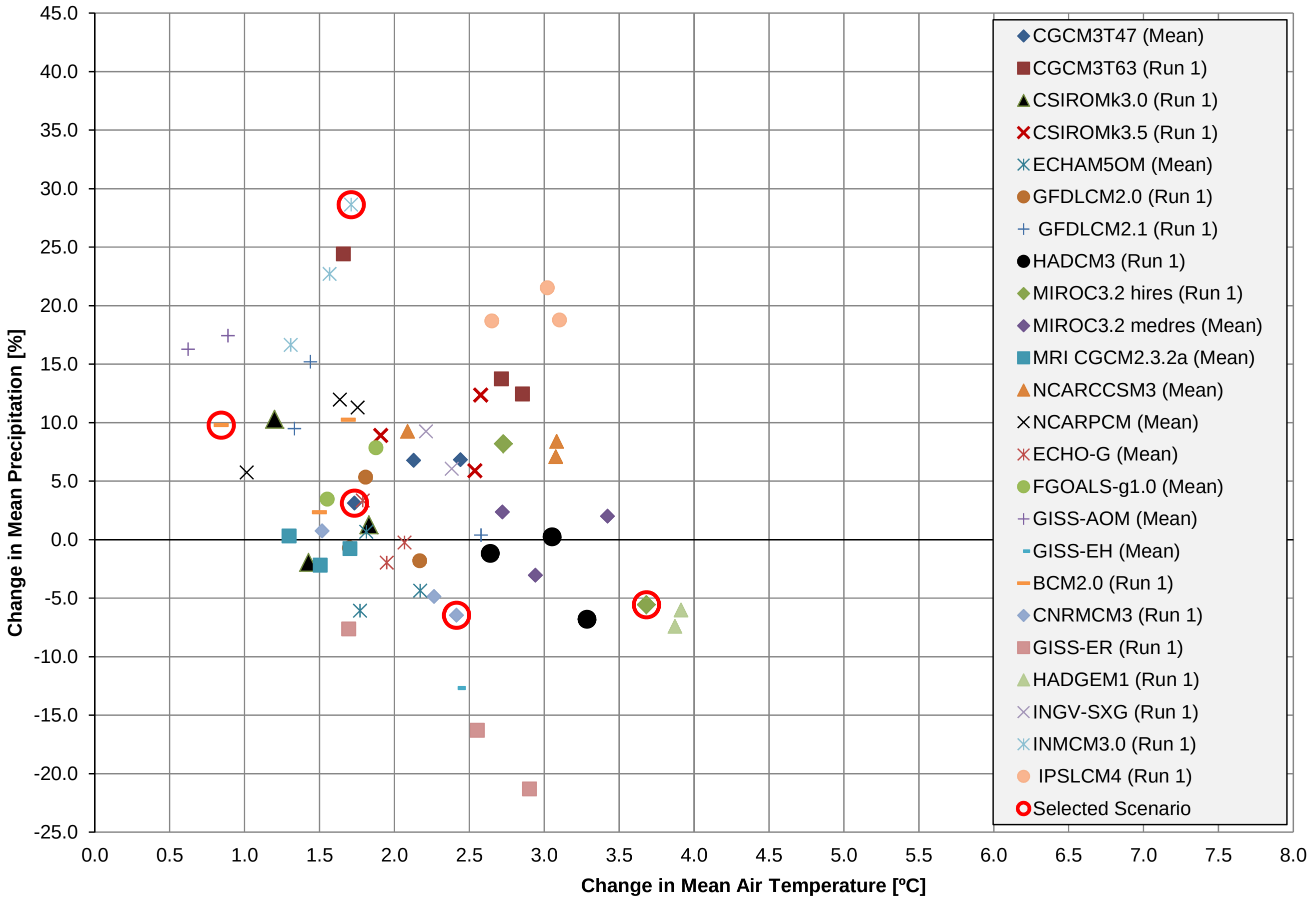


Figure E-19 Climate Change Forecasts at Slave Lake Climate Station for 2041-2070 Based on 1961-1990 Base – Autumn Season Average (September to November)

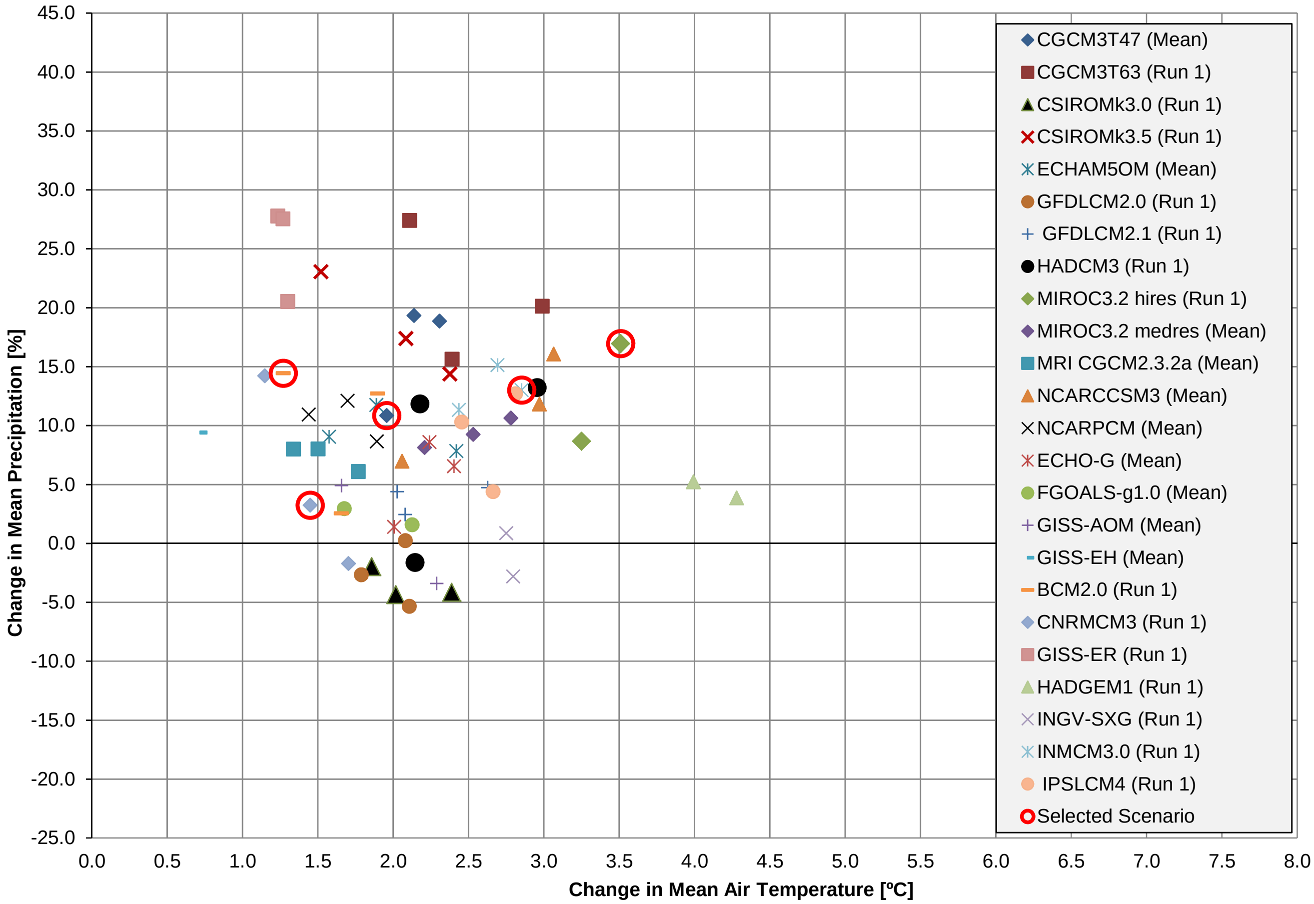


Figure E-20 Climate Change Forecasts at Slave Lake Climate Station for 2041-2070 Based on 1961-1990 Base – Winter Season Average (December to February)

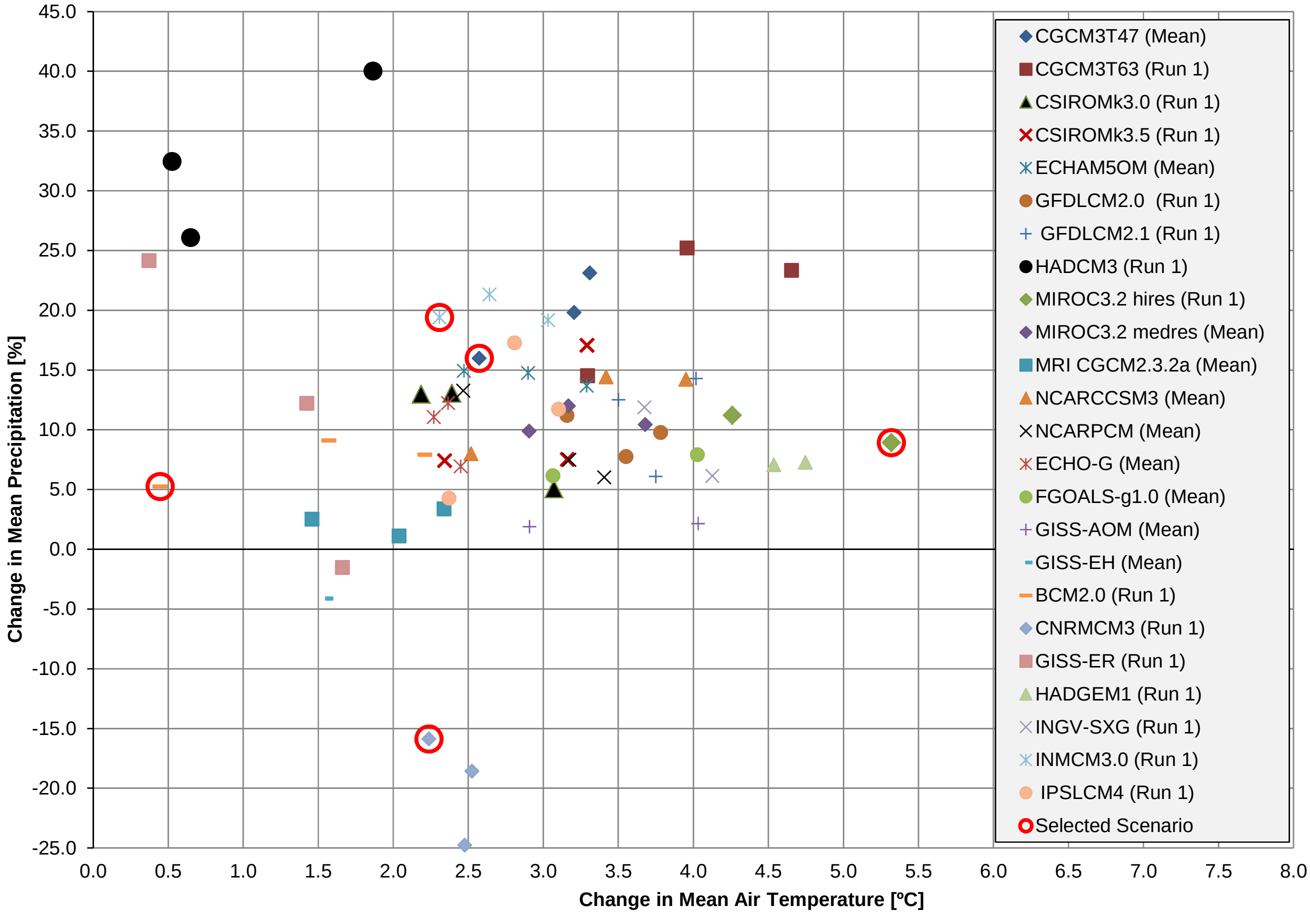


Figure E-21 Climate Change Forecasts at Lac La Biche Climate Station for 2041-2070 Based on 1961-1990 Base – Annual Average

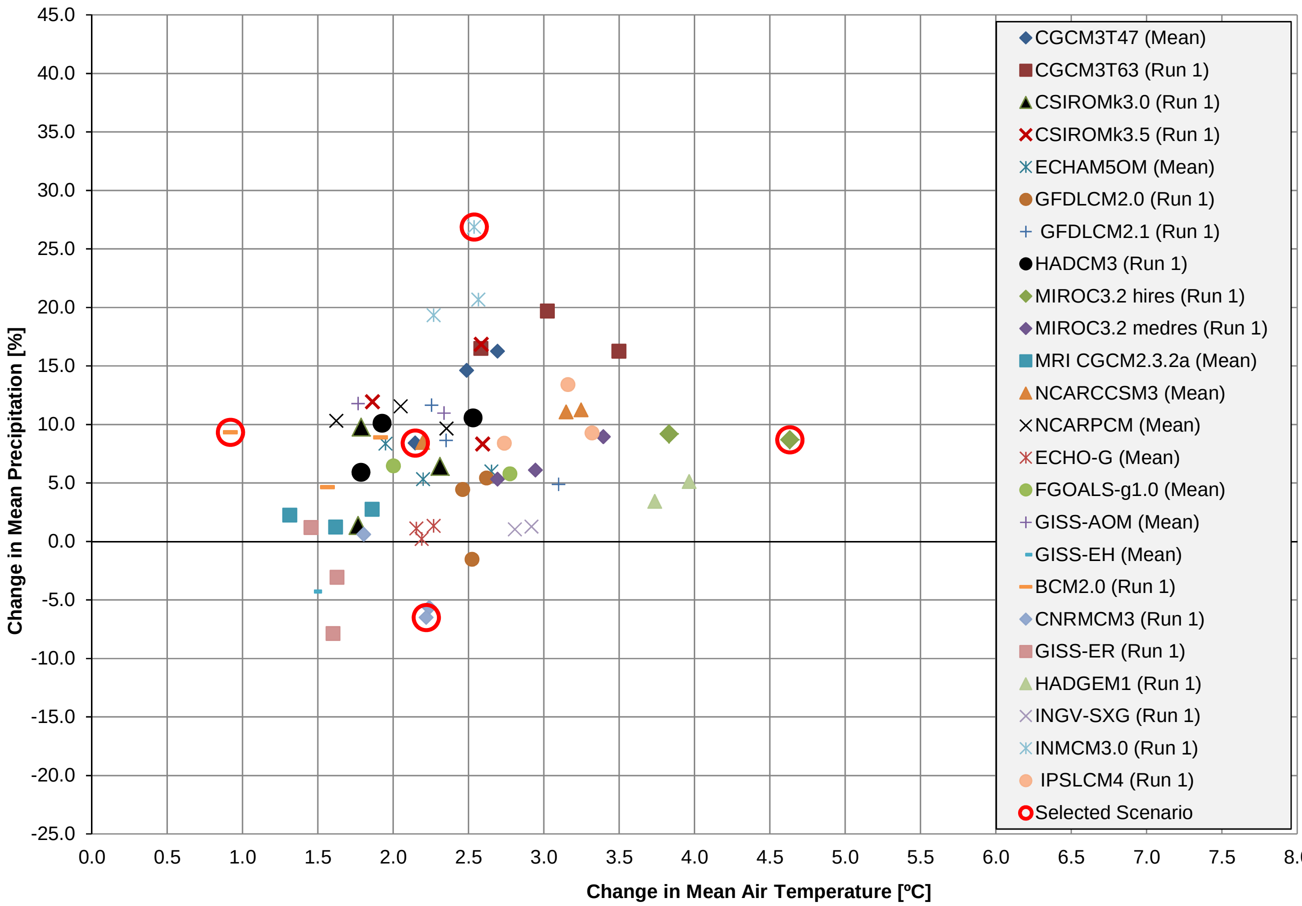


Figure E-22 Climate Change Forecasts at Lac La Biche Climate Station for 2041-2070 Based on 1961-1990 Base – Spring Season Average (March to May)

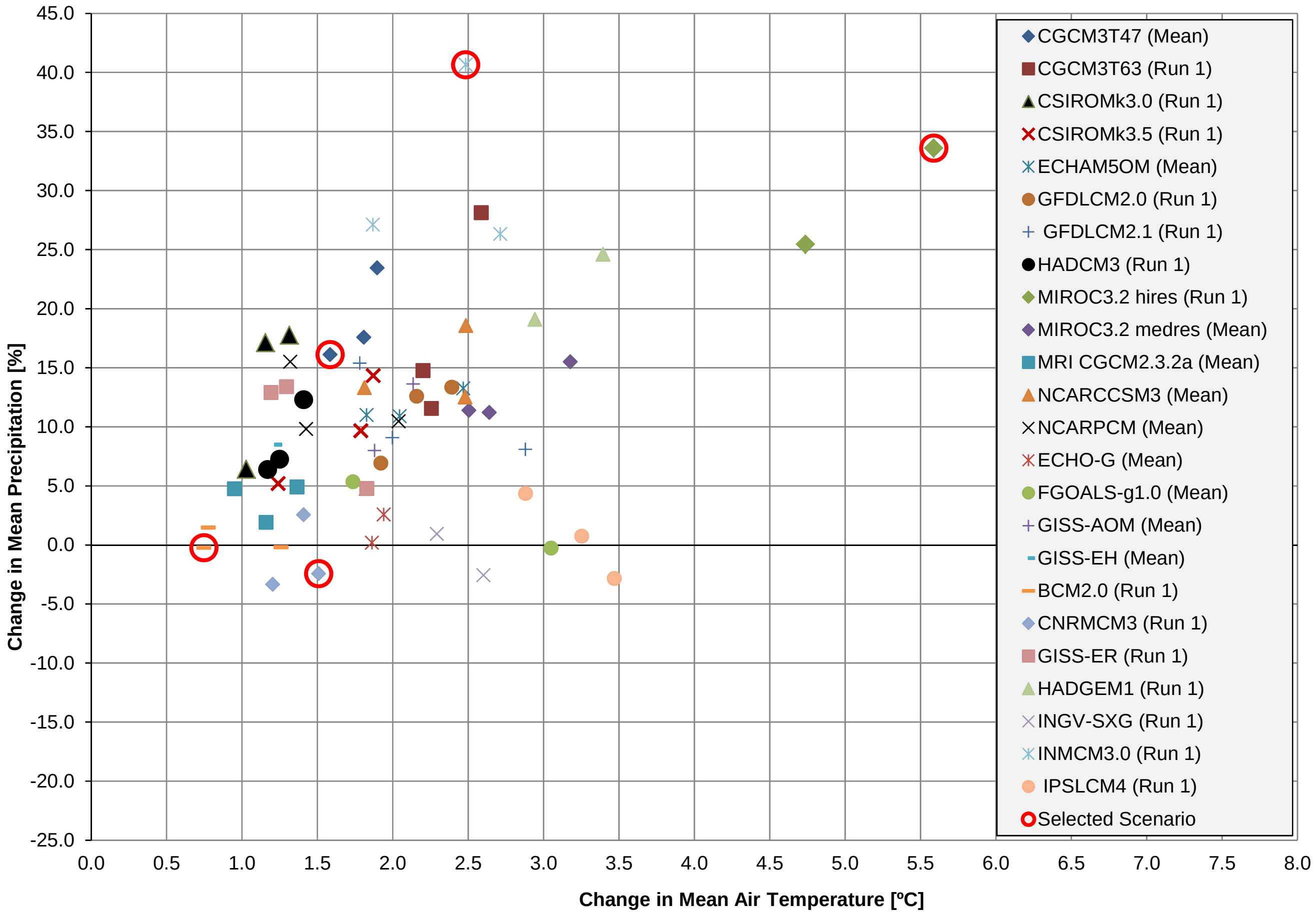


Figure E-23 Climate Change Forecasts at Lac La Biche Climate Station for 2041-2070 Based on 1961-1990 Base – Summer Season Average (June to August)

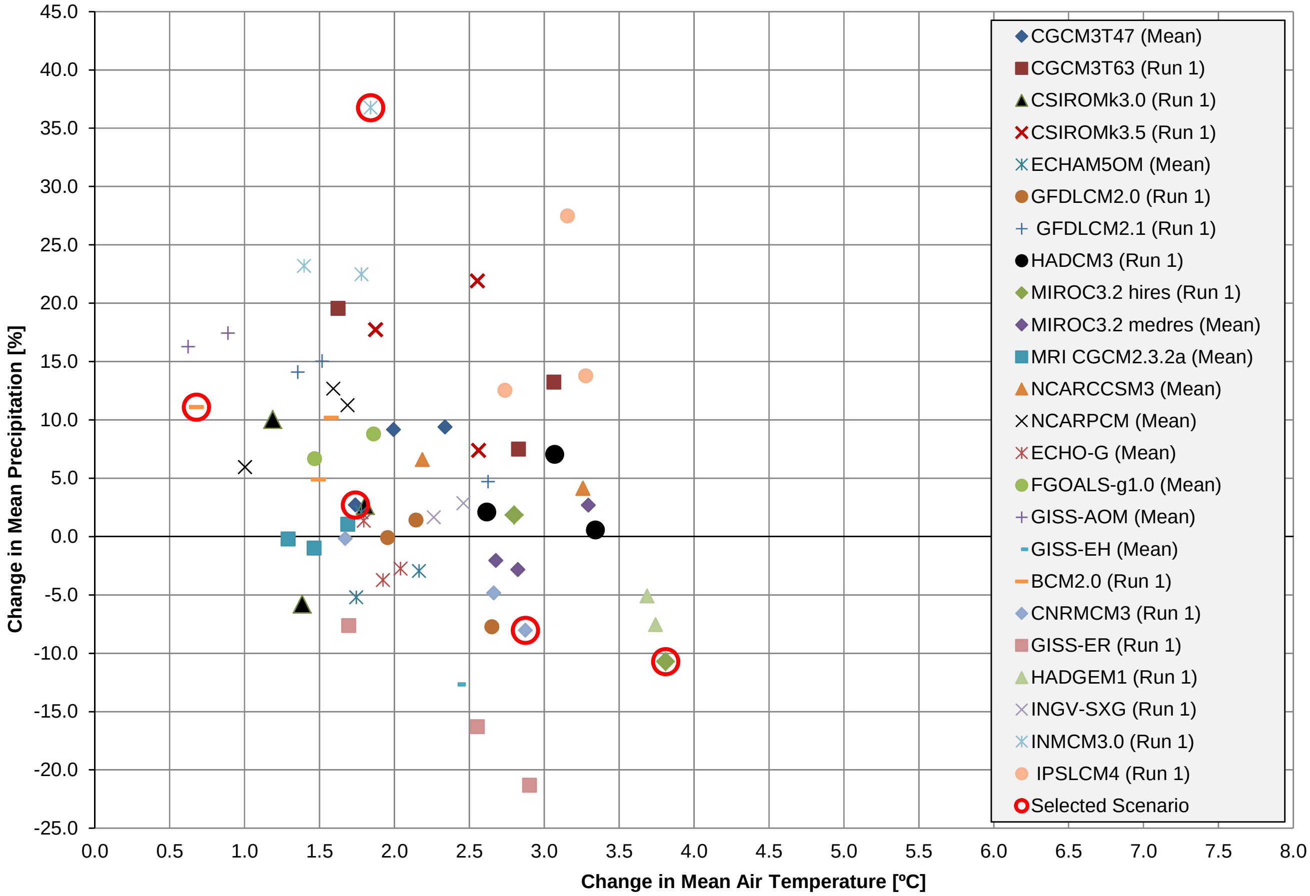


Figure E-24 Climate Change Forecasts at Lac La Biche Climate Station for 2041-2070 Based on 1961-1990 Base – Autumn Season Average (September to November)

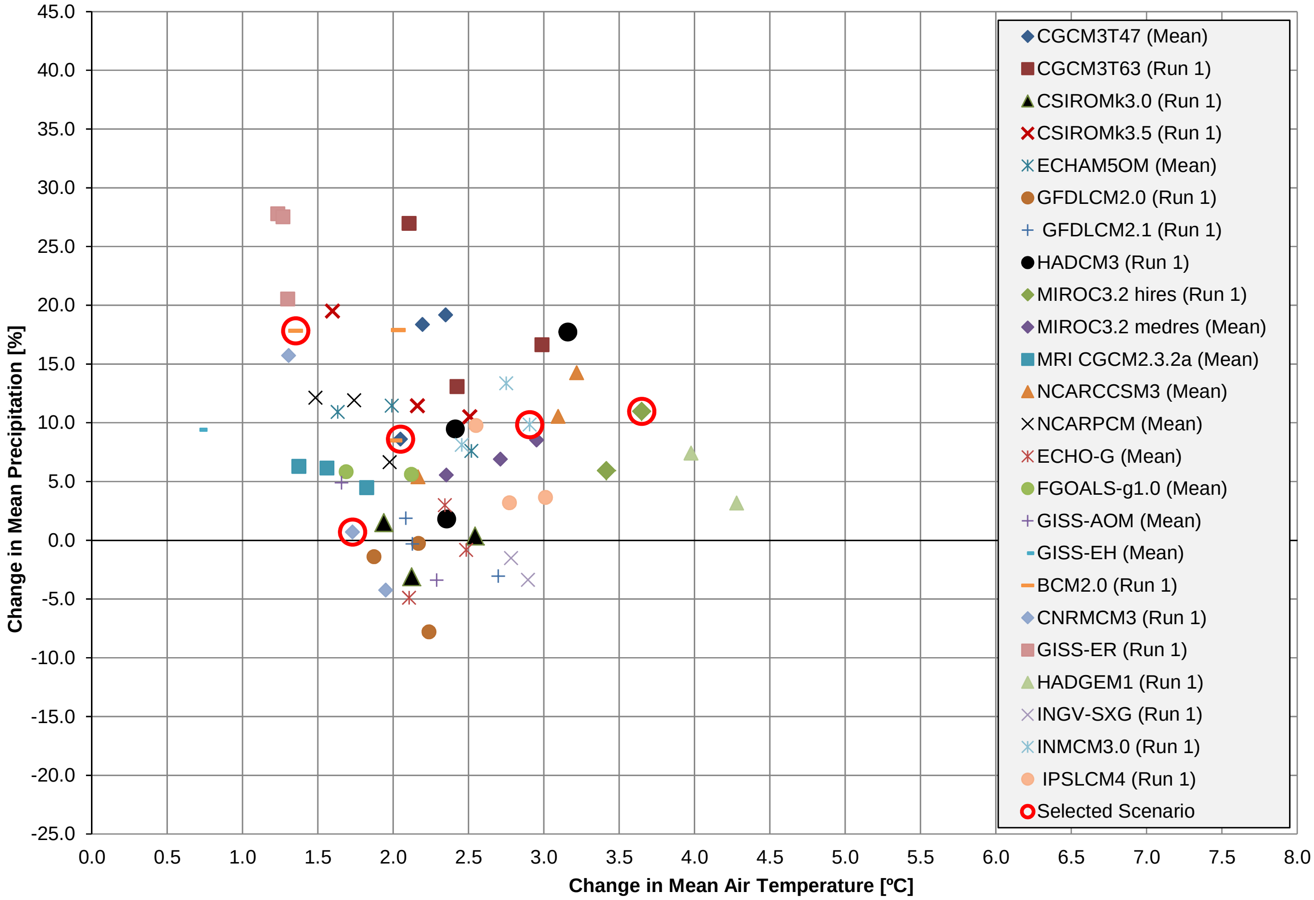


Figure E-25 Climate Change Forecasts at Lac La Biche Climate Station for 2041-2070 Based on 1961-1990 Base – Winter Season Average (December to February)

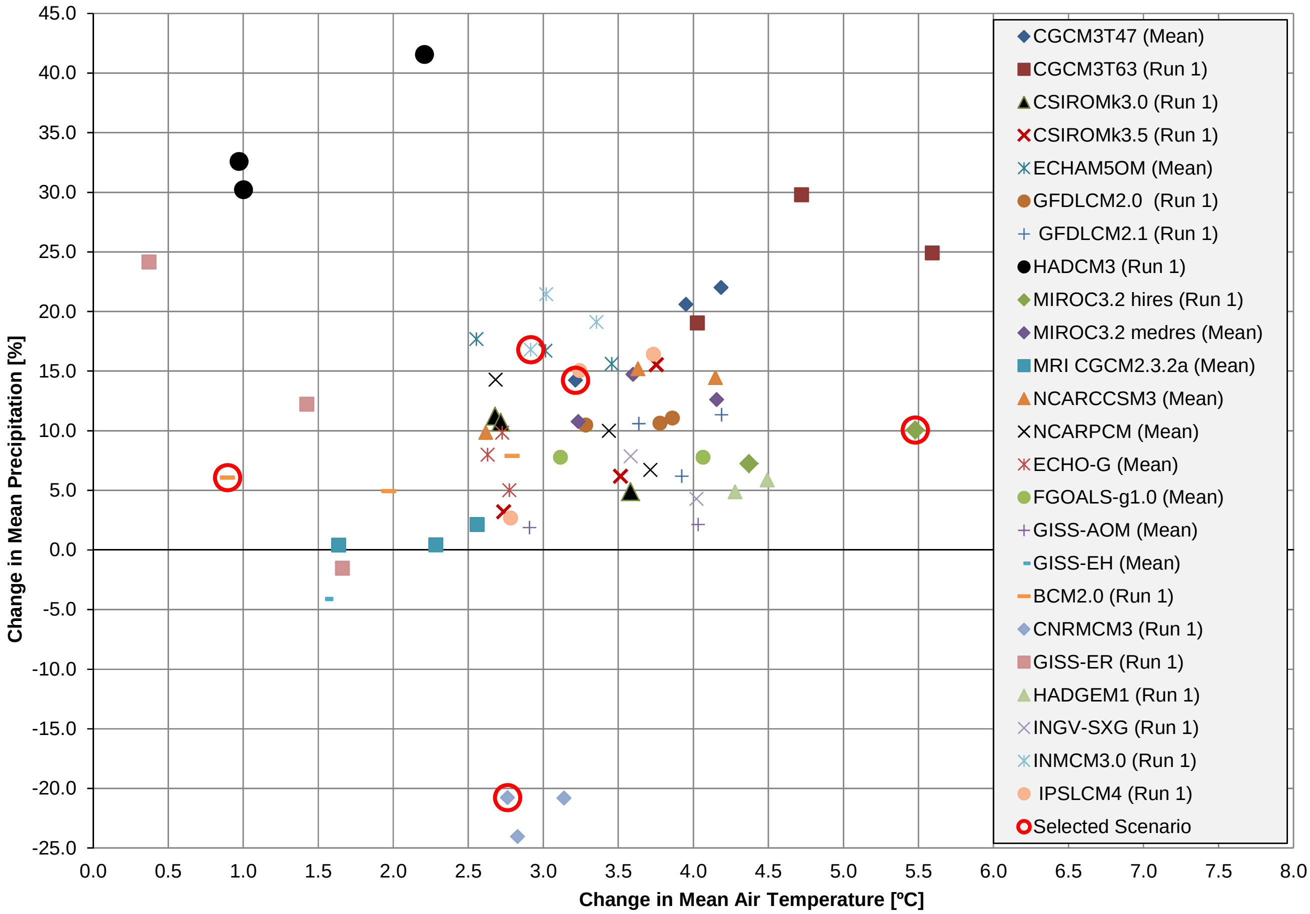


Figure E-26 Climate Change Forecasts at Fort McMurray Climate Station for 2041-2070 Based on 1961-1990 Base – Annual Average

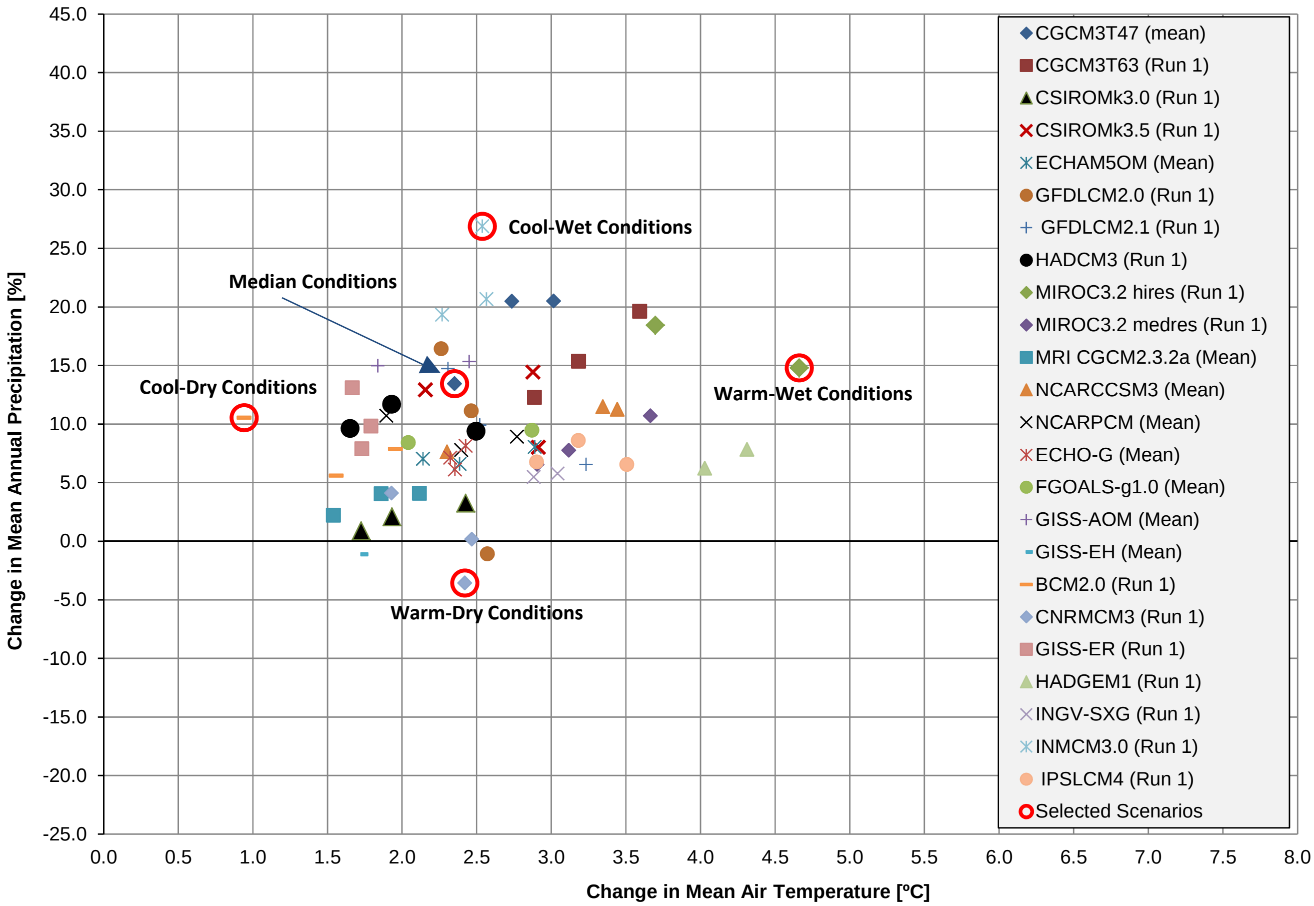


Figure E-27 Climate Change Forecasts at Fort McMurray Climate Station for 2041-2070 Based on 1961-1990 Base – Spring Season Average (March to May)

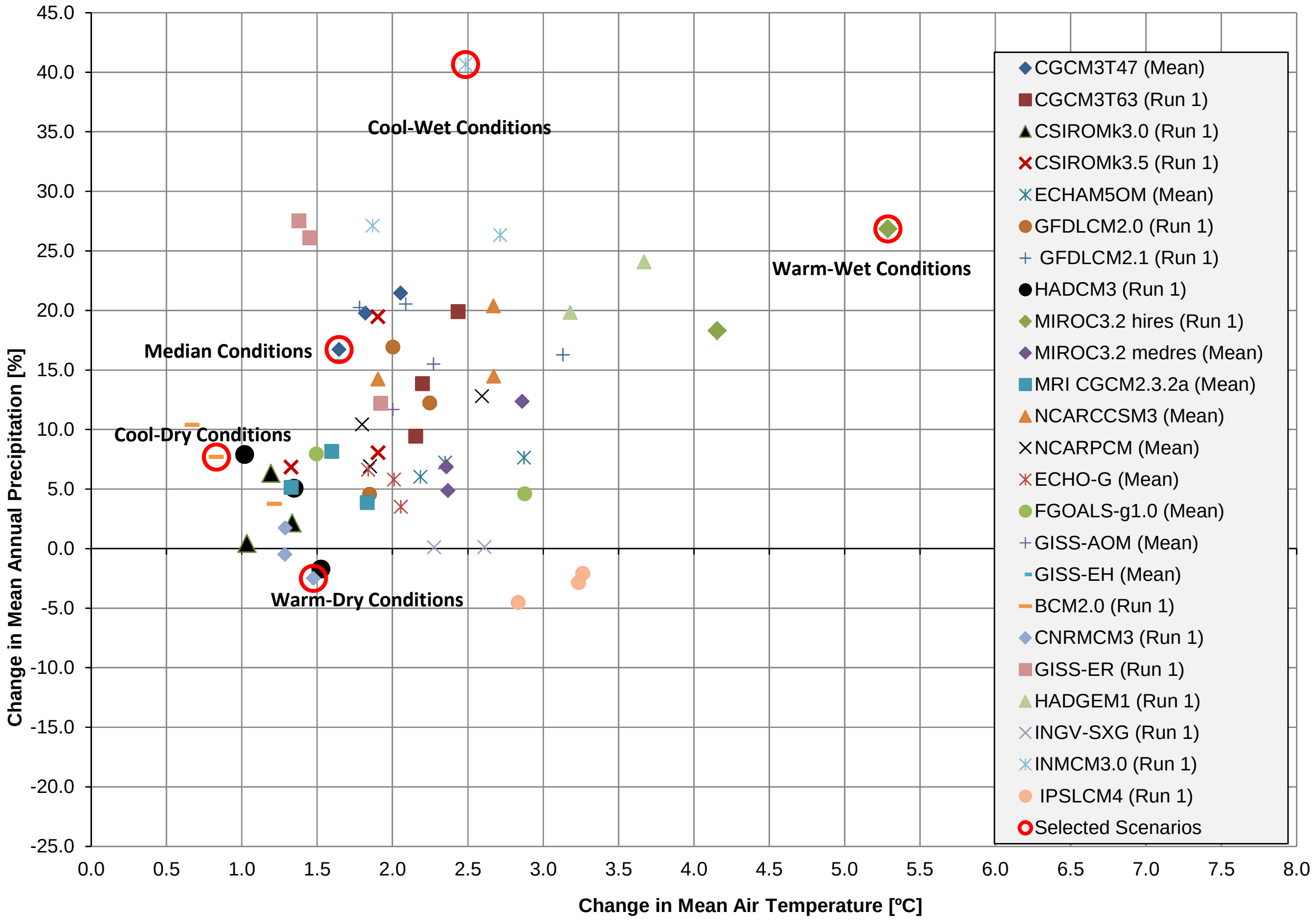


Figure E-28 Climate Change Forecasts at Fort McMurray Climate Station for 2041-2070 Based on 1961-1990 Base – Summer Season Average (June to August)

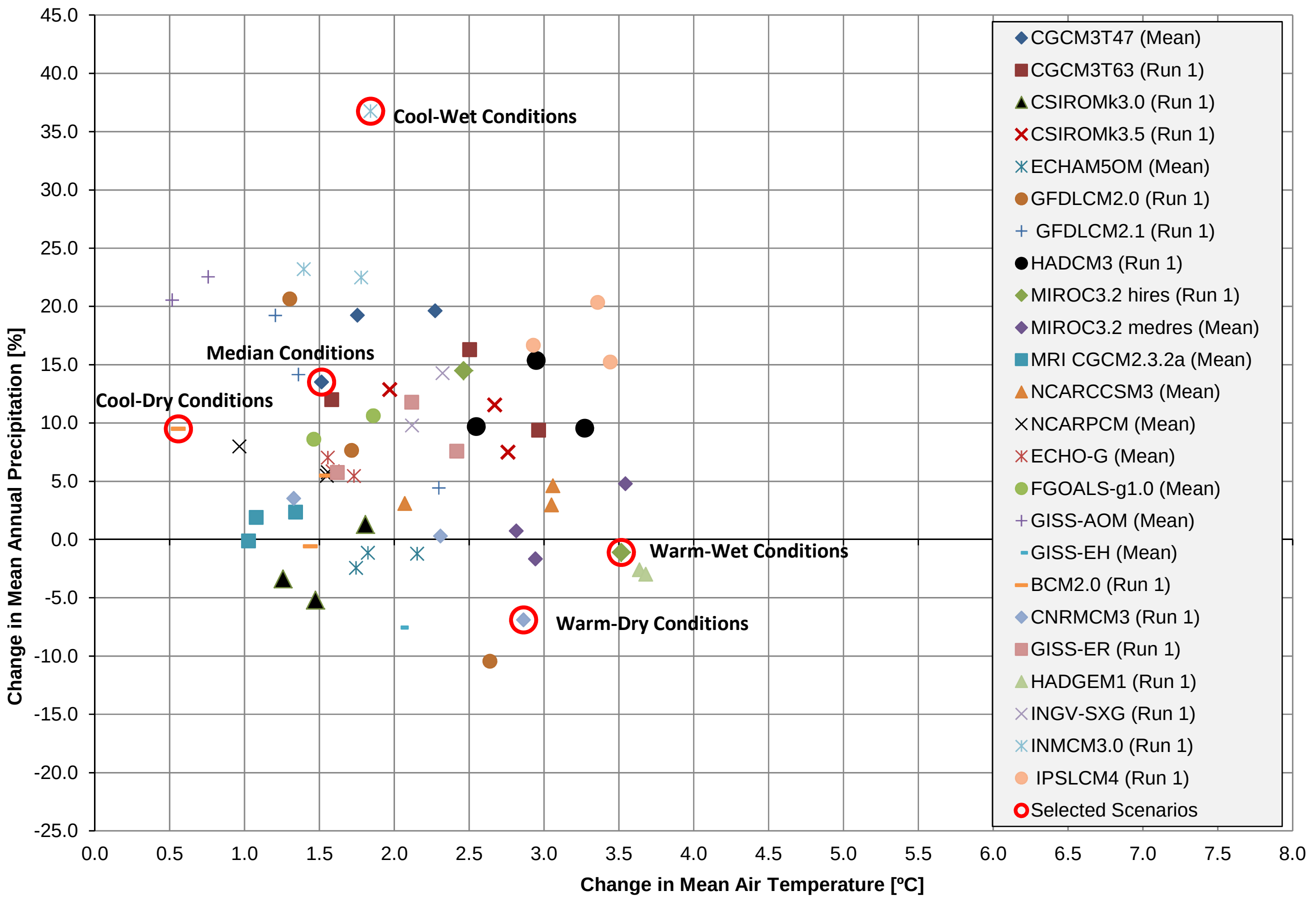


Figure E-29 Climate Change Forecasts at Fort McMurray Climate Station for 2041-2070 Based on 1961-1990 Base – Autumn Season Average (September to November)

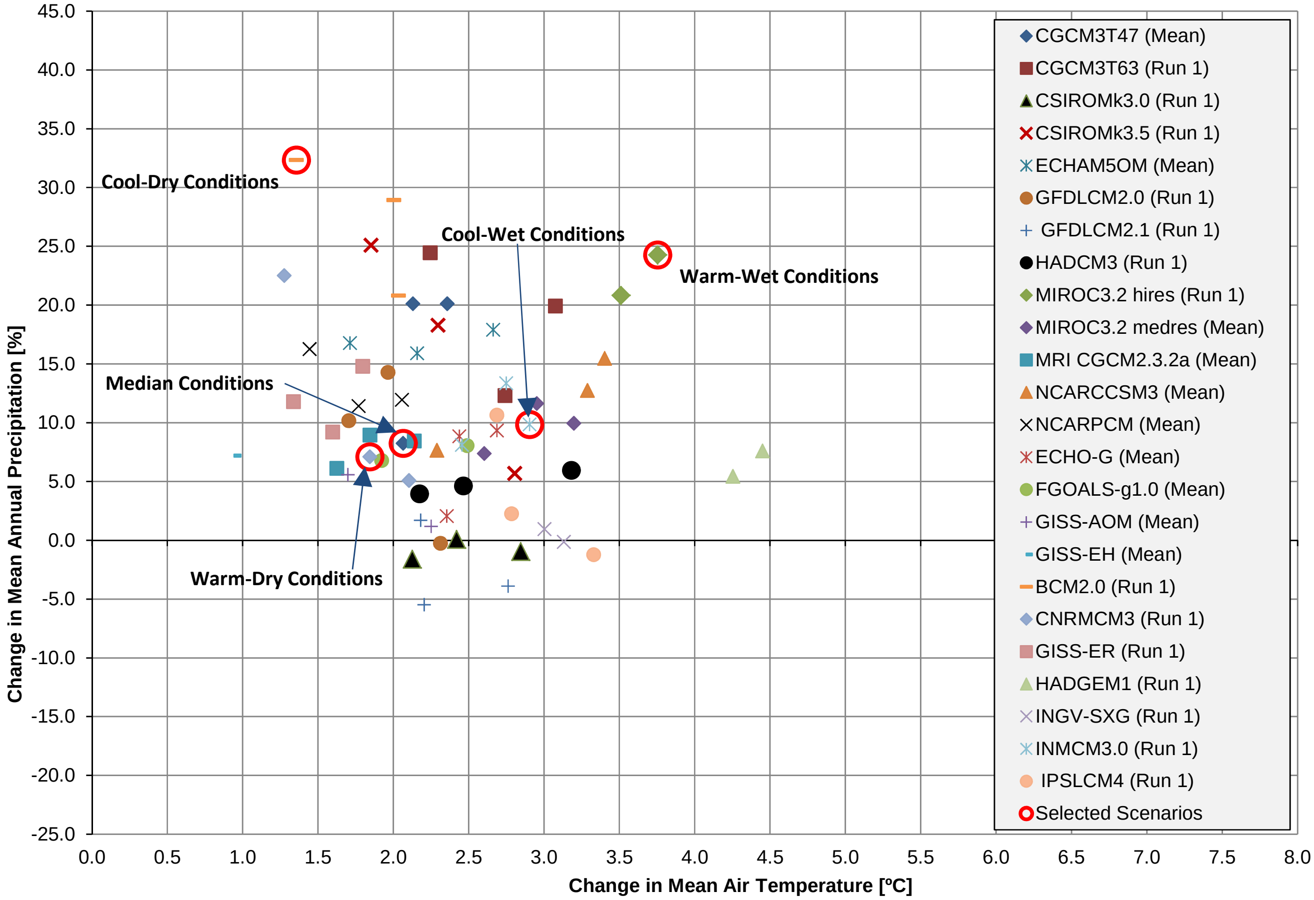
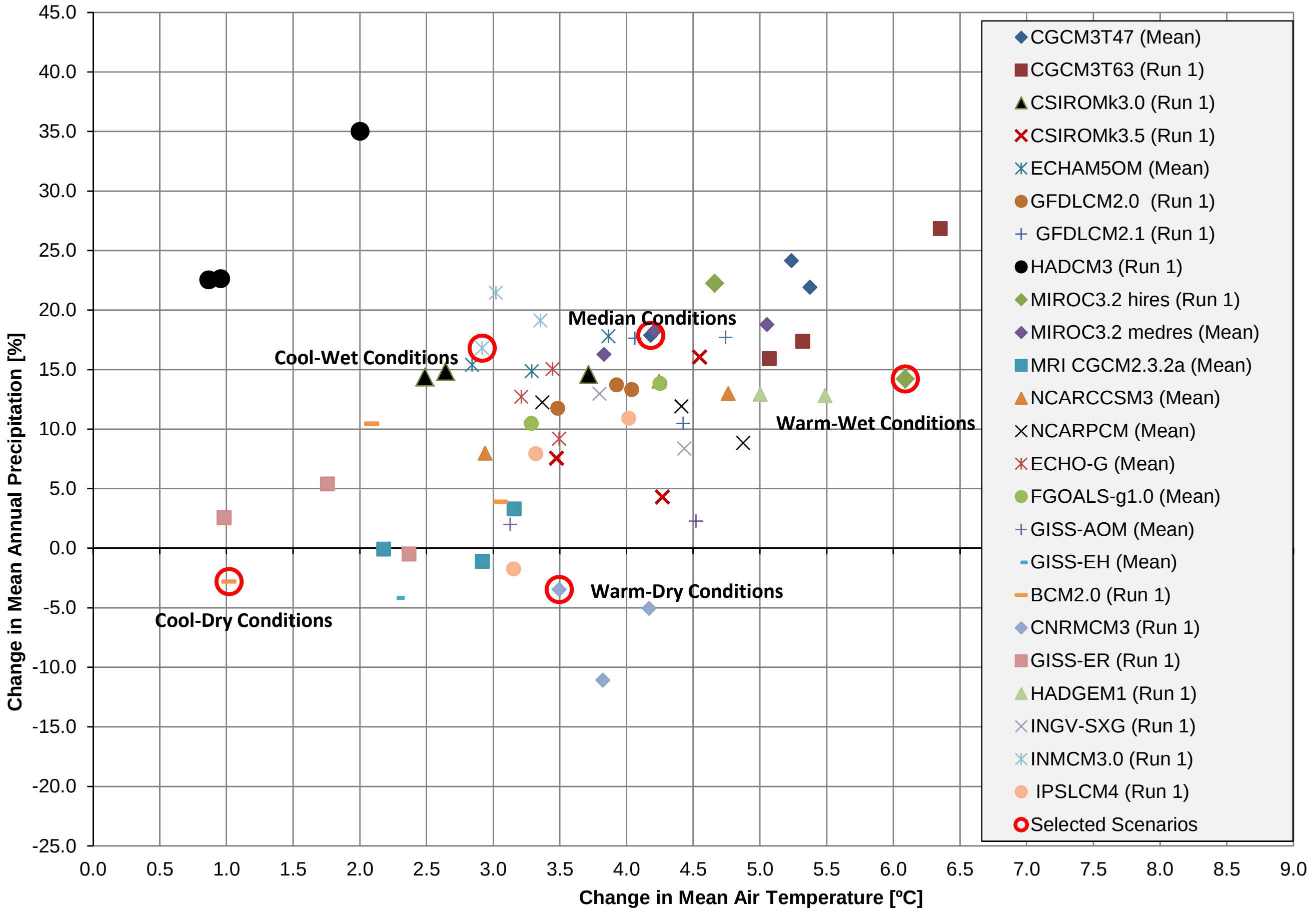


Figure E-30 Climate Change Forecasts at Fort McMurray Climate Station for 2041-2070 Based on 1961-1990 Base – Winter Season Average (December to February)



ATTACHMENT F

Climate Change Update

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1.0 INTRODUCTION

The potential effects of climate change must be evaluated as part of the Environmental Impact Assessment (EIA) for new projects in Alberta. Guidance on how such evaluations should be made is provided by the EIA Terms of Reference (TOR; AENV 2007) and in federal guidance documents (FPTCCCEA 2003). This section has been prepared to summarize the findings for climate change and to demonstrate that the expectations of provincial and federal agencies have been addressed for climate change issues.

1.1 Guidance for Incorporating Climate Change

The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment (FPTCCCEA) supported by the Canadian Environmental Assessment Agency issued a general guidance document in 2003 for practitioners to use when incorporating climate change issues into environmental assessments (*Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners* [FPTCCCEA 2003]). The guidance document sets out the following two approaches for incorporating climate change considerations:

- Greenhouse Gas (GHG) considerations where the proposed project may contribute to GHG emissions; and
- impact considerations where changing climates may have an impact on the proposed project.

The federal guidance document indicates that projects are typically more closely aligned with one of the considerations, but provides for cases where both considerations could be addressed. A review of oil sands projects suggests that they would be more aligned with the first consideration, which is consistent with past oil sands EIAs that have incorporated and documented the climate change issue through considerations of the GHG emissions associated with the Pierre River Mine (PRM). However, recent oil sands project EIAs (e.g., Imperial Oil 2005; Shell 2005; Suncor 2005, 2007) also considered potential impacts of climate change on future temperatures, precipitation and hydrological flows in key Oil Sands Region watercourses.

The TOR for the Jackpine Mine Expansion and Pierre River Mine Project EIA incorporates specific sections dealing with climate change considering “GHG emissions” and “impact on project” considerations (EIA, Volume 3, Appendix 3-1).

This report includes a summary of the impact considerations related to climate change as set out in federal guidance and the TOR for the EIA. The requirement for assessing GHG emission contributions was dealt with directly in the air quality section (EIA, Volume 3, Section 3).

1.2 Report Organization

This report is organized as follows. Section 2 provides the summary and conclusions of the updated climate change assessment. The assessment approach, a discussion of historic and future climate change, and the model scenarios used in the environmental assessment are provided in Section 3. A summary of the climate change considerations for air quality is in Section 4. A summary of the effects of climate change on hydrogeology (groundwater) is in Section 5. A summary of the effects on fish and fish habitat is provided in Section 6. Climate change effects on terrestrial resources and human health are discussed in Sections 7 and 8, respectively. The potential effects of climate change on the PRM are discussed in Section 9.

2.0 SUMMARY AND CONCLUSIONS

Climate change considerations for the PRM included evaluations of the contribution of the PRM to GHG emissions and an evaluation of the effects of climate change on the PRM and EIA predictions. The climate change considerations were from the recommendations of the guidance evaluations provided by the EIA TOR and the FPTCCCEA guidance document - *Incorporating Climate Change Considerations in Environmental Assessment* (FPTCCCEA 2003). Information on how the PRM may contribute to GHG emissions is provided in the air quality assessment (EIA, Volume 3, Section 3.4).

Current and potential future climate change effects must be considered before evaluating the potential effects on oil sands projects. Establishing historic climate change relied on the long-term climate records available for the community of Fort McMurray (1951 to 2010). Climate forecasts applied for the Fort McMurray area were used to determine future climate change.

Applicable climate forecast data from the Canadian Climate Change Scenarios Network website (Environment Canada 2013a) were considered to ensure a thorough evaluation. Several model scenarios were selected to represent the range of change in future temperature and precipitation. These predictions were used to evaluate the effects of climate change on the air quality, terrestrial resources, aquatic resources and human health components.

The results indicate the potential future climate change would not affect the EIA assessment results and the predicted environmental consequences of the PRM.

3.0 CLIMATE CHANGE

3.1 Assessment Approach

An evaluation of the potential effects of climate change on the PRM and impact predictions requires an understanding of how the climate has been changing and how it might change in the future. Historic climate change was evaluated using the long-term climate records available for Fort McMurray.

Climate forecasts have been used to determine future climate change in the Fort McMurray area. Applicable climate forecast data from the Canadian Climate Change Scenarios Network website (Environment Canada 2013a) corresponding to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) were considered for a thorough evaluation.

3.1.1 Climate Forecast Models

Creating predictions of future climate requires the use of sophisticated mathematical computer programs called General Circulation Models (GCMs). Numerous GCMs have been developed by international government laboratories and academic institutions. The IPCC has been charged with providing state-of-the-art reviews of climate change science produced by researchers at these international institutions.

Climate simulations produced by these models vary because each model uses a different combination of algorithms to describe and couple Earth's atmospheric, oceanic and terrestrial processes. Thus, an ensemble approach or combining the results from multiple GCMs provides the best, unbiased approach to evaluating climate change predictions. The GCMs used in this assessment (Table F-1) are highly regarded, have been validated against observations, and the interpretation of their results has been peer reviewed. Rather than selecting a single model, the climate change projections from all the models were considered in the assessment. This approach allows for a range of results that should capture the actual outcome which is an inherent unknown.

Table F-1 GCMs Used in the Future Climate Change Assessment

Centre	Country	Model
Beijing Climate Center	China	BCCCM1
Bjerknes Centre for Climate	Norway	BCM2.0
Canadian Centre for Climate Modelling and Analysis	Canada	CGCM3T47, CGCM3T63
Centre National de Recherches Météorologiques	France	CNRMCM3
Commonwealth Scientific and Industrial Research Organisation	Australia	CSIROMk3, CSIROMk3.5
Max-Planck Institute für Meteorologie	Germany	ECHAM5OM
Meteorological Institute, University of Bonn Meteorological Research Institute of KMA	Germany	ECHO-G
State Key Laboratory Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics	China	FGOALS-g1.0
Geophysical Fluid Dynamics Laboratory	USA	GFDLCM2.0, GFDLCM2.1
Goddard Institute for Space Studies	USA	GISS-AOM, GISS-EH, GISS-ER
Met Office	United Kingdom	HADCM3, HADGEM1
National Institute of Geophysics and Volcanology	Italy	INGV-SXG
Institute for Numerical Mathematics	Russia	INMCM3.0
Institute Pierre Simon Laplace	France	IPSLCM4
National Institute for Environmental Studies	Japan	MIROC3.2hires, MIROC3.2medres
Meteorological Research Institute, Japan Meteorological Agency	Japan	MRICGCM2.3.2a
National Center for Atmospheric Research	USA	NCARCCSM3, NCARPCM

3.1.2 Forecast Scenarios

Given the range of inputs available to GCMs, the IPCC has established a series of global GHG emission scenarios based on several potential socio-economic development paths (IPCC 2000). While the IPCC identifies many scenarios, the following three scenarios, A1B, A2 and B1 were selected for this study and are the most common scenarios used for assessment.

- Scenario A1B — the A1 family of scenarios describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 family includes three groups of scenarios that describe alternative directions in the energy system. The A1B scenario is distinguished by a balance across all sources of energy – green and fossil.

- Scenario A2 — the A2 scenario family describes a world with an underlying theme of self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is regionally oriented and per capita economic growth and technological change more fragmented and slower than for other scenarios.

- Scenario B1 — the B1 scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter (similar to the A1 scenarios). The B1 family has rapid change in economic structures toward a service and information economy, with reductions in raw material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

Most GCMs produce results for the above three emission scenarios. The A1B and A2 scenarios represent a focus on economic growth while the B1 scenario represents a shift towards more environmentally conscious solutions to growth. Scenarios A1B and B1 include a shift towards global solutions, while the A2 scenario includes growth based on regional models.

Although IPCC has not stated which of these scenarios are most likely to occur, the A2 scenario most closely reflects the current global socio-economic situation. In relation to the A2 scenario, scenarios A1B and B1 result in lower long-term GHG emissions over the next century. Of the A1 scenarios, A1B yields high emissions in the first half of the 21st century due to increasing population and high dependence on fossil fuels for energy.

3.1.3 Understanding Climate Projections and their Limitations

The GCMs used for this assessment have inherent limitations that are important to understand 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 institutions' 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 ensemble approach described above was used for this assessment to account for these uncertainties and limitations.

Due to limitations on computing power, the GCM outputs are limited to grid cells of 1 degree to 2.5 degrees (approximately 110 to 275 km) and a small number of vertical layers in the atmosphere. These grid cells represent a mathematically defined region and are different between models. Although the appropriate grid cell was selected to represent the PRM location from each model and the data extracted from each grid cell, this scale is much larger than that of weather processes, such as convective thunderstorms. In addition, local changes in topography cannot be represented at this scale. The GCM simulations are run on monthly time scales; therefore, only monthly average predictions are available as outputs.

The Earth's climatological processes and feedbacks are very complex and therefore have to be approximated into the model simulations. Mathematical parameterizations of these processes are required to reduce the computational burden within the simulations. Examples of these parameterizations include aerosols and cloud cover. Climate model simulations represent average conditions and typically do not consider the influence of unpredictable episodic events such as volcanic eruptions. Events of a certain magnitude tend to occur at a certain frequency; however, their actual magnitude and timing is unknown and are not predictable in the GCMs.

3.1.4 Baseline Climate

Climate change analysis not only depends on future conditions, but also on the baseline climate to which the predictions are compared. Baseline climate information is important for describing average conditions, spatial and temporal variability, anomalous events, and calibrating and testing climate models (Environment Canada 2013a).

The IPCC recommends that 1961 to 1990 be adopted as the climatological baseline period in impact assessments (Environment Canada 2013a). This period has been selected since it is considered to:

- be representative of the present-day or recent average climate;
- be of a sufficient duration to encompass a range of climatic variations, including several significant weather anomalies;
- cover a period for which data on all major climatological variables are abundant, adequately distributed over the Earth and readily available;
- include data of sufficiently high quality for use in evaluating impacts; and
- be comparable with baseline climatologies used in other impact assessments.

This assessment is based on the baseline period 1961 to 1990.

3.2 Historic Climate Change

Analyzing historic climate change in the Fort McMurray region involves reviewing the climate normals. Climate normals refer to calculated averages of observed climate values for a given location over a specified time period. The World Meteorological Organization recommends that climate normals be prepared at the end of every decade over a 30-year period (e.g., 1961 to 1990; 1971 to 2000). A summary of the calculated climate normals observed at Fort McMurray based on hourly data from Environment Canada (Environment Canada 2013b) is provided in Table F-2.

The trends in annual and seasonal temperature and precipitation from 1951 to 2010 were also evaluated. The trends 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 90th, 95th, 99th and 99.9th percentile levels. A trend that is not determined to be significant at the 90th percentile is classified as being "not significant." A trend that is determined to be significant at the 99.9th percentile level indicates that there is a 99.9% probability that the direction of the trend is correct. This assessment method was developed by Finnish Meteorological Institute and is widely used to assess climate changes predicted from weather data (FMI 2013). Both the Mann-Kendall test and the Sen's Method were applied to the available climate data.

An upward trend in annual and seasonal temperatures is indicated in Table F-2. The annual temperature shows an increasing trend of 0.03°C per year which is significant at the 99.9th percentile (i.e., there is a 99.9% probability that the direction of the trend is correct). The change in annual precipitation from 1951 to 2010 shows a decrease of 1.39 mm per year which is significant to the 95th percentile. The spring and summer precipitation did not show any significant trends. The fall and winter precipitation show a decreasing trend.

Table F-2 Observed Climate Normals and Trends at Fort McMurray

Parameter	Season	Period 1951 to 1980	1961 to 1990	1971 to 2000	1981 to 2010	1951 to 2010 Trend per Year	Level of Statistical Significance
Average Temperature [°C]	annual	-0.1	0.3	0.8	1.0	+0.03	significant at the 99.9th percentile
	spring	0.9	1.6	2.4	2.2	+0.05	significant at the 99th percentile
	summer	15.0	15.5	15.6	15.7	+0.02	significant at the 99th percentile
	fall	1.4	1.1	1.2	1.3	+0.01	not significant
	winter	-18.0	-17.3	-16.4	-15.5	+0.06	significant at the 99th percentile
Total Precipitation [mm]	annual	472.9	464.3	454.9	414.4	-1.39	significant at the 95th percentile
	spring	77.7	80.6	74.6	72.5	-0.15	not significant
	summer	216.2	214.8	228.7	211.5	+0.08	not significant
	fall	112.1	109.4	98.1	85.3	-0.73	significant at the 95th percentile
	winter	67.3	60.6	53.8	45.8	-0.75	significant at the 99.9th percentile

3.3 Future Climate Change

Climate forecast data from various models and emissions scenarios were analyzed to determine potential climate change in the region. Since the models are susceptible to inter-decadal variability, the analysis uses the average of 30 years of data, centred on the decade of interest. The future conditions have been represented by the 30-year period between 2041 and 2070, representative of the mid-2050s. This period is near the end of the life of the PRM and incorporates the post-operations management and closure period of the PRM.

The forecast change in climate relative to the 1961 to 1990 baseline represents the total change forecast between the modelled 30-year average for 1961 to 1990 and the modelled future conditions, as represented by the 30-year period between 2041 and 2070 (i.e., the 2050s).

The annual climate change forecasts for the 2050s relative to the 1961 to 1990 baseline period are illustrated in Figure F-1. The seasonal changes in temperature and precipitation are illustrated in Figure F-2. The annual average temperature is predicted to increase from between +0.9°C to +4.7°C. The change in annual precipitation is predicted to range from -3.6% to +26.9%.

Figure F-1 Forecast Annual Climate Change Relative to the 1961 to 1990 Baseline

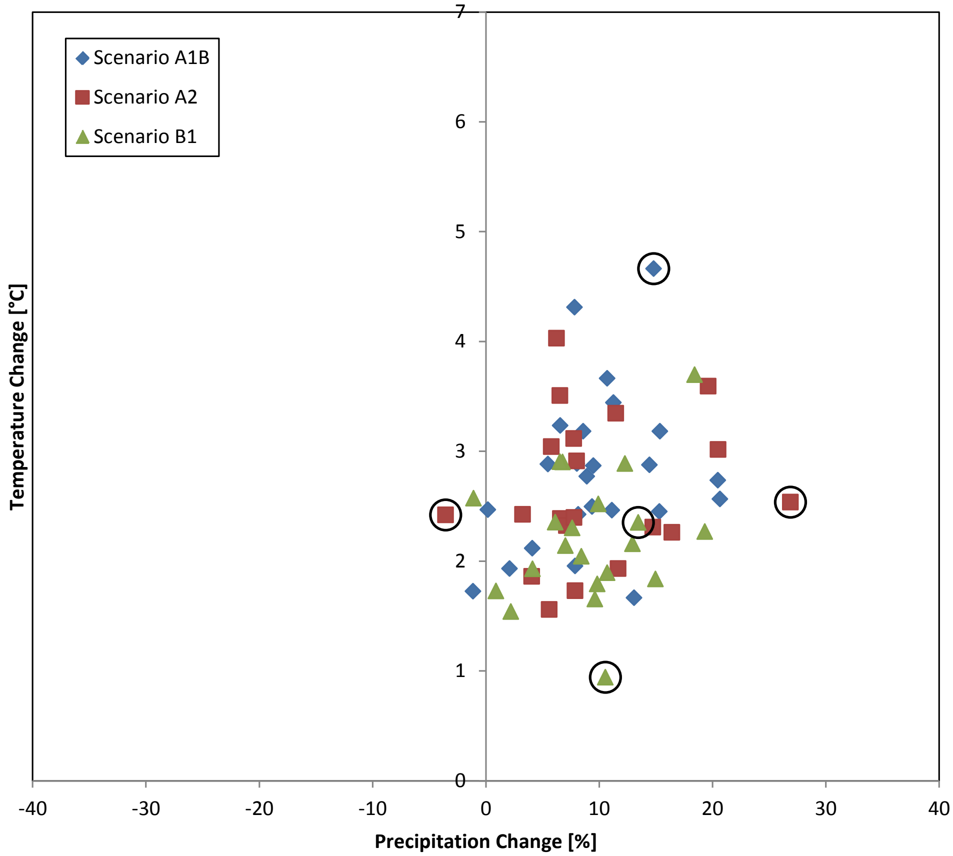
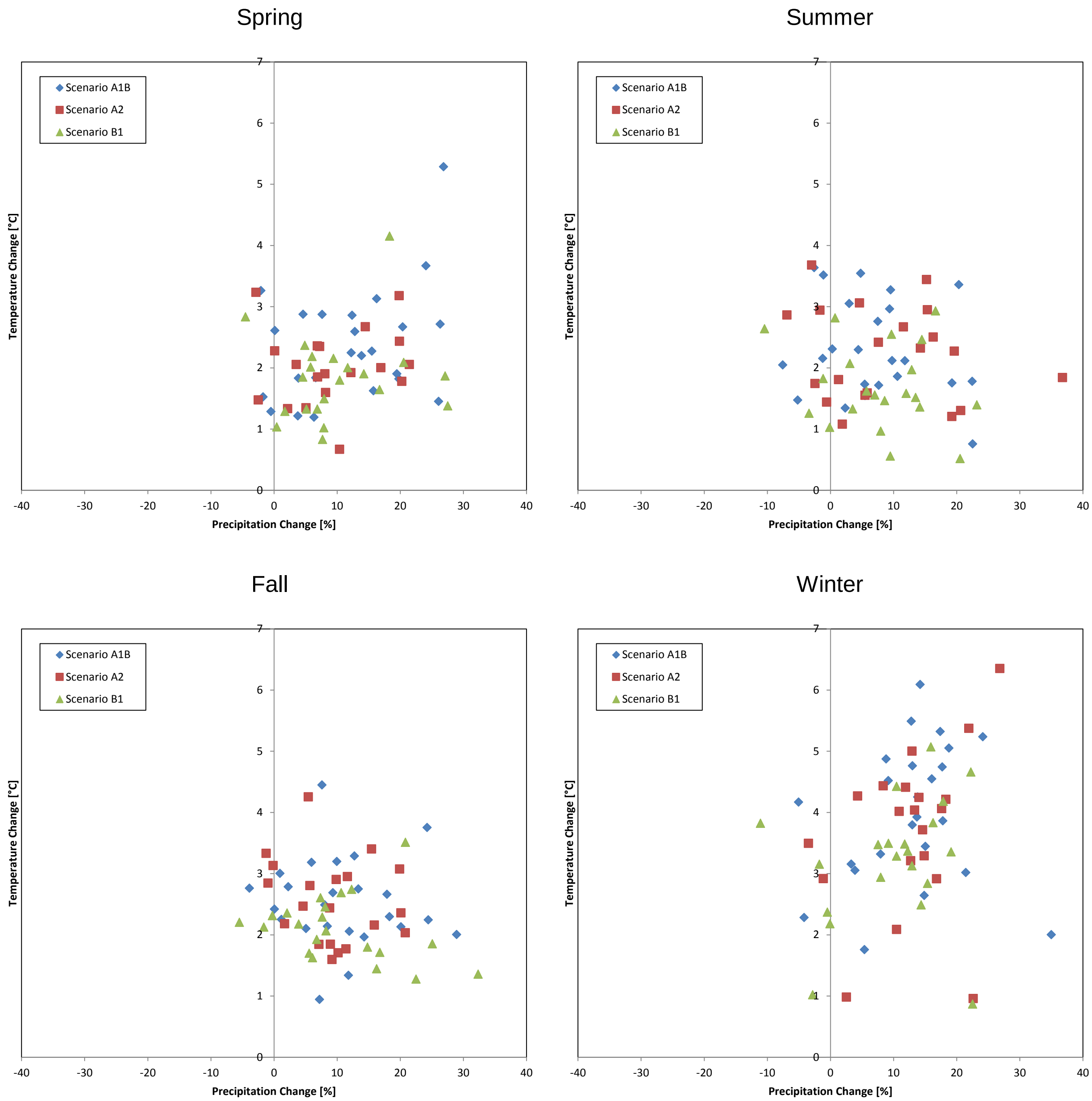


Figure F-2 Forecast Seasonal Climate Change Relative to the 1961 to 1990 Baseline



Several model scenarios were selected to represent the range of possible future climate change for the assessment of the effects of climate change on the various components of the EIA. Four model scenarios were selected to capture the minimum and maximum changes in annual temperature and annual precipitation. A fifth scenario was selected to provide a median change in annual temperature and annual precipitation. The model scenarios are consistent with the scenarios chosen for the hydrological modelling. The selected scenarios are listed below and are highlighted in Figure F-1:

- median temperature and precipitation change - CGCM3T47 Scenario B1;
- maximum temperature change - MIROC3.2 hires Scenario A1B;
- minimum temperature change - BCM2.0 Scenario B1;
- maximum precipitation change - INMCM3.0 Scenario A2; and
- minimum precipitation change - CNRMCM3 Scenario A2.

The change in temperature and precipitation for the five scenarios for the 2050s relative to the 1961 to 1990 baseline is summarized in Table F-3. The annual temperature change ranges from +0.9°C to +4.7°C. The annual precipitation change ranges from -3.6% to +26.9%. The corresponding seasonal changes are also shown for each model. The summer temperatures are predicted to increase between +0.6°C and +3.5°C while the summer precipitation is predicted to change by -6.9% to +36.8%. The winter temperature is predicted to increase between +1.0°C and +6.1°C and the winter precipitation is predicted to change by -3.5% to +17.9%.

Table F-3 Climate Change Forecasts for 2050s Relative to the 1961 to 1990 Baseline

Season	Temperature Change [°C]					Precipitation Change [%]				
	CGCM3T47 SR-B1	MIROC3.2 hires SR-A1B	BCM2.0 SR-B1	INMCM3.0 SR-A2	CNRMCM3 SR-A2	CGCM3T47 SR-B1	MIROC3.2 hires SR-A1B	BCM2.0 SR-B1	INMCM3.0 SR-A2	CNRMCM3 SR-A2
annual	2.4	4.7	0.9	2.5	2.4	13.5	14.8	10.5	26.9	-3.6
spring	1.6	5.3	0.8	2.5	1.5	16.7	26.9	7.7	40.6	-2.5
summer	1.5	3.5	0.6	1.8	2.9	13.5	-1.1	9.5	36.8	-6.9
fall	2.1	3.8	1.4	2.9	1.8	8.2	24.3	32.3	9.8	7.1
winter	4.2	6.1	1.0	2.9	3.5	17.9	14.2	-2.8	16.8	-3.5

The forecast temperatures and precipitation amounts for the 2050s are provided in Table F-4. These values were calculated by applying the changes presented in Table F-4 to the observed 1961 to 1990 climate normals from Fort McMurray. The annual average temperature is predicted to be between +1.2°C and +4.9°C, while the annual total precipitation is predicted to range between 448 and 589 mm in the 2050s.

Table F-4 Forecast Temperature and Precipitation for 2050s Based on 1961 to 1990 Observed Climate Normals

Season	Temperature [°C]		Precipitation [mm]	
	1961 to 1990 Observed Climate Normals	2050s Forecast	1961 to 1990 Observed Climate Normals	2050s Forecast
annual	0.3	1.2 to 4.9	464	448 to 589
spring	1.6	2.5 to 6.9	81	79 to 113
summer	15.5	16.0 to 19.0	215	200 to 294
fall	1.1	2.5 to 4.9	109	117 to 145
winter	-17.3	-16.3 to -11.2	61	58 to 71

4.0 EFFECTS OF CLIMATE CHANGE ON AIR QUALITY PREDICTIONS

Air quality is influenced by meteorological conditions and is therefore sensitive to climate change. Estimates of climate change effects on air quality have been studied through correlations with meteorological variables, and perturbation analyses in coupled general circulation model and chemical transport model (GCM-CTM) simulations (Jacob and Winner 2009).

Most of the studies regarding effects of climate change on air quality are focused on surface ozone and particulate matter. Investigations show that ozone is strongly correlated with temperature (Camalier et al. 2007; Cox and Chu 1995). General degradation of air quality is expected in polluted regions of the world with warmer temperatures. Climate change may increase the concentration of ground-level ozone, but the magnitude of the effect is uncertain (Parry et al. 2007). Coupled GCM–CTM studies show that climate change may increase summertime surface ozone in polluted regions; however, higher water vapour is expected to lower the background ozone concentration. These studies indicate that ozone pollution and background ozone have opposite sensitivities to climate change (Jacob and Winner 2009; Parry et al. 2007; U.S. EPA 2013).

A study of historical and current surface ozone from background stations in Canada, United States and around the world indicates that background ozone levels over the mid-latitudes of the Northern Hemisphere have continued to rise over the past three decades although current trends are not uniform. A substantial component of the background ozone concentration in western North America may be due to long-range transport from Asia (Vingarzan 2004).

The effect of climate change on particulate matter is more complicated and less definitive than for ozone. Precipitation frequency and mixing depth are important driving factors, but their projections are often unreliable (Jacob and Winner 2009). Particulate matter concentrations generally decrease as a result of increased atmospheric humidity and increased precipitation (U.S. EPA 2009). Wildfires caused by climate change could become an increasingly important particulate matter source (Jacob and Winner 2009).

Several indirect effects could impact the air quality predictions presented in the EIA. Changing climate could alter several meteorological parameters that could affect the EIA air quality predictions. A summary of the primary linkages between climate change and air quality is presented in Table F-5.

Table F-5 Primary Links between Climate Change and Air Quality

Air Quality Subject	Precipitation	Temperature	Wind Speed
Acid Deposition (Potential Acid Input)	Higher rainfall rates would result in higher wet deposition and PAI. Lower rainfall rates would result in lower wet deposition and PAI.	Increased temperatures during the spring and fall could result in more of the precipitation falling in the form of rain, which would result in higher wet deposition and PAI.	no linkage
Atmospheric Dispersion	no linkage	no linkage	Higher wind speeds tend to enhance dispersion resulting in lower short term concentrations. Lower wind speeds tend to hinder dispersion resulting in higher short-term concentrations.
Ground-level Ozone	no linkage	Increased temperatures could result in an enhanced potential for formation of ground-level ozone.	no linkage

4.1 Acid Deposition

Climate change should not directly affect the predictions of Potential Acid Input (PAI) presented in the EIA; however, increased rainfall could lead to higher wet deposition and higher predictions of PAI. Warming temperatures that could cause a shift from snowfall to rainfall could be an incremental contributor to PAI. The greatest effect on the PAI predictions is likely to occur with the change in summer precipitation. The change in summer precipitation ranges from -6.9% to +36.8% (Table F-4).

The current GCMs do not have the resolution necessary to simulate all of the parameters necessary to model PAI. However, it is possible to compare the 1995 and 2002 meteorological data sets used to model PAI in the Fort McMurray region with the observed climate normals to determine if the current predictions can indicate how changing climate may affect PAI.

The 1995 and 2002 meteorological data sets are compared with the 1961 to 1990 Fort McMurray climate normals and the forecast values for the 2050s in Table F-6. The 1995 annual precipitation is within the range of the 2050s forecast values. The summer precipitation in 1995 is higher than the 2050s forecast. The 2002 annual precipitation is slightly lower than the forecast values while the summer precipitation is within the range of the 2050s forecast. Because the 1995 and 2002 summer precipitation data used in the dispersion modelling are within the range of the 2050s forecast values, the dispersion modelling is considered to provide representative estimates of the current and expected future deposition rates.

Table F-6 Comparison of 1995 and 2002 Precipitation to Climate Normals and the 2050s Forecast at Fort McMurray

Season	1961 to 1990 Observed Normals [mm]	2050s Forecast	1995 Observation [mm]	2002 Observation [mm]
annual	464.3	448 to 589	509.4	422.3
spring	80.6	79 to 113	56.8	38.8
summer	214.8	200 to 294	337.0	262.5
fall	109.4	117 to 145	70.1	84.7
winter	60.6	58 to 71	30.1	36.3

4.2 Atmospheric Dispersion

The change in wind speed is the parameter likely to have the greatest effect on the dispersion predictions. The forecast changes in wind speed for the five scenarios are provided in Table F-7. The forecast change in annual average wind speed from the 1961 to 1990 baseline ranges from -0.06 to 0.46 km/h.

Table F-7 Wind Speed Forecast for 2050s Relative to the 1961 to 1990 Baseline

Season	Wind Speed Change [km/h]				
	CGCM3T47 SR-B1	MIROC3.2 hires SR-A1B	BCM2.0 SR-B1	INMCM3.0 SR-A2	CNRMCM3 SR-A2
annual	0.46	0.15	-0.06	0.13	0.15
spring	0.21	0.06	-0.15	-0.28	-0.07
summer	0.47	0.11	-0.11	0.37	-0.20
fall	0.57	0.21	0.00	1.13	0.38
winter	0.60	0.23	0.01	-0.70	0.52

Generally, lower wind speeds are associated with higher ground-level concentrations. Therefore, the lower predictions from Table F-8 represent the conditions likely to most affect the predictions presented in this assessment. While the current GCMs do not have the resolution necessary to simulate all of the parameters to complete dispersion modelling for the Oil Sands Region, it is possible to compare the 1995 and 2002 meteorological data sets used in the modelling with the observed Fort McMurray climate normals and forecast trends.

Table F-8 Forecast Wind Speed for 2050s Based on 1961 to 1990 Observed Climate Normals

Season	Average Wind Speed [km/h]			
	1961 to 1990 Observed Climate Normals	2050s Forecast	1995 Observation	2002 Observation
annual	9.6	9.5 to 10.0	8.8	9.6
spring	10.7	10.4 to 10.9	9.7	11.4
summer	9.2	9.0 to 9.7	8.2	9.5
fall	9.7	9.7 to 10.8	8.6	9.3
winter	8.8	8.1 to 9.4	8.8	8.2

The average wind speeds in 1995 and 2002 are compared to the observed 1961 to 1990 normals for Fort McMurray in Table F-8. The forecast average wind speed for the 2050s is also shown. In general, there is little variation in the average wind speeds for the 2050s and the 1995 and 2002 observations are within the range of observed historical and future predictions.

4.3 Ground-level Ozone

Ground-level ozone can be attributed to three causes in Canada:

- photochemical ozone formation;
- stratospheric intrusion; and

- long-range transport.

The meteorological conditions ideally suited to the formation of ground-level ozone are rare in northern Alberta, which has led to the suggestion that photochemical ozone formation is not possible in northeastern Alberta because the region does not experience the necessary weather conditions. However, monitoring data from the Oil Sands Region has shown patterns of ozone concentrations that are consistent with photochemical ozone formation (i.e., hourly ozone concentrations that rise to peak levels near the middle of the day, then fall off rapidly at night). The low number of hours when the observed ozone readings were above the 1-hour Alberta Ambient Air Quality Objective (AAAQO) suggests that photochemical reactions are relatively weak in the Oil Sands Region. This result is likely due to the relatively cool regional temperatures compared to the optimal conditions for ozone formation (i.e., greater than 25°C). However, changing climate may result in higher temperatures and enhance the potential for photochemical ozone formation in the region.

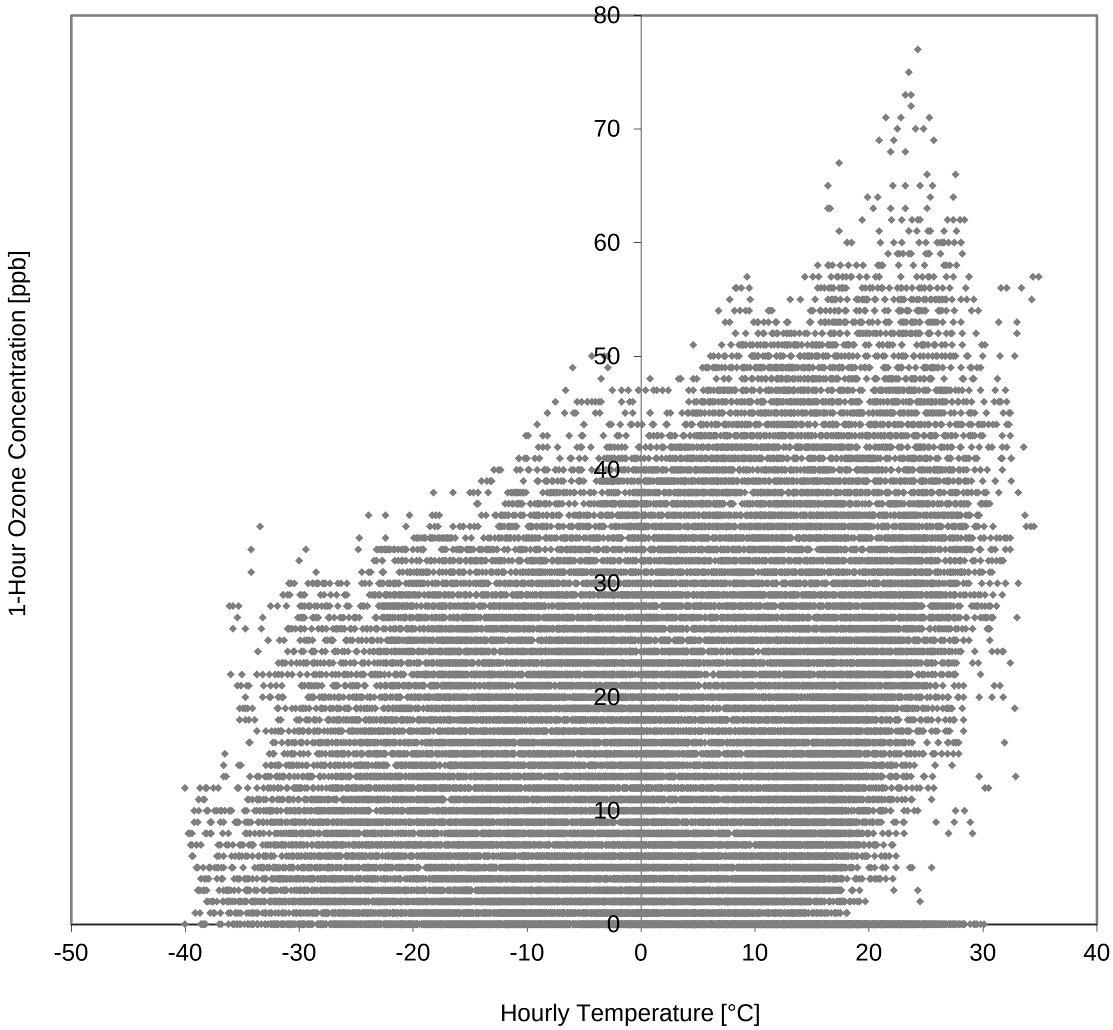
Summer temperature is one of the climate parameters likely to affect ground-level ozone concentrations. The forecast summer temperature for the 2050s is predicted to range from 16.0 to 19.0°C (Table F-5).

While higher summer temperatures could result in an increased potential for ground-level ozone formation in the region, this relationship is not clearly evident from the monitoring results from ambient monitoring stations operated by the Wood Buffalo Environmental Association (WBEA). A comparison of hourly temperatures and hourly ozone concentrations from the Fort McMurray Athabasca Valley station from 2008 through 2012 is presented in Figure F-3. Monitoring results at the Patricia McInnes, Fort McKay, Fort Chipewyan and Syncrude UE1 stations demonstrate similar patterns to those shown in Figure F-3.

If there was a strong correlation between the maximum temperatures and the peak ozone concentrations in the region, it should be evident in the monitoring data. However, the peak ozone concentrations do not always correspond to the highest temperatures (Figure F-3). On days when temperatures are greater than 30°C, ozone concentrations range from approximately 12 to 57 ppb, indicating that higher temperatures do not always correspond to high ozone concentrations. High ozone concentrations (up to 50 ppb) are also occurring during periods when the daily maximum temperature is below 0°C. Although the forecast change in summer temperature may result in higher temperatures, this may not correspond to increased peak ozone concentrations.

The Ozone Management Framework for the Regional Municipality of Wood Buffalo (CEMA 2006) contains ozone management strategies based on four trigger levels that will manage ozone levels in the future. Additional research and modelling for the Oil Sands Region is currently being conducted by Environment Canada and Alberta Environment and Sustainable Resource Development.

Figure F-3   Comparison of Hourly Ozone and Temperature at Fort McMurray – Athabasca Valley



4.4 Summary

In conclusion, the air quality predictions in the assessment are considered representative of current and expected future conditions since the 1995 and 2002 meteorological data (temperature, wind speed and precipitation) cover the range of climate forecast values. The effect of climate change on ground-level ozone concentrations is not well known; however, current observations show that an increase in temperature may not correspond to increased peak ozone concentrations.

5.0 EFFECTS OF CLIMATE CHANGE ON HYDROGEOLOGICAL PREDICTIONS

Changes in temperature, precipitation and evapotranspiration associated with climate change may influence recharge to groundwater. It is not clear, however, whether climate change will reduce or increase the overall recharge rates, or alter the seasonal distribution of recharge. Short periods of intense rainfall lead to excess surface water and relatively low recharge rates. However, prolonged steady rain leads to more effective recharge of aquifers.

Groundwater flow systems are characterized by large storage and slow rates of groundwater flow, which leads to a longer residence time in aquifers compared to surface water systems. Hence, aquifers attenuate variations in recharge and produce a relatively smooth, continuous discharge. Shallow groundwater flow systems are more susceptible to climate change and, consequently, would be the first to respond to climate effects through changes in the water table levels in shallow unconfined aquifers. Intermediate and deeper aquifers, however, would be expected to be largely buffered from climate fluctuations due to the longer residence times, larger storage volume and lower recharge rates.

Section 3.3 discussed the effects of climate change on precipitation and indicated that possible variations ranged from -3.6% to +26.9% for annual average precipitation; -6.9% to +36.8% for summer average precipitation; and -3.5% to +17.9% for winter average precipitation. If it is assumed that changes in precipitation would result in similar changes in groundwater recharge, a reasonable range for changes in recharge due to climate change would be from about -4% to about +37% from the 1961 to 1990 baseline. The high possible changes predicted for the winter average precipitation, however, are less likely to influence recharge because the higher precipitation values might result in winter runoff as snow melt in late fall or early glacial melt in late winter.

The effects of climate change on groundwater recharge were considered as another aspect of uncertainty. An assessment of the uncertainties in the groundwater predictions is presented in the EIA, Volume 4, Section 6.3.9 and in Appendix 4-1. In the sensitivity simulations, groundwater recharge was varied by ±40% from the baseline values. This range of variation addresses possible changes in groundwater recharge due to climate change. The results of the sensitivity simulations showed that the effect of climate change on uncertainty in the model predictions is expected to be minimal.

6.0 EFFECTS OF CLIMATE CHANGE ON FISH AND FISH HABITAT

The effects of climate change on fish and fish habitat were assessed based on the results of the hydrology and water quality assessments. A summary of potential linkages between climate change and fish and fish habitat was provided in the EIA, Appendix 3-4, Section 8. Species at the edge of their geographical range, such as Arctic grayling, are likely the more sensitive to changes in climate while most fish species found within the LSA are adapted to a range of environmental conditions throughout their geographic distribution that are within the range of variability predicted under climate change. Changes to hydrologic and thermal regime caused by changes in climate may be more beneficial to some species and detrimental to other species.

The five forecasted climate scenarios evaluated predict a range of potential outcomes which may result in either an increase or a decrease in flow conditions in the Athabasca River and the small streams within the PRM LSA. In the Athabasca River, the implementation of the Water Management Framework (AENV and DFO 2007) would mitigate potential effects to fish habitat. Under climate scenarios that predict more frequent low flow periods, water withdrawal restrictions would be implemented more frequently and, as a result, water withdrawals attributed to PRM would not contribute to further reductions in low flow conditions beyond what would be predicted under climate change alone. At closure, geomorphically designed channels will be constructed to convey flows from the Eymundson Creek and Pierre River watersheds. The channels will be designed to provide habitat for target fish species in the region and will designed to accommodate the predicted flow conditions and can accommodate any potential changes in flow that may occur under climate change at the time of design and construction. Climate change scenarios that predict increases in winter flows would be considered beneficial to many regional fish species as overwintering fish habitat is generally considered to be limited in the small streams within the LSA due to low winter flow conditions.

As a component of the PRM, South Redclay Lake is proposed as fish habitat compensation to offset project related effects to fish habitat. South Redclay Lake will remain a sustainable option under the climate change scenarios evaluated and the conclusions presented in the Draft No Net Loss Plan will remain valid. The outlet channel for South Redclay Lake will be designed to suit the predicted flow regime at the time of construction to provide habitat conditions suitable for the target fish species. As a result, the losses to fish habitat as a result of PRM can still be fully compensated under climate change.

Water quality conditions under climate change for the 2013 PRM Application Case were predicted to be negligible compared to the EIA Application Case. While some variability in water quality results are predicted under the 2013 PRM Planned Development Case under the climate change scenarios evaluated, water quality constituents remain below applicable thresholds and the conclusions presented in the EIA would remain unchanged, and therefore the predicted effects of water quality on fish and fish habitat would also remain unchanged from the EIA.

Taking into account the mitigation and compensation associated with the PRM, as well as regional adaptive management programs, the cumulative effects of climate change are not expected to change the overall effects assessment and classification for the PRM.

7.0 EFFECTS OF CLIMATE CHANGE ON THE TERRESTRIAL ASSESSMENT

An evaluation of the historic and predicted future changes in temperature and precipitation was completed. The possible changes in temperature and precipitation were then considered in the evaluation of effects to the PRM for the success of the reclaimed landscape.

7.1 Effects of Climate Change on the Growing Season in the Boreal Forest

The reclaimed landscape for the PRM will be planted with typical boreal forest vegetation communities. These vegetation communities are found at various latitudes and elevations throughout the boreal forest and are exposed to a wide range of climatic conditions. Temperature data from the southern edge of the boreal forest (Bisset, Manitoba and Athabasca, Alberta) and the northern edge (Yellowknife, NWT) were evaluated to determine whether predicted future temperatures in the Fort McMurray area will be within the range of temperatures currently experienced in the boreal forest region. Climate normal data was obtained from the Canadian Climate Normals 1971 to 2000 (Environment Canada 2013c).

The annual average temperatures in the boreal forest range from 1.4°C (Bisset) and 2.1°C (Athabasca) in the south to -4.6°C in the north (Yellowknife) (Environment Canada 2013c). The average annual temperature in Fort McMurray is 0.3°C. The predicted future climate trends indicate that the average annual temperature is expected to rise between 0.9 and 4.7°C in the Fort McMurray area from the 1961 to 1990 baseline (Table F-4). Based on these predicted trends, future annual average temperatures in the Fort McMurray area will be comparable to temperatures currently experienced at the southern edge of the boreal forest.

The minimum monthly temperatures observed in Athabasca and Yellowknife are -19.9°C and -30.9°C, respectively (Environment Canada 2013c). The minimum monthly temperature in Fort McMurray is -24.0°C. The predicted future climate change in winter temperatures shows an increase of 1.0°C to 6.1°C from the 1961 to 1990 baseline (Table F-4). This predicted trend indicates that minimum monthly temperature in the Fort McMurray area will be within the temperature range already experienced within the boreal forest region.

The maximum monthly temperatures observed in Athabasca and Yellowknife are 22.2°C and 21.1°C, respectively (Environment Canada 2013c). The maximum monthly temperature in Fort McMurray (23.2°C) is already warmer than the maximums observed at either the southern limit or the northern limits of the boreal forest. This suggests that maximum monthly temperatures currently recorded in the boreal forest are more localized phenomena. The future temperature change in Fort McMurray is predicted to increase between 0.9°C and 4.7°C from the 1961 to 1990 baseline (Table F-4). Although the future monthly maximum temperature for Fort McMurray is predicted to be higher than other boreal forest regions in Alberta or the Northwest Territories, it is still within the temperature range experienced by other boreal forest regions in Canada. For example, the monthly maximum temperature at Bisset, Manitoba is 24.9°C.

Summer temperature and precipitation account for the growing season and moisture availability required for vegetation development. An average summer temperature between 16.0°C and 19.0°C is predicted for the Fort McMurray region (Table F-5). Average winter temperatures are expected to be between -16.3°C and -11.2°C. Annual precipitation is predicted to range from 448 to 589 mm per year.

The climate ranges for tree species found in the regional study area are listed in Table F-9. As a major component of boreal vegetation communities, tree species show the range of climate variation for which boreal species are adapted. The forecasted Fort McMurray average temperatures for the 2050s are well within these species ranges of tolerances.

Table F-9 Boreal Tree Species Ranges of Climatic Tolerance

Tree Species	Summer (July) Mean Temp. [°C]	Lowest Mean Temp. [°C]	Highest Mean Temp. [°C]	Mean Annual Precipitation [mm]
trembling aspen	16 to 23	-34 to -61	32 to 41	180 to 1,020
balsam poplar	12 to 24	-18 to -62	30 to 44	150 to 1,400
paper birch	13 to 21	–	–	300 to 1,520
jack pine	13 to 22	-21 to -46	29 to 38	250 to 1,400
white spruce	13 to 21	-29 to -54	34 to 43	250 to 1,270
black spruce	16 to 24	-34 to -62	27 to 41	380 to 760
tamarack	13 to 24	-29 to -62	29 to 43	180 to 1,400
balsam fir	16 to 18	–	–	390 to 1,400

Note: Table adapted from Burns and Honkala (1990).

– = No data.

7.2 Soil Responses to Climate Change

Soil is a part of the natural world that is both affected by and contributing to global warming. Research indicates that climate change could affect soil in a variety of ways. The primary result of increased air temperatures are subsequent increases in soil temperatures (Golder 2005; Gundersen et al. 2006; Nakawatase and Peterson 2006). Increased winter air temperatures could also affect snowpack depth (Nakawatase and Peterson 2006). Snowpack depth affects soil temperature and the start and length of the growing season (Körner 1995). Furthermore, a reduced snowpack would reduce soil moisture (Nakawatase and Peterson 2006), which in combination with higher summer temperatures may lead to an increase in summer soil moisture stress for vegetation.

Changes in air temperature are expected to result in chemical, hydrological and biological changes in the soil environment (Golder 2005). Changes to the structure (e.g., horizon development), productivity, nutrient status and quality may be a result of warming soils. A variety of research predicts changes in the rates of soil/litter decomposition and nutrient cycling (Gundersen et al. 2006; Jamieson et al. 1999; Price et al. 1999). Changes in soil decomposition rates/litter decay rates are predicted to increase between 4% to 7% in northern Alberta (Golder 2005).

Many researchers have also suggested that increased precipitation would lead to increased leaching of soil nutrients in some soils, especially if temperature is increasing decomposition. Jamieson et al. (1999) predicted short-term positive increases in gross nitrogen (N) mineralization and hence nutrient availability. Gundersen et al. (2006) also predicted sustained high mineralization and nitrification rates. Another report found that the response to warming was an increase of 46% in net N mineralization (Rustad et al. 2001). Boreal forest growth is strongly limited by the availability of nitrogen in the soils (Jerabkova et al. 2006). Changes to soil biogeochemistry resulting in increases in N mineralization levels could result in short-term increases in vegetation productivity.

Lastly, greenhouse gases are increasing levels of carbon dioxide (CO_2) and N deposition to the soils. While both may act as a fertilizer, N deposition is also speculated to acidify soils and reduce tree growth in some circumstances (Loehle 2003). Soil is one of the largest sources of carbon in the world (Soil-Net 2006). It is primarily accumulated through plants that “fix” the carbon from CO_2; the soil then directly absorbs the carbon as the plants decay. Gundersen et al. (2006) found that increased atmospheric CO_2 initially results in increased storage of carbon in the upper soil layers and biomass. However, carbon is naturally broken down in the soil and released to the atmosphere as CO_2 gas.

As the air temperature increases, decomposition occurs more rapidly, which may potentially contribute to global warming (Jamieson et al. 1999; Zhou et al. 2005). Complex interactions exist among variables such as temperature, moisture, decomposition and nutrient cycling. Thus, medium- to long-term effects of climate change to soil biogeochemistry have been more difficult to predict (Jamieson et al. 1999).

7.3 Vegetation Responses to Climate Change

Spatial distribution and species composition of the boreal forests are expected to change with the anticipated change in climate (Jamieson et al. 1999; Loehle 2003; Zhou et al. 2005). Biogeographic models predict widespread species migration (i.e., southern communities migrating northward) (Nakawatase and Peterson 2006). Some research predicts that many important species, particularly northern pines (Pinus spp.) and spruces (Picea spp.) may be extirpated from some areas because of climate change (Scheller and Mladenoff 2005; Walker et al. 2002). Loehle (2003) states that the rate at which a forest can be invaded, even by a much superior competitor, is limited by the rate at which openings become available (i.e., by disturbance). Intact forests are resistant to invasion and their response to moderate climate change should be slow with a prolonged transition on the order of 500 to 3,000 years. It will take hundreds to thousands of years for the forest population to come to a new equilibrium. Reclaimed ecosystems may be less resistant to invasion than established ecosystems.

Recent observations have strengthened the concept that species respond individually to climate change and not as a cohesive unit (Brooks et al. 1998; Loehle 2003; Nakawatase and Peterson 2006). Qinfeng et al. (2004) report that growth trajectories and responses of species under the same climate regimes were clearly highly individualistic, and even the same species performed differently under different climate conditions or when planted with different species. Because forest growth responds differently to climactic variability in different environments, management of forest ecosystems will need to consider growth response at local to watershed scales (Nakawatase and Peterson 2006).

Research indicates that the southern boundary of the central Canadian boreal forest is controlled by water limitations and fire frequency, while the northern boundary is controlled by temperature limitations (Brooks et al. 1998). Because temperature and precipitation are two of the dominant controlling factors in the central Canadian boreal forest boundary, they are two of the most important factors to examine when considering vegetation response to climate change in the boreal forest.

Temperature affects many processes in plants including photosynthesis, respiration and growth, as well as the flux of pollutants to the plant (Brooks et al. 1998). Warm and dry summer conditions increase respiration rates, and reduce photosynthetic production, leaf area and energy reserves (Nakawatase and Peterson 2006). Furthermore, in areas that become drier, fire return intervals are expected to become shorter and fire intensities are expected to increase (Golder 2005; Nakawatase and Peterson 2006). Warmer spring temperatures lengthen the growing season by accelerating snowmelt. Theurillat and Guisan (2001) concludes that since the early 1960s the average annual growing season in a European study area has lengthened 11 days, and is the result of an increase in mean annual air temperature.

Precipitation also has many effects on vegetation, with the most prominent being on soil properties including moisture and temperature (Brooks et al. 1998). An important factor regarding changes in climate is that seasonal distribution of increased precipitation and temperature are usually more important than annual amounts (Brooks et al. 1998). Bell and Threshow (2002) also indicates that changes in the climate could also lead to changes in the development pattern of species, thus affecting inter-specific and dependent relationships within natural communities.

Potential responses to climate change include persistence in the modified climate, migration to more suitable climates, or extinction. Potential persistence outcomes include gradual genetic adaptation of populations, phenotypic plasticity (individual variations in properties produced by given genotypes in conjunction with the environment), or ecological buffering (edaphic climax as opposed to climatic climax) (Theurillat and Guisan 2001). Evidence gleaned from past climate change has indicated that species are more likely to respond by migration as opposed to adapting genetically. Thus, increased temperature could result in migration of species to traditionally cooler areas, including migration further north and higher in elevation (Theurillat and Guisan 2001).

Disturbance plays an important role in a community's response to climate change. Active competition among trees is largely confined to the seedling and sapling stage, with the duration of canopy occupancy also playing a competitive role (Loehle 2003). Forest invasion is limited by open spaces that are created via disturbance. It has been found that increased disturbance speeds up competitive displacement and clearly speeds up the invasion process. Disturbance may accelerate the shift toward more southern species, although the effect is variable across the landscape (Scheller and Mladenoff 2005).

Regardless of which response vegetation has to climate change, each species will adapt based on their most limiting factors, thus complete communities may not respond the same way, or at all, to changes in the climate.

7.4 Impacts of Climate Change on Wildlife in the Oil Sands Region

Climate change may impact wildlife by changing boreal forest and river and delta habitat conditions within the boreal forest natural region. The boreal forest is home to the largest diversity of birds in North America. Surveys prior to disturbance of an oil sands lease identified 197 species of birds (Doucet 2004). The oil sands lease area was also identified as a primary migratory route for water birds. A total of 44 mammal species, 23 to 27 fish species, over 191 taxa of phytoplankton, and well over 50 taxa of benthic invertebrates have been identified within the oil sands region (Doucet 2004).

The impacts of climate change on wildlife are difficult to predict (Cohen 1997). The lack of long-term data, complexity of life cycles, and incomplete information on wildlife responses to previous environmental changes impede research. Ecosystems will not move wholesale in response to climate change, rather, each species will react differently (Markham 1996). In general natural adaptation can take three main forms, including evolution, acclimatization or migration to suitable sites, with the latter probably the most common response (Markham 1996; Reed 2001).

The current rate of climate change creates a situation in which many organisms are unlikely to be able to adapt or migrate fast enough (Markham 1997; Weber and Flannigan 1997). Changes in climatic are predicted to range from one to two orders of magnitude faster than the rates experienced by the boreal forest during the past 100,000 to 200,000 years (Weber and Flannigan 1997). Poleward migration rates of 1.5 to 5.5 km/year would be necessary, a fact which severely restricts the development and migration of ecosystems (Gear and Huntley 1991 in Weber and Flannigan 1997). These migration rates have the potential to reduce biodiversity by selecting for highly mobile and opportunistic species (Malcolm et. al. 2002; Peters and Darling 1985 in Markham 1996).

Wildlife face further challenges for migration. For example, although most birds are extremely mobile, some species will not cross open clearings even as small as tree fall gaps (Markham 1996). Therefore, ecosystems already stressed by human activities will be more vulnerable to climactic threats. Other animals are associated with specific vegetation species or formations and may fail to migrate or may migrate in synchrony with the availability of transient food sources.

Another concern is the affect of increasing wildfires to wildlife migration (Cohen 1997). It has been largely recognized that the new climate scenario may result in increased fire frequency and an increase in the area to potentially be burned (Li et. al. 2000; Natural Resources Canada 2007; Rothman and Herbert 1997 in Cohen

1997; Weber and Flannigan 1997). Wildlife species with a body size greater than 1 kg will be most affected by shifts in landscape structure associated with the rapid forest cover changes from wildfires (Thompson et al. 1997 in Weber and Flannigan 1997). An example is the impacts of wildfire to caribou habitat; the distribution and abundance of terrestrial lichens are reduced and will not recover for decades following a fire (Boutin et. al. 2006). Thus, changing fire patterns will likely affect the distribution of caribou.

Another challenge associated with climate change could be lower water levels during fall and winter (Kerr 1997 in Cohen 1997), which could reduce the probability of spring flooding in wetlands and deltas (Cohen 1997). Flooding is vital, especially to the perched ponds and lakes that are separated from the open-water channel system. In-stream flow requirements for ecological purposes are very important for fish, birds and other wildlife. The Peace-Athabasca Delta provides important habitat for fish, migratory waterfowl, and large populations of waterfowl, muskrat, beaver and free-ranging wood bison (Cohen 1997; Environment Canada 2007; Environmental Research and Studies Centre 2007). This delta has recently experienced low water levels (Kerr 1997 in Cohen 1997) that have been attributed to climate variation and the flow regulation of the Bennett Dam (Environmental Research and Studies Centre 2007). During prolonged dry periods in the last 25 years, some aquatic ecosystems have turned into terrestrial ecosystems. This change may cause declines in fish and small-mammal habitats and populations (Environment Canada 2007).

Changes to water flow are predicted due to climate change. Increased evaporation is expected to offset increased precipitation and reduce river flows, causing fish stocks to decline (Baxter 2006). Studies imply that low flows also reduce oxygen levels during winter months, when rivers are sealed under ice and snow, because of continued respiration and decomposition of organic matter. Reduced oxygen concentrations under ice are known to be detrimental to the eggs and fry of fall-spawning species such as lake whitefish and bull trout. Other concerns are that late fall-early winter river stages may be too low for fall spawning fish to reach spawning sites or to allow fry to occupy key nursery sites in the river during winter (Environmental Research and Studies Centre 2007).

8.0 EFFECTS OF CLIMATE CHANGE ON THE HUMAN HEALTH ASSESSMENT

A literature review was conducted to summarize the potential linkages between climate change and effects on human and wildlife health. This literature review is not meant to be exhaustive, but it does highlight the key human health concerns related to climate change and provides a basis for interpretation of climate change predictions associated with the PRM.

Potential direct effects on human health include:

- temperature changes and heat waves;
- extreme weather events; and
- ultraviolet light.

Potential indirect effects on human health include:

- air pollution;
- communicable and vector borne diseases;

- flooding or drought; and
- food and water insecurity.

The relationship between climate change and potential health effects is uncertain. Much research has focused on infectious disease transmission and the relationship between daily weather and mortality. Since the Intergovernmental Panel on Climate Change's Third Assessment Report (IPCC 2001), extensive research has quantified the effect of heat waves on human health and additional research has increased our understanding of health risks associated with climate-related changes in air quality, disease, food-safety and water-related infections. Furthermore, climate change health-impact assessments have now been conducted in several countries and increased emphasis has been placed on the development of health policy to address climate change. However, studies of long-term trends in health impact as a result of climate are limited and progress remains slow in the development of climate-health impact models (IPCC 2007a). Some of the key challenges include (IPCC 2001):

- isolating the effects of climate change from the many other factors that affect human health (i.e., determining causality);
- recognizing variations in vulnerability of different human populations and the interactions between climate change effects and vulnerability variables;
- characterizing the uncertainty in the models used for estimating potential health impacts;
- understanding the interaction of climate change variables with other large-scale environmental changes (e.g., forest clearance, human population density, changing land use patterns, population movement);
- estimating exposure-response relationships for climate variables; and
- understanding the capacity of human populations to adapt to new climate conditions, either through physical adaptations in individuals or adaptation of public health systems, and the costs associated with such adaptation.

8.1 Temperature Change

According to the IPCC (2007b), global GHG emissions will continue to increase for the next three decades, further inducing temperature changes. Furthermore, global average temperatures are projected to increase by 0.2°C per decade for the next two decades (IPCC 2007b). The increased ambient temperatures as a result of climate change may have direct effects on human health due to increases in the frequency and intensity of heat waves, as well as warmer summers and milder winters (IPCC 2007a). Milder winters will likely reduce mortality due to cold; however, more frequent heat waves may increase the risk of heat-related mortality (IPCC 2007a). In particular, children and elderly, chronically ill and poor urban populations may be at greater risk (IPCC 2007a; WHO 2012). Populations in warm regions are typically sensitive to low temperatures and populations in cooler regions are typically sensitive to heat (Patz and Kovats 2002). Predicted changes in temperatures for the Oil Sands Region, assessed herein, are not such that they are expected to have health impacts to the resident communities.

8.2 Air Pollution

Climate change can influence the transport and/or formation of various airborne chemicals. Current research suggests that climate change may play a significant role in air quality due to factors such as changing weather conditions, chemical reaction rates, and airflow (Balbus et al. 2012; Ebi and McGregor 2008). Among the air pollutants, ground-level ozone and fine particulate matter are potential contributors to morbidity and mortality (Balbus et al. 2012; IPCC 2007a). Rising temperatures may also increase the vulnerability of humans to these harmful air pollutants. For example, higher temperatures have been found to increase cardiovascular stress, causing increased sensitivity to fine particulate matter (Balbus et al. 2012; Ebi and McGregor 2008). Overall, there remain minimal health risk studies regarding the interactions between high temperatures and exposure to air pollutants (Qian et al. 2008; Sujaritpong et al. 2012). The effects of climate change on air quality predictions were evaluated in Section 4 of this Attachment. The assessment indicates that the EIA process and predictions represent conservative estimates of current and future conditions. Therefore, the health assessment results for the air quality pathway, as presented in the EIA, would apply even under the considered climate change scenarios.

8.3 Water Quality

Water demand is expected to increase globally as the world population continues to grow rapidly, with climate change negatively impacting freshwater resources over time (IPCC 2007a). Changes in rainfall patterns and intensified runoff events due to climate change have been associated with reductions in water quality from aspects such as increased pathogen, microbial and nutrient loading (IPCC 2007a). The effects of climate change on water quality predictions were evaluated in Section 4 of Appendix 4. The results of the evaluation indicated that predicted water concentrations of all parameters evaluated under the climate change scenario were slightly higher than predicted water concentrations evaluated in the health assessment; however, concentrations of all parameters were predicted to remain below applicable thresholds in the Athabasca River. Therefore, the health assessment results for the water ingestion pathway would apply even under the climate change scenarios.

9.0 SENSITIVITY OF THE PIERRE RIVER MINE TO CLIMATE CHANGE

Section 3 discusses the potential climate change scenarios from the 1961 to 1990 baseline. Some potential climatic changes include:

- A rise in average annual temperatures of +0.9°C to +4.7°C.
- A change in precipitation ranging from -4% to 37%. A generally warmer and somewhat wetter climate. It is unclear whether this change will increase the frequency and severity of droughts.

9.1 Project Sensitivity and Adaptability to Climate Change

Following Canadian Environmental Assessment Agency guidance, the sensitivity and adaptability of the PRM to the potential impacts of climate change identified above was assessed qualitatively with the help of technical experts.

It is unlikely that a change in weather conditions would impact the transportation of materials and construction of facilities during the life of the PRM.

During the operations phase, an increase in average air temperature and in the number of high-temperature days will have little impact on the heat demand of the Projects. Fewer sub-zero days during the winter could slow mine operations slightly, but could be offset through increased investment in road construction. A rise in high-precipitation events could reduce the stability of mine faces, but this change could be managed through improvements in drainage at the site. Should evidence of increased rainfall be forthcoming, site surface drainage and siltation management could be adjusted to accommodate this. In addition, the water balance could experience minor changes, with increased water quantities coming from surface drainage and the larger tailings pond due to precipitation and somewhat reduced need for fresh water withdrawal from the Athabasca River.

A reduction in water availability from the Athabasca River on a seasonal basis is a potential risk, but one which is shared by many users in the river basin. The PRM has taken this risk into consideration and has proposed a large external water reservoir that can provide a source of fresh water to these projects during low flow periods of the Athabasca River. The capacity of the external water reservoir will provide for a minimum of 30 days of storage of fresh water such that withdrawals from the Athabasca River can be reduced to a minimum for a minimum of 30 days during low flow events. Shell has an operating history in the region and is familiar with extreme weather events relative to the operation of an industrial facility in the area. The existing Muskeg River Mine has been constructed to meet extreme weather criteria and is not sensitive to observed climatic extremes.

The nature and the success of re-vegetation activities at the site during the decommissioning phase will depend on climate conditions at that time.

9.2 Follow-Up and Monitoring

The availability of water from the Athabasca River is an important element for the PRM success, and will be assessed and input into the detailed design that precedes construction of each phase of the PRM. Alteration in the magnitude and frequency of high and low water flow regimes in the river or to the level of ground water in the area will be reflected in detailed Project design. Changes to precipitation patterns, where these might impact the stability of mine face slopes or tailings pond containment capacity, will be closely monitored.

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11.0 ABBREVIATIONS

%	Percent
°C	Temperature in degrees Celsius
AAAQO	Alberta Ambient Air Quality Objectives
AENV	Alberta Environment
AET	Actual Evapotranspiration
CCP	Conceptual Compensation Plan
CEMA	Cumulative Environmental Management Association
CGCM2	Canadian Global Coupled Model – Version 2
CHTD	Canadian Historical Temperature Database
CICS	Canadian Institute for Climate Studies
CO_2	Carbon dioxide
CONRAD	Canadian Oil Sands Network for Research and Development
DO	Dissolved Oxygen
e.g.	For example
EIA	Environmental Impact Assessment
FPTCCCEA	Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment
GCM	General Circulation Model
GHG	Greenhouse Gas
HSPF	Hydrological Simulation Program-Fortran
i.e.	That is
INAC	Indian and Northern Affairs Canada
IPCC	Intergovernmental Panel on Climate Change
m^3/s	Cubic metres per second
PAI	Potential Acid Input
SWWG	Surface Water Working Group of CEMA
TDS	Total Dissolved Solids
TOR	Terms of Reference
WBEA	Wood Buffalo Environmental Association
WITG	Watershed Integrity Task Group of the Cumulative Environmental Management Association

12.0 GLOSSARY

Benthic Invertebrates — Invertebrate organisms living at, in or in association with the bottom (benthic) substrate of lakes, ponds and streams. Examples of benthic invertebrates include some aquatic insect species (such as caddisfly larvae) that spend at least part of their lifestages dwelling on bottom sediments in the waterbody. These organisms play several important roles in the aquatic community. They are involved in the mineralization and recycling of organic matter produced in the water above, or brought in from external sources, and they are important second and third links in the trophic sequence of aquatic communities. Many benthic invertebrates are major food sources for fish.

Community — Plant or animal species living in close association or interacting as a unit.

Compensation (Fisheries) — The replacement of natural habitat, increase in the productivity of existing habitat or maintenance of fish production by artificial means in circumstances dictated by social and economic conditions, where mitigation techniques and other measures are not adequate to maintain habitat for Canada's fisheries resources.

Connectivity — A measure of how connected or spatially continuous a corridor or matrix is.

Cumulative Environmental Management Association (CEMA) — An association of oil sands industry, other industry, regional community representatives, regulatory agencies and other stakeholders designed to develop systems to manage cumulative effects associated with developments in the Oil Sands Region.

Dissolved Oxygen (DO) — Measurement of the concentration of dissolved (gaseous) oxygen in the water, usually expressed in milligrams per litre (mg/L).

Diversity — The variety, distribution and abundance of different plant and animal communities and species within an area.

Ephemeral — A phenomenon or feature that lasts only a short time (e.g., an ephemeral stream is only present for short periods during the year).

Evapotranspiration — The process by which water is transmitted as a vapor to the atmosphere as the result of evaporation from any surface and transpiration from plants.

Filterable Residue — Materials in water that pass through a standard-size filter (often 0.45 µm). This is a measure of the "total dissolved solids" (TDS), i.e., chemicals that are dissolved in the water or that are in a particulate form smaller than the filter size. These chemicals are usually salts, such as sodium ions and potassium ions.

Fish Habitat (*Fisheries Act*)	Spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly to carry out their life processes.
Guild	A set of co-existing species that share a common resource.
Hypolimnion	The deep, cold layer of a lake lying below the metalimnion (thermocline) during the time a lake is normally stratified.
Key Indicator Resources (KIRs)	Environmental attributes or components identified as a result of a social scoping exercise as having legal, scientific, cultural, economic or aesthetic value.
Littoral Zone	The zone in a lake that is closest to the shore. It includes the part of the lake bottom, and its overlying water, between the highest water level and the depth where there is enough light (about 1% of the surface light) for rooted aquatic plants and algae to colonize the bottom sediments.
Migration Route	The term for a pathway a fish follows to move from one area to another. Migration routes typically occur between areas that provide different habitat types or provide seasonal habitat needs for the fish. An example of a migration route is the route a fish uses to move from overwintering habitat to spring spawning habitat.
Piscivorous Diet	Feeding on fish.
Population	A collection of individuals of the same species that potentially interbreed.
Recharge/Discharge Area	Areas that either contribute (recharge) or take away (discharge) to/from the overall volume of groundwater in an aquifer.
Sediment	Solid material that is transported by, suspended in, or deposited from water. It originates mostly from disintegrated rocks; it also includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope soil characteristics, land usage and quantity and intensity of precipitation.
Spawning	The reproductive stage of adult fish which includes fertilization and deposition of eggs.
Stratify	Layering of lakes into two or more non-mixing layers; in summer, typically a layer of warmer, less dense water lies on a cooler, denser layer; in winter, typically a layer of very cold (<4°C), less dense water overlies warmer, denser water (approximately 4°C).

Total Dissolved Solids (TDS)	The total concentration of all dissolved compounds solids found in a water sample. See filterable residue.
Turbidity	An indirect measure of suspended particles, such as silt, clay, organic matter, plankton and microscopic organisms, in water.
Yield	The harvest, actual or estimated, of living organisms, expressed as numbers, weight, or as a proportion of the standing crop, for a given period of time.
Young of the Year (YOY)	Fish at age 0, within the first year after hatching.

ATTACHMENT G

Water Quality Figures

Figure G-1 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 PRM Application Case

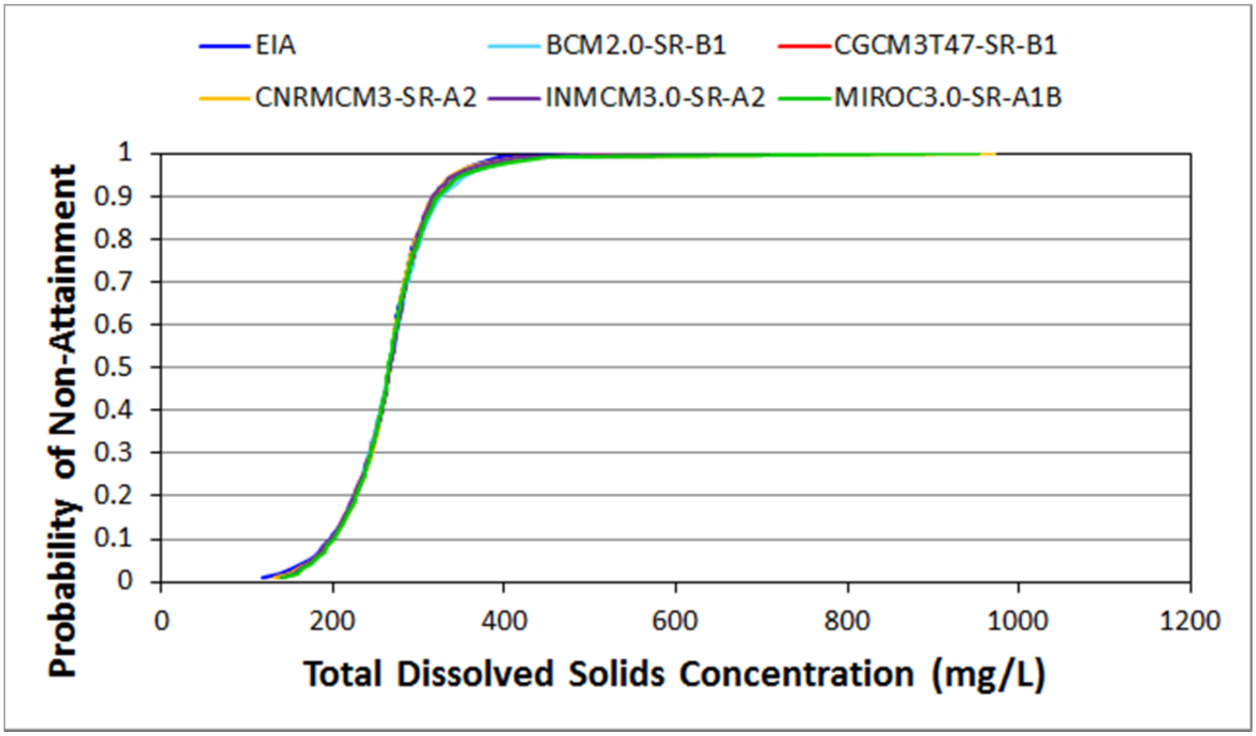


Figure G-2 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 PRM Application Case

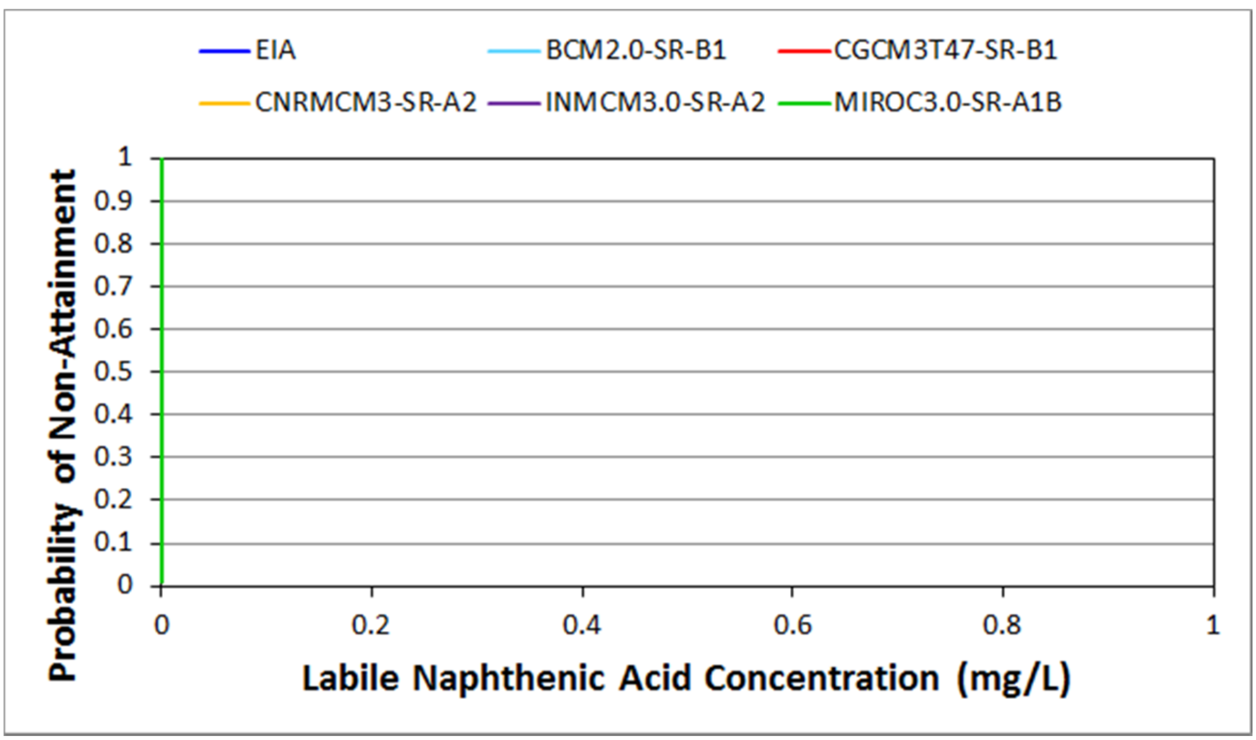


Figure G-3 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 PRM Application Case

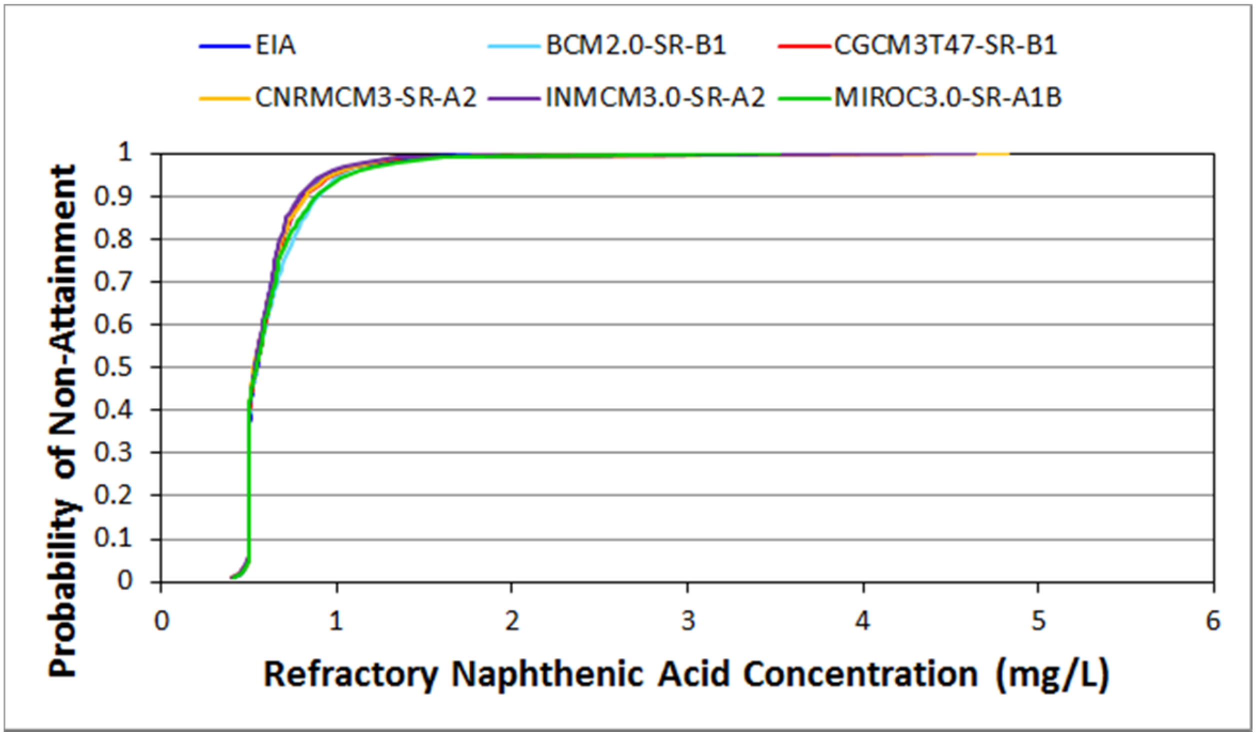


Figure G-4 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 PRM Application Case

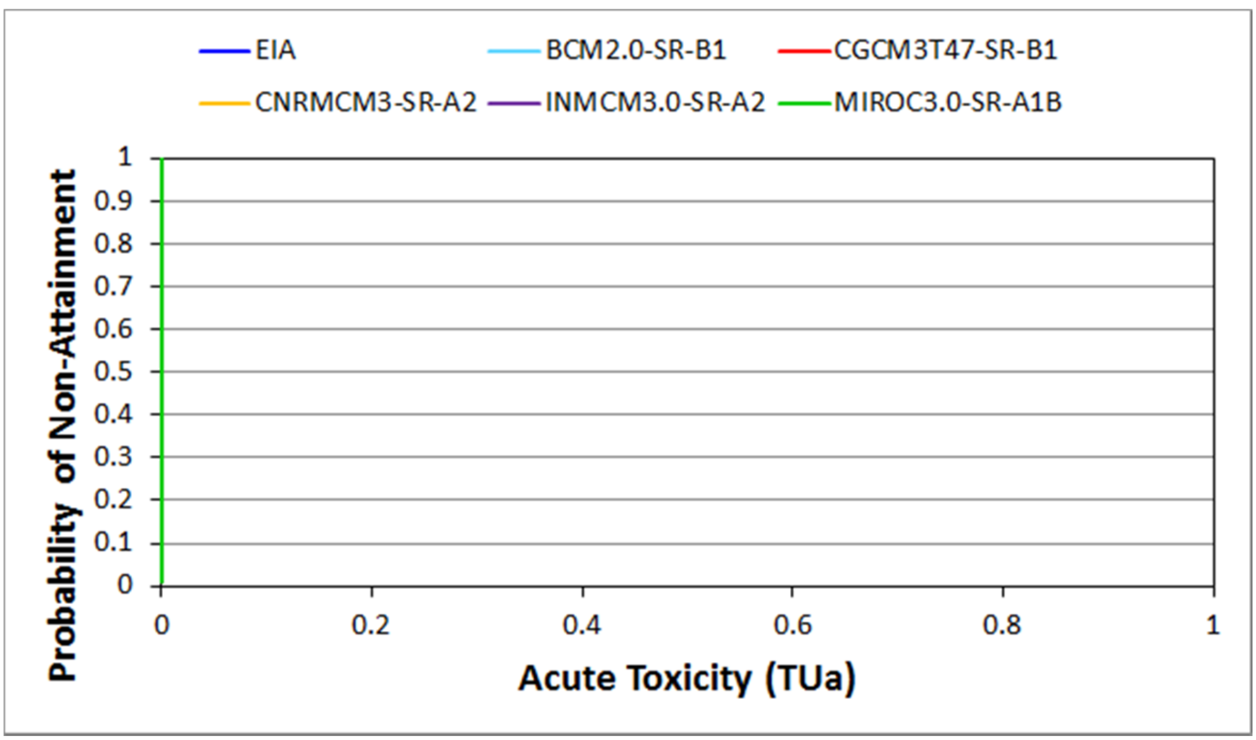


Figure G-5 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 PRM Application Case

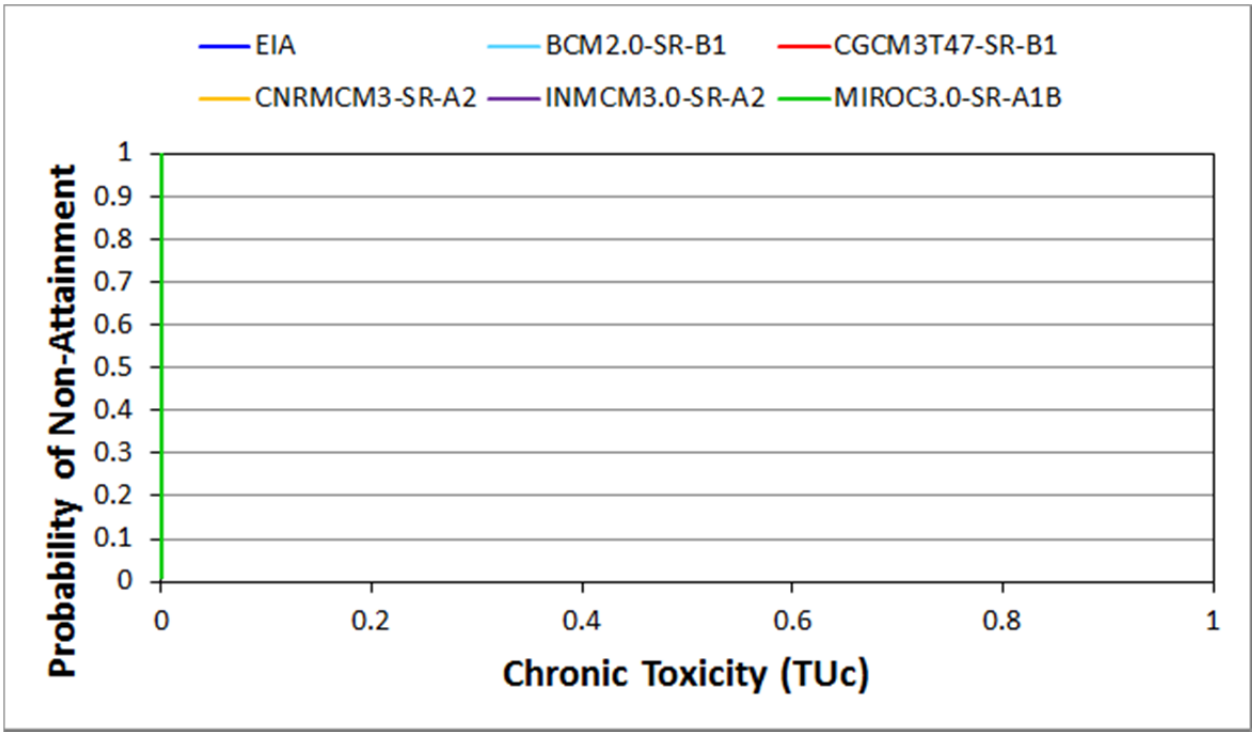


Figure G-6 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 Planned Development Case

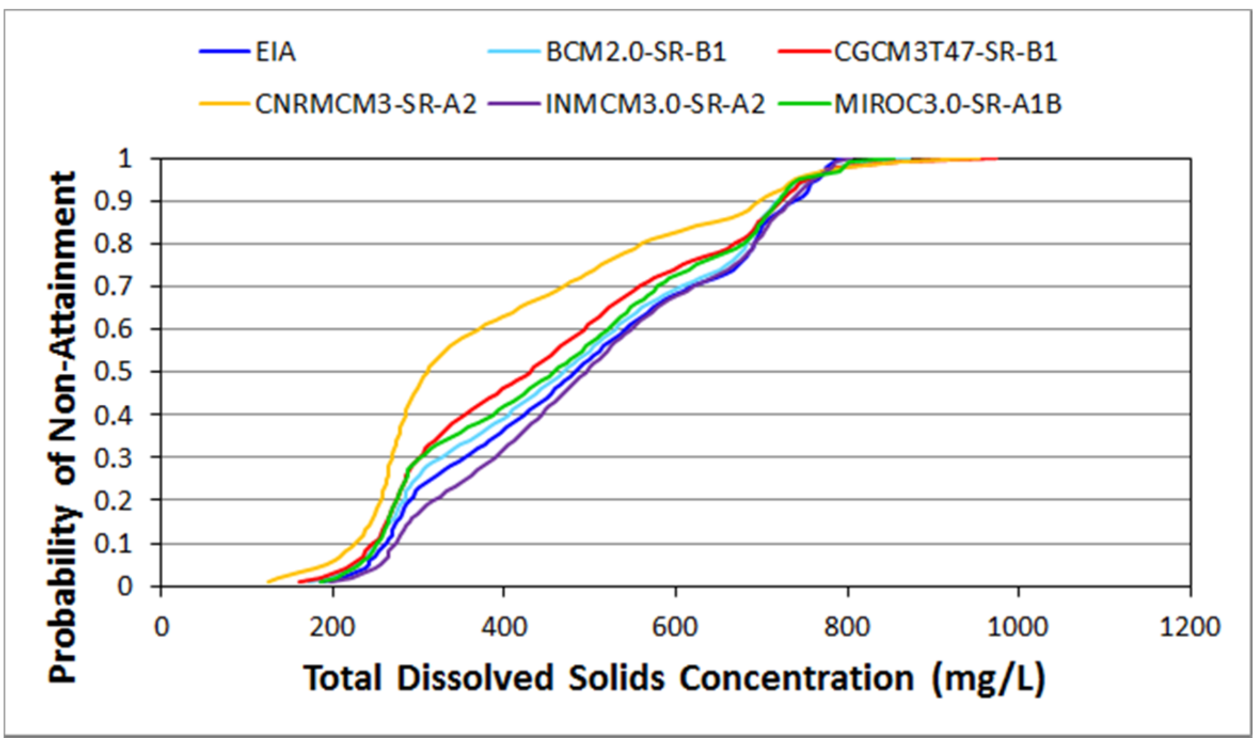


Figure G-7 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 Planned Development Case

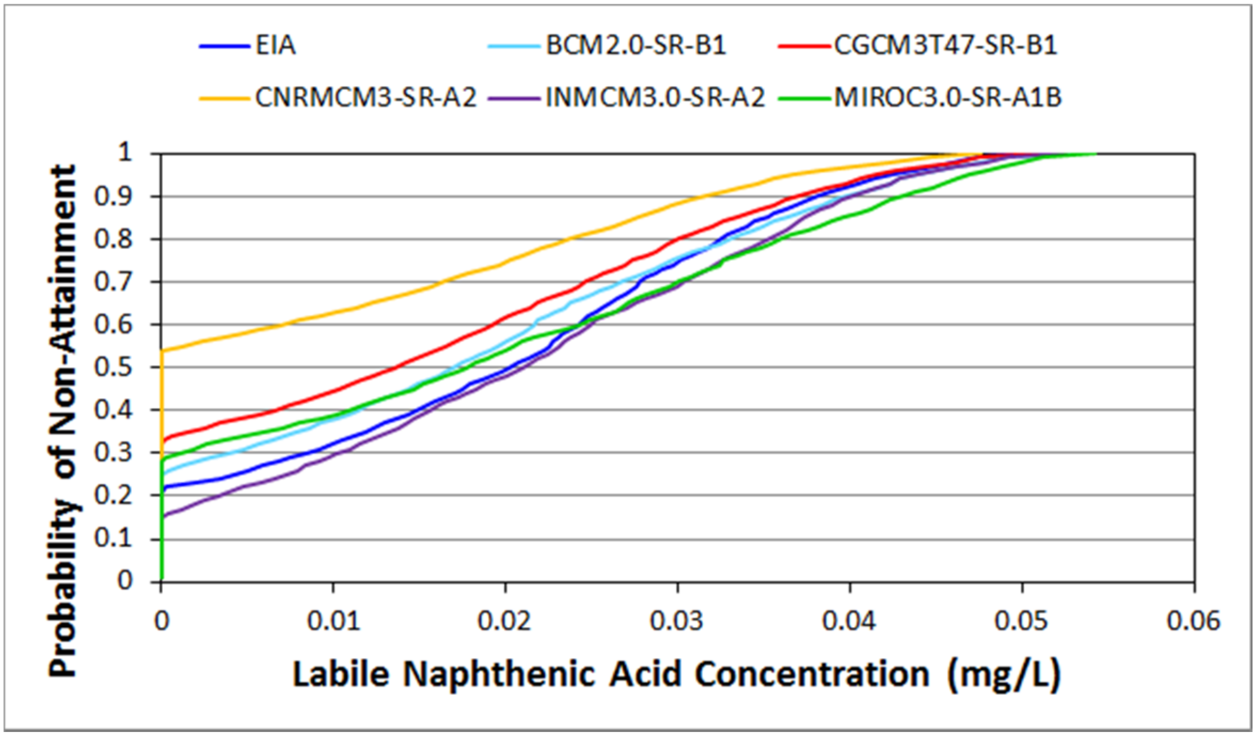


Figure G-8 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 Planned Development Case

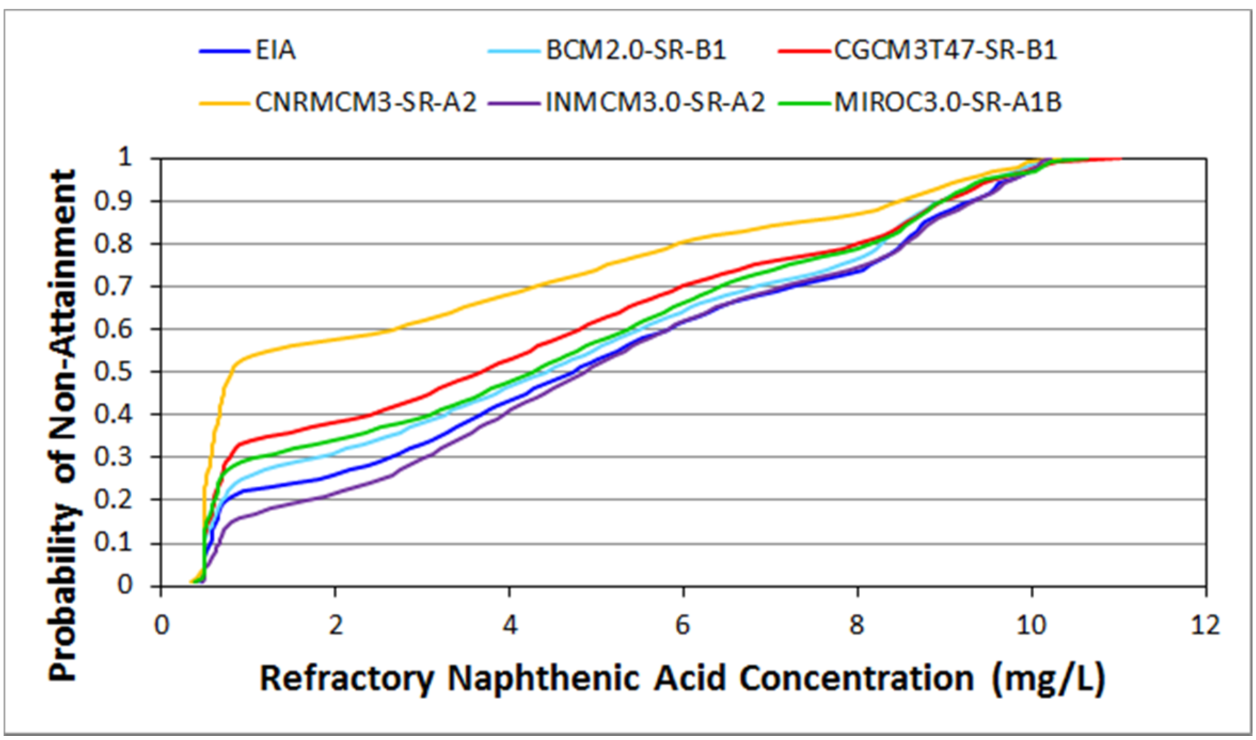


Figure G-9 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 Planned Development Case

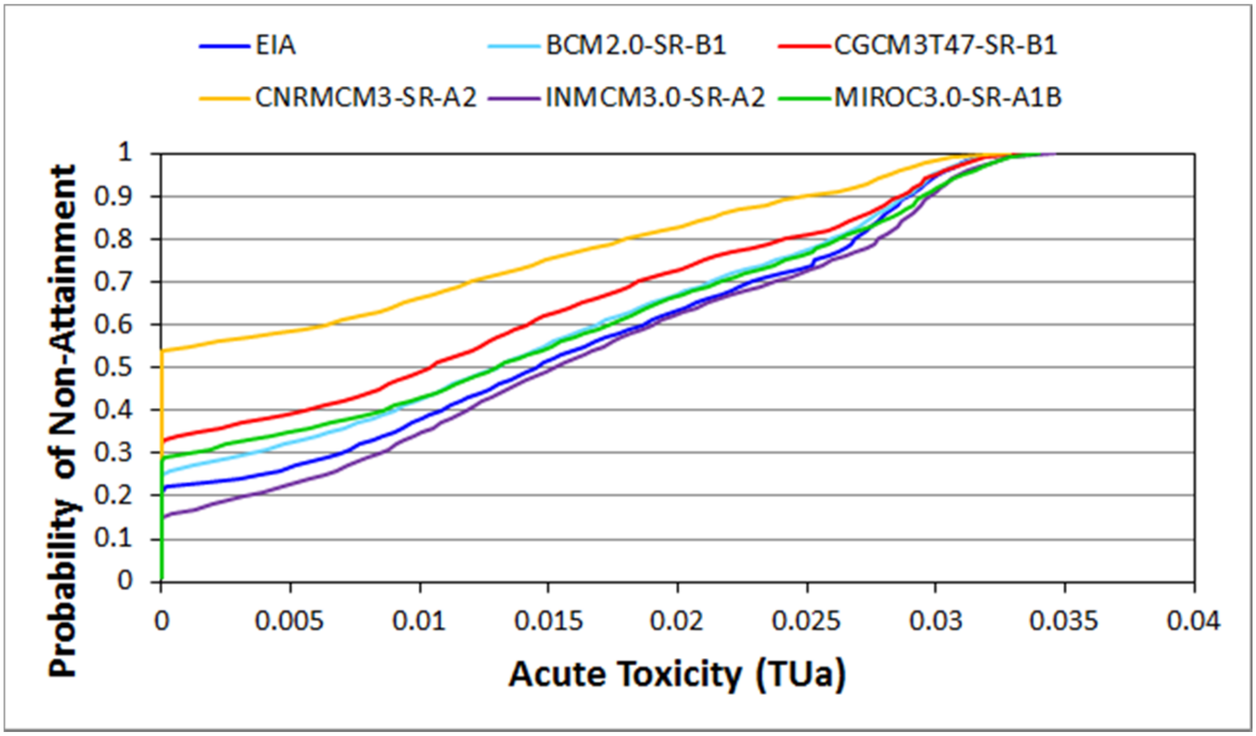


Figure G-10 Predicted Concentration Distribution Under Various Climate Scenarios at Big Creek for the 2013 Planned Development Case

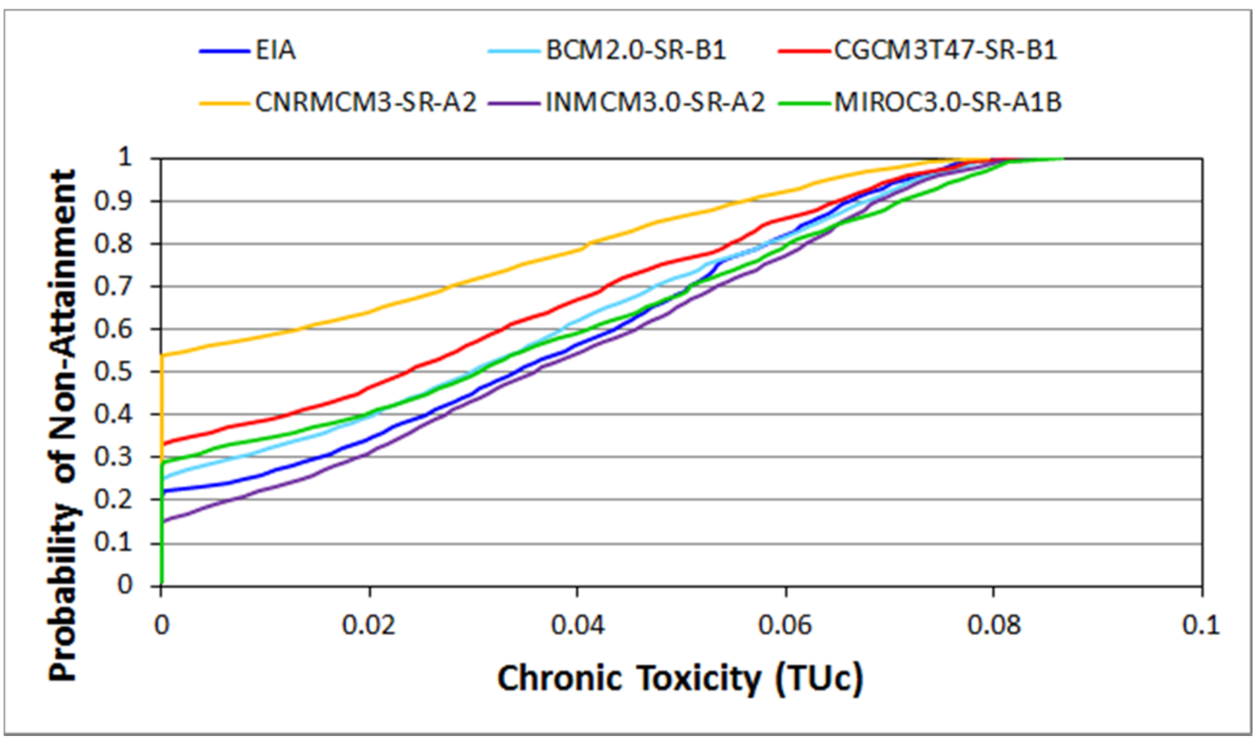


Figure G-11 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 PRM Application Case

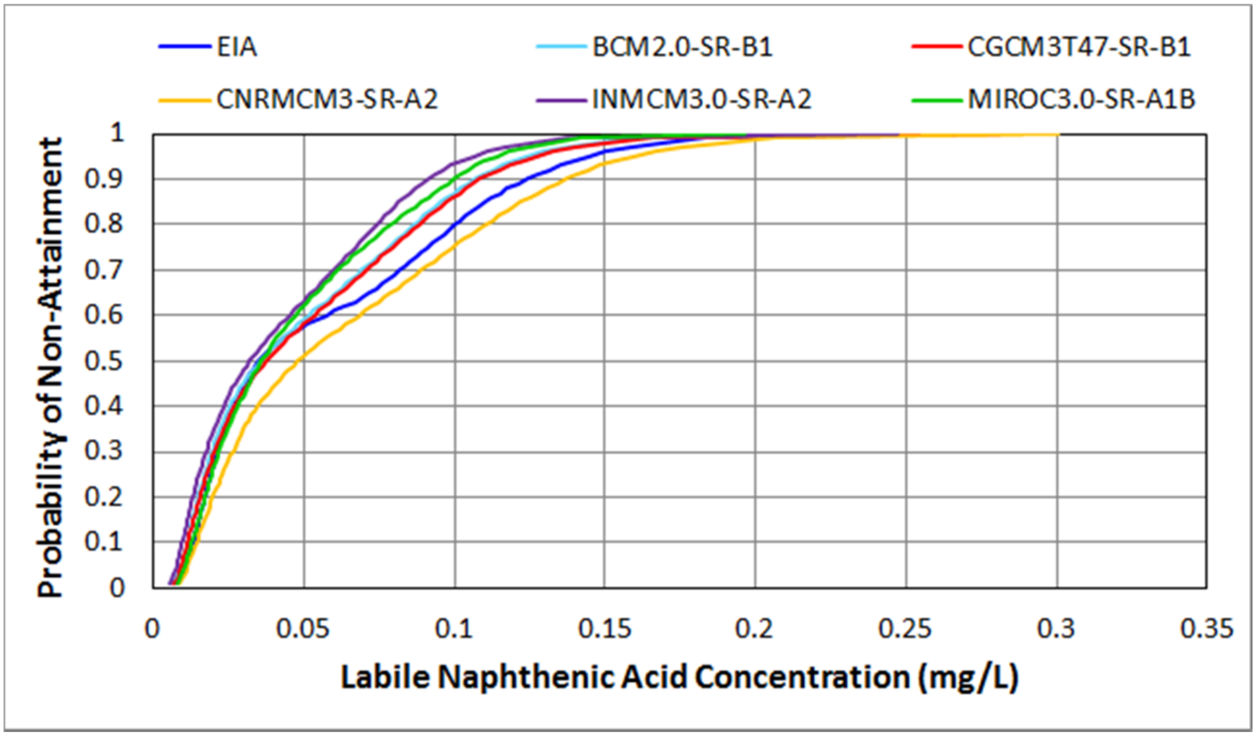


Figure G-12 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 PRM Application Case

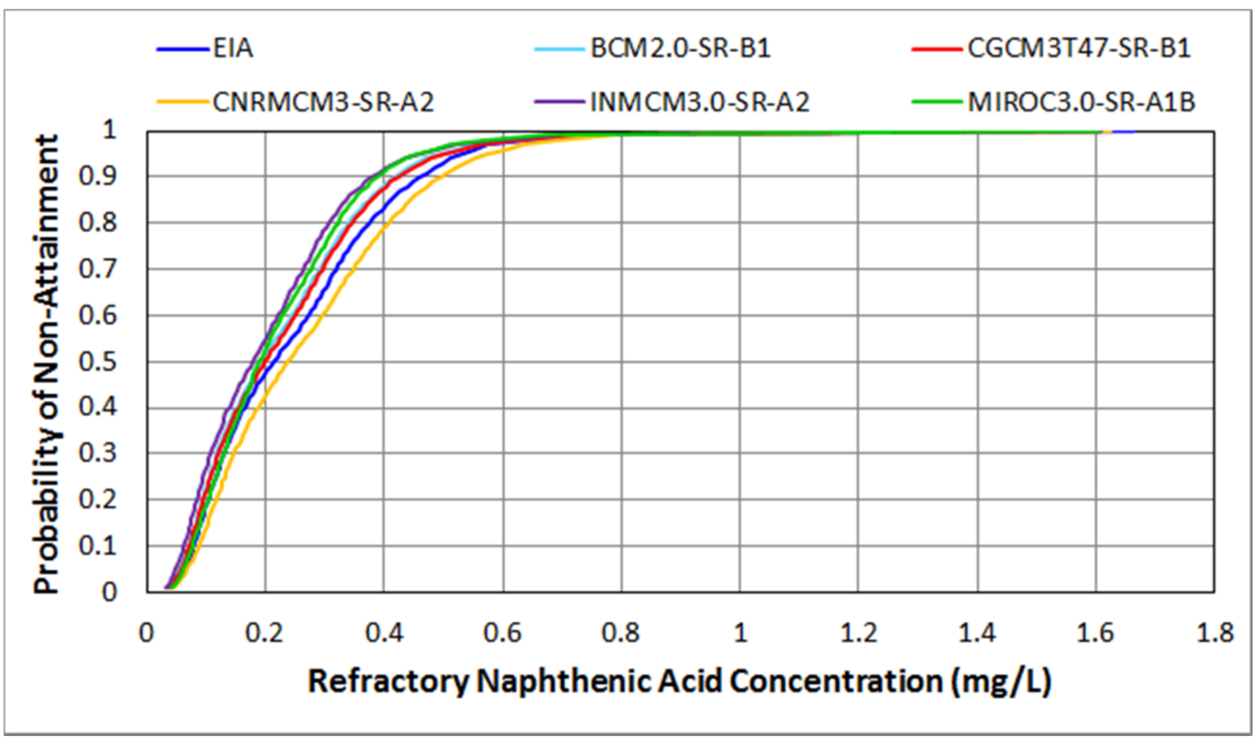


Figure G-13 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 PRM Application Case

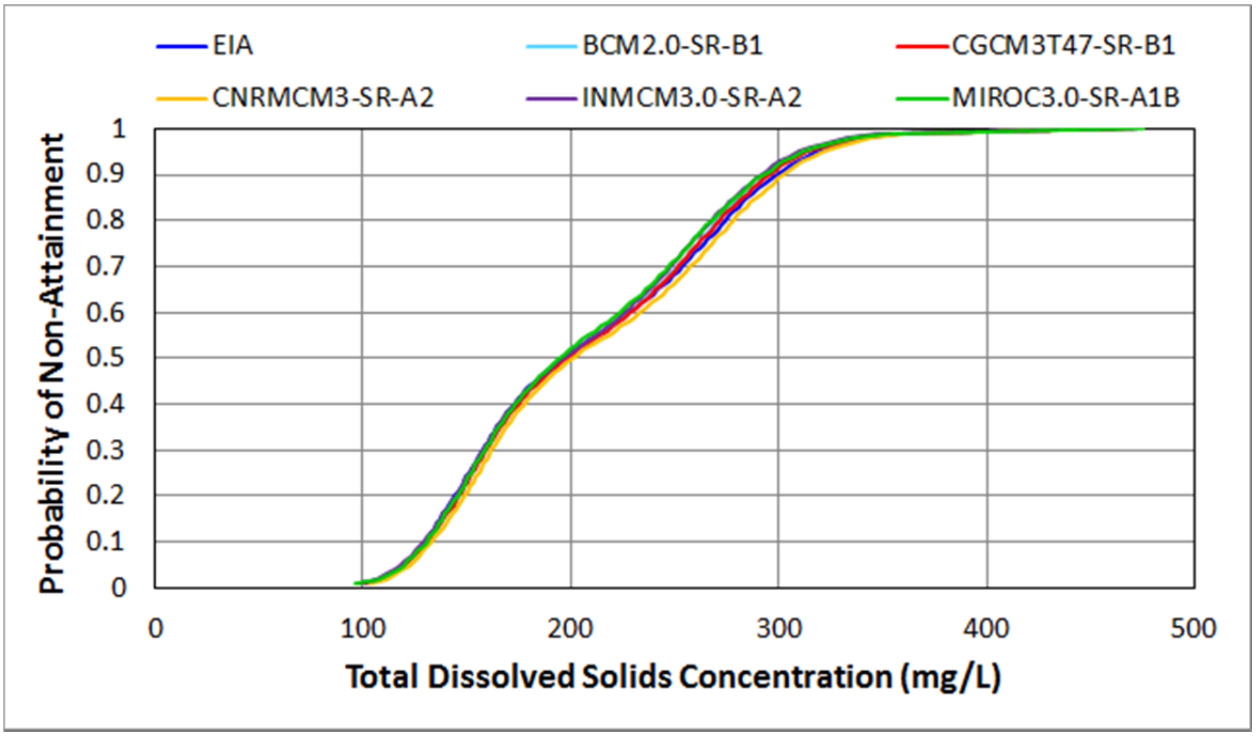


Figure G-14 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 PRM Application Case

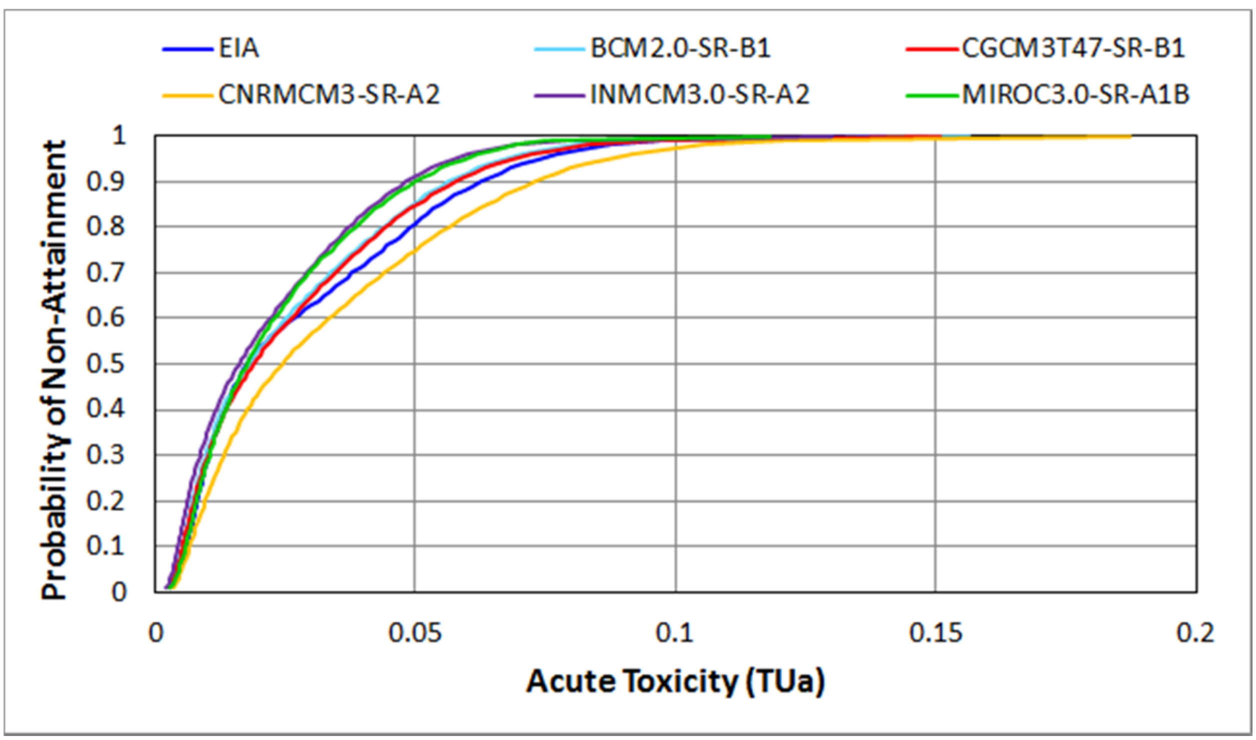


Figure G-15 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 PRM Application Case

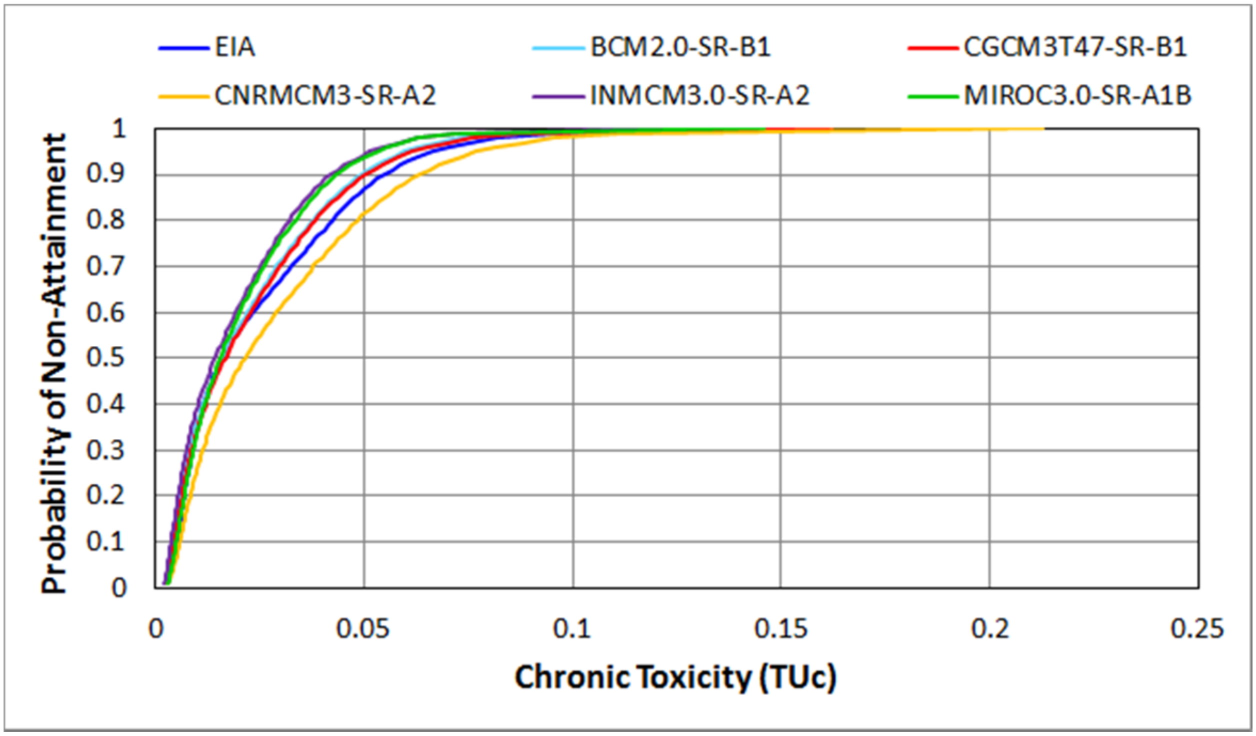


Figure G-16 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 Planned Development Case

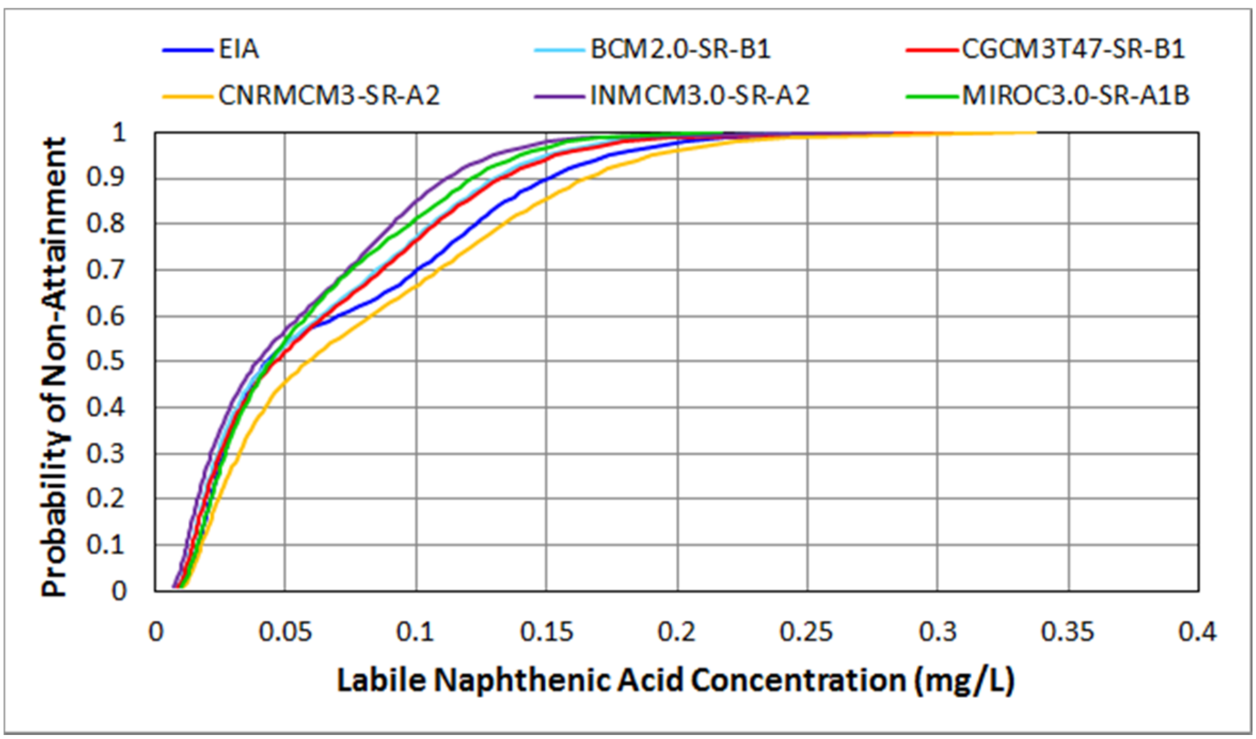


Figure G-17 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 Planned Development Case

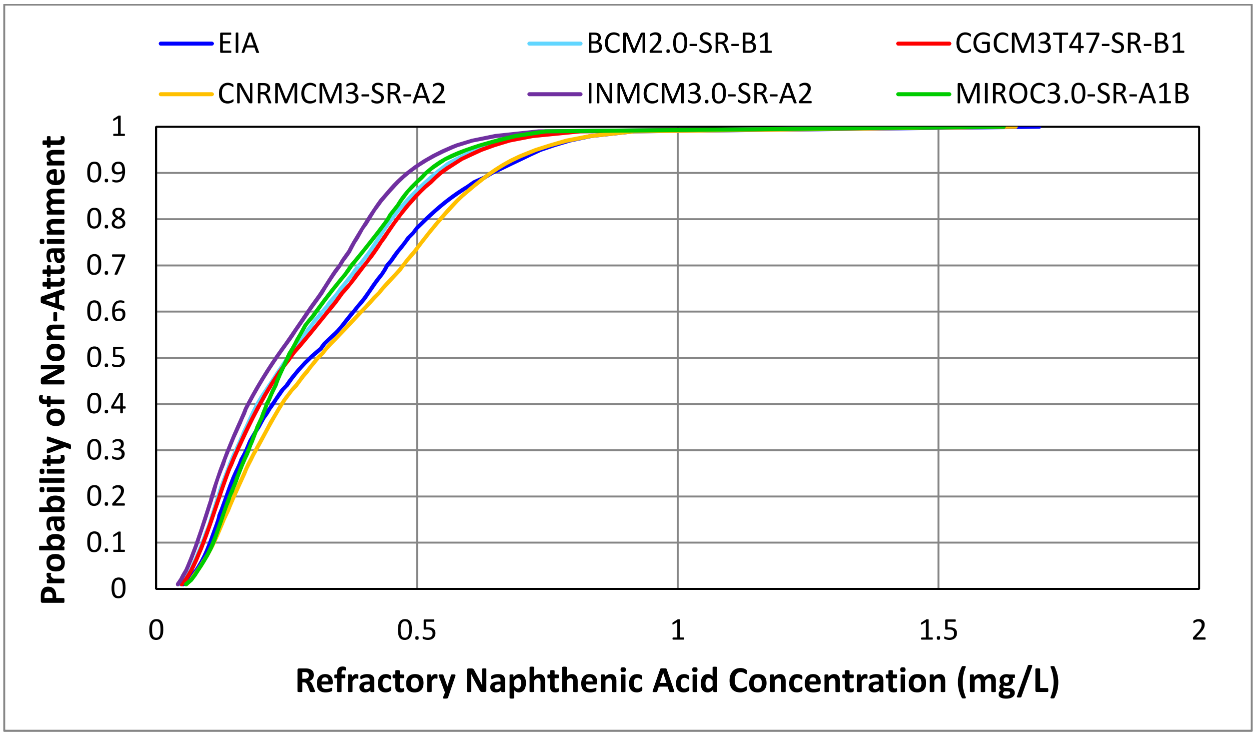


Figure G-18 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 Planned Development Case

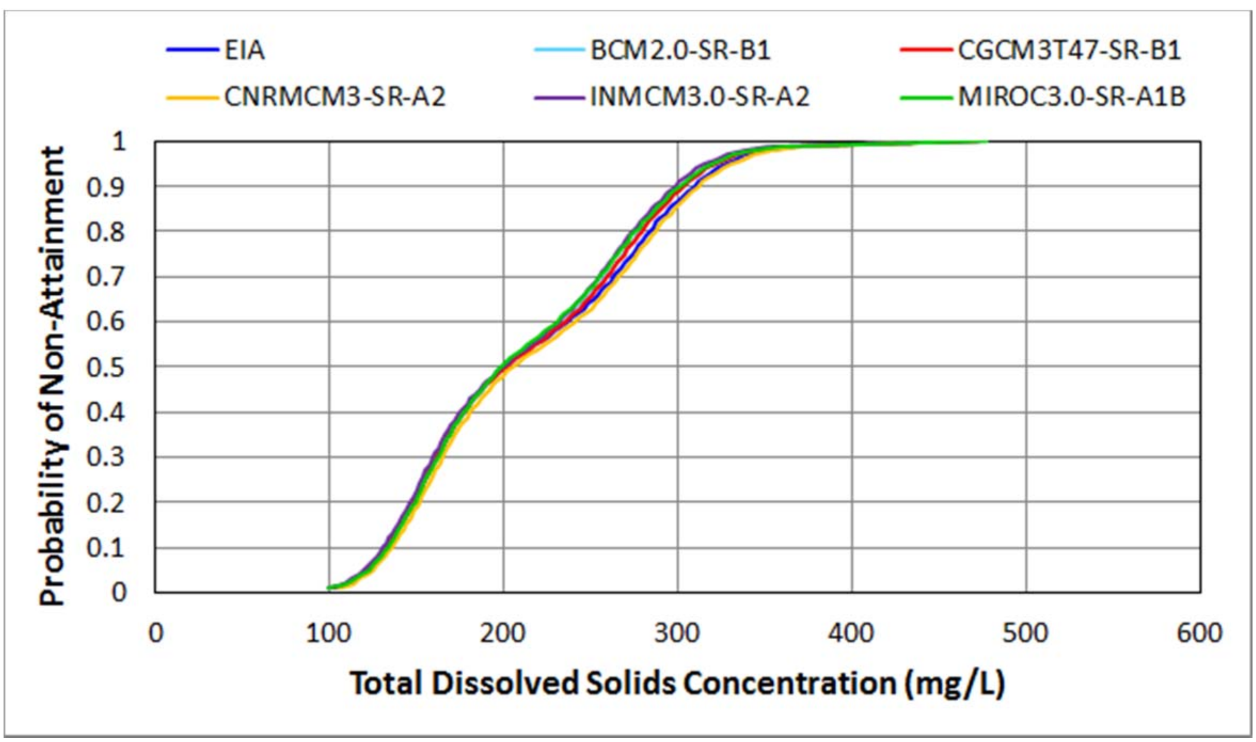


Figure G-19 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 Planned Development Case

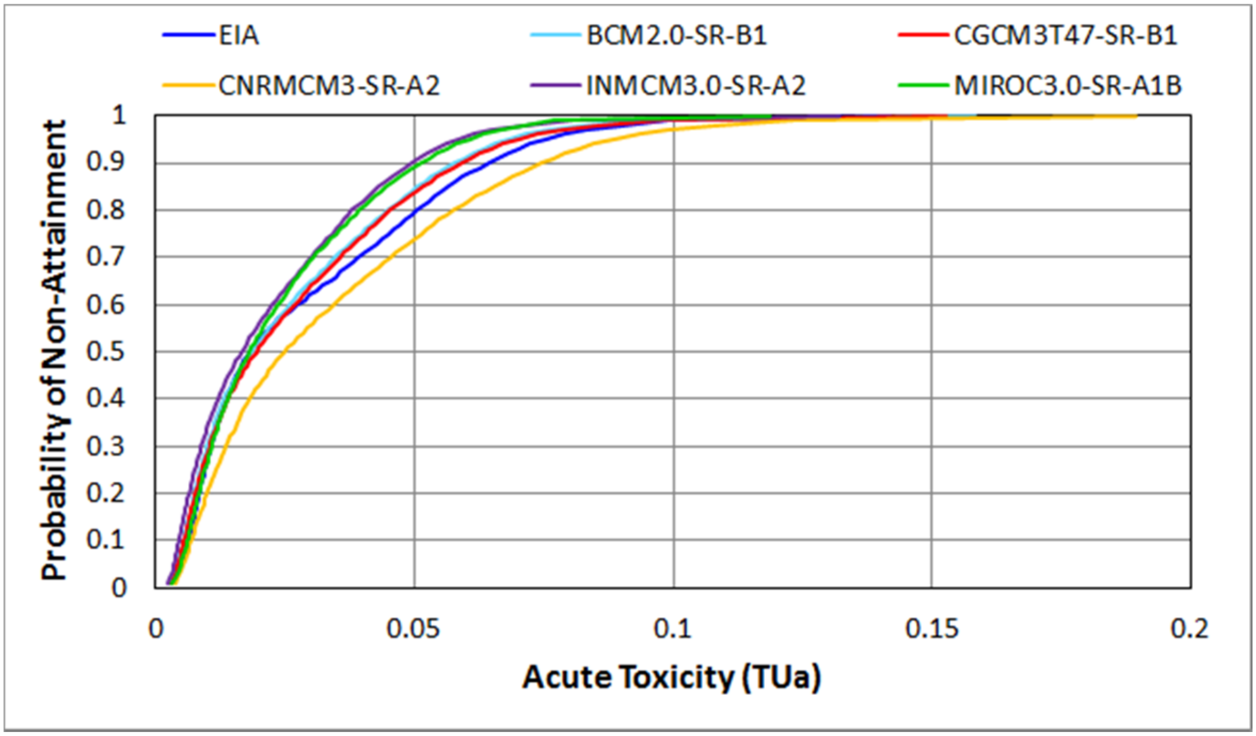


Figure G-20 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Redclay Creek for the 2013 Planned Development Case

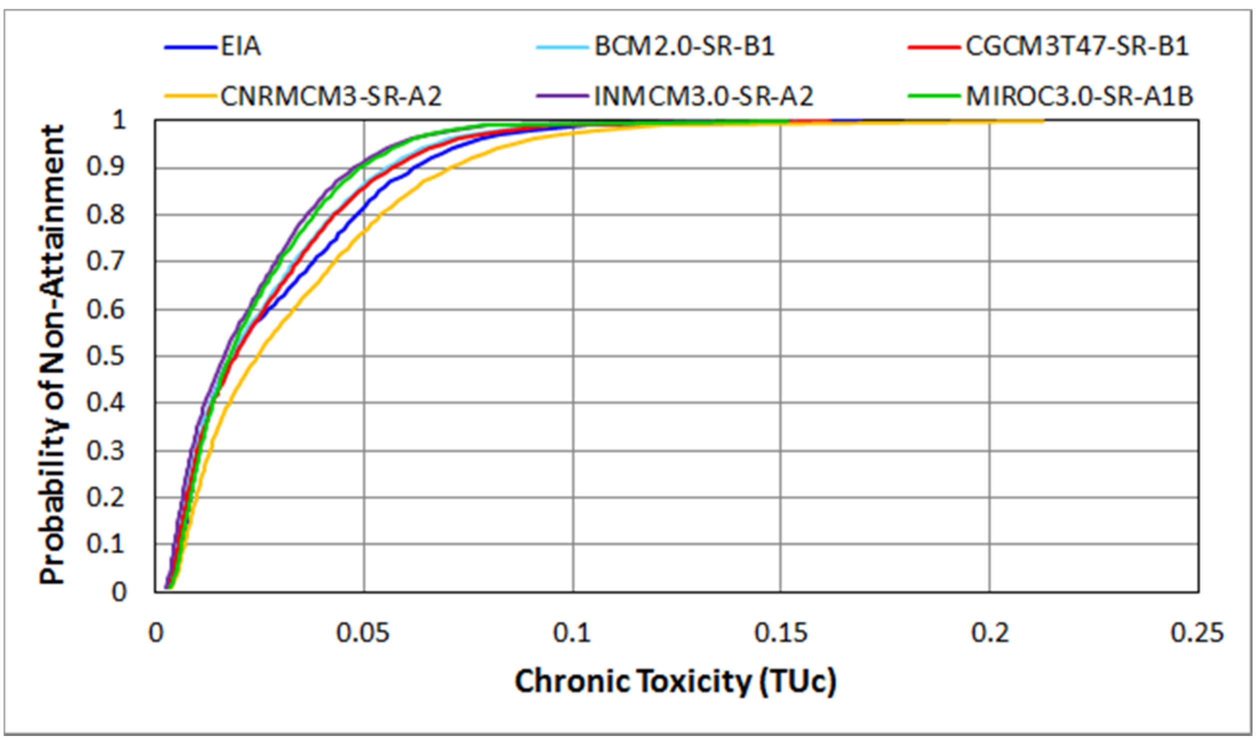


Figure G-21 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 PRM Application Case

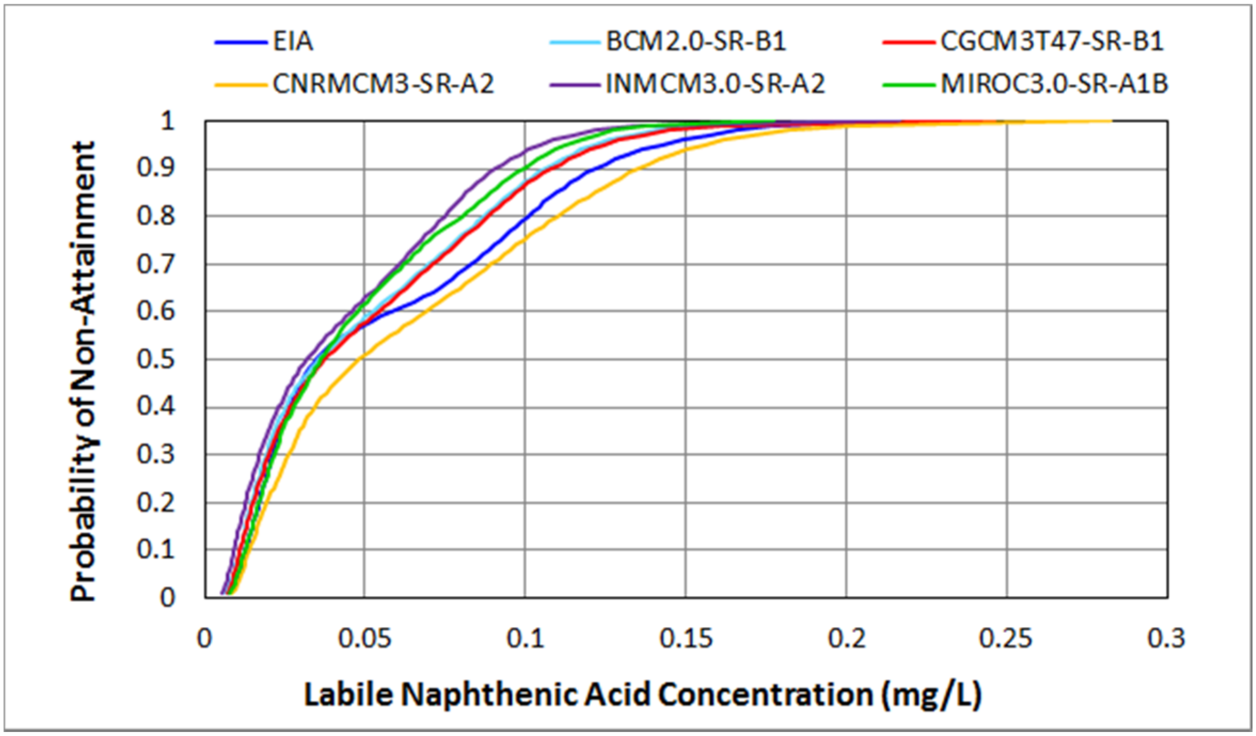


Figure G-22 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 PRM Application Case

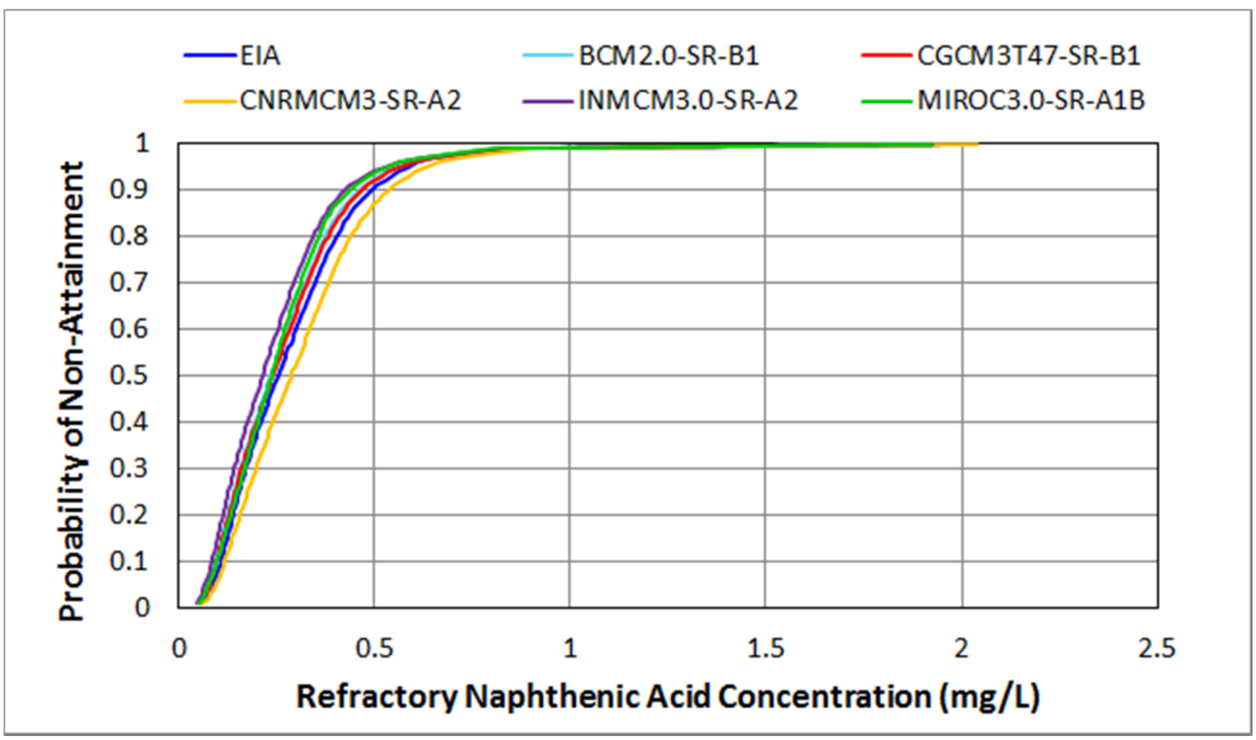


Figure G-23 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 PRM Application Case

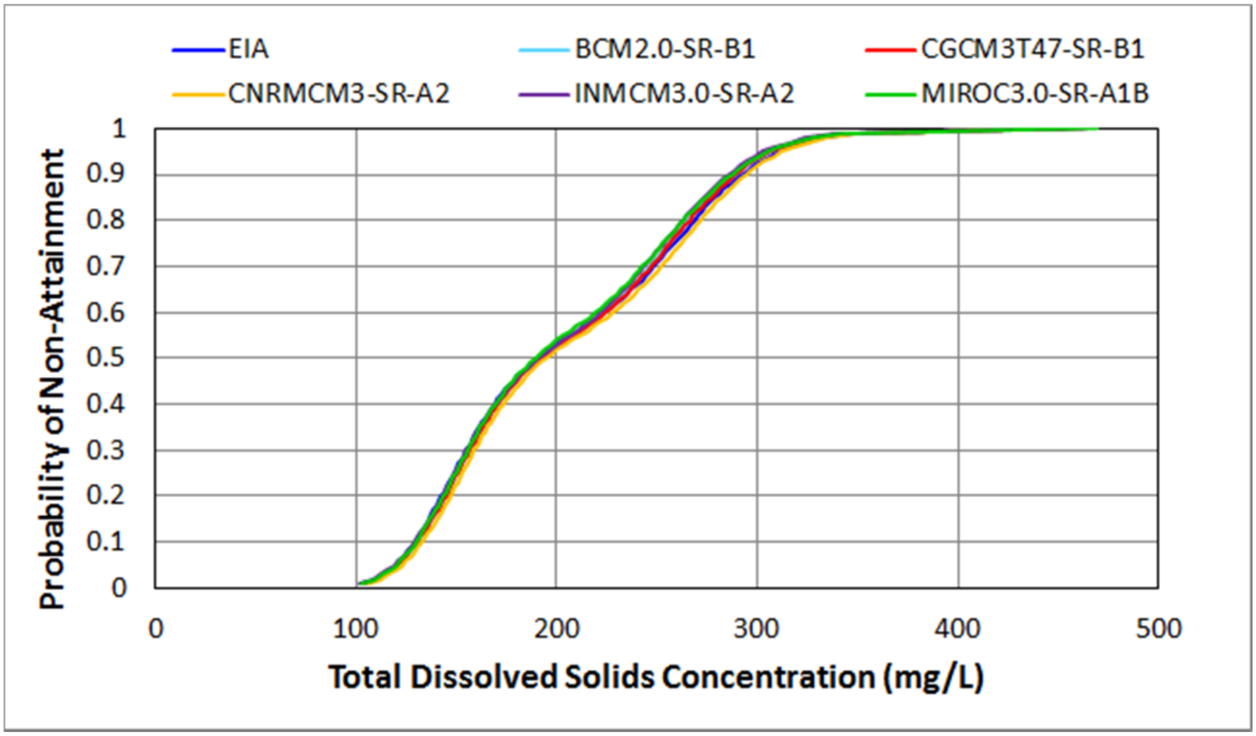


Figure G-24 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 PRM Application Case

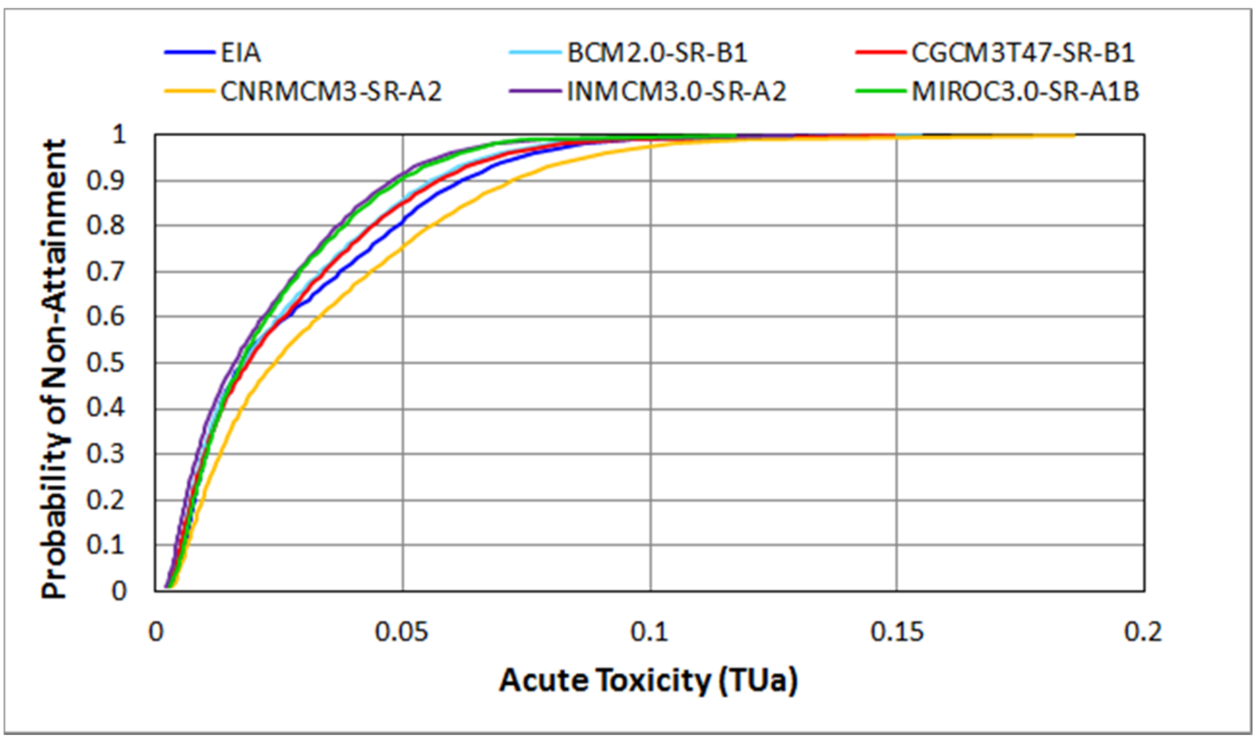


Figure G-25 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 PRM Application Case

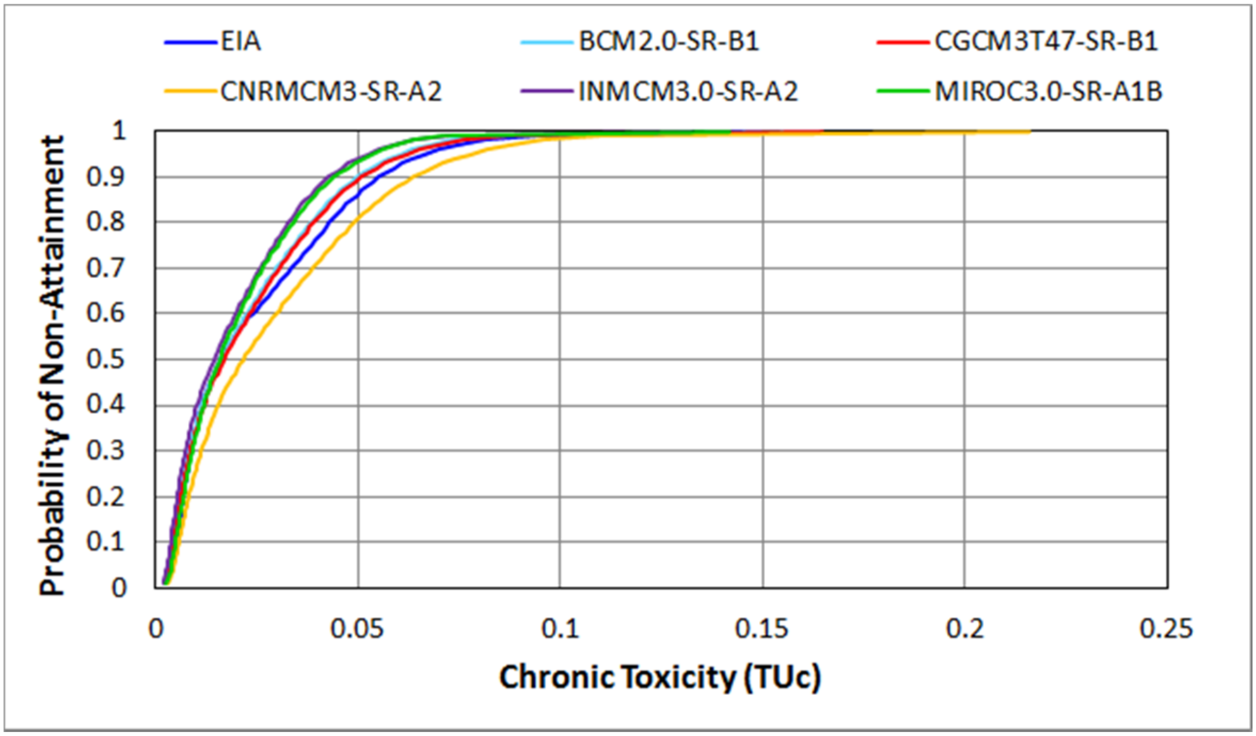


Figure G-26 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 Planned Development Case

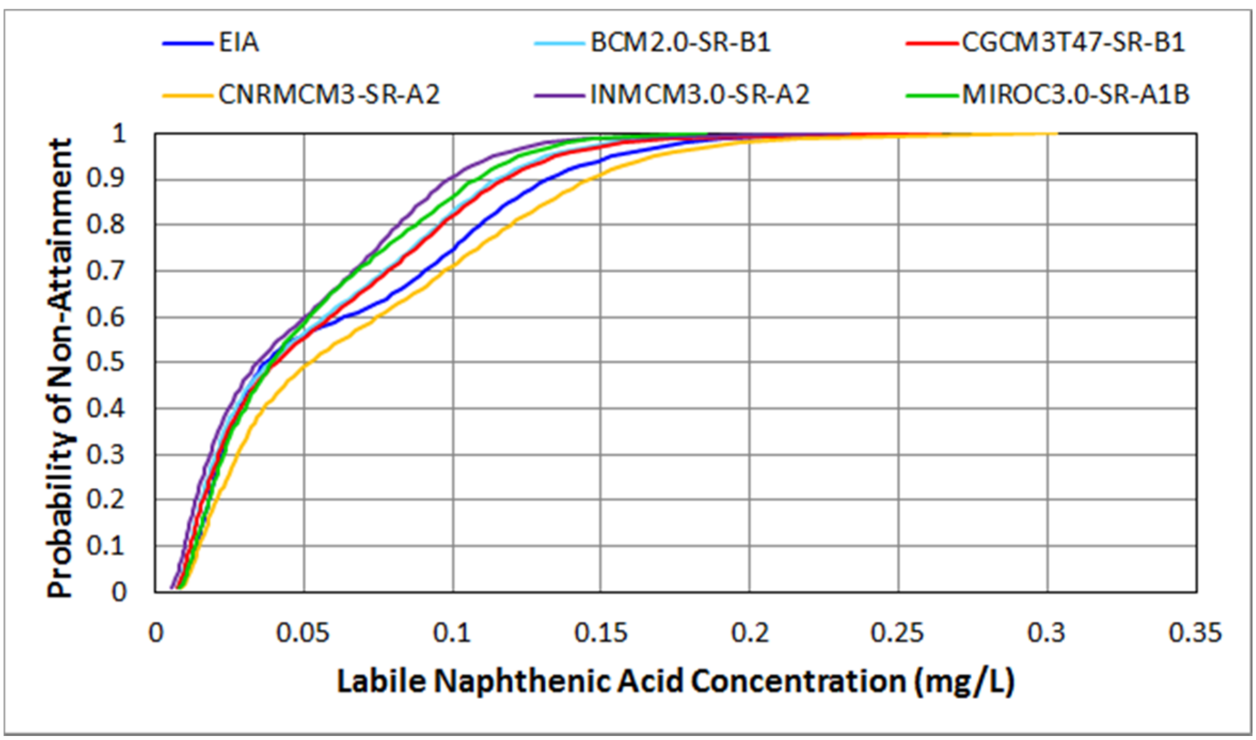
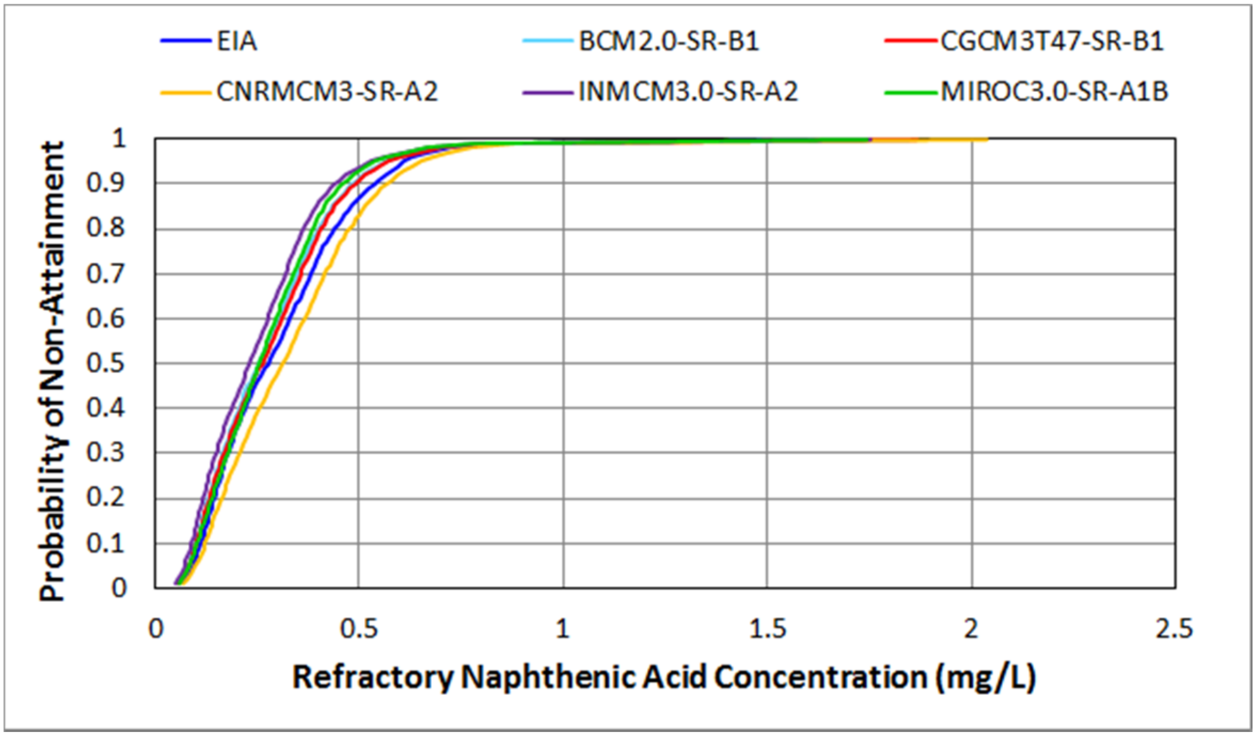


Figure G-27 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 Planned Development Case



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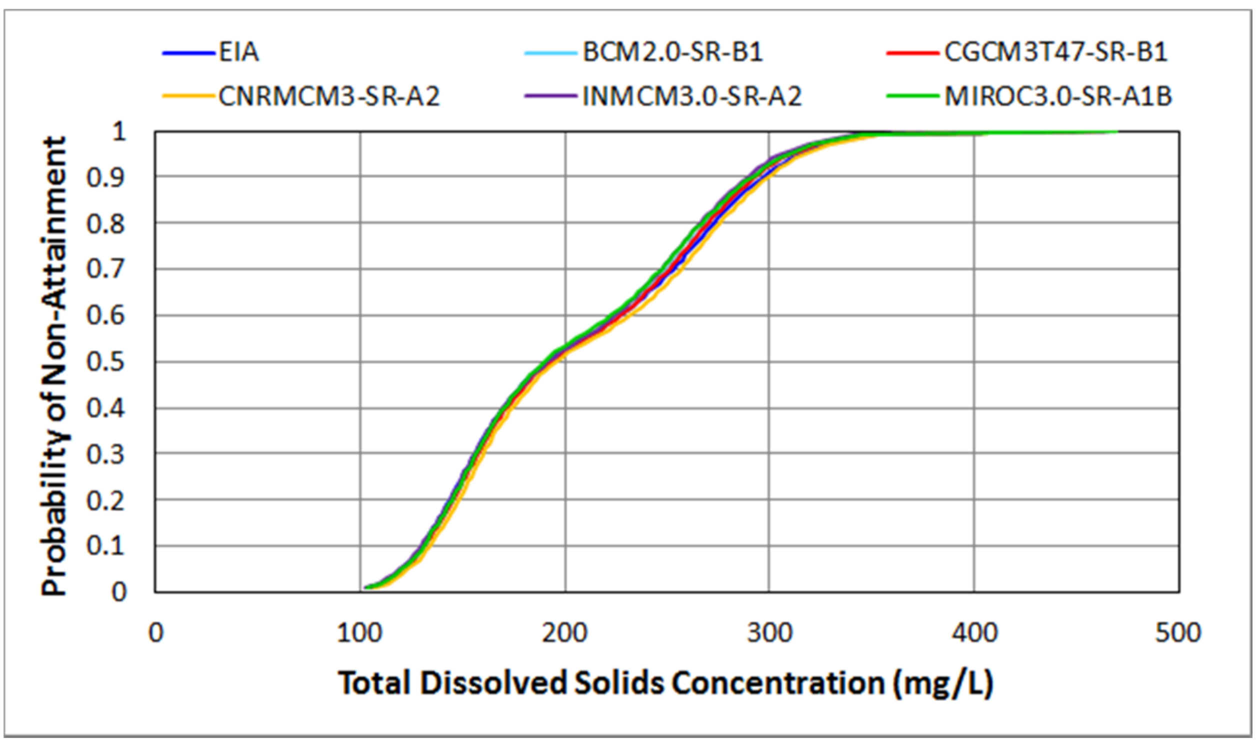

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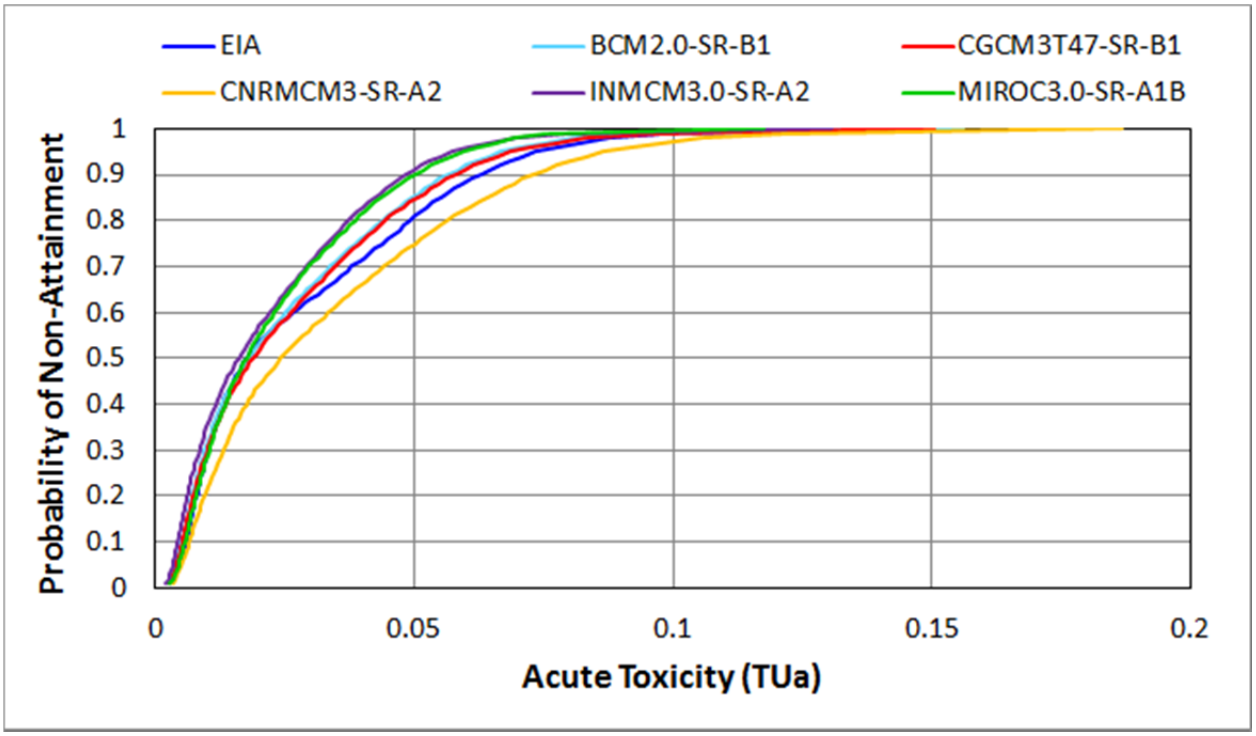
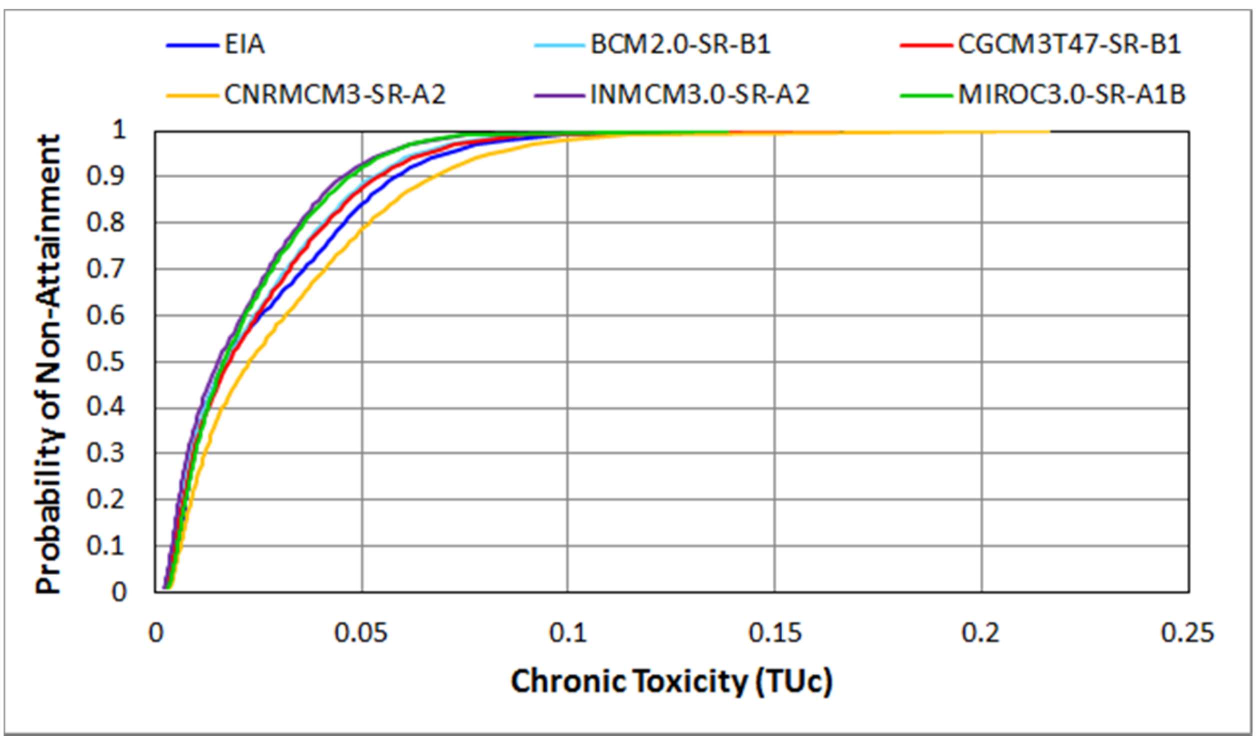


Figure G-30 Predicted Concentration Distribution Under Various Climate Scenarios in the Athabasca River at Embarras for the 2013 Planned Development Case



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