

## **11 CLIMATE CHANGE**

### **11.1 Introduction**

#### **11.1.1 Background**

Information collected over many years at northern climate stations, suggests that the climate in the Mackenzie Delta and the Mackenzie Valley region might be changing. Communities and other stakeholders are concerned about the potential effects of climate change on the northern environment and the economy. This section considers:

- potential climate change in the local and regional study areas over the life of the project
- potential changes to the assessment because of predictions about climate change

The potential effects of the environment on the project, e.g., construction practices and design criteria, are discussed in Section 14, Environmental Effects on the Project.

#### **11.1.2 Summary of Findings**

The relationship between climate change and the Mackenzie Gas Project (the project) has been reviewed in reference to the potential effects of climate change on baseline conditions and on the results of the assessment. The conclusion is that although some uncertainty exists, and climate change could affect the northern environment, over time, it is unlikely that the effects of climate change over the life of the project will change baseline conditions to such an extent that the assessment of the potential effects of the project will change.



## 11.2 Potential Climate Change

This section provides an overview of changes in the climate of the Northwest Territories over time and compares them with potential future climate changes. The information is summarized by region.

### 11.2.1 Climate Change Trends

Current climatic conditions and past climate trends for each region were derived from temperature and precipitation data collected between 1951 and 2000 for each of the stations identified in Table 11-1.

**Table 11-1: Climate Stations used for Temperature and Precipitation Analysis**

| Station Name  | Region <sup>1</sup>                                    | Latitude  | Longitude  | Elevation (m) |
|---|--|-----------|------------|---------------|
| Sachs Harbour   | Inuvialuit Settlement Region                           | 72° 0' N  | 125° 16' W | 87            |
| Cape Parry  | Inuvialuit Settlement Region                           | 70° 10' N | 124° 41' W | 17            |
| Komakuk Beach   | Inuvialuit Settlement Region                           | 69° 35' N | 140° 11' W | 14            |
| Tuktoyaktuk   | Inuvialuit Settlement Region                           | 69° 27' N | 133° 0' W  | 18            |
| Shingle Point   | Inuvialuit Settlement Region                           | 68° 57' N | 137° 13' W | 55            |
| Inuvik  | Inuvialuit Settlement Region, Gwich'in Settlement Area | 68° 18' N | 133° 29' W | 59            |
| Aklavik   | Gwich'in Settlement Area                               | 68° 13' N | 135° 0' W  | 11            |
| Fort McPherson  | Gwich'in Settlement Area                               | 67° 26' N | 134° 53' W | 30            |
| Fort Good Hope  | Sahtu Settlement Area                                  | 66° 16' N | 128° 37' W | 52            |
| Norman Wells  | Sahtu Settlement Area                                  | 65° 17' N | 126° 48' W | 67            |
| Wrigley   | Deh Cho Region   | 63° 13' N | 123° 26' W | 150           |
| Fort Simpson  | Deh Cho Region   | 61° 45' N | 121° 14' W | 168           |
| Hay River   | Deh Cho Region   | 60° 50' N | 115° 47' W | 164           |
| Fort Liard  | Deh Cho Region   | 60° 14' N | 123° 28' W | 215           |
| Fort Nelson, British Columbia   | Northwestern Alberta                                   | 58° 50' N | 122° 35' W | 382           |
| High Level, Alberta   | Northwestern Alberta                                   | 58° 37' N | 117° 10' W | 338           |
| NOTE:   |  |           |            |               |
| 1 Identifies stations used to characterize current and past climatic conditions for each region |  |           |            |               |

The current meteorological conditions are based on the averages for the five-year period from 1996 to 2000. A five-year average was selected because that average is consistent with guidelines for the use of weather data in air assessments and because it provides a reliable representation of the current conditions. A full 50 years of available data was used to determine the climate trends for the 30 years from 1971 to 2000.

### 11.2.1.1 Methods

#### Climate Parameters

Changes in climate can be characterized by changes in:

- temperature (e.g., average, maximum and minimum)
- precipitation
- extreme events (e.g., peak precipitation rates)

This assessment focuses on changes in average temperature and precipitation. Because future climate trends are based on climate model estimates that focus on likely average climate outcomes over large areas, they are not suitable for predicting extreme events, which occur on a more local scale.

#### Global Climate Models

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was formed by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to review international climate change data. Improvements in global climate models arose from concerns over future climate trends and the impact of human activities on climate, which could affect natural ecosystems and the economy.

Modelling climate is a complex process that involves the mathematical representation of global land, sea and atmosphere interactions over a long period. There is substantial uncertainty in climate change predictions. The results of global climate models are subject to many uncertainties and interpretations. This assessment uses various scenarios to partially address this concern.

#### Northern Climate Change Scenarios

Scenarios were developed based on the results of a multistakeholder workshop sponsored by Indian and Northern Affairs Canada (INAC). The purpose of the workshop was to develop a process to select appropriate climate change scenarios that could be used to evaluate the potential effects of climate change in the project study area. The workshop was attended by technical specialists representing Environment Canada, INAC, representatives of nongovernment organizations and a representative of the project proponents. The results of this workshop are presented in Burn (2003) and were used as the basis for this assessment.

Less confidence is generally placed in precipitation predictions than in temperature predictions from the global climate models. Precipitation can change quite rapidly from one location to another and the current resolution of global climate models cannot account for this variation. It is also not possible to interpret seasonal increases in precipitation or whether the precipitation will occur as rain

or snow. Temperatures do not change as rapidly from one location to another and are better resolved by current global climate models. Temperature trend forecasts during the life of the project are typically in the range of values observed over the last 30 years. However, predicted future precipitation changes are highly variable in both magnitude and direction and from one location to another.

Twenty-nine simulations were done using global climate models approved by the IPCC:

- CSIRO2B (Australia)
- HADCM3 (Britain)
- CGCM2 (Canada)
- ECHAM4 (Germany)
- CCSR98 (Japan)
- NCARPCM (U.S.)
- GFDLR30 (U.S.)

Emission scenarios from the Special Report on Emissions Scenarios (SRES) were used in the models (IPCC 2000).

Given the wide range of possible inputs to global climate models, the IPCC has established a series of socio-economic scenarios that help define the future levels of global greenhouse gas emissions. The Third Assessment Report (IPCC 2001) identifies four general scenarios, A1, B1, A2 and B2. The A1 and A2 scenarios represent a focus on global economic growth, whereas B1 and B2 represent a shift toward more environmentally conscious solutions to growth. Both Scenario A1 and Scenario B1 include a shift toward global solutions whereas Scenario A2 and Scenario B2 include growth based on regional models. These four socio-economic scenarios are described in detail in the IPCC report (IPCC 2001).

The IPCC does not endorse any of these scenarios as being the most likely, because the future is unpredictable and views differ on which scenario is more likely to occur. Seasonal and annual trends were analyzed for the northern and southern parts of the Mackenzie Valley. Depending on the model, the Mackenzie Valley is covered by three or four model grid cells. The potential change in climate for each grid cell was based on the weighted average of the cell and the eight cells surrounding it. The northern grid cell results showed a distinct difference in climate change from the southern grid cell results for most of the model simulations. The Mackenzie Valley was divided into northern and southern regions based on these results with the boundary located at the latitude of Fort Good Hope.

For this assessment, the Inuvialuit Settlement Region, the Gwich'in Settlement Area and the Sahtu Settlement Area are included in the northern part of the Mackenzie Valley, and the Deh Cho Region and northwestern Alberta in the southern part.

### 11.2.1.2 Summary of Effects by Region

Climate change information is discussed here by settlement region or area. Climate change information is not sufficiently detailed to be applied at the locations of individual project components.

Figure 11-1 shows average annual temperature and Figure 11-2 shows winter temperature trends. Figure 11-3 shows total precipitation and precipitation trends for all assessed regions.

Natural variability, expressed as averages over the last 30 years, shows variations in average annual temperatures of 3 to 6°C. Depending on the climate model scenario used, these exceed by two to three times the average annual temperature increases obtained from the model. Nonetheless, based on observed trends and on future modelled predictions, there is a consistent and gradual warming trend. Generally, model results indicate a warming trend in air temperature of up to 2.5°C and an increase in precipitation of up to 11.8% in the 30 years between 2010 and 2039. Results are provided in detail for each settlement region or area.

### 11.2.1.3 Inuvialuit Settlement Region

Table 11-2 summarizes the current climatic conditions as well as past and future climate trends in the Inuvialuit Settlement Region. Expected future temperature changes will be comparable to the changes that have occurred over the last 30 years. For example, the future change in average temperature is between +1.3°C and +2.5°C. These values are similar to the +1.5°C increase observed between 1971 and 2000. The current average annual temperature is -10.3°C and the annual average winter temperature is -26.5°C.

**Table 11-2: Climate Conditions and Change in the Inuvialuit Settlement Region**

| Parameter                                    | Current <sup>1</sup> Conditions | Trend<br>(1971 to 2000) | Forecast Trend <sup>2</sup><br>(2010 to 2039) |        |        |
|--|---------------------------------|-------------------------|---|--------|--------|
|  |                                 |                         | Low   | Medium | High   |
| Average annual temperature (°C)              | -10.3                           | +1.5                    | +1.3  | +1.6   | +2.5   |
| Average winter temperature <sup>3</sup> (°C) | -26.5                           | +2.1                    | +1.3  | +2.1   | +2.2   |
| Total precipitation <sup>4,5</sup> (mm)      | 191.0                           | +5.2                    | +2.1%   | +7.4%  | +11.8% |

NOTES:  
 1 Current conditions are based on 1996 to 2000 observations  
 2 Trend estimate ranges from Burn (2003)  
 3 Winter temperatures are based on December, January and February  
 4 Total precipitation is presented as millimetres of equivalent rainfall  
 5 Future trends are presented as percentage change from the 1961 to 1990 climate normals

The future trend in total precipitation in this region ranges from 2.1 to 11.8% above the 1961 to 1990 climate normals. Total precipitation in the Inuvialuit Settlement Region has increased by 5.2 mm during the past 30 years. Current annual total precipitation is 191 mm.

**Figure 11.1 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.**

**Figure 11.2 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.**

**Figure 11.3 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.**

### 11.2.1.4 Gwich'in Settlement Area

Table 11-3 summarizes the current climatic conditions as well as past and future climate trends in the Gwich'in Settlement Area. The climate forecasts indicate that the average annual temperature is predicted to rise by +1.3 to +2.5°C, compared with an observed increase of +2°C between 1961 and 2000. Winter temperatures are forecast to increase by +1.3 to +2.2°C, compared with an increase of +3.1°C between 1971 and 2000.

**Table 11-3: Climate Conditions and Change in the Gwich'in Settlement Area**

| Parameter  | Current <sup>1</sup> Conditions | Trend<br>(1971 to 2000) | Forecast Trend <sup>2</sup><br>(2010 to 2039) |        |        |
|--|---------------------------------|-------------------------|---|--------|--------|
|  |                                 |                         | Low   | Medium | High   |
| Average annual temperature (°C)  | -7.6                            | +2.0                    | +1.3  | +1.6   | +2.5   |
| Average winter temperature <sup>3</sup> (°C)   | -25.8                           | +3.1                    | +1.3  | +2.1   | +2.2   |
| Total precipitation <sup>4,5</sup> (mm)  | 347.5                           | +1.5                    | +2.1%   | +7.4%  | +11.8% |
| NOTES:<br>1 Current conditions are based on 1996 to 2000 observations<br>2 Trend estimate ranges from Burn (2003)<br>3 Winter temperatures are based on December, January and February<br>4 Total precipitation is presented as millimetres of equivalent rainfall<br>5 Future trends are presented as percentage change from the 1961 to 1990 climate normals |                                 |                         |   |        |        |

The future trend in total precipitation in this region ranges from 2.1 to 11.8% above the 1961 to 1990 climate normals. Total precipitation in the Gwich'in Settlement Area has increased by 1.5 mm during the past 30 years. Current annual precipitation is 347.5 mm.

### 11.2.1.5 Sahtu Settlement Area

Table 11-4 summarizes the current climatic conditions as well as past and future climate change trends in the Sahtu Settlement Area. As in the Inuvialuit Settlement Region, there is reasonable agreement between the observed trends in temperatures and the future temperature forecasts. The past trend of +1.3°C is similar to the forecast trend of +1.3 to +2.5°C.

Total precipitation in the Sahtu Settlement Area decreased by 49 mm between 1971 and 2000. Current annual precipitation is 210.3 mm.

### 11.2.1.6 Deh Cho Region

Table 11-5 summarizes the current climatic conditions as well as past and future climate change trends in the Deh Cho Region. The future trends in average temperature ranges from +1 to +2.1°C, which is similar to the +1.7°C observed between 1971 and 2000. The forecast increases in winter temperatures of +1 to +2.2°C are lower than the past trend of +4.4°C.

**Table 11-4: Climate Conditions and Change in the Sahtu Settlement Area**

| Parameter                                    | Current <sup>1</sup> Conditions | Trend<br>(1971 to 2000) | Forecast Trend <sup>2</sup><br>(2010 to 2039) |        |        |
|--|---------------------------------|-------------------------|---|--------|--------|
|  |                                 |                         | Low   | Medium | High   |
| Average annual temperature (°C)              | -5.6                            | +1.3                    | +1.3  | +1.6   | +2.5   |
| Average winter temperature <sup>3</sup> (°C) | -25.5                           | +3.6                    | +1.3  | +2.1   | +2.2   |
| Total precipitation <sup>4,5</sup> (mm)      | 210.3                           | -49.0                   | +2.1%   | +7.4%  | +11.8% |

NOTES:  
 1 Current conditions are based on 1996 to 2000 observations  
 2 Trend estimate ranges from Burn (2003)  
 3 Winter temperatures are based on December, January and February  
 4 Total precipitation is presented as millimetres of equivalent rainfall  
 5 Future trends are presented as percentage change from the 1961 to 1990 climate normals

**Table 11-5: Climate Conditions and Change in the Deh Cho Region**

| Parameter                                    | Current <sup>1</sup> Conditions | Trend<br>(1971 to 2000) | Forecast Trend <sup>2</sup><br>(2010 to 2039) |        |       |
|--|---------------------------------|-------------------------|---|--------|-------|
|  |                                 |                         | Low   | Medium | High  |
| Average annual temperature (°C)              | -2.1                            | +1.7                    | +1.0  | +1.3   | +2.1  |
| Average winter temperature <sup>3</sup> (°C) | -20.9                           | +4.4                    | +1.0  | +1.0   | +2.2  |
| Total precipitation <sup>4,5</sup> (mm)      | 390.8                           | +5.1                    | +0.9%   | +6.2%  | +9.6% |

NOTES:  
 1 Current conditions are based on 1996 to 2000 observations  
 2 Trend estimate ranges from Burn (2003)  
 3 Winter temperatures are based on December, January and February  
 4 Total precipitation is presented as millimetres of equivalent rainfall  
 5 Future trends are presented as percentage change from the 1961 to 1990 climate normals

The future trend in total precipitation in this region ranges from 0.9 to 9.6% above the 1961 to 1990 climate normals. Total precipitation in the Deh Cho Region has increased by 5.1 mm during the past 30 years. Current annual total precipitation is 390.8 mm.

### 11.2.1.7 Northwestern Alberta

Table 11-6 summarizes the current climatic conditions as well as past and future climate change trends in northwestern Alberta. Future trends in average temperature ranged from +1 to +2.1°C, spanning the +1.1°C observed in the past. The increase in winter temperature of +2.8°C between 1971 and 2000 is higher than the forecast change of +1 to +2.2°C.

The future trend in total precipitation in this region ranges from 0.9 to 9.6% above the 1961 to 1990 climate normals. Total precipitation in northwestern Alberta has increased by 9.2 mm during the past 30 years. Current annual total precipitation is 317.6 mm.

Table 11-6: Climate Conditions and Change in Northwestern Alberta

| Parameter  | Current <sup>1</sup> Conditions | Trend<br>(1971 to 2000) | Forecast Trend <sup>2</sup><br>(2010 to 2039) |        |       |
|--|---------------------------------|-------------------------|---|--------|-------|
|  |                                 |                         | Low   | Medium | High  |
| Average annual temperature (°C)  | -0.6                            | +1.1                    | +1.0  | +1.3   | +2.1  |
| Average winter temperature <sup>3</sup> (°C)   | -19.2                           | +2.8                    | +1.0  | +1.0   | +2.2  |
| Total precipitation <sup>4,5</sup> (mm)  | 317.6                           | +9.2                    | +0.9%   | +6.2%  | +9.6% |
| NOTES:<br>1 Current conditions are based on 1996 to 2000 observations<br>2 Trend estimate ranges from Burn (2003)<br>3 Winter temperatures are based on December, January and February<br>4 Total precipitation is presented as millimetres of equivalent rainfall<br>5 Future trends are presented as percentage change from the 1961 to 1990 climate normals |                                 |                         |   |        |       |

### 11.3 Potential Effects on Baseline Conditions

This section evaluates any effects the predicted climate changes might have on the biophysical resources and the predicted project effects.

These evaluations are difficult, and therefore have some uncertainty, for the following reasons:

- natural systems are complex, and effects of climate on them are not fully understood
- the difference between natural variability and trends within a range can be difficult to discern
- environmental responses to a trend might not become apparent for a long time
- natural systems might be buffered or might adapt to change

Because of the relatively brief period involved during project construction; i.e., a few years, the results of this evaluation apply to the much longer period of project operations and possibly beyond.

#### 11.3.1 Aquatic Ecosystems

##### 11.3.1.1 Groundwater

Groundwater patterns could change over the life of the project in response to climate change. It is unlikely that any of the changes associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment. There are no potential effects on groundwater that would be magnified by the effects of such a climate change during the life of the project.

The potential effects of climate change on groundwater would most likely affect permafrost distribution. The hydrogeological effects might not be as pronounced in the southern section of the pipeline, where the right-of-way runs through sporadic discontinuous permafrost, or in sections of the pipeline where groundwater flow is strongly influenced by the presence of karst topography. Possible effects of permafrost degradation caused by climate change and the related change in the groundwater regime over the pipeline route are:

- a decrease in land area underlain by permafrost, causing a general northward shifting of the boundaries between continuous permafrost and the various categories of discontinuous permafrost
- thicker active layer

- increase in areal extent and depth of taliks beneath surface waterbodies
- surface waterbodies remaining free of ice for longer periods
- reduced number and volume of icings caused by perennial springs in streambeds
- drop in water table because of increased groundwater movement in a thicker and more persistent active zone
- reduced ice buildup around springs

In summary, the effects of climate warming will reduce the extent of permafrost, which will in turn affect groundwater. A reduction in the extent of permafrost in a region will bring about groundwater distribution and flow similar to those observed in nonpermafrost areas. In areas where karst topography acts as a strong controlling factor, climate change will have less of an effect on groundwater distribution. Where permafrost is sporadic or nonexistent, changes in groundwater flow are subject to changes in precipitation patterns, but climate warming will not in itself be a strong determinant of change in the groundwater regime.

Climate change is unlikely to affect any of the potential environmental effects of the project on groundwater during the life of the project.

#### 11.3.1.2 Hydrology

Hydrological patterns could change over the life of the project in response to climate change. It is unlikely that any of the changes associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment. There are no potential effects on hydrology that would be magnified by the effects of such a climate change during the life of the project.

Climate change has the potential to change:

- baseline hydrological regimes
- hydraulic characteristics of channels and distributaries in the Mackenzie Delta
- sea levels in the Beaufort Sea
- river and coastal ice processes in the project area

These changes could affect permafrost regimes, landform characteristics and channel morphology.

An increase in precipitation could cause an increase in mean annual runoff at a regional scale. However, the increase in mean annual runoff will likely be less than the predicted increase caused by an 11.8% maximum increase in precipitation. Annual runoff amount varies from year to year (Woo and

Thorne 2003). The standard deviation of a series of annual runoff amounts can be about 30% of the mean annual runoff, so the expected increase in mean annual runoff caused by predicted climate changes would be relatively small compared with the annual variability in annual runoff.

Other factors that affect the change in mean annual runoff, both regionally and locally, include:

- increased lake evaporation caused by higher mean annual temperatures
- changes in regional vegetation types, densities and growth rates caused by higher mean annual temperatures that increase evapotranspiration rates
- differences in predicted increases in mean annual temperature and precipitation across the Mackenzie River watershed
- increased infiltration of runoff into nonpermafrost areas enlarged by higher air and soil temperatures

Current model simulations of the various climate change scenarios cannot predict changes in rainstorm intensity, duration or frequency. It has been hypothesized in the literature that storm intensity increases with increasing temperature. However, this hypothesis cannot be validated with current models.

Climate change simulations predict an increase in temperature of about 2.5°C at ground level. The increases at higher elevations are unknown. It is expected that an increase in mean winter temperature will increase the timing and rate of snowmelt. The timing of ice breakup might also occur earlier in the season.

Climate change might affect baseline water levels in the outer delta by changing the runoff regime with increased meltwater and by raising sea levels with melting sea ice and expanding warmer waters.

Rainfall intensity is an important factor in estimating sediment yield from watersheds, whereas flow velocity affects erosion rates of streambeds and banks. A relatively small increase in rainfall intensity or flow velocity would not affect the baseline sediment yield of watersheds or the baseline sediment regime in streams enough to change the results of this assessment.

Changes in outer delta channel flow depths and velocities caused by climate change effects, such as sea level rise and higher runoff, could change the baseline delta channel morphologic characteristics. Higher temperatures might also melt some of the permafrost and increase the thickness of the active zone. This could have an effect on channel morphology, although the delta morphology is already dynamic under baseline conditions.

The changes in baseline flow depths and velocities are not expected to affect the conclusions of the project's impact assessment, and climate change is unlikely to affect any of the potential environmental effects of the project on hydrology.

### 11.3.1.3 Water Quality

Water quality could change over the life of the project in response to climate change. However, it is unlikely that any of the changes associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment. There are no potential effects on water quality that would be magnified by the effects of climate change during the life of the project.

Climate change could affect surface water quality through changes in hydrology, water temperature and vegetation. Climate change could affect surface water quality through changes in hydrology, water temperature and vegetation (Murdoch et al. 2000, Rouse et al. 1997, Schindler 2001). For example, altered runoff amounts and associated sediment inputs might alter nutrient levels in rivers and lakes. Also, higher water temperature might affect biological characteristics of lakes, such as phytoplankton dynamics, which might affect water quality.

Although there is uncertainty, changes in water quality because of climate change are unlikely to affect water quality during the life of the project. Flooding and storm surges during the spring have the potential to affect baseline surface water quality. Magnitude cannot be predicted, but effects might include:

- elevated levels of suspended sediments and associated water quality parameters during and after floods
- a greater degree of saltwater intrusion during storm surges

These effects would likely be restricted to periods after unusually intense floods and storm surges. Therefore, baseline water quality might change in affected waterbodies, but the effects of climate change from these pathways are not expected to interact with the project's predicted effects on water quality.

Increased air temperature from climate change can be expected to increase surface water temperatures in the open-water season. Higher mean annual air temperatures might cause earlier ice breakup and later freezeup and extend the growing season of algae and aquatic plants. Warmer water temperatures would also favour algal growth during the open-water period and could increase rates of microbial action and weathering, which increase rates of nutrient loading to lakes. These changes might increase primary productivity or the accumulation of algal biomass in standing waters.

The predicted change in air temperature from 2010 to 2039 is in most regions similar to the increase observed over the past 30 years. Evaluation of baseline

water quality data did not identify notable differences between data from the recent past and data collected in 2002 and 2003. The effects of increased air and water temperatures on baseline water quality would likely be small and probably not measurable. Similarly, climate change is not expected to affect the predicted effects of the project on water quality.

The potential for a change in the input of organic material to surface waters has been identified near the northern treeline as a potential effect of climate change on water quality. It is expected that there would be insufficient time for movement of the treeline to affect water quality over the life of the project.

Climate change is unlikely to affect any of the potential environmental effects of the project on water quality during the life of the project.

#### 11.3.1.4 Fish and Fish Habitat

Fish and fish habitat could change over the life of the project in response to climate change. It is unlikely that any of the changes in temperature and precipitation associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment. The potential effects of the project on fish and fish habitat occur primarily during construction. The potential effects of climate change on fish and fish habitat occur over a long period (Walters and Parma 1996; DeAngelis and Cushman 1990). There are no effects on fish or fish habitat that would be magnified by the effects of climate change during the life of the project.

Changes in fish and fish habitat could occur over the long term. Spring breakup could occur earlier and freezeup later because of climate change. Longer open-water periods and higher summer air temperatures could mean that the distribution and relative abundance of some species of fish and invertebrates could change. The ranges of those species that prefer warmer water, like walleye and pike, could expand, whereas the range of cold-water species, like Arctic grayling and lake trout, could become more restricted.

Invasion of fish species from the Pacific coast already appears to be in progress and is likely to expand. Chum salmon have been recorded in the past in the upper Mackenzie River system (see Section 7.2, Assessment Approach), e.g., Great Slave Lake, Slave River and Liard River, and chinook and pink salmon are also beginning to appear in several locations.

Species shifts might also affect forage fish species to the possible detriment or benefit of large-bodied fish species. Cyprinid species, such as emerald shiner, spottail shiner, finescale dace and flathead chub, which are well-represented in southern-sector waterbodies, are likely to expand their range northward. Piscivorous types, such as northern pike and walleye, benefit by feeding extensively on these species. Invading minnow species might displace resident species.

The water temperature regime in all waterbodies in the study area will be affected to some extent over time. The aquatic ecosystems that will undergo the greatest change are likely to be the small- to medium-sized streams and shallow lakes. The changes in temperature regime could alter the timing of the onset of spawning, with spring-spawning species spawning earlier, and fall-spawning species later. Although it is difficult to predict what this will mean to the year-class survival and overall population dynamics, changes are likely to be adverse in direction. For example, the timing of the hatch generally coincides with the availability of appropriate water flow and food organisms.

Climate change is unlikely to affect any of the potential environmental effects of the project on fish and fish habitat during the life of the project.

### **11.3.2 Terrestrial Ecosystems**

#### **11.3.2.1 Soils, Landforms and Permafrost**

Soils, landforms and permafrost could change over the life of the project in response to climate change. It is unlikely that any of the changes associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment. There are no potential effects on soils, landforms and permafrost that would be magnified by the effects of climate change during the life of the project.

Changes that could be related to climate change are primarily related to potential effects on permafrost in the pipeline corridor. The distribution of shallow permafrost (5 to 7 m deep), could become more restricted along southern parts of the route, e.g., south of Fort Good Hope. This would correlate with a northward movement of the boundary of discontinuous permafrost.

The extent of thermokarst might increase, especially if the active layer meets massive ice deposits, such as is found in regions of continuous permafrost. A deeper active layer could change surface drainage by causing:

- surface water ponding
- ground settling
- increased erosion
- slumpage on slopes
- degradation of peat bogs

#### **Thaw Depth**

The most useful indicator of permafrost change is thaw depth, which is the depth to discontinuous or melting permafrost. This depth varies according to soil type, rate of air temperature warming and location along the pipeline corridor, i.e., latitude and location transversely across the right-of-way. Possible effects of permafrost change on the project are considered in more detail in Section 14, Environmental Effects on the Project.

Figure 11-4 and Figure 11-5 are examples of the potential effects of climate change on thaw depth across the pipeline right-of-way. The figures illustrate possible site-specific effects of climate change on thaw depth but might not represent all locations and conditions along the pipeline route. In the figures, minimum, medium and maximum refer to the global scenarios described in Section 11.2.1.1, Methods.

Figure 11-4 shows a case where the gas temperature in the pipeline is above 0°C and the mean annual air and ground temperatures are several degrees colder, i.e., several degrees below 0°C, at the same location. This could occur at the pipeline inlet immediately downstream of a compressor station in the northern portion of discontinuous permafrost.

Figure 11-5 shows a condition where gas temperatures are above 0°C but the ground temperatures are close to 0°C, as might occur in the southern portions of the route. In this case, thaw across the right-of-way and beneath the pipe is more or less uniform.

These figures illustrate that the thaw depth can vary considerably across the right-of-way depending on site-specific ground conditions, level of surface disturbance and pipeline operating temperatures. The effects of warming air temperature can be relatively small and difficult to detect compared with project effects in some locations, but might provide a detectable contribution to thaw depth in other locations. However, these changes can be managed through ongoing monitoring and mitigation of potential effects.

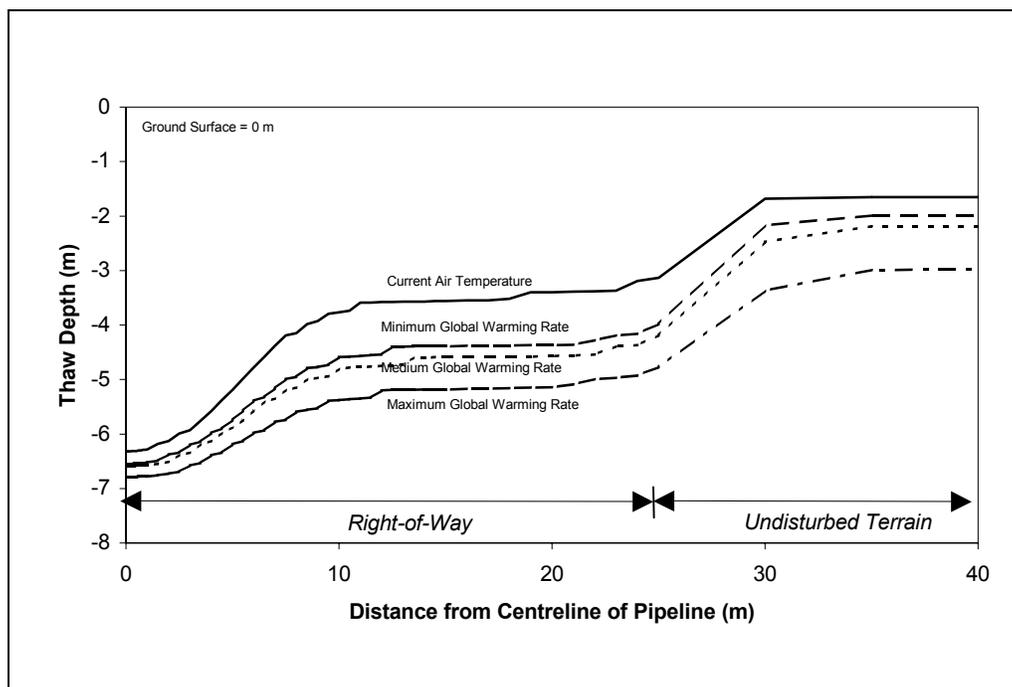
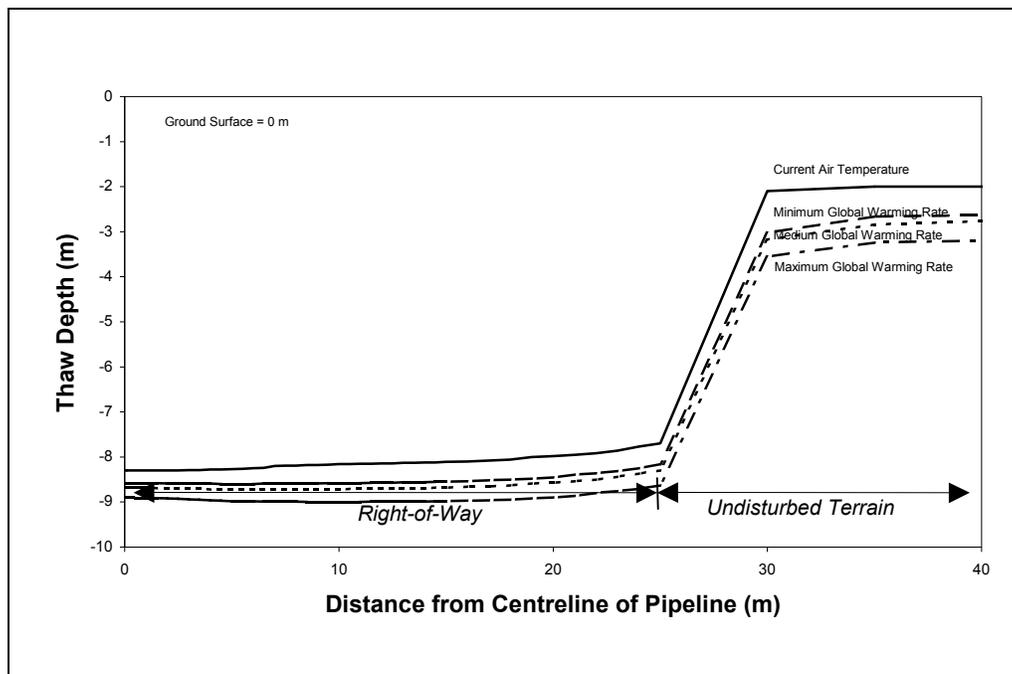


Figure 11-4: Thaw Depth from Pipeline Centreline (Ground Temperatures Colder than Gas)



**Figure 11-5: Thaw Depth from Pipeline Centreline (Ground Temperatures Warmer than Gas)**

The potential for slope instability because of permafrost thaw was evaluated in the soils, landforms and permafrost assessment (see Section 8, Soils, Landforms and Permafrost) using baseline parameters for air temperatures. That assessment concluded that slope instability from project effects could occur in some areas shortly after construction, or during operations in areas where the thaw depth exceeded a critical thaw depth. Slope instability can be avoided or reduced through route selection, monitoring and stabilization measures. The potential effects from slope instability are not significant based on assessed areas of potential instability and consideration of monitoring and stabilization during construction and operations.

If climate change occurs, thaw depths could exceed those estimated using baseline temperatures. However, thawing because of climate change will likely occur more slowly than from project effects. For areas south of the Transition Forest Ecological Zone, thaw depths from project disturbances will exceed the critical thaw depth. These effects can be managed using monitoring and stabilization measures.

In the Transition Forest Ecological Zone and Tundra Ecological Zone, predicted thaw depths from project disturbances are less likely to be greater than the critical depth for slope stability. However, a considerable range in thaw depth was noted in these zones depending on the material types and input parameters used in the analyses. Potential increases in thaw depth because of climate change might be difficult to quantify because they could be overshadowed by increases in thaw depth resulting from project disturbances. Changes in permafrost because of climate change are expected to occur slowly.

Climate change is unlikely to affect the potential effects of the project on soils, permafrost and landforms.

### 11.3.2.2 Vegetation

Vegetation could change at the local level over the life of the project in response to climate change. However, it is unlikely that any of the changes associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment.

Over the life of the project, there could be changes in vegetation at the local level because of a change in climate, but changes at the population or community level will likely be within the range of natural variability. Future vegetation communities in the project area will develop from response of each species to:

- ambient temperatures
- length of the growing season (Cohen 1997)
- growing degree days
- cloud cover
- changes in soil moisture, acidity and temperature
- frequency of fires, insects and diseases (Cohen 1997)
- changes in floodplains (Cohen 1997)
- grazing and browsing by wildlife

The response of plant species to these factors can include:

- increased or decreased growth
- changes in phenology (e.g., timing of flowering and fruiting)
- increased or decreased seed germination and seedling survival
- changes in resistance to fires, insects, diseases, and grazing and browsing

Plants adapted to a wide range of growing conditions might thrive, whereas the distribution of other plants adapted to a narrower range of temperature and moisture conditions might become more restricted. Potential effects on lichens will be of particular interest, because lichens are the primary food of caribou.

The frequency and severity of fires might increase during the life of the project, and the size of the areas burned could increase. If annual average temperatures continue to increase as forecast, the fire season might begin earlier and might not be tempered by the effects of increased precipitation. Tundra fires can cause a substantial increase in ground temperature and depth of the active layer (Kasischke et al. 1995) and an increase in tall shrubs and deciduous trees (Kasischke et al. 1995; Landhäusser and Wein 1993).

Peatland distribution could also change with climate change as climate is the dominant factor influencing type and location of peatlands (Damman 1979, Glaser and Janssens 1986; Halsey et al. 1997; Vitt et al. 2000). Changes in the distribution of permafrost will affect the ecology of bogs and peat plateaus, and

could further encourage tree growth. These predictions suggest that, although fen types might remain along the proposed pipeline route, peat plateaus could eventually be less abundant, particularly at lower latitudes, i.e., south of Wrigley (Gignac et al. 1998). Other studies predict a northward shift of permafrost and peat plateaus along the proposed pipeline route (Zoltai 1995; Anisimov and Nelson 1996; Kettles and Tarnocai 1999).

Although changes in peatlands are predicted in the Mackenzie Basin, significant time lags might occur before species appear in new locations and communities, because of the delay in melting of well-insulated or large peatlands (Halsey et al. 1995; Gignac et al. 1998). Climate change might result in the migration and changes in dominance of individual species, rather than in the locations of entire communities changing at once (Molau 1997; Heal 2001; Bergengren et al. 2001).

Tundra plant communities will probably change if the climate changes, although there might be a time lag before the treeline changes. Boreal species are expected to respond to increasing temperatures more than arctic-alpine species (Graglia et al. 1997) because their distribution is controlled primarily by temperature. For example, the range of flat-leaved willow (*Salix planifolia* spp. *pulchra*), an arctic species, might shrink, whereas the range of beaked willow (*Salix bebbiana*), a common boreal species, might expand. In the long term, tundra communities are expected to be dominated by deciduous shrubs, sedges, cotton-grasses and sedges, with a decline in abundance of evergreen shrubs, mosses and lichens (Chapin III et al. 1997). Unique communities, such as grasslands, could develop on disturbances, especially if reclamation introduces new species (Forbes et al. 1999; Huntley 1997).

No real shift in the position of the treeline has occurred over the last 30 years, in spite of the warming trend in this region. The boreal forest could expand into the tundra, but expansion might be delayed by slow tree-migration rates. The invasion of deciduous trees, such as paper birch and balsam poplar, will be particularly evident in areas where the forest-tundra transition area is narrow, and where major northward-flowing river valleys, such as the Mackenzie, protect small outlier forests and scattered trees (Kasischke et al. 1995). Black and white spruce could increase with increased fire frequency, as mineral soil suitable for germination is exposed, but an increase in fire frequency might eliminate them before they can set seed. The geographic distribution of some tree species might not change as fast as the projected shifts in suitable climate, so shifts in species distribution might occur.

Forests in the Transition Forest Ecological Zone, North Taiga Plains Ecological Zone and South Taiga Plains Ecological Zone will also experience changes because of climate change. As temperatures increase, southern boreal species adapted to warmer conditions and higher nutrient levels are expected to increase, resulting in faster growth of deciduous shrubs, herbs and graminoids, which are expected to outcompete evergreen shrubs and trees, as well as mosses and lichens.

The possible increase in fire frequency could result in shifts from conifer-dominated to deciduous-dominated forests. The potential effects of increased fires on peatlands could be substantial, particularly for peat plateaus, where fires result in thermokarst development and carbon loss (Vitt et al. 2000; Turetsky et al. 2002).

Any potential effects of climate change on vegetation would only become evident over the long term. Climate change is unlikely to affect any of the potential environmental effects of the project on vegetation during the life of the project.

### 11.3.2.3 Wildlife

Wildlife could change over the life of the project in response to climate change. It is unlikely that any of the changes associated with a maximum 2.5°C change in temperature and up to an 11.8% increase in precipitation would affect the results of the assessment. There are no potential effects on wildlife that would be magnified by the effects of climate change during the life of the project.

As the climate changes, wildlife species that are well-adapted to a wide range of environmental conditions will survive, whereas the distribution of species adapted to specific current temperature and moisture conditions could become more restricted. Examples of the kinds of changes in distribution and relative abundance of wildlife that could occur because of climate change are described in the following discussion.

#### **Barren-Ground Caribou**

The two factors related to increases in mean annual temperature and precipitation that could have the greatest effect on the distribution, productivity and relative abundance of barren-ground caribou are snow and insects. Freezing rain and thaw-freeze cycles are of particular concern, because they can cause icing conditions in which caribou cannot access their food. When forage is substantially reduced, calf survival is low. Conditions can also occur where caribou break through the crust into deep snow, impeding migration and feeding, resulting in increased predation by wolves.

Insect harassment reduces foraging time and is a critical concern when temperatures are 13°C and higher and wind speed is less than 3 m/s. An increase in the mean annual temperature of 1.4 to 2.5°C might increase the number of days each year when potential harassment is at or beyond threshold levels (Russell et al. 1993; Murphy and Lawhead 2000).

#### **Woodland Caribou**

Woodland caribou are listed as a species at risk (COSEWIC-threatened). An increase in mean annual temperature and precipitation could result in snow conditions that make it much easier for wolves to kill caribou at certain times of the year, such as in late winter.

Woodland caribou prefer ground and tree lichens in old-growth forests and treed muskeg. The distribution of old-growth forests and the relative abundance of lichens could change as the climate changes, particularly as spruce is sensitive to increases in mean daily temperature in summer. An increase in snow depth could restrict the access woodland caribou have to their food. Icing conditions could have consequences for woodland caribou, particularly for pregnant females in spring.

Increases in the frequency, severity and extent of forest fires could make large areas of habitat unsuitable for woodland caribou. Lichens can take as long as a century to recover and any lichens that remain can be much harder to access, as snow becomes deeper and harder and fallen trees make it harder for woodland caribou to move around.

### **Moose**

Willow is the single most important food in the diet of moose. The distribution and relative abundance of willow is affected by fire and flooding, which could increase with increases in mean annual temperature and precipitation.

Predation is a critical factor in the ecology of moose. Wolves respond to deep snow conditions by hunting in large packs. The number of moose killed by wolves could increase during high-snowfall years.

### **Grizzly Bear**

With increases in mean annual temperature, grizzly bears could be active for more of the year than they are under colder conditions. The distribution and abundance of ground squirrels could increase and they could become the single most important source of food for grizzly bears. The timing and duration of denning could change as conditions become warmer (Shideler and Hechtel 2000).

Climate change is unlikely to affect any of the project's environmental effects on wildlife during the project. The footprint of the proposed project is relatively small, so changes in the environment in a broad geographic context because of climate change might be of greater concern than any potential effects of the proposed project on wildlife.

### **All Species**

Climate change is unlikely to affect any of the potential environmental effects of the project on wildlife during the life of the project.

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