CHAPTER 7
Prairies

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KEY FINDINGS

Increases in water scarcity represent the most serious climate risk. The Prairies are Canada's major dryland. Recent trends and future projections include lower summer streamflows, falling lake levels, retreating glaciers, and increasing soil- and surface-water deficits. A trend of increased aridity will most likely be realized through a greater frequency of dry years. Water management and conservation will continue to enable adaptation to climate change and variability. This could include technologies for improved efficiency of water use, as well as water pricing regimes that would more accurately reflect the real costs of water treatment and supply, and help to ensure that an increasingly scarce resource is properly allocated. Higher forest, grassland and crop productivity from increased heat and atmospheric CO_2 could be limited by available soil moisture, and dry soil is more susceptible to degradation. Water scarcity is a constraint on all sectors and communities, and may constrain the rapid economic and population growth in Alberta.

Ecosystems will be impacted by shifts in bioclimate, changed disturbance regimes (e.g. insects and fire), stressed aquatic habitats and the introduction of non-native plants and animals. Impacts will be most visible in isolated island forests and forest fringe areas. There are implications for livelihoods (e.g. Aboriginal) and economies (e.g. agriculture, forestry) most dependent on ecological services. Adjustments to ecosystem management are required to enable change to occur in a sustainable manner.

The Prairies are losing some advantages of a cold winter. Cold winters help limit pests and diseases, facilitate winter operations in the forestry and energy sectors, and allow access to remote communities though the use of winter roads. As winter temperatures continue to increase, these advantages will be reduced or lost. For example, the mountain pine beetle may spread into the Prairies' jack pine forests, exploration and drilling sites may become less accessible, and reductions in the length of winter road seasons are likely.

Resources and communities are sensitive to climate variability. The Prairies have one of the world's most variable climates. This variability has been both costly (e.g. an approximate $3.6 billion drop in agricultural production during the drought of 2001–2002) and the stimulus for most of the adaptive responses to climate variability. Projections of future climate conditions include more frequent drought, but also increased precipitation in the form of rain and higher probability of severe flooding. Extreme events, and an expanded range of year-to-year departures from climate norms, represent greater risks to the economy of the Prairies than a simple shift in mean conditions.

Adaptive capacity, though high, is unevenly distributed. As a result, levels of vulnerability are uneven geographically (e.g. rural communities generally have less resources and emergency response capacity) and among populations (e.g. elderly, Aboriginal and recent immigrant populations are the fastest growing and more vulnerable to health impacts). Climate change could encourage further migration from rural to urban communities and to regions with the most resources (e.g. Alberta cities). Adaptive capacity will be challenged by projected increases in climatic variability and frequency of extreme events.

Adaptation processes are not well understood. Although a high adaptive capacity could reduce the potential impacts of climate change, it is unclear how this capacity will be applied. Most existing research does not capture adaptation measures and processes. Capacity is only potential — institutions and civil society will play a key role in mobilizing adaptive capacity. Recent adaptations, such as minimum tillage practices and crop diversification in the agriculture sector, water policy in Alberta, re-engineering of the Red River floodway, municipal infrastructure and water conservation programs, have enhanced resilience and increased adaptive capacity.

1 INTRODUCTION

Most climate models project the largest increases in mean annual temperature in the high latitudes of the Northern Hemisphere (Cubasch et al., 2001). Consistent with these projections, temperature records from the Prairies show significant positive trends, especially since the 1970s (Figure 1). The favourable consequences of this general warming, and higher spring temperatures in particular, are a warmer and longer growing season and enhanced productivity of forests, crops and grassland where there is adequate soil moisture.

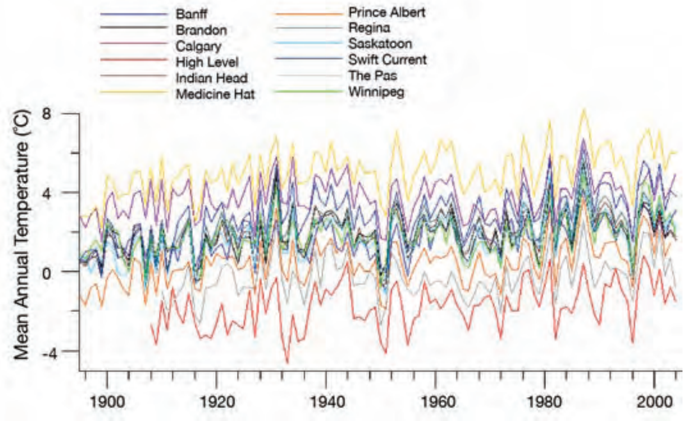

FIGURE 1: Trends in mean annual temperature since 1895 for 12 climate stations spread across the Prairies. The average increase in mean annual temperature for the 12 stations is 1.6°C. *Source:* Environment Canada, 2005.

Unfortunately, summertime drying of the earth's midcontinental regions is also projected, as greater water loss by evapotranspiration is not offset by increased precipitation (Gregory et al., 1997; Cubasch et al., 2001). Projections vary from slight (Seneviratne et al., 2002) to severe (Wetherald and Manabe, 1999) moisture deficits, depending mainly on the complexity of the simulation of land-surface processes. Elevated aridity has major implications for the Prairies, the driest major region of Canada. Recurrent short-term water deficits (drought) impact the economy, environment and culture of the Prairies. Seasonal water deficits occur in all regions of Canada, but only in the Prairies can precipitation cease for more than a month, surface waters disappear for entire seasons, and water deficits persist for a decade or more, putting landscapes at risk of desertification.

Declining levels of prairie lakes (Figure 2) also suggest drying of the prairie environment. Closed-basin lakes are sensitive indicators of hydrological and climatic change (van der Kamp and Keir, 2005; van der Kamp et al., 2006). Fluctuations in lake levels can be related to land use and water diversions, but similar patterns for lakes across the Prairies implicate the influence of climate parameters, particularly rising temperatures, changes in the amount of snow (Gan, 1998) and changes in the intensity of rain (Akinremi et al., 1999), on the water budgets of these lakes.

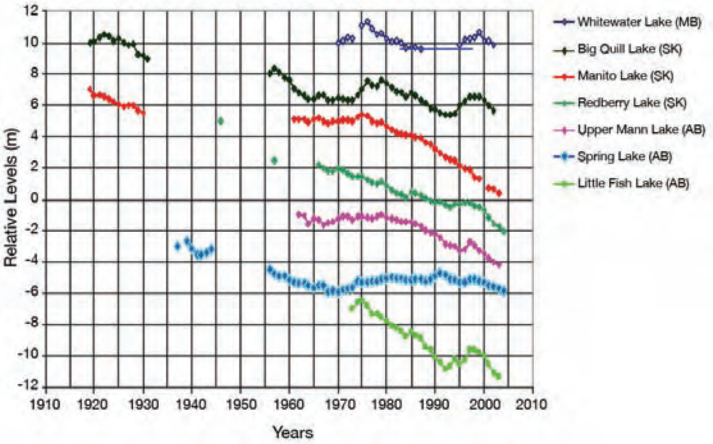

FIGURE 2: Historical water levels for closed basin prairie lakes
Source: van der Kamp et al., 2006; van der Kamp and Keir, 2005.

The communities and institutions of the Prairies have considerable capacity to take advantage of higher temperatures and minimize the adverse impacts of climate change due to the relative abundance of financial, social and natural capital. Subregional disparities result, however, from strengths and weaknesses with respect to the determinants of adaptive capacity (Table 1). There are also key socioeconomic and environmental factors that underlie the vulnerability of the region to climate change. For example, the Prairies:

- are Canada's largest dryland, where seasonal and prolonged water deficits define the natural environment and strongly influence human activities;
- contain more than 80% of Canada's farmland, where production and landscapes are sensitive to climatic variability;
- rely on irrigation water from the Rocky Mountains, where the hydrology is expected to change with climate change;
- have a climate that, since European settlement, has not included the prolonged droughts of previous centuries;
- are projected to experience more severe drought under some climate change scenarios;
- require water for processing Canada's largest reserves of oil and gas;
- include some of Canada's fastest growing cities and economies; and
- have an Aboriginal population that is the most concentrated in Canada outside the northern territories and is the fastest growing segment of the region's population.

TABLE 1: Adaptive capacity in the Prairies: strengths and weaknesses.

Determinant	Strengths	Weaknesses
Economic resources	Major, especially in Alberta and urban centres.	Remote rural communities lack economic diversification; individuals versus corporations (e.g. family versus corporate farms)
Technology	Alternative energy and greenhouse gas emission reduction technology	Less adaptation technology (e.g. water conservation)
Information and skills	Various climate change research programs associated with universities and government agencies	Cutbacks in climate- and water- monitoring programs; poor understanding of the social dimensions of climate change
Infrastructure	Well developed in populated areas; current designs that are addressing climate change (e.g. Winnipeg floodway); delays in upgrading and replacing infrastructure provide opportunities to consider future climate	Vast area (e.g. Saskatchewan has more roads than any other province; Nix, 1995); deficits from budget constraints in the 1990s
Institutions	Engaged in building capacity and assessment of vulnerability (e.g. Alberta Vulnerability Assessment; Davidson, 2006; Sauchyn et al., 2007)	Focus on mitigation; only beginning to develop adaptive strategies
Equity	Social programs	Health impacts on more vulnerable populations: First Nations, rural communities and especially remote settlements, elderly and children

Although the Prairies are only about 25% prairie, they are known to Canadians as the ‘Prairies’; therefore, that terminology is adopted here. When this chapter refers to the prairie ecosystem, the formal designations ‘Prairie Ecozone’, ‘grassland’, ‘mixed-grass prairie’ or ‘prairie’ (lower case) are used. These geographic concepts are defined in the following section, which outlines the environment and economy of the Prairies. Section 2 describes climatic and socioeconomic characteristics that expose the population to current and future climate risks and opportunities. Sections 3 and 4 discuss sensitivities to current climate and key vulnerabilities to climate change with respect to natural capital and socioeconomic sectors. The process of adaptation and the concept of adaptive capacity are discussed in Section 5. The chapter concludes with a synthesis of the main findings.

1.1 DESCRIPTION OF THE PRAIRIE REGION

With 5 428 500 people and almost 2 million km^2 of land and surface water, the Prairies represent 20% of Canada by area (Table 2) and 17% by population. Alberta, Saskatchewan and Manitoba are roughly equal in area but not in population (Table 3). Increasingly the population is urban (centres of >1000 people) and concentrated in Alberta. Between 1901 and 2001, the proportion of the population classified as urban grew from less than 25% to more than 75% (*see* Section 2.1).

The Prairies extend west from Hudson Bay to the crest of the Rocky Mountains, thus spanning several major climatic, biogeographic and geological zones and watersheds (Figure 3). Because of the region's mid-latitude location in the rain shadow of the Rocky Mountains, the climate is generally cold and subhumid. There are extreme differences in seasonal temperatures. During the period 1971–1990, mean temperatures in the coldest and warmest months were –7.8°C and 15.5°C, respectively, at Lethbridge and –17.8°C and 19.5°C, respectively, at Winnipeg. Mean annual temperatures are highest in southern Alberta, elevated by winter chinooks, and decrease towards the short, cool summers and long, cold winters of northern Alberta, Saskatchewan and Manitoba (Figure 4a). Annual precipitation varies considerably from year to year, ranging from less than 300 mm in the semiarid grassland to about 700 mm in central Manitoba (Figure 4b) and more than 1000 mm at high elevations in the Rocky Mountains. Throughout the Prairies, snow is important for water storage and soil moisture recharge. The wettest months are April to June.

The temperature and precipitation patterns in Figure 4 result in annual moisture deficits in the southern and western plains, and moisture surpluses in the Rocky Mountains and foothills, and in the northern and eastern boreal forest. Most runoff is shed from these wetter regions eastward via the Saskatchewan-Nelson-Churchill river system into Hudson Bay, and northward via the Athabasca, Peace and Hay rivers into the Mackenzie River and Arctic Ocean (Figure 3). Little runoff is generated across the

TABLE 2: Land and freshwater areas (in km^2) of Canada and the Prairies (*from* Natural Resources Canada, 2001).

	Total area	Land	Freshwater	Percentage of total area
Canada	9 984 670	9 093 507	891 163	100.0
Manitoba	647 797	553 556	94 241	6.5
Saskatchewan	651 036	591 670	59 366	6.5
Alberta	661 848	642 317	19 531	6.6
Prairies	1 960 681	1 787 543	173 138	19.6

TABLE 3: Population of Canada and the Prairie provinces (*from* Statistics Canada, 2005a).

	Population (thousands)	
	2001	2005
Canada	31 021.3	32 270.5
Manitoba	1 151.3	1 177.6
Saskatchewan	1 000.1	994.1
Alberta	3 056.7	3 256.8
Prairies	5 208.1	5 428.5

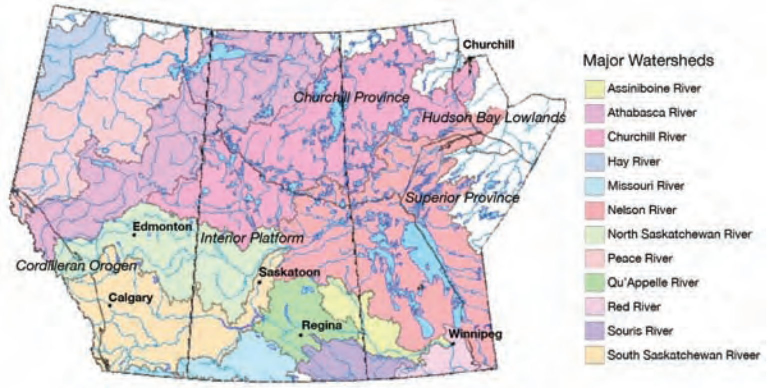

FIGURE 3: Major watersheds and the geological provinces of the Prairies.

southern Prairies, and large areas are drained internally by intermittent streamflow. The few permanent streams in the south are thus important as local water sources. The heavy demand for water from rivers that cross the southern plains is in sharp contrast to the large rivers, countless lakes and sparse population of the northern forests and shield.

1.2 ENVIRONMENT AND ECONOMY BY ECOZONE

The Terrestrial Land Classification of Canada includes seven ecozones that lie within the Prairies (Figure 5). The Prairie and Boreal Plains ecozones represent more than 50% of the area and have most of the population. The 25% of the Prairies occupied by the **Prairie Ecozone** is the region's agricultural and industrial heartland. It is the most extensively modified region of the country — there remain only remnants of the original mixed- and tall-grass prairie, and less than half the presettlement wetland area. The pattern of settlements reflects their original functions as regional service centres and collection points along rail lines for agricultural products. Hundreds of communities have vanished with rural depopulation, the consolidation of farms and the grain collection system, abandonment of rail lines and

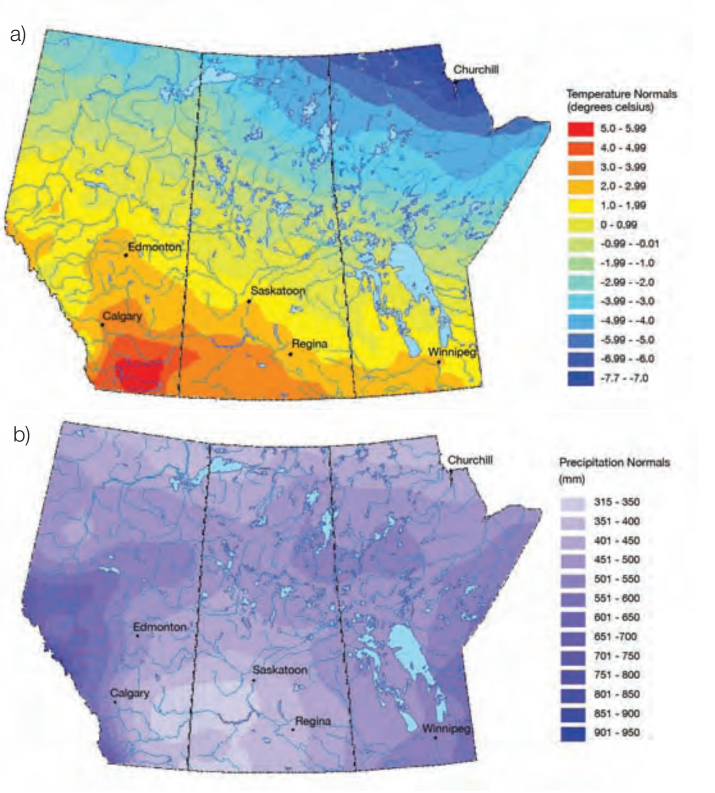

FIGURE 4: Climate normals (1961-1990) for the Prairies: a) temperature, and b) precipitation.

FIGURE 5: Ecozones of the Prairies.

concentration of population, services and wealth in urban centres. TD Bank Financial Group (2005) recently reported that per capita GDP (a measure of standard of living) in the Calgary-Edmonton corridor increased by US$4 000 between 2000 and 2003 to US$44 000, 47% above the Canadian average.

The Prairies have about 50% of Canada's farms but more than 80% of the farmland (Table 4), mostly in the Prairie Ecozone. Historically, the export of grains, oilseeds and animal products has been an important source of Canada's foreign exchange. Agriculture now accounts for only a small percentage of the gross provincial GDPs relative to other industries (*see* Section 2.2), particularly mining and energy production. Average farm size is significantly larger in Saskatchewan (greater than 500 ha) than in the other two provinces. The Prairie Ecozone is characterized by persistent, and sometimes severe, moisture deficits. Droughts are most frequent and severe in the mixed grassland, one of the five ecoregions that constitute the Prairie Ecozone. This area is commonly known as Palliser's Triangle, because it was described as "forever comparatively useless" by John Palliser following a survey in 1857–1859. In this subregion of southern Alberta and southwestern Saskatchewan, crop and forage production is sustained by irrigation that depends on runoff from the Rocky Mountains and Cypress Hills. Irrigation is the major water use in Alberta and Saskatchewan, with Alberta having almost two-thirds of Canada's irrigated land.

North of the prairie and aspen parkland, vegetation shifts to mixed and coniferous forest — there are about 97 million hectares of forest in the Prairies. **The Boreal Plains Ecozone** of central Manitoba, central Saskatchewan and most of central and northern Alberta was the area first visited by Europeans, since it has navigable rivers and fur-bearing animals. The boreal plains are now once again the new frontier, with large oil and gas reserves, nearly all the commercial forestry, expanding farmland in northern Alberta, and hydroelectric power plants in Manitoba and Saskatchewan. The Aboriginal peoples of this ecozone are tied to a traditional way of life, with wildlife a particularly valuable resource.

The **Boreal Shield Ecozone** lies north and east of the interior plains in northern Saskatchewan and northern and eastern Manitoba. Frontier resource development, particularly mining, is the backbone of the economy. Cree and Dene First Nations account for most of the population.

The remaining four ecozones are on the margins of the Prairies and account for small portions of the area and population. The **Taiga Plains Ecozone** extends from the Mackenzie River valley of the Northwest Territories up the tributary valleys of northwestern Alberta. The productivity of the 'taiga' forest is limited by the cooler climate and shorter growing season. The **Taiga Shield Ecozone** extends across Canada's subarctic, including the northern reaches of Manitoba and Saskatchewan and a small part of northeastern Alberta. Like the Boreal Shield, it is rich in mineral resources and supports the traditional livelihood of the Cree and Dene First Nations. The **Hudson Plains Ecozone**, adjacent to Hudson Bay in northeastern Manitoba, is dominated by extensive wetlands. Churchill is an important seaport and railway terminus. The **Montane Cordillera Ecozone** of the Rocky Mountains in western Alberta has high ecological diversity associated with landscapes of high relief, ranging from low-elevation fescue grassland through montane forest to subalpine forest and alpine tundra. The dominant economic activities are cattle ranching and outdoor recreation. Much of the area is designated as national and provincial parks and protected areas. Resource extraction, coal mining, forestry, and oil and gas production are increasingly in conflict with ecological and watershed conservation. Mountain snowpacks and glaciers of the Cordillera are the source of most of the river flow and water supply across the southern Prairies.

TABLE 4: Number of farms and area (ha) of farmland in Canada and the Prairies, 2001 (*from* Statistics Canada, 2001b).

	Alberta	Saskatchewan	Manitoba	Prairies	Canada
Number of farms	53 652	50 598	21 071	125 321	246 923
Area of farmland (ha)	21 067 486	26 265 645	7 601 779	54 934 910	67 502 447

2 REGIONAL CLIMATE AND SOCIOECONOMIC CHARACTERISTICS

2.1 DEMOGRAPHICS

This demographic profile of the Prairies was assembled from reports by Statistics Canada (2001a, 2005a, b, d–g) and the Canada West Foundation (Azmier, 2002; Hirsch, 2005a, b). The number of people in the Prairies has doubled during the past 50 years to more than 5 million. Population growth, however, is not shared equally among the provinces (Figure 6). Alberta now has slightly less than two-thirds of the population of the region, compared to slightly more than a third in 1951 (Figure 6). Alberta's population is the youngest of the three provinces and it has the largest working-age population (aged 20–64), at 61.4% of its total population. A decline in Saskatchewan's population has resulted from net interprovincial out-migration exceeding the small increases through natural population growth and net international immigration, whereas Alberta has experienced increases in all three population growth components (Table 5). In all three provinces, urban populations dominate, making up 64.3 % (Saskatchewan) to 80.9% (Alberta) of the total population (Table 6). In 2001, Alberta had the largest Aboriginal population (168 000); at 5.5%, however, Aboriginal people represented a smaller proportion of the general population than in Manitoba and Saskatchewan, where 14% of the residents are of Aboriginal ancestry.

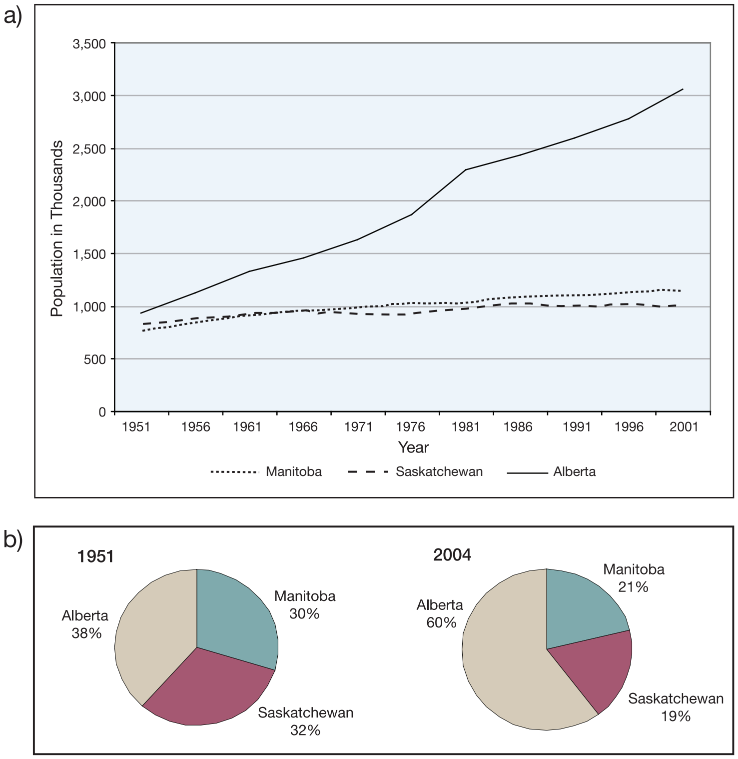

FIGURE 6: Population of the Prairies: a) trend, by province, 1951–2001; and b) relative distribution, by province, 1951 and 2004 (*from* Statistics Canada, 2005d).

TABLE 5: Components of population change, 2001-2004 (*from* Sask Trends Monitor, 2005).

	Total change (in thousands; three-year totals)				
Province	Natural growth	Net international migration	Net interprovincial migration	Total	Average annual increase (%)
Manitoba	11.7	16.6	-9.3	19.0	0.5%
Saskatchewan	8.7	3.4	-16.9	-4.7	-0.2%
Alberta	59.6	36.5	49.0	145.2	1.6%

TABLE 6: Urban and rural populations of the Prairies, 2001 (*from* Statistics Canada, 2001a).

Province	Rural	Urban
Alberta	19.1%	80.9%
Manitoba	28.1%	71.9%
Saskatchewan	35.7%	64.3%

2.2 ECONOMIC ACTIVITIES AND EMPLOYMENT

In 2004, the Prairies contributed $202 billion in value-added activities to the Canadian gross domestic product (GDP). Alberta had the highest per capita GDP at $41 952 in 2004, with lower values in Saskatchewan ($33 282) and Manitoba ($30 054). The per capita average for all of Canada in 2004 was $40 386.

Primary resource sectors are the largest contributors to GDP in the region, with about 25% of the total value added (Table 7). These data are for 2001, a drought year for much of Alberta and Saskatchewan, when contributions from agriculture were lower than normal. The Prairies share dependence on primary resource production, specifically agriculture, forestry and mining, and have relatively small manufacturing sectors compared to the rest of Canada, although the nature of primary production differs among the three provinces (*see* Table 7). Service industries are the largest source of employment in the region and a major growth sector. Next are trade industries, contributing around 15% of total employment, whereas the primary resources sector represents only 11% of employment (Figure 7). These primary resource industries, particularly agriculture, were the major employer in the past, but technological change has lowered the demand for labour.

Manitoba has shown continued growth in population and employment in a diversified economy. In 2000, manufacturing accounted for almost half of the GDP from all goods-producing industries. Manitoba real GDP grew by 2.9% in 2005, equal to that of Canada and the strongest since 2000. Saskatchewan's economy has shown promising signs of diversification, despite a continued dominance of farming and resources (Hirsch, 2005a). Manufacturing shipments have increased by 55% during the last decade. The economy is export oriented, with exports including crude petroleum oil, potassium chloride, spring and durum wheat, and canola. Alberta's economy has been booming during the past decade, sparked by high prices for oil and natural gas (Hirsch, 2005b). Other growing sectors of the Alberta economy include manufacturing, construction, services and public finance.

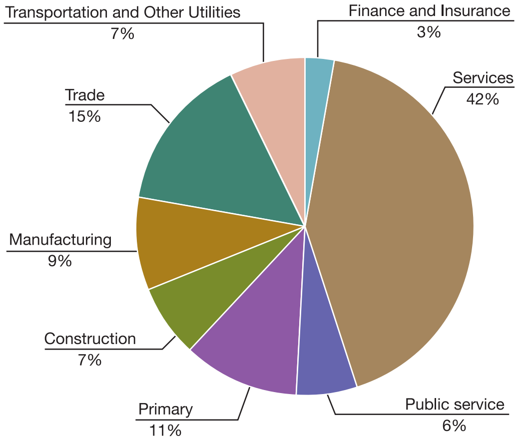

FIGURE 7: Distribution of employment in the Prairies by major industry groups, 2001 (*from* Statistics Canada, 2005d). Note that primary industries include agriculture, fisheries, mining and forestry.

TABLE 7: Distribution of gross domestic product by industry for the Prairies, 2001 (*from* Statistics Canada, Special Tabulation).

	Percentage of total gross domestic product			
Industry	Manitoba	Saskatchewan	Alberta	Prairies
Crop and animal production	3.5	3.9	1.4	2.1
Mining	1.8	17.9	26.5	21.5
Other primary goods-producing industries	0.3	0.4	0.2	0.3
Manufacturing	13.6	7.9	9.1	9.6
Construction	4.6	5.9	7.5	6.8
Trade	12.0	10.7	8.8	9.5
Utilities	14.1	11.2	9.2	10.0
Public administration	18.8	17.4	10.2	12.6
Other services	31.3	24.7	27.1	27.4
Total	100.0	100.0	100.0	100.0

2.3 ECONOMIC AND SOCIAL TRENDS AND PROJECTIONS

Recent regional climate change assessments elsewhere in the world (e.g. Holman et al., 2005a, b; Schröter et al., 2005) have shown that socioeconomic scenarios can often be more important than climate scenarios in impact assessments, particularly in determining economic impacts and adaptive capacity (see Chapter 2 for discussion of adaptive capacity). However, predicting economic and social trends is problematic for a region that is as dependent on export markets and as heterogeneous as the Prairies.

Population projections are available for the region (Azmier, 2002; Sauvé, 2003; Statistics Canada, 2005e, f, g). By 2031, the population of the Prairies could be as high as 7 million, an increase of almost 30%. This projected growth ranges from less than 3% in Saskatchewan to almost 40% in Alberta (Table 8). Aboriginals, visible minorities and seniors are at the core of the demographic changes expected in the coming decades (Statistics Canada, 2005e, g).

Alberta, with its booming energy-based economy, is where most of the population increase for the region has occurred during the past 50 years (as evident in Figure 6), and this trend is likely to continue for the next 30 years (based on the data presented in Table 8). Manitoba and Saskatchewan will face the challenges associated with growth of the major cities at the expense of the rural population. In Manitoba, urban population growth will come mainly from immigration (Azmier, 2002); for Saskatchewan, it will come mostly from a rise in the Aboriginal population. A developing trend is worker shortages (Sauvé, 2003), which might be alleviated somewhat with immigration. Change in the Prairie economy over the last few decades has been driven by advances in oil sands recovery techniques, improved forest management and productivity, growth in the film industry, increased agricultural productivity, widespread adoption of computer technology, consolidation of warehousing and industrial production, and increased tourism (Roach, 2005).

These trends and projections suggest potential for differing levels of vulnerability in the various Prairie provinces. Population and wealth are expected to continue to be concentrated in Alberta, leaving the other provinces with relatively fewer resources to address adaptation needs. Differential impacts of climate change among regions and sectors will interact with uneven economic growth, causing population shifts and putting more strain on the socioeconomic fabric of the region. The migration from rural to urban areas undermines the viability of rural communities, which have more limited resources than cities to address climate change and are also more dependent on climate-sensitive resources, such as agriculture and forestry.

2.4 PAST CLIMATE

Most weather records in the Prairies are less than 110 years in length. A longer perspective from geological and biological archives provides information on low-frequency (decades or longer) variability, gradual responses to climate forcing and a larger range of climate variability than is contained in the instrumental climate record, and can potentially provide historical analogues of future climate. In the Prairies, variations

TABLE 8: Future population growth, Prairies and Canada, 2005-2031 (*from* Statistics Canada, 2005b).

		2031 Population (Thousands)					
Province/ region	**2005 population (Thousands)**	**Low Growth**	**Medium Growth (Recent migration)**	**Medium Growth (Medium migration)**	**Medium Growth (West coast migration)**	**Medium Growth (Central-west migration)**	**High Growth**
Manitoba	1 178	1 259	1 375	1 356	1 335	1 378	1 447
Saskatchewan	994	937	967	976	981	1 064	1 023
Alberta	3 257	3 925	4 391	4 145	3 892	4 543	4 403
Prairies	5 429	6 121	6 733	6 477	6 208	6 985	6 873
Canada	32 271	36 261	39 045	39 029	39 015	39 052	41 811
Prairies as a percentage of Canada	17%	17%	17%	17%	16%	18%	16%

in climate are reflected in the shifting of vegetation, fluctuations in the level and salinity of lakes, patterns in tree rings, and the age and history of sand dunes (Lemmen and Vance, 1999). Temperatures inferred from boreholes on the Canadian Plains (Majorowicz et al., 2002) and from tree rings at high elevations in the Rocky Mountains (Luckman and Wilson, 2005) show that the warmest climate of the past millennium was during the twentieth century.

Soil moisture inferred from tree rings, and lake salinity inferred from diatoms, indicate that the climate of the twentieth century was relatively favourable for the settlement of the Prairies, as it lacked the sustained droughts of preceding centuries that affected sand dune activity, the fur trade and the health of Aboriginal people (Sauchyn et al., 2002a, 2003). The short duration of drought since the 1940s may be more linked to multi-decadal climate variability than to climate change, which is expected to cause increased aridity and more frequent drought (Wetherald and Manabe, 1999; Kharin and Zwiers, 2000). High-resolution lake sediment records reveal multi-centennial shifts in moisture regime (Michels et al., 2007), and tree rings suggest repeated multi-decadal wet and dry cycles (St. George and Sauchyn, 2006; Watson and Luckman, 2006) across the region. These natural cycles will underlie the trend of climate change. Tree-ring and archival records from Manitoba (Blair and Rannie, 1994; St. George and Nielsen, 2003; Rannie 2006) have highlighted the recurrence of wet years and flooding, and point to a contrast in climate between the western and eastern Prairies.

During the period of instrumental record, there was an average increase in temperature of 1.6°C for 12 stations on the Prairies, most with data since 1895 (Figure 1). Spring shows the greatest warming, a trend that extends from Manitoba to northern British Columbia (Zhang et al., 2000). More extensive regional warming has been experienced over the past 50 years, with significant trends in January, March, April and June (Gan, 1998). Precipitation data indicate a generally declining trend during the months of November to February, with 30% of the monthly data from 37 stations showing a significant decrease during the period 1949–1989 (Gan, 1998). Only one of the 37 stations showed a significant positive trend (Gan, 1998). Although the number of days with precipitation has increased on the Canadian Prairies during the last 75 years (Akinremi et al., 1999), more than half of those precipitation days had total amounts of less than 5 mm.

2.5 SCENARIOS OF FUTURE CLIMATE

Climate scenarios were derived from climate change experiments based on seven global climate models (GCMs) and the Intergovernmental Panel on Climate Change *Special Report on Emissions Scenarios* (Nakićenović and Swart, 2000; *see* Chapter 2). Maps and scatterplots illustrate the scenarios of projected climate change from 1961–1990 to the 2020s (2010–2039), 2050s (2040–2069) and 2080s (2070–2099).

Scatterplots

Scatterplots (*see* Appendix 1 of Chapter 2) for the Prairies present change fields averaged over two regions, the southern grassland zone and the northern forest zone. The scatterplots show the modelled changes in mean annual (Figure 8a) and mean seasonal (Figure 8b) temperature and precipitation for the forest and grassland regions for the 2020s, 2050s and 2080s.

With the exception of a few scenarios for the 2020s, all models forecast climates that lie outside the range of natural variability. Temperature scenarios are similar for the forest and grassland regions, but increases in precipitation are larger for the northern forest. The scatter of data increases over time, reflecting the greater uncertainly in the modelling of climate change later in the twenty-first century. Much of the projected increase in temperature and precipitation will occur in winter and spring for both forest and grassland regions.

Scenario Maps

The scenario maps present a geographic summary of the GCM-derived climate changes illustrated on the scatterplots (*see* Appendix 1 of Chapter 2). The minimum, median and maximum projections of changes in temperature and precipitation have been plotted using the Canadian Coupled Global Climate Model 2 (CGCM2) grid. Temperature scenarios are mapped for the 2020s, 2050s and 2080s in Figure 9a and by season for the 2050s in Figure 10a, while corresponding precipitation scenarios are shown in Figures 9b and 10b. Besides illustrating the extreme scenarios and seasonal contrasts, the maps show that greatest warming is projected to occur in the north and east. These regions are also projected to have the largest increases in precipitation, with smaller increases, and even decreased precipitation in summer for the worst-case (minimum) scenarios, to the west and south.

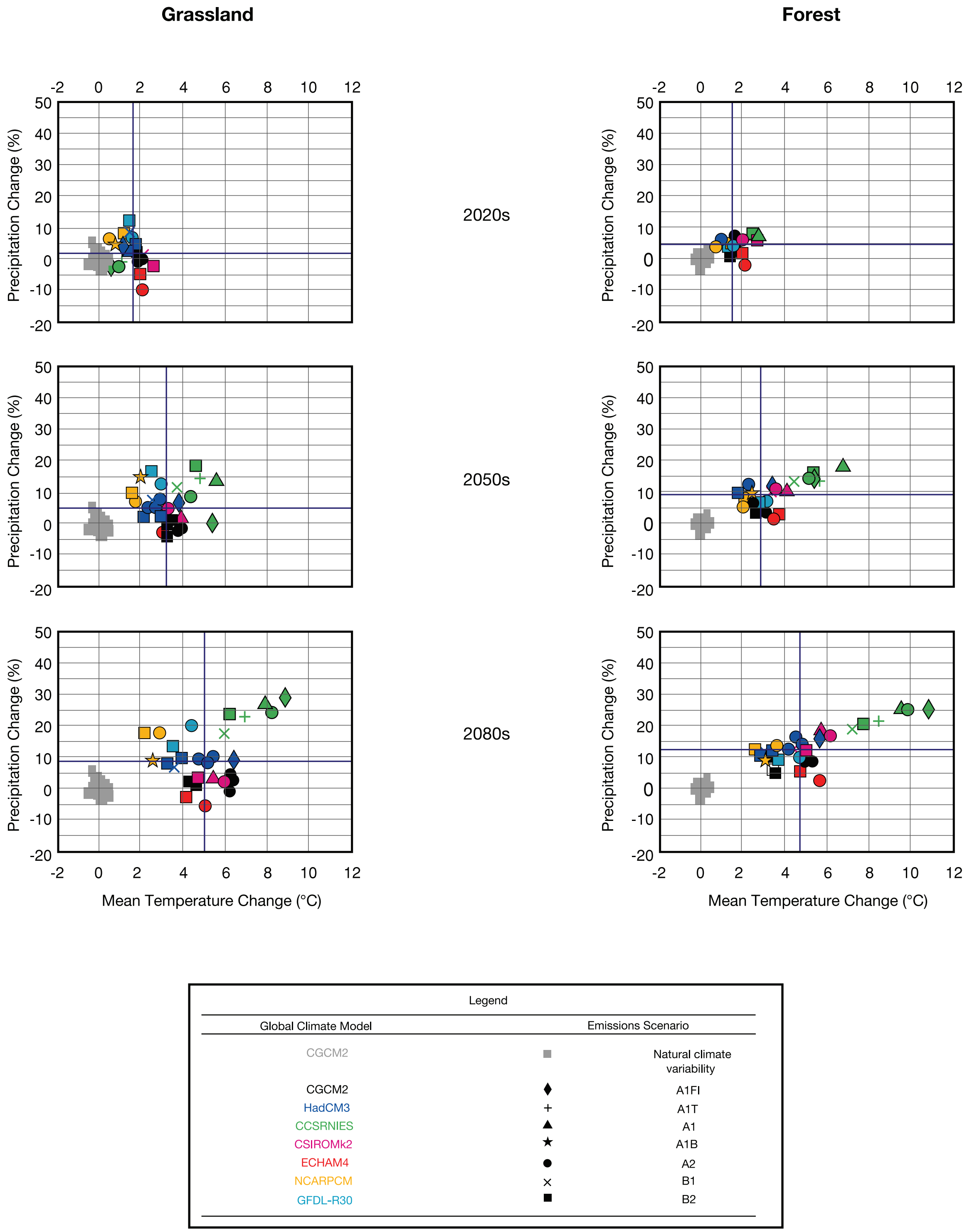

FIGURE 8a: Scatterplots of projected changes for the forest and grassland regions of the Prairies for the 2020s, 2050s and 2080s in mean annual temperature and precipitation. The grey squares indicate the 'natural' climate variability simulated by a long control run of the Canadian Coupled Global Climate Model 2 (CGCM2), in which there is no change in forcing over time. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot.

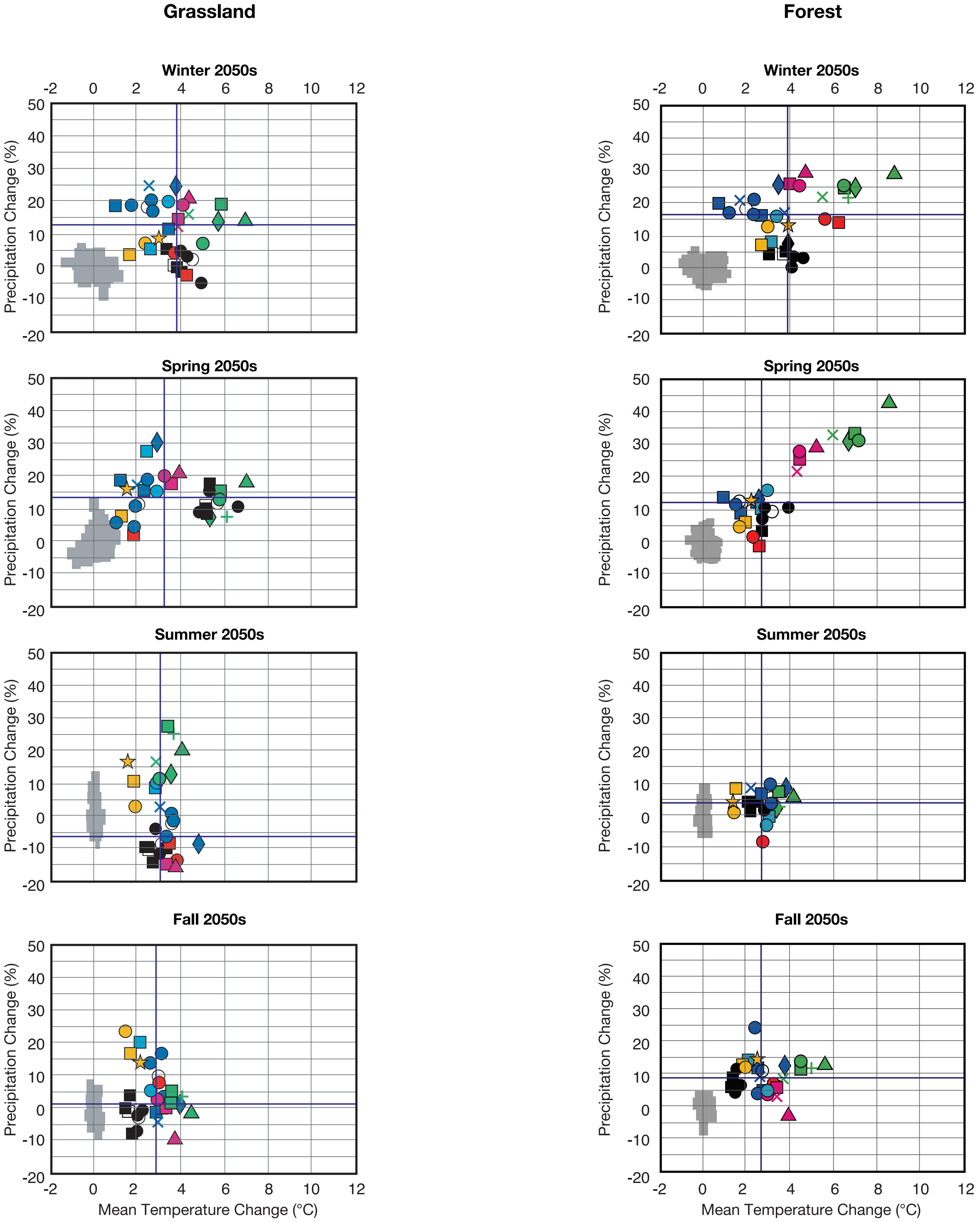

FIGURE 8b: Scatterplots of projected changes for the forest and grassland regions of the Prairies for the 2050s in mean seasonal temperature and precipitation. The grey squares indicate the 'natural' climate variability simulated by a long control run of the Canadian Coupled Global Climate Model 2 (CGCM2), in which there is no change in forcing over time. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot.

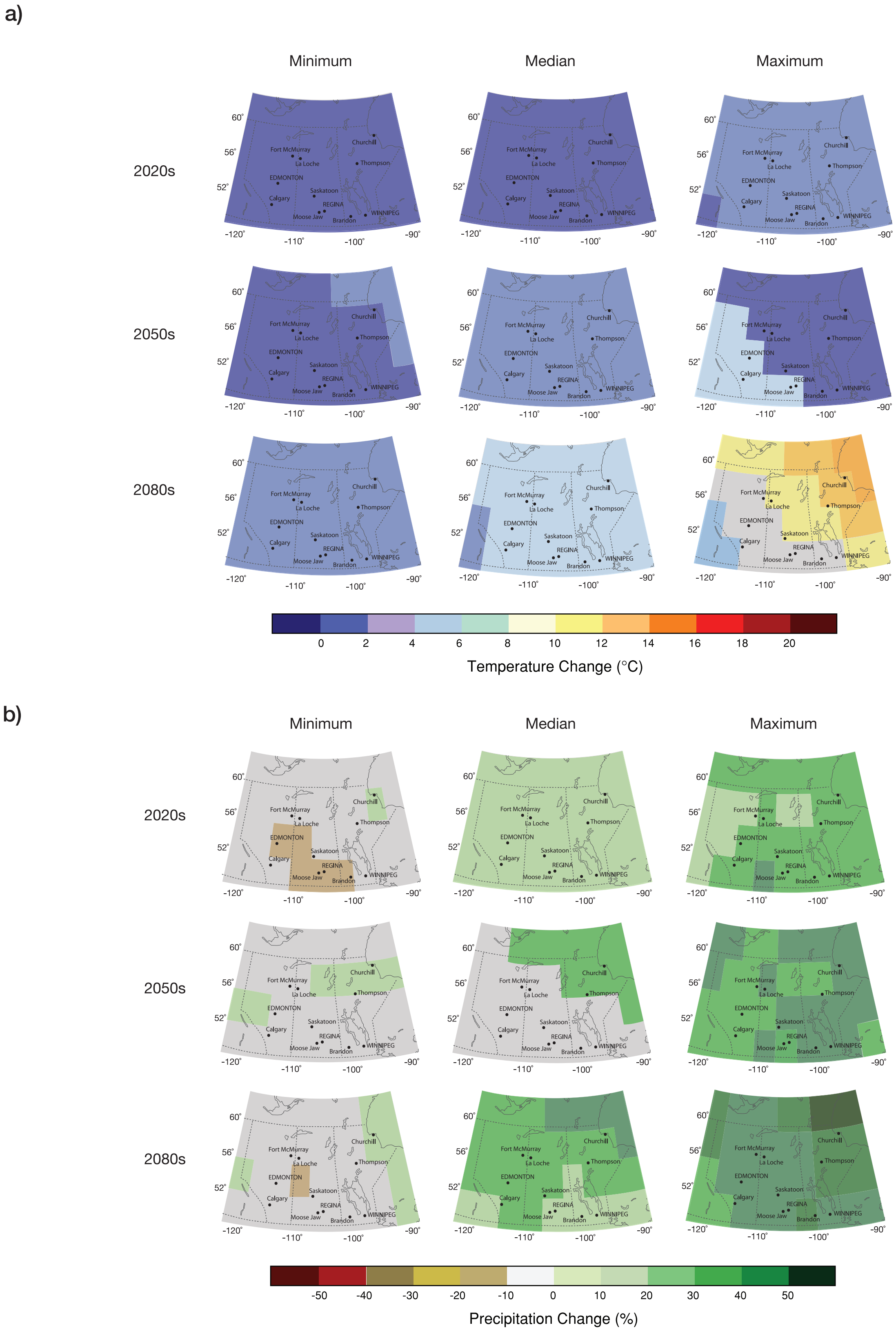

FIGURE 9: Climate change scenario maps for the Prairies in the 2020s, 2050s and 2080s, showing minimum, median and maximum projections of changes in a) mean annual temperature, and b) mean annual precipitation. Note that maximum and minimum changes for precipitation refer to wettest and driest scenarios, respectively (*see* Appendix 1 of Chapter 2).

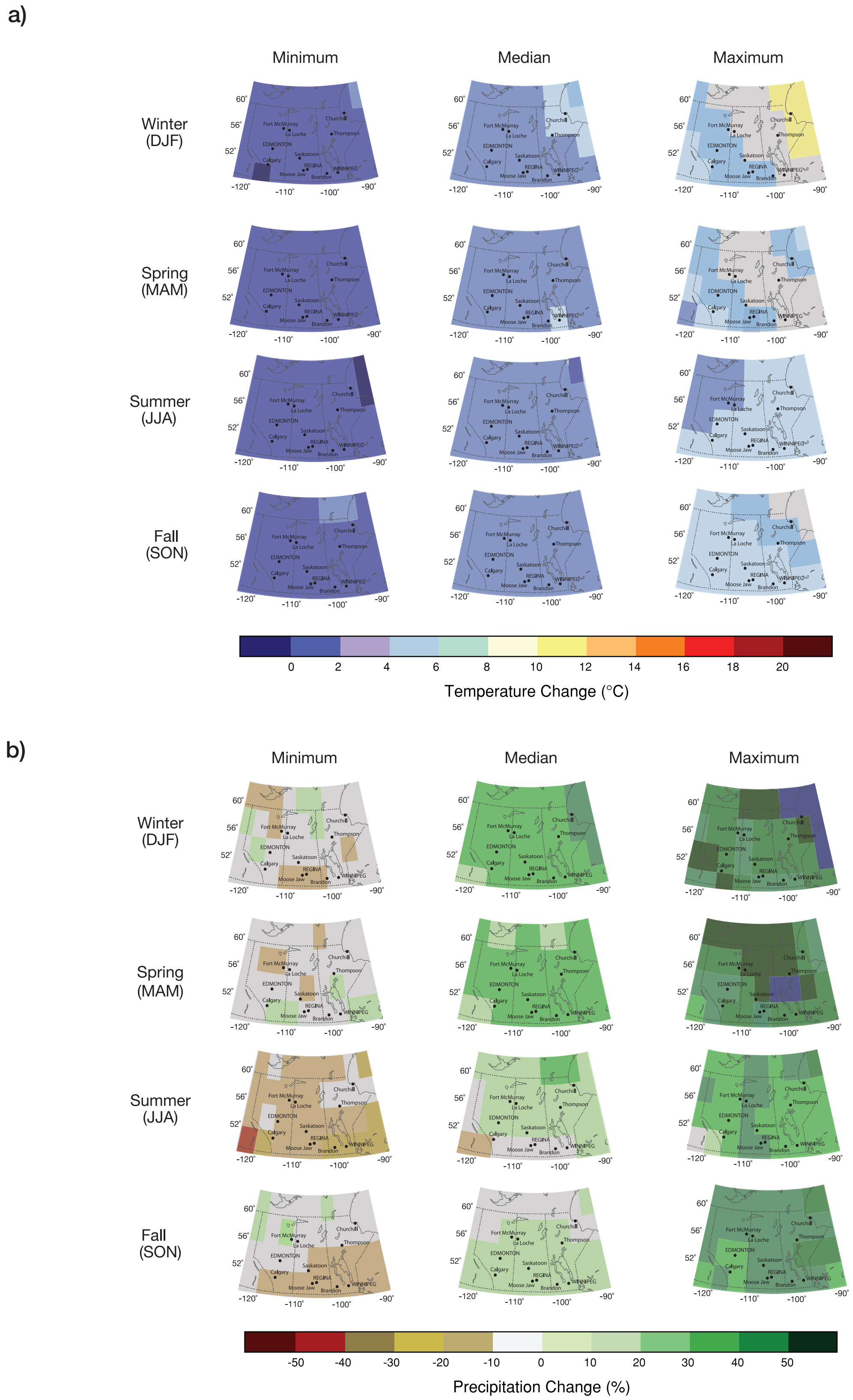

FIGURE 10: Climate change scenario maps for the Prairies in the 2050s, showing minimum, median and maximum projections of changes in a) mean seasonal temperatures and b) mean seasonal precipitation. Upper-case letters in parentheses after each season represent the months in that season. Note that maximum and minimum changes for precipitation refer to wettest and driest scenarios, respectively (*see* Appendix 1 of Chapter 2).

3 SENSITIVITIES AND KEY VULNERABILITIES: NATURAL CAPITAL

3.1 WATER RESOURCES

Changing climate is, and will continue to be, reflected in the key variables governing the hydrological cycle: temperature, evapotranspiration, precipitation, and snow and ice. The natural health and wealth of the Prairies are intimately linked to the quality and quantity of the water. It impacts almost every aspect of society: health and well-being, agriculture, food production and rural life, cities and infrastructure, energy production and cost, forestry, recreation and other sectors. Some of the greatest societal stresses endured in the Prairies have been directly related to extremes in the hydrological climate system.

Surface Water Resources

Changes in winter precipitation, temperature and duration will have substantial impacts on surface water supplies. Winter warming will reduce snow accumulations in alpine areas (Leung and Ghan, 1999; Lapp et al., 2005) and across the Prairies. This will cause declines in annual streamflow and a notable shift in streamflow timing to earlier in the year, resulting in lower late-season water supplies. Runoff from small prairie and parkland rivers is almost exclusively due to snowmelt runoff over frozen soil (Byrne, 1989). Reduced winter snowfall in the latter half of the twentieth century (Akinremi et al., 1999) contributed to the observed trend of declining streamflows. This is already a critical issue for many rivers in the southern Prairies, such as the Bow, Oldman and Milk, particularly in dry years.

Monthly mean streamflow at 50 gauges in the Prairies showed positive trends in March and negative trends in the autumn months between the late 1940s–early 1950s and 1993 (Gan, 1998). This increase in the March streamflow can be attributed both to an increase in spring precipitation as rain and to earlier snowmelt (Burn, 1994; Gan, 1998; Zhang et al., 2001; Yue et al., 2003). Burn (1994) found that 30% of unregulated rivers in western Canada showed a statistically significant trend towards earlier spring runoff by the 1990s, with greater advances in peak runoff observed in rivers at higher latitudes.

Widespread glacier retreat during the last century has resulted in a measurable decline of summer and fall runoff, impacting rivers during the period of lowest water flow and highest water demand (Demuth and Pietroniro, 2003). Continued glacier retreat will exacerbate water shortages already apparent in many areas of Alberta and Saskatchewan during drought years. Demuth and Pietroniro (2003, p. iv.) concluded that:

> *"The reliability of water flow from the glaciated headwater basins of the upper North Saskatchewan River Basin has declined since the mid-1900s. Hydrologic and ecological regimes dependent on the timing and magnitude of glacier-derived meltwater may already be experiencing the medium-long-term impacts of climate change discussed by the IPCC."*

Since headwaters of the upper North Saskatchewan River are close to those of the Athabasca River and Bow River systems, all three river systems are likely experiencing the same changes in streamflow now, and will continue to do so in future.

Most scenarios suggest higher winter and spring flows, when more precipitation, especially rainfall, is projected. Reductions in flow are generally projected for the summer, the season of greatest demand for surface water. Pietroniro et al. (2006) coupled hydrological models and climate change scenarios to estimate the following mean annual changes in flow by the 2050s:

- Red Deer River at Bindloss: –13%
- Bow River at the mouth: –10%
- Oldman River at the mouth: –4%
- South Saskatchewan River at Lake Diefenbaker: –8.5%.

Groundwater Resources

Groundwater is the source of potable water for about 21% of Manitoba residents, 23% of Albertans and 43% of Saskatchewan's population (Environment Canada, 2004b). Future groundwater supplies will decline in some regions but may increase in others, reflecting a dynamic equilibrium between recharge, discharge and groundwater storage (Maathuis and Thorleifson, 2000; Chen et al., 2002). Increased rainfall in early spring and late fall will enhance recharge if soil water levels are high; otherwise, water will be retained in the soil, benefiting ecosystem and crop productivity. Drier soils due to higher rates of evapotranspiration result in decreased recharge, which would lead to a slow but steady decline in the water table in many regions. When groundwater levels decline due to reduced recharge, prolonged drought or overpumping, water supply and quality are adversely affected. This occurred in central Alberta during the 2001–2003 drought, which was the most intense long-duration drought in recorded history (Kienzle, 2006). Declines in groundwater levels in a carbonate aquifer near Winnipeg could cause salinization of water wells as the saline-freshwater boundary potentially moves eastward in response to climate change (Chen et al., 2002).

Water Demand

Increases in the demand for water will compound issues of water supply. The magnitude of potential demand is clearly illustrated in the following estimates for the South Saskatchewan River basin (Alberta Environment, 2002, 2005, 2006):

- Demand from non-irrigation could increase between 35% and 67% by 2021 and between 52% and 136% by 2046.
- Irrigation districts have the potential to expand by up to 10% and 20% in the Oldman River and Bow River basins, respectively.
- Population in the South Saskatchewan River basin is expected to grow from 1.3 million in 1996 to more than 2 million by 2021, and to more than 3 million by 2046.
- About 65% of the average natural flow of the Oldman River and its tributaries has been allocated (Government of Alberta, 2006). Most of these allocations (almost 90%) are committed to irrigated agriculture. New water license allocations are not available in the Oldman River and Bow River basins, so all growth must occur within existing allocations.

Water Quality

Aquatic ecosystems and water resources in the Prairies face a range of threats related to water quality that will be exacerbated by climate change. These include (Environment Canada, 2001):

- physical disruptions associated with 1) land-use impacts of agriculture and forestry, 2) urban water withdrawals, 3) sewage effluent and storm water runoff, and 4) impacts of dams and diversions;
- chemical contamination, including 1) persistent organic pollutants and mercury, 2) endocrine-disrupting substances, 3) nutrients (nitrogen and phosphorus), 4) urban runoff and municipal wastewater effluent, and 5) aquatic acidification; and
- biological contamination, such as waterborne pathogens.

Reductions in streamflow under climate warming will worsen these impacts. Dilution capacity will likely decline as streamflows decrease and lake residence times increase accordingly. Droughts could result in enhanced soil erosion from both agricultural lands and areas burned by forest fires. This erosion will increase stream sediment loads and enhance nutrients in local water systems, leading to eutrophication of water bodies and increased pathogen loading in streams during the summer (Hyland et al., 2003; Johnson et al., 2003; Little et al., 2003). The Millennium Ecosystem Assessment (2005) identified the joint effects of climate change and nutrient overenrichment as the major threat to drylands agro-ecosystems. The size of the massive algae blooms in Lake Winnipeg correlate with higher summer temperatures (McCullough et al., 2006). Since the Lake Winnipeg watershed encompasses much of the Prairie Ecozone, the lake receives runoff from a large proportion of Canada's agricultural land.

Impacts of Extreme Hydrological Events

The few studies that have examined GCM outputs for extremes of future climate (e.g. Kharin and Zwiers, 2000) suggest an increased probability of extreme conditions, including a greater frequency of flooding and severe drought. A likelihood of increased drought severity is also inferred from both recent and prehistoric conditions of the western interior. The recent climate (since the 1940s) has been characterized by severe droughts (large water deficits) of relatively short duration compared to preceding centuries (Sauchyn et al., 2003). The natural climate cycles that underlie climate change include drought of much longer duration than those that occurred in the twentieth century (*see* Section 2.4).

In the boreal forest and taiga areas, increased drought frequency, including persistent multi-year droughts (Sauchyn et al., 2003), will result in declining soil water and increased forest fire extent and net area burned. During recent extreme droughts, organic soils have dried and burned with forests, resulting in an almost total loss of vegetation and soil cover, and subsequently the ability to store water locally. Under these conditions, runoff becomes instantaneous, resulting in flash floods.

Increasing annual and seasonal temperatures will exacerbate drought conditions (Laprise et al., 2003), but warmer temperatures also increase the likelihood of extreme rainfall events (Groisman et al., 2005). Such events frequently cause local or regional flooding, such as that experienced in the South Saskatchewan River basin in 1995 and 2004. These and the other recent flood and drought events listed below demonstrate the pressures on water resource management that are expected to increase in future:

- An Edmonton thunderstorm dropped 150 mm of rain in under an hour on a city already saturated by earlier storms. Losses were estimated at $175 million (Environment Canada, 2004a).

- The instrumental records indicate that the recent sustained drought of 2000–2003 recorded far less total precipitation than that of the mid-1930s (Kienzle, 2006). The most severe impacts on soil moisture and groundwater levels are from multi-year droughts.

- Environment Canada (2004a) characterized the 2002 crop year as "the worst ever for farmers in Western Canada."

- In 2001, the St. Mary River Irrigation Project in southern Alberta had insufficient water to meet annual allocations: farms were only provided with 60% of their water allocations.

Adaptation

Adaptation to changes in the hydrology of the Prairies will be challenging, especially where current water supplies are almost fully allocated. Future water scarcity could lead to abandonment and/or underutilization of major infrastructure (canals, pipelines, dams and reservoirs) worth billions of dollars. Rising demand due to warmer climate and a decline in summer runoff in some years will lead to calls for increased storage and diversion of water away from areas with water surpluses. However, reservoirs are greenhouse gas sources (St. Louis et al., 2000), and dams and diversions have well-documented negative environmental impacts (Environment Canada, 2001; Mailman et al., 2006). Adaptation in the water resources sector is also discussed in Section 5.1.1.

3.2 ECOSYSTEMS

In a global analysis, climate change is rated as second only to land use in importance as a factor that is expected to determine changes in biodiversity during the current century (Sala et al., 2000). Changes in climate will alter environmental conditions to the benefit of some species and the detriment of others, often with economic consequences. For example, as vegetation and insects shift in response to changing climate, tourism and recreation activities such as bird watching will be affected, and agricultural, forestry and urban pest management practices may have to adjust.

Biodiversity and Productivity

In the absence of moisture limitations or other constraints, plant productivity should rise with an increase in temperature and length of growing season. Increased photosynthetic activity for much of Canada during the period 1981–1991 has been attributed to a longer growing season (Myneni et al., 1997). Little is known, however, about which species or assemblages will be relatively advantaged or disadvantaged in increasingly moisture-constrained ecosystems. Changes in the timing and intensity of freeze-thaw events, diurnal temperature patterns (Gitay et al., 2001), and storm and wind stress events may influence vegetation distribution or survival, especially of various tree species (Macdonald et al., 1998), but the details of how this will occur are not known.

Factors other than temperature and precipitation will also affect prairie ecosystems. For example, CO_2 fertilization increases the efficiency of water use by some plant species (Lemon, 1983), although there are many uncertainties about the sum effect (Wheaton, 1997). While studies have reported a positive CO_2 enrichment effect on the growth of white spruce in southwestern Manitoba (Wang et al., 2006), modelling and an empirical study (Gracia et al., 2001) suggested that any positive CO_2 fertilization effect is neutralized among evergreens because growth is constrained by moisture limitations. Prediction of overall changes in forest CO_2 uptake and storage, independent of interspecies variations, is not yet possible (Gitay et al., 2001). One major problem in predicting the impacts of CO_2 enrichment on a specific species is that the impact occurs on all vegetation simultaneously. It is not enough to know the CO_2 response of one species; rather, one needs to know the relative growth advantage, if any, gained by all vegetation species competing for resources at a given site.

Ultraviolet B radiation and ground-level ozone levels are increasing and are expected to negatively impact vegetation, possibly nullifying any positive CO_2 enrichment effect (Henderson et al., 2002). In addition, nitrogen deposition from industrial activity may be affecting species growth and competitive interactions, even in locations far from industrial centres (Kochy and Wilson, 2001).

Changes in forest disturbance regimes induced by climate change may be substantial enough to alter current forest ecosystems (Loehle and LeBlanc, 1996). Henderson et al. (2002) noted two pathways of forest change: 1) slow and cumulative decline; or 2) catastrophic loss, such as a major fire. Increased average winter temperatures will lead to greater overwinter survival of pathogens and increased disease severity (Harvell et al., 2002). Drought conditions weaken trees' defences to more virulent pathogens (Saporta et al., 1998). As conditions become more xeric, the lifespan of conifer needles is reduced, placing conifers under increasing stress (Gracia et al., 2002). The boreal forest is expected to be significantly affected by climate change, especially at its southern boundary (Herrington et al., 1997; Henderson et al., 2002; Carr et al., 2004). Major changes in species representation are projected for Saskatchewan's boreal forest by 2080 through impact modelling (utilizing the CGCM1 and the A1 emission scenario; Carr et al., 2004).

Changes in the Timing of Biological Events

Early settlers and Aboriginal people recognized the timing of biological events as a function of season and weather, and used these indicators to forecast the timing and success of planting, fishing and hunting activities (Lantz and Turner, 2004). The dates and rates of spring flowering of widely distributed wild plants are among the most reliable events that can be monitored and used as an index of weather and climate. A program called 'Plantwatch' monitors the phenology of flowering of key wild plants through the reports of a network of volunteers, and has become an important tool for tracking the impacts of changing climate (Beaubien, 1997). Dates of flowering of key perennial plants in Alberta are closely related to the average temperature two months prior to bloom (Beaubien and Freeland, 2000). A 26-day shift to earlier onset of spring has already occurred over the past century (Beaubien and Freeland, 2000). The spring flowering index derived from the Plantwatch data was found to be correlated with Pacific sea-surface temperatures, including El Niño events.

Vegetation Zone Response

Models of vegetation zonation have shown a northward shift of the forest-grassland boundary in the Prairies with climate change (Hogg and Hurdle, 1995; Vandall et al., 2006). Grasslands are also projected to change, with aspen parkland and fescue prairie of the present northern fringe giving way to variants of mixed prairie. These modelled shifts in zonation do not specify the exact composition of future vegetation because of lags in migration of some species. However, the following trends are projected from the present to the 2050s (Vandall et al., 2006):

- In forest regions, there will be a general reduction in tree growth, regeneration failure in dry years and a gradual reduction in tree cover and expansion of grassland patches.
- In the aspen parkland, there will be shrinking of aspen groves, reduced invasion of grassland patches by shrubs and poplar sprouts, and decreasing shrub cover.

The most significant impacts can be expected to occur at the interfaces of drier grassland with the moister foothills grassland, and at the interface of grassland with parkland and forest.

Grassland production is limited by moisture supply. Although the warmer and drier climate projected for the Prairies would suggest declining production and grazing capacity, actual changes in grassland production are likely to be modest, given a longer growing season, reduced competition from shrubs and trees, and increases in warm-season grasses that have higher water-use efficiency (Thorpe et al., 2004).

Impact models that consider simply the current (static) positions of ecoregions (e.g. Davis and Zabinski, 1992) have projected significant changes in boreal forest area and quality. Models based on plant growth and population dynamics would yield more robust predictions. The northern extremes of the boreal forest will likely extend under climate warming, but the rate of northern extension of the forest is uncertain, and will take decades as trees respond to variations in soil temperature, permafrost and uncertain seed dispersal and establishment (Lloyd, 2005). An associated change in the southern boundary of the forest is likely, but would be influenced by droughts and associated large-scale fire events.

Estimating the timing of ecological changes is difficult, in part because of inability to predict precise thresholds. Vegetation responds after the fact to climate change (autonomous adaptation), and it is natural for a given ecosystem to be 'behind' environmental conditions to some degree, a condition termed ecological inertia (*see* Henderson et al., 2002). Anderson et al. (1997) warned that ecosystems can absorb stresses over long periods of time before crossing a critical threshold, which may lead to rapid ecosystem and landscape modification. The climate change impact on mature trees is not likely to be noticeable until biological thresholds are reached and dieback results (Saporta et al., 1998).

Climate change will be significant in all of the prairie-parkland national parks (Elk Island, AB; Prince Albert, SK; Riding Mountain, MB) and Wood Buffalo National Park, NT (Scott and Suffling, 2000). These parks can expect increases in forest fire frequency and intensity, increased forest disease outbreaks and insect infestations, and loss of boreal forest to grassland and temperate forest (de Groot et al., 2002). Climate change represents "an unprecedented challenge for Parks Canada" and "current ecological communities will begin to disassemble and 'resort' into new assemblages" (Scott and Suffling, 2000). To address this challenge, Henderson et al. (2002, p. 3) stated that "In a world of climate change, selection of protected areas may need to focus on site heterogeneity and habitat diversity (as these provide some buffer against climate change) rather than on representativeness." For example, high-relief terrain, such as the Cypress Hills landscape, can always be expected to provide a range of habitats and ecosystems different from the surrounding plains, and therefore contribute to biodiversity, even as the nature of these habitats and ecosystems changes over time (*see* Case Study 1). However, a low-relief landscape, such as Prince Albert National Park, which is mandated to protect fescue grassland, aspen parkland and southern boreal forest within the national parks system, may fail to preserve these landscape elements over time, just as Wapusk National Park, MB may fail to protect polar bear habitat, its mandated raison d'être.

Wildlife

The prairie pothole region of central North America is the single most productive habitat for waterfowl in the world, with the Canadian Prairies providing breeding grounds for 50 to 80% of the Canadian duck population (Clair et al., 1998). Increasing aridity in the prairie grasslands is likely to negatively impact migratory waterfowl populations (Poiani and Johnson, 1993) as waterfowl numbers decrease in response to drought and habitat loss (Bethke and Nudds, 1995). Weather fluctuations during the breeding season account for more than 80% of the variation in population growth rate of mallards and other ducks (Hoekman et al., 2002). In northern regions, earlier dates of disappearance of snow and increasing average temperatures have resulted in earlier nesting and hatching of geese (e.g. LaRoe and Rusch, 1995).

Wildlife migration patterns and population size have already been affected by recent climate trends, and further impacts are expected with climate change (Inkley et al., 2004). This will affect hunting-based industries, environmental activities, fishing regulations and production, and traditional ways of life reliant on vertebrate biodiversity. Relatively sessile animals, such as reptiles and amphibians, are at greater risk of extirpation than relatively mobile birds or butterflies. Aquatic ecosystems will be stressed by warmer and drier conditions, and a large number of prairie aquatic species are at risk of extirpation (James et al., 2001). Many fish species, for example, are sensitive to small changes in temperature, turbidity, salinity or oxygen regimes. For the Prairies, larger algal blooms, accelerated eutrophication and serious impacts on fish species are expected, due to a combination of climate change, increasing nutrient runoff and increasing human use pressures on natural water systems (Schindler and Donahue, 2006).

Adaptation

Conservation policy can aim to extend ecological inertia, have no impact on it or reduce it (Henderson et al., 2002). Vegetation associations that are most 'in tune' with the evolving climate will require the least degree of human intervention. Conversely, those vegetation ensembles that are outside their natural climate norms will require increasingly intensive and active human intervention and management to survive. However, with a high degree of human intervention, it will be possible at some sites to maintain vegetation (and associated fauna) that would otherwise certainly disappear.

CASE STUDY 1

Climate Change Impacts on the Island Forests of the Great Plains

Scattered from the plains of central Alberta to Texas are island forests: refugia of trees and tree-dependent species isolated in a sea of grass. Henderson et al. (2002) examined the impacts that climate change will have on five of these ecosystems in the southern Prairies and adjacent North Dakota and Montana: the Cypress Hills, Spruce Woods, Turtle Mountain, Moose Mountain and the Sweet Grass Hills (Figure 11). These island forests have considerable regional significance in terms of biodiversity, wildlife habitat, grazing land and sources of timber, and as the headwaters of many prairie streams.

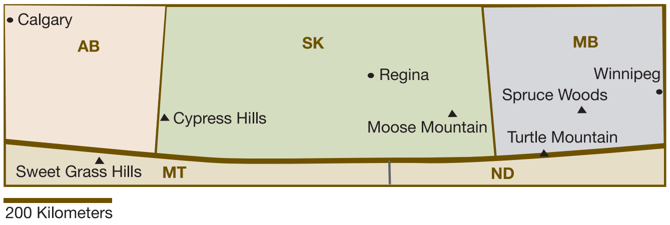

FIGURE 11: Location of the island forest study sites.

Plains island forests are at risk from climate change. They are marginal or ecotone systems, borderline between grassland and forest ecosystems, and therefore sensitive to small changes in environmental conditions. As they are relatively small ecosystems, island forests may exhibit lower genetic diversity and greater vulnerability to catastrophic disturbance, such as wildfire, pathogen attack or severe drought.

The study used a range of climate scenarios derived from three global climate models (HadCM3, CGCM2, and CSIROMk2b) to determine the future moisture regimes for the five island forests and to consider the implications of these moisture regimes for the dominant tree species. In the plains, a region always on the edge of drought stress, soil moisture levels represent the single most important climate change parameter for natural ecosystems. The net effect on moisture levels of the modelled changes in both temperature and precipitation is shown in Figure 12. Increased temperatures will have a powerful evaporation effect, such that soil moisture balances will decline substantially.

FIGURE 12: Summary of the projected changes in soil moisture levels (averaged over the five island forest study sites) for the 2020s, 2050s and 2080s. The thin vertical lines in the plot indicate the range of possible future moisture levels compared with the climate of 1961-1990. The boxes indicate the moisture level ranges within which 50% of the scenario projections fall. The horizontal dash within each box indicates the median moisture scenario.

Henderson et al. (2002) concluded that the island forests will suffer serious challenges to ecosystem integrity. Highly intensive management will likely be necessary to preserve some type of forest cover at these sites. Management that aims simply to retain existing vegetation, or to restore historical vegetation distributions and ecosystems, will fail as the climate moves farther away from recent and current norms. Possible adaptation actions range from protecting the forests by maintaining a diversity of age stands and responding aggressively to pathogen disturbances, to actively regenerating the forest with existing or alien tree species that are better adapted to the new climate parameters.

Increasing connectivity between protected areas to facilitate migration of particular species populations is commonly proposed as one method of coping with climate change (e.g. Malcolm and Markham, 2000; James et al., 2001; Joyce et al., 2001). Although some species might be able to migrate, others will be threatened by the arrival of new competitors or by the pathogens that increased connectivity supports. Thus, increased connectivity may also hasten the decline of some ecosystems by favouring alien invasions.

Intentional introduction of a species native to a nearby area may be a useful tool for adaptation to climate change, and such introductions are less likely to be ecologically disruptive than Eurasian exotic species (Thorpe et al., 2001). Yet the most drought-hardy trees that could potentially survive in the northern plains derive from central Asia (Henderson et al., 2002). Western conifers, such as Douglas fir and ponderosa pine, and hardwoods of the southern Prairies, such as Manitoba maple and green ash, may be suited to future climates of the western Boreal Ecozone (Thorpe et al., 2006). Native boreal species, on the other hand, are expected to shift northward and decline in the southern parts of their current range.

In restoration ecology, "it is often assumed that understorey vegetation will establish over time ('plant trees and the rest will come'), but natural invasion may not automatically bring back all species desired" (Frelich and Puettmann, 1999). However, little is known about alien tree introductions in prairie forests, and virtually nothing about mid- and understorey introductions. Biodiversity managers need to think of themselves not as practitioners of preservation, but as 'creation ecologists', as antecedent landscapes can no longer be effectively targeted. We have options, but the past is not one of them. The future ecosystems that result from climate change in the Prairies will be unprecedented.

3.3 SOIL LANDSCAPES

The Rocky Mountains of western Alberta and the dryland landscapes of the Prairie Ecozone are highly dynamic and active landscapes. Catastrophic and hazardous geological processes associated with extreme climate events are common on the long, steep slopes of the Canadian Cordillera. For example, in August 1999, a debris flow at Five-Mile Creek in Banff National Park blocked the Trans-Canada Highway for several days at the peak of the tourist season (Evans, 2002). Such events are nearly always triggered by excess rainfall or by runoff from rapid melting of snow or ice. An increased frequency of landslides, debris flows, rock avalanches and outburst floods is probable, given current and projected future trends in hydrology and climate that include increased rainfall (especially in winter), rapid snowmelt and shrinking glaciers (Evans and Clague, 1994, 1997). These changes will affect public safety and the maintenance of infrastructure, especially with increasing recreational activity and residential development in the Rocky Mountains. In the longer term, further warming, drought and the complete wastage of glaciers could cause catastrophic events to taper off; however, the decay of permafrost could accelerate slope failures at high elevations for many decades (Evans and Clague, 1997).

Most of the Prairies region is underlain by poorly consolidated sediments that erode and fail where they are exposed to the forces of wind, water and gravity on valley sides, and where farming or aridity limit the vegetation cover. The most active landscapes are the dune fields and river valleys (Lemmen et al., 1998) that are sensitive to hydrological and climatic variation and extremes (Lemmen and Vance, 1999). Projected increases in drought and aridity will likely result in more widespread wind erosion and increased sand dune activity (Wolfe and Nickling, 1997). Current dune activity in the dry core of the mixed grassland ecoregion serves as an analogue of the potential response of currently stable dune fields on the moister margins of the Prairie Ecozone and the southern boreal plains (Wolfe and Nickling, 1997). Global climate model–based assessments of future vegetation and soil moisture (Thorpe et al., 2001) suggest that vegetation will shift towards more open grassland, with increased potential for sand dune activity. Climate at the driest sites may exceed thresholds for active sand dune crests, and would require proactive land-use management and stringent enforcement of current guidelines and regulations to limit dune activity. Slopes and stream channels exposed to less frequent but more intense rainfall will also be subjected to enhanced erosion and shallow slope failures because the protective vegetation cover will suffer from the prolonged dry spells (Sauchyn, 1998; Ashmore and Church, 2001).

With the modification of about 90% of the Prairie Ecozone for agriculture, tens of millions of hectares were exposed to soil erosion. Annual soil loss from cropland is two to three orders of magnitude higher than on rangeland (Coote, 1983). Wind and water erosion are episodic: centimetres of topsoil can be removed during a single event, reversing centuries or millennia of soil formation and seriously reducing the natural fertility of cropland. The semiarid to subhumid mixed grassland ecoregion, an area of approximately 200 000 km^2, is at risk of desertification. The human impacts on prairie soils are reduced by soil conservation but can be exacerbated by social and economic factors, including the declining national significance of prairie agriculture since the 1960s, the rising influence of global market forces and multinational corporations, declining rural population, and reduced support for agricultural research, farm crisis relief, income support programs and grain transportation (Knutilla, 2003).

Whereas social and economic futures are not easily predicted (*see* Section 2.3), projections of future aridity can be derived from GCMs. When the Aridity Index (ratio of precipitation to potential evapotranspiration, or P/PET) was computed for 1961 to 1990 and for the 2050s, using output from the Canadian CGCM2 and emission scenario B2, the area of land at risk of desertification (P/PET <0.65; Middleton and Thomas, 1992) increased by about 50% (Sauchyn et al., 2005). In the scatterplots of future climate (Figure 8), this scenario would plot above the median temperature and below the median precipitation; it is a moderately warm and dry climate scenario. With the high inter-annual variability in prairie climate, the trend towards increased aridity will be realized with droughts that are more frequent and/or sustained than the intervening years of normal to above-average moisture. Prolonged droughts are likely to exceed soil moisture thresholds beyond which landscapes are more vulnerable to disturbance and potential desertification (Prairie Farm Rehabilitation Administration, 2000).

4 RISKS AND OPPORTUNITIES: SOCIOECONOMIC SECTORS

4.1 AGRICULTURE

> *"Agriculture is both extremely important to the Canadian economy and inherently sensitive to climate."* (Lemmen and Warren, 2004, p. xi)
>
> *"Agricultural production, more so than any other form of production, is impacted the most by the weather."* (Stroh Consulting, 2005)

Biophysical Impacts and Adaptation

Agriculture in the Prairies could benefit from several aspects of the warming climate, depending on the rate and amount of climate change and ability to adapt (Table 9). Benefits could result from warmer and longer growing seasons and a warmer winter. Increasing temperature will be positive for crop growth and yield, up to certain thresholds. As agricultural producers are highly adaptive, they should be able to take advantage of these positive changes. Negative impacts may result from changes in the timing of precipitation, increased risk of droughts and associated pests, and excessive moisture (Table 9). Newly emerging threats and opportunities, such as the increased probability of drought in areas where frost or excess moisture are currently greater threats, will be more challenging to adapt to, as people in those areas have had less experience in dealing with drought.

Climate change projections have been used to drive crop production models for many years (e.g. Williams et al., 1988). However, results of assessments are still wide ranging, depending on the climate scenarios and impact models used, the scale of application, the assumptions made (e.g. Wall et al., 2004) and how adaptation is incorporated. One of the most important climate change impacts relates to changes in the availability of water for agriculture. All types of agriculture depend upon a suitable amount, quality and timing of water. Agriculture is Canada's largest net consumer of water (71%; Harker et al., 2004; Marsalek et al., 2004; *see* Case Study 2). Agricultural water use has shown steady growth since 1972, and this trend is likely to continue (Coote and Gregorich, 2000). Irrigated agriculture and large-scale livestock production are constrained by water availability (Miller et al., 2000), especially in drought years (Wheaton et al., 2005a). For example, animals require more water during times of heat stress, and water stress during critical times for plants (e.g. flowering) is especially harmful. Alberta has about 60% of Canada's irrigated cropland (Harker et al., 2004) and, in 2001, the Prairies had more than 67% of the beef cattle, dairy cattle, hogs, poultry and other livestock in Canada (Beaulieu and Bédard, 2003). Populations of both cattle and hogs have increased steadily in the past 10 years (Statistics Canada, 2005c). The demand for water for irrigation and livestock is expected to rise with increasing temperatures and expansion in these sectors.

Irrigation is the major agricultural adaptation to annual soil water deficits (*see* Case Study 2), and the move in recent decades to more efficient irrigation techniques has dramatically increased on-farm irrigation efficiencies. However, the continued loss of water from irrigation reservoirs and open-channel delivery systems due to evaporation, leakage and other factors indicate the need for further improvement in the management of limited water resources. Recent publications (e.g. Irrigation Water Management Study Committee, 2002) suggest that the Oldman River and Bow River basins could sustain expansion of irrigation by 10 and 20%, respectively. However, as climate change results in declining streamflows (*see* Section 3.1) and higher crop water demands (due to greater evapotranspiration and a longer growing season), these basins are expected to experience acute water shortfalls under current irrigation development. To what extent higher levels of atmospheric CO_2 will enhance the water efficiency of plants is still uncertain, and depends on the crops grown, nutrient and water availability (Van de Geijn and Goudriaan, 1996), and other factors (*see* Section 3.2). The use of crop varieties with greater drought tolerance is a common adaptation measure.

CASE STUDY 2

Agricultural Adaptation through Irrigation

Irrigation is the primary adaptation of agriculture in dry environments. It reduces the impacts of drought and other farm risks, supports higher crop diversity, increases profit margins and improves the long-term sustainability of smaller farm units. Irrigated agriculture is by far the largest water user on the Prairies, and small improvements in irrigation efficiency save considerable amounts of water. The Prairies have about 75% of Canada's irrigated land: Saskatchewan has 11%, and more than 60% is in southern Alberta (Irrigation Water Management Study Committee, 2002). Irrigation occurs on 4% of the cultivated land in southern Alberta's irrigation districts, where production represents 18.4% of Alberta's agri-food gross domestic product, exceeding the productivity of dryland farming by 250 to 300%. Major food-processing industries have evolved in southern Alberta, where the production of specialty crops (potatoes, beans, sugar beets) is enabled by the longer growing season, high heat units and relatively secure water supply derived mainly from snowmelt in the Rocky Mountains.

Advances in centre-pivot systems, including the irrigation of field corners and low-pressure application devices, have significantly improved the efficiency and effectiveness of irrigation. With labour savings and ability to irrigate rolling land and land 'above the ditch', the irrigated area in Alberta has more than doubled since 1970. In 2006, the irrigation infrastructure consisted of 7796 km of conveyance works (canals and pipelines) and 49 reservoirs. Off-stream reservoirs accommodate seasonal variations in supply and demand, but are not as effective as the on-stream reservoirs in meeting in-stream flow needs and apportionment. Capital costs are considerable for water distribution. For example, a plan to distribute water in eastern Alberta had an estimated price tag of $168 million using pipelines, canals and reservoirs to rejuvenate one of the most arid regions of the province (Special Areas Board, 2005). The net benefits of this project were 8 000 to 12 000 hectares (20 000–30 000 acres) of irrigation development for an investment of $15 000 to 20 000 per hectare.

A study of irrigation requirements and opportunities was initiated in 1996 by the Alberta Irrigation Projects Association (AIPA), representing the 13 irrigation districts in Alberta, the Irrigation Branch of Alberta Agriculture, Food and Rural Development (AAFRD) and the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada. The project report *Irrigation in the 21st Century* includes the following key findings:

- A move towards increased forage production to support the livestock industry, and an increased area of specialty crops for value-added processing, will result in slightly higher future water requirements than those of the current crop mix.
- On-farm application efficiency, the ratio between the amount of irrigation water applied and retained within the active root zone and the total amount of irrigation water delivered into the on-farm system, increased from approximately 60% in 1990 to about 71% by 1999. Efficiencies could approach 78% with new technologies, although a 75% on-farm application efficiency is considered to be a reasonable target for planning purposes for the foreseeable future.
- Properly levelled and designed surface irrigation systems can have efficiencies of up to 75%, whereas poorly designed and managed systems may have efficiencies less than 60%. Low-pressure, down-spray sprinklers can range in efficiency from 75 to 90%.
- Canal and reservoir evaporation losses are estimated to be about 4% of the licence volume. Decreases in evaporation losses have occurred with installation of pipelines. Although new storage reservoirs can significantly improve district operations and reduce return flows, reservoirs themselves are water users. This water use should be considered in decisions related to new storage development. Efficient storage sites that maximize the ratio of storage capacity to surface area should be given preference.
- The level of consumptive use, on average, is about 84% of that required for optimum crop yields. The level of crop water management is expected to increase in the future, assuming:
    - a further transformation of methods from surface to sprinkler irrigation;
    - a shift in irrigated crop types from cereals to higher value specialty crops;
    - that training and education of irrigation farmers on techniques and benefits of higher levels of crop water management will increase;
    - that improvements in irrigation scheduling technology and widespread use of scheduling techniques will continue; and
    - that on-farm system design will continue to improve.

The AIPA study was based on a simulation of the effects of on-farm and district water management demand variables on gross irrigation demand, and the ability of the river basins to meet that demand. Modelling was conducted for streamflow and climatic conditions in the South Saskatchewan River basin for the historical period 1928 to 1995. Even if water supply deficits occur with increasing magnitude, frequency and duration as a result of irrigation expansion, the economic sustainability of farm enterprises could still be maintained through improvements in efficiency of water use and increases in on-farm water applications. This is particularly important for those farm enterprises that can transfer water from low-value crops to higher value crops during water-deficit years.

Significant gains in on-farm application efficiencies have been realized as irrigation methods have changed and system technology has advanced. Improved on-farm irrigation management will result in future water applications meeting 90% of optimum crop water requirements for the types of crops grown and the cultural practices in southern Alberta. The water loss from irrigation reservoirs and the open channel delivery systems is still significant due to evaporation and leakage, for example, and will require even better management of limited water resources.

Whereas climate change and adaptation have yet to be explicitly addressed at the institutional level of irrigation districts and government agencies, there is evidence that adaptation and increased irrigation efficiency are being contemplated by individual irrigators (*see* Section 5). Some irrigators have proposed "alternatives to costly and environmentally sensitive dams" by "encouraging a study to look at the possibility of on farm storage, particularly on the corners of pivot irrigation land" (Kent Bullock, District Manager, Taber Irrigation District, pers. comm., November 14, 2006). This additional storage would provide water for agriculture in the early and late season if required.

TABLE 9: Future possible changes in agri-climates for the agricultural region of the Prairies, and examples of possible advantages and disadvanages for agriculture.

Index	Changes (relative to 1961-1990 unless noted)	Climate model and emission scenario	Period and spatial pattern	Reference	Possible advantages for agriculture[1]	Possible disadvantages for agriculture[1]
Thermal indices:						
Growing degree-days	25 to 40%	CSIROMk2b B2, greater changes with the other models	2050s; greater changes in the north	Thorpe et al. (2004)	More crop options; more crops per year; improved crop quality; shifts to earlier spring and later fall growth	Accelerated maturation rates and lower yields; increased insect activity; changed herbicide and pesticide efficacy
	42 to 45%	CGCM1 GA1	2050s for Lethbridge and Yorkton	CCIS[2] (2002)		
Heating degree-days	–23%	CGCM1 GA1	2050s for Lethbridge and Yorkton	CCIS[2] (2002)	Decreased heating costs	
Cooling degree-days	146 to 218%	CGCM1 GA1	2050s for Lethbridge and Yorkton	CCIS[2] (2002)		Increased ventilation for barns, more cooling shelters and air conditioning
Hot spells: 20-year return period of maximum temperature	1 to 2°C increase	CGCM2 A2	2050	Kharin and Zwiers (2005)		Heat stress to plants and animals; increased transpiration rates can reduce yields; increased need for water for cooling and drinking
Cold spells: 20-year return period of minimum temperature	2 to >4°C increase from 2000	CGCM2 A2	2050	Kharin and Zwiers (2005)	Decreased heat stress to animals	Increased pests and diseases; increased winterkill potential
Moisture indices:						
Soil moisture capacity (fraction), annual	>0 to <–0.2; mostly drying	CGCM2 A2 ensemble mean	2050s; greatest decreases in south to southeast	Barrow et al.(2004)		Increased moisture stress to crops; decreased water availability
Palmer Drought Severity Index	Severe droughts twice as frequent	Goddard Institute for Space Studies	Doubled CO_2 for southern Saskatchewan	Williams et al. (1988)		Increased damages and losses from droughts; increased costs of adaptation, etc.
Moisture deficit: annual precipitation minus potential evapo-transpiration (P-PET)	–60 to –140 mm (i.e. increased deficit of 0 to –75mm	CGCM1 and HadCM3	2050s	Gameda et al. (2005)	As for droughts	As for droughts
		CGCM1 GA1	2050s	Nyirfa and Harron (2001)	As above	As above
Aridity Index (AI): ratio of annual precipitation and potential evapotranspiration (P/PET)	Area of AI <0.65 increases by 50%	CGCM2 B2	2050s	Sauchyn et al. (2005)	As above	As above

Notes:

[1] Most of the advantages and disadvantages are summarized from Wheaton (2004)

[2] Climate Change Impacts Scenarios (CCIS) project

TABLE 9: (Continued)

Index	Changes (relative to 1961-1990 unless noted)	Climate model and emission scenario	Period and spatial pattern	Reference	Possible advantages for agriculture[1]	Possible disadvantages for agriculture[1]
Number of dry days: time between 2 consecutive rain days (>1 mm)	Modest and insignificant changes	CGCM2 A2	2080 to 2100	Kharin and Zwiers (2000)		
Number of rain days	Modest and insignificant changes	CGCM2 A2	2080 to 2100	Kharin and Zwiers (2000)		
Precipitation extremes: 20-year return period of annual extremes	Increase of 5 to 10 mm and return period decreases by about a factor of 2	CGCM2 A2	2050	Kharin and Zwiers (2005)		More flooding and erosion concerns; more difficult planning for extremes
Snow cover	Widespread reductions	CGCM2 IS92a	Next 50 to 100 years	Brown (2006)	Decreased snow ploughing; increased grazing season	Decreased quantity and quality of water supplies
Other indices:						
Wind speed, annual	<5 to >10%	CGCM2 A2 ensemble mean	2050s	Barrow et al. (2004)	Greater dispersion of air pollution	Greater soil erosion of exposed soils; damage to plants and animals
Wind erosion of soil	16% –15%	Manabe and Stouffer Goddard Institute for Space Studies	Doubled CO_2 Doubled CO_2	Williams and Wheaton (1998)		
Incident solar radiation	<–2 to <–6 W/m^2	CGCM2 A2 ensemble mean	2050s; greatest decreases in central north	Barrow et al. (2004)	Decreased radiation may partially offset heat stress	Reduced plant growth if thresholds are exceeded
Climate Severity Index[3]	–3 to –9	CGCM1 IS92a	2050s; greatest improvements in Alberta and Manitoba	Barrow et al. (2004)		Less severe climates for outside work; more suitable for animals
Carbon dioxide	Various emission scenarios used (e.g., 1% per year)	IS92a		Leggett et al. (1992)	Increased plant productivity, depending on other limits	Possible reduced quality of yield

Notes:

[3] Climate Severity Index (CSI) is an annual measure of the impact of climate on human comfort and well-being, and of the risk of certain climatic hazards to human health and life, with a scale ranging from 0 to 100 (Barrow et al., 2004); higher CSI indicates more severe climates; severity is weighted equally between winter and summer discomfort factors, and psychological, hazards and outdoor mobility factors.

Economic Assessment

Results from studies on the economic impacts of climate change on Prairies agriculture are highly variable from region to region and from study to study. Some studies suggest that overall economic consequences will be negative and small (Arthur, 1988), whereas others indicate positive and large economic impacts (Weber and Hauer, 2003). Manitoba, the least water deficient province, has been projected to benefit from warming as producers shift to higher value crops, resulting in an increased gross margin of more than 50% (Mooney and Arthur, 1990). Although mostly adverse impacts were initially predicted for Saskatchewan (Williams et al., 1988; Van Kooten, 1992), this conclusion has been questioned by American studies of areas neighbouring the Prairies, which project agricultural benefits from longer growing seasons and warmer temperatures (Bloomfield and Tubiello, 2000). Similarly, studies using a land value approach (Weber and Hauer, 2003) estimate a positive impact on Prairies agriculture, with average gains in land values of $1551 per hectare, an increase of approximately 200% over the 1995 values. These land values are driven by the increase in the length of the growing season and production of more valuable crops.

Three major limitations of the available evidence on the economic impacts of climate change on agriculture are as follows:

- Most economic impact studies do not consider impacts associated with extreme climate events, such as droughts and floods, which can have devastating effects on the regional economy (*see* Case Study 3; Wheaton et al., 2005a, b).
- Many studies do not utilize integrated approaches, such as bioeconomic models, to estimate economic impacts of climate change on Prairies agriculture. There is a need for more integrated biophysical-socioeconomic assessment of climate change impacts. A conceptual methodology for such analysis is shown in Figure 13.
- Very few studies address livestock production. Climate change will result in both economic losses and gains in livestock production. Losses will occur through heat stress on livestock and incidence of new pests and diseases, while gains are expected from improved feed efficiency under a warmer climate.

Net agricultural economic impacts on the Prairie region would also be affected by trade linkages, both within Canada and with the rest of the world (*see* Chapter 9). For example, Canada's position in the production and trade of wheat and grain corn may improve relative to rest of the world (Smit, 1989; *see* Chapter 9). Wheat production in Canada, for instance could rise by 4.5 to 20% (Reilly, 2002).

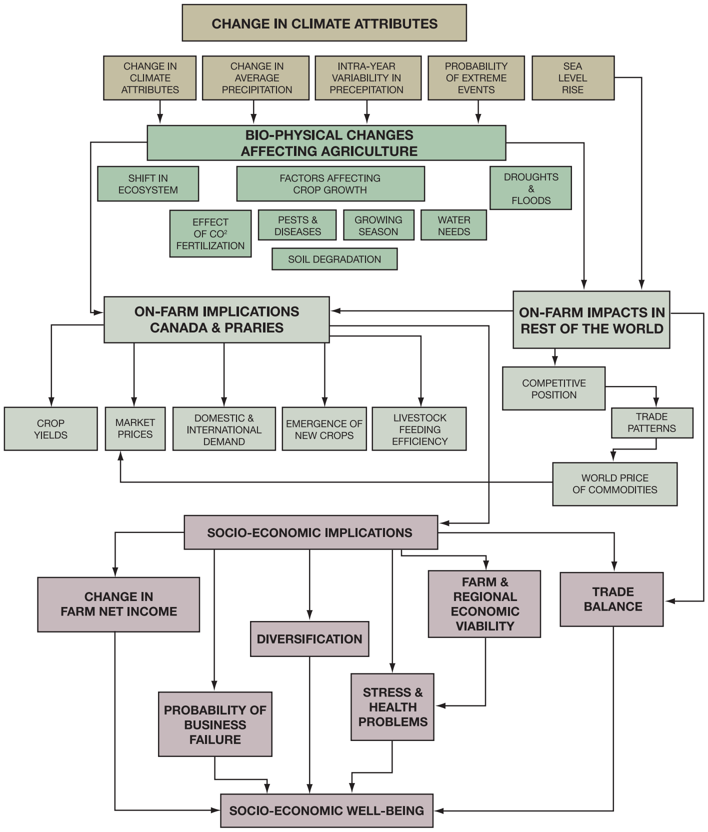

FIGURE 13: Interrelationships between climate change and socio-economic impacts related to agriculture.

Conclusions

Opportunities for agriculture may result from continued expansion of the growing season, increased heat units and milder, shorter winters. Negative impacts of climate change include increased frequency and intensity of extremes, such as drought and intense storms, and rapid rates of change that may exceed certain thresholds. The net impacts on agriculture are not clear and depend heavily on assumptions, including the effectiveness of adaptation. Several aspects of adaptation are poorly understood, including the process of implementation and the potential effectiveness of different approaches.

CASE STUDY 3

The 2001 and 2002 Droughts on the Prairies

Droughts have major impacts on the economy, environment, health and society. The droughts of 2001 and 2002 in Canada, which brought conditions unseen for at least a hundred years in some regions, were no exception. In general, droughts in Canada affect only one or two regions, are relatively short lived (one or two seasons) and only impact a small number of economic sectors. In contrast, the drought years of 2001 and 2002 covered massive areas, were long lasting and brought substantial impacts to many economic sectors. The 2001 and 2002 droughts were among the first coast-to-coast droughts on record, and struck areas that are less accustomed to dealing with water scarcity. Although national in scale, the droughts were concentrated in western Canada, with Saskatchewan and Alberta being the hardest hit provinces (Wheaton et al., 2005a, b).

Repercussions of the droughts were far reaching, and included the following:

- **Agricultural production** dropped an estimated $3.6 billion for the 2001 and 2002 drought years, with the largest loss in 2002, at more than $2 billion.
- The **gross domestic product** was reduced by some $5.8 billion for 2001 and 2002, again with the larger loss in 2002, at more than $3.6 billion.
- **Employment losses** exceeded 41 000 jobs, including nearly 24 000 jobs in 2002.
- **Production losses** were devastating for a wide variety of crops across Canada. Alberta's lost crop production was about $413 million in 2001 and $1.33 billion in 2002. The estimated value of reduced crop production in Saskatchewan was $925 million in 2001 and $1.49 billion in 2002.
- **Net farm income** in 2002 was negative in Saskatchewan and zero in Alberta.
- **Severe wind erosion** events occurred, even with the improvements provided by conservation tillage.
- **Livestock production** was especially difficult due to the widespread scarcity of feed and water.
- **Water supplies** that were previously reliable failed to meet requirements in some areas, necessitating numerous adaptation projects, ranging from repairing existing dams, dugouts and wells to developing new dugouts and wells. Livestock were culled or moved to areas where forage and water were more accessible. Communities required supplemental water from various sources. These adaptations resulted in additional costs to the communities, and crop and livestock production losses.
- There was a pronounced decrease in the growth of **aspen forests**, and a massive dieback of aspen and other trees in the most strongly drought-affected areas in western Canada. Planted birch, ash and other trees in urban areas, such as Edmonton, were also severely affected (Hogg et al., 2006). A major collapse in aspen productivity likely occurred during this drought (Hogg et al., 2005).
- **Multi-sector effects** occurred, with documented impacts on agricultural production and processing, water supplies, recreation, tourism, health, hydroelectric power generation and transportation.
- **Long-lasting impacts** included soil and other damage by wind erosion, and deterioration of grasslands.

Several government response and safety net programs partially offset negative socioeconomic impacts of the 2001 and 2002 drought years. These and other adaptation measures, some costly and disruptive, were used to address these impacts. Many adaptations proved insufficient to deal with such an intense and persistent drought over such a large area. Since more intense and longer droughts are projected for the Prairies in future, these recent impacts underline western Canada's vulnerability and the need to enhance adaptive capacity in all areas.

4.2 FORESTRY

Forest Operations and Management

Short-term climate events can affect forest operations and access to harvestable wood supplies. Impacts include flooding, leading to the loss of roads, bridges and culverts; higher winter temperatures, which affect the duration of frozen ground for winter operations, including the ability to construct and maintain ice roads (*see* Section 4.3); and water-logged soils in cut blocks, which prevent equipment operations (Archibald et al., 1997). In wet areas or periods of high precipitation, soils may be deeply rutted by equipment operations, affecting long-term site productivity, ability to regenerate the site and the potential for erosion (Archibald et al., 1997; Grigal, 2000). Steep topography can exacerbate these conditions and may lead to landslides (Grigal, 2000). Other impacts result from improper maintenance of roads, resulting in increased slope erosion, and of water-control structures, causing waterlogged soils and flooding. Forest operations are often carried out in winter because the frozen soil is relatively impervious to the impact of heavy equipment (Grigal, 2000). Flooding or severe erosion caused by extreme precipitation events can reduce or eliminate the opportunities for rehabilitation of temporary forest roads (Van Rees and Jackson, 2002). Road crossings over creeks and rivers affect water quality and fisheries habitat by introducing sediment, but these effects are generally minor, except under extreme events (Steedman, 2000). Current adaptive responses to these conditions include the use of high-flotation tires on logging equipment for wet soil conditions (Mellgren and Heidersdorf, 1984); reallocating harvest operations to drier sites; and switching from winter to summer operations. However, equipment modifications can be expensive and difficult to maintain.

In the long term, climate affects the growth and continued productivity of forest stands. Temperature, moisture and nutrient availability, and atmospheric CO_2 concentrations all affect tree growth directly (Kimmins, 1997). In managed forests, planted seedlings are climate sensitive, and natural regeneration following disturbance is highly sensitive to climate in the early stages of establishment (Parker et al., 2000; Spittlehouse and Stewart, 2003). Climatic factors, mediated by soils and topography, also affect the species composition of forest stands and landscapes (Rowe, 1996).

Forest productivity and species composition at the landscape level are also affected by large-scale disturbances, which are strongly influenced by climate. For Canadian forests, the most important disturbance agents are forest fires (Weber and Flannigan, 1997) and insect outbreaks (Volney and Fleming, 2000). For example, insect pests in the Prairies affected an average of 3.1 million hectares per year between 1975 and 2003, with extreme values of 10 to 12 million hectares in the mid-1970s (National Forestry Database Program, 2005). Forest fires in the Prairies burned an average of slightly less than 1 million hectares per year between 1975 and 2005, but this figure reached 3 to 4 million hectares during some years in the 1980s (National Forestry Database Program, 2005).

To assess ecosystem impacts in commercial forests, comprehensive ecosystem models are required that include both local-scale ecosystem processes (e.g. productivity) and landscape-scale processes (e.g. seed dispersal, disturbance). These dynamic global vegetation models can be used as stand-alone simulators or can be coupled to global climate models. Examples include the Integrated Biosphere Simulator (IBI; Foley et al., 1996), Lund-Potsdam-Jena model (Gerber et al., 2004) and MC1 (Bachelet et al., 2001). Further regional-scale application of these models is needed, including detailed parameterization and validation of results. This approach has been applied in several recent European forestry assessments (Kellomäki and Leinonen, 2005; Schröter et al., 2005; Koca et al., 2006).

Future Vulnerabilities

Climate scenarios for the Prairies suggest the future will bring warmer winters with greater precipitation, earlier springs, and summers with reduced soil moisture (*see* Section 2.5). Under these conditions, transportation in spring on forest roads may be reduced. Erosion at susceptible sites (e.g. road crossings) is likely to increase in response to higher and more intense precipitation (Spittlehouse and Stewart, 2003). Flooding would remain a concern and would necessitate closer attention to sizing of culverts and other water-control structures (Spittlehouse and Stewart, 2003). In areas where winter operations are important, the shorter period of frozen ground conditions will limit woods operations and affect scheduling of harvesting equipment among cutting areas. Potential adaptation measures for dealing with such changes, and other climate impacts, are listed in Table 10.

Higher temperatures increase the rate of both carbon uptake (photosynthesis) and carbon loss (respiration), so the effect of higher temperatures will depend on the net balance between these processes (Amthor and Baldocchi, 2001). Both photosynthesis and respiration have been shown to adjust to a change in environmental conditions (acclimation), so any increases may be short lived. Changes in photosynthesis have been shown to be highly dependent on nutrient (especially nitrogen) and water availability (Baldocchi and Amthor, 2001). Generally, net primary productivity is expected to increase under warmer temperatures and longer growing seasons, if water and nutrients are not limiting (Norby et al., 2005).

TABLE 10: Examples of adaptation measures for forest management, as identified by Spittlehouse and Stewart (2003).

Gene management	Breeding for pest resistance and climate stresses and extremes
Forest protection	Altering forest structure and developing 'fire smart' landscapes (i.e. creating areas of reduced flammability through fuel modification)
Forest regeneration	Assisting the migration of commercial tree species from present to future ranges through artificial regeneration
Silvicultural management	Pre-commercial thinning to enhance growth and insect/disease resistance
Protection of non-timber resources	Minimizing fragmentation of habitat and maintaining connectivity
Park and wilderness area management	Managing these areas to delay, ameliorate and direct change

Soil temperatures are also likely to increase. Although no soil warming studies have been conducted on the Prairies, experimental soil warming in northern Sweden (64°N) resulted in increased basal area growth and demonstrated that the addition of fertilizer and water dramatically increases volume growth relative to warming alone (Stromgren and Linder, 2002). In a wide-ranging review of other soil warming experiments, increased rates of nitrogen availability have been found in nearly all locations and vegetation types (Rustad et al., 2001). However, this is dependent on water availability, and will also be affected by nitrogen deposition from industrial sources (Kochy and Wilson, 2001).

Much of the southern boundary of the boreal forest in the Prairies is currently vulnerable to drought impacts, and this vulnerability is expected to increase in the future (Hogg and Bernier, 2005). Available water-holding capacity (AWC) of the soil is a critical factor in determining water availability for uptake by the trees' root systems. Simulated future drought reduced productivity of white spruce in Saskatchewan by about 20% on sites with low AWC (Johnston and Williamson, 2005).

Higher levels of atmospheric CO_2 improve water-use efficiency (WUE); that is, less water is lost for a given unit of CO_2 uptake (Long et al., 2004). Increased WUE could be particularly important on water-limited sites, such that tree growth might continue where it would be severely limited under current CO_2 levels. Johnston and Williamson (2005) found that, even under severe drought conditions, increased WUE under a high CO_2 future would result in an increase in productivity relative to current conditions. Free-air CO_2 enrichment (FACE) experiments expose trees to levels of CO_2 roughly twice that of the pre-industrial period. In one such experiment, an initial increase in net primary production (NPP) was observed for loblolly pine, but was relatively short lived (3–4 years) and only occurred when soil nutrient and water levels were relatively high (DeLucia et al., 1999; Oren et al., 2001). Trees were found to respond to increased CO_2 concentrations more than other vegetation, with biomass production increasing an average of about 20 to 25% (Long et al., 2004; Norby et al., 2005).

The effect of climate change on disturbance regimes could be considerable. For the Prairies region, forest fires are expected to be more frequent (Bergeron et al., 2004), of higher intensity (Parisien et al., 2004) and to burn over larger areas (Flannigan et al., 2005), although the magnitude of these changes is difficult to predict. Insect outbreaks are also expected to be more frequent and severe (Volney and Fleming 2000). Of particular concern is the mountain pine beetle, currently in a major outbreak phase in the interior of British Columbia (*see* Chapter 8). It is now beginning to spread east, with approximately 2.8 million trees affected in Alberta as of spring 2007 (Alberta Sustainable Resource Development, 2007). The beetle is limited by the occurrence of -40°C winter temperatures: with warming, this limiting temperature is likely to occur farther to the north and east, allowing the beetle to spread into jack pine in the Prairies. Jack pine's distribution is nearly continuous from Alberta to New Brunswick, so the spread of the beetle across the Canadian boreal forest is a possible future scenario (Logan et al., 2003; Carroll et al., 2004; Moore et al., 2005; Taylor et al., 2006). The long-term effect of insect outbreaks on forest management is difficult to predict, although increased tree mortality in the southern margin of the boreal forest is projected as a result of the interaction of insects, drought and fire (Hogg and Bernier, 2005; Volney and Hirsch, 2005).

Increased rates of fire disturbance will differentially affect tree species due to differences in flammability and their ability to regenerate (Johnston, 1996). Some coniferous species are inherently more flammable than hardwood species (Parisien et al., 2004), so increased forest fire activity will likely favour hardwood species (e.g. aspen) over some conifers (e.g. white spruce). As a result, wood supply to oriented strand board (OSB) mills in Canada, which generally use 90 to 100% hardwood (mainly aspen) as feedstock, would not be as affected by increased forest fires as saw mills that depend on fire-susceptible softwood species for lumber production.

Economic and Social Impacts

Climate change impacts outside the region will have implications for the Prairies forest industry. Given the importance of forest products to the building sector, increases in natural disturbances could stimulate the forest products sector. For example, the price of oriented strand board panels went up by more than 50% in the weeks following Hurricane Katrina in the fall of 2005 (National Association of Home Builders, 2005). On sites with adequate water and nutrients, increased tree growth may result in an increased wood supply. This could depress the market price but provide a benefit to consumers (Sohngen and Sedjo, 2005). Alternatively, large-scale disturbance and tree dieback could reduce the wood supply, thereby increasing prices and leading to local or regional wood shortages (Sohngen and Sedjo, 2005). Associated impacts could include mill closures and the attendant economic effects on small forest-dependent communities (Williamson et al., 2005). Changes in species composition due to disturbance and growth conditions in the future may require mills to change processing capacity and introduce new products. Salvage harvesting following large-scale disturbances may provide additional woody biomass for use in bioenergy production; this is currently being considered in British Columbia for forests affected by the mountain pine beetle (Kumar, 2005; *see* Chapter 8). However, impacts of intensive salvage harvesting on ecosystem function and biodiversity may be negative (Lindenmayer et al., 2004).

4.3 TRANSPORTATION

The transportation network in the Prairies is extensive and diverse. The public road network consists of more than 540 000 km of two-lane-equivalent roads, accounting for 52% of the national total (Transport Canada, 2005). About 20% of the road network is paved. Several thousand kilometres of public winter (ice) roads are built each year in the region, mostly in Manitoba, where some 2300 km of winter roads provide access to communities not serviced by permanent roads (Manitoba Transportation and Government Services, 2006). The railway network (Figure 14) is also important the region, and includes a railway to the region's only ocean port at Churchill, Manitoba. Fifty-one airports were in operation in the region in 2004 (Statistics Canada, 2004).

FIGURE 14: Railway tracks near Red Deer River valley, near Drumheller, Alberta.

Transportation is a vital component of almost all economic and social activities, and transportation systems are very sensitive to extreme weather events (Andrey and Mills, 2003a). With climate change resulting in warmer winter temperatures, it is likely that more of the cold-season precipitation will come in the form of rain or freezing rain. Increased frequencies of extreme precipitation events (Kharin and Zwiers, 2000) and increased inter-annual climate variability are likely to result in increased damage to roads, railways and other structures as a result of flooding, erosion and landslides.

Some climate changes may result in economic savings, such as reduced need for road snow clearing, whereas other changes may require significant capital investments, such as improvements to storm-water management (IBI Group, 1990; Marbek Resource Consultants, 2003). Since weather is a key component of many transportation-related safety issues, including automobile and aircraft accidents, climate change will affect the risks associated with the transportation of people and goods, and perhaps the associated costs of insurance. The demand for transportation may also be affected, since many of the region's transportation-sensitive sectors, including agriculture, energy and tourism, will also be impacted by climate change.

Infrastructure Impacts

Each component of the extensive and diverse transportation infrastructure of the Prairies requires proper design, construction and maintenance to operate as safely and reliably as possible over its design lifetime. There are significant costs associated with transportation infrastructure, most incurred by local, municipal, provincial and federal governments. Private companies and corporations also have major investments in transportation infrastructure, such as in the railway industry.

Arguably, the most significant negative impact of climate change on transportation infrastructure in the Prairies is related to winter roads (*see* Case Study 4). Winter roads are a vital social, cultural and economic lifeline to remote communities (Kuryk, 2003; Centre for Indigenous Environmental Resources, 2006). Shipping bulk goods by air is prohibitively costly; thus, the threats that changing climate poses to winter road operations is a concern to each of the provincial governments mandated to provide surface transport, as well as to the communities currently serviced by these roads. During the warm El Niño winter of 1997–1998, $15 to 18 million were spent airlifting supplies into remote communities in Manitoba and northern Ontario because winter roads could not be built or maintained for sufficient periods of time (Paul and Saunders, 2002; Kuryk, 2003).

In contrast, the warmer winters may result in substantial reductions in the costs associated with non–ice road infrastructure. Cold temperatures and frequent freeze-thaw cycles cause much of the deterioration of paved and non-paved surfaces (Haas et al., 1999). In the southern parts of the Prairies, where the vast majority of the permanent road surfaces are found, reductions in the length and severity of the frost-affected season could result in long-term cost savings associated with repairs and maintenance. However, winter warm spells or increased inter-daily temperature variability may cause the frequency of freeze-thaw cycles to increase, if only during a period of a few decades, while winters become warmer. Additionally, in some northern areas, paved roads are stabilized by frozen substrates during winter, and may therefore be compromised by warmer winter temperatures.

Increases in mean temperature and the frequency of hot days during summer are expected to lead to increased road-related infrastructure costs. Asphalt-covered surfaces, particularly those with large amounts of heavy truck traffic, are especially susceptible to damage during heat waves. Potential problems include rutting of softened surfaces, and the flushing and bleeding of liquid asphalt from poorly constructed surfaces (Lemmen and Warren, 2004). Of these, rutting is the most serious and costly type of damage to repair. Each is largely preventable with proper design and construction practices. To date, it is not clear which is likely to be greater in the region: savings associated with less frost-related damage to roads or the costs of increased damage to roads due to warmer summer temperatures.

Maintenance of railway infrastructure is likely to cost less as a result of warmer winter temperatures. Extreme cold temperatures cause broken railway ties, failure of switches and physical stress to railway cars; thus, fewer extremely cold temperatures should result in smaller costs associated with these problems. In the summer, however, rail damage caused by thermal expansion (Grenci, 1995; Smoyer-Tomic et al., 2003) will likely increase as heat waves become more frequent. More significant, perhaps, is the likelihood that northern railways with lines passing through areas of permafrost, such as the one serving the Port of Churchill in northern Manitoba, will require frequent and significant repair, if not replacement, as a result of continued permafrost degradation (Nelson et al., 2002).

CASE STUDY 4

Winter Roads in Northern Manitoba

The most significant negative impact of climate change on transportation infrastructure in the northern part of the Prairies is related to winter roads. In Manitoba, where the majority of the region's winter roads are built, more than 25 000 people in 28 communities rely on winter roads (Centre for Indigenous Environmental Resources, 2006). The population of these communities is expected to double in the next 20 years. Some 2300 km of winter roads are built annually to provide access to communities not serviced by permanent roads (Manitoba Transportation and Government Services, 2006).

Winter roads are vital links between northern Aboriginal communities and to other parts of Canada. They are social, cultural and economic lifelines in remote communities, enabling the delivery of such essential goods as food, fuel, and medical and building supplies (Kuryk, 2003; Centre for Indigenous Environmental Resources, 2006). There are also safety-related issues, since many northerners use winter roads and trails for hunting, fishing and cultural and recreational activities (*see* Section 4.4).

In its study of five First Nations in Manitoba (Barren Lands, Bunibonibee Cree, Poplar River, St. Theresa Point and York Factory Cree), the Centre for Indigenous Environmental Resources (2006) reported the following key issues:

Reliability of Winter Roads

Northern communities perceive the two most common causes of poor winter road conditions to be 1) warmer weather (attributed to both natural cycles and human-induced climate change), and 2) high, rapidly fluctuating water levels with strong currents (attributed to flow-control structures and naturally high runoff). Poor conditions include:

- weaker and thinner ice;
- shortened and delayed winter road seasons;
- excess slush, earth patches, potholes, hanging ice and ice pockets on roads; and
- less direct routes than those that cross water bodies.

With climate change, the average length of the winter road season in Manitoba is expected to decrease by 8 days in the 2020s, 15 days in the 2050s and 21 days in the 2080s (Prentice and Thomson, 2003).

Winter Road Failure and Emergency Management

Manitoba Transportation and Government Services (MTGS) has reported decreased ice thickness, poor ice texture and density, delayed winter road seasons, problematic muskeg areas and decreased load limits. There have been cases of equipment damaged beyond repair from a single trip on the winter road. Emergency responses to winter road failure, including the airlifting of supplies, are costly, as described previously for the warm winter of 1997–1998.

Personal Safety on Winter Roads, Trails and Frozen Water Bodies

When winter road seasons are short, some community members take additional risks on winter roads, trails and water bodies. A road construction worker from Wasagamack First Nation drowned in 2002 when the grader he was driving broke through the ice.

Personal Health Concerns

There are concerns about access to health centres and other medical assistance when winter roads and trails are not available. In addition, high rates of diabetes in Aboriginal communities have been linked to decreased access to affordable healthy foods, whether from stores or from the wild. Stress is another health-related concern with connections to shortened winter road seasons, in terms of increased financial pressures and greater social isolation.

High Cost of Living

Transportation by winter roads minimizes the cost of fuel, goods and services. The cost of shipping goods by air is two to three times greater than that for ground transportation on winter roads. Lower prices also are available at larger centres accessible via all-weather roads. The cost of food is a significant issue, given that unemployment rates in northern communities are as high as 80 to 90%. Accessing wild meat and fish allows individuals to offset the high cost of food at the local store, but warmer winters are restricting the gathering of traditional foods (*see* Section 4.4).

Decreased Participation in Social and Recreational Activities

Winter roads, access trails and frozen waters play important social and cultural roles in northern communities. They provide access to neighbouring communities and larger centres to shop, visit with friends and family, gather for social events (e.g. marriages, births and funerals), participate in recreational activities (e.g. bingos, festivals and fishing derbies) and visit friends, family or the elderly in hospitals or care facilities.

Furthermore, community members use trails for recreational riding. In recent years, some fishing derbies and winter carnivals have had to be cancelled. Overall, individuals feel more disconnected from their friends and relatives in neighbouring communities when winter road seasons are shorter and less reliable. Helicopter flights are available, but most cannot afford the high fares.

Hindrance of Community Operations and Economic Development

Much economic activity is related to access provided by frozen ground and water bodies. Thin ice cover and poor winter road conditions have restricted some income-generating activities, including commercial ice fishing and the export of resources (e.g. fish and furs) for sale in larger centres. Winter roads enable communities and businesses to more efficiently acquire goods and supplies required for regular operations, maintenance and repairs. Also, the winter roads provide First Nations with income generated from road construction and maintenance contracts with MTGS. Thus the length and timing of winter road operations can impact economic development, housing, capital, special projects and equipment maintenance.

The Centre for Indigenous Environmental Resources (2006) recommended a variety of actions at the community and government levels to address issues related to degrading winter roads. These can be summarized as follows:

- Increase security of winter roads (both levels).
- Develop community climate change action plans (community) and provide support for implementing these plans (government).
- Develop a communication strategy (community) and increase communication with other First Nations (government).
- Increase social and cultural-recreational opportunities (community) and provide support for these opportunities (government).
- Increase consumption of local foods (community) and provide support for consumption of these foods (government).
- Enhance community safety (both levels).
- Increase funding opportunities for community operations (both levels).

Sea-level rise will impact the shores of Hudson Bay (Overpeck et al., 2006), even though the land is rising due to a high rate of glacioisostatic rebound. The Port of Churchill and its associated facilities may experience more frequent and severe erosion by water and ice, which would affect shipping infrastructure. On the other hand, the significantly longer ice-free season in Hudson Bay and northern channels resulting from continued climate warming (Arctic Climate Impact Assessment, 2005) will increase opportunities for ocean-going vessels to use the Port of Churchill as a point of departure and arrival for grain and other bulk commodities (*see* Chapter 3).

Operations and Maintenance

Climate change will potentially affect transportation service availability, scheduling, efficiency and safety (e.g. Andrey and Mills, 2003b). All modes of transport are at least occasionally unavailable, or schedules are disrupted, due to weather-related events. The majority of weather-related delays and cancellations occur in the winter, usually as a result of heavy snowfalls, blizzards and freezing rain, but also as a result of extreme cold snaps. As warmer winters will be associated with fewer cold snaps, there should be fewer and shorter delays related to this type of event in the future. There is some evidence that a warmer climate will be associated with fewer and less intense blizzards (Lawson, 2003). If this is correct, there may be substantial savings to the transportation industry, particularly in the airline and trucking sectors. For trucking, there are often significant costs and penalties associated with delayed shipments of, for example, perishable produce.

A warmer climate may result in fewer weather-related accidents, injuries and fatalities (Mills and Andrey, 2002), particularly in the winter, if snowfall events become less intense and frequent. Traffic accidents are strongly and positively correlated with precipitation frequency (Andrey et al., 2003). A reduction in the number of blizzards on the Prairies has already been reported (Lawson, 2003). Snowfall events account for a large proportion of the reductions in road traffic efficacy and safety in Canada (Andrey et al., 2003), and are associated with large road-clearing expenditures. For example, in the winter of 2005–2006, the Manitoba government conducted 1 455 193 pass kilometres of snow clearing and 220 945 pass kilometres of ice blading; almost 57 000 tonnes of de-icing chemicals were applied to provincial highways; and 42% of the year's $80 million in road maintenance expenditures was spent in the winter (Manitoba Transportation and Government Services, 2006). Thus, warmer winters with fewer snow events may substantially lower costs associated with the removal of snow and ice from roads (e.g. IBI Group, 1990; Jones, 2003), and the application of less salt on icy roads may substantially reduce damage to vehicles, bridges and other steel structures (Mills and Andrey, 2002). However, these potential savings are very temperature sensitive, and it remains possible that the number of days requiring the application of salt may, in fact, increase if there is an increase in the number of days with freezing rain.

Even if the total amounts of precipitation do not change substantially, it is generally acknowledged that the frequency of extreme precipitation events will increase (Groisman et al., 2005), that more of the winter precipitation will fall as rain (Akinremi et al., 1999) and that the distribution of precipitation throughout the year will change (Hofmann et al., 1998). Increased frequency of extreme precipitation events in the summer would likely increase the frequency of road accidents. Intense precipitation and excess water also hinder transportation operations. For example, increased and more intense precipitation in the mountains would likely result in a higher incidence of flash floods and debris flows (*see* Section 3.3), thereby disrupting key transportation links. Associated with increased storminess would be an increase in the frequency of extreme winds, which would cause air transport delays and risks.

4.4 COMMUNITIES

The vulnerability of communities on the Prairies to climate change varies due to relative differences in adaptive capacity and direct exposure to potential impacts. To assess adaptive capacity, it is necessary to consider social, cultural, economic and institutional characteristics (Davidson et al., 2003; *see* Chapter 2). Historically, societies have shown a remarkable ability to adapt to local climatic conditions (Ford and Smit, 2003), but repeated or continuous stressors, such as those posed by climate change, can increase vulnerability, particularly when they occur in combination with other stress-inducing factors and at high enough frequencies to prevent recuperation.

Urban Centres

Most of the population on the Prairies is concentrated in a few metropolitan centres, although the size of the cities is relatively small, with only Calgary approaching one million residents. Overall, major urban centres generally have greater levels of adaptive capacity than smaller cities and rural communities. Cities have well-developed communication and transportation infrastructure; in most cases, they have economic reserves and well-developed emergency response capacities, and tend to have greater political influence (Crosson, 2001). However, a study of the adaptive capacity of cities in the Prairies found a lack of knowledge and awareness among decision-makers of the potential impacts of climate change and of the need for adaptation (Wittrock et al., 2001).

The primary climate impacts of concern for cities on the Prairies are extreme weather events, drought, disease, heat stress and the gradual ecological transformation of urban green space.

Extreme weather: Flood control may be the most significant climate-related concern for urban areas (Wittrock et al., 2001). Cities were not historically planned for flood prevention, such that many neighbourhoods are located in flood-prone areas and existing risk management approaches are often inadequate. Existing water management infrastructure (storage and drainage systems) may not be suited to projected future changes in precipitation and snowmelt.

Drought: Cities are generally more insulated from the effects of drought than are rural communities, having more sophisticated water acquisition and storage infrastructure. Nonetheless, projected increases in the magnitude and frequency of drought will certainly impact water supply and utilization in cities on the Prairies, and place an emphasis on water efficiency initiatives.

Heat stress: Heat stress associated with increasing global temperatures is exacerbated in cities due to 'heat island' effects (e.g. Arnfield, 2003). Although the highest temperatures ever recorded in Canada are from the Prairies, this heat is rarely associated with high humidity. This has resulted in relatively limited adoption of policies and technologies to deal with heat stress, such as residential air conditioning and city shelters. Cities on the Prairies also are not associated with air pollution levels typical of urban centres in Ontario and Quebec, and are therefore less likely to suffer the cumulative effects of heat stress and heavy air pollution (*see* Chapters 5 and 6). Nonetheless, extreme heat days are significant in Prairie cities, particularly for the more vulnerable populations.

Green space: Urban green spaces are susceptible to long-term shifts in both average temperatures and precipitation, thus making existing species poorly suited to emergent climate trends and more acute events, such as drought, which can place vegetation and wildlife under extreme stress. One significant expense for Prairie cities during the most recent drought (2000–2002) was the loss of ornamental trees. For example, the City of Edmonton (2007) estimated that they have lost approximately 23 000 trees since 2002 as a result of drought; they have resources to replace approximately 8 300 of these trees.

Rural Communities

Thirty-six percent of the population of Saskatchewan and 28% of Manitoba's live in rural communities. Alberta is more urbanized, with only 19% of the population in rural areas. Some rural communities are experiencing rapid population and economic growth, while others, particularly many agricultural communities in the southern Prairies, are in decline. Few rural communities have access to the same level of disaster management resources (e.g. emergency response and health care programs) as larger cities. For remote northern communities, transport of materials and supplies into the community, or transporting residents out of the community in times of hazard, becomes a limitation due to the small number of transport routes. In a small town, moreover, even a modest hazardous event can be locally disastrous, simply because it is likely to affect a greater proportion of the population (the 'proportionality impact'; Mossler, 1996).

In general, rural communities are also more sensitive to climate change impacts than cities, largely due to their economic dependence on natural-resource sectors and lack of opportunities for economic diversification. More than 25% of the jobs in rural communities in Canada are in resource-based industries, and a far greater proportion of employment is indirectly dependent upon these sectors. In the Prairies region, 78% of resource-related jobs are in agriculture (Stedman et al., 2005). Many rural communities on the Prairies are already stressed due to both climate events, such as the 2001–2002 drought, and non-climatic stresses, such as softwood lumber trade issues and outbreaks of bovine spongiform encephalopathy (BSE). These communities are therefore simultaneously characterized by a reduced coping range — as community and household economic and social capital reserves are exhausted — and a reduced likelihood of engaging in proactive planning, due to the low degree of salience that may be placed on climate change relative to other, more immediate stressors.

Most rural communities in the region are located in the Prairie Ecozone. The risks and opportunities for agricultural communities are strongly tied to climate change impacts on agriculture, as described in Section 4.1. Climate change impacts of greatest concern include extreme weather events, droughts and ecosystem shifts. Drought is of particular concern, as rural communities are largely dependent on well water or smaller reservoirs that can dry up during severe drought. It is broadly acknowledged that there is relatively high potential adaptive capacity in the agricultural sector, involving both farm- and sector-level adaptations. With recent agricultural restructuring and the trend towards larger farms, many communities have experienced a significant exodus of their younger population, such that the average farmer in Canada is 55 years old (Voaklander et al., 2006). An aging farm population may be less innovative in terms of willingness to implement new adaptive measures, while industrial-scale farms have more capital but not necessarily the same level of commitment to the sustainability of local communities.

Forest-based communities, primarily in the Boreal Ecozone, make up a small proportion of rural communities, with the forest sector accounting for about 2% of regional employment in the Prairies (Stedman et al., 2005). The forest industry in Alberta is significantly larger than in Manitoba or Saskatchewan. Given the potential impacts of climate change on forest ecosystems (*see* Section 3.2) and commercial forestry (*see* Section 4.2), forest-based communities will face a great degree of uncertainty

(Mendis et al., 2003). They also may be vulnerable because of the relative inflexibility of modern industrial forestry, particularly in the Prairies, whose forest industry is relatively young. The region is characterized by large forest management areas managed under 10-year planning horizons, and modern, high-capacity processing facilities that may only be suitable for one or two species. As with other rural communities, forest-based communities may also be severely constrained with respect to emergency response capacity. Many forest-based communities are located in remote regions with limited transportation access, which can be a liability if extreme weather or forest fires compromise the primary transportation routes.

Mining- and energy-based communities, primarily in the Boreal and Taiga ecozones, could be vulnerable given the impacts of climate change on these sectors (*see* Section 4.6). Of particular concern are projected reductions in water supplies, as many processes in these sectors are heavily water dependent. Other factors include disruptions to power supplies and transportation networks serving remote communities in the north. Rapid population growth in some energy-based communities, such as Fort McMurray, AB, may exacerbate vulnerability to climate change, as the demands have already exceeded existing infrastructure of all sorts, including basic housing. Social services may be stretched, particularly when many of the incoming residents are from diverse cultural backgrounds. Consequently, the ability to respond to extreme weather events, forest fires and health risks is a significant concern. Rapid growth also has a deleterious effect on social integration and community satisfaction, both of which affect the ability to respond to unanticipated crises. Communities with stable populations tend to recover better from crises.

Several Prairie communities have strong economic reliance on tourism and nature-based recreation activities. The potential economic impacts of climate change on tourism are most acute in Alberta, whose tourism industry generated more than $4.96 billion in revenue for the province in 2005 (Alberta Economic Development, 2006), mostly related to national and international visitors to the national parks in the Canadian Rockies. Banff alone has received between 3 and 5 million visitors per year during the past decade (Service Alberta, 2005). Nature-based tourism, and the communities that depend on this industry, face several challenges as climate change impacts ecosystems (*see* Section 3.2) and the related outdoor recreation (*see* Section 4.7). The parks most severely affected, with local economic impacts, are the island forests (*see* Case Study 1) and small recreation areas of the southern Prairies, where the water and trees that draw visitors are particularly sensitive to changing climate (Figure 15).

Aboriginal communities have the highest rates of poverty and unemployment throughout the Prairies. Approximately half of the Prairies Aboriginal population lives in cities; the remainder live in or near their traditional territories, which are directly exposed to the impacts of changing climate on ecosystems, water and forestry (*see* Case Study 5). Many Aboriginal communities are also at least partly dependent on subsistence activities for their livelihood, with local food supplies supplementing their diets to a far greater extent than for non-Aboriginal people. Impacts of climate change have implications for flora and fauna, and declines or annual uncertainties in the availability of moose, caribou, deer, fish and wild rice will increase dependence on imported foods, with both economic and health implications for residents. Residents are already concerned about decreased participation in subsistence activities owing to difficulties in accessing reserve lands and traditional territories in winter. Unsuitable snow and ground conditions greatly hamper travel, by foot or by snowmobile, to trap lines, hunting grounds and fishing areas. Communities report decreased levels of these traditional activities due to concerns about personal safety.

FIGURE 15: A Prairie wetland in the Dirt Hills near Claybank, Saskatchewan.

CASE STUDY 5

First Nations' Traditional Ways of Life and Climate Change: The Prince Albert Grand Council (PAGC) Elders' Forum, February 2004

Aboriginal people of the Prairies region, and Elders in particular, are contributing their knowledge about climate change, particularly in northern regions where livelihood activities remain tied to the land. Recent initiatives point to the growing need for collaboration between researchers and Aboriginal communities to understand and address climate change issues. The Prince Albert Grand Council (PAGC) Elders' forum on climate change in February 2004 (Ermine et al., 2005) was based on respectful learning and traditional protocols, in which Elders from the PAGC area shared information about climate change with one another and with members of the research community. For the most part, the observations of the PAGC Elders reinforced, confirmed and enhanced scientific observations. Elders brought forward the collective wisdom of generations living in specific locations, adding depth to the scientific view of climate change impacts and adaptation. The Elders relate to climate change as a broader process that encompasses the sociocultural aspects of their lives. They spoke of the land with passion, honouring a way of life that provides for their health and well-being through, for example, trapping, hunting and fishing.

Observations of Changes and Impacts

The Elders recognized that annual variability is part of the normal pattern of nature. However, they identified several trends of concern, including the following:

- Extreme weather events, such as tornadoes and hailstorms, have occurred more frequently in recent years.
- Shifts in seasonal characteristics were felt to be more worrisome, and indicative of the more serious nature of climate change, than isolated climate events. For example, summer and autumn seasonal conditions were observed to extend farther into the traditional 'winter' months.
- Recently, summers were observed to be abnormally dry, with rainfall having no appreciable effect on moisture levels.
- The quantity and quality of water is deteriorating in their territories, in part due to human activity.
- A general imbalance in nature, reflected in the condition of wildlife and inferred from abnormal wildlife behaviour, includes changes in migration patterns and population ranges within their territories.
- New species are starting to inhabit areas where they were not previously seen. These include previously uncommon birds being observed more frequently and animals (e.g. cougars and white-tailed deer) wandering into areas far from their usual ranges.
- Increased summer heat is affecting the health of children and the elderly.
- Unpredictability of weather is influencing their preparedness for outdoor activities.
- Plants, including trees and berry-producing shrubs, are showing the effects of heat and associated drought, such that useful products from these sources are no longer as abundant.
- Decreases in the quality and thickness of the winter coats of fur-bearing animals are affecting the livelihood of northern people engaged in trapping.

Adaptation and Adaptive Capacity

The Elders trust that patterns of climate are part of existence. They have always lived within the patterns of nature. Prophesies would have been a traditional mechanism for adaptation, preparing people for the future. As an example, an Elder recounted behaviours of bees that presaged the kind of winter to expect. Animal behaviour is acutely observed and used as the basis for predictions.

Sustaining connections to the land and environment is an important foundation for healthy individuals and communities. When people become disconnected from the land, the lines of communication between the natural and social worlds are severed. Elders expressed a strong sentiment that it was their responsibility to keep and protect the land for future generations. They wished to take action, but were concerned about their ability to influence the activities of industrial corporations. Co-operation between sectors of society was strongly emphasized. The forum itself was considered part of the solution, and Elders expressed appreciation for the involvement of western scientists in the discussion of climate change.

The Elders deliberately refrained from making resolutions and formal recommendations. They identified their role as strengthening their own local communities and cultural connections to the land, particularly by working with youth. One of the results emerging from the Elders' forum was the way that climate change is framed. From the Elders' perspective, global changes have been singularly isolated and prematurely labelled by western scientists as the primary dimension of 'climate change', with the result that the human realm has been largely removed. The value of the Elders' perspective is to reprioritize the human element, in terms of both impacts and responsibility.

4.5 HEALTH

Human health and well-being are intimately linked to climate and weather patterns. Under climate change, the populations of the Prairies may experience additional negative health burdens from air pollution, food-borne pathogens, heat-related illnesses, poor mental health, particulate matter, water-borne pathogens and vector-borne diseases (Séguin, in press). Subpopulations most at risk for negative health consequences are children, the elderly, Aboriginal peoples, those with low socioeconomic status, the homeless and people with underlying health conditions. Aspects of changing climate that directly and indirectly affect health and well-being of Prairies residents include drought, flooding, ecosystem changes and increased temperatures.

Drought

Drought reduces surface waters, leading to increased concentration of pathogens and toxins in domestic water supplies (Charron et al., 2003; World Health Organization, 2003). It enhances dust production from open sources (e.g. unpaved roads, fields and forest fires), which makes up 94% of particulate matter emissions in Canada (Smoyer-Tomic et al., 2004). The major health effect from inhaling dust is airway inflammation, manifesting as asthma, allergic rhinitis, bronchitis, hypersensitivity pneumonitis and organic dust toxic syndrome (do Pico, 1986; Rylander, 1986; do Pico, 1992; Lang, 1996; Simpson et al., 1998).

Drought exacerbates wildfires (Smoyer-Tomic et al., 2004), which are associated with increases in respiratory conditions, hospital visits and mortality (Bowman and Johnston, 2005), and related economic costs (*see* Rittmaster et al., 2006). Forest fires can also produce mental health stress, because of hastened evacuations and displacement (Soskolne et al., 2004). During a May 1995 forest fire, the only road access to Fort McMurray was cut off, causing difficulties for transport of medical emergencies and certain supplies (Soskolne et al., 2004).

Drought is also a source of distress for farming lifestyles, mostly because of associated financial problems (Olson and Schellenberg, 1986; Walker et al., 1986; May, 1990; Ehlers et al., 1993; Deary and McGregor, 1997). Stress in agricultural occupations not only affects the farmers but also cascades into family life (Plunkett et al., 1999).

Flooding

Flooding can set the stage for a population explosion of disease-carrying vectors, such as mosquitoes and rodents. Outbreaks of water-borne disease have been linked to intense precipitation, flooding and run-off from agricultural livestock areas (Millson et al., 1991; Bridgeman et al., 1995; Charron et al., 2003, 2004; Schuster et al., 2005). A case-control study in southern Alberta (Charron et al., 2005) found that each extra day of rain in the preceding 42 days increased the risk of hospitalization for gastrointestinal illness. However, if the number of rain days exceeded the 95th percentile during this time period, the odds of hospitalization decreased, possibly due to dilution or cessation of pathogens. These findings were opposite to those in an Ontario case study (Charron et al., 2005), thereby suggesting that regional differences are important in determining the potential impact of climate change on waterborne diseases.

Slow-rising riverine floods have a low potential for mortality, and the major health effects may be longer term psychological problems (Phifer et al., 1988; Phifer, 1990; Durkin et al., 1993; Ginexi et al., 2000; Tyler and Hoyt, 2000), as well as moulds and mildew and the associated respiratory ailments from extremely wet conditions (Square, 1997; Greenough et al., 2001). Losing a home or witnessing it being destroyed, being evacuated on short notice, or being displaced for an extended period of time all cause great anxiety (Soskolne et al., 2004). Flooding causes economic loss, which in turn creates stress and hardship for those experiencing the loss. Uncertainty about who is expected to pay for the loss is also a source of stress (Soskolne et al., 2004).

Changing Ecosystems and Vector-Borne Diseases

Hantaviruses are transmitted to humans via the inhalation of aerosolized hantavirus from rodent excreta and saliva (Stephen et al., 1994; Gubler et al., 2001), giving rise to hantavirus pulmonary syndrome (HPS) in humans. The deer mouse is most often associated with HPS (Stephen et al., 1994; Glass et al., 2000). Between, 1989 and 2004, there were 44 cases of HPS, all from western Canada, with the majority of cases (27) in Alberta (Public Health Agency of Canada, 2000, 2006). Mortality is 40 to 50% (Public Health Agency of Canada, 2001). Human cases of HPS seem to reflect the yearly and seasonal patterns of high rodent population densities (Mills et al., 1999). Large increases in rodent populations have been linked to mild wet winters, and to above-average rainfall followed by drought and higher-than-average temperatures (Engelthaler et al., 1999; Gubler et al., 2001), climate conditions that are projected to become increasingly common in the Prairies (*see* Section 2.5).

West Nile virus (WNV) is transmitted from its natural bird reservoirs by mosquitoes (primarily the genus *Culex*). The climatological conditions that favour the WNV are mild winters, coupled with prolonged drought and heat waves (Epstein, 2001; Huhn et al., 2003). The *Culex* mosquito can overwinter in the standing water of city sewer systems, and heat tends to speed up the viral development within the mosquito (Epstein, 2001). The Prairies have recorded a disproportionate number of WNV cases, accounting for 91.2% of the 1478 documented cases in Canada in 2003 (Public Health Agency of Canada, 2004a). In 2004 and 2005, the numbers of clinical cases in the Prairies were 36.0% (of the 25 in Canada) and 58.6% (of the 210 in Canada), respectively (Public Health Agency of Canada 2004b, c). Fortunately, the majority of people (80%) infected with WNV are asymptomatic, with severe symptoms (e.g. coma, tremors, convulsions, vision loss) showing up in approximately 1 in 150 people infected (Centers for Disease Control and Prevention, 2005).

Although Lyme disease is expected to be a significant public health threat in eastern Canada, the Prairies will likely remain too dry for this to become a major health concern. Other diseases affected by climate change or resulting ecosystem changes that may become a health threat in the Prairies are western equine encephalitis, rabies, influenza, brucellosis, tuberculosis and plague (Charron et al., 2003). These diseases have either an animal reservoir population, known human cases or a history in the Prairies, and are sensitive to changes in climate (Charron et al., 2003).

Higher Average Temperatures

Increasing temperatures could exacerbate food poisoning because longer, warmer summers are conducive to accelerated growth of bacterial species and to the survival of bacterial species and their carriers (e.g. flies; Bentham and Langford, 2001; Rose et al., 2001; Hall et al., 2002; D'Souza et al., 2004; Kovats et al., 2004; Fleury et al., 2006). Fleury et al. (2006) confirmed cases of food-borne diseases in Alberta, finding a positive association between ambient temperature and disease for all time lags (0 to 6 weeks) and for every degree increase in weekly temperature above the threshold temperature (0 to –10°C). Depending on the pathogen type, the relative risk of infection increased from 1.2 to 6.0%.

Warmer temperatures enhance the production of secondary pollutants, including ground level ozone (Last et al., 1998; Bernard et al., 2001). Although cities on the Prairies have relatively low concentrations of air pollution (Burnett et al., 1998; Duncan et al., 1998), current pollution levels do affect morbidity and mortality (Burnett et al., 1997, 1998). The elderly, those with pre-existing medical conditions, and children are likely to be at higher risk from the negative health impacts resulting from climate change, population growth and increasing pollution concentrations in the major centres (Last et al., 1998). Increased winter temperatures will decrease the number of cold-related deaths. More people generally die in winter than in summer, mainly from infectious diseases (e.g. influenza) or heart attacks (McGeehin and Mirabelli, 2001).

Economic Vulnerability

Economic vulnerability to climate change indirectly affects health and well-being. It often precedes negative health outcomes from extreme weather events. Economic losses, especially ones that individuals cannot afford, are a major source of stress. Economic vulnerability is closely linked to whether individuals can afford insurance, the socioeconomic status of individuals, and the wealth and resources of communities and governments.

Losing property during an extreme event is costly, as not all losses are covered by insurance or government aid programs (Soskolne et al., 2004). The financial stresses associated with disasters have the greatest effect on families with low socioeconomic status and on the elderly with fixed incomes, who are least able to afford insurance and the cost of damages, and are most likely to be living in vulnerable areas. In the future, these groups may be even less able to purchase insurance and afford the costs of adapting to extreme weather events. Drought disaster assistance programs attempt to cover uninsured crop losses; however, these rarely cover the season's initial investment, thereby increasing personal debt. Inability to repay debt tends to lead to increased financial pressures and, in turn, can lead to depression, stress and even suicide (Soskolne et al., 2004).

Certain segments of society are more vulnerable to the health threats described above by virtue of their demographics, community setting and infrastructure, health, and regional, socioeconomic or cultural circumstances (Smit et al., 2001). Vulnerable populations will likely bear a disproportionate burden of the future economic costs and negative health consequences. Table 11 presents a summary of the various vulnerable populations and explains how they are at increased risk from climate sensitive health outcomes.

There will likely be additional costs to the public health care system as a result of the costs of treatment (e.g. medications or emergency room visits) and/or containment of various diseases, screening, community surveillance, monitoring and intervention.

4.6 ENERGY

Climate change will impact the petroleum industry in the Prairies by affecting exploration and production, processing-refining and transportation, storage and delivery. Key climate variables of concern are increasing temperature, changing precipitation and extreme events (Huang et al., 2005). Of greatest concern is, and will continue to be, water scarcity, as current production of oil, and even some natural gas, relies on significant quantities of water (Bruce, 2006).

Most exploration and drilling programs are currently carried out in northern parts of the Prairies during winter, when frozen soils and wetlands are easily crossed and ice roads provide comparatively inexpensive routes for heavy transport across boreal terrain. Although warmer, shorter winters may make outside work slightly less dangerous from a health and safety perspective, this modest advantage will be countered by increased costs resulting from shortened winter work seasons.

Warming is already causing substantial permafrost degradation in many parts of the north (*see* Chapter 3; Majorowicz et al., 2005; Pearce, 2005), which will lead to land instability, soil collapse and slope failures. These changes, combined with increased frequency of extreme climate events, will create problems for infrastructure, including building foundations, roads and pipeline systems, resulting in pipeline ruptures and costs to reroute current pipelines to more stable locales (Huang et al., 2005).

The refining sector will experience increased potential for vapourization leaks as a result of longer and hotter summers. Greater cooling capacity will be needed at a time when local and regional water supplies — a key cooling fluid — will be warming beyond historical temperature peaks. These changes could disrupt refinery operations due to safety concerns and environmental and health issues, all with potential to cause economic losses (Huang et al., 2005).

TABLE 11: Prairie populations with increased vulnerability to climate change.

Vulnerable population	Characteristics of increased vulnerability	Higher temperatures and heat waves	Drought	Extreme hydrological events	Changing ecosystems
Elderly	- More likely to have underlying health conditions (see below) - Social isolation and decreased social networks - More susceptible to food-borne diseases - Fixed incomes - 50+ age group at greater risk of developing severe West Nile virus illness	x	x	x	x
Children	- Immature systems and rapid growth and development may enhance toxicity and penetration of pollutants, decrease thermoregulatory capacity and increase vulnerability to water- and food-borne diseases - Exposure per unit body mass is higher than for adults - Dependent on adult caregivers - Lower coping capacity	x	x	x	
People with underlying health conditions	- Cardiovascular and respiratory conditions increase risk - Medications decrease thermoregulatory capacity and heat tolerance - Mental illnesses, such as schizophrenia, alcohol abuse and dementia, are a risk factor for death during heat waves - Reduced mobility or a need for regular medical attention makes evacuation more difficult	x	x	x	
People of lower socio-economic status (SES)	- Associated with poorer health overall - Have less control over life's circumstances, especially stressful events, and are less able to better their outcome - More likely to be located in higher risk areas - Higher heat-related mortality is associated with lower income neighbourhoods - Less likely to afford recovery or adaptation measures - Homelessness is often associated with underlying mental health conditions (see above)	x	x	x	
Aboriginal peoples	- More likely to have lower SES (see above) - Traditional livelihoods at risk - Poorer infrastructure - Limited access to medical services	x	x	x	x

Coal-Fired and Natural Gas–Fired Electricity Generation

Coal-fired electricity generation creates large quantities of waste heat that is dispersed using cooling water from nearby water sources. Degradation in cooling water quality (e.g. from increases in dissolved solids) creates engineering problems for the cooling systems of coal plants because the water must either be treated before use or a scale-removal program must be in place to prevent inappropriate scale build-up (Demadis, 2004).

Declining water quantity in the Prairies region resulting from climate change will reduce the supply of cooling water to power plants during drought periods or in other low-flow periods. When cooling water is in short supply, plants must cut back on operations, resulting in financial losses on a daily basis; and the coolant water that is used may be returned to the source watershed at temperatures high enough to damage aquatic ecosystems. Environmental impacts of coolant water will be exacerbated by temperature increases resulting from changing climate (Jensen, 1998).

Hydroelectric Generation

Approximately 95% of the electricity generated in Manitoba comes from renewable water energy (Manitoba Science, Technology, Energy and Mines, 2007). In Alberta and Saskatchewan, hydroelectric power is a modest but important part of the electrical generating capacity. Forecasts of future capacity for generating hydroelectric power must take into account decreasing average spring and summer flows for the western portion of the Prairies due to glacial ice decline (Demuth and Pietroniro, 2003) and lower overall snow accumulations (Leung and Ghan, 1999; Lapp et al., 2005).

Oil Sands Mines

Oil sands operations in northern Alberta are expanding at a dramatic rate. They currently produce more than 1 million barrels per day of synthetic crude oil, and production is forecast to be 3 million barrels per day by 2020 (Alberta Energy, 2005). Projected investments in oil sands recovery are $125 billion for the period 2006–2015 (National Energy Board, 2006). Oil sand mining, and oil extraction and refining, are water- and energy-intensive processes. Best current estimates are that the operations that produce synthetic crude oil or upgraded bitumen require 2 to 4.5 barrels of water for each barrel of oil (Griffiths et al., 2006). Assuming similar water/oil ratios in the future, production of more than 3 million barrels per day in 2010 would require 6 to 13.5 million barrels of water per day.

Testimony of witnesses at the Energy and Utilities Board hearings in the fall of 2003 addressed the Environmental Impact Assessments for two proposed oil sands plants. Presentations argued that 1) neither plant could sustain operations during low-flow periods of the Athabasca River without damaging the aquatic ecology, and 2) the effects of climate change on water supplies would reduce low-flow quantities and increase the length of low-flow periods. In a recent analysis of trends in both water demand for oil sand projects and water availability under climate change, Bruce (2006, p. 13–14) concluded that:

"…even at the lower end of the water withdrawals from oil sands projects, there would have been 10 times during the past 25 years where the minimum flows of the Athabasca River would have been insufficient to avoid short term impacts on ecosystems. For longer term ecosystem impacts, the recommended water restrictions on oil sands project withdrawals, indicate that minimum flows would not have met full development needs in 34 of the past 35 years."

Oil sands operations are in water-rich regions of the boreal forest. Large engineering works are needed to dewater regions and to store water previously stored in wetlands. Large-scale tailings ponds are also typical of open pit mines. Extreme precipitation events could cause overflows and spillage of contaminated or fresh water in storage. Tailings ponds contain naphthenic acids, a toxic and corrosive pollutant (McMartin et al., 2004) produced in large quantities by oil sands extraction and upgrading processes. These acids are persistent in water, but their occurrence and fate have been minimally studied (Headley and McMartin, 2004). This pollutant could affect up to 25 000 km^2 of oil sands developments, and much more if tailings ponds leak or overflow due to extreme climate events.

Renewable Energy Sources and Climate Change

Little research has been done on the possible impacts of climate change on the renewable energy sector. Renewable energy sources include solar- and wind-generated power, geothermal heat exchange and hydroelectric power. Climate change is not likely to have a substantive effect on solar-generated power unless there is a large change in cloud cover.

Wind-generated power has substantial potential across the Prairies Provinces, as sustained winds are common. Southern Alberta and southwestern Saskatchewan have considerable wind development already, and there are plans for more developments. Changes in sustained wind speeds under climate warming are possible as temperature gradients from the equator to the pole are reduced. One American study (Breslow and Sailor, 2002) has projected a modest decline in winds over the continental United States.

4.7 TOURISM AND RECREATION

A study of the potential impacts of climate change on visitation to national parks in the southern boreal forest (e.g. Prince Albert National Park, SK) suggests that visitation would increase by 6 to 10% in the 2020s, 10 to 36% in the 2050s and 14 to 60% in the 2080s, based on a relationship between temperature and visitor days (Jones and Scott, 2006). The primary impact of climate change was to increase the length of the shoulder seasons (i.e. spring and autumn). In grassland areas, biodiversity is likely to be impacted due to changing habitat and invasive species. Climatic conditions along the southern boundary of the boreal forest will cause a shift in vegetation to more drought-resistant species, especially grasses (Thorpe et al., 2001; Hogg and Bernier, 2005). Loss of stands of trees at some sites and other vegetation changes are unavoidable.

Changes in vegetation will impact wildlife habitat and change species distributions (Gitay et al., 2002). Species of interest may no longer inhabit protected areas, where they have been traditionally viewed or hunted. On the other hand, an increase in forest fire activity under future climate conditions (Flannigan et al., 2005) could provide increased habitat for species, such as deer and moose, that are dependent on early to mid-successional forests. Wildlife species important for viewing and hunting will adjust rapidly to changing environmental conditions. However, a major impact on hunting could be a loss in waterfowl habitat as prairie potholes dry up, resulting in a decline of as much as 22% in duck productivity (Scott, 2006). Communities dependent on these activities could experience reduced tourism revenues (Williamson et al., 2005).

Lower lake and stream levels, particularly in mid- to late summer (*see* Section 3.1), may reduce opportunities for water-based recreation: swimming, fishing, boating, canoe-tripping and whitewater activities. Early and rapid spring snowmelt may prevent spring water-based activities due to high or dangerous water conditions. Changes in water temperatures and levels will affect fish species distributions (Xenopoulos et al., 2005). Warmer springs would result in earlier departure of ice from lakes, limit the ice fishing season and increase the likelihood of unsafe ice conditions.

In Alberta's mountain parks, climate change has already caused vegetation and associated wildlife species to migrate to higher elevations (Scott et al., 2007), and this will accelerate under future warming. Scott and Jones (2005) and Scott et al. (2007) examined the potential impacts of climate change on visitation patterns in Banff and Waterton Lakes national parks, respectively, utilizing a number of climate change scenarios. They found that climate change could increase visitation to Banff by 3% in the 2020s and 4 to 12% in the 2050s, depending on the scenarios used. For Waterton Lakes, increases associated with changing climate were forecast to be 6 to 10% for the 2020s and 10 to 36% for the 2050s. In both cases, increases were due mainly to increased temperatures. However, Banff's ski industry may be negatively affected by less snowfall. The skiing season could decline by 50 to 57% in the 2020s and 66 to 94% in the 2050s in areas less than 1500 m in elevation, although snowmaking will help reduce these impacts (Scott and Jones, 2005). Higher altitude ski areas would be affected much less. Less snow cover and a shorter season will also affect the timing and amount of opportunities for cross-country skiing, snowshoeing and snowmobiling (Nicholls and Scott, in press).

5 ADAPTATION AND ADAPTIVE CAPACITY

Establishing and sustaining communities and economies in the Prairies, at the northern margins of agriculture and forestry in a dry variable climate and at great distances from export markets, have involved considerable adaptation to climate. Economic and social development will be sustained under climate change by tapping into and boosting the accumulated adaptive capacity of the region. Adaptive capacity is an attribute that provides an indication of a system or region's ability to adapt effectively to change. A system with a high adaptive capacity would be able to cope with, and perhaps even benefit from, changes in the climate, whereas a system with a low adaptive capacity would be more likely to suffer from the same change (*see* Chapter 2).

Nearly all adaptation in the region has been in reaction to specific climate events and departures from average conditions. The post-settlement history of the Prairies is punctuated by social and institutional responses to drought and, to a much lesser extent, floods. Planning for changing future environmental conditions is a relatively new policy and management paradigm. Many current examples of adaptation involve institutions and individuals adjusting their activities to prevent a repeat of the impacts of recent climate events, with the implicit assumption that such events will reoccur, potentially with greater frequency and/or intensity as the result of climate change.

The possible adjustments to practices, policies and infrastructure are so numerous that only categories and examples can be discussed here. For this assessment of adaptation and adaptive capacity, the authors make the distinction between the roles of formal and informal institutions and individuals, and between responses to impacts of historical events versus building adaptive capacity and developing approaches in anticipation of further climate changes.

5.1 FORMAL INSTITUTIONS AND GOVERNANCE

Institutions impose a body of regulations, rules, processes and resources that may either sustain or undermine the capacity of people to deal with challenges such as climate change (O'Riordan and Jager, 1996; O'Riordan, 1997; Willems and Baumert, 2003). Risk-management strategies that increase coping resources and enhance adaptive capacity in a context of a sustainable future are key to reducing vulnerability to climate change (Kasperson and Kasperson, 2005). Governance institutions and political and administrative systems play a central role in developing and strengthening adaptive capacity, supporting private efforts and implementing policies that allocate resources in a consistent manner (Hall, 2005). This may require institutional arrangements that differ from those fashioned around traditional policy problems. Addressing climate change requires cutting across traditional sectors, issues and political boundaries, and dealing with complexity and uncertainty (Homer-Dixon, 1999; Diaz et al., 2003; Willows and Connell, 2003; Diaz and Gauthier, 2007).

Although led by risk-taking innovators and early adopters, adaptation will generally be slow to be implemented, and adaptive capacity slow to develop, without involvement of all levels of government and other decision-makers. Coping with the impacts of climate change requires more than a myriad of unrelated adaptation measures; it ideally involves a structured response that allows for the identification, prevention and resolution of problems created by the impacts of climate change. Policy frameworks may help achieve such a systematic and efficient response.

Provincial policy documents that provide direction on climate change (e.g. Albertans and Climate Change: Taking Action) are focused largely on emissions reduction. They make reference to adaptation, but lack specifics regarding the nature of anticipated impacts or steps to adapt. In the Prairies, programs are quite advanced in Alberta, where the provincial government has established an Alberta Climate Change Adaptation Team, which initiated province-wide and multi-sectoral assessments of vulnerability and adaptation strategies (Barrow and Yu, 2005; Davidson, 2006; Sauchyn et al., 2007). In many cases, significant adaptation could be achieved and supported with adjustments to existing programs and policy mechanisms. In agriculture, for example, the Agricultural Policy Framework, National Water Supply Expansion Program, environmental farm plans and various other federal and provincial policies and programs can both accommodate adaptation options and provide the means of enhancing adaptive capacity.

The roles of institutions and government in enhancing adaptive capacity and facilitating adaptation implementation, drawing from both observed examples and potential futures, are provided in the following sectoral discussions.

5.1.1 Water Resource Management

There is significant scope for enhanced institutional adaptive capacity in the water sector through changes in the management of watersheds and reservoirs (Wood et al., 1997). For example, operating rules of water resource systems, which will be especially important given earlier spring runoff and increased summer water demands, may be adjusted to increase system efficiency and capacity. Process changes, including changing the timing of irrigation (Figure 16) to after sunset and using more efficient irrigation methods, can help offset increasing water demands from other sources (Bjornlund et al., 2001). Increasing water recycling or issuing licenses to industries that are based on best water management practices and water recycling standards are other opportunities for process change (Johnson and Caster, 1999). Holistic watershed management has been recognized and adopted in many regions already (Serveiss and Ohlson, 2007), and opportunities exist for community level adaptation to climate change for watershed-scale management authorities (Crabbé and Robin, 2006).

FIGURE 16: Irrigation on the Prairies (Frenchman River valley, southwestern Saskatchewan).

A comparative study of two dryland watersheds, the South Saskatchewan River basin (SSRB) in the Canadian Prairies and the Elqui River basin in north-central Chile, was undertaken to understand the role of regional institutions in formulating and implementing adaptation related to water resource management (www.parc.ca/mcri). Results indicated that communities identify climate risks as problematic and that significant efforts are made to manage them. The study further noted that climate risks are compounded by non-climatic stimuli that increase vulnerability, and that communities perceive shortcomings in the capability of governance institutions to reduce the vulnerability of rural populations. A study of local involvement in water management in the Oldman River sub-basin of the SSRB (Stratton et al., 2004; Stratton, 2005) concluded that adaptation has been more reactive than anticipatory, and has focused mainly on the supply of water, rather than demand. Another project in the same basin found that, at the local level, there were both water-based consciousness and successful adaptation measures to water shortages (Rush et al., 2004). There are major challenges, however, related to attitudes towards the likelihood of climate change impacts on water supplies for all users, the long-term protection of water resources, and accepting water conservation as an adaptation approach. Policy and legislation could provide flexible economic and regulatory instruments to better manage increasing variability and scarcity of water, encourage greater efficiency, expand capacity to adapt to climate change, and facilitate trade-offs among water users that reflect their differing levels of vulnerability to water scarcity.

Given the inherent uncertainties regarding the magnitude and rate of climate change, water management and planning processes require flexibility to allow for responses to new knowledge about the expected impacts. These processes must also involve stakeholders at the local level to identify local vulnerabilities and appropriate adaptation approaches. These principles were criteria for Alberta's Water for Life Strategy (Government of Alberta, 2003), the province's plan to develop a new water management approach with specific actions to ensure reliable, quality water supplies for a sustainable economy. Institutional reforms being considered include the use of economic instruments, best management practices and watershed management plans involving local communities to achieve a 30% increase in the efficiency and productivity of water use, while securing social, economic and environmental outcomes. This strategy anticipates that these instruments will be adopted on a voluntary basis and that water will be reallocated from existing users to satisfy the increasing demand from other economic sectors. It further guarantees that existing rights will be respected, that nobody will be forced to give up water. The Water for Life Strategy also includes the intention to construct flood risk maps and warning systems for communities at risk, as part of a long-term management plan.

Drought is of greater concern for cities in the Prairies than for urban centres elsewhere in Canada. In response to the 1988 drought, the City of Regina has developed drought contingency plans, including water conservation programs and expansion of water treatment and delivery capacity (Cecil et al., 2005). Other cities on the Prairies do not currently have such contingency plans in place (Wittrock et al., 2001).

5.1.2 Ecosystem Management

Managing natural capital in such a way that ecosystems already under stress continue to provide value as climate changes presents challenges for governments and resource industries. The assumption that protected areas are biogeographically stable will be proven incorrect, and biodiversity protection planning may need to protect “a moving target of ecological representativeness” (Scott and Lemieux, 2005). Aiming to build resilience into ecosystems, rather than seeking stability, is a more appropriate goal (Halpin, 1997). Proactive management of disturbance and habitat, with species-specific intervention strategies, may be the only alternative to “reconfigure protected areas to new climatic conditions” (Lopoukhine, 1990; Scott and Suffling, 2000). In Canada’s national parks, a landscape maintenance strategy may be materially impossible, whatever its philosophical merits or demerits (Scott and Suffling, 2000). Changing climate will result in areas being no longer suitable for the maintenance of the species and ecosystems they were originally designed to conserve (Pernetta, 1994). For example, Manitoba’s Wapusk National Park, on the shores of Hudson Bay, was established for the protection of denning polar bears (Scott et al., 2002), but these bears are near the southern limits of their range and may be en route to extirpation as ice conditions deteriorate (*see* Chapter 3).

Managing natural ecosystems may also require challenging policies that discourage alien introductions, and developing strategies for introducing new species to maintain biodiversity and increase ecosystem resiliency (e.g. species ‘redundancy’; Malcolm and Markham, 1996). Current policies do not favour alien introductions (e.g. Alberta Reforestation Standards Science Council, 2001; Alberta Sustainable Resource Development, 2005; Manitoba Conservation, 2005), in part due to the assumption that it is possible to maintain existing vegetation mosaics. But if native species cannot regenerate, the policy options are not clear. There seem to be no legal prohibitions to the introduction of alien tree species, and alien species are already frequently planted on freehold land. The Government of Saskatchewan (2005) is heavily promoting agro-forestry, with the goal of converting 10% of the province’s arable land base to trees within 20 years. Most converted cultivated acreage is expected to be along the fringe of the southern boreal forest, so exotic trees could potentially invade the native forest. Another potentially controversial management option is to “accelerate capture before loss” (Carr et al., 2004). Under this option, timber harvest would be accelerated if necessary to maximize one-off resource use of a forest not expected to regenerate.

5.1.3 Agriculture

Historically, federal and provincial governments have responded to drought with safety net programs to offset negative socioeconomic impacts (Wittrock and Koshida, 2005) and, more recently, through development of drought management plans. These programs have included crop insurance, the Rural Water Development Program, the National Water Supply Expansion Program, the Net Income Stabilization Account (NISA), the Canadian Agricultural Income Stabilization (CAIS) program, the Canadian Farm Income Program (CFIP) and the Tax Deferral Program. Types of assistance include helping producers access new water sources, offsetting the costs of producing crops and deferring tax income from culling herds. Claims from crop insurance and assistance from safety net programs soared in the drought years of 2001 and 2002, especially in Alberta and Saskatchewan (Wittrock and Koshida, 2005).

Soil and water conservation programs have been an integral part of agricultural adaptation to the dry and variable prairie climate (Sauchyn, 2007). Predating settlement of the Prairies, a network of experimental farms was established during the 1890s to early 1900s to develop dryland farming practices. The first Canadian government programs to combat land degradation, including the Prairie Farm Rehabilitation Administration (PFRA), were created in response to the disastrous experience of the 1930s, when drought impacts were exacerbated by an almost uniform settlement of farmland that did not account for variation in the sensitivity of soil landscapes and the capacity of the climate and soil to produce crops.

Recent institutional initiatives to reduce soil degradation have included the soils component of the Agricultural Green Plan, the National Soil Conservation Program (NSCP), the National Farm Stewardship Program, the Environmental Farm Plan and the Greencover Canada program. In the Prairies, a major component of the NSCP was the Permanent Cover Program (PCP; Vaisy et al., 1996). The initial PCP was fully subscribed within a few months, removing 168 000 ha of marginal land from annual crop production. In 1991, an extension to the original program converted another 354 000 ha. The PCP represented a policy adaptation that has reduced sensitivity to climate over a large area, even though this was not an explicit objective of the program.

5.1.4 Forestry

Mechanisms that encourage sustainable forest management in Canada should help to enhance adaptive capacity in the forestry sector, even though they do not explicitly address climate change adaptation. Such mechanisms include the criteria for Sustainable Forest Management, as set out by the Canadian Council of Forest Ministers (Canadian Council of Forest Ministers, 2003), as well as certification procedures indicating that forestry products are produced from a sustainably managed forest land base.

If present practices of restocking or natural regeneration fail, it could become increasingly difficult to regenerate any forest environment as the climate becomes warmer and drier (Hogg and Schwarz, 1997). Forest loss could therefore be irreversible if adaptation is slow or only reactive. Proactive adaptation could involve introducing certain alien species, although that also brings a risk of hybridization or the import of unintended species or pathogens associated with the alien species. Introducing alien species with no hybridization potential and of low invasiveness appears to be the most reversible adaptation option, but there is no guarantee of either reversibility or successful naturalization.

5.1.5 Health and Well-Being

Protecting the most vulnerable citizens will go a long way in safeguarding the health and well-being of all residents of the Prairies under climate change. Some adaptation responses in other sectors will directly alleviate the health consequences of climate change. For example, successful adaptation in the agriculture sector to drought will decrease the stress and financial constraints experienced by agricultural workers, their families and associated communities. Health care is a defining characteristic of Canadian culture, and existing monitoring or surveillance measures may need only modification to be made more applicable to climate change. Building the capacity to link current climate-sensitive health outcomes (e.g. respiratory illnesses) to weather and climate variables will allow researchers to better determine how changes in climate might affect illness patterns in the future. Other research gaps and capacity needs are listed in Table 12.

The costs associated with disaster assistance and aid programs during and after disasters will be a rising expense for governments unless effective adaptation is implemented (Soskolne et al., 2004).

TABLE 12: Examples of research gaps and additional capacity needed to reduce specific health-related outcomes.

Climate-sensitive health outcomes	Additional capacity needed or research gaps
Drought-related stress/anxiety in agricultural workers	Linking health and well-being to agri-economic and farm employment statistics
Dust-related illnesses/conditions	Education and awareness for populations at risk; link dust levels with weather variables
Wildfire-related illnesses/conditions	Baseline incidence and prevalence rates of known health outcomes
Waterborne diseases and illness from poor water quality	Link water quality, outbreak data and boil-water orders to weather variables locally and distally (e.g. watershed)
Increasing average temperatures and foodborne diseases (FBD)	Link FBD and food-borne pathogens (along the food-processing chain) to weather variables
Air pollution and respiratory illnesses	Baseline incidence and prevalence rates needed; connect weather variables and air pollution levels; use of air mass analysis
Flooding and post-traumatic stress disorder/stress/anxiety	Additional community support for flood prevention
West Nile virus (WNV) and hantavirus pulmonary syndrome (HPS)	Continued monitoring and surveillance

5.2 LOCAL ADAPTATION, INFORMAL INSTITUTIONS AND SOCIAL CAPITAL

Individual farm families manage more than 80% of Canada's agricultural land, so much rural adaptation continues to be local innovations. This is in contrast to the other sectors, specifically forestry, mining, energy, transportation and cities, where the resources are generally owned or leased by corporations and much of the adaptation is therefore implemented at the institutional scale.

Globalization is shifting the responsibility for adaptation to agri-business, national policy makers and the international level (Burton and Lim, 2005). Larger and automated farm equipment and larger scales of production enable fewer producers to produce more commodities. This industrial scale may favour technological and economic adaptations to climate change and variability, but it tends to displace a robust and cohesive network of rural communities (Diaz et al., 2003), thereby affecting social capital for adaptation. Although the agriculture industry has become much more diversified and therefore resilient, there is evidence that this has been achieved in part by regional specialization and therefore less diversity, and greater vulnerability at the individual farm level (Bradshaw et al., 2004). Although the adaptive capacity of agriculture producers appears relatively high (e.g. Burton and Lim, 2005), coping thresholds will be exceeded by departures from normal conditions that are outside the historical experience (Sauchyn, 2007).

There are opportunities for more efficient use of agricultural water supplies, especially improved management of water use by livestock (e.g. McKerracher, 2007) and irrigated crops (*see* Case Study 2). Anecdotal evidence suggests that owners and managers of agricultural land are giving more thought to restoring natural storage and traditional practices, such as rainwater collection systems, and using the storage capacity of wetlands and riparian ecosystems. However, the large scale of modern farming is a barrier to the restoration of wetlands, as wetland restoration may result in greater inefficiency of operating large farm equipment and may require compensation for flooded cropland.

Because farm-scale management practices have more immediate influences than climate change (Jones, 1993), they have the potential to either reduce or exacerbate climate impacts. Soil conservation is a prime example of a 'no regrets' strategy, since preventing soil loss is beneficial whether or not impacts of climate change occur as projected. Since the adoption of modern soil conservation practices, particularly reduced tillage, the average number of bare soil days dropped by more than 20% in the Prairies between 1981 and 1996, with a resulting 30% reduction in the extent of land at risk of wind erosion (McRae et al., 2000). The cost of soil and water conservation is usually borne primarily by the land manager.

"Very severe wind and water erosion is dominated by infrequent occurrences when highly erosive events impact exposed soil. Such events may only happen once during the farming lifetime of an individual farmer, making it difficult to justify the expense and inconvenience of many soil conservation practices." (Prairie Farm Rehabilitation Administration, 2000, p. 33)

Some forms of social capital, such as knowledge sharing and participation in support networks, reduce vulnerability by intensifying mutual support and reciprocity (Portes, 1998; Field et al., 2000; Glaeser, 2001; Putnam, 2001; Policy Research Initiative, 2005). Social capital facilitates an understanding of challenges and coping instruments, and can be used to mobilize resources to ensure the well-being of persons, groups and communities. Existing adaptive capacity is "bound up in the ability of societies to act collectively" (Adger, 2003, p. 29), which involves social networks, relationships and trust. Social capital can complement, and even substitute for, the state's efforts in terms of dealing with climatic hazards (Adger, 2000; Sygna, 2005). Particularly in rural communities, such informal institutions as church groups and agricultural societies are an effective mechanism for helping to address issues like climate change.

Surveys of six rural communities in southern Saskatchewan provided clear evidence of high levels of social capital. Trust and participation in formal organizations and networks are distributed among community members (Diaz and Nelson, 2004; Jones and Schmeiser, 2004). Individuals who have medium or high levels of social capital are, on average, more informed, more optimistic and more empowered when it comes to climate change and water quality issues (Diaz and Nelson, 2006). Those with lower levels of social capital seem to have a more pessimistic outlook on climate change and are less optimistic about the ability to do something about it. In urban contexts, there is greater variability among neighbourhoods in terms of social capital, reflecting specific economic and social conditions within the city (Cecil et al., 2005).

The residents of rural communities may be more likely than urban residents to treat information about climate change with scepticism (Neudoerffer, 2005). This could present a barrier to participation in adaptation initiatives. Furthermore, the autonomy of community-level institutions is becoming threatened by large-scale market forces and administrative structures dominated by multi-national corporations and regional governments eager to attract new investment (Epp and Whitson, 2001). A reduced sense of autonomy could also discourage local adaptation planning.

In Aboriginal communities, the adoption of non-traditional lifestyles in recent years has eroded local knowledge and practices, while growing dependence on waged labour and external assistance have served to undermine local adaptive capacity (Ford and Smit, 2004). Traditional knowledge and land management systems served as a source of resiliency in the past, and could play an important role in restoring and strengthening adaptive capacity in the future.

Many resort-based communities and recreational facilities involve enormous fixed capital expenditures, such as ski lifts, snow-making equipment, lodges and expensive vacation homes. Where such communities are limited to winter activities, the potential for economic losses as a result of changing climate are high. However, net economic impacts could be ameliorated with diversification, to capitalize on more summer-like conditions in the spring and fall (Scott and Jones, 2005). Tourism-based communities tend to be more diversified economically than communities dependent on a single resource-based sector (i.e. agriculture, mining or forestry), and residents are likely to have a broader skill set that strengthens adaptive capacity.

Learning from past disasters provides insight into adaptive strategies. Newspapers detail the impacts of these events from the perspective of individuals and communities, and can document a crucial link between disasters and negative health outcomes that is not easily measured by conventional scientific research methods (Soskolne et al., 2004). Descriptions of the hardships endured by communities and individuals highlight those circumstances that negatively affect health and well-being during a disaster. These stories can provide insight into where community adaptation may be best incorporated, such as the development of alternative evacuation routes for remote communities. Although the current health care system is generally able to effectively handle direct health outcomes from disasters, more frequent and severe extreme climate events could cause health services to become inundated.

6 SYNTHESIS

Key climate change risks and opportunities in the Prairies stem from the dry and variable climate; projected temperature increases that are greater than elsewhere in southern Canada; sensitivity of water resources, ecosystems and resource economies to seasonal and inter-annual variations in climate; and especially large departures (e.g. drought) from normal conditions. Recent rapid economic growth (especially in Alberta), a population shift from rural to urban, and most of Canada's agricultural landscape and irrigated land are also important factors influencing vulnerability in the Prairies. Through the assessment of vulnerability for the region, the following conclusions can be drawn:

- ***Projected climate change is outside the range of recent experience with natural variability.***

Significant recent warming, evident in instrumental and proxy climate records, is consistent with projections from global climate models (GCMs). With the exception of a few scenarios for the 2020s, all models forecast climates that are outside the range of natural variability experienced and observed in the twentieth century. The authors' assessment of the sensitivities and vulnerabilities of natural resources and human activities reveals that the most significant threat posed by climate change in the Prairies is the projected increase in climate variability and frequency of extreme events. Climatic extremes, and especially droughts, will limit the opportunities afforded by changing climate and present the greatest challenges for adaptation. Climate models are unable to simulate extreme events and the variability of hydroclimate with the same level of certainty as that for future trends and variability in temperature. The most costly climate events in Canadian history have been droughts on the Prairies. Flooding is another costly climate event, with associated health impacts that include waterborne disease outbreaks, stress and anxiety. The historic recurrence of social and economic impacts resulting from drought suggest that future droughts of extreme severity or long duration will be the element of climate change and variability most likely to exceed the coping and adaptive capacities of communities and industries in the Prairies.

- ***Most economies and activities are not presently adapted to the larger range of climate conditions projected.***

Some adaptation of prairie communities and economies has occurred in response to climate conditions of the twentieth century. From this short perspective, climate and water seem rather consistent, and resource management practices and policies therefore reflect a perception of relatively abundant water supplies and ecological resources within a relatively stationary environment. Future water and ecosystem management will have to abandon the assumption of a stationary environment, given the longer perspective from climate models and paleoenvironmental data, and the projected shifts in climate variability, biodiversity, disturbance regimes and distribution of water resources and ecological services.

- ***The major climate change vulnerabilities relate to changes in water availability and ecosystem distributions.***

One of the most certain projections about future hydroclimate is that extra water will be available in winter and spring, whereas summers will generally be drier as the result of earlier spring runoff and a longer, warmer summer season of water loss by evapotranspiration. The net result will very likely be less surface water and soil moisture, but also greater variation from season to season and year to year. Water scarcity in some years will be a constraint for all sectors and communities, and could ultimately limit the current rapid economic growth, including development related to oil sands and expanded irrigation.

Major ecosystem shifts are expected with climate warming and drying. Aquatic habitats will be stressed, affecting various fish species, and some waterfowl populations will decline substantially. Change in terrestrial ecosystems will be most visible near sharp ecological gradients, such as in the mountains, in island forests and along the margins of the northern and western coniferous forests. Non-native plants and animals will appear on the landscape. Some native species will decline or disappear entirely. Other species will increase in numbers or geographic distribution, given adequate connectivity. Changing ecosystems could make some vector-borne diseases, such as West Nile virus and hantavirus pulmonary syndrome, more common.

- ***There are both advantages and disadvantages to shorter, warmer winters.***

Much of the projected increase in temperature and precipitation will occur in winter and spring. There are several advantages of such changes, including reduced energy demand for heating and decreased mortality from extreme cold. On the other hand, there are advantages of cold winters, related to winter recreation, transportation over lake ice and frozen ground, and especially the storage of water as ice and snow, which is presently the most abundant, reliable and predictable source of water.

- ***Planned adaptation is a component of adaptive management and sustainable economic development.***

Increasing demands on natural resources, combined with a current paradigm of sustainable development, have led to policy and processes in all sectors that are relevant to planned adaptation to climate change. Relevant existing policy and management instruments include sustainable community initiatives, infrastructure renewal, environmental farm plans, watershed basin councils and principles of adaptive forest management and integrated water resource management. With rapid urbanization in Alberta and general depopulation of rural areas throughout the Prairies, strategies for sustainable urban growth and for sustaining rural economies need to include the evaluation of climate risks and opportunities relevant to different sectors of the population and regional economies. For example, rural economic development will be strongly influenced by the impacts of climate change on natural resources, especially water supplies.

- ***There is a moderate to high level of adaptive capacity in the Prairies, but it is unevenly distributed and must be mobilized to reduce vulnerability.***

An evaluation of the conventional determinants of adaptive capacity (natural and human capital, infrastructure, technology, etc.) suggests that there is a relatively high level of such capacity on the Prairies. A history of adaptation to a variable and harsh climate has built substantial adaptive capacity in the agriculture sector, which can now rely on various precedents for adapting to threats to productivity. Policies and management practices have been adjusted to address, for example, soil degradation, trade barriers and changes in export markets and transportation subsidies. The history of prairie agriculture has been a continuous process of adaptation and drought-proofing through innovation and improvements in water, soil, crop and pasture management. More severe drought will test this accumulated adaptive capacity.

Moderate to high adaptive capacity in other sectors can be attributed to risk management strategies and adaptive management practices, although these mechanisms have generally not been tested with respect to climate change. Barriers to adaptation may include lack of financial capacity, lack of understanding of the implications of climate change among managers, and existing policies that may prevent the implementation of adaptation measures.

Adaptive capacity is uneven geographically and among segments of society by virtue of their demographic, health, regional, socioeconomic or cultural circumstances. Populations most vulnerable in the Prairies include the elderly, children, those with underlying health problems, those with lower socioeconomic status, the homeless, family farmers and Aboriginal peoples. The elderly, Aboriginal and immigrant populations are the fastest growing and also among the most vulnerable to health impacts. Economic vulnerability often precedes negative health outcomes associated with extreme weather.

The present uneven geographic distribution of people and resources, with population and wealth concentrated in Alberta, will likely be further amplified by changing climate. Economic and social stresses related to climate change could encourage further migration from rural to urban communities and to regions with the most resources. A population shift from rural areas to large urban centres undermines the viability of rural communities and may put additional social pressures on cities. Rural communities, especially isolated ones with limited economic diversity, are most at risk due to limited emergency response capacity and dependence on climate-sensitive economic sectors (agriculture, forestry). Rural Aboriginal communities will experience these same stresses, in addition to threats to a subsistence-based livelihood.

Formal and informal institutions interact to either sustain or undermine capacities to deal with global challenges such as climate change. Efforts to improve adaptive capacity must deal with the existing institutional factors. To the extent that governance institutions organize the relationships between the state and civil society, they are fundamental in developing adaptive capacity. Social capital can be used to mobilize resources in order to ensure the well-being of persons, groups and communities. Social capital may be particularly important in dealing with the uncertainties and instabilities that climate change creates, complementing and even substituting efforts by governments. The few available studies show that people with higher levels of social capital are, on average, more informed, more optimistic and more empowered when it comes to dealing with climate change and water quality issues.

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