APPENDIX 2-III

CLIMATE CHANGE CONSIDERATIONS

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APPENDIX 2-III

CLIMATE CHANGE CONSIDERATIONS

REPORT ON

PRE-DISTURBANCE ASSESSMENT OF

THE CHRISTINA LAKE REGIONAL PROJECT PHASE 3

FOR MEG ENERGY CORP.

Submitted to:

MEG Energy Corp.

April 2008 **07-1346-0009**

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1 INTRODUCTION

Evaluations of climate change are required as part of the Environmental Impact Assessment (EIA) for new projects in Alberta. Guidance on how such evaluations should be made is provided both by the EIA Terms of Reference (TOR) for the MEG Energy Corp. (MEG) Christina Lake Regional Project Phase-3 (the Project) (AENV 2008) as well as in federal guidance documents (FPTCCCEA 2003).

This section has been prepared to summarize the findings with regards to potential climate change impacts and to address regulatory guidance with respect to climate change issues.

1.1 GUIDANCE FOR INCORPORATING CLIMATE CHANGE

The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment (FPTCCCEA) issued a general guidance document in November 2003 for practitioners to use when incorporating climate change issues into environmental assessments (FPTCCCEA 2003). The guidance document sets out the following two approaches for incorporating climate change considerations:

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

The federal guidance document indicates that projects are typically more closely aligned with one type of consideration or the other, but provides for cases where both considerations could be addressed.

In this application, production and management of GHG emissions is addressed in the air quality section of the EIA (Volume 3, Section 1). Consideration and predictions of how changing climates may have an impact on the Project are addressed in this Appendix.

2 CLIMATE CHANGE

2.1 ASSESSMENT APPROACH

An evaluation of the potential effects of climate change on the Project and the assessment predictions as required by the TOR requires an understanding of historic climate changes in order to predict how it might change in the future.

Determining historic climate change is relatively straightforward, relying on the long-term climate records. The closest long-term source for the Project is the climate station located near the community of Cold Lake and the available records are from the years 1954 to 2000. This data was used to determine recent climatic trends in the vicinity of the Project.

Climate forecasts for the Cold Lake area were used to determine future climate changes. Applicable climate forecast data from the Canadian Climate Impacts Scenarios Project website run by the Canadian Institute for Climate Studies (CICS) have been considered to ensure a thorough evaluation. For example, when the forecasted temperature change for a given model and scenario is presented, the corresponding forecasted precipitation change for the same model and scenario is also presented.

This assessment focused on the changes to temperature and precipitation to represent the impacts of climate change on the Project. Temperature and precipitation are the most common parameters for determining climate change and can be used as indicators for other parameters. Historical temperature and precipitation records and forecast data were also readily available. Wind speed and solar radiation forecast data were incorporated into the climate change assessments for air quality and water quality, respectively.

2.1.1 Climate Forecast Models

Climate forecasts require the use of sophisticated mathematical computer models called General Circulation Models (GCMs). These models simulate the interactions of airborne emissions, the atmosphere, land surfaces and oceans and can take several months to run. The Intergovernmental Panel on Climate Change (IPCC) has made use of several different GCMs. The seven models presented in Table 1 are recommended for use by the IPCC (IPCC 2005, Website). Canadian forecast data from these models has been made available by the CICS as part of the Canadian Climate Impacts Scenarios Project.

Table 1 General Circulation Models Considered in the Assessment

Research Centre/Model Name	Abbreviation	Country	Model Resolution[a] [km²]
Centre for Climate System Research/National Institute for Environmental Studies	CCSR/NIES	Japan	168,000
Canadian Global Coupled Model (Version 2)	CGCM2	Canada	74,000
Commonwealth Scientific and Industrial Research Organization Mark 2	CSIRO MK2b	Australia	95,000
Max Planck Institute for Meteorology/Deutsches Klimarechenzentrum	ECHAM4/OPYC3	Germany	41,000
Geophysical Fluid Dynamics Laboratory	GFDL R30	United States	44,000
Hadley Centre Coupled Model	HadCM3	United Kingdom	50,000
National Centre for Atmospheric Research Parallel Climate Model[b]	NCAR-PCM	United States	41,000

(a) The model resolution represents the area of each grid cell used in the respective models.

(b) Canadian climate forecasts from the NCAR-PCM model were not available from the CICS Website.

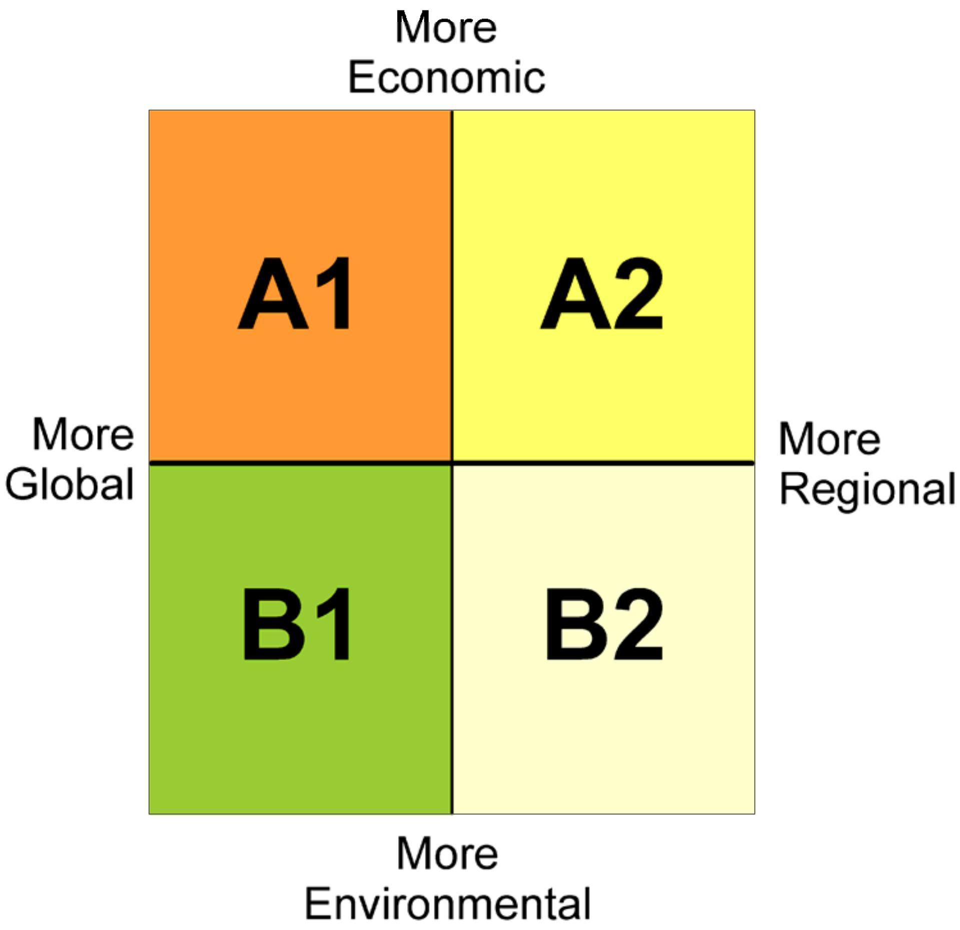
2.1.2 Forecast Scenarios

Given the wide range of inputs available to GCMs, the IPCC has established a series of global GHG emission scenarios based on four potential socio-economic development paths. The *Third Assessment Report* (IPCC 2001) identifies these scenarios as ***A1***, ***B1***, ***A2*** and ***B2***. The ***A1*** and ***A2*** scenarios represent a focus on economic growth while the ***B1*** and ***B2*** scenarios represent a shift towards more environmentally conscious solutions to growth. Both scenarios ***A1*** and ***B1*** include a shift towards global solutions while the ***A2*** and ***B2*** scenarios include growth based on more localized and regional approaches. Figure 1 provides an illustrative summary of the four emission scenarios, which are described more fully in the IPCC Special Report on Emissions Scenarios (IPCC 2000).

Although the IPCC has not stated which of the emission scenarios is most likely to occur, the ***A2*** scenario most closely reflects the current global socio-economic situation, and is closely related to the emission scenario (***IS92a)*** that was used by IPCC in its historical climate assessments. In relation to the ***A2*** scenario, scenarios ***A1***, ***B1*** and ***B2*** result in lower long-term GHG emissions over the next century. Within the ***A1*** scenario, the following three classifications of growth indicators are included:

- fossil-fuel intensive (FI): A socio-economic condition that was dependent on fossil fuels for energy. For example, the first half of the 21st century would be sub-categorized as A1FI due to increasing population and a high dependency on fossil fuels for energy;
- non-fossil-fuel intensive (T): A socio-economic condition that was less fossil-fuel dependent; and
- balanced (B): A socio-economic condition that relied on both fossil fuels and non-fossil-fuels.

L:\2007\1346 Oil Sands\07-1346-0009-MEG EXPANSION\5100\5190\Vol 2-Appendix-III-Climate Change\ Drawing file: Fig 1_Intergovernmental Panel on Climate Change Emission Scenarios.dwg Apr 03, 2008 -



PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE EMISSION SCENARIOS

Golder Associates
Calgary, Alberta

PROJECT	07.1346.0009.5100		FILE No. Clima Change Emiss.
DESIGN	CB	12/12/07	SCALE NTS REV. 0
CADD	YAW	03/04/08	
CHECK	NP	03/04/08	**FIGURE: 1**
REVIEW	IGG	03/04/08	

While the IPCC supports all of these scenarios, forecast data is not available from each scenario for all seven of the GCMs listed in Table 1. A summary of the forecast data available from the CICS website is provided in Table 2. All available models and emissions scenarios were considered in this assessment.

Table 2 Summary of Available Climate Forecasts

Climate Model	Forecast Period	SRES Scenario[(a)]					
		A1FI	A1T	A1	A2	B1	B2
CCSR/NIES	2010 to 2069	n/d	A1T	A1(1)	A2(1)	B1(1)	B2(1)
CGCM2	2010 to 2069	n/d	n/d	n/d	A2(1) A2(2) A2(3) A2(x)	n/d	B2(1)
CSIRO MK2b	2010 to 2069	n/d	n/d	A1(1)	A2(1)	B1(1)	B2(1)
ECHAM4/OPYC3	2010 to 2069	n/d	n/d	n/d	A2(1)	n/d	B2(1)
GFDL R30	2010 to 2069	n/d	n/d	n/d	A2(1)	n/d	B2(1)
HadCM3	2010 to 2069	A1FI	n/d	n/d	A2(1) A2(2) A2(3) A2(x)	B1(1)	B2(1) B2(2)
NCAR-PCM[(b)]	2010 to 2069	n/d	n/d	n/d	n/d	n/d	n/d

(a) The numbers in parenthesis beside the SRES scenarios represent the model ensemble number. An ensemble simulation consists of several modelling runs for the same scenario but with different initial conditions. Each of these runs is referred to by an ensemble number.

(b) Canadian climate forecasts from the NCAR-PCM model were not available from the CICS Website.

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

n/d = No data.

2.1.3 Baseline Climate

An analysis of climate change not only depends on the future conditions but also on the baseline climate to which the predictions are compared. Baseline climate information is important for describing average conditions, spatial and temporal variability and anomalous events as well as calibrating and testing climate models (CICS 2005, Website).

The IPCC recommends that 1961 to 1990 be adopted as the climatological baseline period in assessments (CICS 2005, Website). This period has been selected since it is considered to:

- be representative of the present-day or recent average climate;
- be of a sufficient duration to encompass a range of climatic variations, including several significant weather anomalies;
- cover a period for which data on all major climatological variables are abundant, adequately distributed over space and readily available;

- include data of sufficiently high quality for use in evaluating impacts; and
- be comparable with baseline climatologies used in other impact assessments.

The scenarios available from CICS are based on the 1961 to 1990 baseline period; therefore, this assessment is also based on the same period.

2.2 HISTORIC CLIMATE CHANGE

Temperature and precipitation normals for the Project area were obtained from the Cold Lake Airport meteorological station which is operated by the Meteorological Service of Canada. Analyzing historic climate change in the Cold Lake region involves reviewing current climate normals. Climate normals refer to calculated averages of observed climate values for a given location over a specified time period. The World Meteorological Organization recommends that climate normals be prepared at the end of every decade for a 30-year period (e.g., 1961 to 1990; 1971 to 2000). Table 3 provides a summary of the climate normals observed at Cold Lake. The four seasonal values were determined as follows:

- spring – March, April and May;
- summer – June, July and August;
- fall – September, October and November; and
- winter – December, January and February.

Table 3 Observed Multiple Climate Normals – Cold Lake

Climate Data	Season	Observed Normals	
		Temperature [°C]	Precipitation [mm]
Cold Lake (1951 to 1980)	annual	1.2	461.4
	spring	1.9	82.3
	summer	15.7	233.6
	fall	13.7	82.9
	winter	-15.5	62.1
Cold Lake (1961 to 1990)	annual	1.5	432.4
	spring	2.5	78.7
	summer	15.8	221.9
	fall	14.2	76.8
	winter	-15.1	54.6
Cold Lake (1971 to 2000)	annual	1.8	427.2
	spring	3.2	81.7
	summer	15.9	217.3
	fall	14.3	78.2
	winter	-14.5	50.9

Table 4 provides a listing of the observed changes in climate conditions relative to the 1961 to 1990 climate normals. The comparison shows that the 1951 to 1980 period was 0.2°C cooler and received 6% more precipitation annually than the 1961 to 1990 period. The 1971 to 2000 period was 0.3°C warmer and received slightly less precipitation than the 1961 to 1990 period.

Table 4 Observed Climate Change – Cold Lake Relative to 1961 to 1990 Normals

Climate Data	Season	Observed Climate Change[a] Temperature [°C]	Observed Climate Change[a] Precipitation [%]
1951 to 1980 normals	annual	-0.2	+6.3
	spring	-0.6	+4.4
	summer	-0.2	+5.0
	fall	-0.4	+7.4
	winter	-0.4	+12.1
1971 to 2000 normals	annual	+0.3	-1.2
	spring	+0.6	+3.7
	summer	+0.0	-2.1
	fall	+0.1	+1.8
	winter	+0.6	-7.3

[a] Observed climate change was determined as the change relative to the 1961 to 1990 normals.

2.3 FUTURE CLIMATE CHANGE

Climate forecast data from various models and emissions scenarios were analyzed to determine potential climate change in the region. Since the models are susceptible to annual variability, the analysis uses the average of 30 years of data, centred on the decade of interest. The future conditions have been represented by the 30-year period between 2010 and 2039, which would represent the life of the Project excluding the post operations management and reclamation period of the Project.

Two separate forecasts of climate change have been presented. The first forecast provides the change between the 2010 to 2039 period and the baseline period (1961 to 1990). The second forecast represents the climate change expected over the life of the Project, acknowledging that some of the changes in climate since the baseline period will have already occurred.

2.3.1 Climate Change Relative to the Baseline (1961 to 1990)

The forecasted change in climate relative to the baseline is the difference between the modelled 30-year average for 1961 to 1990 and the modelled future conditions, as represented by the 30-year period between 2010 and 2039. This 30-year average would be representative of the Project life as illustrated in Figure 2.

The forecast changes in temperature and precipitation between the baseline and future conditions (i.e., 2010 to 2039), presented in Tables 5 through 10, were determined for each of the models/scenarios available on the CICS website for the corresponding model grid cell that covered the Project and the Cold Lake region. Summer values represent data from June, July and August and winter values represent data from December, January and February.

Figure 3 illustrates the annual climate change forecasts relative to the baseline period, while the summer and winter changes are illustrated in Figure 4, both based on the data in Table 5 to Table 10.

Table 5 Centre for Climate System Research/National Institute for Environmental Studies Climate Forecasts Relative to the Baseline (1961 to 1990)

Climate Model	SRES Scenario	Season	Change from Baseline (1961 to 1990)	
			Temperature [°C]	Precipitation [%]
CCSR/NIES	A1T	annual	+1.1	-0.7
		summer	+1.0	-2.0
		winter	-0.1	-4.6
CCSR/NIES	A1(1)	annual	+1.6	n/a[(a)]
		summer	+1.2	n/a[(a)]
		winter	+1.0	n/a[(a)]
CCSR/NIES	A2(1)	annual	+1.0	-1.7
		summer	+1.1	-3.4
		winter	+0.3	-2.1
CCSR/NIES	B1(1)	annual	+1.3	+4.1
		summer	+1.1	+8.6
		winter	+0.9	-2.2
CCSR/NIES	B2(1)	annual	+1.7	+5.5
		summer	+1.7	+5.5
		winter	+1.0	-1.9

(a) Precipitation data are not available for the CCSR/NIES A1(1) scenario.

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

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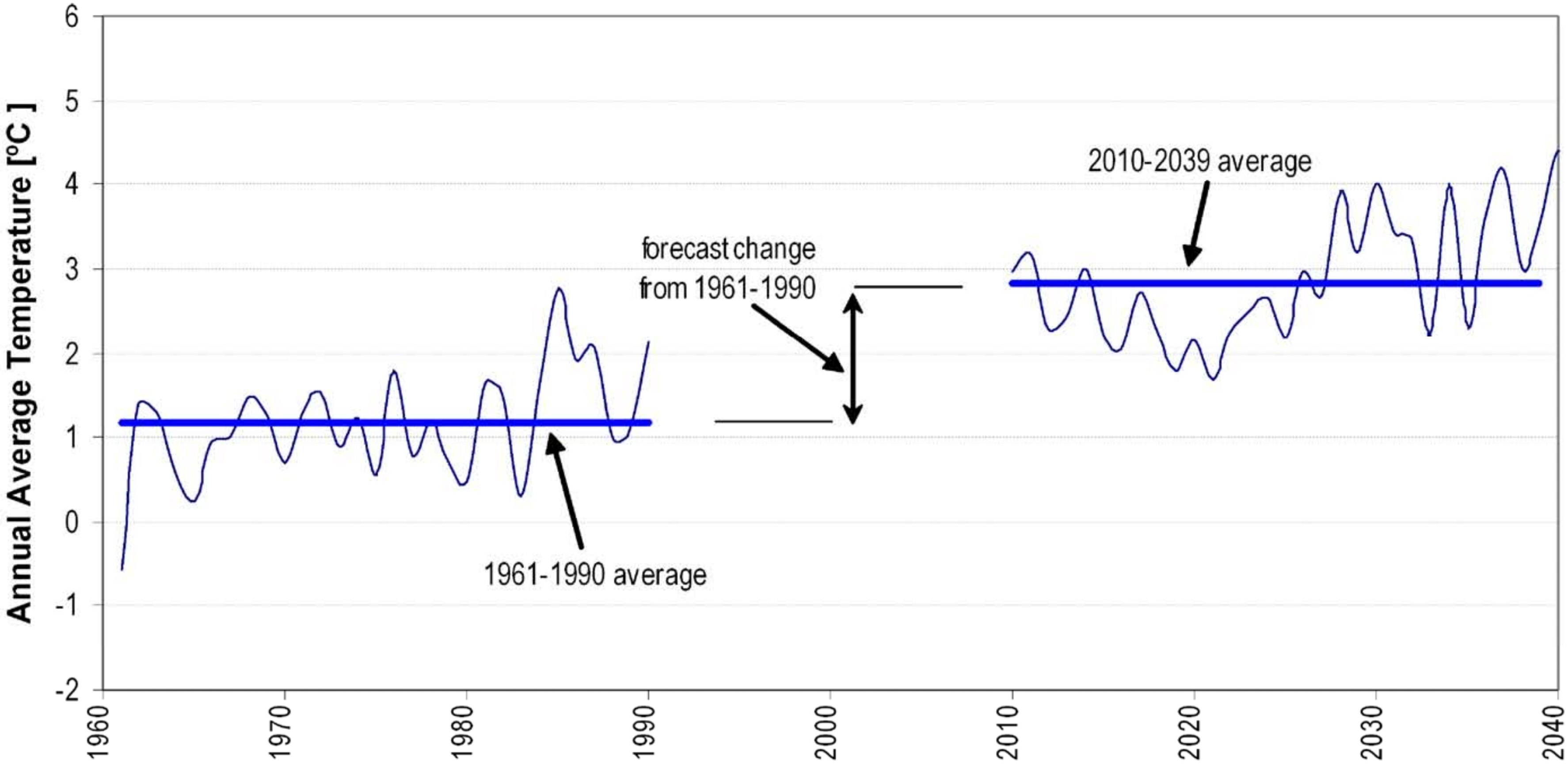


PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

DETERMINING CHANGE RELATIVE TO BASELINE (1961 TO 1990)

Golder Associates
Calgary, Alberta

PROJECT 07.1346.0009.5100		
DESIGN	CM	12/12/07
CADD	PSR	03/04/08
CHECK	NP	03/04/08
REVIEW	IGG	03/04/08

FILE No. change relative–base
SCALE AS SHOWN REV. 0

FIGURE: 2

Table 6 Canadian Global Coupled Model (Version 2) Climate Forecasts for 2010 to 2039 Relative to Baseline (1961 to 1990)

Climate Model	SRES Scenario	Season	Change from Baseline (1961 to 1990)	
			Temperature [°C]	Precipitation [%]
CGCM2	A2(1)	annual	+1.6	-1.5
		summer	+1.6	-11.0
		winter	+0.8	-2.5
CGCM2	A2(2)	annual	+1.8	+12.6
		summer	+1.3	+12.2
		winter	+2.6	+8.8
CGCM2	A2(3)	annual	+1.6	+9.3
		summer	+1.2	+6.2
		winter	+3.1	+7.1
CGCM2	A2(x)	annual	+1.7	+6.2
		summer	+1.4	+1.6
		winter	+2.2	+4.1
CGCM2	B2(1)	annual	+1.6	+0.4
		summer	+1.6	-3.4
		winter	+1.9	-5.9

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 7 Commonwealth Scientific and Industrial Research Organization Mark 2 Climate Forecasts for 2010 to 2039 Relative to Baseline (1961 to 1990)

Climate Model	SRES Scenario	Season	Change from Baseline (1961 to 1990)	
			Temperature [°C]	Precipitation [%]
CSIRO Mk2b	A1(1)	annual	+1.9	+3.0
		summer	+1.2	-8.1
		winter	+2.1	+12.6
CSIRO Mk2b	A2(1)	annual	+1.7	+6.1
		summer	+0.9	+3.1
		winter	+2.4	+18.0
CSIRO Mk2b	B1(1)	annual	+2.2	+3.2
		summer	+1.1	+1.8
		winter	+2.6	+8.2
CSIRO Mk2b	B2(1)	annual	+2.5	+2.1
		summer	+1.2	-0.3
		winter	+3.1	+7.7

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 8 ECHAME4/OPYC3 Climate Forecasts for 2010 to 2039 Relative to Baseline (1961 to 1990)

Climate Model	SRES Scenario	Season	Change from Baseline (1961 to 1990)	
			Temperature [°C]	Precipitation [%]
ECHAM4/OPYC3	A2(1)	annual	+2.3	-14.3
		summer	+2.2	-22.0
		winter	+3.0	-6.5
ECHAM4/OPYC3	B2(1)	annual	+2.1	-6.3
		summer	+1.7	-10.0
		winter	+3.2	+0.8

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 9 Geophysical Fluid Dynamics Laboratory Climate Forecasts for 2010 to 2039 Relative to Baseline (1961 to 1990)

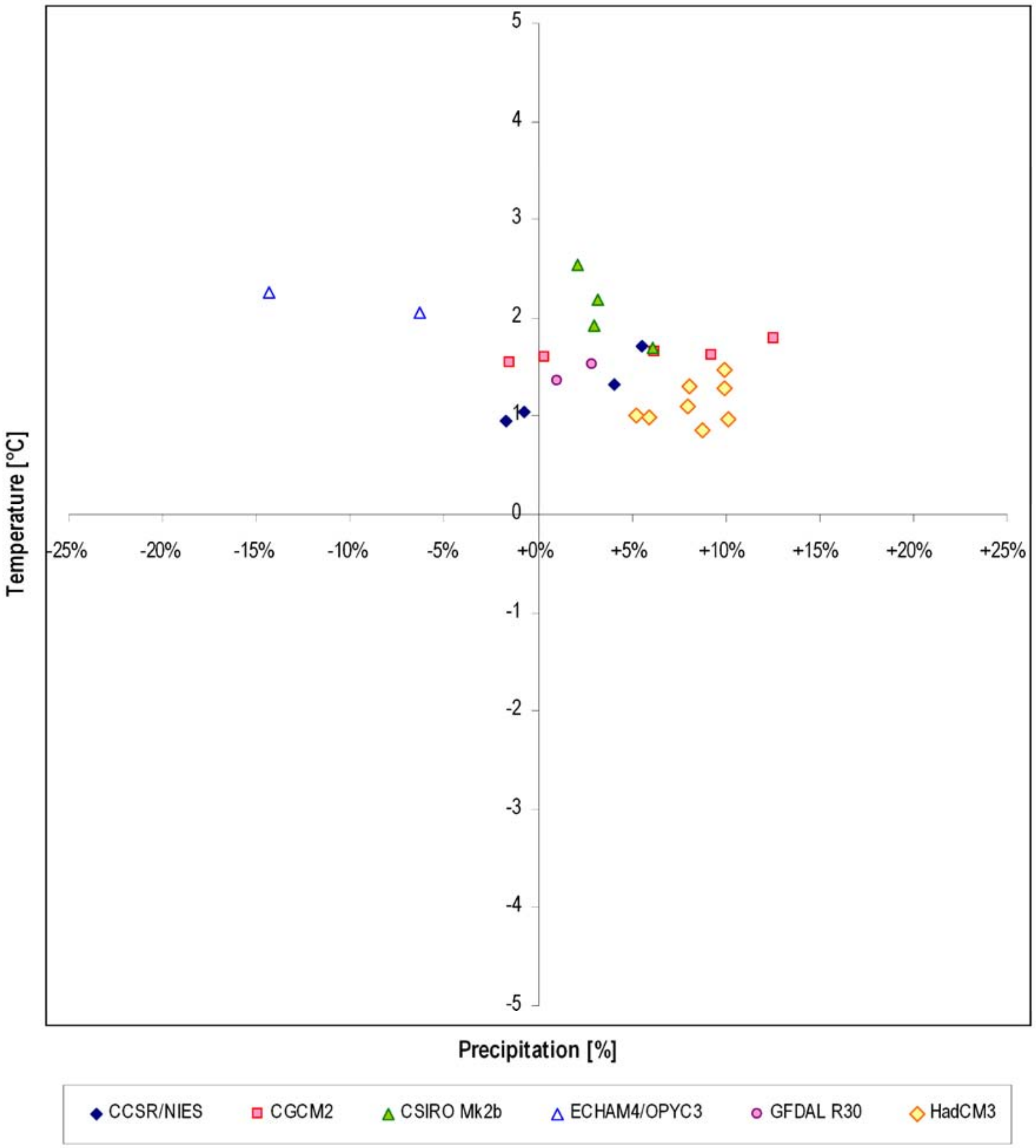
Climate Model	SRES Scenario	Season	Change from Baseline (1961 to 1990)	
			Temperature [°C]	**Precipitation [%]**
GFDL R30	A2(1)	annual	+1.5	+2.9
		summer	+1.2	+4.5
		winter	+1.9	+6.0
GFDL R30	B2(1)	annual	+1.4	+1.1
		summer	+2.2	-12.4
		winter	+0.9	+3.4

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 10 HadCM3 Climate Forecasts for 2010 to 2039 Relative to Baseline (1961 to 1990)

Climate Model	SRES Scenario	Season	Change from Baseline (1961 to 1990)	
			Temperature [°C]	**Precipitation [%]**
HadCM3	A1FI	annual	+1.3	+8.1
		summer	+1.5	+6.6
		winter	+1.4	+8.5
HadCM3	A2(1)	annual	+0.8	+8.8
		summer	+1.5	+5.9
		winter	+0.2	+7.4
HadCM3	A2(2)	annual	+1.5	+10.0
		summer	+1.5	+6.7
		winter	+2.2	+18.1
HadCM3	A2(3)	annual	+1.0	+5.9
		summer	+1.6	+5.9
		winter	+0.9	+7.7
HadCM3	A2(x)	annual	+1.1	+7.9
		summer	+1.5	+6.1
		winter	+1.1	+11.0
HadCM3	B1(1)	annual	+1.3	+9.9
		summer	+1.2	+7.1
		winter	+1.5	+12.5
HadCM3	B2(1)	annual	+1.0	+10.1
		summer	+1.5	+1.3
		winter	+0.5	+16.2
HadCM3	B2(2)	annual	+1.0	+5.3
		summer	+1.6	-0.4
		winter	+1.0	+9.2

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).



PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

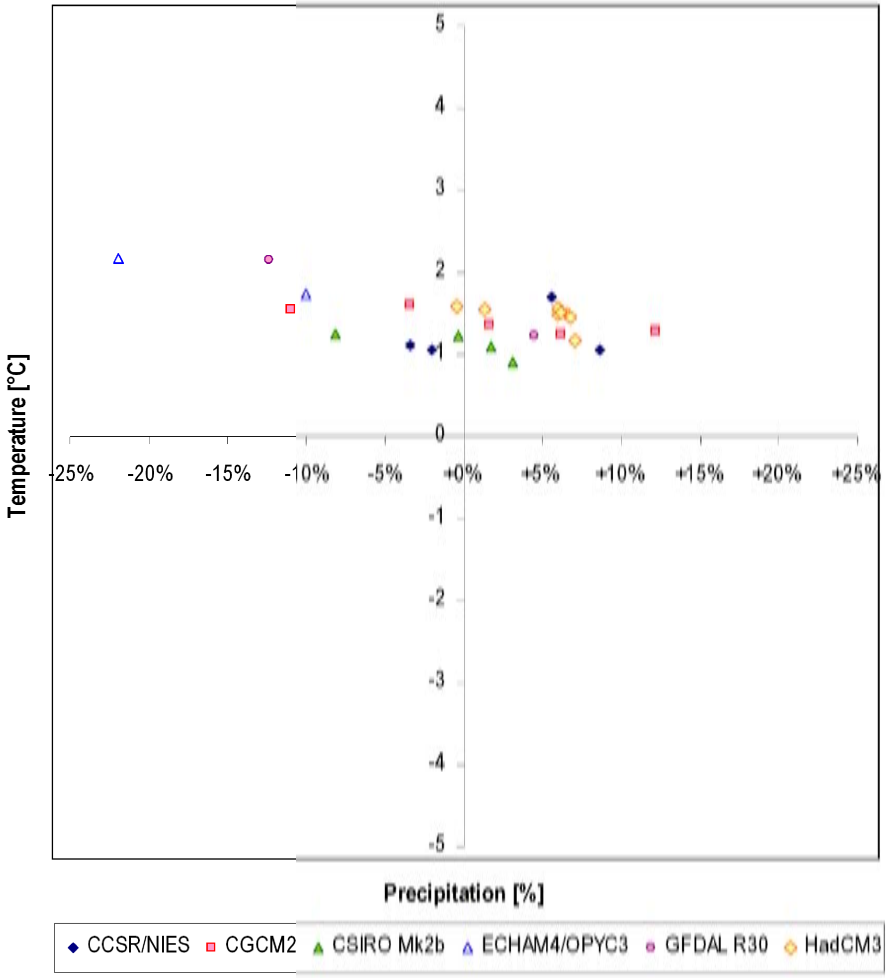
FORECAST ANNUAL CLIMATE CHANGE RELATIVE TO BASELINE (1961 TO 1990)

Golder Associates
Calgary, Alberta

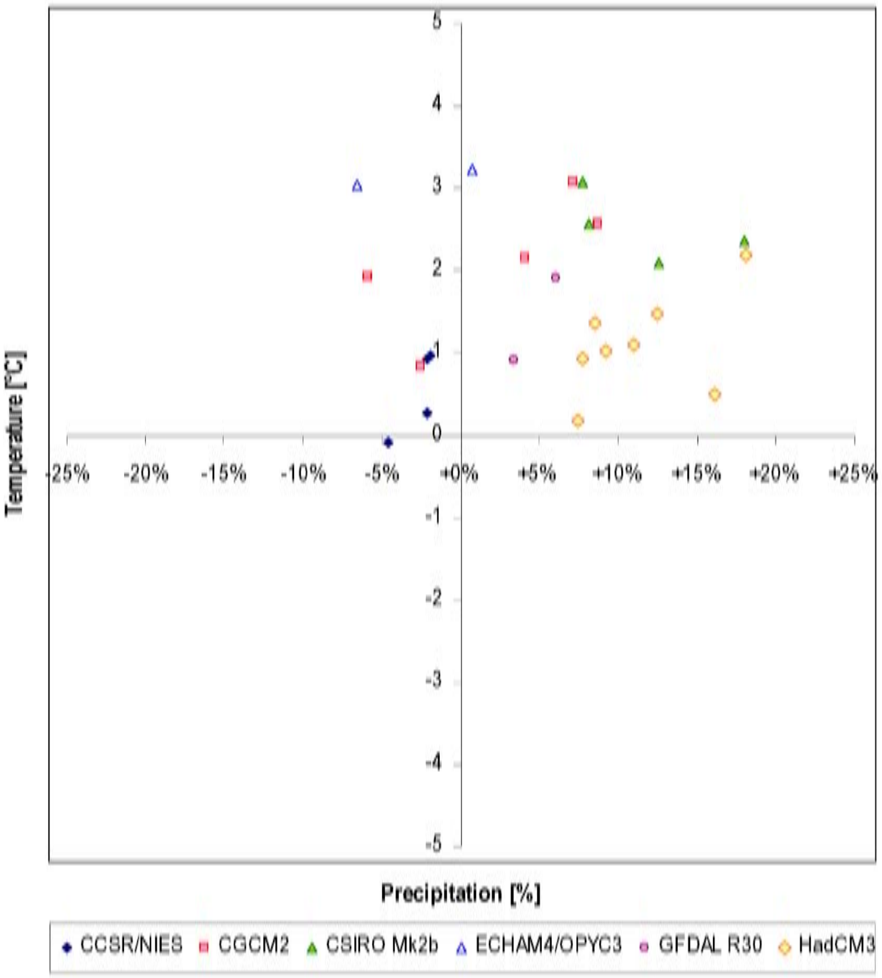
PROJECT	07.1346.0009.5100		FILE No. Climate Change Emis.	
DESIGN	CM	12/12/07	SCALE NTS	REV. 0
CADD	TRE	03/04/08	**FIGURE: 3**	
CHECK	NP	03/04/08		
REVIEW	IGG	03/04/08		

L:\2007\1346 Oil Sands\07-1346-0009-MEG EXPANSION\5100\5190\Vol 2-Appendix-III-Climate Change\ Drawing file: Fig 3_Forecast Annual Climate Change Relative to 1961 to 1990.dwg Apr 03, 2008 - 1:59p

L:\2007\1346 Oil Sands\07-1346-0009-MEG EXPANSION\5100\5190\Vol 2-Appendix-III-Climate Change\Fig 4_Forecast Summer and Winter Climate Change Relative to 1961 to 1990.dwg Apr 03, 2008 – 2:17p



Summer



Winter

PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

FORECAST SUMMER AND WINTER CLIMATE CHANGE RELATIVE TO BASELINE (1961 TO 1990)

Golder Associates
Calgary, Alberta

PROJECT 07.1346.0009.5100			FILE No. change 1961–1990	
DESIGN	CM	12/12/07	SCALE AS SHOWN	REV. 0
CADD	YAW	03/04/08	**FIGURE: 4**	
CHECK	NP	03/04/08		
REVIEW	IGG	03/04/08		

Table 11 provides a summary of the range of changes in temperature and precipitation forecasts relative to the baseline for each of the 26 modelled climate forecast scenario combinations. Annual forecast changes in temperature range from +0.8 to +2.5°C while annual forecast changes in precipitation range from -14.3 to +12.6%.

Table 11 Comparison of Climate Change Forecasts for 2010 to 2039 Relative to Baseline (1961 to 1990)

Climate Model	Period	Change from Baseline (1961 to 1990)	
		Temperature [°C]	Precipitation [%]
CCSR/NIES	annual	+1.0 to +1.7	-1.7 to +5.5
	summer	+1.0 to +1.7	-3.4 to +8.6
	winter	-0.1 to +1.0	-4.6 to -1.9
CGCM2	annual	+1.6 to +1.8	-1.5 to +12.6
	summer	+1.2 to +1.6	-11.0 to +12.2
	winter	+0.8 to +3.1	-5.9 to +8.8
CSIRO MK2	annual	+1.7 to +2.5	+2.1 to +6.1
	summer	+0.9 to +1.2	-8.1 to +3.1
	winter	+2.1 to +3.1	+7.7 to +18.0
ECHAM4/OPYC3	annual	+2.1 to +2.3	-14.3 to -6.3
	summer	+1.7 to +2.2	-22.0 to -10.0
	winter	+3.0 to +3.2	-6.5 to +0.8
GFDL R30	annual	+1.4 to +1.5	+1.1 to +2.9
	summer	+1.2 to +2.2	-12.4 to +4.5
	winter	+0.9 to +1.9	+3.4 to +6.0
HadCM3	annual	+0.8 to +1.5	+5.3 to +10.1
	summer	+1.2 to +1.6	-0.4 to +7.1
	winter	+0.2 to +2.2	+7.4 to +18.1

While all of the forecast information is valuable, it is not practical to evaluate the potential impacts for every possible scenario. The challenge of selecting the appropriate scenarios to be evaluated can be addressed by using the approach of Burn (2003). Specifically, model forecasts are ranked in ascending order by annual average temperature, summer (i.e., June, July and August) average temperature, winter (i.e., December, January and February) average temperature, annual precipitation, summer precipitation and winter precipitation. Temperature has priority over precipitation in the ranking. Within each of the six ranking methods, the combinations of models and scenarios are ranked and the temperature and precipitation changes for the 3rd highest (88th percentile), 12th highest (approximately the median) and 23rd highest (12th percentile) scenarios are determined. Burn (2003) recommended using the 86th percentile forecasts in environmental assessments in the Mackenzie Valley, which are approximated by the 3rd highest ranked values in Table 12.

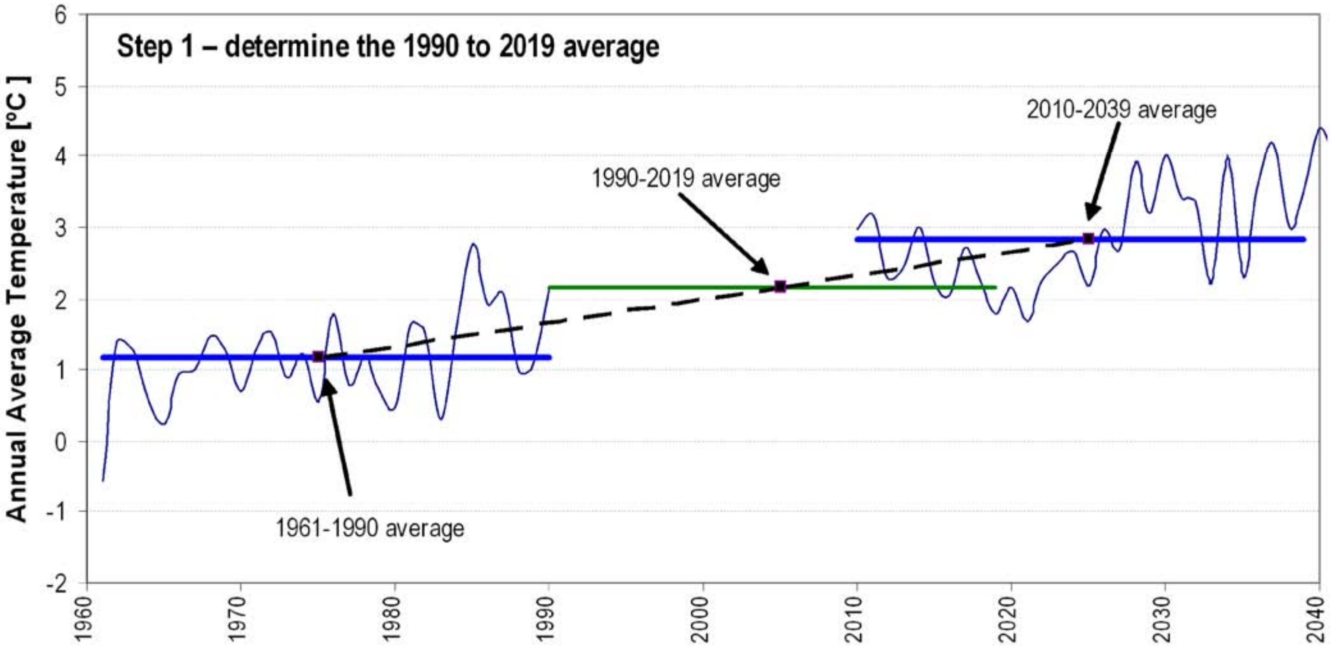
Table 12 Summary of Ranked Climate Scenarios Based on Change Relative to Baseline (1961 to 1990)

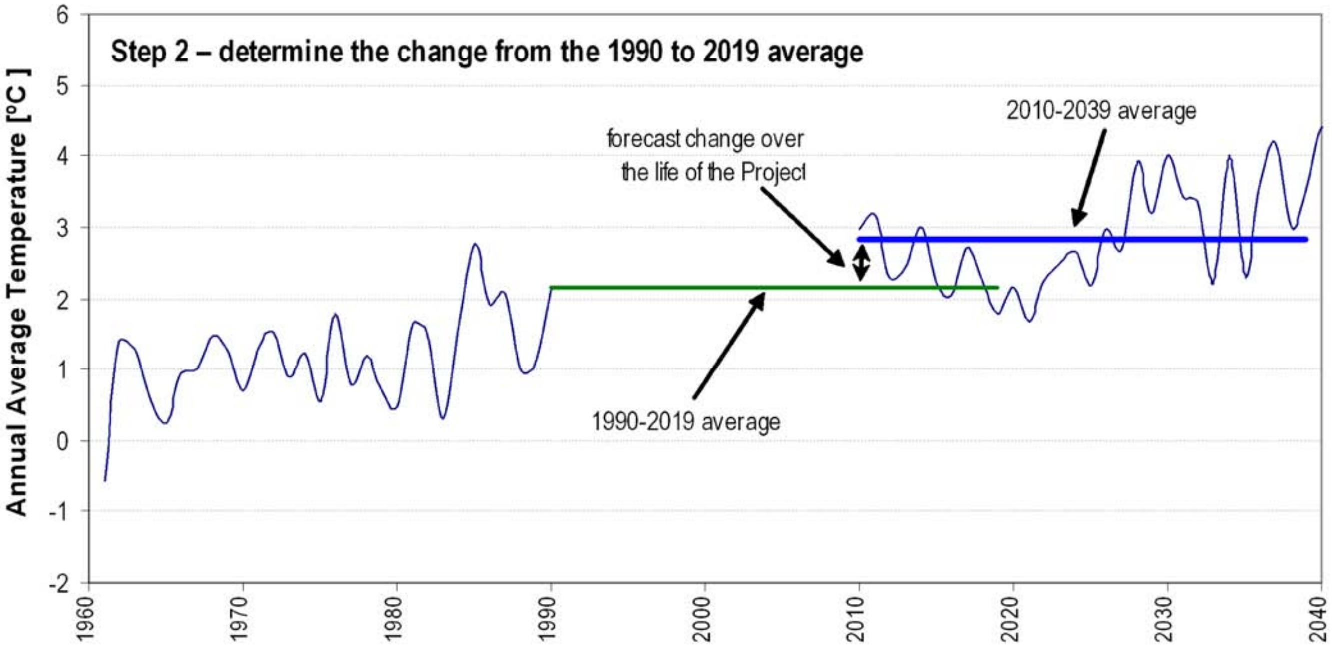
Ranking Method	Rank	Model and SRES Scenario	Change from Baseline (1961 to 1990)	
			Temperature [°C]	Precipitation [%]
annual temperature	3rd highest	CSIRO Mk2–B1(1)	+2.2	+3.2
	12th highest	CCSR/NIES–A1(1)	+1.6	+0.0
	23rd highest	HadCM3–A2(3)	+1.0	+5.9
summer temperature	3rd highest	ECHAM4/OPYC3-B2(1)	+1.7	-10.0
	12th highest	HadCM3–A1FI	+1.5	+6.6
	23rd highest	CSIRO Mk2–B1(1)	+1.1	+1.8
winter temperature	3rd highest	CSIRO Mk2–B2(1)	+3.1	+7.7
	12th highest	GFDL R30–A2(1)	+1.9	+6.0
	23rd highest	HadCM3–B2(1)	+0.5	+16.2
annual precipitation	3rd highest	HadCM3–A2(2)	+1.5	+10.0
	12th highest	CCSR/NIES–B2(1)	+1.7	+5.5
	23rd highest	CCSR/NIES–A2(1)	+1.0	-1.7
summer precipitation	3rd highest	HadCM3–B1(1)	+1.2	+7.1
	12th highest	CSIRO Mk2–A2(1)	+0.9	+3.1
	23rd highest	CGCM2–A2(1)	+1.6	-11.0
winter precipitation	3rd highest	HadCM3–B2(1)	+0.5	+16.2
	12th highest	HadCM3–A2(3)	+0.9	+7.7
	23rd highest	CCSR/NIES–A1T	-0.1	-4.6

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

2.3.2 Climate Change Over the Project Life

While the forecast climate change relative to the baseline presented in Section 2.3.1 is interesting from an academic perspective and for comparison to historic observations, these predictions do not indicate how the climate might change over the life of the Project. To determine how climate might change over the life of the Project, it is necessary to determine the difference between the climate near the end of the Project life, represented by the 30-year average for 2010 to 2039, and the 30-year average centred on the current conditions. This acknowledges that some of the changes in climate since the baseline period will have already occurred. Therefore, the current period is represented by the 30-year period from 1990 to 2019, which was scaled for each model/scenario combination using the baseline and 2010 to 2039 forecasts as illustrated in Figure 5.


Step 1 – determine the 1990 to 2019 average


Step 2 – determine the change from the 1990 to 2019 average

PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

DETERMINING CHANGE OVER THE PROJECT LIFE

Golder Associates
Calgary, Alberta

PROJECT	07.1346.0009.5100		FILE No.	Change–Project life
DESIGN	CM	03/04/08	SCALE AS SHOWN	REV. 0
CADD	YAW	03/04/08	**FIGURE:5**	
CHECK	NP	03/04/08		
REVIEW	IGG	03/04/08		

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Future changes in temperature and precipitation have been determined for each of the 26 model and scenarios combinations. Tables 13 to 18 provide a summary of the forecast change over the life of the Project (i.e., difference between 2010 to 2039 average and 1990 to 2019 average) for the Cold Lake area.

Table 13 CCSR/NIES Climate Forecasts Over the Project Life

Climate Model	SRES Scenario	Season	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
CCSR/NIES	A1T	annual	+0.4	-0.3
		summer	+0.4	-0.8
		winter	0.0	-1.8
CCSR/NIES	A1(1)	annual	+0.6	n/a[(a)]
		summer	+0.5	n/a[(a)]
		winter	+0.4	n/a[(a)]
CCSR/NIES	A2(1)	annual	+0.4	-0.7
		summer	+0.4	-1.4
		winter	+0.1	-0.9
CCSR/NIES	B1(1)	annual	+0.5	+1.6
		summer	+0.4	+3.5
		winter	+0.4	-0.9
CCSR/NIES	B2(1)	annual	+0.7	+2.2
		summer	+0.7	+2.2
		winter	+0.4	-0.8

Precipitation data are not available for the A1(1) scenario.

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 14 CGCM2 Climate Forecasts Over the Project Life

Climate Model	SRES Scenario	Season	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
CGCM2	A2(1)	annual	+0.6	-0.6
		summer	+0.6	-4.4
		winter	+0.3	-1.0
CGCM2	A2(2)	annual	+0.7	+5.0
		summer	+0.5	+4.9
		winter	+1.0	+3.5
CGCM2	A2(3)	annual	+0.7	+3.7
		summer	+0.5	+2.5
		winter	+1.2	+2.8
CGCM2	A2(x)	annual	+0.7	+2.5
		summer	+0.5	+0.7
		winter	+0.9	+1.6
CGCM2	B2(1)	annual	+0.6	+0.1
		summer	+0.6	-1.4
		winter	+0.8	-2.4

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 15 CSIRO Mk2b Climate Forecasts Over the Project Life

Climate Model	SRES Scenario	Season	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
CSIRO Mk2b	A1(1)	annual	+0.8	+1.2
		summer	+0.5	-3.2
		winter	+0.8	+5.0
CSIRO Mk2b	A2(1)	annual	+0.7	+2.4
		summer	+0.4	+1.2
		winter	+0.9	+7.2
CSIRO Mk2b	B1(1)	annual	+0.9	+1.3
		summer	+0.4	+0.7
		winter	+1.0	+3.3
CSIRO Mk2b	B2(1)	annual	+1.0	+0.9
		summer	+0.5	-0.1
		winter	+1.2	+3.1

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 16 ECHAM4/OPYC3 Climate Forecasts Over the Project Life

Climate Model	SRES Scenario	Season	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
ECHAM4/OPYC3	A2(1)	annual	+0.9	-5.7
		summer	+0.9	-8.8
		winter	+1.2	-2.6
ECHAM4/OPYC3	B2(1)	annual	+0.8	-2.5
		summer	+0.7	-4.0
		winter	+1.3	+0.3

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 17 GFDL R30 Climate Forecasts Over the Project Life

Climate Model	SRES Scenario	Season	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
GFDL R30	A2(1)	annual	+0.6	+1.2
		summer	+0.5	+1.8
		winter	+0.8	+2.4
GFDL R30	B2(1)	annual	+0.5	+0.4
		summer	+0.9	-4.9
		winter	+0.4	+1.3

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Table 18 HadCM3 Climate Forecasts Over the Project Life

Climate Model	SRES Scenario	Season	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
HadCM3	A1FI	annual	+0.5	+3.2
		summer	+0.6	+2.6
		winter	+0.5	+3.4
HadCM3	A2(1)	annual	+0.3	+3.5
		summer	+0.6	+2.4
		winter	+0.1	+3.0
HadCM3	A2(2)	annual	+0.6	+4.0
		summer	+0.6	+2.7
		winter	+0.9	+7.2
HadCM3	A2(3)	annual	+0.4	+2.4
		summer	+0.6	+2.4
		winter	+0.4	+3.1
HadCM3	A2(x)	annual	+0.4	+3.2
		summer	+0.6	+2.5
		winter	+0.4	+4.4
HadCM3	B1(1)	annual	+0.5	+4.0
		summer	+0.5	+2.8
		winter	+0.6	+5.0
HadCM3	B2(1)	annual	+0.4	+4.0
		summer	+0.6	+0.5
		winter	+0.2	+6.5
HadCM3	B2(2)	annual	+0.4	+2.1
		summer	+0.6	-0.2
		winter	+0.4	+3.7

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

Figure 6 illustrates the forecast changes in annual precipitation and temperature over the life of the Project. The forecasted changes in the summer and winter temperature and precipitation are illustrated in Figure 7.

Table 19 provides a summary of the forecast changes in temperature and precipitation over the life of the Project. Annual forecast changes in temperature range from 0.3 to 1.0°C. Annual forecast changes in precipitation range from -5.7 to +5.0%.

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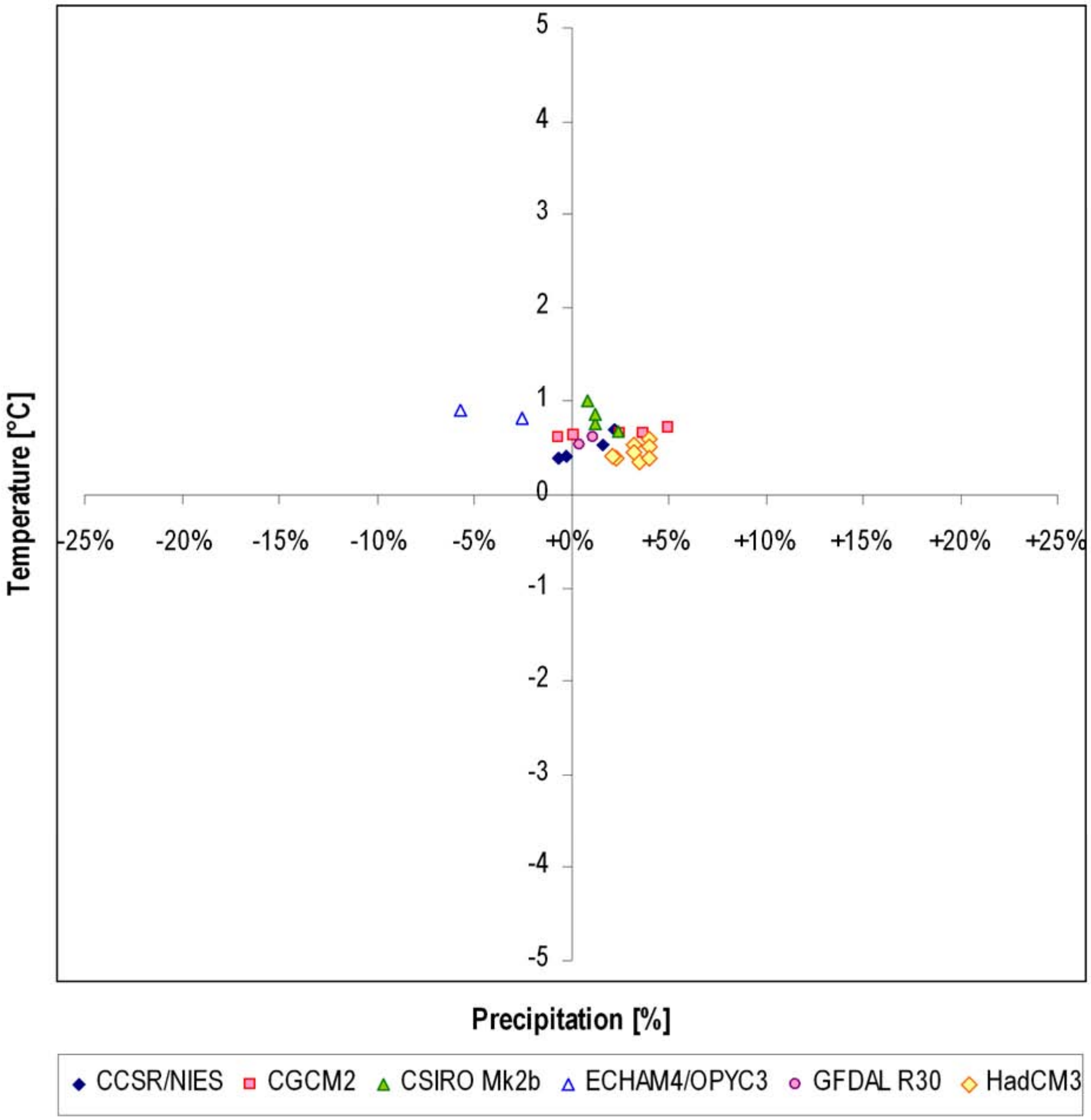


PROJECT

CLIMATE CHANGE CONSIDERATIONS

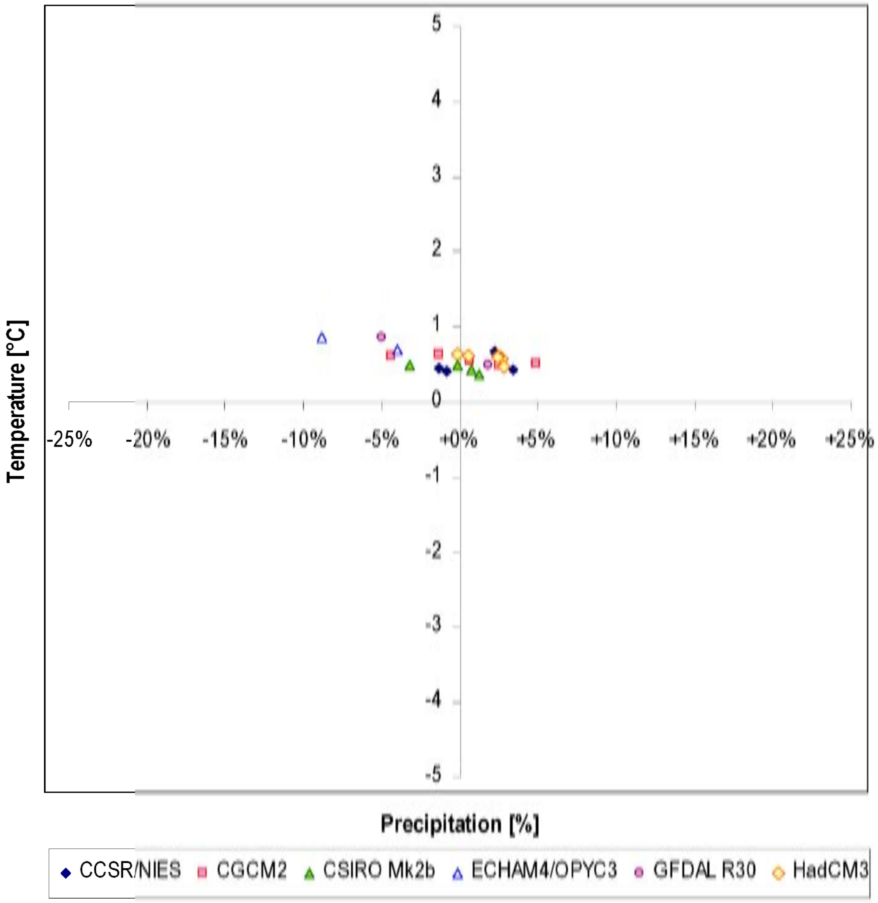
TITLE

FORECAST ANNUAL CLIMATE CHANGE OVER THE PROJECT LIFE

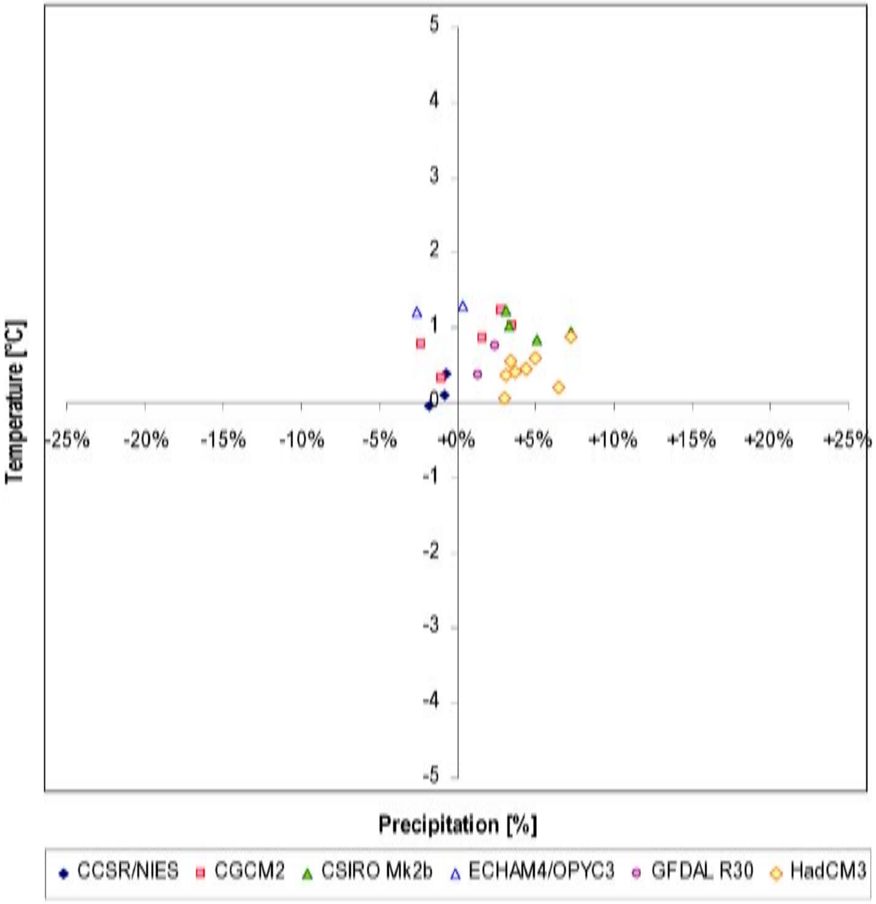
Golder Associates
Calgary, Alberta

PROJECT	07.1346.0009.5100		FILE No. change–project life
DESIGN	CM	12/12/07	SCALE NTS REV. 0
CADD	YAW	03/04/08	
CHECK	NP	03/04/08	**FIGURE: 6**
REVIEW	IGG	03/04/08	

L:\2007\1346 Oil Sands\07-1346-0009-MEG EXPANSION\5100\5190\Vol 2-Appendix-III-Climate Change\Fig 7_Forecast Summer and Winter Climate Change Over the Project Life.dwg Apr 03, 2008 - 3:38pm



Summer



Winter

PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

FORECAST SUMMER AND WINTER CLIMATE CHANGE OVER THE PROJECT LIFE

Golder Associates
Calgary, Alberta

PROJECT	07.1346.0009.5100		FILE No.	Climate Chane-LOP
DESIGN	CM	12/12/07	SCALE AS SHOWN	REV. 0
CADD	YAW	03/04/08		
CHECK	NP	03/04/08	FIGURE: 7	
REVIEW	IGG	03/04/08		

Table 19 Comparison of Climate Change Values Over the Project Life

Climate Model	Period	Change Over Life of Project	
		Temperature [°C]	Precipitation [%]
CCSR/NIES	annual	+0.4 to +0.7	-0.7 to +2.2
	summer	+0.4 to +0.7	-1.4 to +3.5
	winter	0.0 to +0.4	-1.8 to -0.8
CGCM2	annual	+0.6 to +0.7	-0.6 to +5.0
	summer	+0.5 to +0.6	-4.4 to +4.9
	winter	+0.3 to +1.2	-2.4 to +3.5
CSIRO MK2	annual	+0.7 to +1.0	+0.9 to +2.4
	summer	+0.4 to +0.5	-3.2 to +1.2
	winter	+0.8 to +1.2	+3.1 to +7.2
ECHAM4/OPYC3	annual	+0.8 to +0.9	-5.7 to -2.5
	summer	+0.7 to +0.9	-8.8 to -4.0
	winter	+1.2 to +1.3	-2.6 to +0.3
GFDL R30	annual	+0.5 to +0.6	+0.4 to +1.2
	summer	+0.5 to +0.9	-4.9 to +1.8
	winter	+0.4 to +0.8	+1.3 to +2.4
HadCM3	annual	+0.3 to +0.6	+2.1 to +4.0
	summer	+0.5 to +0.6	-0.2 to +2.8
	winter	+0.1 to +0.9	+3.0 to +7.2

As discussed in the previous section, the approach from Burn (2003) was used for choosing scenarios to evaluate climate change in northern Canada. The model forecasts were ranked by annual, summer and winter average temperature, as well as the annual, summer and winter precipitation. For each of the six ranking methods, the combinations of models and scenarios have been ranked and the temperature and precipitation changes for the 3rd highest (88th percentile), 12th highest (approximately the median) and 23rd highest (12th percentile) scenarios determined. The ranked model scenarios are provided in Table 20.

Table 20 Ranked Forecast Scenarios for Climate Change Over the Project Life

Ranking Method	Rank	Model and SRES Scenario	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
annual temperature	3rd highest	CSIRO Mk2b–B1(1)	+0.9	+1.3
	12th highest	CCSR/NIES–A1(1)	+0.6	n/a
	23rd highest	HadCM3–A2(3)	+0.4	+2.4
summer temperature	3rd highest	ECHAM4/OPYC3–B2(1)	+0.7	-4.0
	12th highest	HadCM3–A1FI	+0.6	+2.6
	23rd highest	CSIRO Mk2b–B1(1)	+0.4	+0.7
winter temperature	3rd highest	CSIRO Mk2b–B2(1)	+1.2	+3.1
	12th highest	GFDL R30–A2(1)	+0.8	+2.4
	23rd highest	HadCM3–B2(1)	+0.2	+6.5

Table 20 Ranked Forecast Scenarios for Climate Change Over the Project Life (continued)

Ranking Method	Rank	Model and SRES Scenario	Change Over Project Life	
			Temperature [°C]	Precipitation [%]
annual precipitation	3rd highest	HadCM3–A2(2)	+0.6	+4.0
	12th highest	CCSR/NIES–B2(1)	+0.7	+2.2
	23rd highest	CCSR/NIES–A2(1)	+0.4	-0.7
summer precipitation	3rd highest	HadCM3–B1(1)	+0.5	+2.8
	12th highest	CSIRO Mk2b–A2(1)	+0.4	+1.2
	23rd highest	CGCM2–A2(1)	+0.6	-4.4
winter precipitation	3rd highest	HadCM3–B2(1)	+0.2	+6.5
	12th highest	HadCM3–A2(3)	+0.4	+3.1
	23rd highest	CCSR/NIES–A1T	-0.0	-1.8

n/a = Not available.

Note: SRES = Special Report on Emissions Scenarios (IPCC 2000).

2.4 MODEL SCENARIOS FOR USE IN ENVIRONMENTAL ASSESSMENTS

As outlined in Sections 2.3.1 and 2.3.2, the climate models and scenarios were ranked by annual, summer and winter average temperature, as well as the annual, summer and winter precipitation. For each ranking methods, the 3rd highest (88th percentile), 12th highest (approximately the median) and 23rd highest (12th percentile) scenarios were determined. For the purposes of the environmental assessment, the combinations of models and scenarios that yielded the 3rd highest changes in annual, summer and winter temperatures along with the 3rd and 23rd highest changes in annual, summer and winter precipitation over the Project life will be carried forward into the assessment. These nine combinations of models and scenarios are consistent with the Indian and Northern Affairs Canada (INAC) recommendations for representing the upper bounds for changes in temperature and upper and lower bounds for changes in precipitation. Tables 21 to 29 show the results of these combinations and the upper bounds. For reference, the tables include the change from the baseline information for each model forecast.

Table 21 provides the predicted changes for the upper annual temperature scenario, corresponding with the CSIRO Mk2b–B1(1) model forecast. This scenario and model combination yielded the 3rd highest forecast of annual temperature change.

Table 21 Future Climate Trend Forecasts — Upper Annual Temperature

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
CSIRO Mk2b–B1(1)	annual	+2.2	+3.2	+0.9	+1.3
	spring	+3.2	+11.6	+1.3	+4.6
	summer	+1.1	+1.8	+0.4	+0.7
	fall	+1.8	-8.7	+0.7	-3.5
	winter	+2.6	+8.2	+1.0	+3.3

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 22 provides the climate change for the upper summer temperature scenario, corresponding with the ECHAM4/OPYC3–B2(1) model forecast. This scenario and model combination yielded the 3rd highest forecast of summer temperature change, which corresponds with the 88th percentile prediction.

Table 22 Future Climate Trend Forecasts — Upper Summer Temperature

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
ECHAM4/OPYC3–B2(1)	annual	+2.1	-6.3	+0.8	-2.5
	spring	+1.5	-9.3	+0.6	-3.7
	summer	+1.7	-10.0	+0.7	-4.0
	fall	+1.8	-6.6	+0.7	-2.7
	winter	+3.2	+0.8	+1.3	+0.3

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 23 provides the climate change for the upper winter temperature scenario, corresponding with the CSIRO Mk2b–B2(1) model forecast. This scenario and model combination yields the 3rd highest forecast (i.e., 88th percentile prediction) of winter temperature change.

Table 23 Future Climate Trend Forecasts — Upper Winter Temperature

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
CSIRO Mk2b–B2(1)	annual	+2.5	+2.1	+1.0	+0.9
	spring	+3.8	+10.9	+1.5	+4.4
	summer	+1.2	-0.3	+0.5	-0.1
	fall	+2.0	-9.8	+0.8	-3.9
	winter	+3.1	+7.7	+1.2	+3.1

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 24 provides the climate change for the upper annual precipitation scenario that corresponds with the HadCM3–A2(2) model forecast. This scenario and model combination yielded the 3rd highest forecast of annual precipitation change (i.e., 88th percentile prediction).

Table 24 Future Climate Trend Forecasts — Upper Annual Precipitation

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
HadCM3–A2(2)	annual	+1.5	+10.0	+0.6	+4.0
	spring	+0.8	+7.7	+0.3	+3.1
	summer	+1.5	+6.7	+0.6	+2.7
	fall	+1.5	+7.4	+0.6	+3.0
	winter	+2.2	+18.1	+0.9	+7.2

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 25 provides the climate change for the upper summer precipitation scenario that corresponds with the HadCM3–B1(1) model forecast. This scenario and model combination yielded the 3rd highest (i.e., 88th percentile) forecast of summer precipitation change.

Table 25 Future Climate Trend Forecasts — Upper Summer Precipitation

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
HadCM3–B1(1)	annual	+1.3	+9.9	+0.5	+4.0
	spring	+1.3	+8.3	+0.5	+3.3
	summer	+1.2	+7.1	+0.5	+2.8
	fall	+1.2	+11.9	+0.5	+4.7
	winter	+1.5	+12.5	+0.6	+5.0

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 26 provides the climate change for the upper winter precipitation scenario that corresponds with the HadCM3–B2(1) model forecast. This scenario and model combination yielded the 3rd highest forecast of winter precipitation change (i.e., 88th percentile prediction).

Table 26 Future Climate Trend Forecasts — Upper Winter Precipitation

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
HadCM3–B2(1)	annual	+1.0	+10.1	+0.4	+4.0
	spring	+0.5	+19.7	+0.2	+7.9
	summer	+1.5	+1.3	+0.6	+0.5
	fall	+1.4	+3.1	+0.6	+1.2
	winter	+0.5	+16.2	+0.2	+6.5

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 27 provides the climate change for the lower annual precipitation scenario that corresponds with the CCSR/NIES–A2(1) model forecast. This scenario and model combination yielded the 23rd highest (12th percentile) forecast of annual precipitation change.

Table 27 Future Climate Trend Forecasts — Lower Annual Precipitation

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
CCSR/NIES–A2(1)	annual	+1.0	-1.7	+0.4	-0.7
	spring	+1.6	+2.3	+0.6	+0.9
	summer	+1.1	-3.4	+0.4	-1.4
	fall	+0.8	-3.7	+0.3	-1.5
	winter	+0.3	-2.1	+0.1	-0.9

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 28 provides the climate change for the lower summer precipitation scenarios that corresponds with the CGCM2–A2(1) model forecast. This scenario and model combination yielded the 23rd highest forecast (12th percentile) change for annual precipitation.

Table 28 Future Climate Trend Forecasts — Lower Summer Precipitation

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
CGCM2–A2(1)	annual	+1.6	-1.5	+0.6	-0.6
	spring	+3.0	+8.5	+1.2	+3.4
	summer	+1.6	-11.0	+0.6	-4.4
	fall	+0.8	-1.2	+0.3	-0.5
	winter	+0.8	-2.5	+0.3	-1.0

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

Table 29 provides the climate change for the lower winter precipitation scenario that corresponds with the CCSR/NIES–A1T model forecast. This scenario and model combination yielded the 23rd highest (i.e., 12th percentile) forecast of winter precipitation change.

Table 29 Future Climate Trend Forecasts — Lower Winter Precipitation

Climate Model	Season	Change from Baseline (1961 to 1990)		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
CCSR/NIES-A1T	annual	+1.1	-0.7	+0.4	-0.3
	spring	+2.5	+4.1	+1.0	+1.6
	summer	+1.0	-2.0	+0.4	-0.8
	fall	+0.8	-0.3	+0.3	-0.1
	winter	-0.1	-4.6	-0.0	-1.8

Note: Shaded row indicates 3rd highest ranking for titled climate parameter.

3 EFFECT OF CLIMATE CHANGE ON AIR QUALITY PREDICTIONS

3.1 INTRODUCTION

Changing climate could alter some meteorological parameters that could, in turn, affect air quality and the EIA air predictions. A summary of the primary linkages between climate change and air quality are shown in Table 30. Each of the linkages listed in the table will be discussed separately below.

Table 30 Primary Links Between Climate Change and Air Quality

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

3.2 ACID DEPOSITION

As per Table 30, increased rainfall could lead to higher wet deposition. Since frozen precipitation is a relatively small contributor to Potential Acid Input (PAI), warming temperatures that could cause a shift from snowfall to rainfall creating a small incremental contribution to PAI.

Of the scenarios identified, the greatest effect on the PAI predictions is likely to occur with the upper summer precipitation case because summer rainfall has the greatest effect on PAI. As shown in Table 20 and detailed in Table 25, the HadCM3 model with the B1(1) scenario yielded the 3rd highest or 88th percentile estimates for changes in summer precipitation over the Project life. The forecasts associated with this scenario and model are reproduced in Table 31.

Table 31 Upper Bound Forecasts for Changes in Summer Precipitation Over the Project Life

Climate Model	Season	Precipitation Change [%]	
		Change Between Baseline and 2010 to 2039	Change Over Project Life
HadCM3–B1(1)	annual	+9.9	+4.0
	spring	+8.3	+3.3
	summer	+7.1	+2.8
	fall	+11.9	+4.7
	winter	+12.5	+5.0

Since the current GCMs do not have the resolution necessary to simulate all of the parameters necessary to model PAI, it is not feasible to model this specific scenario. However, it is possible to compare the 2002 meteorological data set used to model PAI in the Project region with the observed climate normals to see whether the current predictions can offer an indication of how changing climate may affect the PAI.

Table 32 compares the 2002 meteorological data set, that was used to model PAI to the 1961 to 1990 Cold Lake climate normals. The annual precipitation during 2002 was 37.7% lower than normal and rainfall was 45.8% lower during the summer months.

Table 32 Comparison of 2002 Precipitation to Climate Normal

Season	1961 to 1990 Normals [mm]	2002 Observation [mm]	Difference from Normals for 2002 Observation [%]
annual	432.4	269.3	-37.7
spring	78.7	73.0	-7.2
summer	221.9	120.3	-45.8
fall	76.8	52.0	-32.3
winter	54.6	24.0	-56.0

In contrast, the upper bound summer precipitation forecast for scenario B1(1) from the HadCM3 model indicated a change in summer precipitation of +7.1% from the baseline.

The average summer precipitation in 2002 was 46% lower than normal which would result in lower deposition rates than could be expected in the future.

As discussed in the air emission effects assessment (Volume 3, Section 4), the effects of acidifying emissions on soils, vegetation, and lakes and streams are considered negligible as a result of the Project. Because of these negligible changes and the short-term nature of the Project, climate change is not expected to alter the conclusions of the acidification assessment.

3.3 ATMOSPHERIC DISPERSION

Table 33 presents a summary of the range of forecast wind speed changes from the baseline and over the Project life. Forecast changes in wind speed range from -3.1 to +9.2% over the Project life.

Table 33 Comparison of Forecast Changes in Wind Speed

Climate Model	Period	Wind Speed Change [%]	
		Change Between the Averages of Baseline and 2010 to 2039	Change Over Project Life
CCSR/NIES	annual	-5 to -0.9	-3.1 to -0.6
	summer	-3.1 to +1.7	-1.9 to +1.1
	winter	-8.3 to +0.1	-5.2 to 0
CGCM2	annual	+5.4 to +5.4	+3.4 to +3.4
	summer	+1.5 to +1.5	+0.9 to +0.9
	winter	+8.5 to +8.5	+5.3 to +5.3
CSIRO MK2	annual	-1.9 to -0.4	-1.2 to -0.2
	summer	-5.2 to -3.9	-3.3 to -2.5
	winter	-1.5 to +4	-0.9 to +2.5
ECHAM4/OPYC3	annual	+6.2 to +6.8	+3.8 to +4.3
	summer	-2.4 to -1.1	-1.5 to -0.7
	winter	+14 to +14.7	+8.8 to +9.2
GFDL R30[a]	annual	n/a	n/a
	summer	n/a	n/a
	winter	n/a	n/a
HadCM3	annual	-1.2 to +2.8	-0.7 to +1.8
	summer	-3.8 to -1.4	-2.4 to -0.9
	winter	+0.2 to +9.5	+0.1 to +5.9

[a] Wind speed data were not provided for this model.

n/a = Not available.

Table 34 shows the forecast change in wind speed for the ranked scenarios over the Project life (as shown in Table 20). Generally, lower wind speeds are associated with increased ground-level concentrations. Therefore, the lower bound predictions from Table 34 represent the conditions most likely to affect the air quality predictions. Available GCMs do not have the resolution necessary to simulate all of the parameters necessary to complete dispersion modelling for the Project region. However, it is possible to compare the 2002 meteorological data set used in the modelling with the observed Cold Lake climate normals and forecast trends.

Table 34 Summary of Climate Scenarios for Wind Speed

Ranking Method	Rank	Model and SRES Scenario	Wind Speed Change [%] Change Between the Averages of Baseline and 2010 to 2039	Wind Speed Change [%] Change Over Project Life
annual temperature	3rd highest	CSIRO Mk2b–B1(1)	-0.4	-0.2
	12th highest	CCSR/NIES–A1(1)	n/a	n/a
	23rd highest	HadCM3–A2(3)	+0.4	+0.2
summer temperature	3rd highest	ECHAM4/OPYC3–B2(1)	+0.5	+0.2
	12th highest	HadCM3–A1FI	-2.1	-0.9
	23rd highest	CSIRO Mk2b–B1(1)	-0.8	-0.3
winter temperature	3rd highest	CSIRO Mk2b–B2(1)	+0.4	+0.1
	12th highest	GFDL R30–A2(1)	n/a	n/a
	23rd highest	HadCM3–B2(1)	+1.6	+0.7
annual precipitation	3rd highest	HadCM3–A2(2)	+0.4	+0.1
	12th highest	CCSR/NIES–B2(1)	-1.7	-0.7
	23rd highest	CCSR/NIES–A2(1)	-1.8	-0.7
summer precipitation	3rd highest	HadCM3–B1(1)	-2.7	-1.1
	12th highest	CSIRO Mk2b–A2(1)	-0.3	-0.1
	23rd highest	CGCM2–A2(1)	+4.8	+1.9
winter precipitation	3rd highest	HadCM3–B2(1)	+1.6	+0.7
	12th highest	HadCM3–A2(3)	+1.3	+0.5
	23rd highest	CCSR/NIES–A1T	-7.0	-2.8

n/a = Not available.

Table 35 shows how the average wind speeds in 2002 compared to the long-term normals for the region. During 2002, the annual wind speeds were 6.6% below the climate normals. The difference between the 2002 annual average wind speed and the baseline normal (-6.6%) is similar to the largest forecast change in wind speed of -7.0%.

Table 35 Comparison of 2002 Average Wind Speeds to Climate Normals

Season	Average Wind Speed [km/hr] 1961 to 1990 Normals	2002 Observation	Difference from Normals for 2002 [%]
annual	12.1	11.3	-6.6
spring	13.1	13.3	1.5
summer	12.3	12.2	-0.8
fall	12.2	10.9	-10.7
winter	10.6	8.8	-17.0

Table 36 shows the frequency of occurrence of different wind speed categories for the 1961 to 1990 normals and 2002. Overall, 2002 had about the same number of calm hours as the normals and about 5% more hours with wind speeds less than 10 km/hr.

Table 36 Comparison of Wind Speed Categories

Wind Speed Category	Frequency of Occurrence [%] 1961 to 1990 Normals	2002 Observation	Difference from Normals for 2002 [%]
calm	11.8	11.7	-0.1
1 to 5 km/hr	8.7	10.4	1.7
6 to 10 km/hr	25.8	29.1	3.3
11 to 15 km/hr	23.1	22.4	-0.7
16 to 20 km/hr	15.2	14.1	-1.1
>20 km/hr	15.5	12.2	-3.3

Depending on the models considered, the average wind speeds in the Cold Lake Region are predicted to either increase (i.e., enhanced dispersion) or decrease (i.e., reduced dispersion). However, 2002 data used to model concentrations in the region had average wind speeds below historic observation and had a greater number of hours with lower wind speeds. Therefore, it is expected that the 2002 wind speed data used in the assessment of climate change and air quality results in ground-level concentrations that are higher than those if historic normals were used. The impacts of climate change are not expected to affect the conclusions of the air quality assessment.

3.4 GROUND-LEVEL OZONE

Ozone is an essential part of the upper atmosphere that protects us from most of the sun’s harmful ultra-violet radiation. Ozone can also be present at the earth’s surface. Ground-level ozone in Canada can be the result of photochemical ozone formation, stratospheric intrusion and long-range transport.

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

Summer temperature is one of the climate parameters likely to affect ground-level ozone concentrations. The forecasts from the ECHAM4/OPYC3 model for scenario B2(1) yielded the upper summer temperatures over the life of the Project. Table 37 summarizes the climate trends forecast for that model and scenario combination (reproduced from Table 22).

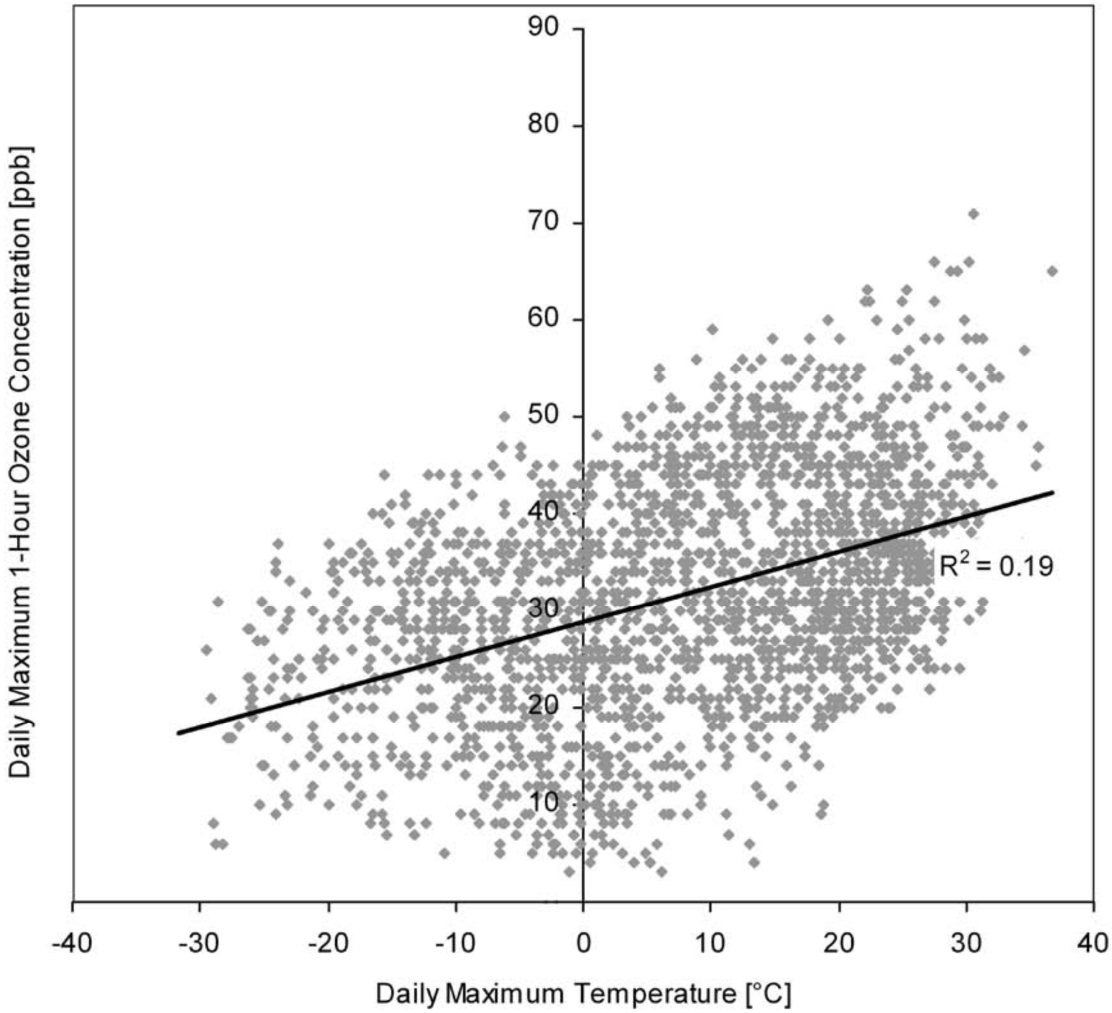
Table 37 Upper Bound Forecasts for Changes in Summer Temperature Over the Project Life

Climate Model	Season	Temperature Change [°C]	
		Change between the averages of Baseline and 2010 to 2039	Change over Project Life
ECHAM4/OPYC3–B2(1)	annual	+2.1	+0.8
	spring	+1.5	+0.6
	summer	+1.7	+0.7
	fall	+1.8	+0.7
	winter	+3.2	+1.3

While higher summer temperatures could result in an increased potential for ground-level ozone formation in the region, this relationship is not clearly evident from the monitoring results from stations operated by the Wood Buffalo Environmental Association (WBEA). Figure 8 presents a comparison of daily maximum temperatures and the corresponding 1-hour maximum ozone concentration. This data was collected at the WBEA Athabasca Valley Station from 1998 through 2004. Monitoring results at the Patricia McInnes, Fort McKay and Fort Chipewyan stations demonstrate similar patterns as those shown in Figure 8.

As illustrated in Figure 8, there is a weak positive correlation between maximum temperature and peak ozone concentrations ($R^2 = 0.19$, assuming a linear trend). On days when temperatures are greater than 30ºC, ozone concentrations range from approximately 24 to 71 ppb. There are also high ozone concentrations occurring during periods when the daily maximum temperature is below 0ºC. Although the upper summer temperature forecast change of +0.7°C (Table 37) over the life of the Project may result in increased daily maximum temperatures, this may not correspond to increased peak ozone concentrations. It is predicted that these changes may not correspond to peak ozone concentrations.

L:\2007\1346 Oil Sands\07-1346-0009-MEG EXPANSION\5100\5190\Vol 2-Appendix-III-Climate Change\ Drawing file: Fig 8_Comparison of Daily Maximum Temperatures and Daily Maximum 1 Hour Ozone Concentratio



PROJECT

CLIMATE CHANGE CONSIDERATIONS

TITLE

COMPARISON OF DAILY MAXIMUM TEMPERATURES AND DAILY MAXIMUM 1-HOUR OZONE CONCENTRATIONS

Golder Associates
Calgary, Alberta

PROJECT	07.1346.0009.5100		FILE No.	Temp-1hr ozone
DESIGN	CM	12/12/07	SCALE NTS	REV. 0
CADD	YAW	03/04/08		
CHECK	NP	03/04/08	**FIGURE: 8**	
REVIEW	IGG	03/04/08		

3.5 SUMMARY

In conclusion, the air quality predictions in the assessment are considered representative of conditions over the life of the Project since the 2002 meteorological data (temperature and wind speed) cover the range of climate forecast values. Due to lower precipitation amounts, the use of 2002 data in the air modelling may underestimate deposition rates that may be expected in the future. The effect of climate change on ground-level ozone concentrations is not clearly established; however, current observations show that an increase in temperature may not correspond to increased peak ozone concentrations.

4 EFFECT OF CLIMATE CHANGE ON HYDROGEOLOGY PREDICTIONS

4.1 INTRODUCTION

Climate change forecasts from six GCMs are discussed in Section 2 of this Appendix. The GCMs were used to predict changes in temperature and precipitation for as many as six different IPCC scenarios. Forecast results for the 2010 to 2039 period in the Cold Lake area are compared to baseline data collected at Cold Lake over a 30-year baseline period of 1961 to 1990. The forecast results predict average annual temperatures will increase between 0.8 and 2.5˚C and the average annual precipitation rate will decrease as much as 14.3% or increase as much as 12.6%.

All else being equal, an increase in temperature could increase evaporation rates and therefore decrease groundwater recharge rates and water levels. However, given that the predicted change in temperature is relatively small and that the range of predicted change in precipitation is relatively large, a change in temperature of this predicted magnitude is expected to have no direct measurable effect on groundwater levels. While a change in average temperature is unlikely to have a direct impact on groundwater levels, changes in precipitation may affect shallow groundwater availability and surface water-groundwater interactions.

Decreased precipitation rates may lower the shallow water table resulting in decreased discharge to surface waterbodies and decreased recharge from shallow, near-surface aquifers to deeper aquifers. Conversely an increase in precipitation rates may raise the shallow water table and increase the amount of discharge to surface waterbodies and recharge to deep aquifers.

A summary of the primary linkages between climate change and hydrogeology are set out in Table 38 and evaluated with respect to EIA predictions in the following discussion.

Table 38 Primary Links Between Climate Change and Hydrogeology

Hydrogeology Attribute	Change in Temperature (Increase)	Change in Precipitation	
		Increase	Decrease
water levels/aquifer productivity	no linkage	More recharge would result in higher water levels and aquifer productivity.	Less recharge would result in lower water levels and aquifer productivity.
change in groundwater flux	no linkage	More recharge would result in more groundwater discharge to surface waterbodies and deeper aquifers.	Less recharge would result in less groundwater discharge to surface waterbodies and deeper aquifers.
water quality	no linkage	no linkage	no linkage

4.2 DISCUSSION

In the Project area, groundwater in the Quaternary, Tertiary and Cretaceous hydrostratigraphic units are recharged by surface water. Baseline climate data have been collected at Cold Lake over a 30-year period from 1961 to 1990. The average annual precipitation rate between 1961 and 1990 is 432.4 mm/year and has achieved equilibrium with the hydrologic environment at Cold Lake. Precipitation is in equilibrium with evaporation, transpiration, runoff and groundwater recharge.

Shallow groundwater levels are known to fluctuate as a result of seasonal changes in precipitation. In periods of lower relative precipitation (fall and winter) recharge decreases and groundwater levels drop. In periods of higher relative precipitation (summer), recharge increases and groundwater levels rise. The effects of seasonal fluctuations generally decrease with increasing depth from surface. Seasonal changes in hydraulic head become muted and are ultimately undetectable when separated from surface by sufficient distance or low permeability hydrostratigraphic units.

Similar to these observed seasonal fluctuations, the average shallow groundwater level in the Project area will likely increase or decrease over time in response to changes in the annual precipitation rate. If the annual precipitation rate decreases, groundwater levels in the shallow sediments will likely decrease, resulting in decreased discharge to surface waterbodies and underlying aquifers (specifically the Empress and Mannville aquifers). If the annual precipitation rate increases, groundwater levels in the shallow sediments will likely increase, resulting in increased discharge to surface waterbodies and underlying aquifers.

4.3 PROJECT IMPACTS AND UNCERTAINTIES INTRODUCED BY CLIMATE CHANGE

The Project requires 7,766 m^3/cd of groundwater for the operation of Phase 3. This water will be sourced primarily from the Clearwater Formation (6,678 m^3/cd) which occurs at a depth of approximately 270 mbgs. The potential for groundwater withdrawal to decrease shallow groundwater levels and impact surface waterbodies was assessed in Volume 4 of this application. Make-up water withdrawal associated with the Project is not expected to result in detectable drawdown in near surface aquifers. Similarly no detectable change in groundwater discharge to or from surface waterbodies is predicted to occur over the timeframe of the Project.

As discussed above, climate change may result in changes in precipitation and therefore changes in groundwater conditions. In the scenario of decreased precipitation the following changes to groundwater conditions may occur:

- lowering of the water table;
- decreased discharge to surface waterbodies; and
- decreased recharge to underlying aquifers.

In the scenario of increased precipitation the following changes to groundwater conditions may occur:

- rising of the water table;
- increased discharge to surface waterbodies; and
- increased recharge to underlying aquifers.

These potential climate-related changes represent an impact to groundwater resources but are independent of the predicted impacts related to make-up water withdrawal. Most specifically related to this assessment, is the potential change in recharge to the Empress and Mannville aquifers. Over time, water levels in the Empress and Mannville aquifers would potentially respond to a climate change related long-term increase or decrease in precipitation. This effect however will be substantially muted and temporally delayed as compared to water level changes in the uppermost aquifers. Given that climate-related water level changes in the Clearwater water sand will be slight (possibly non-detectable) and may not occur during the lifetime of this Project, the uncertainties related to climate change with respect to the conclusions of the Empress and Mannville hydrogeologic impact assessment are judged to be negligible.

Ongoing water level monitoring in the Clearwater water sand and selected overlying aquifers will be conducted throughout the lifetime of the Project. If observed water level changes differ significantly with respect to water level changes predicted in this assessment, adjustments to project operation may be required.

4.4 SUMMARY

The Hydrogeology Impact Assessment Methodology and impact assessment results (Volume 4) support the following conclusions regarding climate change and its influence on hydrogeology:

- climate change is predicted to result in higher temperatures and either increased or decreased precipitation in the project area;
- these climate related changes may result in three changes to shallow hydrogeology: an increase or decrease of the water table, increased or decreased discharge to surface waterbodies, and increased or decreased recharge to deeper aquifers;
- project operations are not predicted to impact shallow aquifers or surface waterbodies therefore the climate-related impacts would exist whether groundwater withdrawal associated with the Project was occurring or not; and
- the impact assessment results for the Project are not sensitive to additional uncertainties related to climate change.

5 EFFECT OF CLIMATE CHANGE ON HYDROLOGY PREDICTIONS

5.1 INTRODUCTION

The potential effects of the CLRP project on local and regional hydrology were assessed in Volume 4 of this application. The effects were examined in the context of two key questions:

- What effects could existing and approved developments and the Project have on open water areas, flows and groundwater levels in receiving and nearby water bodies?
- What effects could existing and approved developments and the Project have on the geomorphic conditions of watercourses and the concentrations of suspended sediments in these watersheds and drainage systems?

Surface runoff, streamflows and lake levels are the result of the interaction between many factors including vegetation, surficial geology and climate. Climate change therefore has the potential to impact key climatic factors, most notably precipitation and temperature, which affect hydrology. Table 39 summarizes the hydrologic variables that may be impacted by climate change due to changes in temperature and precipitation.

Table 39 Primary Links Between Climate Change and Hydrology

Hydrology Attribute	Change in Temperature (Increase)	Change in Precipitation	
		Increase	Decrease
open water areas and lake water levels	increased evaporation and therefore decreased lake levels and open water areas (if precipitation unchanged or decreased)	increased lake levels and open water areas (unless offset by temperature increase)	decreased lake levels and open water areas
streamflows	increased evaporation and evapotranspiration and therefore decreased streamflows (if precipitation unchanged or decreased)	increased streamflows (unless offset by temperature increase)	decreased streamflows
stream geomorphic conditions and suspended sediments	no direct linkage	if extreme rainfall events increase in magnitude or frequency, potential for increased erosion, suspended sediment loads and geomorphic change	decreased precipitation will result in decrease channel forming flows and hence change in stream geomorphology.

5.2 REVIEW OF KEY CLIMATE FACTORS WITH AN INFLUENCE ON HYDROLOGY

Section 2 of this Appendix evaluated the potential impacts of climate change on precipitation and temperature over the project life, as well as historic climate change as measured by a comparison of climate normals for the Cold Lake meteorological station.

The analysis of climate normals for Cold Lake for the periods 1951 to 1980, 1961 to 1990, and 1971 to 2000 were presented in Section 2.2 of this appendix. The results of this may be summarized as follows:

- mean annual temperatures increased over the three periods from 1.2°C (1951 to 1980) to 1.5°C (1961 to 1990) to 1.8°C (1971 to 2000); and
- mean annual precipitation decreased from 461 mm to 432 to 427 mm for the same periods.

Mean temperature and precipitation for each season (spring, summer, fall and winter) followed similar trends.

To predict changes in temperature and precipitation over the life of Project forecasts from individual GCMs were employed. The GCM model forecasts were ranked by annual, summer and winter average temperature, as well as the annual, summer and winter precipitation. For each of the six ranking methods, the combinations of models and scenarios were ranked and the temperature and precipitation changes for the 3rd highest (88th percentile), 12th highest (approximately the median) and 23rd highest (12th percentile) scenarios. A summary of the forecasted changes in temperature and precipitation over the Project life (i.e., the change from 2010 to 2039) and between the 1961 to 1990 climate normals and 2039 are provided in Table 40. This table summarizes the information presented in Tables 21 through 27 in Section 2.4.

Table 40 Summary of Future Climate Trend Forecasts

Variable	Model	Change from 1961 to 1990 Baseline		Change Over Project Life	
		Temperature [°C]	Precipitation [%]	Temperature [°C]	Precipitation [%]
upper annual temperature	CSIRO Mk2b–B1(1)	+2.2	+3.2	+0.9	+1.3
upper summer temperature	ECHAM4/OPYC3–B2(1)	+1.7	-10.0	+0.7	-4.0
upper winter temperature	CSIRO Mk2b–B2(1)	+3.1	+7.7	+1.2	+3.1
upper annual precipitation	HadCM3–A2(2)	+1.5	+10.0	+0.6	+4.0
upper summer precipitation	HadCM3–B1(1)	+1.2	+7.	+0.5	+2.8
upper winter precipitation	HadCM3–B2(1)	+0.5	+16.2	+0.2	+6.5
lower annual precipitation	CCSR/NIES–A2(1)	+1.0	-1.7	+0.4	-0.7
lower summer precipitation	CGCM2–A2(1)	+1.6	-11.0	+0.6	-4.4
lower winter precipitation	CCSR/NIES-A1T	-0.1	-4.6	-0.0	-1.8

The results from Table 40 may be summarized as follows:

- The 3rd highest GCM forecasts a temperatures increases of 1.2°C in the winter over the project life and 3.1°C in winter relative to the 1961 to 1990 climate normals. Smaller summer and annual temperature increases are also forecast. Increases in precipitation are forecast for these model scenarios in winter and annually, but decreases are forecast for summer.
- The 3rd highest GCM forecasts a precipitation increase of 6.5% in winter over the project life, and of 16.2% relative to the 1961 to 1990 climate normals. The models predict smaller summer and annual precipitation increases, coupled with temperature increases of up to 1.5°C.
- The 3rd lowest GCM predicts decreases in precipitation of 4.4% in summer over the project life and 11% relative to the 1961 to 1990 normals. Smaller decreases are predicted for annual and winter precipitation. The GCMs predict corresponding temperatures increases from nearly 0 to 1.6°C.

In addition to long-term seasonal and annual changes to temperature and precipitation, there is a possibility of impacts from climate change on extreme precipitation events, which could in turn impact peak runoff rates, and stream erosion and geomorphic stability. Differing opinions exist concerning the historical trends in extreme rainfall events. Frich et al. (2001) showed that the maximum annual five-day total precipitation data for the Oil Sands Region show a positive trend of greater than 15% for the period of 1961 to 1990. Other researchers have also reported increases in heavy precipitation, and snowfall amounts north of 55°N (IPCC 2001; Zhang et al. 2000a,b). However, Hogg and Carr (1985) found that there is a slight but insignificant increase in extreme rainfall across Canada.

5.3 ANALYSIS

While there are some surface water withdrawals for dust suppression, ice road construction, and drilling, the primary effect of the Project on surface water hydrology within the LSA and RSA is due to changes in land surface. Most changes will result in a negligible change or increase in runoff. For example, land types such as roads, cuts lines, wellpads, and much of the plant site will generate higher runoff than the natural watershed, where water is often ponded and prone to evaporation. There are some very small areas, most notably a small portion of the plant sites, from which no runoff will be released, but overall the effect of the Project will be an increase in runoff.

The effects of the Project on the hydrology of the RSA was evaluated in Volume 4, Section 5.2. Because the surface disturbances due to the Project comprise only a small fraction of the RSA, their impacts on the four watersheds presented in Volume 4, Section 5.2 of the EIA is expected to be negligible. Land disturbances within the RSA represent only 0.2% of the total land area, and 1.1% of the most affected sub-watershed (Christina Lake at its outlet). Regionally, therefore, the effects of the Project on hydrology are expected to be negligible. Changes to regional hydrology over the Project life would therefore occur primarily due to the effects of climate change, and would not be appreciably influenced by the Project.

Within the LSA, the potential effects of the Project were considered to be large enough that further assessment was required. Changes to runoff were calculated for each type of land disturbance within the LSA for both the EAC and the EAC plus Project cases. These results are summarized in Volume 4, Section 5.2. Changes in land use due to the Project are forecast to increase runoff within the LSA by approximately 8% relative to pre-development conditions. Existing and approved developments also contribute to a predicted increase in runoff of 10%, for a total change of 18% relative to pre-development conditions. Potential effects within some watersheds are potentially higher, with predicted runoff increases of up to 23% due to existing and approved projects and the Project.

Upon reclamation, the effects of surface disturbances on hydrology will be significantly reduced.

There is a general agreement amongst GCMs of increased temperature within the area occupied by the Project, and therefore increased evaporation and evapotranspiration is expected. There is less agreement between models on changes to precipitation: the 3rd highest GCMs predict an increases in annual and seasonal precipitation, while the 3rd lowest GCMs predict decreases in annual and seasonal precipitation. The combination of increased temperature and decreased precipitation would result in decreased runoff, while the combination of increased in temperature and precipitation is unclear, and could result in either increased or decreased runoff (and vary seasonally).

Detailed computer modelling would be necessary to quantify the potential changes to hydrology of climate change and changes to land type. This level of investigation was not considered warranted for the level of surface disturbance associated with the Project. However, a qualitative assessment has been made of the combination of the effects of climate change and the Project on surface water hydrology.

If the effect of climate change were an overall decrease in runoff, then this decrease in runoff would be partially or totally offset by the anticipated increases in runoff caused by surface disturbances. After reclamation, the increased runoff caused by Project disturbances would become negligible, and most changes from the present day to local and regional hydrology would be due to climate change alone.

If the effect of climate change were an increase in runoff, then the increased runoff from the Project would add to this increase. This effect would occur if increased runoff were to occur on an annual or seasonal basis, or due to more frequent or extreme precipitation events. The potential effects of increased runoff are increased water supply, larger lake, pond and wetlands surface areas, as well as increased flooding, increased erosion within watercourses and consequent increased suspended solids loads. The latter two effects occur primarily due to increases in peak runoff rather than moderate long-term increases in runoff. Due to the relatively small and disperse nature of SAGD development, it is expected that the impact of the moderate increases in runoff predicted will be negligible due to the generally flat topography of the LSA and RSA, the attenuating effects of ponds, wetlands, and large waterbodies such as Christina Lake, and the mitigation measures proposed in Volume 4, Section 3 of the EIA. The latter commits MEG to several measures designed to reduce the effects of surface disturbances on peak runoff, the most notable being the design of berms and retention ponds to contain and slowly release the 24 hour, 25-year storm event from the well pads and plant and camp sites. These measures will serve to improve the quality of water released to the environment, and will minimize local effects of increased runoff on receiving streams and wetlands.

5.4 SUMMARY

There is considerable uncertainty regarding the magnitude of the potential impacts of climate change on hydrology within the LSA and RSA. However, it is clear that if climate change were to decrease runoff, then the increased runoff Project surface disturbances would either partially or totally offset these climate change induced effects. If climate change were to instead increase runoff, then there would be a net increase in runoff within the LSA and RSA. Potential negative impacts of increased peak runoff include flooding, erosion, and geomorphic instability of channels.

Given the relatively small disturbance area occupied by the Project, the generally flat topography of the LSA and RSA, and the attenuating effects of ponds, wetlands and large waterbodies such as Christina Lake, the predicted impact of the Project on local hydrology is small. The predicted changes resulting from climate change are not expected to change the predictions of the EIA.

6 EFFECT OF CLIMATE CHANGE ON SURFACE WATER QUALITY PREDICTIONS

6.1 INTRODUCTION

The potential effects of the Project on water quality were assessed in Volume 4, Section 5.3. Climate change has the potential to affect water quality indirectly through changes in hydrologic variable and directly through changes in water temperature (Table 41). A review and discussion of existing studies and information on climate change with reference to surface water quality in the Oil Sands Region is provide in Section 6.2. The interrelation of climate change and potential effects of the project on water quality are described in Section 6.3.

Table 41 Primary Links Between Climate Change and Water Quality

Attribute	Change in Temperature (Increase)	Change in Precipitation	
		Increase	Decrease
water quality via changes to water levels and flows	increased evapotranspiration	increases to inflows and outflows of rivers and lakes	decreases to inflows and outflows of rivers and lakes
direct changes to water quality	lower DO concentrations and saturation levels deepening lake thermoclines and longer stratification periods Shortening of ice-cover periods	decreases in nutrients and parameter concentrations from changes in residence times and assimilative capacity	increases in nutrients and parameter concentrations from changes in residence times and assimilative capacity

6.2 LITERATURE REVIEW

Most of the existing literature is focused on effects of climate change on meteorological parameters, such as air temperature and precipitation, and not on water quality. Changes to meteorological parameters such as air temperature and precipitation can lead to changes in infiltration, snow cover, evapotranspiration and ultimately, streamflow, which could affect water quality (Chalecki and Gleick 1999; Murdoch et al. 2000). Most of the literature that describes potential effects of climate change on water quality focuses on water temperature, dissolved oxygen and nutrients. Changes in streamflow due to climate warming have the potential to alter prediction of effects on streamflow and sediment loadings to local waterbodies.

Anthropogenic (man-made) effects, such as changes in land and water use management related to climate change, may have similar or greater impacts on water quality than climate change itself, depending on the region (Cruise et al. 1999; Murdoch et al. 2000; Hutjes et al. 1998). Many studies have focused on differentiating these effects (Worrall et al. 2003; Cruise et al. 1999; Moore et al. 1997; Walker et al. 2000; Interlandi and Crockett 2003; Ramstack et al. 2004). However, anthropogenic effects are not always considered in the literature, so conclusions regarding the effects of climate change on water quality must be carefully evaluated. A summary of key findings is provided below.

General warming trends are expected to increase water temperature as a result of shorter ice-covered periods in rivers and lakes (Beltaos 2000; Stefan et al. 1993; Fang and Stefan 1997, 2000; Fang et al. 1999; Prowse and Beltaos 2002; Ozaki et al. 2003; Jansen and Hesslein 2004; Magnuson et al. 1997; Cohen 1995, 1997a). Shorter ice-covered periods should allow biochemical reactions that normally cease during anoxic (i.e., ice cover) conditions to occur for a longer period, because of increased aeration.

Warmer water temperature would also favour algal growth during the open-water period and could increase rates of microbial action and weathering, which in turn may result in increased rates of nutrient loading to lakes. Overall, these changes may be reflected in increased primary productivity, or the accumulation of greater algal biomass in standing waters (Rouse et al. 1997). Increased biological activity could lead to increased oxygen demands, with a net result of lower overall dissolved oxygen concentrations in the water column. In addition, dissolved oxygen saturation levels decrease with rising water temperature, limiting the volume of oxygen in the water column (Thomann and Mueller 1987).

Climate change may also lead to changes in lake hydrodynamics. Warmer water temperatures could lead to deepened thermoclines and alter the ratio of water present in the epilimnion and hypolimnion. Stefan et al. (1993) expect longer stratification periods for certain types of lakes, which may prevent lake mixing and thereby limit the influx of oxygen from the surface to the hypolimnion. Temperate dimictic lakes (i.e., those that mix twice a year) may become monomictic (i.e., mix once a year), and cold monomictic lakes may become stratified (Schindler 1997; Hostetler and Small 1999; Magnuson et al. 1997; Stefan et al. 1993). Maxwell et al. (1997) and Schindler (2001) also concluded that warmer air temperatures and lower streamflows could lead to the reduction, if not the disappearance, of many wetlands. Since some wetlands act as purification facilities, water chemistry in some receiving streams may also change.

Some studies have been completed on the effect of climate and anthropogenic changes on targeted water quality parameters (Moore et al. 1997; Cruise et al.

1999; Walker et al. 2000; Interlandi and Crockett 2003; Ramstack et al. 2004; Boesch et al. 2001; Boorman 2003; Worrall et al. 2003; Struyf et al. 2004). Differences in water temperature due to climate change could potentially result in changes in solubility (Thomann and Mueller 1987). Most of the studies focus on nutrients, which is generally an issue in densely populated areas with heavy agricultural activities. Limited attention has so far been given to metals or organics.

Based on these studies it appears that the main pathway for effects on water quality may be through changes in surface flow. For example, warmer air temperatures may gradually increase evaporation, which could lead to a reduction in water levels and flows in lakes and rivers. This reduction in assimilative capacity could, subsequently, lead to increased in-stream concentrations. The linkage between warmer air temperature and reduced surface water flow has not, however, been clearly established (Section 5.2), as the various climate change models presented in Section 2.1 predict either increases or decreases in precipitation, with increased temperature.

6.3 ANALYSIS

Although some climate change effects on water quality cannot be ruled out, past modelling experience for oil sands EIAs suggests that the effects on water quality resulting from increased air and water temperatures would likely be small and not measurable (Shell 2005). Similarly, climate change is not expected to measurably affect the predicted effects of the Project on water quality.

There is a general agreement amongst GCMs of increased temperature within the area occupied by the project. Increased air temperatures resulting from climate change are likely to increase the temperature of surface waters. This could increase algal productivity in the surface waters (Rouse et al. 1997) resulting in lower nutrient levels and increased oxygen demand. These affects, however, are independent of the Project and increases in temperature will not change any of the Project's affects on the surface waters.

There is not a strong agreement between models on changes to precipitation: the 3rd highest GCMs predict relatively large increases in precipitation, while the 3rd lowest GCMs predict decreases. Increased precipitation could lead to increased site runoff (Section 5.3); however, with mitigation measures proposed in Volume 4, Section 3 of the EIA it is expected that site runoff will be contained as much as possible and it is not expected than increased runoff will have a significant effect on the surface water quality. The increased site runoff could also be limited by the increased evaporation due to the predicted temperature increase (Section 5.3).

Project-related activities do have potential impact to water quality including increased suspended sediments in surface water runoff and the release of treated domestic wastewater (Volume 4, Section 5.3). Based on the anticipated management of both the surface water runoff and the treated domestic water, the effects on surface water quality due to these processes were predicted to be negligible (Volume 4, Section 5.3). The management practices are not expected to change as a result to changes in the climate. Thus, the conclusions of the water quality assessment are not expected to change.

6.4 SUMMARY

Based on the MEG's proposed management of runoff, no effects are predicted on water quality from this pathway. Under climate change scenarios evaluated in this assessment, the conclusions of the water quality assessment would remain unchanged.

7 EFFECT OF CLIMATE CHANGE ON FISH AND FISH HABITAT PREDICTIONS

7.1 INTRODUCTION

The evaluation of the potential effects of climate change on the fish and fish habitat impact assessment considers the potential effects that climate change may have on aspects of the Project that could be influenced, in a cumulative manner, by climate change. These aspects include stream discharge, water level and water quality, as influenced by possible changes in air temperature, evaporation and precipitation. Such changes may affect the availability, quality or quantity of fish habitat, as well as potentially affecting fish abundance and fish habitat diversity. A summary of the primary links between climate changes and fish and fish habitat are shown in Table 42.

Table 42 Primary Links Between Climate Change and Fish and Fish Habitat

Attribute	Change in Water Temperature (Increase)	Change in Precipitation	
		Increase	Decrease
changes to stream discharge	increased evapotranspiration	increases to inflows and outflows of rivers and lakes decreases in lake residence times increase in size and location stream habitats increased connectivity between waterbodies	decreases to inflows and outflows of rivers and lakes increases in lake residence times reduction in size and location of stream habitats reduced connectivity between waterbodies
changes to water levels	increased evapotranspiration from surface of lakes and rivers	increase in size and location of littoral and pelagic zone, wetland and stream habitats	reduction in size and location of littoral and pelagic zone, wetland and stream habitats
changes to water quality and aquatic thermal regimes	lower DO concentrations and saturation levels Deepening lake thermoclines and longer stratification periods Shorter ice-covered periods	decreases in nutrients and parameter concentrations from changes in residence times and assimilative capacity	increases in nutrients and parameter concentrations from changes in residence times and assimilative capacity

7.2 APPROACH

The approach included a literature review to compile existing information concerning the effects of climate change on freshwater fish populations and fish habitats, with emphasis on northern Alberta. This information was used as a basis for a general evaluation of the potential cumulative effects of the Project under climate change. The results of the literature review are presented in Section 7.3. The assessment was also based on the outcome of the analyses conducted by the hydrology (Section 5.2) and water quality (Section 6.3) components to assess the effects of climate change on watercourses and waterbodies in the Project study area.

Specific predictions regarding changes in water temperature and thermal regime effects on fish and fish habitat due to climate change were not completed as there are no predicted affects of the Project on thermal regime in any watercourse or waterbody and, therefore, no predicted cumulative effects resulting from climate change.

7.3 LITERATURE REVIEW

Annual surface temperatures have generally increased during the 20th century (as described in Section 3). This increase in global average surface temperatures has said to have been accompanied by retreat of glaciers and a reduction in the duration of lake and river ice cover by two weeks in the middle and high latitudes of the northern hemisphere (Shuter et al. 2002). It is predicted that global surface temperatures will continue to increase with the most pronounced effects occurring at high latitudes and during the winter. Greater variation in precipitation and increased frequency of droughts and floods are also predicted (Shuter et al. 2002).

Human-induced climate change scenarios for northern Canada include further temperature increases (Reist 1994). Climate changes are expected to be accompanied by more extreme variation in precipitation as well as continued reductions in periods of ice cover for lakes and rivers. Climate changes are expected to have both indirect and direct physical effects on aquatic environments in northern parts of Canada (Von Finster 2001). Many of these physical changes are interrelated but for practical purposes can be placed into five categories:

- changes to water budget;
- changes to aquatic thermal regimes;

- changes to water quality;
- reduced system stability; and
- changes to aquatic connectivity.

With consideration of the Project area, potential linkages of climate change to physical changes to aquatic systems within each of these five categories include the following:

1) Changes to Water Budget

- changes to total inflow of surface waters;
- increased evaporation from the surface of lakes and rivers;
- reduced outflow from lakes; therefore, reduced flows to outlet streams and rivers, resulting in the dewatering of stream channels downstream of the outlets;
- reduced recharge of aquifers located upslope of the lakes;
- modifications to river flow;
- modifications to water level and volume of lakes;
- modifications to size and location of marginal habitats such as the littoral zones, wetlands and stream banks; and
- changes to residence time of water in lakes.

2) Changes to Aquatic Thermal Regimes

- warmer average water temperatures;
- earlier onset of stratification in lakes;
- changes in evaporation;
- warmer and deeper hypolimnion in lakes;
- warmer groundwater source;
- shorter winters and longer summers; and
- reduced ice cover and earlier ice-off.

3) Changes to Water Quality

- changes to oxygen availability (e.g., reduced oxygen under increasing water temperature);
- changes to the availability of nutrients due to changes in lake residence times and inflow;
- altered density of groundwater discharges; and
- changes to turbidity as a result of lower sedimentation which can lead to greater light penetration and thus productivity.

4) Reduced System Stability

- more frequent flooding events;
- more frequent drought events;
- increased deposition of organic or inorganic sediments into streams; and
- fluctuating water levels.

5) Changes to Aquatic Connectivity

- reduced connectivity between waterbodies due to the transition of permanent streams to ephemeral waterbodies; and
- decreased connectivity of waterbodies under reduced surface and groundwater conditions (fragmentation).

Changes to the aquatic ecosystem as a result of the climate change relationships described above can potentially result in changes to growth, recruitment and abundance of fish populations, changes to fisheries yields, changes to geographical distribution of fish species, changes to fish health and changes to species diversity and community composition.

7.4 ANALYSIS

This section provides an assessment of the possible cumulative effects of climate change on the specific predictions for the Project related to fish and fish habitat that are sensitive to the possible relationships provided above. These relationships include potential effects on fish habitat, fish abundance, fish health and fish and fish habitat diversity.

There were no residual impacts predicted in the Fish and Fish Habitat assessment for the Project for changes in fish health, fish abundance and fish and fish habitat diversity. The linkage analysis for effects on fish habitat was considered to be valid through the pathway of change in stream flows and fish habitat for the Jackfish River at the outlet of Christina Lake and for direct changes to habitat, increased sediment deposition and changes in benthic invertebrate communities associated with construction of watercourse crossings. The direction of the impact for Jackfish River was considered to be neutral and negligible in magnitude. For watercourse crossings, the direction of the effect was considered to be negative and negligible in magnitude.

Therefore, there was no environmental consequence of the Project on fish habitat, fish health or fish abundance. As potential effects were considered to result in no or negligible residual impacts, the cumulative effects of climate change would not be expected to change the overall effects assessment and classification for the Project

As discussed in the hydrology component (Section 5), Project effects (i.e., on stream discharge, water levels and channel morphology) were considered to be negligible and short-term, and mitigated as appropriate; the potential longer-term effects (i.e., beyond the operational life of the Project) of climate change are not likely to be influenced by the Project.

Climate change is also not expected to measurably affect the predicted effects of the Project on water quality (Section 6). Based on the mitigation measures and management practices to be employed, effects on surface water quality were predicted to be negligible.

As described above, any additional changes to stream discharge, water levels, channel morphology and water quality due to the effects of climate change were predicted to be negligible; thus, predicted changes to fish habitat, fish abundance, fish health, or fish and fish habitat diversity for the Project due to climate change were also considered to be negligible over the operational life of the Project.

7.5 SUMMARY

Predicted changes to fish habitat, fish abundance, fish health, and fish and fish habitat diversity for the Project under climate change scenarios evaluated in this assessment would remain unchanged from the Fish and Fish Habitat assessment.

8 EFFECT OF CLIMATE CHANGE ON TERRESTRIAL RESOURCES PREDICTIONS

8.1 INTRODUCTION

The evaluation of the potential effects of climate change on terrestrial resources predictions considers the potential effects that climate change may have on vegetation, soils and wildlife (Table 43).

Soil is a part of the natural world that is both affected by and contributes to global warming. Research indicates that climate change threatens to significantly affect soil in a variety of ways. This is discussed further in Section 8.3.2.

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

Table 43 Primary Links Between Climate Change and Terrestrial Resources

Attribute	Precipitation	Temperature
Soil and Terrain	• Increased precipitation would lead to increased leaching of soil nutrients in some soils, especially if temperature is increasing decomposition. • Increased precipitation could lead to short-term positive increases in gross nitrogen (N) mineralization and hence nutrient availability. • Increased precipitation is predicted to cause sustained high mineralization and nitrification rates. Changes to soil biogeochemistry resulting in increases in N mineralization levels could result in short-term increases in vegetation productivity.	• Increased winter air temperatures could affect snowpack depth which affects soil temperature and both the start and length of the growing season. Furthermore, a reduced snowpack would reduce soil moisture which in combination with higher summer temperatures, may lead to an increase in summer soil moisture stress for vegetation. • Changes in air temperature are expected to result in chemical, hydrological and biological changes in the soil environment. For example: changes to the structure (e.g., horizon development), productivity, nutrient status, quality, litter composition and decay, and nutrient cycling.

Table 43 Primary Links Between Climate Change and Terrestrial Resources (continued)

Attribute	Precipitation	Temperature
Vegetation	• With increased temperatures, as areas become drier, fire return intervals are expected to become shorter and fire intensities are expected to increase. • Changes in precipitation have the potential to effect vegetation through changes in soil properties.	• Warm and dry summer conditions increase respiration rates, reduce photosynthate production, reduce leaf area, and reduce energy reserves. • Warm summer temperatures lengthen the growing season by accelerating snowmelt. • Changes in the climate could lead to changes in the development pattern of species, affecting inter-specific and dependant relationships within natural communities. • Spatial distribution and species composition of the boreal forests are expected to change with the anticipated change in climate. • Climate change will not cause species mortality but will alter competitive interaction among plants. Increased temperature could result in migration of species to traditionally cooler areas.
Wildlife	• Impacts on wildlife are difficult to predict. The lack of long-term data, complexity of life cycles, and incomplete information on wildlife responses to previous environmental changes impede research. • Reductions in precipitation could lower water levels during fall and winter, which could reduce the probability of spring flooding in wetlands and deltas, affecting wildlife species that utilize these habitats. • Increased evaporation is expected to offset increased precipitation and reduce river flows, causing fish stocks to decline. Studies imply that low flows also reduce oxygen levels during winter months, with detrimental effects on aquatic life.	• Wildlife species with a body size of more than 1kg will be most affected by shifts in landscape structure associated with the rapid forest cover changes from wildfires. • Changing fire patterns will likely affect the distribution of caribou.

8.2 APPROACH

An evaluation of the historic changes in temperature and precipitation as well as the predicted changes in the future was completed for the Project. The possible changes in temperature and precipitation were then considered in the evaluation of effects to soils and vegetation for the success of what will be a reclaimed landscape for the Project. However, given the complex nature of soils and vegetation responses to changes in climate, it is not possible to accurately assess how Project effects are affected by predicted climatic changes. Thus, specific information concerning project effects on soils and vegetation in relation to climate change are not described. Instead, a general assessment of possible vegetation and soils responses is presented from a review of the literature, from which general conclusions can be drawn.

8.3 ANALYSIS

8.3.1 Potential Future Changes

The reclaimed landscape for the Project will be planted with typical boreal forest vegetation communities. These vegetation communities are found at various latitudes and elevations throughout the boreal forest and are exposed to a range of climatic conditions. To determine a range of temperatures in the boreal forest, temperature data from Athabasca, Alberta was chosen to reflect the warmer extent of temperatures and Yellowknife, NWT was chosen to represent the cooler extent of temperatures. An analysis of temperature data from Athabasca to Yellowknife was performed to evaluate whether predicted future temperatures in the Cold Lake area will be within the range of temperatures currently experienced in the boreal forest region. Climate normal data is taken from the Canadian Climate Normals 1971 to 2000 (Environment Canada 2007a, Website).

Average annual temperatures in the boreal forest range from 2.1°C (Athabasca) to –4.6°C (Yellowknife) (Environment Canada 2007a, Website). The average annual temperature in Cold Lake is 1.7°C. The predicted future climate trends indicate that the average annual temperature is expected to rise between +0.4 and +1.3°C in the Cold Lake area over the life of the Project (Table 21 and Table 22). Based on these predicted trends, annual average temperatures in the Cold Lake may potentially fall outside of the range of average annual temperatures currently experienced in the boreal forest. Consequently, an increase in average annual temperature could result in changes in the spatial distribution and composition of plant species in the Cold Lake region reflective of a warmer climate.

The minimum monthly temperatures observed in Athabasca and Yellowknife are –19.9 and –30.9°C, respectively (Environment Canada 2007a, Website). The minimum monthly temperature in Cold Lake is –21.7°C, with future climate trends predicting between a +1.0 to +1.2°C increase in minimum monthly temperatures over the life of the Project (Table 21 and Table 23). This predicted trend indicates that minimum monthly temperatures in the Cold Lake area will be within the temperature range already being experienced in the boreal forest region.

The maximum monthly temperatures observed in Athabasca and Yellowknife are 22.2 and 21.1°C, respectively (Environment Canada 2007a, Website). The maximum monthly temperature in Cold Lake (22.9°C) is currently warmer than the maximums observed in the boreal forest. This suggests that maximum monthly temperatures in the boreal forest are more localized phenomena. The future climate trends for maximum monthly temperatures in Cold Lake are predicted to increase between +0.4 and +0.7°C over the life of the Project. Although the future monthly maximum temperature for Cold Lake is predicted to be higher than other boreal forest regions in Alberta or the NWT, it is still within the temperature range experienced by other boreal forest regions in Canada. For example, the monthly maximum temperature at Bissett, Manitoba is 24.9°C.

Tables 21 to 29 model climatic variables applicable to vegetation growth and the predicted future normals to 2039. Upper summer temperature, and upper and lower precipitation account for the growing season and moisture availability required for vegetation development. An average summer temperature between 16.3 and 16.6°C is predicted for the Cold Lake region. Average winter temperatures are expected to range between –14.5 and –13.2°C. Annual rainfall is predicted to vary from 416.5 to 444.3 mm per year.

Table 44 lists the climate ranges for all tree species found in the Project Regional Study Area (RSA). As a major component of boreal vegetation communities, tree species show the range of climate variation for which boreal species are adapted. The forecasted Cold Lake normals for between 2010 and 2039 are well within these species ranges of tolerances (Section 2.4).

Table 44 Boreal Tree Species Ranges of Climatic Tolerance

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

n/d = No data.

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

8.3.2 Soil Responses to Climate Change

The primary result of increased air temperatures are subsequent increases in soil temperatures (Golder 2005; Gundersen et al. 2006; Nakawatase and Peterson 2006). Increased winter air temperatures could also affect snowpack depth (Nakawatase and Peterson 2006). Snowpack depth affects soil temperature and both the start and length of the growing season (Körner 1995). Furthermore, a reduced snowpack would reduce soil moisture (Nakawatase and Peterson 2006), which in combination with higher summer temperatures, may lead to an increase in summer soil moisture stress for vegetation.

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

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

Greenhouse gases increase levels of carbon dioxide (CO_2) and nitrogen (N) deposition to the soils. While both may act as a fertilizer, N deposition is also speculated to acidify soils and reduce tree growth in some circumstances (Loehle 2003). Soil is one of the largest sources of carbon in the world (Soil-Net 2006, Website). It is primarily accumulated through plants which “fix” the carbon from CO_2; the soil then directly absorbs the carbon as the plants decay. Gundersen et al. (2006) found that increased atmospheric CO_2 initially results in increased storage of carbon in the upper soil layers and biomass. However, carbon is naturally broken down in the soil and released to the atmosphere as CO_2 gas. As the air temperature increases, decomposition occurs more rapidly, which may potentially contribute to global warming (Jamieson et al. 1999; Zhou et al. 2005). Complex interactions exist among variables such as temperature, moisture, decomposition and nutrient cycling. Thus, medium to long-term effects of climate change to soil biogeochemistry have been more difficult to predict (Jamieson et al. 1999).

8.3.3 Vegetation Responses to Climate Change

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

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

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

Spatial distribution and species composition of the boreal forests are expected to change with the anticipated change in climate (Jamieson et al. 1999; Loehle 2003; Zhou et al. 2005). Biogeographic models predict widespread species migration (i.e., southern communities migrating northward) (Nakawatase and Peterson 2006). Some research predicts that many important species, particularly northern pines (*Pinus* spp.) and spruces (*Picea* spp.) may be extirpated from some areas because of climate change (Walker et al. 2002; Scheller and

Mladenoff 2005). The previous discussion indicated the forecasted climate normals for the Cold Lake region are within the climatic ranges of tolerance for boreal tree species (Table 39).

Loehle (2003) states that the rate at which a forest can be invaded, even by a much superior competitor, is limited by the rate at which openings become available (i.e., by disturbance). Climate change will not cause species mortality but will alter competitive interaction among plants. Species mortality would open up forest canopy leaving an ecosystem vulnerable to invasion from weeds. As this is not predicted to be the case, climate change should not increase weed invasion in intact forest. Intact forests are resistant to invasion and their response to moderate climate change should be slow with a prolonged transition on the order of 500 to 3,000 years. It will take forests hundreds to thousands of years for the population to come to a new equilibrium. Reclaimed ecosystems may be less resistant to invasion than established ecosystems (Loehle 2003).

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

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

8.3.4 Wildlife Responses to Climate Change

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

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

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

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

Another concern is the affect of increasing wildfires to wildlife migration (Cohen 1997b). It has been largely recognized that the new climate scenario may result in increased fire frequency and an increase in the area to potentially be burned (Rothman and Herbert 1997 in Cohen 1997; Weber and Flannigan 1997; Li et. al. 2000; Natural Resources Canada 2007b, Website). Wildlife species with a body size of more than 1kg will be most affected by shifts in landscape structure associated with the rapid forest cover changes from wildfires (Thompson et al. 1997 in Weber and Flannigan 1997). An example is the impacts of wildfire to caribou habitat; the distribution and abundance of terrestrial lichens are reduced and will not recover for decades following a fire (Boutin et. al. 2006). Thus, changing fire patterns will likely affect the distribution of caribou.

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

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

8.4 SUMMARY

Climate change may have significant effects on both soils, vegetation and wildlife. Soil conditions may be altered through increases in summer moisture stress, short-term increases in productivity and potential increases to decomposition rates. However, the medium to long-term effects to soil conditions are difficult to predict. In terms of vegetation, the predicted responses to climate change can include persistence, migration or extinction of specific species or groups of species. Regardless of which response vegetation has to climate change, it is important to note that each species will adapt based on their most limiting factors, thus entire communities may not respond in the same way, or at all, to changes in climate. Wildlife species will all react differently to climate change, responses and adaptation will accomplished through evolution, acclimatization, and most likely, migration to suitable sites.

In light of the range of potential effects climate change can have on soils, vegetation and wildlife, it is not possible to accurately predict the degree to which climate change may affect the conclusions provided in the EIA. Nonetheless, there are some general conclusions that can be derived given our understanding of general soil, vegetation and wildlife responses to climate change.

Vegetation and wetlands resources, which includes wildlife habitat of the Project will be affected primarily through surface disturbances associated with construction of the Project. Changes to the Project area vegetation due to climate change are not likely to occur during the operational and closure phases of the Project. In the longer term, a possible effect may occur if invasive species in open (i.e., disturbed) areas, supported by changed climatic conditions, alter post-development landscapes. Additionally, for boreal tree species in the Project region, the forecasted temperature normals to 2039 are within the range of tolerance for these species. Thus, shifts in the abundance or distribution of boreal trees species in the Project area are not likely to occur, at least over the short to mid-term period. No changes are expected in EIA predictions with regards to vegetation and wetlands resources.

9 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

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