Appendix 28a.1 Climate Change

Table of Contents

List of Tables

List of Figures

List of Attachments

28a.1.1 Introduction

28a.1.1.1 Background

Teck submitted an Integrated Application and supporting environmental impact assessment (EIA) for the Frontier Oil Sands Mine Project (the Project) in November 2011. As part of the regulatory review process for the Project, Alberta Environment and Sustainable Resource Development (ESRD) requested additional information in the first round of supplemental information requests (ESRD/CEAA SIR 86b) regarding the implications of the natural flow decline observed on the Athabasca River below Fort McMurray on the model, with respect to flow and water quality. During the second round of SIRs, ESRD requested a reassessment of the changes in flows and water levels in the Athabasca River using flow trends derived from data on flows recorded at the Athabasca River below Fort McMurray hydrometric station (ESRD/CEAA Round 2 SIR 28).

Teck believes that estimating future flow changes by extrapolating historical trends over a part of a cycle likely exaggerates potential future effects on flows. This is true even when using a 50-year record of flows for Athabasca River below Fort McMurray. In addition, this type of estimate may not be consistent with the predictions based on most climate change scenarios and, therefore, may not be appropriate for use in the assessment of hydrologic effects.

To address the concerns raised by ESRD, the effects of potential climate change on the Athabasca River flows were further assessed using outputs from climate change scenarios projected by a number of General Circulation Models (GCMs). Forecasts of future climate conditions were analyzed using a calibrated and validated hydrologic model (i.e., the Hydrological Simulation Program-Fortran [HSPF] model) 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 or drier and warmer or 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 2051 to 2080 period was selected to quantify the hydrologic effects of potential future climate forecasts because this period corresponds to a time when all mine development areas are expected to have been reclaimed (see the response to ESRD/CEAA Round 1 SIR 462c, Figure 462c-1). 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 GCMs.

This appendix presents an assessment of the effects of potential climate change scenarios on the Athabasca River flows and water levels.

28a.1.1.2 Athabasca River Basin Characteristics

The Athabasca River starts in the Rocky Mountains near Mount Columbia (elevation 3,747 m amsl and flows northeast for 1,300 km before discharging through the Peace-Athabasca Delta and emptying into Lake Athabasca (elevation 208 m amsl) (RAMP 2013a; Volume 2, Section 4.3.4.1). Flows from the basin eventually make their way to the Arctic Ocean via the Slave and Mackenzie River systems. The river drains an area of approximately 138,000 km². The river flows past the urban centres of Jasper, Hinton, Whitecourt, Athabasca and Fort McMurray prior to 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 factor affecting river flow conditions. Cold winters, when most of the seasonal precipitation falls as snow, 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) (University of Alberta 2005):

- Rocky Mountain (Alpine, Subalpine, Mountain)
- Boreal Foothills
- Boreal Mixedwood (dry and wet)
- Boreal Uplands
- Boreal Lowlands
- Canadian Shield (Athabasca Plains)

The surficial geology of a basin is one of the main factors influencing the hydrologic response of the basin. The surficial geology characteristics considered for modelling the Athabasca River basin are shown in Attachment 28a.1A, Figure 28a.1A-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
- impervious/glacier

The head watersheds of the Athabasca River basin are covered by glaciers. Major portions of the upper areas of the Athabasca River basin are 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).

28a.1.2 Assessment Methods

28a.1.2.1 Modelling Approach

To evaluate the potential effects of climate change on the Athabasca River flow, an understanding of how the climate variables have been changing and how they might change in the future is required. General Circulation Models were used to forecast future climate change scenarios in the Athabasca River basin. The continuous (dynamic) 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 ESRD (Golder 2009). As part of the current climate change effect analysis work completed for the Frontier Project, the baseline climate data was extended by five years to 2011, and the HSPF model validation statistics and comparison were re-evaluated based on the longer period of baseline data records.

The recorded climate data series were adjusted using the forecasted monthly climate changes from the GCMs 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 effects of potential climate change.

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

- 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.
- Sub-divide 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 where 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 from 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 GCMs 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 using the baseline data.
- Summarize seasonal changes in mean flows at Fort McMurray hydrometric station. Compare with those using the baseline data.

28a.1.2.1.1 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 subdivided into 75 sub-basins to represent the basin in the HSPF model, based on the drainage network and the locations of 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 28a.1B, Figure 28a.1B-1.

28a.1.2.1.2 Model Data Input

The following data were used to run the HSPF model:

- 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 28a.1C, Figure 28a.1C-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. Hydrologic regions of Alberta were developed by Golder (2006) for ESRD. These regions represent areas within which the climate, geology and hydrologic responses are more or less homogeneous but are different from adjacent regions. Hydrologic regions provide a rationale for assigning climate stations to the sub-basins of the Athabasca River basin. Hydrologic regions of the Lower Athabasca River basin are shown in Attachment 28a.1B, Figure 28a.1B-1. 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 28a.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 (see Table 28a.1-1), and solar radiation data were from the Edmonton Stony Plain station and Aurora climate station. The solar radiation data from the Edmonton Stony Plain station were assumed to be representative of the hydrologic region above Fort McMurray, and the data from the Aurora climate station were assumed to be representative of the hydrologic region below Fort McMurray. 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 of climate data from 1961 to 2011.

Table 28a.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	Climate Station(s) Selected for Wind Speed and Dew Point Temperature Data
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 and 10.2 (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

28a.1.2.1.3 Model Calibration and Validation

The general approach used to calibrate and validate the HSPF model for the Athabasca River basin was 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 select the model parameters for this surficial geology type. Repeat the process for the other surficial geology types. The purpose of this approach was to establish basin-wide model parameters that can be transferred to other sub-basins in the Athabasca River basin that have similar surficial geology. The effects of land cover or vegetation types were indirectly considered during 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 listed in Table 28a.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.

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 listed in Attachment 28a.1D, Table 28a.1D-1. Values in parentheses in Table 28a.1D-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 28a.1-2, and hydrometric stations are shown in Attachment 28a.1B, Figure 28a.1B-1.

Table 28a.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[(1)]	Record Length	On Main Stem?	Calibration or 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 – 100%	1913–2010	Yes	1971	2010
	07AA001	Miette River near Jasper	Calibration	525150	1180621	629	31% Well Drained Till, 49% Impervious, 20% Glacier	3 – 100%	1914–2011	No	1995	2006
	07AA007	Sunwapta River at Athabasca Glacier	Calibration	521258	1171355	29	100% Glacier	3 – 100%	1948–2011	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 – 70%, 4 – 30%	1961–2011	Yes	1962	2011
	07BA003	Lovett River near the Mouth	Calibration	525950	1163920	103	100% Well and Rapidly Drained Till	4 – 100%	1975–2011	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 – 38%, 4 – 26%, 5 – 36%	1960–2011	Yes	1962	2011
	07AF907	Erith River below Hanlan Creek	Calibration	531408	1163355	595	60% Well Drained Till, 40% Well Drained Clay Loam	5 – 100%	1984–1990	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	2C – 4%, 2E – 8%, 3 – 9%, 4 – 9%, 5 – 17%, 8 – 29%, 10 – 23%	1913–2011	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%	1968–2010	No	1987	1998

Table 28a.1-2 Characteristics of Sub-Basins Used for Model Calibration and Validation (cont'd)

Hydrologic Region	Station Number	Sub-Basin Name	Calibration or Validation	Latitude [degminsec]	Longitude [degminsec]	Gross Drainage Area [km²]	Percent Land Type	Percent of Hydrologic Region Contributing to Station[1]	Record Length	On Main Stem?	Calibration or Validation Period	
											Start Year	End Year
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	2C – 4%, 2E – 3%, 3 – 4%, 4 – 4%, 5 – 15%, 8 – 45%, 9A – 5%, 10 – 20%	1957–2011	Yes	1961	2011
	07CD001	Clearwater River at Draper	N/A	564107	1111515	30,800	Calibrated separately (see section 2.1.3 text for details)	8 – 10%, 9A – 90% + SK Province	1930–2010	No	1961	2010
	07DB005	Mackay River above Dunkirk River	Calibration	564535	1123650	1,010	100% Organic	8 – 100%	1983–1991	No	1983	1990

NOTE:
[1] First number represents hydrologic region and the percentage number represents percent of hydrologic region contributing to station.

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

- Model parameters for the well and rapidly drained till land type were calibrated using the recorded stream flows at Lovett River near the Mouth (Environment Canada hydrometric station 07BA003; see Attachment 28a.1B, Figure 28a.1B-1). The entire Lovett River sub-basin is covered by the well and 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 (see Attachment 28a.1C, Figure 28a.1C-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; see Attachment 28a.1B, Figure 28a.1B-1). The surficial geology of the Erith River sub-basin is approximately 60% well and rapidly drained till and 40% well drained clay loam. During the calibration process, the model parameters for the well and 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 (see Attachment 28a.1C, Figure 28a.1C-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; see Attachment 28a.1B, Figure 28a.1B-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 missing winter precipitation data were filled using data from the Fort McMurray Airport climate station (see Attachment 28a.1C, Figure 28a.1C-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; see Attachment 28a.1B, Figure 28a.1B-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 (see Attachment 28a.1C, Figure 28a.1C-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; see Attachment 28a.1B, Figure 28a.1B-1). The surficial geology of the Miette River sub-basin is approximately 31% well and rapidly drained till, 20% glacier and 49% impervious/fractured rock. During the calibration process, the model parameters for the well and 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 (see Attachment 28a.1C, Figure 28a.1C-1).

- Model parameters for the well and rapidly drained sand land type were calibrated using the recorded stream flows at Driftwood River near the Mouth (Environment Canada hydrometric station 07BK007; see Attachment 28a.1B, Figure 28a.1B-1). The surficial geology of the Driftwood River sub-basin is approximately 56% well and rapidly drained till, 3% organic and 41% well and rapidly drained sand. During the calibration process, the model parameters for the well and 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 (see Attachment 28a.1C, Figure 28a.1C-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 28a.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 (see Attachment 28a.1B, Figure 28a.1B-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 was assumed to be covered by rapidly drained sand (i.e., extending the surficial geology data available on the Alberta side of the border), and the calibration and 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)
- 2-, 10- and 25-year peak flood flows

MODEL CALIBRATION AND VALIDATION STATISTICS

Comparisons of simulated and observed flow 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 28a.1-1. Flow statistics and mean monthly plots for the six sub-basins used for validation of the calibrated HSPF model are compared in Figure 28a.1-2.

The outcome of the calibration and validation of the HSPF model was deemed to be good, reasonable or 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%
  - 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 greater than 15%
  - difference between observed and simulated mean monthly flows is greater than 40%, except for winter (very low flow) months when a difference greater than 60% was deemed to be poor

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

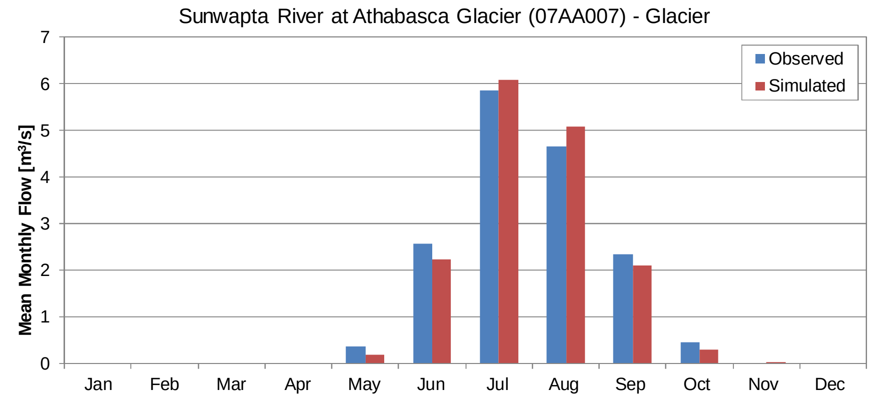
The reasons for some of the significant variances between observed and simulated statistics can be explained as follows. For the calibration of these sub-basins, climate data were not generally available within the sub-basin itself; instead, the data were transferred from other locations. For example, the calibration on the Driftwood River sub-basin was 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 because of 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 significantly influence 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 required data, except perhaps in research basins. Hence, it was difficult to get good calibration for small sub-basins that are more prone to be affected by localized precipitation.

Simulated and recorded flow statistics for Sunwapta River at Athabasca Glacier (Station 07AA007) - Calibration (Glacier) (1994-1996)

Statistic	Calibration Recorded [m³/s]	Calibration Simulated [m³/s]	Difference [%]
Mean Annual Flow	-	-	-
Mean Open-Water Flow [1]	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**	**Simulated**	**Difference**
Jan	-	0.00	-
Feb	-	0.00	-
Mar	-	0.00	-
Apr	-	0.00	-
May	0.36	0.18	-49%
Jun	2.56	2.23	-13%
Jul	5.9	6.09	4%
Aug	4.66	5.09	9%
Sep	2.34	2.10	-10%
Oct	0.46	0.31	-33%
Nov	-	0.03	-
Dec	-	0.01	-

Notes: [1] Open water season is from May to October. - Recorded data are not available.

Figure 2-1a



Simulated and recorded flow statistics for Miette River near Jasper (Station 07AA001) - Calibration (Impervious/Fractured Rock) (1995-2006)

Statistic	Calibration Recorded [m³/s]	Calibration Simulated [m³/s]	Difference [%]
Mean Annual Flow	10.2	10.8	6%
Mean Open-Water Flow [1]	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**	**Simulated**	**Difference**
Jan	1.21	1.54	27%
Feb	1.01	1.42	40%
Mar	0.92	1.34	45%
Apr	1.97	2.63	34%
May	16.9	10.16	-40%
Jun	40.1	29.1	-28%
Jul	27.9	34.9	25%
Aug	12.6	28.3	125%
Sep	8.80	12.44	41%
Oct	6.32	3.98	-37%
Nov	2.85	2.13	-25%
Dec	1.69	1.73	2%

Note: [1] Open water season is from May to October.

Figure 2-1b

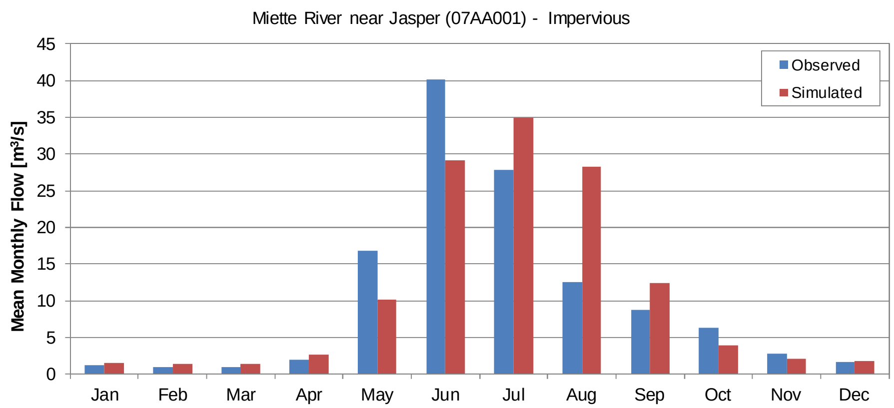


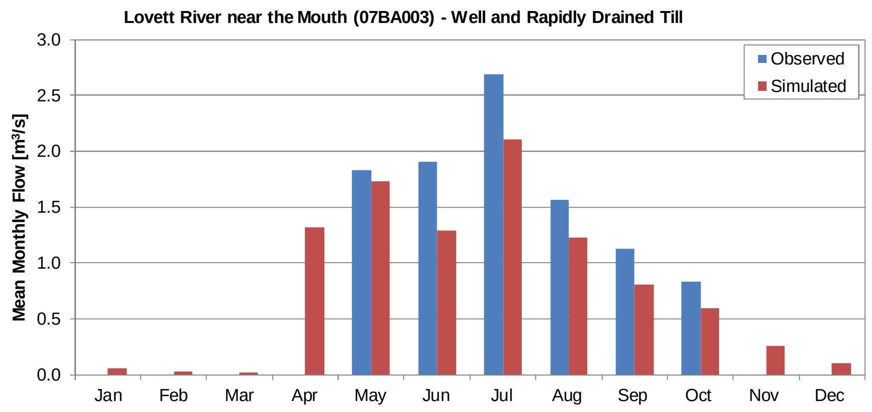
Figure 28a.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins

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 [1]	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**	**Simulated**	**Difference**
Jan	-	0.05	-
Feb	-	0.03	-
Mar	-	0.02	-
Apr	-	1.32	-
May	1.83	1.73	-6%
Jun	1.90	1.29	-32%
Jul	2.7	2.11	-22%
Aug	1.57	1.23	-22%
Sep	1.13	0.80	-29%
Oct	0.83	0.60	-28%
Nov	-	0.26	-
Dec	-	0.10	-

Notes: [1] Open water season is from May to October. - Recorded data are not available.

Figure 2-1c



Simulated and recorded flow statistics for Erith River below Hanlan Creek (Station 07AF907) - Calibration (Well Drained Clay Loam) (1984-1990)

Statistic	Calibration Recorded [m³/s]	Calibration Simulated [m³/s]	Difference [%]
Mean Annual Flow			
Mean Open-Water Flow [1]	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**	**Simulated**	**Difference**
Jan	-	0.20	-
Feb	-	0.12	-
Mar	-	0.08	-
Apr	-	8.09	-
May	6.97	7.72	11%
Jun	6.53	5.67	-13%
Jul	11.0	11.64	6%
Aug	6.67	7.02	5%
Sep	5.04	4.68	-7%
Oct	3.22	3.48	8%
Nov	-	1.22	-
Dec	-	0.43	-

Notes: [1] Open water season is from May to October. - Recorded data are not available.

Figure 2-1d

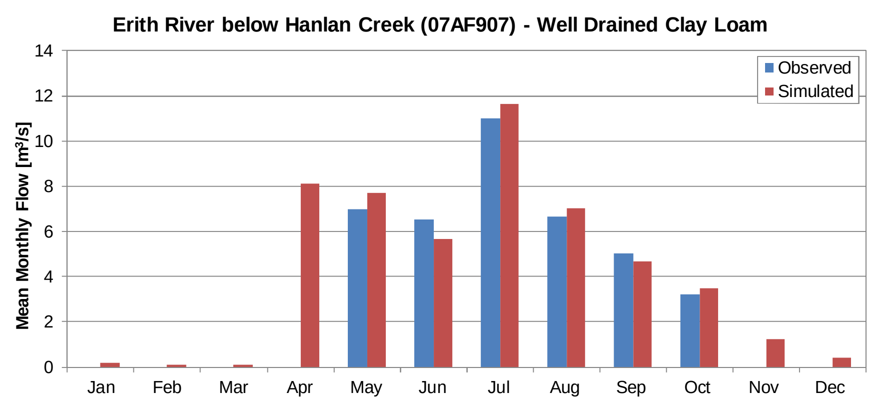


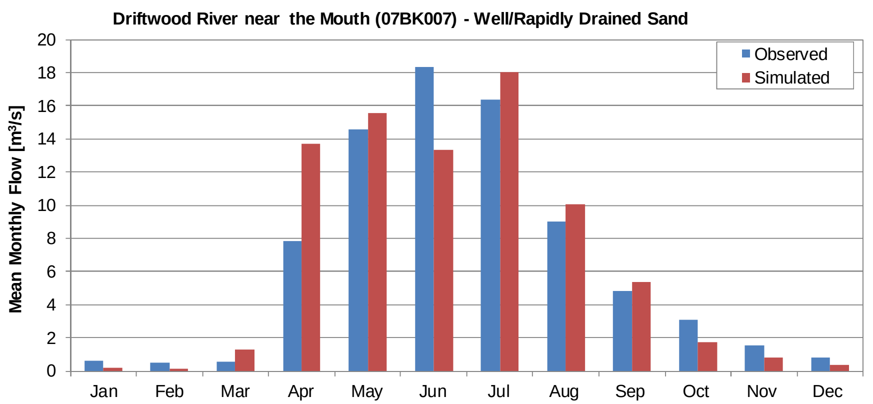
Figure 28a.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (cont'd)

Simulated and recorded flow statistics for Driftwood River near the Mouth (Station 07BK007) (1987-1998) - Calibration (Well and Rapidly Drained Sand)

Statistic	Calibration Recorded [m^3/s]	Calibration Simulated [m^3/s]	Difference [%]
Mean Annual Flow	6.51	6.72	3%
Mean Open-Water Flow [1]	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**	**Simulated**	**Difference**
Jan	0.59	0.20	-66%
Feb	0.50	0.13	-75%
Mar	0.56	1.30	134%
Apr	7.87	13.73	75%
May	14.58	15.56	7%
Jun	18.37	13.31	-28%
Jul	16.38	18.07	10%
Aug	9.02	10.08	12%
Sep	4.81	5.35	11%
Oct	3.09	1.76	-43%
Nov	1.56	0.77	-50%
Dec	0.83	0.35	-57%

Note: [1] Open water season is from May to October.

Figure 2-1e



Simulated and recorded flow statistics for Mackay River above Dunkirk River (Station 07DB005) - Calibration (Organic Soil) (1983-1990)

Statistic	Calibration Recorded [m^3/s]	Calibration Simulated [m^3/s]	Difference [%]
Mean Annual Flow	-	-	-
Mean Open-Water Flow [1]	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**	**Simulated**	**Difference**
Jan	-	0.26	-
Feb	-	0.20	-
Mar	0.04	0.15	273%
Apr	2.67	2.08	-22%
May	7.63	7.81	2%
Jun	7.29	5.85	-20%
Jul	6.6	6.81	2%
Aug	2.36	3.32	41%
Sep	1.17	1.12	-5%
Oct	1.58	0.73	-54%
Nov	-	0.52	-
Dec	-	0.36	-

Notes: [1] Open water season is from May to October. - Recorded data are not available.

Figure 2-1f

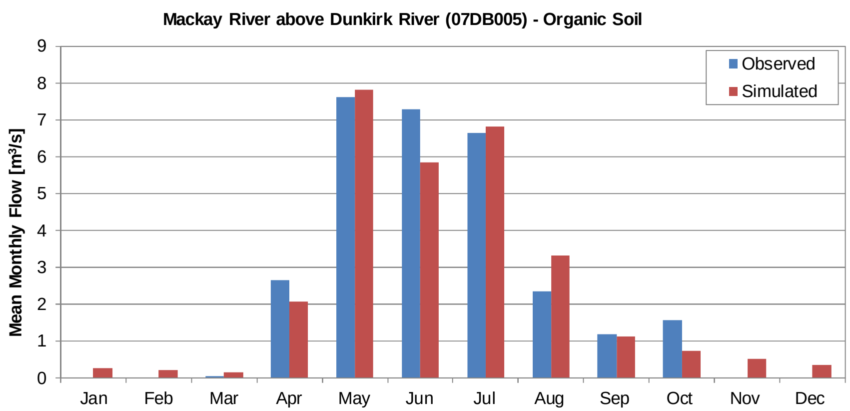


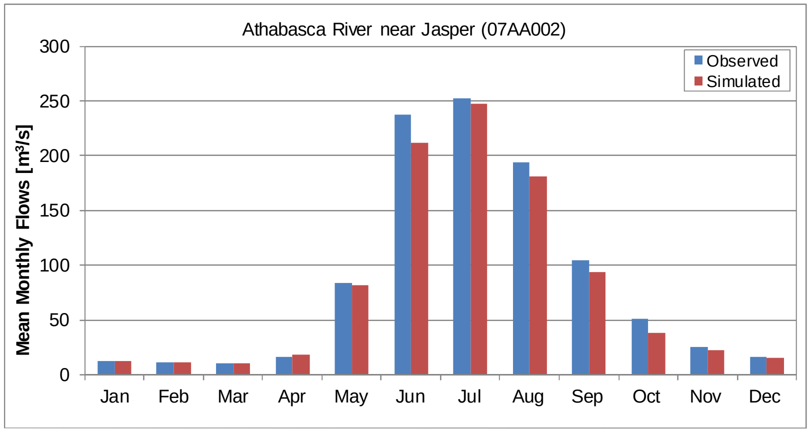
Figure 28a.1-1 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Calibration Sub-Basins (cont'd)

Simulated and recorded flow statistics for Athabasca River near Jasper (07AA002)

Statistic	Validation (1971-2010)		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	84.8	78.7	-7%
Mean Open-Water Flow [1]	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			
Jan	12.8	12.0	-6%
Feb	11.3	11.0	-3%
Mar	10.8	10.0	-8%
Apr	16.5	18.1	10%
May	84.2	82.2	-2%
Jun	238	212	-11%
Jul	252	248	-2%
Aug	194	181	-7%
Sep	105	94.0	-10%
Oct	51.5	38.6	-25%
Nov	25.1	22.1	-12%
Dec	16.8	15.6	-7%

Note: [1] Open water season is from May to October.

Figure 2-2a



Simulated and recorded flow statistics for Athabasca River at Hinton (Station 07AD002)

Statistic	Validation (1962-2011)		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	171	161	-6%
Mean Open-Water Flow [1]	263	253	-4%
2-Year Peak Flow	784	1088	39%
10-Year Peak Flow	1041	1394	34%
25-Year Peak Flow	1157	1438	24%
Mean Monthly Flows			
Jan	36.1	26.9	-26%
Feb	32.6	28.8	-12%
Mar	32.5	25.8	-20%
Apr	44.1	43.9	-1%
May	174	173	0%
Jun	488	436	-11%
Jul	470	507	8%
Aug	341	350	3%
Sep	208	185	-11%
Oct	118	75.5	-36%
Nov	60.7	44.1	-27%
Dec	42.5	33.0	-22%

Note: [1] Open water season is from May to October.

Figure 2-2b

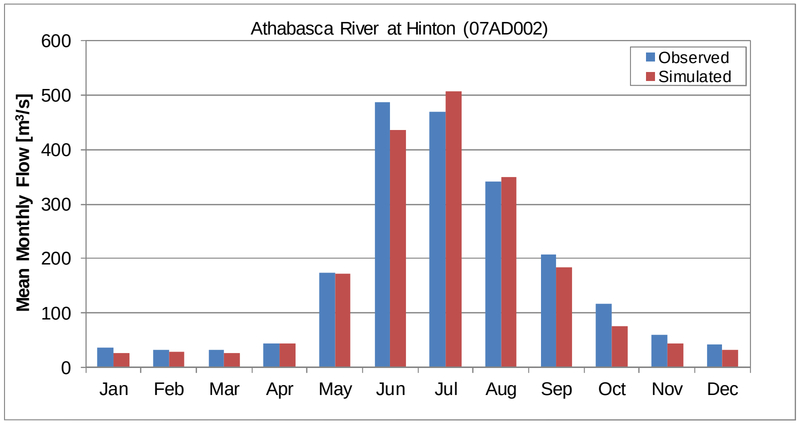


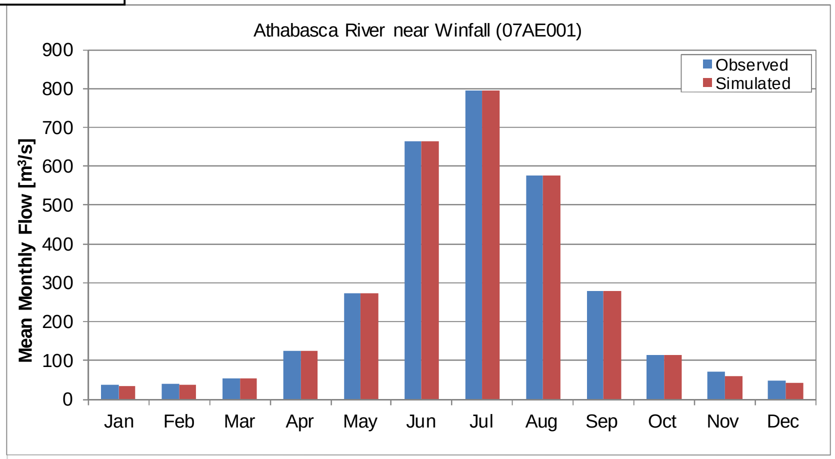
Figure 28a.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins

Simulated and recorded flow statistics for Athabasca River near Windfall (Station 07AE001)

Statistic	Validation (1962-2011) Recorded [m³/s]	Validation (1962-2011) Simulated [m³/s]	Difference [%]
Mean Annual Flow	257	254	-1%
Mean Open-Water Flow [1]	404	404	0%
2-Year Peak Flow	1054	1436	36%
10-Year Peak Flow	1675	2211	32%
25-Year Peak Flow	2048	2542	24%
Mean Monthly Flows			
Jan	38.1	33.7	-12%
Feb	40.3	37.4	-7%
Mar	53.2	53.2	0.0%
Apr	124	124	0.0%
May	273	273	0.0%
Jun	666	666	0.0%
Jul	795	795	0.0%
Aug	577	577	0.0%
Sep	280	280	0.0%
Oct	112	112.5	0.0%
Nov	70.3	58.5	-17%
Dec	49.7	42.4	-15%

Note: [1] Open water season is from May to October.

Figure 2-2c



Simulated and recorded flow statistics for Athabasca River at Athabasca (Station 07BE001)

Statistic	Validation (1962-2011) Recorded [m³/s]	Validation (1962-2011) Simulated [m³/s]	Difference [%]
Mean Annual Flow	420	436	4%
Mean Open-Water Flow [1]	638	663	4%
2-Year Peak Flow	1879	1754	-7%
10-Year Peak Flow	3249	2726	-16%
25-Year Peak Flow	4066	3180	-22%
Mean Monthly Flows			
Jan	98	98	1%
Feb	92	93	1%
Mar	101	126	25%
Apr	330	381	15%
May	654	587	-10%
Jun	987	955	-3%
Jul	1034	1171	13%
Aug	683	830	21%
Sep	466	467	0%
Oct	314	254	-19%
Nov	172	157	-9%
Dec	115	119	4%

Note: [1] Open water season is from May to October.

Figure 2-2d

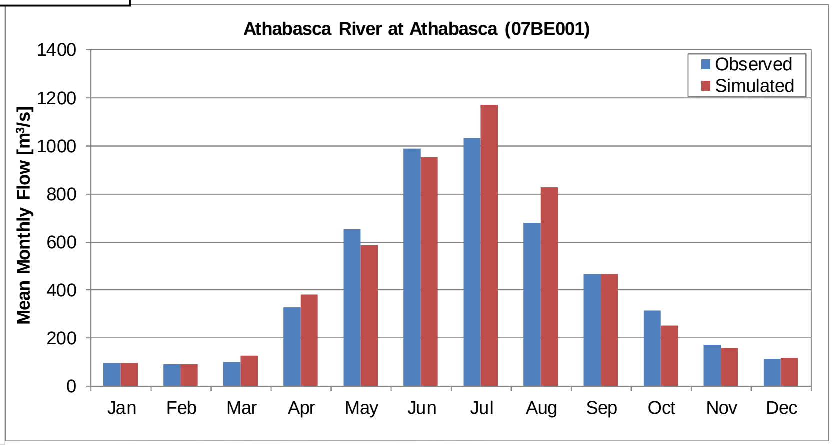


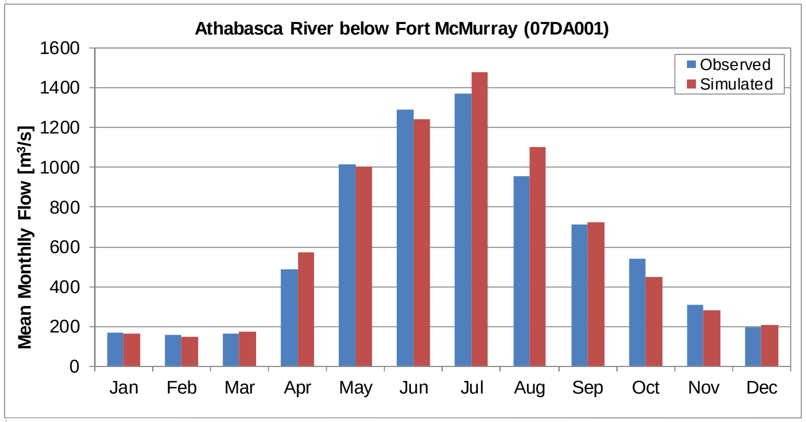
Figure 28a.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (cont'd)

Recorded and simulated flow statistics for Athabasca River below Fort McMurray (Station 07DA001)

Statistic	Validation (1961-2011)		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	615	629	2%
Mean Open-Water Flow [1]	911	938	3%
2-Year Peak Flow	2302	2043	-11%
10-Year Peak Flow	3681	3142	-15%
25-Year Peak Flow	4414	3677	-17%
Mean Monthly Flows			
Jan	172	167	-3%
Feb	158	149	-6%
Mar	166	175	5%
Apr	489	571	17%
May	1017	1004	-1%
Jun	1291	1240	-4%
Jul	1368	1479	8%
Aug	956	1101	15%
Sep	714	722	1%
Oct	539	448	-17%
Nov	310	284	-8%
Dec	194	206	6%

Note: [1] Open water season is from May to October.

Figure 2-2e



Recorded and simulated flow statistics for Clearwater River at Draper (Station 07CD001)

Statistic	Validation (1961-2010)		Difference [%]
	Recorded [m³/s]	Simulated [m³/s]	
Mean Annual Flow	117	109	-7%
Mean Open-Water Flow [1]	157	141	-10%
2-Year Peak Flow	365	334	-8%
10-Year Peak Flow	583	764	31%
25-Year Peak Flow	678	1007	49%
Mean Monthly Flows			
Jan	56.0	57.3	2%
Feb	51.2	51.4	0%
Mar	51.3	52	1%
Apr	130	135	4%
May	222	196	-12%
Jun	183	155	-16%
Jul	169	139	-18%
Aug	140	123	-12%
Sep	130	126	-4%
Oct	121	113	-7%
Nov	87	88	2%
Dec	65	68	3%

Note: [1] Open water season is from May to October.

Figure 2-2f

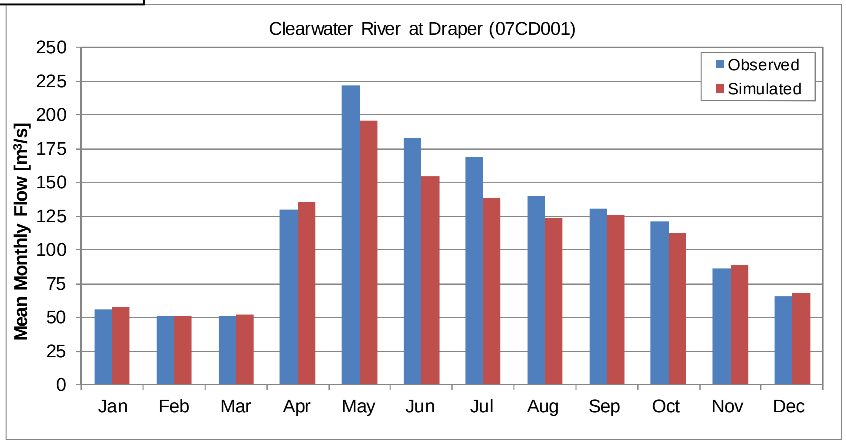


Figure 28a.1-2 Comparisons of Simulated and Observed Flow Statistics and Mean Monthly Flows on Validation Sub-Basins (cont'd)

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 m amsl, 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 m amsl, with a maximum elevation up to 2,500 m amsl. 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 because rainfall tends 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, variable impervious glaciated and fractured areas, and 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 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 listed in Attachment 28a.1D, Table 28a.1D-1 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 (see Figure 28a.1-2). The validation nodes capture sub-basins with different land types (in different percentages within each sub-basin as listed in Table 28a.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 the drainage areas at these nodes are much larger than those of the small sub-basins, and differences in responses between small sub-basins tend to be “masked”, 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.

28a.1.2.2 Baseline Climate Conditions and Future Climate Scenarios

To address the effects of potential 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 GCMs output from the IPCC Fourth Assessment Report (AR4) (IPCC 2007). The average 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 GCMs and associated emission scenarios (the combinations referred to as GCM-scenarios) recommended by IPCC. 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., 2051 to 2080, called the 2060s) 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 28a.1E) to select representative GCM-scenarios associated with the extreme changes forecasted for the basin. The forecasted climate changes at the index climate stations for the 2051 to 2080 period relative to the 1961 to 1990 baseline period for annual and seasonal averages are shown in Attachment 28a.1E, Figures 28a.1E-1 to 28a.1E-6. Five selected representative GCMs and scenarios for the Athabasca River basin are listed in Table 28a.1-3.

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 SR-B1). These five scenarios bound the range of reasonably possible future climate regimes from several GCMs 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 2060s.

Table 28a.1-3 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

28a.1.3 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 use and water management in the basin. Changes in future climate regimes and their effects on flows in the basin were provided.

28a.1.3.1 Baseline Climate for Model Simulations

The HSPF model is a continuous simulation model that requires daily temperature and precipitation data 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 28a.1C, Figure 28a.1C-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 and good quality data with low numbers of missing data, and spatial distribution to cover most of the hydrologic regions in the Athabasca River basin. The index climate stations are the following:

- 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
- 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 station to the index station within the same hydrologic region.

28a.1.3.2 Estimating Changes in Future Temperature and Precipitation

The GCMs 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 listed in Attachment 28a.1E, Tables 28a.1E-1 to 28a.1E-6 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 expressed 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 28a.1-3 and 28a.1-4.

The average changes in mean annual precipitation in the basin vary from -5.2% at Lac La Biche station to +28% at Fort McMurray and Lac La Biche stations as listed in Attachment 28a.1E, Table 28a.1E-1 to 28a.1E-6. The range of the changes in precipitation is much wider on a monthly basis, varying from -22% at Edson and Lac La Biche stations to +99% 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 1.22°C at Jasper station to 5.38°C at Fort McMurray station as listed in Attachment 28a.1E, Tables 28a.1E-1 to 28a.1E-6. 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.

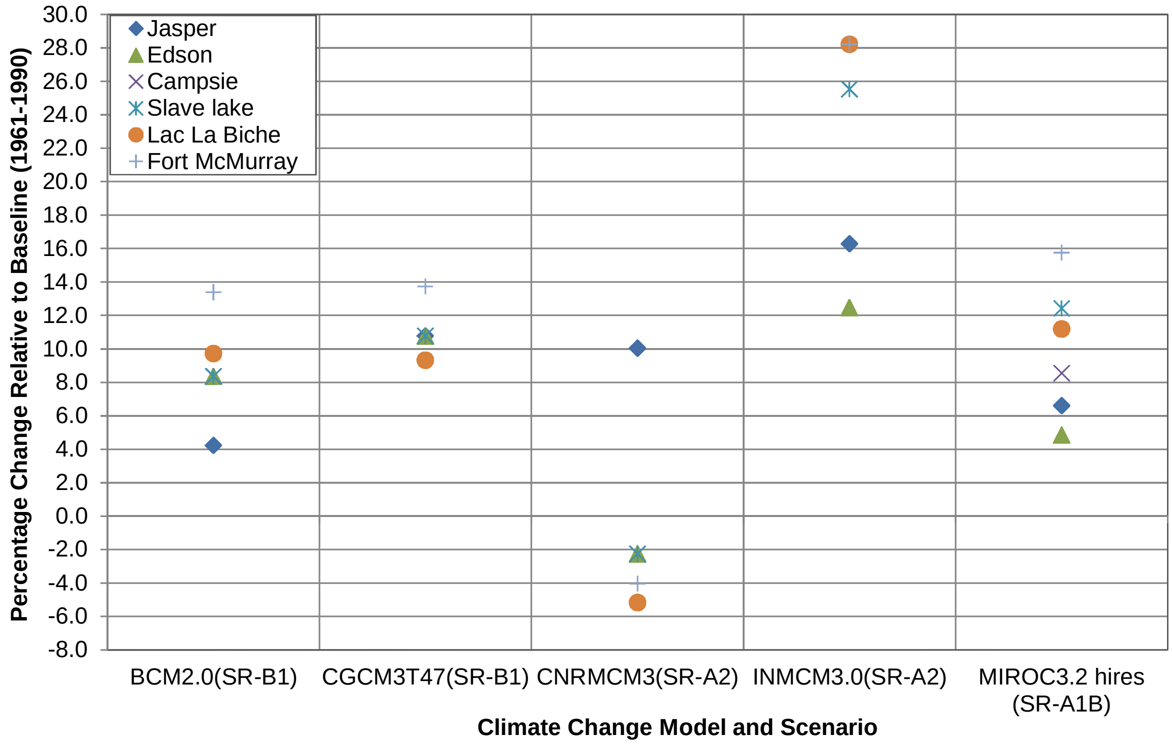


Figure 28a.1-3 Percent Changes in Average Annual Precipitation for the 2060s at Index Climate Stations

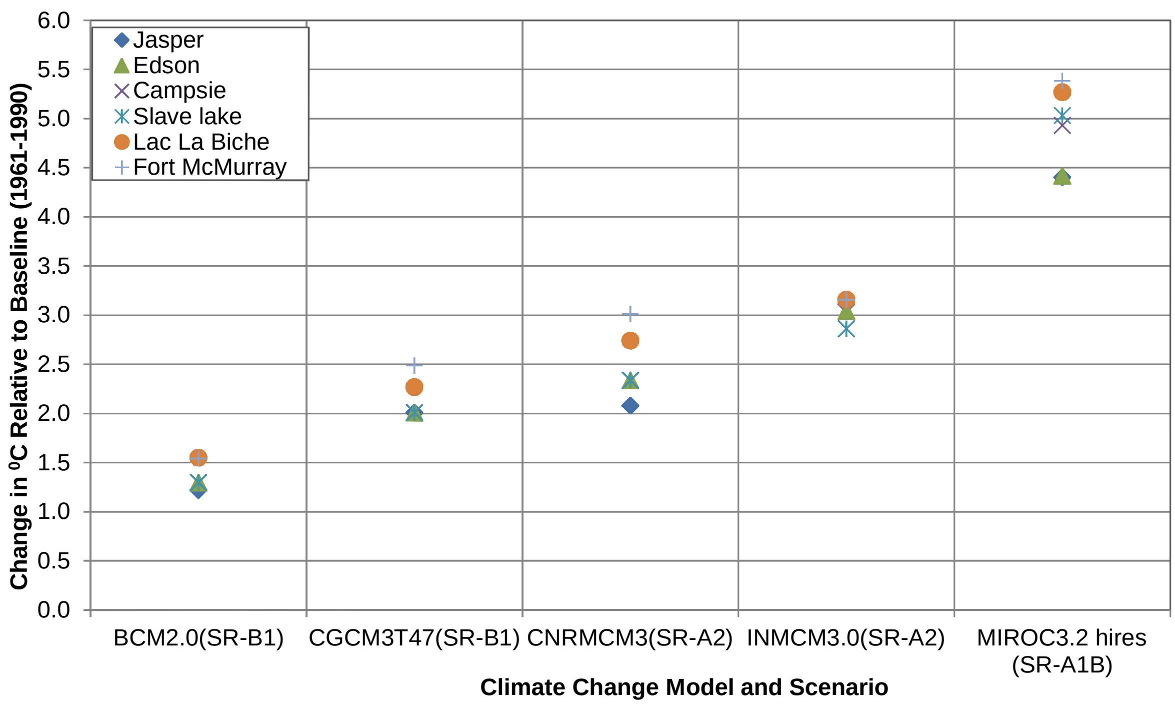


Figure 28a.1-4 Changes in Average Annual Temperature for the 2060s at Index Climate Stations

28a.1.3.3 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 28a.1.3.1 by the differences in the temperature and precipitation forecasted by the selected GCM-scenarios as described in Section 28a.1.3.2.

28a.1.3.3.1 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 28a.1.3.1) and the adjusted future climate data (Section 28a.1.3.3). Results of a comparison between flow statistics (mean annual flow; mean open-water and ice-cover flows; 2-, 10-, 25- and 100-year flood flows; 7Q10 – low flow; and mean monthly flows) for the five selected climate change scenarios are summarized in Table 28a.1-4 for the Athabasca River flow below Fort McMurray station. The forecasted changes in mean monthly flows are presented graphically in Figure 28a.1-5.

General conclusions from the comparison of flow statistics presented in Table 28a.1-4 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 for the August mean monthly flow for which a decrease of about 8% is predicted. The mean annual and mean open-water season flows will increase by about 17% and 13%, respectively. The mean ice-cover flow will increase by about 46%, and the largest increase in the mean monthly flow will be about 88% 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 increase. The largest decrease in the mean monthly flows will be about 23% in August.
- For the warm and dry climate condition represented by CNRMCM3 (Run 1)-SR-A2 climate change scenario, all the flow statistics will decrease except the March mean monthly flow. The mean annual and mean open-water season flows will decrease by about 22% and 25%, respectively. The mean ice-cover flow will decrease by about 3%, and the largest decrease in the mean monthly flow will be about 41% in August.
- For the warm and wet climate condition represented by the MIROC3.2 hires (Run 1)-SR-A1B scenario, most of the forecasted flow statistics will decrease relative to baseline values. The mean annual and mean open-water season flows will decrease by about 18% 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 August.

Table 28a.1-4 Hydrologic Effects of Forecasted Climate Change on Athabasca River Flows

	Forecasted 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 (Cool-Dry Conditions)**	**CGCM3T47 (Mean) – SR-B1 (Median Conditions)**	**CNRMCM3 (Run 1) – SR-A2 (Warm –Dry Conditions)**	**INMCM3.0 (Run 1) – SR-A2 (Cool-Wet Conditions)**	**MIROC3.2 hires (Run 1) – SR-A1B (Warm-Wet Conditions)**
	(m^3/s)	**Change** (%)	**Change** (%)	**Change** (%)	**Change** (%)	**Change** (%)
Mean Annual Flow	718	-1.8%	-2.5%	-22.2%	17.1%	-18.4%
Mean Open-Water Flow	1,073	-4.4%	-5.7%	-24.9%	13.0%	-28.2%
Mean Ice-Cover Flow	216	16.7%	20.2%	-2.8%	46.1%	50.5%
2-Year Peak Flow	2,331	-0.3%	-4.3%	-24.1%	27.7%	-28.0%
10-Year Peak Flow	3,454	8.5%	0.4%	-21.0%	43.3%	-21.4%
25-Year Peak Flow	4,006	10.7%	2.7%	-19.6%	50.4%	-19.4%
100-Year Peak Flow	4,820	12.6%	6.1%	-17.8%	60.4%	-17.2%
7Q10-Low Flow	116	-2.4%	-3.8%	-20.0%	22.7%	-9.1%
Mean Monthly Flows						
Jan	181	6.9%	2.1%	-10.5%	24.1%	4.0%
Feb	160	6.6%	10.8%	-6.9%	38.8%	37.7%
Mar	181	25.2%	52.2%	6.9%	88.1%	149%
Apr	599	20.7%	25.1%	-1.3%	44.0%	50.4%
May	1,139	-6.8%	-1.0%	-22.4%	11.6%	-2.7%
Jun	1,362	-3.0%	9.2%	-10.1%	35.3%	-23.8%
Jul	1,701	-1.8%	-10.0%	-30.6%	16.0%	-49.5%
Aug	1,313	-17.3%	-22.5%	-41.2%	-7.7%	-52.8%
Sep	869	-7.8%	-13.9%	-33.2%	-2.9%	-31.8%
Oct	520	8.4%	-2.0%	-12.7%	12.7%	-5.4%
Nov	324	11.4%	1.4%	-10.6%	20.4%	-2.7%
Dec	228	10.7%	2.6%	-11.6%	24.0%	-0.7%

NOTE:
Baseline flow data (1961–1990) at the Athabasca River below Fort McMurray hydrometric station (WSC 07DA001) are simulated from baseline climate data.

Table 28a.1-4 Hydrologic Effects of Forecasted Climate Change on Athabasca River Flows (cont'd)

	Forecasted Flows at Athabasca River below Fort McMurray WSC 07DA001					
	Baseline Flows (1961–1990)	**BCM2.0 (Run 1) – SR-B1 (Cool-Dry Conditions)**	**CGCM3T47 (Mean) – SR-B1 (Median conditions)**	**CNRMCM3 (Run 1) – SR-A2 (Warm –Dry Conditions)**	**INMCM3.0 (Run 1) – SR-A2 (Cool-Wet Conditions)**	**MIROC3.2 hires (Run 1) – SR-A1B (Warm-Wet Conditions)**
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
Mean Annual Flow	718	706	700	559	841	586
Mean Open-Water Flow	1,073	1,026	1,011	805	1,212	770
Mean Ice-Cover Flow	216	252	259	210	315	325
2-Year Peak Flow	2,331	2,324	2,231	1,769	2,978	1,694
10-Year Peak Flow	3,454	3,746	3,466	2,729	4,949	2,723
25-Year Peak Flow	4,006	4,434	4,114	3,219	6,025	3,231
100-Year Peak Flow	4,820	5,427	5,116	3,960	7,732	3,979
7Q10-Low Flow	116	113	112	92.8	142	105
Mean Monthly Flows						
Jan	181	194	185	162	225	188
Feb	160	171	178	149	223	221
Mar	181	227	276	194	341	452
Apr	599	724	750	591	863	902
May	1,139	1,061	1,127	884	1,271	1,108
Jun	1,362	1,321	1,487	1,225	1,843	1,037
Jul	1,701	1,670	1,531	1,180	1,972	860
Aug	1,313	1,086	1,017	772	1,212	620
Sep	869	802	749	581	844	592
Oct	520	563	509	454	586	492
Nov	324	361	328	289	390	315
Dec	228	253	234	202	283	227

NOTE:
Baseline flow data (1961–1990) at the Athabasca River below Fort McMurray hydrometric station (WSC 07DA001) are simulated from baseline climate data.

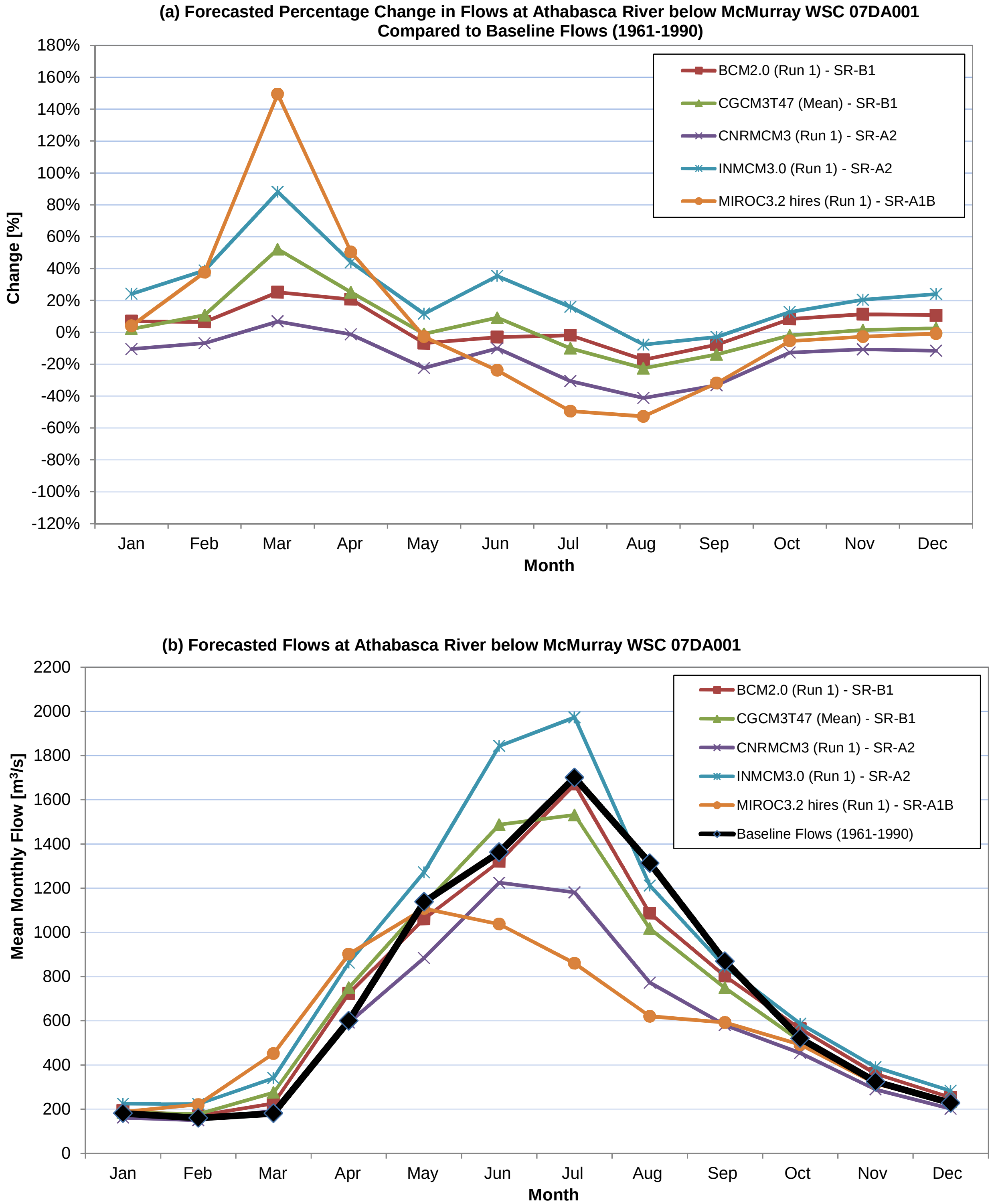


Figure 28a.1-5 Forecasted Effects of Climate Change on Mean Monthly Flows

The forecasted percentage changes in the Athabasca River mean seasonal flows at the station below Fort McMurray compared to baseline flows (1961 to 1990) due to potential climate change by the 2060s are summarized in Table 28a.1-5.

Table 28a.1-5 Forecasted Percentage Changes in Athabasca River Mean Seasonal Flows at Fort McMurray Compared to Baseline Flows (1961–1990) by the 2060s

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]** (%)	**Based on Trend of Historical Recorded Data below Fort McMurray** (%)
Annual	-1.8	-2.5	-22.2	17.1	-18.4	-54
Winter	8.4	4.6	-10.0	28.0	11.0	-37
Spring	4.6	12.0	-13.2	28.8	28.0	-53
Summer	-6.9	-8.0	-27.6	14.7	-42.7	-35
Fall	0.8	-7.3	-22.6	6.3	-18.2	-59

As listed in Table 28a.1-5, in the instances when climate change scenarios result in decreasing flows, the maximum forecasted change in mean annual and seasonal flows for Athabasca River is significantly lower than the percentage change predicted based on trends of recorded historical data. Hence, estimates of future flow changes based on simply extrapolating historical trends over part of a cycle, even when using 50-years of recorded flows for Athabasca River below Fort McMurray, can be grossly exaggerated, may not be consistent with the predictions based on most climate change scenarios and, therefore, may not be appropriate for use in the assessment of hydrologic effects.

28a.1.3.3.2 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 from potential climate change (as listed in Table 28a.1-5, and a summary of water withdrawals from the lower reach of the Athabasca River provided in Volume 5, Section 3, Tables 3-13 and 3-29 and ESRD/CEAA Appendix 308a.3, Table 308a.3-8) 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 from climate change for Base Case, Application Case and Planned Development Case (PDC) are listed in Tables 28a.1-6 and 28a.1-7. 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 from water withdrawal are less relative to those without the effects of climate change or climate change scenarios that increase flows in Athabasca River (INMCM3.0 [Run 1] - SR-A2).

28a.1.3.3.3 Summary

The results of simulations of five forecasted climate conditions (median and extremes of wet or dry and cool or warm conditions) on the Athabasca River support the conclusion that, 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.

Table 28a.1-6 Change to Athabasca River Flows in Reach 4 Considering Climate Change Effects in the 2060s

Model Scenario	Season	Baseline Flow (1961–1990)	Flows – with Climate Change (No Water Withdrawal)		Climate Change plus Water Withdrawal for Frontier Project					
					Base Case		Application Case		Planned Development Case	
		Stream Flow Discharge	Stream Flow Discharge	Change from 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	218	11.0	195	-0.7	191	-2.7	187	-4.7
	spring	602	771	28.0	748	24.2	744	23.5	737	22.4
	summer	1,463	839	-42.7	816	-44.3	811	-44.6	804	-45.0
	fall	617	505	-18.2	482	-21.9	478	-22.6	471	-23.8
CNRMCM3 (Run 1) - SR-A2	winter	196	177	-10.0	154	-21.5	152	-22.6	150	-23.4
	spring	602	523	-13.2	500	-17.0	497	-17.5	493	-18.2
	summer	1,463	1,060	-27.6	1,037	-29.2	1,032	-29.5	1,025	-30.0
	fall	617	478	-22.6	455	-26.3	451	-27.0	444	-28.1
INMCM3.0 (Run 1) - SR-A2	winter	196	251	28.0	229	16.3	224	14.2	218	11.0
	spring	602	776	28.8	753	25.0	749	24.3	742	23.1
	summer	1,463	1,679	14.7	1,656	13.1	1,651	12.8	1,644	12.3
	fall	617	656	6.3	633	2.6	629	1.9	622	0.7
BCM2.0 (Run 1) - SR-B1	winter	196	213	8.4	190	-3.3	186	-5.3	183	-7.1
	spring	602	630	4.6	607	0.8	603	0.1	598	-0.7
	summer	1,463	1,362	-6.9	1,340	-8.5	1,335	-8.8	1,328	-9.3
	fall	617	622	0.8	599	-2.9	595	-3.6	588	-4.8
CGCM3T47 (Mean) - SR-B1	winter	196	206	4.6	183	-7.1	179	-8.9	176	-10.5
	spring	602	675	12.0	652	8.2	647	7.5	642	6.6
	summer	1,463	1,346	-8.0	1,323	-9.6	1,319	-9.9	1,312	-10.4
	fall	617	572	-7.3	549	-11.0	545	-11.7	538	-12.9

Table 28a.1-7 Change to Athabasca River Water Level in Reach 4 Considering Climate Change Effects in 2060s

Model Scenario	Season	Baseline Water Level (1961–1990)	Water Level – with Climate Change (No Water Withdrawal)		Climate Change plus Water Withdrawal for Frontier Project					
					Base Case		Application Case		Planned Development Case	
		Stream Flow Discharge	Water Level	Change from 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	226.01	0.04	225.97	0.00	225.97	-0.01	225.96	-0.02
	spring	226.68	226.96	0.27	226.92	0.24	226.91	0.23	226.90	0.22
	summer	227.96	227.06	-0.90	227.03	-0.94	227.02	-0.94	227.01	-0.95
	fall	226.71	226.52	-0.19	226.48	-0.23	226.47	-0.23	226.46	-0.25
CNRMCM3 (Run 1) - SR-A2	winter	225.98	225.94	-0.04	225.90	-0.08	225.89	-0.08	225.89	-0.08
	spring	226.68	226.55	-0.13	226.51	-0.17	226.51	-0.18	226.50	-0.18
	summer	227.96	227.40	-0.56	227.36	-0.60	227.36	-0.60	227.35	-0.61
	fall	226.71	226.47	-0.23	226.43	-0.27	226.43	-0.28	226.41	-0.29
INMCM3.0 (Run 1) - SR-A2	winter	225.98	226.08	0.10	226.03	0.06	226.03	0.05	226.02	0.04
	spring	226.68	226.96	0.28	226.93	0.25	226.92	0.24	226.91	0.23
	summer	227.96	228.24	0.27	228.21	0.25	228.20	0.24	228.19	0.23
	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	225.96	-0.01	225.96	-0.02	225.95	-0.03
	spring	226.68	226.73	0.05	226.69	0.01	226.68	0.00	226.67	-0.01
	summer	227.96	227.83	-0.13	227.80	-0.17	227.79	-0.17	227.78	-0.18
	fall	226.71	226.72	0.01	226.68	-0.03	226.67	-0.04	226.66	-0.05
CGCM3T47 (Mean) - SR-B1	winter	225.98	225.99	0.02	225.95	-0.03	225.94	-0.03	225.94	-0.04
	spring	226.68	226.80	0.12	226.76	0.08	226.76	0.07	226.75	0.07
	summer	227.96	227.81	-0.16	227.77	-0.19	227.77	-0.19	227.76	-0.20
	fall	226.71	226.63	-0.07	226.59	-0.11	226.59	-0.12	226.57	-0.13

28a.1.4 References

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28a.1.5 Abbreviations

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
m amsl .... metres above mean sea level
PDC .... Planned Development Case
U.S. EPA .... United States Environmental Protection Agency
WSC .... Water Survey Canada

Attachment 28a.1A

Athabasca River Basin Surficial Geology

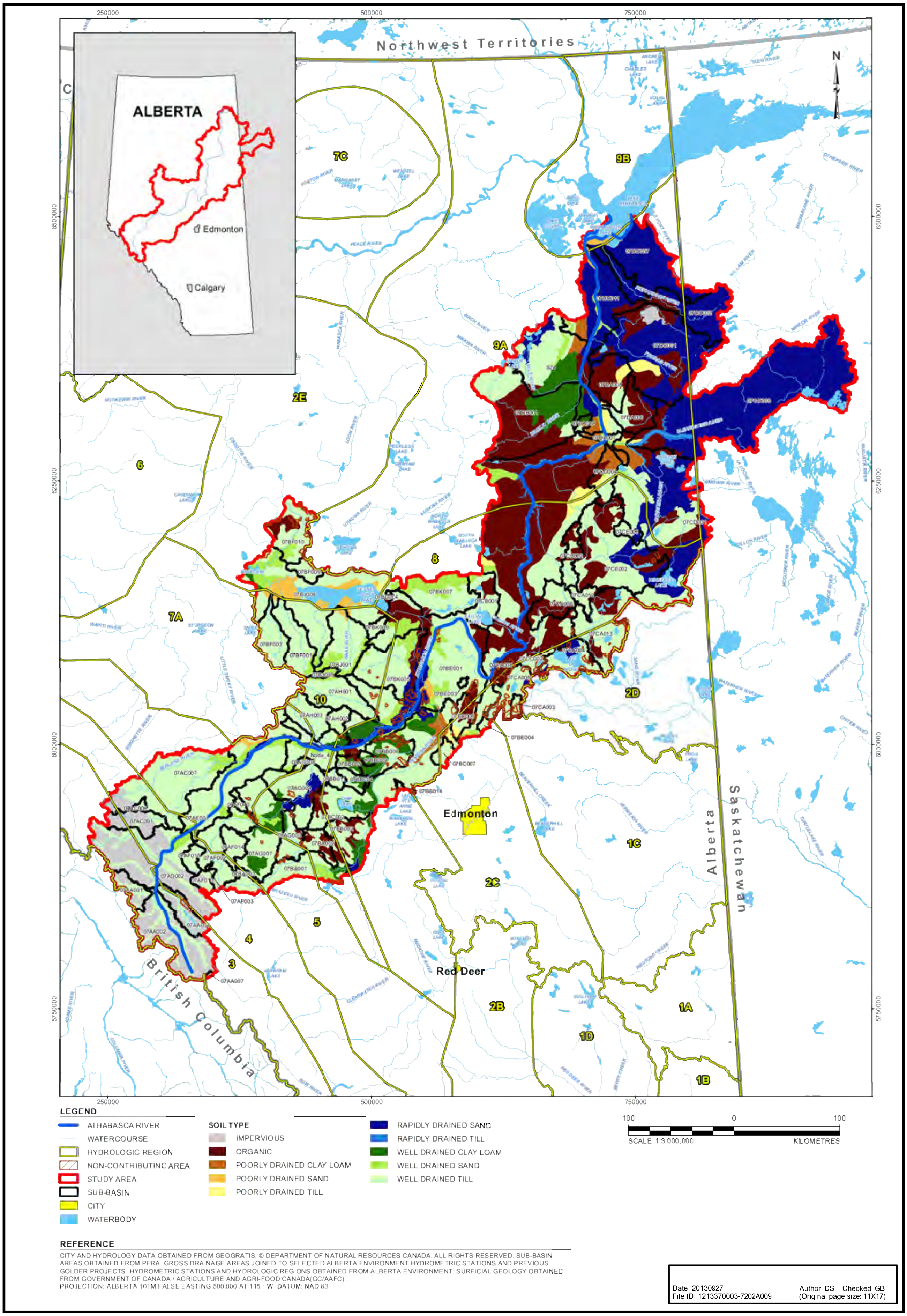

Figure 28a.1A-1: Surficial Geology of Athabasca River Basin

Attachment 28a.1B

Hydrometric Stations in the Athabasca River Basin

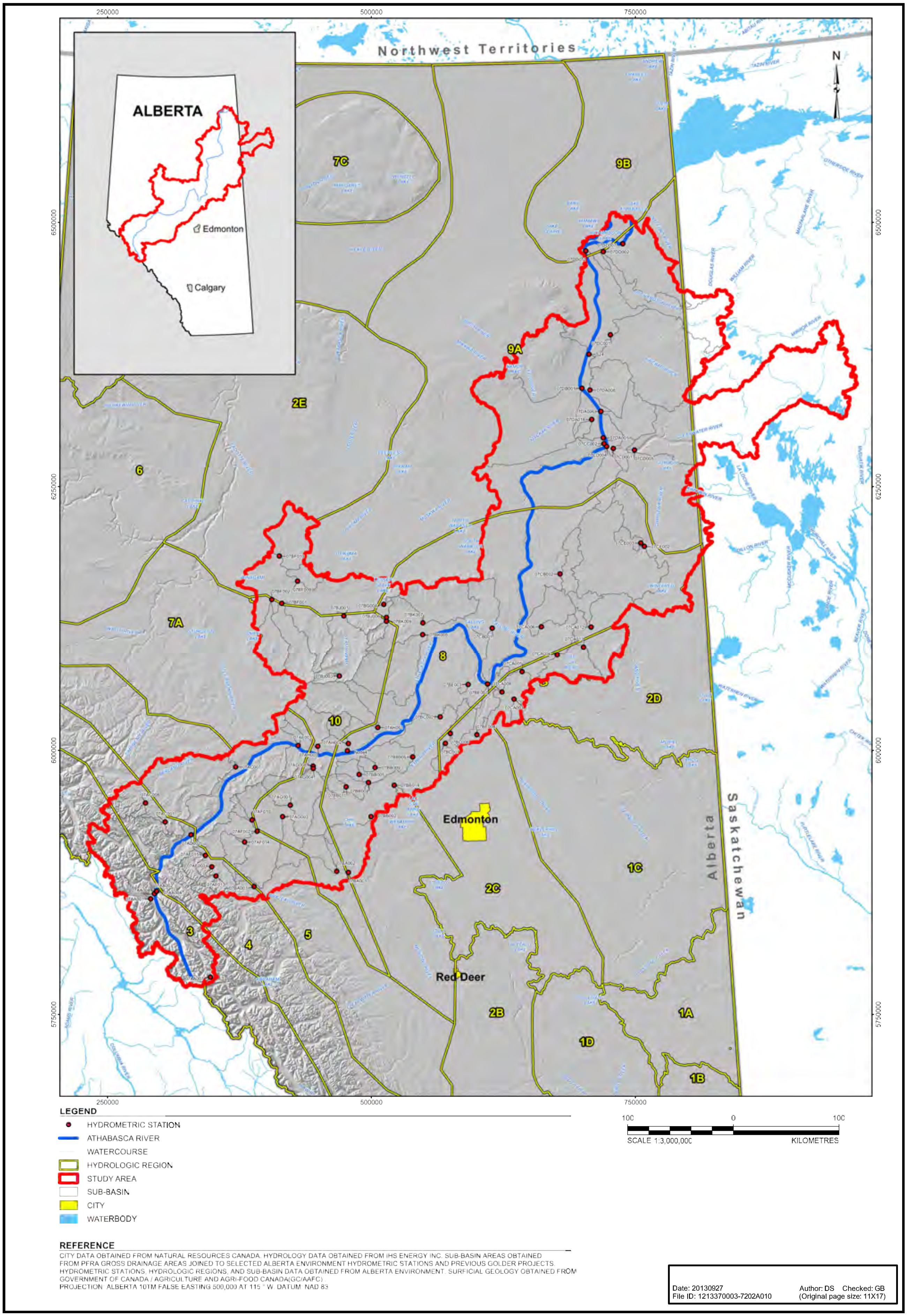

Figure 28a.1B-1: Hydrometric Stations in the Athabasca River Basin

Attachment 28a.1C

Climate Stations in the Athabasca River Basin

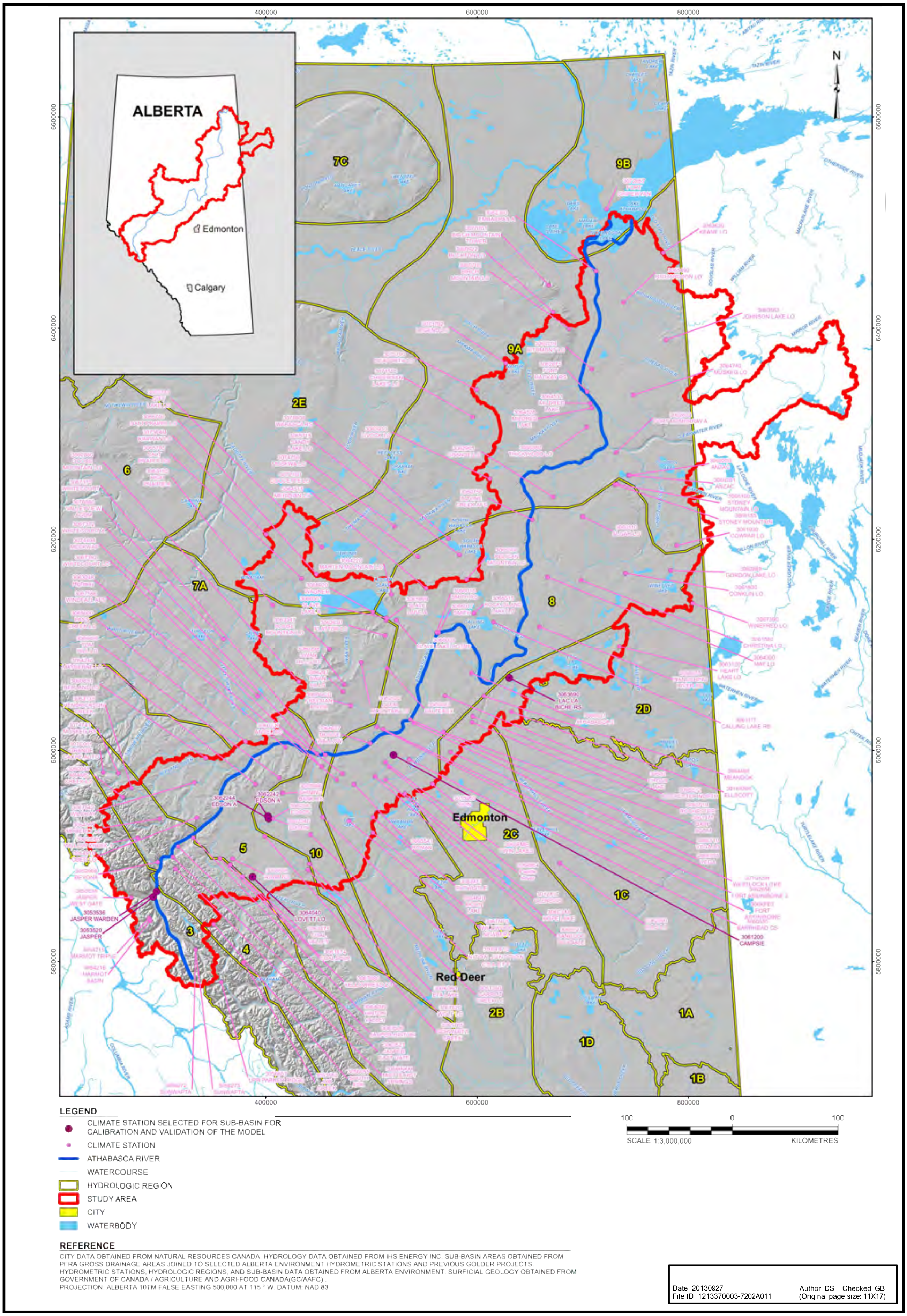

Figure 28a.1C-1: Climate Stations in the Athabasca River Basin

Attachment 28a.1D

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

Table 28a.1D-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	in	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	in/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/in	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.	degF	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.	degF	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

Table 28a.1D-1 Calibrated HSPF Model Parameters for the Athabasca River Basin (cont'd)

PERVIOUS LAND PARAMETERS (CONT'D)

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)
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.	in	see monthly table	see monthly table	see monthly table	see monthly table	0.1	0.10	see monthly table	see monthly table
UZSN	Upper zone nominal storage.	in	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.	complex	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 28a.1D-1 Calibrated HSPF Model Parameters for the Athabasca River Basin (cont'd)

MONTHLY INTERCEPTION MONTHLY

	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)
Jan	0.5	0.5	0.5	1	N/A	N/A	1	1
Feb	0.5	0.5	0.5	1	N/A	N/A	1	1
Mar	0.1	0.1	0.1	1.2	N/A	N/A	1.2	1.2
Apr	0.1	0.1	0.1	0.4	N/A	N/A	0.4	0.4
May	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05
Jun	0.1	0.1	0.1	0.1	N/A	N/A	0.1	0.1
Jul	0.05	0.05	0.05	0.05	N/A	N/A	0.05	0.05
Aug	0.35	0.35	0.35	0.35	N/A	N/A	0.35	0.35
Sep	0.4	0.4	0.4	0.4	N/A	N/A	0.4	0.4
Oct	0.4	0.4	0.4	0.4	N/A	N/A	0.4	0.4
Nov	0.4	0.4	0.4	0.4	N/A	N/A	0.4	0.4
Dec	0.4	0.4	0.4	0.4	N/A	N/A	0.4	0.4

Table 28a.1D-1 Calibrated HSPF Model Parameters for the Athabasca River Basin (cont'd)

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)
Jan	0.3	0.3	0.3	0.01	N/A	N/A	0.3	0.3
Feb	0.5	0.5	0.5	0.01	N/A	N/A	0.5	0.5
Mar	0.6	0.6	0.6	0.01	N/A	N/A	0.6	0.6
Apr	0.8	0.8	0.8	0.1	N/A	N/A	0.8	0.8
May	0.2	0.2	0.2	0.1	N/A	N/A	0.2	0.1
Jun	0.2	0.2	0.2	0.1	N/A	N/A	0.2	0.1
Jul	0.2	0.2	0.2	0.1	N/A	N/A	0.2	0.2
Aug	0.4	0.4	0.4	0.1	N/A	N/A	0.4	0.4
Sep	0.5	0.5	0.5	0.1	N/A	N/A	0.5	0.5
Oct	0.5	0.5	0.5	0.1	N/A	N/A	0.5	0.2
Nov	0.5	0.5	0.5	0.1	N/A	N/A	0.5	0.2
Dec	0.6	0.6	0.6	0.01	N/A	N/A	0.6	0.2

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.	in	0
PETMAX	The air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series.	degF	48
PETMIN	The temperature below which E-T will be zero regardless of the value in the input time series.	degF	40
RETS	The initial retention storage.	in	0.001
SURS	The initial surface (overland flow) storage.	in	0.001

Table 28a.1D-1 Calibrated HSPF Model Parameters for the Athabasca River Basin (cont'd)

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	in/day.F	0	0	0	0	0	0	0	0	0
TBASE	Reference temperature for the temperature index method	degF	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	degF	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	in/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 28a.1E

Climate Change Forecasts at Index Climate Stations

Table 28a.1E-1 Changes in Forecasted Mean Precipitation and Temperature Compared to Baseline Values at Jasper Climate Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
Climate Change Models	**Changes in Forecasted Monthly, Seasonal and Annual Precipitation as a Percentage of Baseline Values** (%)																
BCM2.0 (Run 1) - SR-B1	8.6	4.0	7.9	6.0	4.1	-7.2	-12.0	-8.4	-9.1	18.9	15.1	23.6	11.6	6.0	-9.2	8.7	4.2
CGCM3T47 (Mean) - SR-B1	18.5	9.7	10.5	11.2	28.7	5.6	1.3	-0.7	4.5	16.9	19.0	23.8	17.7	18.8	2.3	13.4	10.8
CNRMCM3 (Run 1) - SR-A2	11.4	8.9	20.4	18.9	12.0	3.7	-13.2	-14.4	-1.2	33.5	42.2	18.6	13.3	16.8	-6.9	26.7	10.0
INMCM3.0 (Run 1) - SR-A2	9.7	31.0	17.6	44.9	33.5	8.3	3.8	-10.0	-14.0	3.5	37.0	29.8	23.5	30.0	2.5	11.7	16.3
MIROC3.2 hires (Run 1) - SR-A1B	12.8	9.5	23.5	28.6	29.2	-8.8	-21.7	-14.0	5.8	19.3	23.8	14.3	12.4	27.3	-14.8	16.3	6.6
Average	**12.2**	**12.6**	**16.0**	**21.9**	**21.5**	**0.3**	**-8.4**	**-9.5**	**-2.8**	**18.4**	**27.4**	**22.0**	**15.7**	**19.8**	**-5.2**	**15.4**	**9.6**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values (^{0}C)																
BCM2.0 (Run 1) - SR-B1	1.48	0.07	0.77	0.94	0.34	0.59	2.12	1.83	1.55	0.77	1.93	2.23	1.26	0.68	1.51	1.42	1.22
CGCM3T47 (Mean) - SR-B1	2.93	3.01	1.99	1.32	1.31	1.82	1.99	1.83	2.12	1.69	2.02	2.06	2.67	1.54	1.88	1.94	2.01
CNRMCM3 (Run 1) - SR-A2	2.82	-0.20	0.47	0.40	1.76	2.97	3.61	3.53	2.54	2.05	1.73	3.24	1.95	0.88	3.37	2.10	2.08
INMCM3.0 (Run 1) - SR-A2	4.57	5.19	4.41	3.13	1.56	1.48	1.99	2.19	2.66	3.59	3.40	3.15	4.30	3.03	1.89	3.22	3.11
MIROC3.2 hires (Run 1) - SR-A1B	4.30	4.45	3.91	3.59	5.92	4.36	4.68	4.78	4.57	3.42	3.19	5.67	4.81	4.47	4.61	3.73	4.40
Average	**3.22**	**2.50**	**2.31**	**1.88**	**2.18**	**2.25**	**2.88**	**2.83**	**2.69**	**2.30**	**2.45**	**3.27**	**3.00**	**2.12**	**2.65**	**2.48**	**2.56**

Table 28a.1E-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	0.3	-9.6	-11.5	14.5	1.2	15.7	13.3	1.1	8.6	23.9	1.0	24.6	4.5	2.2	10.5	10.6	8.4
CGCM3T47 (Mean) - SR-B1	18.5	9.7	10.5	11.2	28.7	5.6	1.3	-0.7	4.5	16.9	19.0	23.8	17.7	18.8	2.3	13.4	10.8
CNRMCM3 (Run 1) - SR-A2	-1.2	-13.3	-2.4	8.5	-8.7	-8.2	2.2	-1.3	12.9	4.8	7.3	-17.9	-11.6	-3.9	-2.9	9.5	-2.3
INMCM3.0 (Run 1) - SR-A2	10.8	22.5	7.8	57.3	52.5	9.1	-5.0	-12.0	-6.8	1.2	26.5	25.8	19.6	38.3	-1.2	7.8	12.5
MIROC3.2 hires (Run 1) - SR-A1B	16.3	8.3	22.4	34.5	23.8	-6.4	-22.4	-16.5	-0.4	21.4	25.2	12.4	12.4	26.6	-14.9	14.3	4.9
Average	**8.9**	**3.5**	**5.3**	**25.2**	**19.5**	**3.2**	**-2.1**	**-5.9**	**3.7**	**13.6**	**15.8**	**13.7**	**8.5**	**16.4**	**-1.3**	**11.1**	**6.8**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values (^{0}C)																
BCM2.0 (Run 1) - SR-B1	1.89	0.29	1.10	1.01	1.12	0.89	1.36	1.31	1.45	0.81	2.59	1.74	1.31	1.08	1.18	1.62	1.30
CGCM3T47 (Mean) - SR-B1	2.93	3.01	1.99	1.32	1.31	1.82	1.99	1.83	2.12	1.69	2.02	2.06	2.67	1.54	1.88	1.94	2.01
CNRMCM3 (Run 1) - SR-A2	3.42	0.79	0.98	1.02	2.32	2.70	3.26	3.01	2.09	2.08	1.99	4.39	2.86	1.44	2.99	2.05	2.34
INMCM3.0 (Run 1) - SR-A2	3.62	4.59	3.70	3.29	2.12	1.88	2.37	2.41	2.82	3.57	3.45	2.66	3.63	3.04	2.22	3.28	3.04
MIROC3.2 hires (Run 1) - SR-A1B	4.32	4.55	4.29	4.07	5.12	4.56	4.69	4.77	4.59	3.49	3.10	5.46	4.77	4.49	4.67	3.73	4.42
Average	**3.24**	**2.64**	**2.41**	**2.14**	**2.40**	**2.37**	**2.73**	**2.67**	**2.61**	**2.33**	**2.63**	**3.26**	**3.05**	**2.32**	**2.59**	**2.52**	**2.62**

Table 28a.1E-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	0.3	-9.6	-11.5	14.5	1.2	15.7	13.3	1.1	8.6	23.9	1.0	24.6	4.5	2.2	10.5	10.6	8.4
CGCM3T47 (Mean) - SR-B1	18.5	9.7	10.5	11.2	28.7	5.6	1.3	-0.7	4.5	16.9	19.0	23.8	17.7	18.8	2.3	13.4	10.8
CNRMCM3 (Run 1) - SR-A2	-1.2	-13.3	-2.4	8.5	-8.7	-8.2	2.2	-1.3	12.9	4.8	7.3	-17.9	-11.6	-3.9	-2.9	9.5	-2.3
INMCM3.0 (Run 1) - SR-A2	8.7	25.4	-8.2	35.1	83.9	50.3	29.5	17.0	18.4	4.0	25.0	14.2	16.1	35.4	32.8	15.1	25.5
MIROC3.2 hires (Run 1) - SR-A1B	18.3	17.3	28.3	42.5	18.2	-7.6	-22.3	-9.7	-2.2	19.6	31.4	14.9	16.8	27.8	-13.2	15.2	8.5
Average	**8.9**	**5.9**	**3.3**	**22.4**	**24.7**	**11.2**	**4.8**	**1.3**	**8.4**	**13.8**	**16.7**	**11.9**	**8.7**	**16.1**	**5.9**	**12.7**	**10.2**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values (^{0}C)																
BCM2.0 (Run 1) - SR-B1	1.89	0.29	1.10	1.01	1.12	0.89	1.36	1.31	1.45	0.81	2.59	1.74	1.31	1.08	1.18	1.62	1.30
CGCM3T47 (Mean) - SR-B1	2.93	3.01	1.99	1.32	1.31	1.82	1.99	1.83	2.12	1.69	2.02	2.06	2.67	1.54	1.88	1.94	2.01
CNRMCM3 (Run 1) - SR-A2	3.42	0.79	0.98	1.02	2.32	2.70	3.26	3.01	2.09	2.08	1.99	4.39	2.86	1.44	2.99	2.05	2.34
INMCM3.0 (Run 1) - SR-A2	3.44	3.05	3.13	3.48	2.03	1.74	2.12	2.20	2.80	4.18	3.64	2.49	2.99	2.88	2.02	3.54	2.86
MIROC3.2 hires (Run 1) - SR-A1B	5.14	5.93	6.73	5.47	4.67	3.97	4.19	4.62	4.51	3.71	3.77	6.43	5.83	5.63	4.26	4.00	4.93
Average	**3.36**	**2.61**	**2.79**	**2.46**	**2.29**	**2.22**	**2.58**	**2.60**	**2.59**	**2.49**	**2.80**	**3.42**	**3.13**	**2.51**	**2.47**	**2.63**	**2.69**

Table 28a.1E-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	0.3	-9.6	-11.5	14.5	1.2	15.7	13.3	1.1	8.6	23.9	1.0	24.6	4.5	2.2	10.5	10.6	8.4
CGCM3T47 (Mean) - SR-B1	18.5	9.7	10.5	11.2	28.7	5.6	1.3	-0.7	4.5	16.9	19.0	23.8	17.7	18.8	2.3	13.4	10.8
CNRMCM3 (Run 1) - SR-A2	-1.2	-13.3	-2.4	8.5	-8.7	-8.2	2.2	-1.3	12.9	4.8	7.3	-17.9	-11.6	-3.9	-2.9	9.5	-2.3
INMCM3.0 (Run 1) - SR-A2	8.7	25.4	-8.2	35.1	83.9	50.3	29.5	17.0	18.4	4.0	25.0	14.2	16.1	35.4	32.8	15.1	25.5
MIROC3.2 hires (Run 1) - SR-A1B	15.9	12.6	23.7	30.1	34.5	-7.3	-9.5	4.9	12.9	8.8	22.7	14.5	14.4	29.9	-4.5	15.1	12.4
Average	**8.4**	**5.0**	**2.4**	**19.9**	**27.9**	**11.2**	**7.4**	**4.2**	**11.5**	**11.7**	**15.0**	**11.8**	**8.2**	**16.5**	**7.6**	**12.7**	**11.0**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values (^{0}C)																
BCM2.0 (Run 1) - SR-B1	1.89	0.29	1.10	1.01	1.12	0.89	1.36	1.31	1.45	0.81	2.59	1.74	1.31	1.08	1.18	1.62	1.30
CGCM3T47 (Mean) - SR-B1	2.93	3.01	1.99	1.32	1.31	1.82	1.99	1.83	2.12	1.69	2.02	2.06	2.67	1.54	1.88	1.94	2.01
CNRMCM3 (Run 1) - SR-A2	3.42	0.79	0.98	1.02	2.32	2.70	3.26	3.01	2.09	2.08	1.99	4.39	2.86	1.44	2.99	2.05	2.34
INMCM3.0 (Run 1) - SR-A2	3.44	3.05	3.13	3.48	2.03	1.74	2.12	2.20	2.80	4.18	3.64	2.49	2.99	2.88	2.02	3.54	2.86
MIROC3.2 hires (Run 1) - SR-A1B	5.52	6.20	6.48	5.63	4.80	3.91	4.09	4.51	4.31	3.80	4.20	6.91	6.21	5.64	4.17	4.10	5.03
Average	**3.44**	**2.67**	**2.74**	**2.49**	**2.32**	**2.21**	**2.56**	**2.57**	**2.55**	**2.51**	**2.89**	**3.52**	**3.21**	**2.51**	**2.45**	**2.65**	**2.71**

Table 28a.1E-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	-4.4	-22.4	-16.4	10.3	4.4	16.4	16.7	2.1	12.3	17.2	1.3	34.7	0.8	3.6	12.2	11.5	9.7
CGCM3T47 (Mean) - SR-B1	13.5	6.5	11.1	7.0	31.2	2.3	4.2	-3.6	0.4	17.3	17.4	25.0	15.4	19.6	1.4	11.4	9.3
CNRMCM3 (Run 1) - SR-A2	-15.2	-19.8	-5.3	5.9	-11.6	-6.8	-5.5	-4.1	14.4	3.5	-3.4	-20.1	-18.6	-6.5	-5.7	8.4	-5.2
INMCM3.0 (Run 1) - SR-A2	0.7	39.4	-4.5	50.3	99.2	64.4	31.2	15.0	12.3	4.7	18.9	14.9	17.6	46.5	36.1	11.5	28.2
MIROC3.2 hires (Run 1) - SR-A1B	12.4	28.0	18.7	43.6	46.8	-14.7	-5.6	-4.5	0.5	6.5	23.7	12.4	16.7	38.1	-9.1	9.7	11.2
Average	**1.4**	**6.3**	**0.7**	**23.4**	**34.0**	**12.3**	**8.2**	**1.0**	**8.0**	**9.8**	**11.6**	**13.4**	**6.4**	**20.2**	**7.0**	**10.5**	**10.7**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values (^{0}C)																
BCM2.0 (Run 1) - SR-B1	2.19	0.94	1.49	1.62	1.41	0.90	1.09	1.21	1.48	0.93	3.03	2.29	1.81	1.51	1.06	1.81	1.55
CGCM3T47 (Mean) - SR-B1	3.41	3.87	2.58	1.52	1.41	1.68	1.99	1.99	2.29	1.76	2.05	2.67	3.32	1.84	1.88	2.03	2.27
CNRMCM3 (Run 1) - SR-A2	3.67	1.45	1.33	1.26	2.56	3.16	3.68	3.57	2.50	2.30	2.23	5.19	3.44	1.72	3.47	2.34	2.74
INMCM3.0 (Run 1) - SR-A2	4.01	3.30	3.40	3.77	2.77	2.23	2.23	2.21	2.71	4.10	3.93	3.20	3.50	3.31	2.22	3.58	3.15
MIROC3.2 hires (Run 1) - SR-A1B	5.54	6.52	7.58	5.96	4.74	4.02	4.28	4.63	4.61	3.88	4.27	7.17	6.41	6.09	4.31	4.25	5.27
Average	**3.76**	**3.22**	**3.28**	**2.83**	**2.58**	**2.40**	**2.65**	**2.72**	**2.72**	**2.59**	**3.10**	**4.11**	**3.70**	**2.89**	**2.59**	**2.80**	**3.00**

Table 28a.1E-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	4.2	-2.2	-15.1	17.5	14.3	18.5	14.0	3.1	34.6	43.8	10.8	7.2	3.3	10.6	12.5	31.2	13.4
CGCM3T47 (Mean) - SR-B1	16.6	14.2	13.4	17.9	21.6	14.7	8.8	17.2	2.8	12.9	11.4	20.6	17.2	18.5	13.2	9.0	13.7
CNRMCM3 (Run 1) - SR-A2	-4.5	-5.2	0.3	11.3	-11.5	-3.8	-8.1	-14.3	5.5	17.8	18.1	-0.1	-3.2	-4.8	-8.2	12.0	-4.0
INMCM3.0 (Run 1) - SR-A2	0.7	39.4	-4.5	50.3	99.2	64.4	31.2	15.0	12.3	4.7	18.9	14.9	17.6	46.5	36.1	11.5	28.2
MIROC3.2 hires (Run 1) - SR-A1B	21.5	30.1	21.2	40.9	20.6	0.4	8.6	-3.3	42.4	1.5	19.2	16.2	21.8	26.5	1.8	19.7	15.7
Average	**7.7**	**15.3**	**3.1**	**27.6**	**28.9**	**18.8**	**10.9**	**3.5**	**19.5**	**16.1**	**15.7**	**11.8**	**11.3**	**19.4**	**11.1**	**16.7**	**13.4**
	Changes in Forecasted Monthly, Seasonal and Annual Mean Temperature as a Difference Relative to Baseline Values (^{0}C)																
BCM2.0 (Run 1) - SR-B1	2.56	1.52	2.08	1.07	1.21	0.71	0.96	0.93	1.30	0.76	3.24	2.12	2.07	1.46	0.87	1.77	1.54
CGCM3T47 (Mean) - SR-B1	4.67	4.77	2.89	1.65	1.19	1.26	1.93	1.67	2.27	1.70	2.19	3.62	4.36	1.91	1.62	2.06	2.49
CNRMCM3 (Run 1) - SR-A2	4.71	2.34	1.55	1.09	2.70	3.27	3.63	3.43	2.23	2.35	2.79	6.00	4.35	1.78	3.45	2.46	3.01
INMCM3.0 (Run 1) - SR-A2	4.01	3.30	3.40	3.77	2.77	2.23	2.23	2.21	2.71	4.10	3.93	3.20	3.50	3.31	2.22	3.58	3.15
MIROC3.2 hires (Run 1) - SR-A1B	6.15	7.01	6.39	6.13	5.39	4.24	3.84	4.23	4.21	3.93	4.93	8.12	7.09	5.97	4.10	4.36	5.38
Average	**4.42**	**3.79**	**3.26**	**2.74**	**2.65**	**2.34**	**2.52**	**2.49**	**2.54**	**2.57**	**3.42**	**4.61**	**4.27**	**2.89**	**2.45**	**2.84**	**3.11**

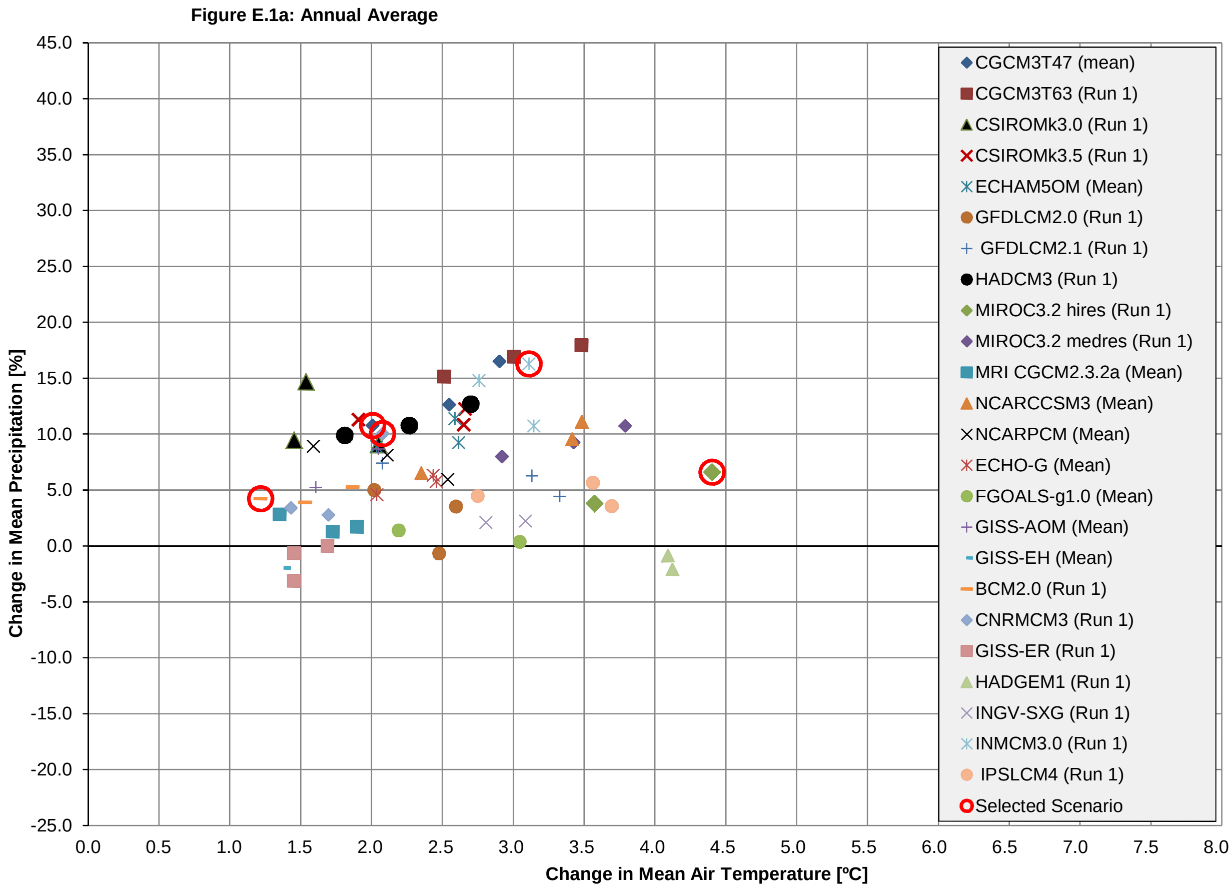

Figure 28a.1E-1 Climate Change Forecasts at Jasper Climate Station for 2051–2080 Based on 1961–1990 Base

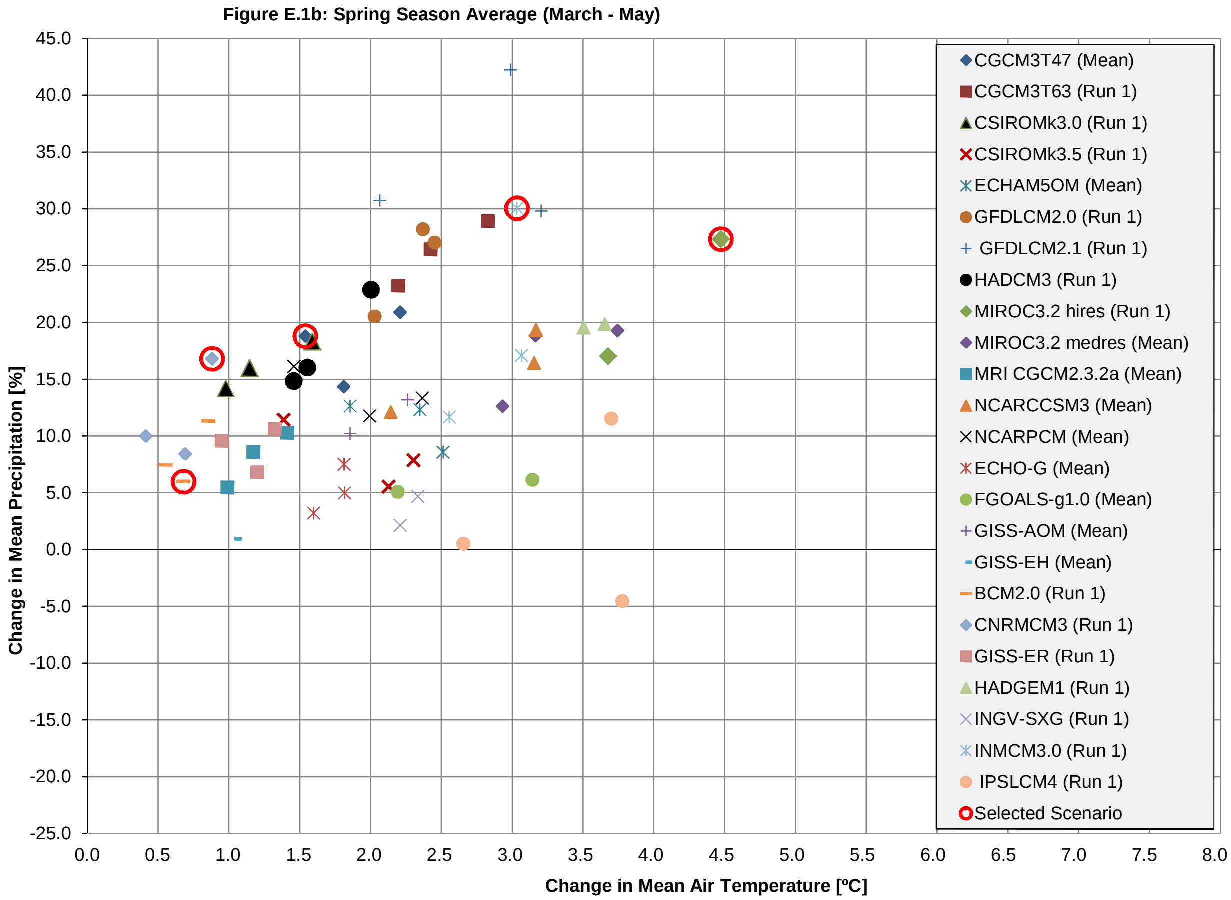

Figure 28a.1E-1 Climate Change Forecasts at Jasper Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

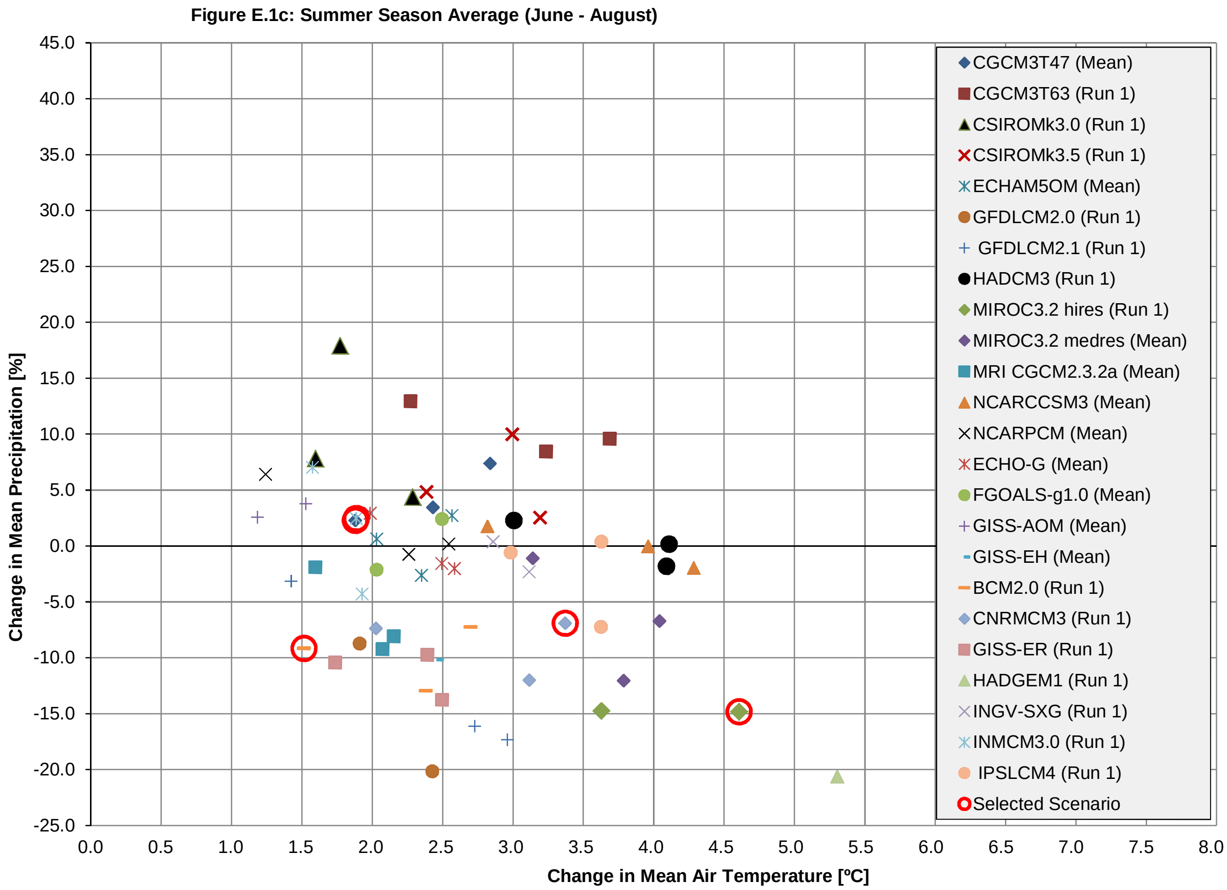

Figure 28a.1E-1 Climate Change Forecasts at Jasper Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

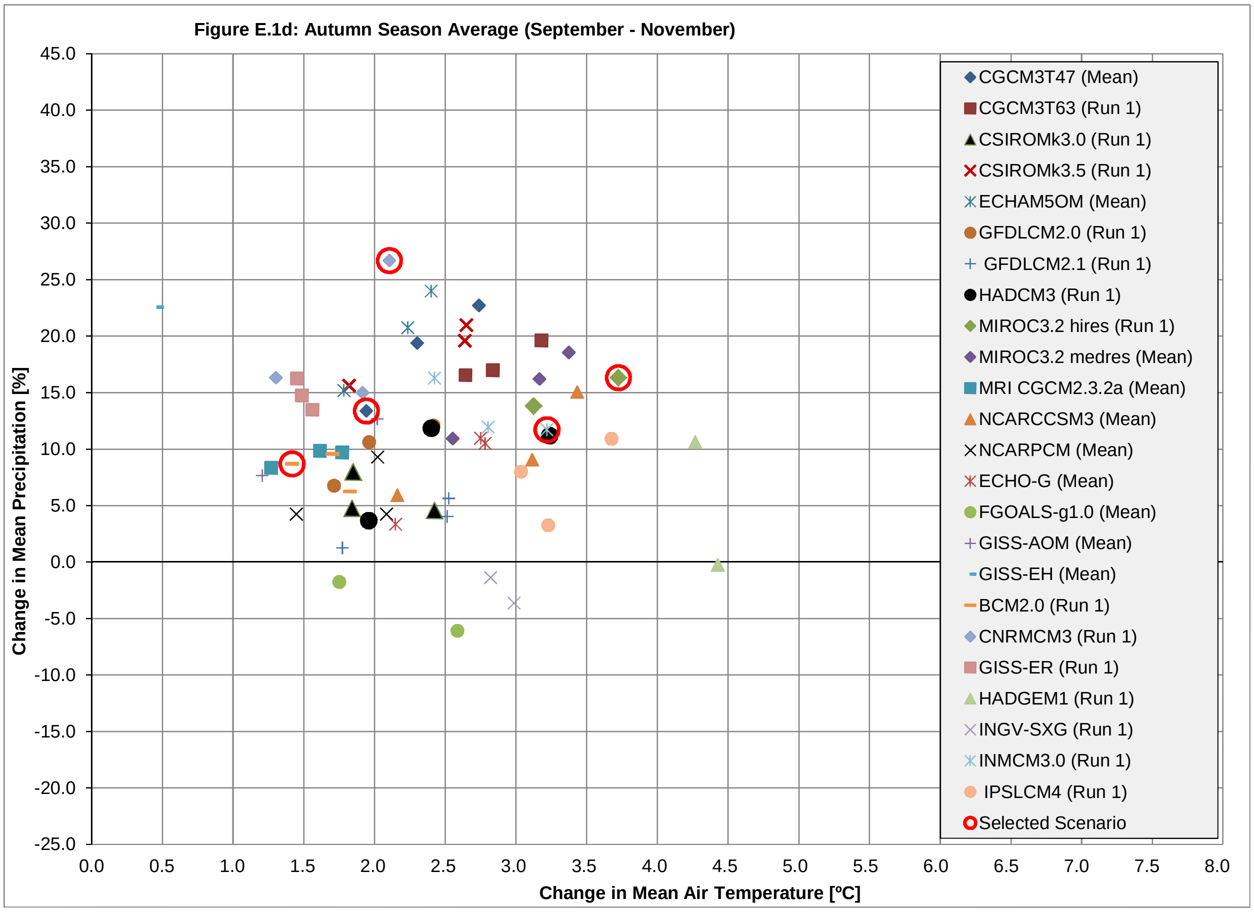

Figure 28a.1E-1 Climate Change Forecasts at Jasper Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

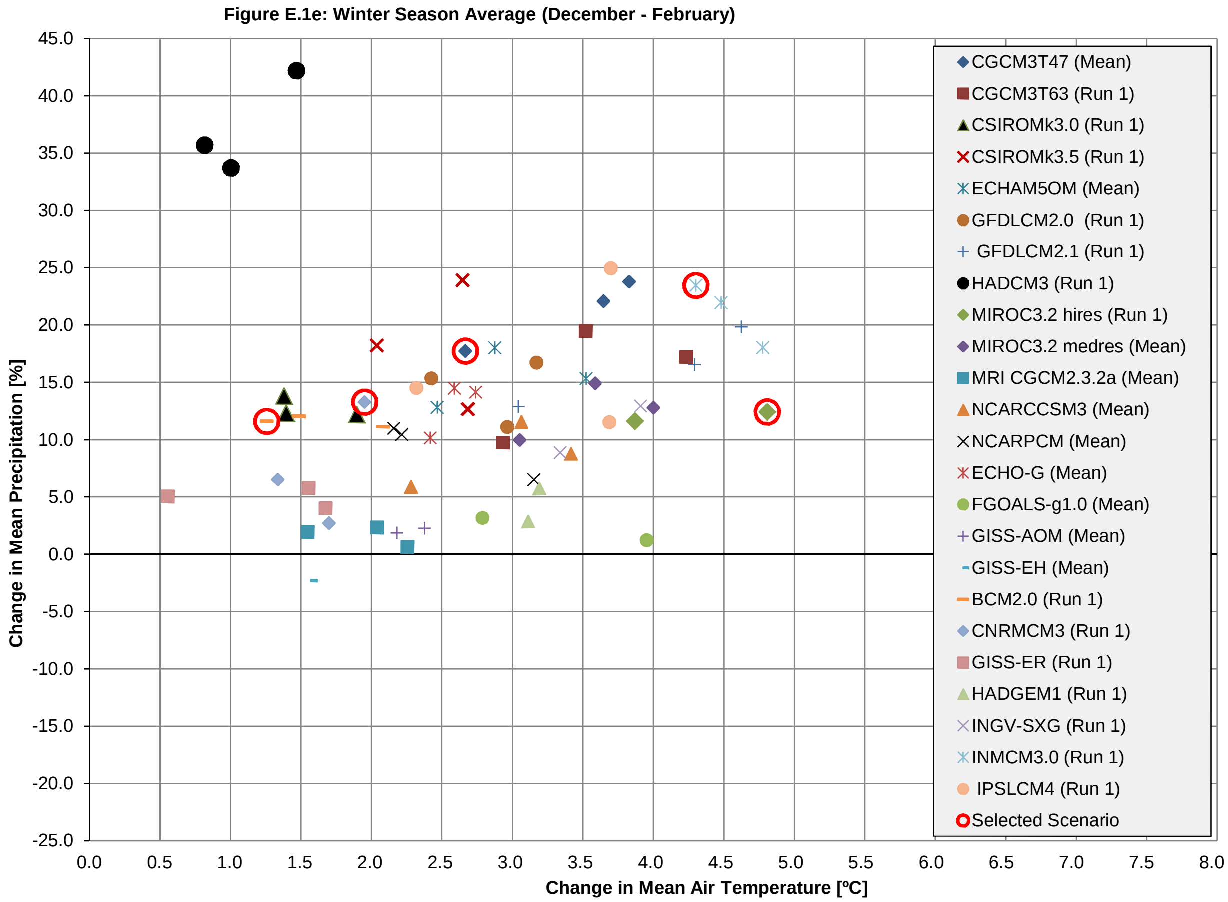

Figure 28a.1E-1 Climate Change Forecasts at Jasper Climate Station for 2051–2080 Based on 1961–1990 Base (cont’d)

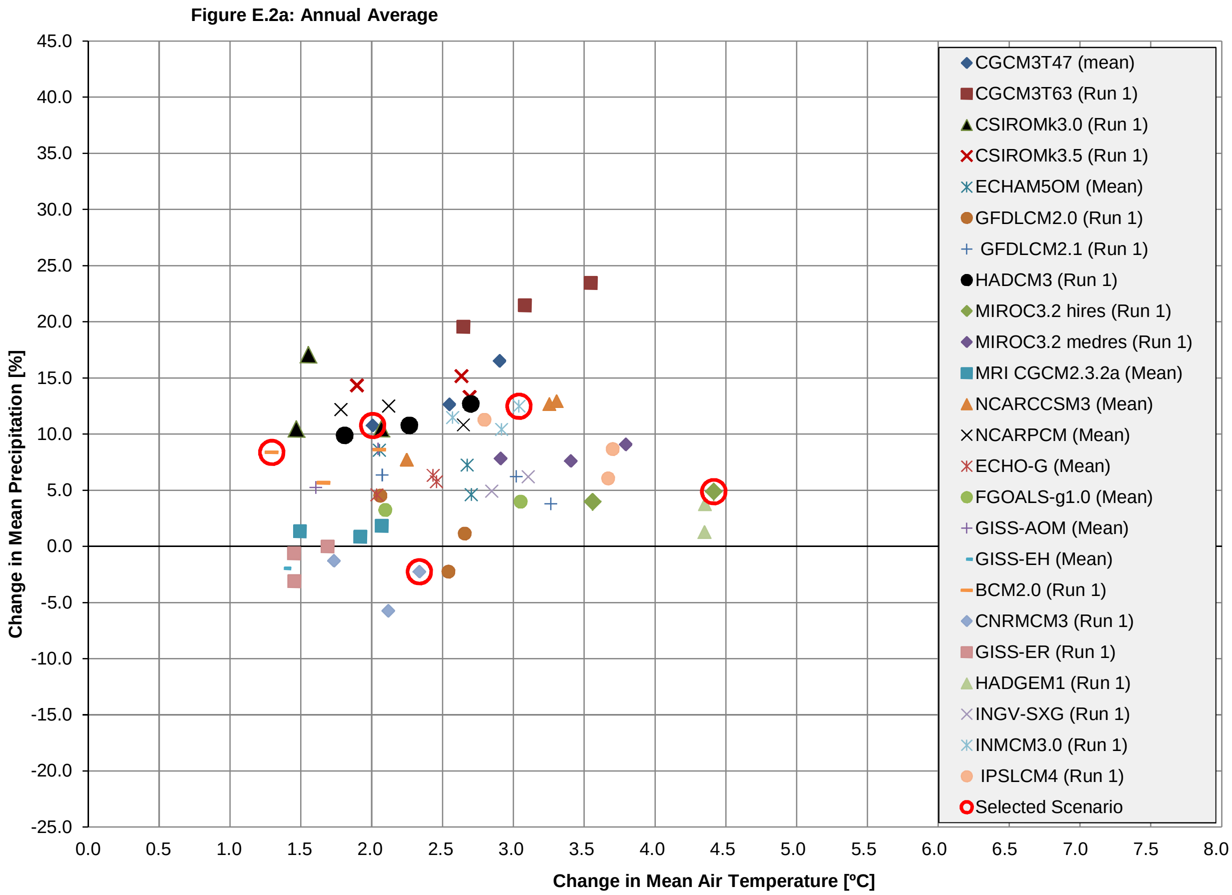

Figure 28a.1E-2 Climate Change Forecasts at Edson Climate Station for 2051–2080 Based on 1961–1990 Base

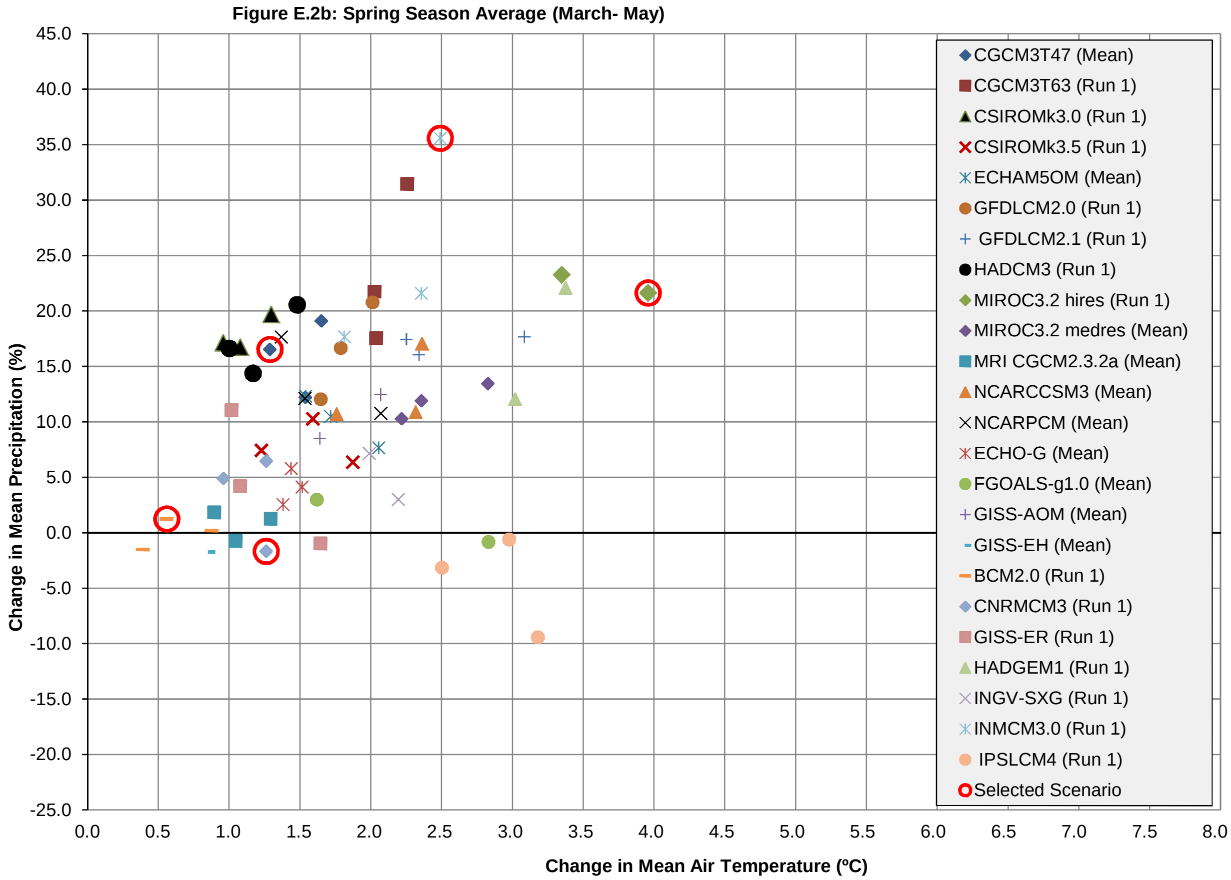

Figure 28a.1E-2 Climate Change Forecasts at Edson Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

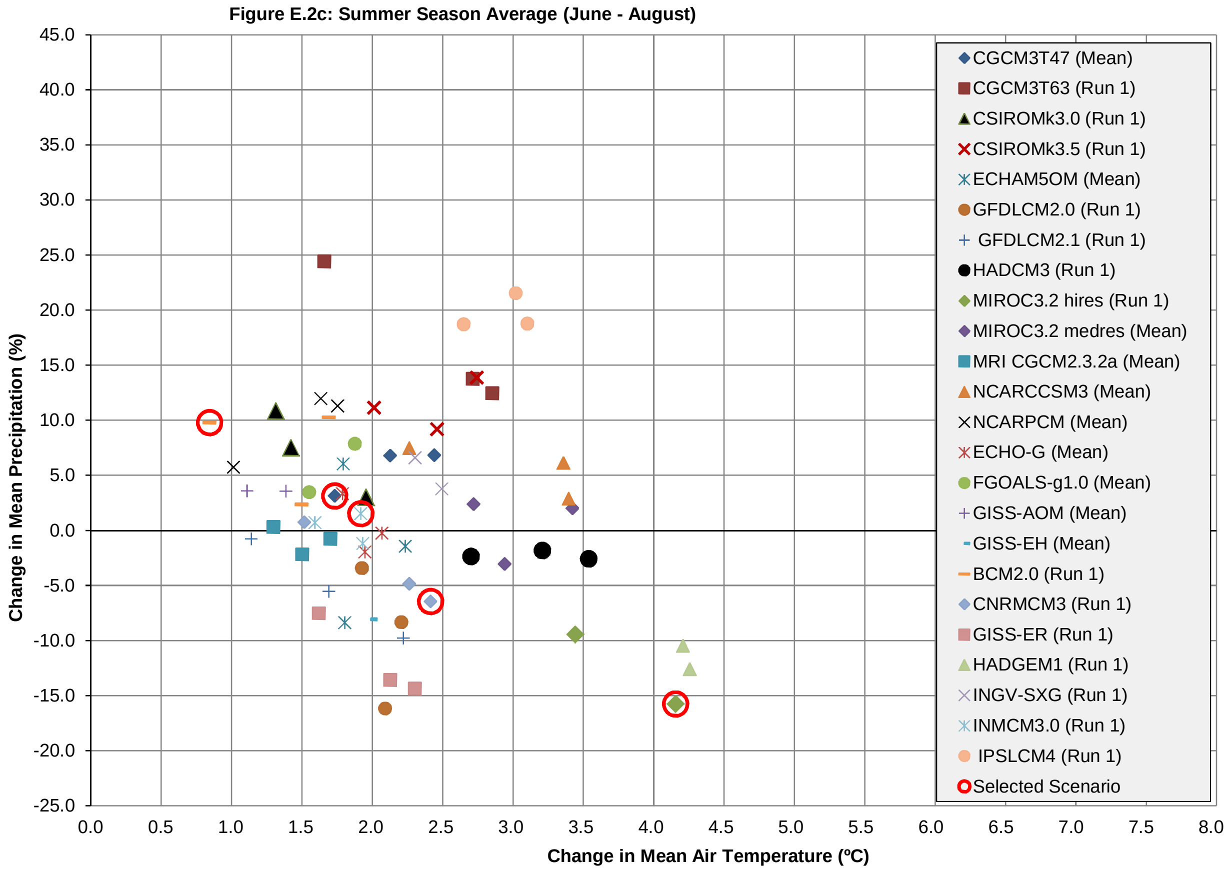

Figure 28a.1E-2 Climate Change Forecasts at Edson Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

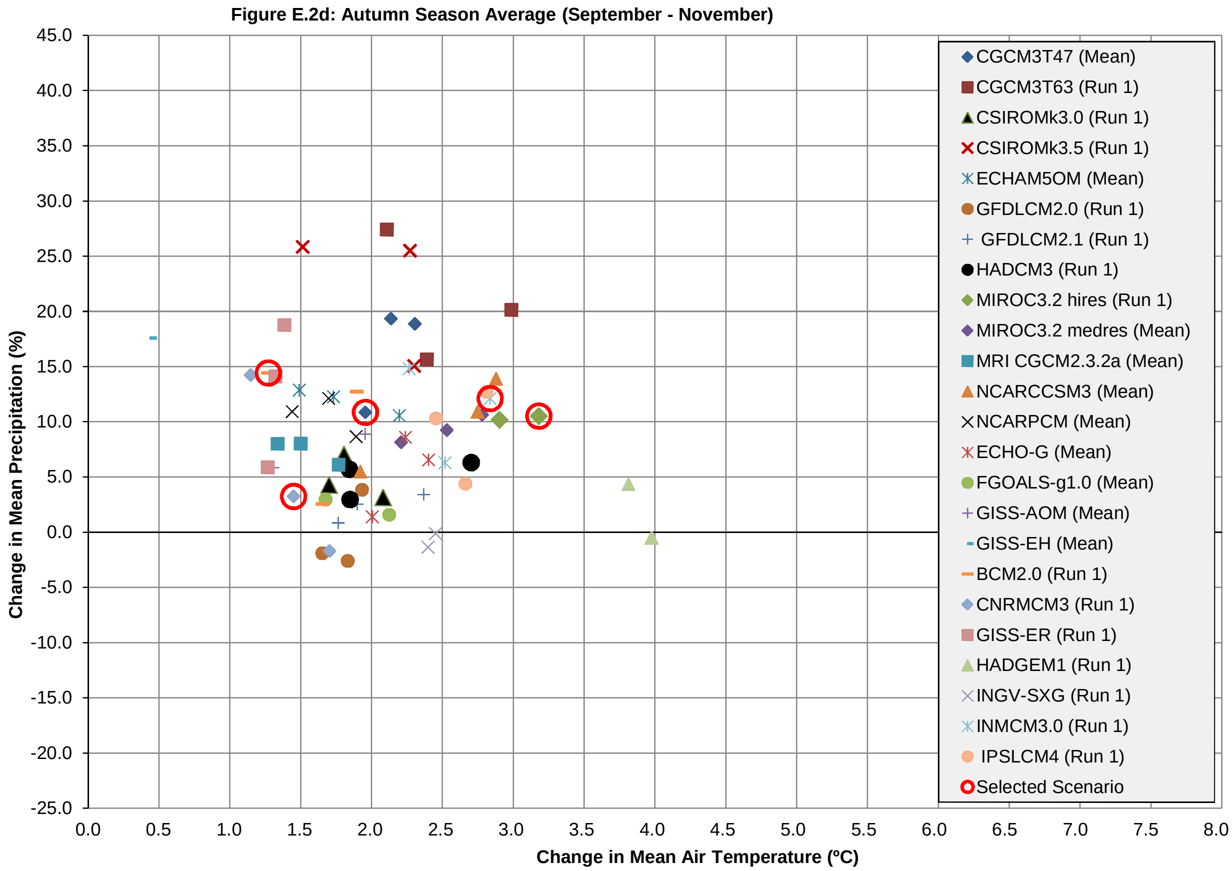

Figure 28a.1E-2 Climate Change Forecasts at Edson Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

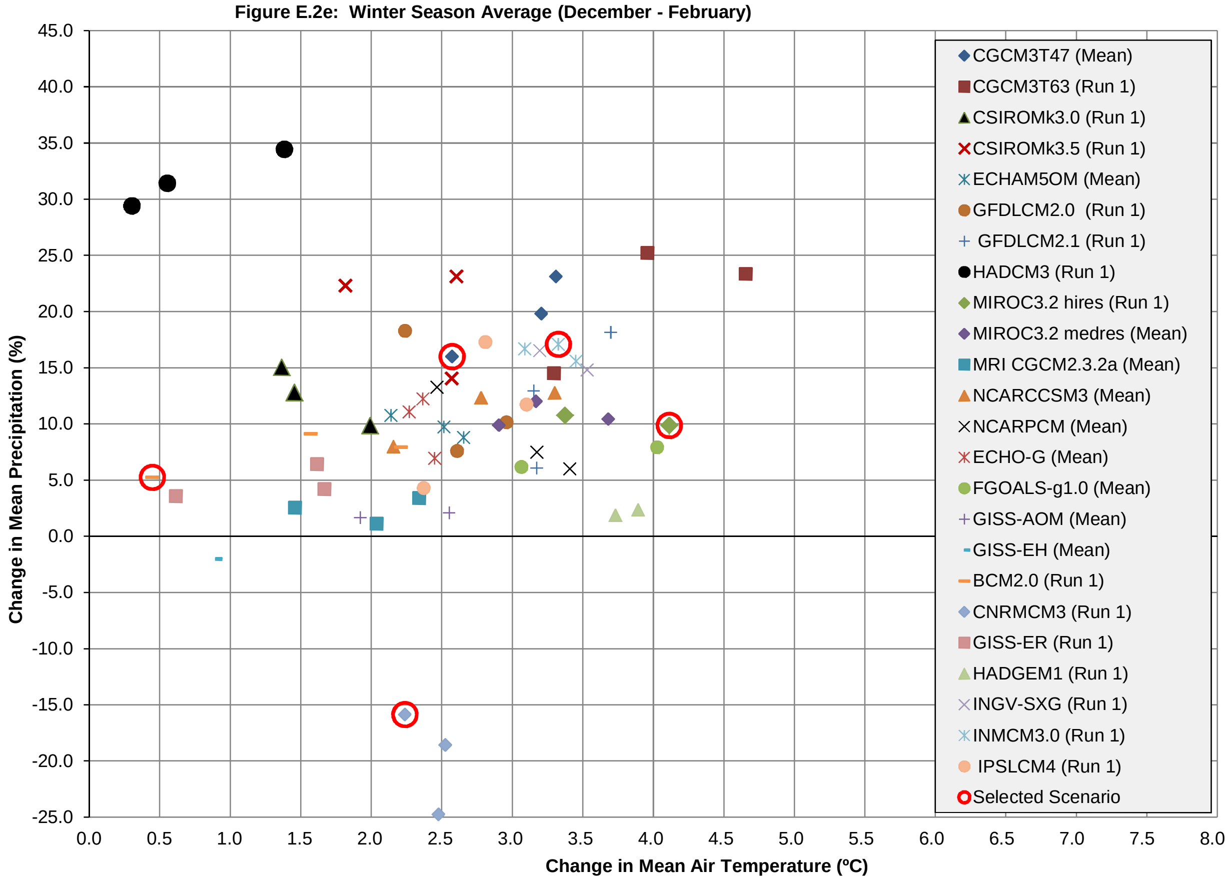

Figure 28a.1E-2 Climate Change Forecasts at Edson Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

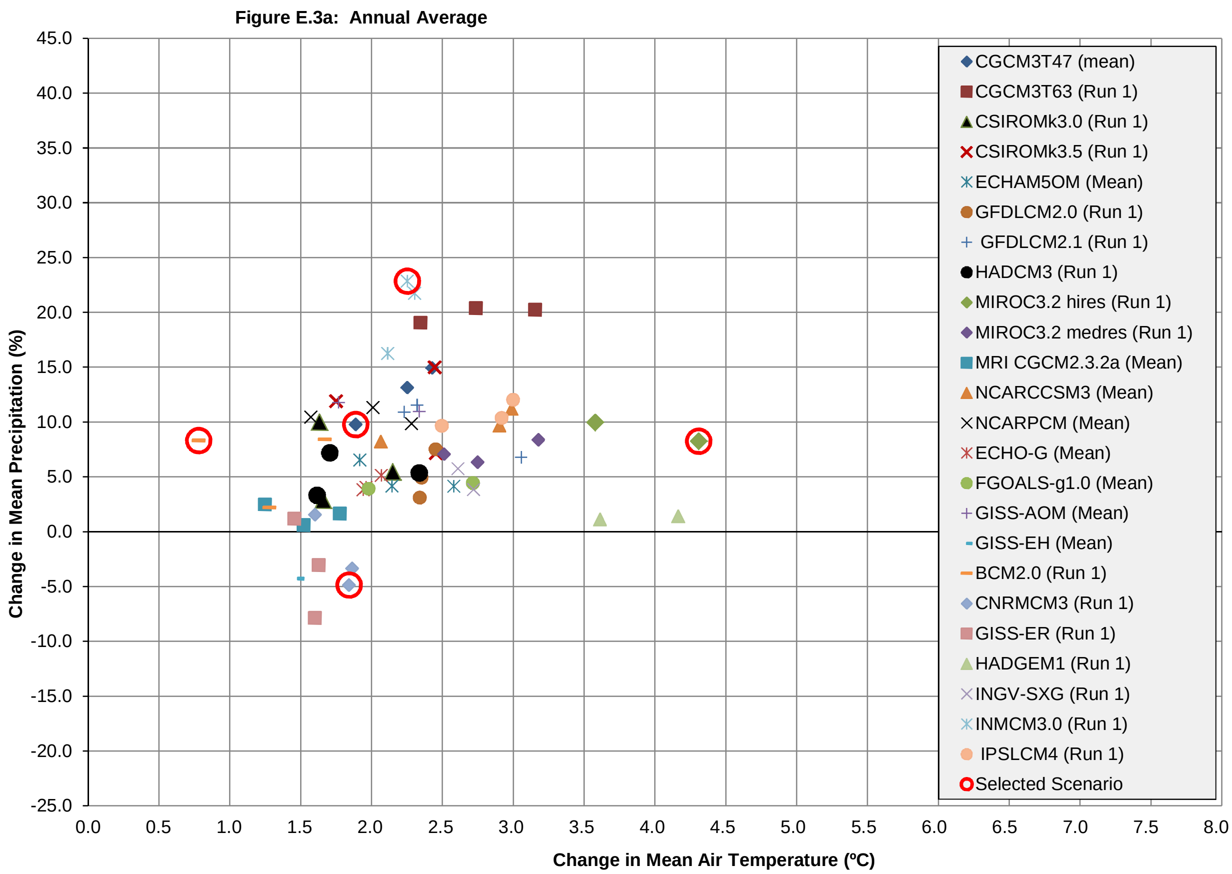

Figure 28a.1E-3 Climate Change Forecasts at Campsie Climate Station for 2051–2080 Based on 1961–1990 Base

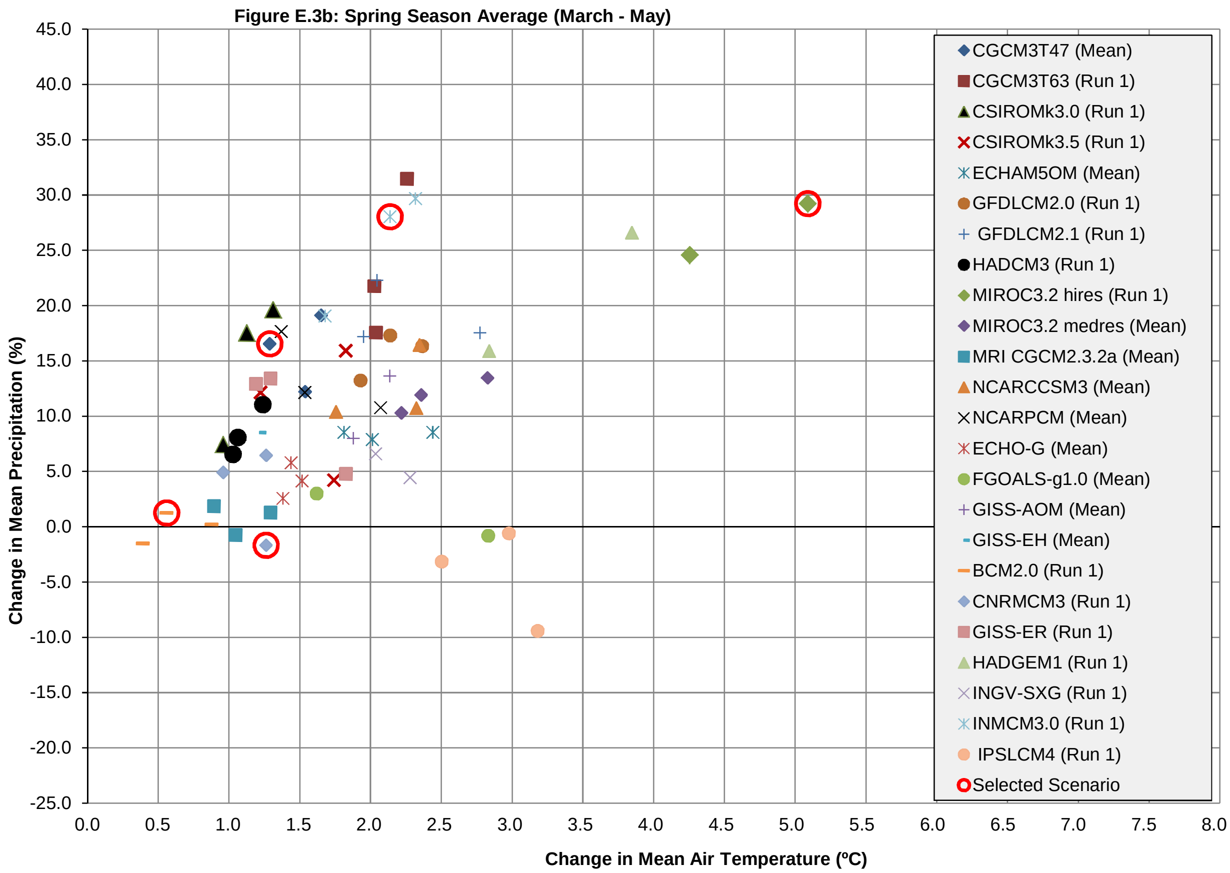

Figure 28a.1E-3 Climate Change Forecasts at Campsie Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

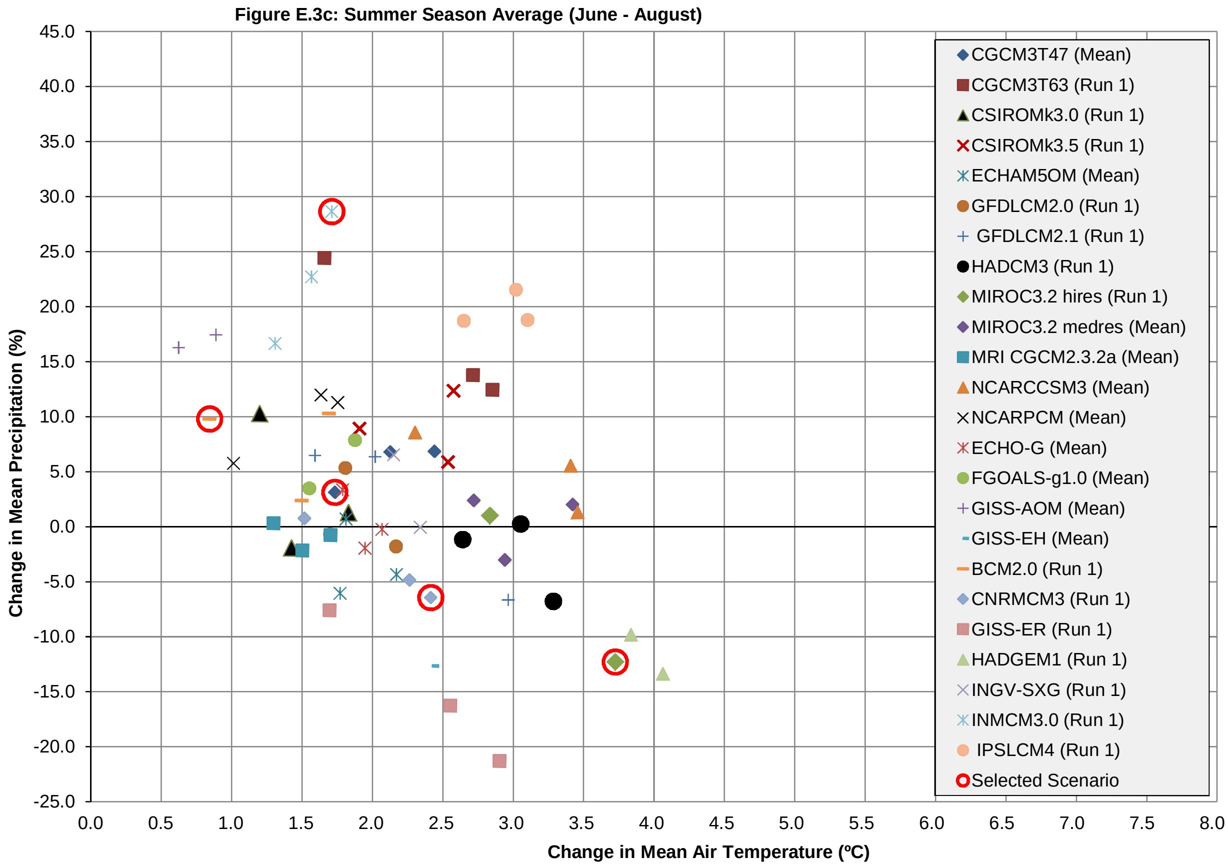

Figure 28a.1E-3 Climate Change Forecasts at Campsie Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

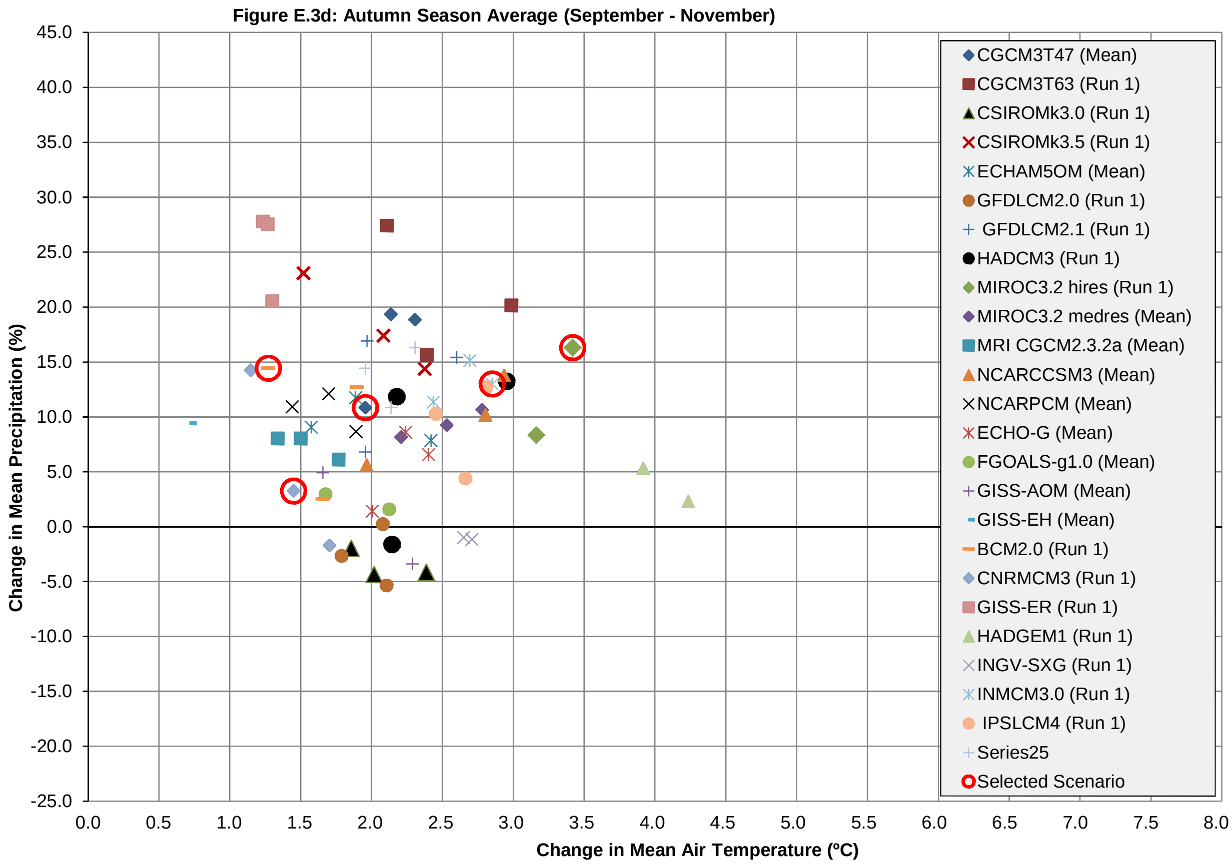

Figure 28a.1E-3 Climate Change Forecasts at Campsie Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

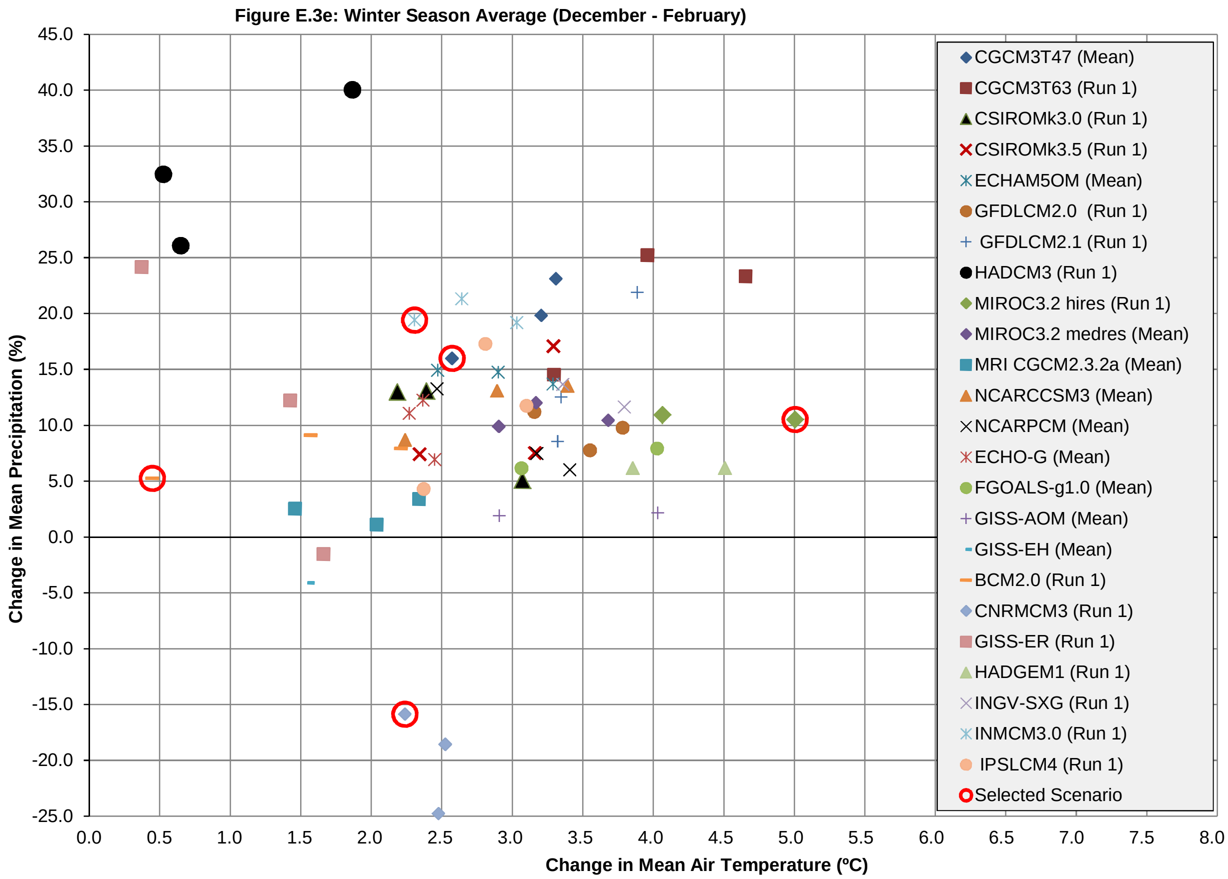

Figure 28a.1E-3 Climate Change Forecasts at Campsie Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

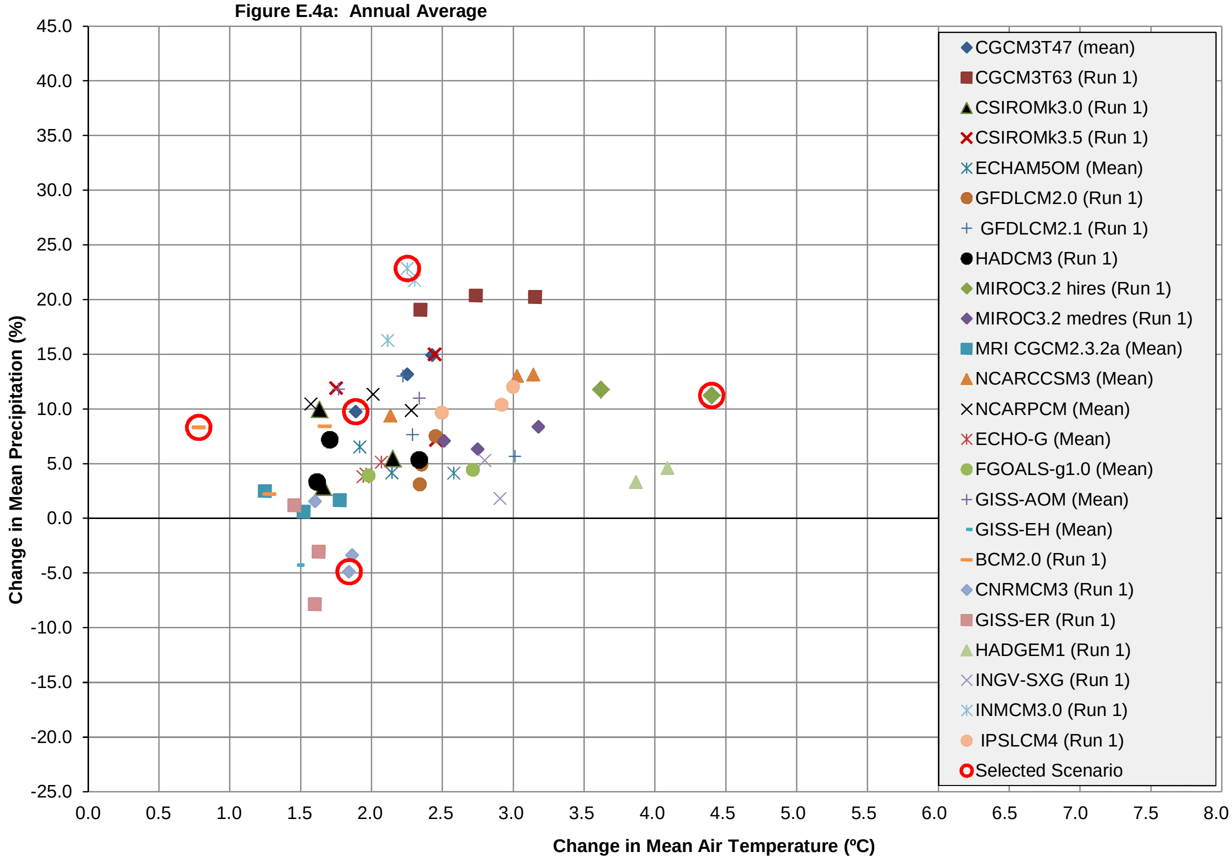

Figure 28a.1E-4 Climate Change Forecasts at Slave Lake Climate Station for 2051–2080 Based on 1961–1990 Base

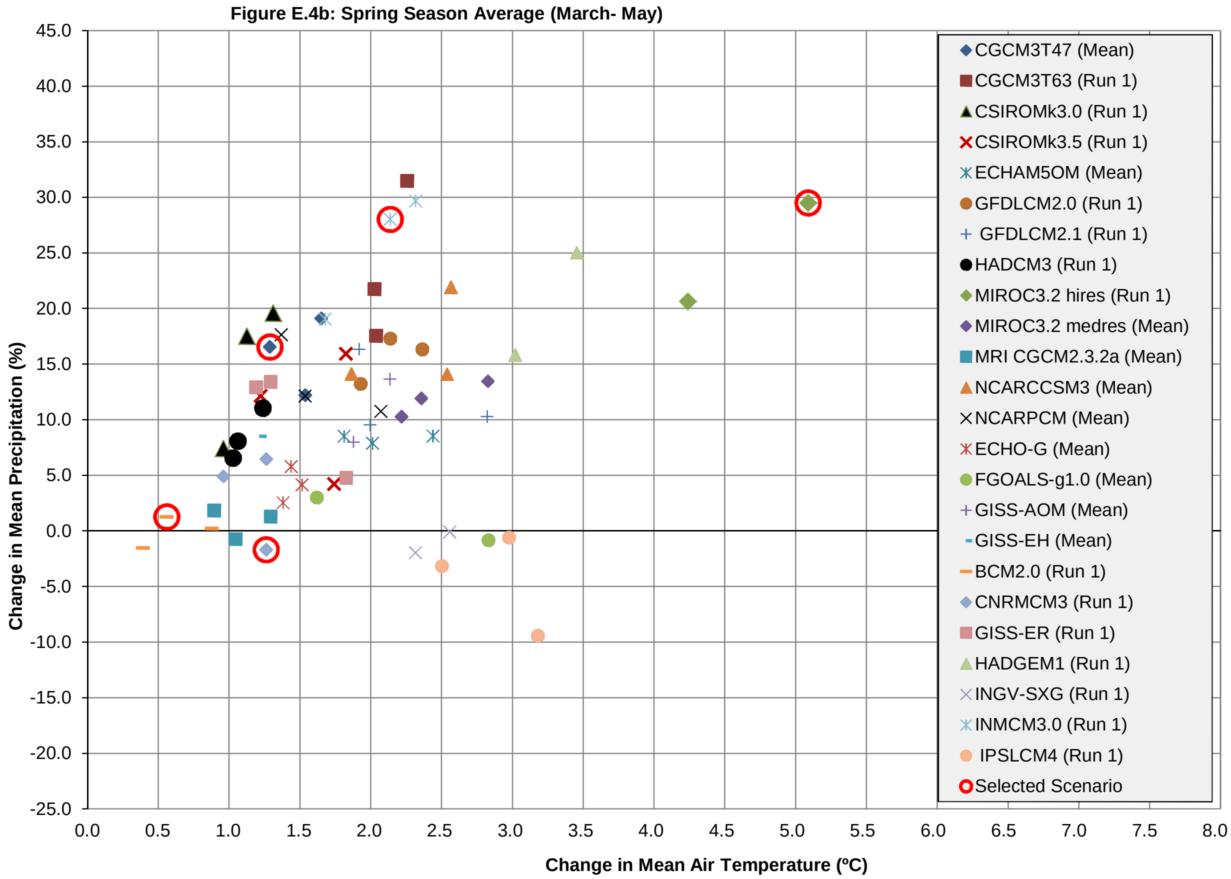

Figure 28a.1E-4 Climate Change Forecasts at Slave Lake Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

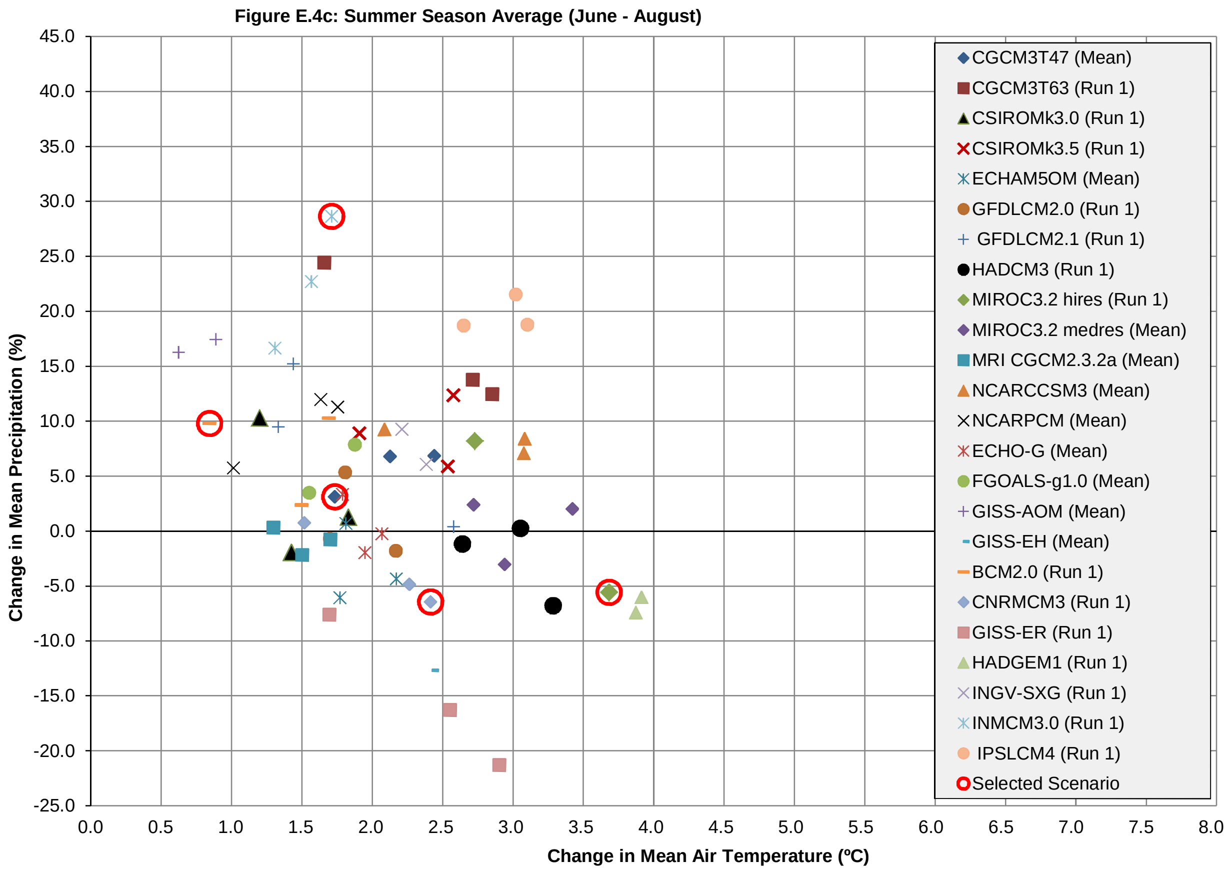

Figure 28a.1E-4 Climate Change Forecasts at Slave Lake Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

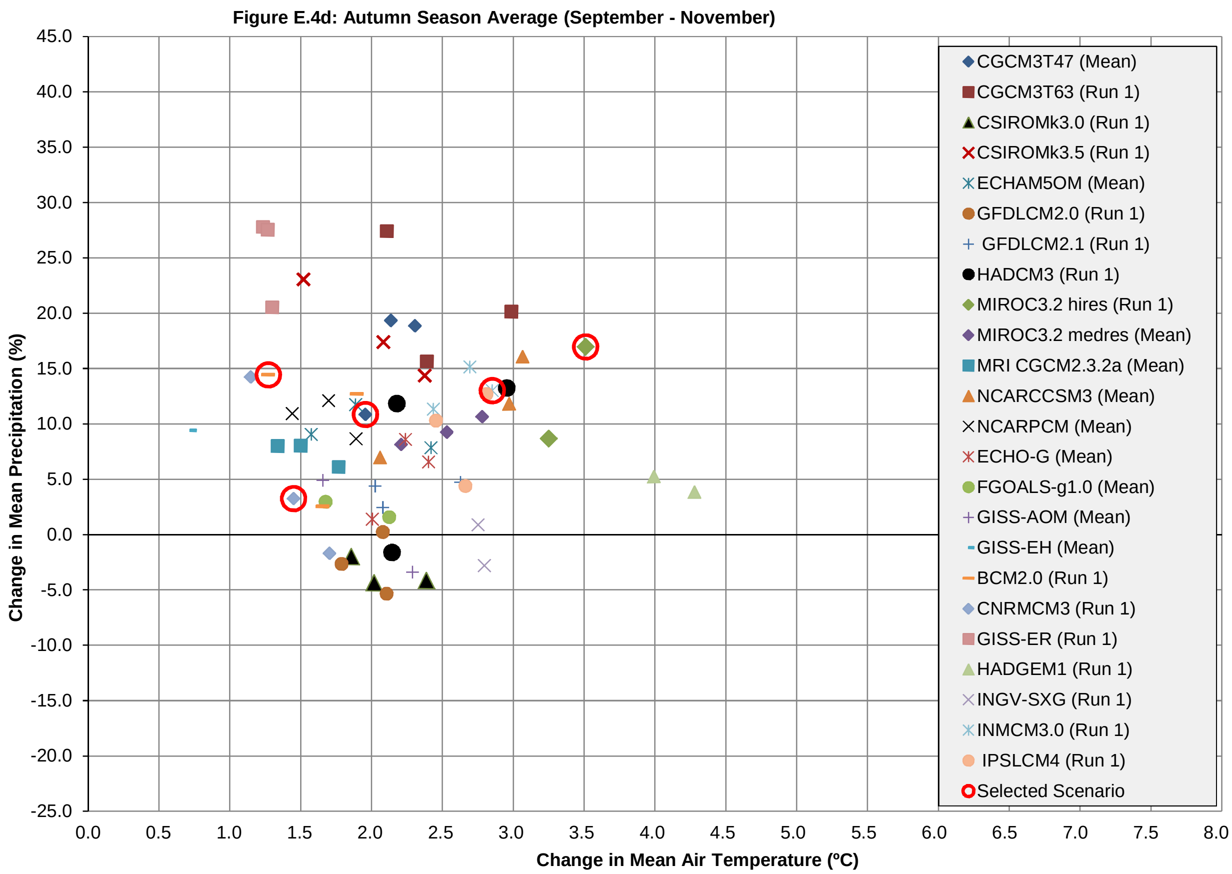

Figure 28a.1E-4 Climate Change Forecasts at Slave Lake Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

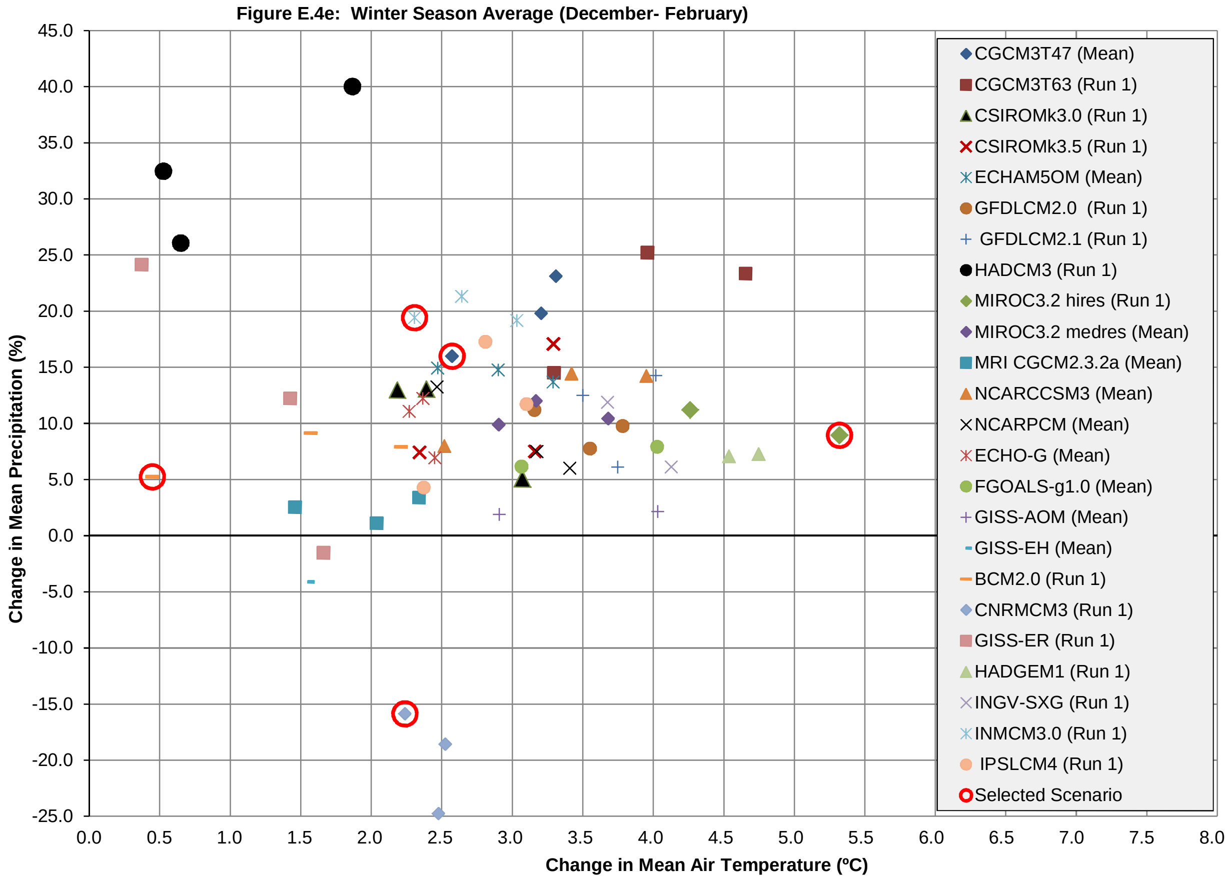

Figure 28a.1E-4 Climate Change Forecasts at Slave Lake Climate Station for 2051–2080 Based on 1961–1990 Base (cont’d)

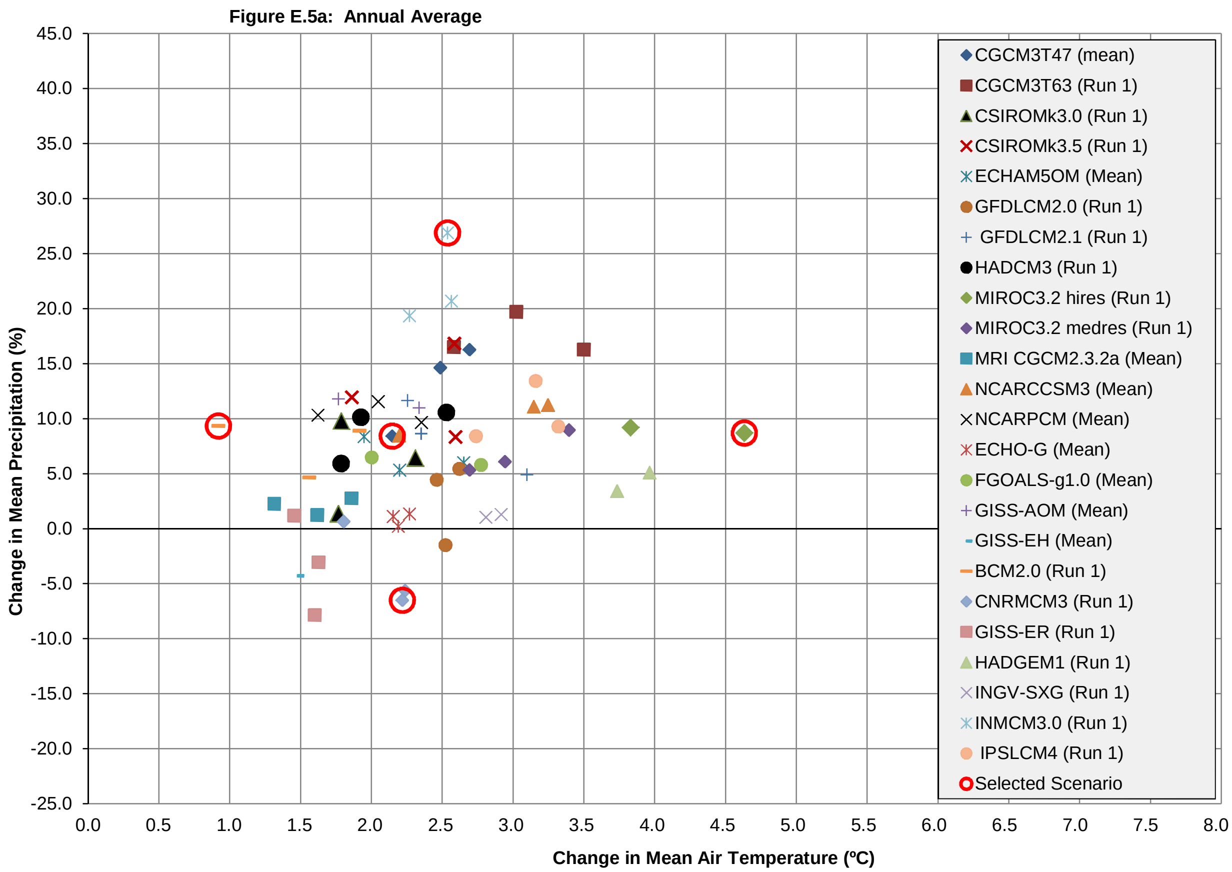

Figure 28a.1E-5 Climate Change Forecasts at Lac La Biche Climate Station for 2051–2080 Based on 1961–1990 Base

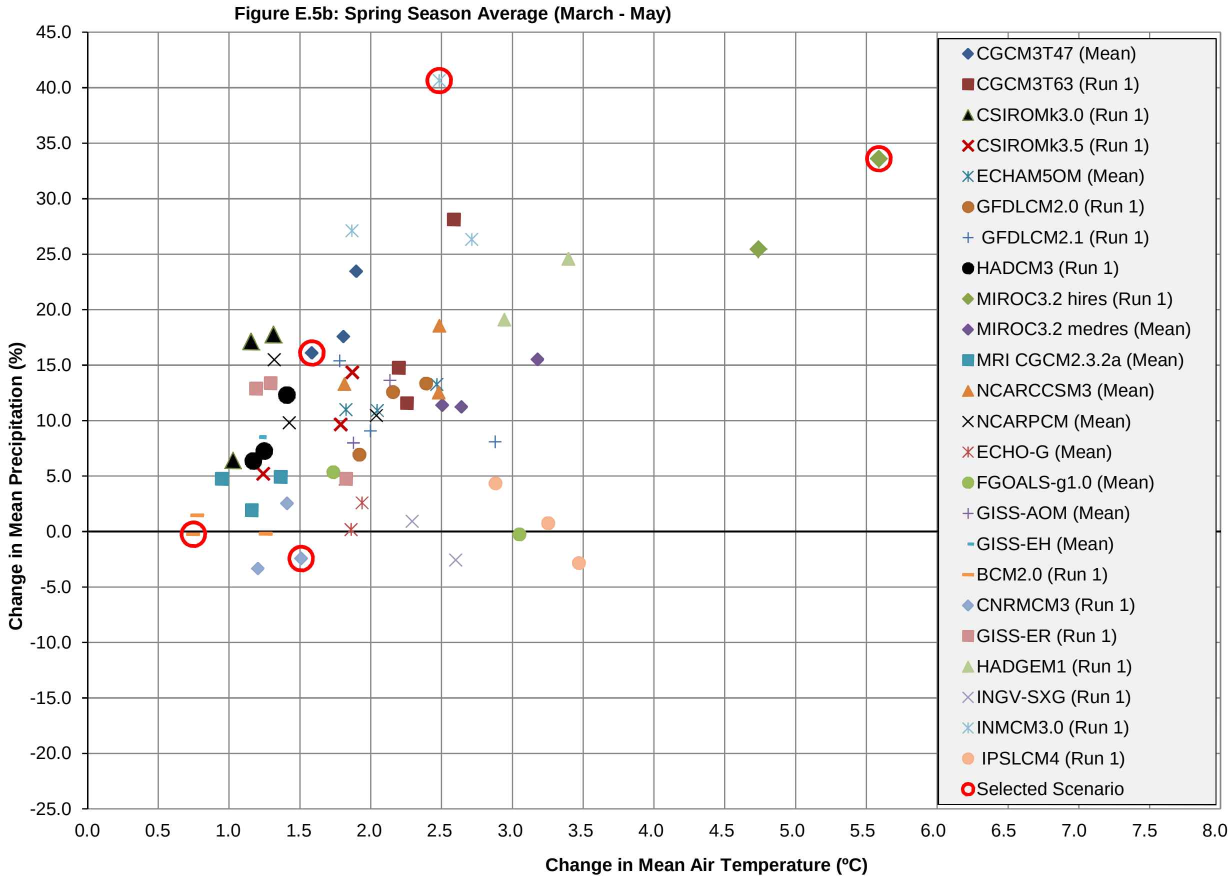

Figure 28a.1E-5 Climate Change Forecasts at Lac La Biche Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

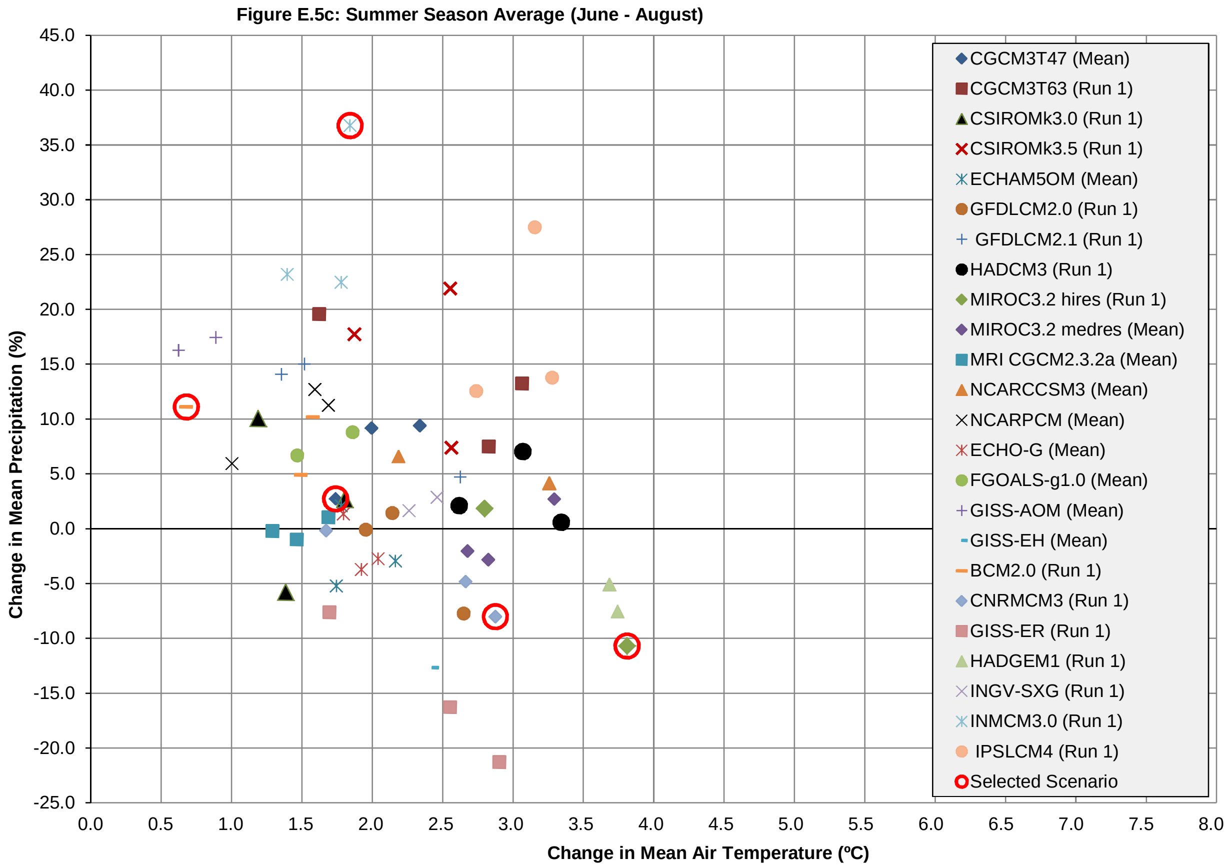

Figure 28a.1E-5 Climate Change Forecasts at Lac La Biche Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

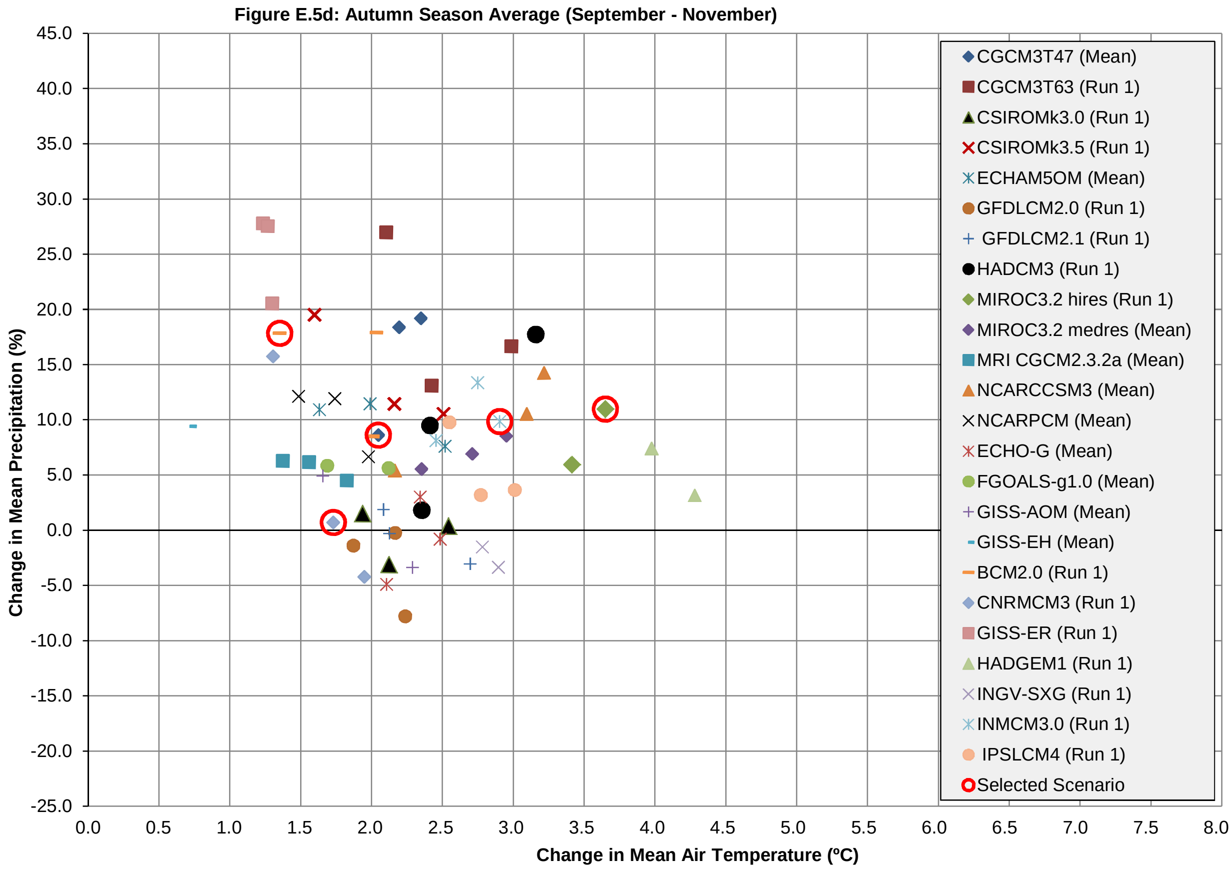

Figure 28a.1E-5 Climate Change Forecasts at Lac La Biche Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

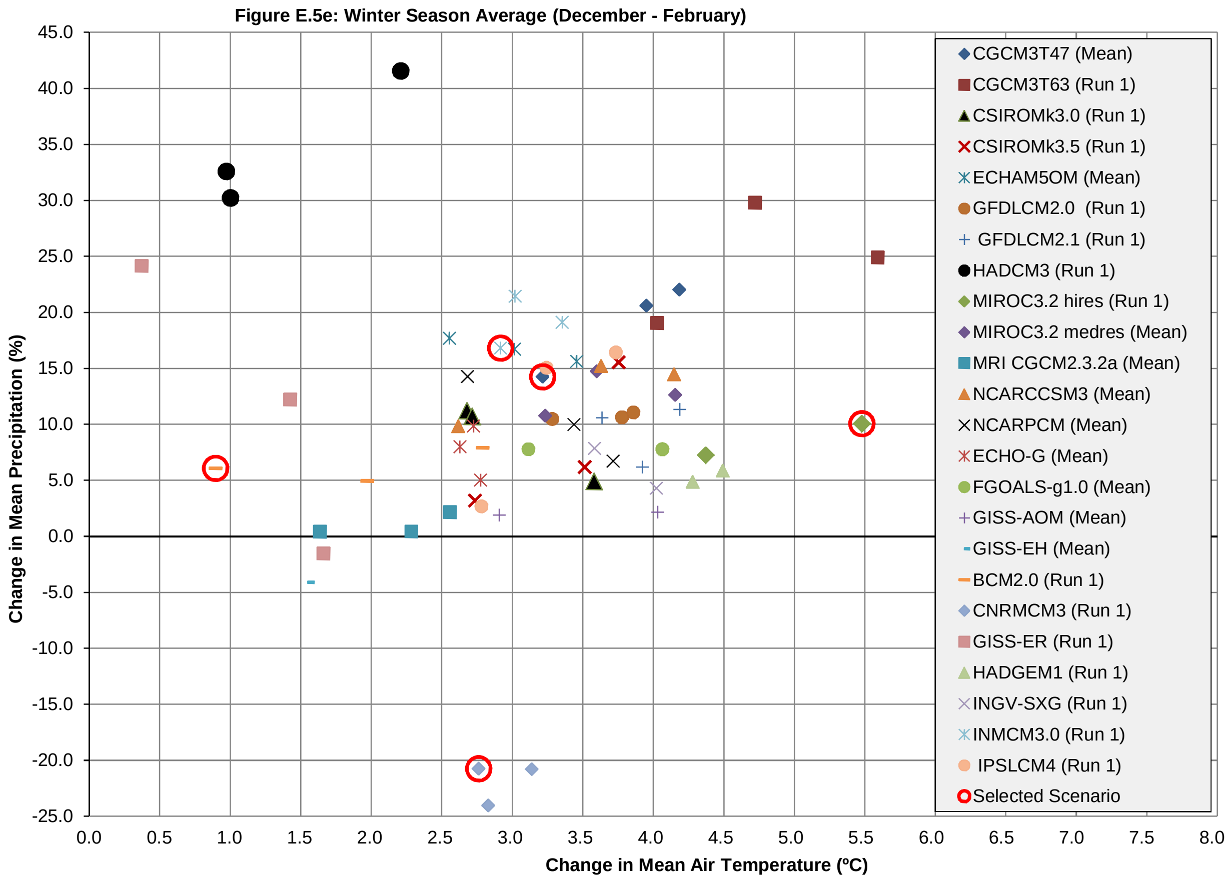

Figure 28a.1E-5 Climate Change Forecasts at Lac La Biche Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

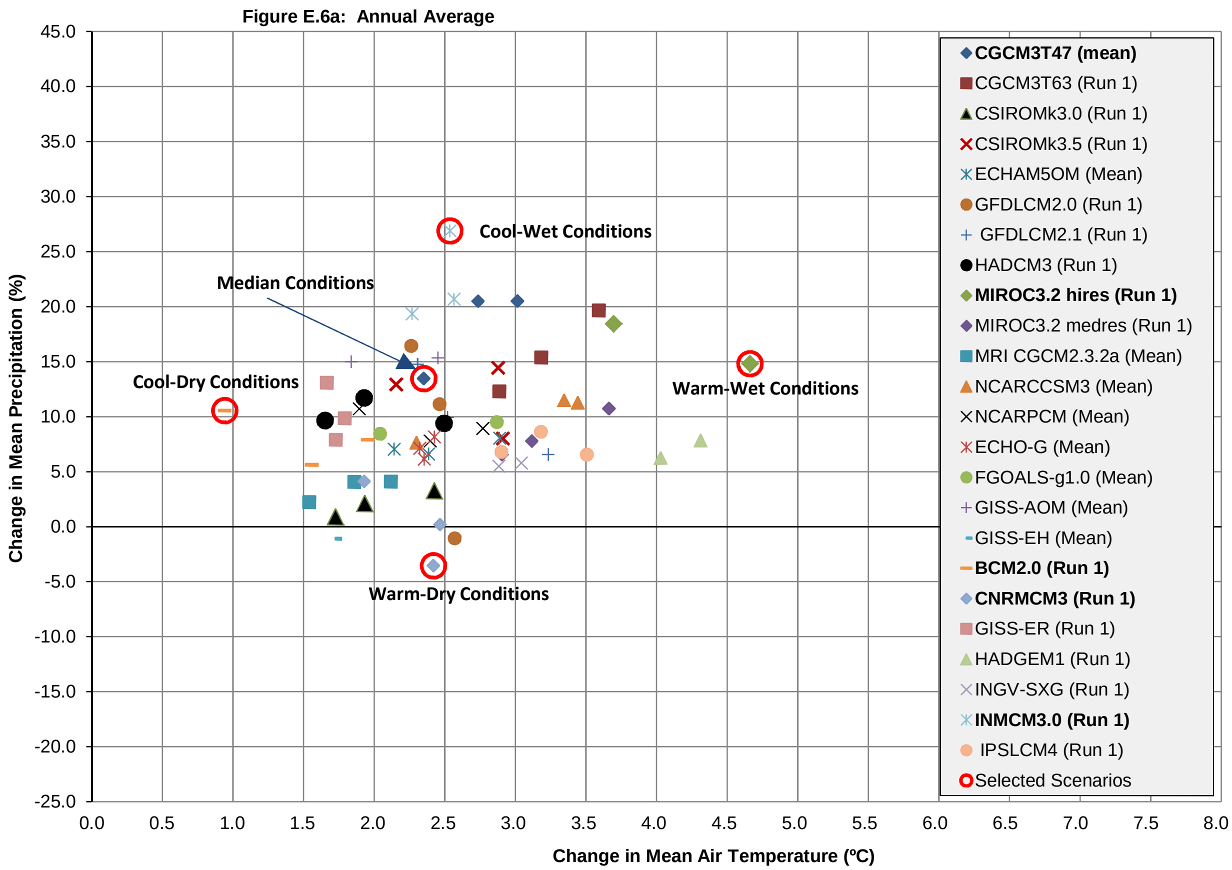

Figure 28a.1E-6 Climate Change Forecasts at Fort McMurray Climate Station for 2051–2080 Based on 1961–1990 Base

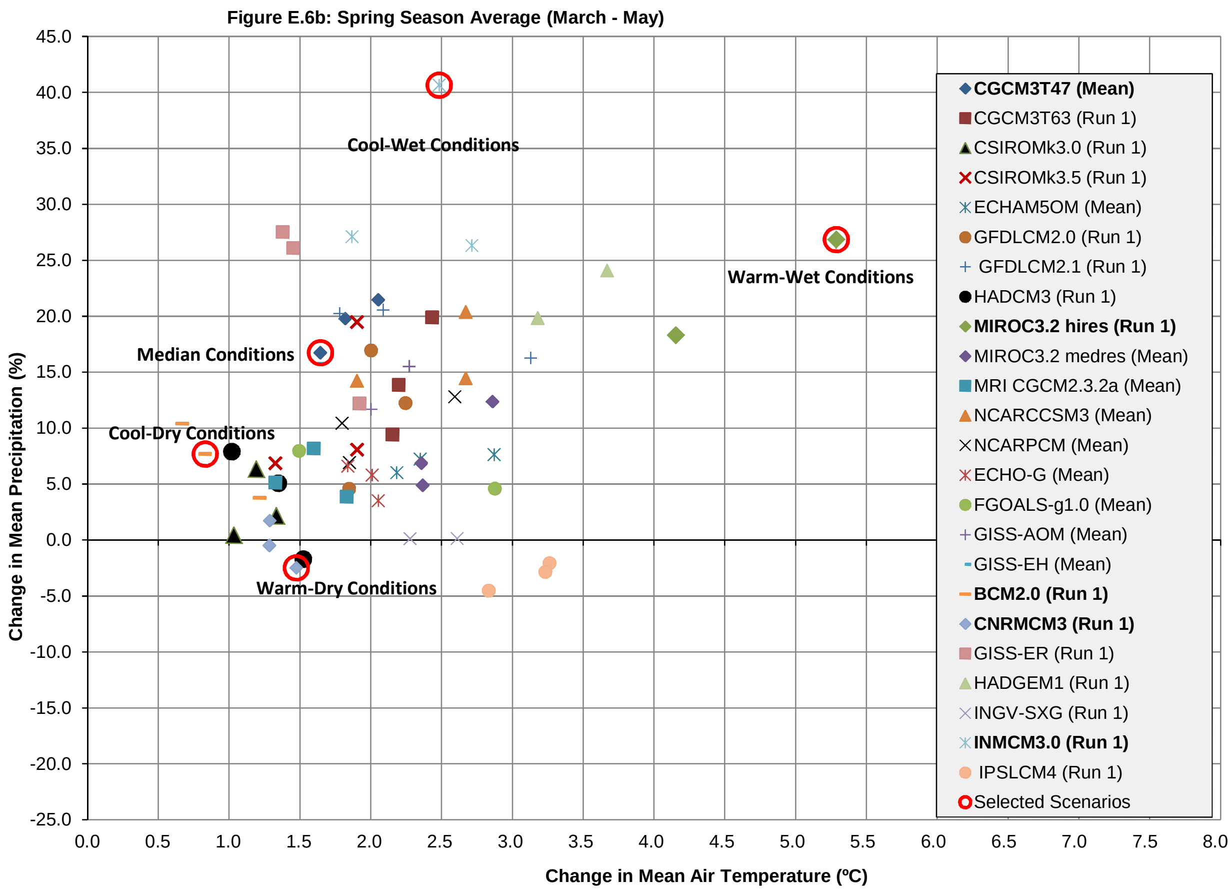

Figure 28a.1E-6 Climate Change Forecasts at Fort McMurray Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

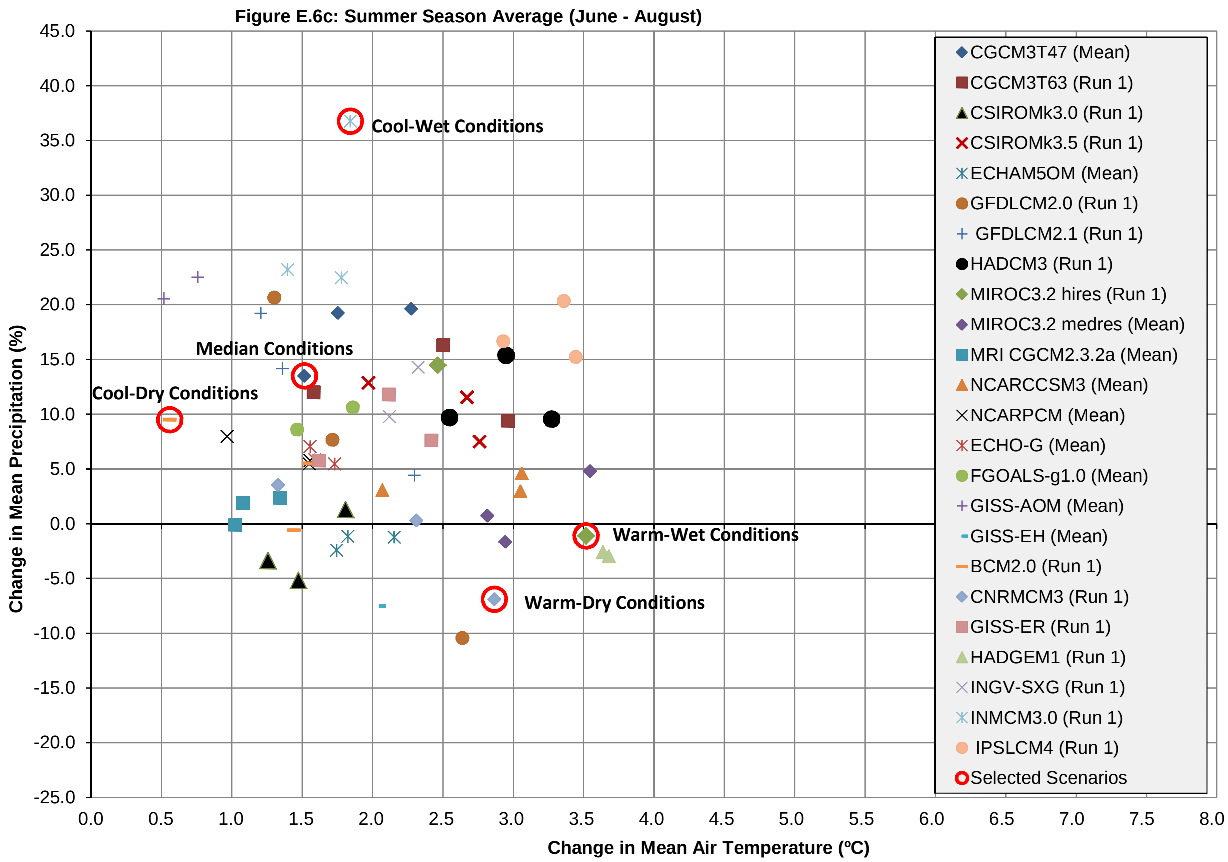

Figure 28a.1E-6 Climate Change Forecasts at Fort McMurray Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

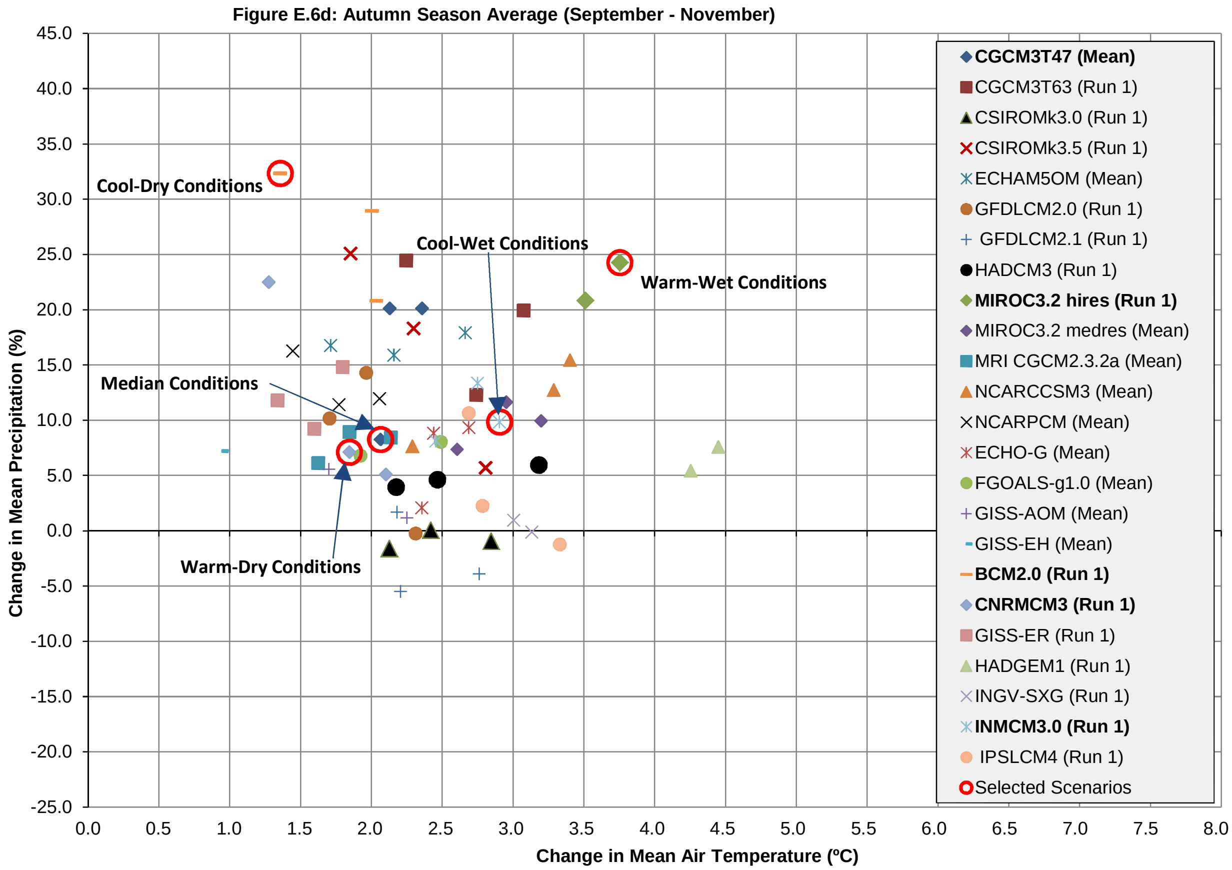

Figure 28a.1E-6 Climate Change Forecasts at Fort McMurray Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)

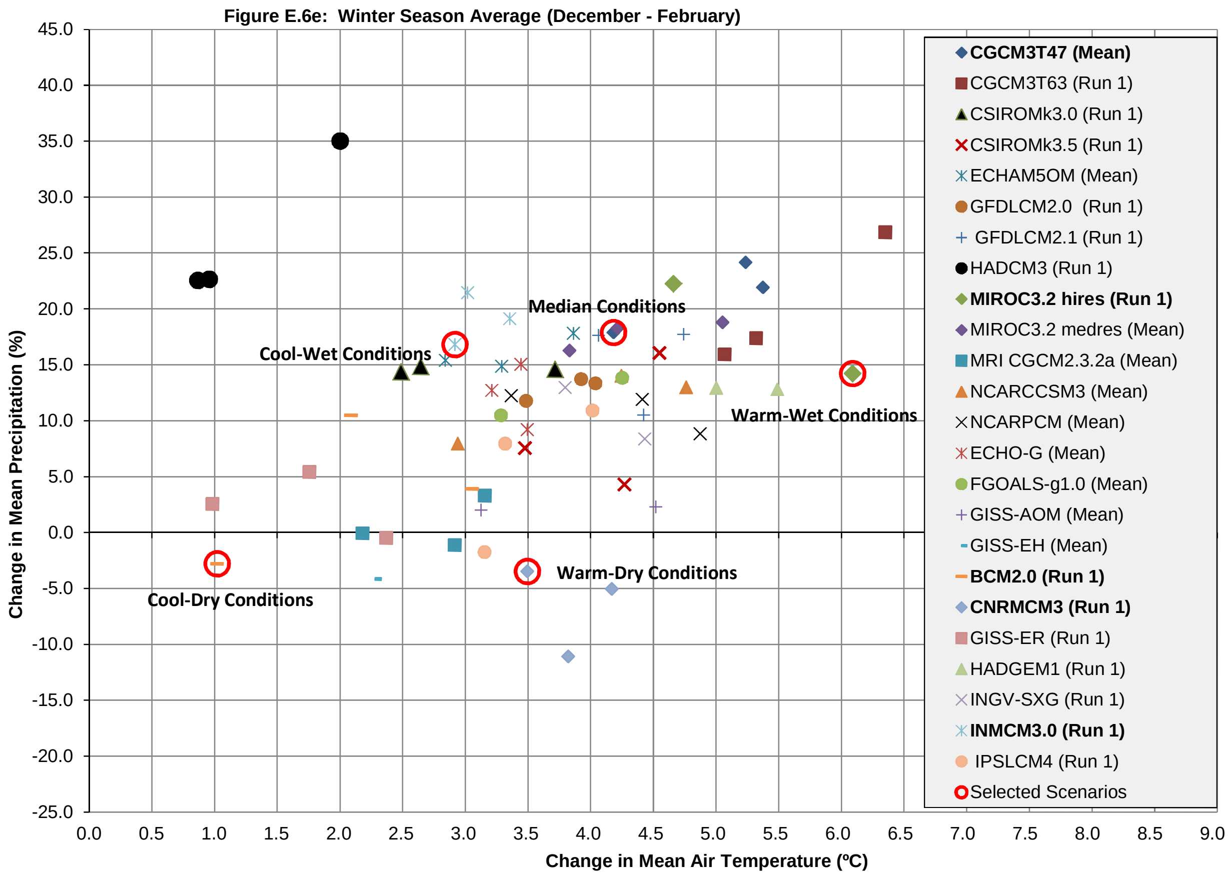

Figure 28a.1E-6 Climate Change Forecasts at Fort McMurray Climate Station for 2051–2080 Based on 1961–1990 Base (cont'd)