FROM IMPACTS TO ADAPTATION:
Canada in a Changing Climate 2007

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Canada

PREFACE

From Impacts to Adaptation: Canada in a Changing Climate 2007 reflects the advances made in understanding Canada's vulnerability to climate change during the past decade. Through a primarily regional approach, this assessment discusses current and future risks and opportunities that climate change presents to Canada, with a focus on human and managed systems. It is based on a critical analysis of existing knowledge, drawn from the published scientific and technical literature and from expert knowledge. The current state of understanding is presented, and key knowledge gaps are identified. Advances in understanding adaptation, as well as examples of recent and ongoing adaptation initiatives, are highlighted throughout the report.

From Impacts to Adaptation: Canada in a Changing Climate 2007

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ISBN: 987-0-662-05176-3
Cat. No.: M174-2/1-2007

This publication is also available at:
http://adaptation2007.nrcan.gc.ca

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Recommended Citation:
Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., editors (2008): From Impacts to Adaptation: Canada in a Changing Climate 2007; Government of Canada, Ottawa, ON, 448 p.

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Synthesis

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Recommended Citation:

Lemmen, D.S., Warren, F.J. and J. Lacroix. (2008): Synthesis: *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 1-20.

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SUMMARY

Adaptation involves making adjustments in our decisions, activities and thinking because of observed or expected changes in climate, in order to moderate harm or take advantage of new opportunities. It is a necessary complement to the reduction of greenhouse gas emissions in addressing climate change. Adaptation in Canada will be informed by knowledge of current and projected impacts of, and vulnerability to, changing climate, as well as lessons learned from practical adaptation experiences. The following bullets represent key conclusions arising from this national-scale assessment of climate change impacts and adaptation, and are discussed in the subsequent sections of this synthesis.

- The impacts of changing climate are already evident in every region of Canada.
- Climate change will exacerbate many current climate risks, and present new risks and opportunities, with significant implications for communities, infrastructure and ecosystems.
- Climate change impacts elsewhere in the world, and adaptation measures taken to address these, will affect Canadian consumers, the competitiveness of some Canadian industries, and Canadian activities related to international development, aid and peace keeping.
- Impacts of recent extreme weather events highlight the vulnerability of Canadian communities and critical infrastructure to climate change.
- Adaptive capacity in Canada is generally high, but is unevenly distributed between and within regions and populations.
- Resource-dependent and Aboriginal communities are particularly vulnerable to climate changes. This vulnerability is magnified in the Arctic.
- Some adaptation is occurring in Canada, both in response to, and in anticipation of, climate change impacts.
- Integrating climate change into existing planning processes, often using risk management methods, is an effective approach to adaptation.
- Barriers to adaptation action need to be addressed, including limitations in awareness and availability of information and decision-support tools.
- Although further research will help to address specific knowledge gaps and adaptation planning needs, we have the knowledge necessary to start undertaking adaptation activities in most situations now.

INTRODUCTION

The impacts of changing climate are already evident in Canada and globally. Climate change will continue for many decades, and even centuries, regardless of the success of global initiatives to reduce greenhouse gas emissions (mitigation). Adaptation is a necessary complement to mitigation in addressing climate change (Figure SR-1). Adaptation involves making adjustments in our decisions, activities and thinking because of observed or expected changes in climate, with the goals of moderating harm and taking advantage of new opportunities (Box SR-1). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC AR4) states that, while neither adaptation nor mitigation actions alone can prevent significant climate change impacts, taken together they can significantly reduce risks. It highlights that there is no optimal mix between adaptation and mitigation, and that climate change policy is not about making choices between the two. Mitigation is necessary to reduce the rate and magnitude of climate change, while adaptation is essential to reduce the damages from climate change that cannot be avoided (Intergovernmental Panel on Climate Change, 2007; Klein et al., 2007).

In this report the term 'climate change' refers to any change in climate over time, whether it is the product of natural factors, human activity or both. This usage is the same as that of the Intergovernmental Panel on Climate Change, but it differs from the usage in the United Nations Framework Convention on Climate Change, which restricts the term to climate changes that can be directly or indirectly related to human activity and are additional to natural climate variability. The term 'changing climate' is used sometimes in this report to highlight that these changes are ongoing.

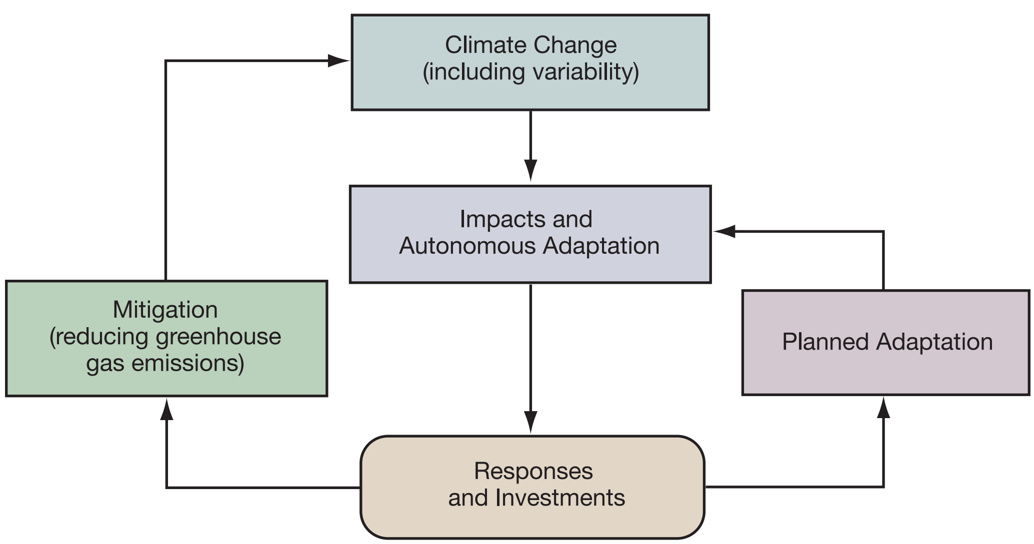


FIGURE SR-1: Adaptation and mitigation in the context of climate change (*modified from* Smit et al., 1999).

This synthesis of *From Impacts to Adaptation: Canada in a Changing Climate 2007* presents conclusions regarding current and future impacts of, and vulnerabilities to, climate change in Canada. It also discusses adaptation actions being taken now to reduce risks and take advantage of opportunities associated with changing climate, and those that could be undertaken in future. Although the identification of specific priority issues for policy and program action requires analyses beyond the scope of this scientific assessment, the conclusions of this assessment do provide input into that detailed analysis. The synthesis is based on information contained within the individual chapters of the report — particularly Chapters 3 through 8, which present regional analyses for Northern Canada, Atlantic Canada, Quebec, Ontario, the Prairies and British Columbia, and Chapter 9, which examines the implications for Canada of climate change impacts and adaptation elsewhere in the world. The key findings of these chapters are summarized in Box SR-2. The remainder of the synthesis provides an integrative analysis of that information at the national scale. As appropriate, the conclusions are linked to findings of the IPCC AR4, demonstrating that the challenges that climate change adaptation presents to Canada are shared with other countries and regions, and that there is a great deal to be learned through the sharing of adaptation experiences.

Information on recent and projected changes in climate is provided in Chapter 2 of the assessment, as well as in the six regional chapters, which discuss current climate, recent climate trends and future projections as input to analyses of sensitivity and vulnerability to climate change.

BOX SR-1

What is adaptation to climate change?

Adaptation to climate change is any activity that reduces the negative impacts of climate change and/or takes advantage of new opportunities that may be presented. Adaptation includes activities that are taken before impacts are observed (anticipatory) and after impacts have been felt (reactive; Table SR-1). Both anticipatory and reactive adaptation can be planned (i.e. the result of deliberate policy decisions), and reactive adaptation can also occur spontaneously. In most circumstances, anticipatory planned adaptations will incur lower long-term costs and be more effective than reactive adaptations.

Table SR-1: Different types of adaptation (*modified from* Smit et al., 1999).

<table>
<tr><th colspan="5">ADAPTATION</th></tr>
<tr><th>Based on</th><th colspan="4">Type of adaptation</th></tr>
<tr><td>Intent</td><td colspan="2">Spontaneous</td><td colspan="2">Planned</td></tr>
<tr><td>Timing (relative to climate impact)</td><td>Reactive</td><td colspan="2">Concurrent</td><td>Anticipatory</td></tr>
<tr><td>Temporal scope</td><td colspan="2">Short term</td><td colspan="2">Long term</td></tr>
<tr><td>Spatial scope</td><td colspan="2">Localized</td><td colspan="2">Widespread</td></tr>
</table>

Adaptation will usually not take place in response to climate change alone, but in consideration of a range of factors with the potential for both synergies and conflicts. Successful adaptation does not mean that negative impacts will not occur, only that they will be less severe than would be experienced had no adaptation occurred. In deciding what adaptation option is most appropriate for a particular situation, attention must be paid to feasibility, likelihood and mechanisms for uptake.

BOX SR-2

SUMMARY OF CHAPTER KEY FINDINGS

NORTHERN CANADA (Chapter 3)

- Current levels of exposure and sensitivity to climate-related changes, as well as limitations in adaptive capacity, make some northern systems and populations particularly vulnerable to the impacts of climate change.
- Climate-induced changes in permafrost, sea ice, lake ice and snow cover have large implications for infrastructure maintenance and design.
- Climate changes will result in shifts in species availability, accessibility and quality, with consequences for biodiversity and human populations that rely on these resources.
- Increased navigability of Arctic marine waters and expansion of land-based transportation networks will bring both opportunities for growth in a range of economic sectors and challenges associated with culture, security and the environment.
- Maintaining and protecting aspects of traditional and subsistence ways of life in many Arctic Aboriginal communities will become more difficult in a changing climate.

ATLANTIC CANADA (Chapter 4)

- Changing climate will result in more storm events, increasing storm intensity, rising sea level, higher storm surges, and more coastal erosion and flooding, affecting coastal communities and their infrastructure and industries.
- Water resources will come under increasing pressure as conditions shift and demands change in response to both climatic and non-climatic factors.
- Impacts on marine fisheries will extend beyond fish species to include numerous aspects of fishery operations, such as transportation, marketing, occupational health and safety, and community health and well-being.
- Although higher temperatures and longer growing seasons could benefit agriculture and forestry, associated increases in disturbances and moisture stress pose concerns.
- Vulnerability of Atlantic communities can be reduced through careful planning, especially in coastal regions and through adaptation focused on limiting exposure to sea-level rise.

QUEBEC (Chapter 5)

- The largest changes in climate in this region are anticipated to occur in Northern Quebec, exacerbating existing problems relating to natural disasters and critical infrastructure, and challenges in maintaining traditional ways of life.
- Climate change impacts on the natural environment will adversely affect ecosystem health, and have especially significant consequences where natural resources are a key component of the economy. Some impacts could be beneficial for certain economic sectors, including hydroelectricity and forestry.
- In the maritime region, there will likely be increased shoreline erosion along the Gulf of St. Lawrence and the St. Lawrence River estuary, where most of the region's social and economic activity is concentrated.
- In southern Quebec, an increase in the frequency, intensity or duration of extreme weather conditions would increase risks for the aging built environment, vulnerable populations and communities in areas exposed to natural hazards.
- Adaptation offers many possible solutions for reducing adverse impacts. Quebec's increasingly diversified knowledge economy provides a high degree of adaptive capacity. Little is generally known about the costs and limitations of adaptation, particularly in the long term.

ONTARIO (Chapter 6)

- Climate-related disruptions to critical infrastructure, including water treatment and distribution systems, energy generation and transmission, and transportation have occurred throughout the province and are likely to become increasingly frequent in the future.
- Water shortages have been documented in southern regions of the province, and are projected to become more frequent as summer temperatures and evaporation rates increase.
- Climate-related events, such as extreme weather, heat waves, smog episodes and ecological changes that support the spread of vector-borne diseases, all present risks to the health of Ontario residents.
- Remote and resource-based communities have been severely affected by climate-related events

that have caused repeated evacuations, disrupted vital transportation links and stressed forest-based economies. The impacts are expected to increase in the future.

- Ontario's ecosystems are currently stressed by the combined influence of changing climate, human activities and natural disturbances.
- Ontario has a strong capacity to adapt to climate change; however, this capacity is not uniform across the region and between sectors.

PRAIRIES (Chapter 7)

- Increases in water scarcity represent the most serious climate risk in the Prairie provinces.
- Ecosystems will be impacted by shifts in bioclimate, changes in fire and insect disturbances, stressed aquatic habitats and the introduction of non-native species, with implications for livelihoods and economies dependent on ecological services.
- The Prairies are losing some advantages of a cold winter. Cold winters limit pests and diseases, facilitate winter operations in the forestry and energy sectors, and provide access to remote communities through the use of winter roads.
- Communities dependent on agriculture and forestry are highly sensitive to climate variability and extremes. Drought, which can have associated economic impacts of billions of dollars, wildfire and severe floods are projected to occur more frequently in the future.
- Adaptive capacity, though high, is unevenly distributed, resulting in differing levels of vulnerability within the region.
- Although adaptation processes are not well understood, institutions and civil society will play a key role in mobilizing adaptive capacity by building on several recent initiatives that enhance resilience.

BRITISH COLUMBIA (Chapter 8)

- Many regions and sectors of British Columbia will experience increasing water shortages and increasing competition among water uses (for example, hydroelectricity, irrigation, communities, recreation and in-stream flow needs), with implications for transborder agreements.
- Extreme weather and related natural hazards have impacted, and will continue to impact, critical infrastructure, affecting communities, industries and the environment.
- British Columbia's forests, forest industry and forest-dependent communities are particularly vulnerable to climate-related risks, including pest infestations and fire.
- Climate change will continue to exacerbate existing stresses on British Columbia's fisheries. The vulnerability of Pacific salmon fisheries is heightened by the unique social, economic and ecological significance of these species.
- British Columbia's agricultural sector is facing both positive and negative impacts from climate change, with more frequent and sustained drought being the greatest risk.
- Integrating climate change adaptation into decision-making is an opportunity to enhance resilience and reduce the long-term costs and impacts of climate change.

CANADA IN AN INTERNATIONAL CONTEXT (Chapter 9)

- Climate change is already affecting the residents, economies and environments of all regions of the world. These impacts, which are primarily related to extreme climate events and changes in water resources, are mostly adverse and are expected to continue and intensify in the future.
- Diseases currently prevalent in warmer climates will become greater threats in Canada as a result of greater incidence of disease and vectors in countries that are involved in trade and travel with Canada.
- The impacts of climate change and the adaptation measures that other countries take to respond to them can affect Canada in a number of ways, with potentially significant implications for competitiveness, health, tourism, disaster relief, development aid and peace-keeping.
- As a developed country, Canada will face increasing demands to support disaster relief efforts and to help developing countries adapt to climate change.

IMPACTS

The impacts of changing climate are already evident in every region of Canada.

Impacts of changing climate on many physical and biological systems, such as ice and snow cover, river, lake and sea levels, and plant and animal distributions, are unequivocal (Table SR-2) and have been documented in other recent climate change assessments (Intergovernmental Panel on Climate Change 2001, 2007; Arctic Climate Impact Assessment, 2005). In addition, increases in the occurrence of heat waves, forest fires, storm-surge flooding, coastal erosion and other climate-related hazards are consistent with observed climate trends. Many of these impacts directly influence human systems. For example, decreases in the thickness and duration of lake and river ice have significantly impacted the viability of many winter road networks that provide access to remote communities and mine sites in northern Canada (including the northern parts of many provinces; Chapters 3, 5, 6 and 7), while coastal erosion has impacted buildings and critical infrastructure, and threatened cultural sites on all of Canada's marine coasts (Chapters 3, 4, 5 and 8).

There is also strong evidence that climate change has been a contributing factor to a number of other environmental, social and economic issues. These include the unprecedented outbreak of mountain pine beetle in British Columbia, which encompassed over 9.2 million ha of forest in 2006, and is now spreading eastward into Alberta. Although fire suppression and other historical factors have contributed to this outbreak, the recent predominance of hot summers that favour beetle reproduction, and mild winters that allow their offspring to survive, have been critical factors (Figure SR-2; Chapter 8). Since 1990 in parts of Atlantic Canada, sea lettuce has been spreading, rendering estuaries less suitable for shellfish or finfish and less attractive to residents and tourists. This spread has been related, in part, to climate-driven reductions in freshwater inflow during summer (Chapter 4).

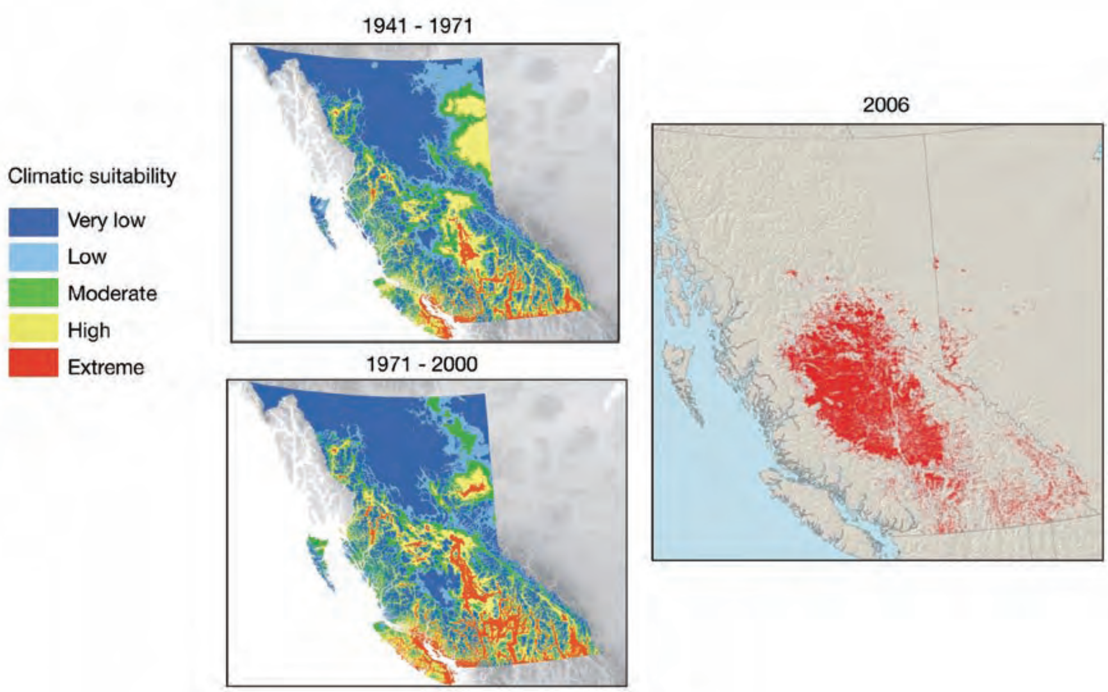


FIGURE SR-2: *Left:* Historical distributions of climatically suitable habitats for the mountain pine beetle (MPB) in British Columbia (*adapted from* Carroll et al., 2004). Areas with 'very low' suitability are unsuitable for MPB, whereas 'extreme' areas are those considered climatically optimal. *Right:* Total area affected by mountain pine beetle in British Columbia in 2006 (Natural Resources Canada, 2007).

TABLE SR-2: Some observed impacts of changing climate on physical and biological systems in Canada.

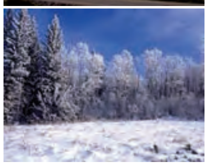
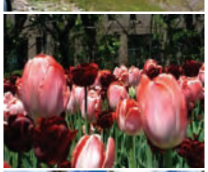
	System and nature of impact	Examples	Relevant chapters
	**Glacier cover** – mass and area; widespread reductions with local variability	• widespread retreat since late 1800s in western Canada, since 1920s in Arctic • glaciers in BC are currently retreating at rates unprecedented in the last 8000 years • estimated loss of ice mass in Canadian Arctic of 25 km^3/a for period 1995–2000	3, 7, 8 and 9
	**Snow cover** – reduced annual extent and duration	• 10% decrease in extent in Northern Hemisphere for period 1972–2003 • decrease of 20 days in duration of snow cover in Arctic since 1950	2, 3 and 5
	**Sea-, lake- and river-ice cover** – reduced extent and duration	• 3% per decade decrease in annual average area of sea ice in Northern Hemisphere for period 1978–2003 • reduction of ice cover season on Great Lakes by 1–2 months during past 150 years	2, 3, 4, 5 and 6
	**Permafrost conditions** – warming and deepening of annual thaw layer	• most significant warming in western Arctic • at least 1°C increase in surface permafrost temperature since 1990 in northern Quebec • increase in summer thaw penetration in the 1990s	2, 3, 5 and 7
	**River and lake levels** – changes in water levels and timing of peak flow events	• decline in summer and fall runoff in Prairies, leading to lower lake and river levels at those times • trend towards earlier spring runoff	2, 5, 6, 7, 8 and 9
	**Plant phenology** – events occurring earlier	• 26-day shift to earlier onset of spring over the past century in Alberta • 5–6 day advance since approximately 1959 in the onset of phenological spring in eastern North America	2, 4, 5, 6 and 7
	**Plant productivity** – lengthening growing seasons and increased productivity	• greater productivity rates of spruce and poplar in Quebec • lengthening of growing season for crop production	5
	**Distribution of some animal species** – northward or upslope shifts in terrestrial ecosystems, shifts towards warmer thermal regimes in freshwater ecosystems	• increasing abundances of cool and warm water fish species relative to cold water species	3 and 6
	**Coastal erosion** – enhanced as a result of decreased ice cover, sea-level rise, increased storminess and non-climatic factors	• accelerated erosion and degradation of the dunes and coastline throughout the Gulf of St. Lawrence, northeastern Prince Edward Island and southwestern, western and eastern Newfoundland	3, 4, 5 and 8

Photo credits: All images are from Natural Resources Canada, except: Glacier cover from Ben W. Bell, Sea-, lake- and river-ice cover from Environment Canada, and Distribution of some animal species from Government of Yukon.

Climate change will exacerbate many current climate risks and present new risks and opportunities, with significant implications for communities, industry, infrastructure and ecosystems.

Climate change is evidenced by changes in average conditions as well as by changes in climate variability and extreme climate events. Many of the most severe and costly impacts will be associated with projected increases in the frequency and magnitude of extreme climate events and associated natural disasters, including flooding due to high-intensity rainfall and storm surges, ice and wind storms, heat waves and drought (Chapters 2–9). An understanding of future climate extremes is particularly important for the design and maintenance of infrastructure, emergency management, and community health and safety (Chapters 5 and 6).

Gradual changes in average temperature, precipitation and sea level also affect community and ecosystem sustainability. Some of the most significant and pervasive impacts in Canada will be related to water resources. Water-stressed areas will expand due to decreased runoff in many areas resulting from changes in precipitation and increased evapotranspiration (Chapter 2), while reduced water quality and quantity will be experienced on a seasonal basis in every region of Canada (Chapters 3–8). Increasing demands on water resources for agriculture, energy production, communities and recreation will have to be managed in consideration of ecosystem needs (Chapters 4–8). In addition to increasing the impacts already observed, changing climate will bring new risks to some areas, such as the introduction of vector-borne diseases into areas where climate conditions presently inhibit survival of the vector host (Chapters 5, 6 and 9). Climate-related impacts on ecosystems will present new challenges to the management of protected areas (Chapters 6, 7, 8).

Climate change will also bring opportunities, including longer and warmer growing seasons, which could increase productivity and allow cultivation of new and potentially more profitable crops and tree species (Chapters 4–8). Agriculture and forestry in Canada are susceptible to changes in disturbance regimes and more frequent drought, demonstrating the need for timely and effective adaptation (Chapters 7 and 8). Decreased sea-, river- and lake-ice cover permit longer shipping seasons, although lower lake and river levels could have negative impacts on transportation (Chapters 3, 4 and 6). Increased marine transport in the Arctic would provide opportunities for economic growth, along with environmental and security risks (Chapter 3).

Impacts will be cumulative and frequently synergistic (Figure SR-3). For example, increased frequency and magnitude of heat waves will result in increased peak electricity demand for air conditioning, while decreased runoff from mountain glaciers in western Canada and lower water levels on the Great Lakes are likely to reduce potential for hydroelectricity generation in these areas. Combined with anticipated increases in demand for electricity related to population and economic growth, changing climate could result in increased numbers of black-out and brown-out events (Chapters 6 and 8). The cumulative nature of impacts, and associated cascading uncertainties, makes it likely that climate change will produce 'surprises' — impacts related to the crossing of critical thresholds that have not been anticipated. As is the case for all human and managed natural systems, the magnitude of impacts can be reduced through adaptation.

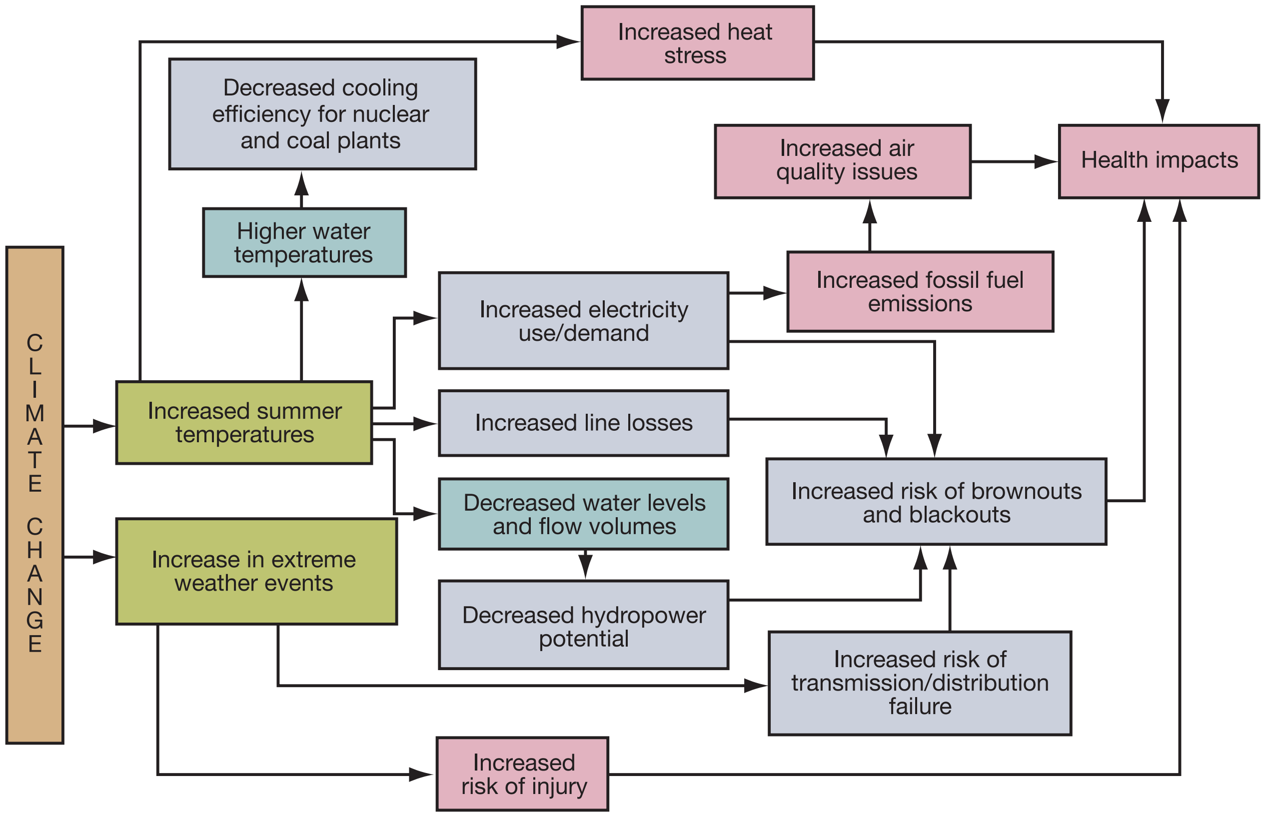


FIGURE SR-3: Illustration of the potential cumulative and synergistic impacts of climate change, using example of how impacts on the energy sector can amplify the direct impacts of climate change on human health.

Climate change impacts elsewhere in the world, and adaptation measures taken to address these will affect Canadian consumers, the competitiveness of some Canadian industries, and Canadian activities related to international development, aid and peace keeping.

Climate change impacts elsewhere in the world will affect supply-demand dynamics and the competitive advantage of some Canadian industries. This will influence the net economic costs of climate change in Canada. For example, although forest productivity may increase in Canada, greater productivity increases in other countries could result in lower forestry-product prices on the global market and a reduced share of the market for Canadian producers (Chapter 9). For tourism, climate change may reduce the attractiveness of some Canadian natural areas (Chapters 3, 4, 5, 7 and 8). When examined in a global context, however, tourism in Canada is expected to be positively impacted by climate change, as warmer temperatures would make Canada a more attractive destination for foreign tourists and encourage more Canadians to forgo vacations to tropical locations due to less severe winters in Canada (Chapter 9).

Climate changes elsewhere in the world will also influence Canadian humanitarian and development activities. In addition to commitments to assist developing countries in their efforts to adapt to climate change, changing climate will increase the need for disaster relief. Observed trends toward increases in the frequency of disasters related to extreme climate events (Figure SR-4) are expected to continue in the future. Extreme events are also expected to become more intense. Environmental stress and scarcity issues (primarily related to food and water) caused by climate changes can exacerbate political, social, economic, ethnic, religious or territorial conflicts, leading to increased political instability and displacement of populations (Chapter 9).

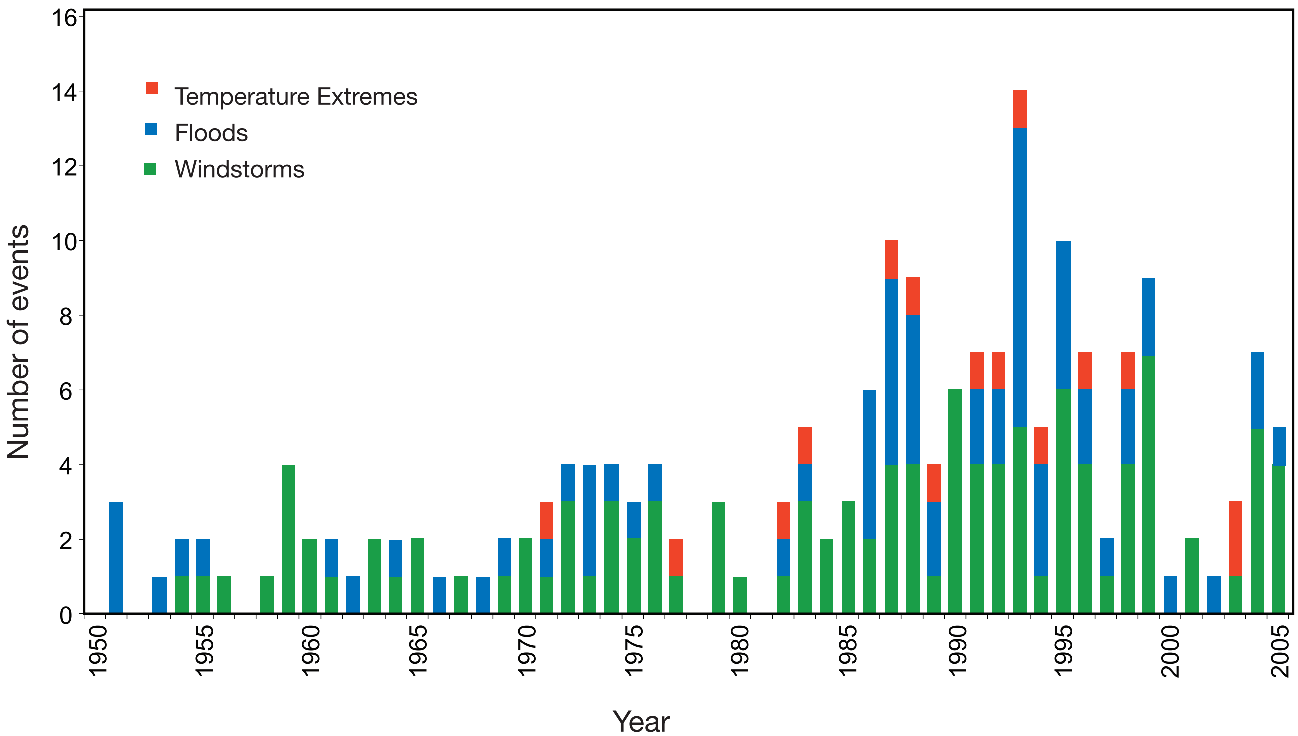


FIGURE SR-4: The number of global climate-related disasters, by event, from 1950 to 2006 (*data from* Munich Reinsurance, 2006).

VULNERABILITY

Impacts of recent extreme weather events highlight the vulnerability of Canadian communities and critical infrastructure to climate change.

The economic costs resulting from extreme weather events in Canada in the past decade (since 1996) have been greater than for all previous years combined. Costs reaching hundreds of millions and even billions of dollars are associated with flooding, wind, hail and ice storms, hurricanes, tornados and wild fires in all regions of southern Canada (Table SR-3), arising from property damage and disruptions in the production and flow of goods and services. Prolonged periods of unusual weather, such as drought, can also result in high economic costs. Six of the ten most costly disasters in Canadian history have been droughts (Public Safety Canada, 2005). The national-scale drought of 2001–2002 resulted in Canada's gross domestic product being reduced by about $5.8 billion, as well as more than 41 000 job losses (Chapter 7). While it is not possible to attribute individual weather events to changing climate, such costs illustrate that Canadian communities and infrastructure are vulnerable to such events. This vulnerability is likely to increase, since climate models project increases in the frequency and magnitude of many types of extreme weather (Chapters 2 and 9).

Extreme weather events affect the health and well-being of Canadians, as they frequently involve job losses, loss of assets, displacements, physical injuries and illnesses, psychological disorders, and loss of lives. The 1998 ice storm resulted in 945 injuries, while wildfires in British Columbia and Alberta resulted in an estimated 45,000 displacements in 2003, both of which are records for natural disasters in Canada (Table SR-3). Heavy rainfall following a period of drought was a contributing factor to the *E. coli* outbreak in Walkerton, Ontario in 2000, which resulted in seven deaths and thousands of people becoming ill (Chapter 6).

TABLE SR-3: Recent costly weather events in Canada, excluding drought (*from* Public Safety Canada, 2005; Environment Canada, 2005; BC Provincial Government, 2003).

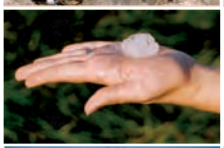
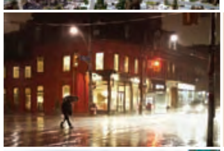
	Event and date	Region	Estimated costs	Deaths	Injuries	Evacuations	Relevant chapters
	**Ice storm**, 1998	Ontario, Quebec, Atlantic Canada	$5.4 billion	28	945	17 800	2, 4, 5, 6
	**Saguenay flood**, 1996	Quebec	$1.7 billion	10	0	15 825	2, 5
	**Calgary hailstorm**, 1991	Prairies	$884 million	0	0	0	2, 7
	**Red River flood**, 1997	Prairies	$817 million	0	0	25 447	2, 7
	**BC/Alberta wildfires**, 2003	British Columbia	$700 million	3	unknown	45 000	7, 8
	**Toronto extreme rain**, 2005	Ontario	>$500 million	0	0	0	6
	**Southern Alberta floods**, 2005	Prairies	>$400 million	4	unknown	>2000	7
	**Calgary hailstorm**, 1996	Prairies	$305 million	0	0	0	2, 7
	**Hurricane Juan**, 2003	Atlantic Canada	$200 million	8	unknown	unknown	2, 4

Photo Credits: Environment Canada, Library and Archives of Canada, Natural Resources Canada, Julian Brimelow and Sam Javanrouh.

Adaptive capacity in Canada is generally high but is unevenly distributed between and within regions and populations.

As a prosperous country with high levels of education, access to technology, and strong and effective institutions, Canada is well positioned to take action on adapting to climate change (Chapter 10). However, there are significant differences in the ability to adapt among different subregions and population groups, resulting in differing vulnerabilities to climate change (Box SR-3). Indeed, the IPCC AR4 has concluded that, in all regions of the world, no matter how prosperous, there are certain areas, sectors and communities that are particularly vulnerable to climate change (Wilbanks et al., 2007).

BOX SR-3

Vulnerability and adaptive capacity

Vulnerability to climate change "is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (Intergovernmental Panel on Climate Change, 2007, p. 21). Three factors influence the vulnerability of any system: 1) the nature of the climate changes to which it is exposed; 2) the climate sensitivity of the system; and 3) the capacity of that system to adapt to changed climate conditions. Therefore, while a sector, community or population may be exposed to significant climate changes, it is not considered vulnerable unless those climate changes could result in significant negative impacts, and it does not have the capability to undertake adaptation actions that would significantly reduce those impacts.

Although extensive research efforts have focused on projecting the magnitude and rate of climate changes, and on understanding the relationships between climate and biophysical systems, the characterization of adaptive capacity is a relatively new area of study. Adaptive capacity is influenced by a number of location-specific social, economic and institutional factors that act to either constrain or enhance the ability to adapt.

Within Canada, there are significant differences in the climate sensitivity of major economic sectors. Among the most sensitive sectors are those dependent upon renewable natural resources, including agriculture, fisheries, forestry and non-commercial food supply, as well as many aspects of tourism and recreation. Adaptive capacity similarly varies widely between sectors, communities and populations. Assessment of vulnerability must consider variability in all these factors.

Since vulnerability refers to the susceptibility of a system to harm, it does not consider the benefits that may result from changing climate. However, the ability to take advantage of such opportunities is also a function of adaptive capacity. Finally, where vulnerability is considered relatively low due to a high capacity to adapt, significant negative impacts may still occur if appropriate adaptation actions are not implemented. Although many societies have high adaptive capacity and the necessary financial resources, they have not taken effective action on adaptation to climate change, variability and extremes (Adger et al., 2007; Field et al., 2007).

Within Canada, differences in adaptive capacity and the perception of the risks presented by climate change have been noted between urban centres and rural/remote communities (Chapters 4–7). Both urban and rural centres have characteristics that enhance or limit adaptive capacity (Table SR-4). Urban centres tend to be places of greater wealth, higher education and skill sets, with easier access to technology and institutions. However, urban centres also tend to have greater reliance on critical energy, transportation and water infrastructure, more severe heat stress and air quality problems, and larger numbers of poor and elderly residents that result in vulnerabilities not shared by most rural communities (Chapters 5 and 6). Northern Canada, with its sparse, widely distributed population, evolving governance and institutions, and significant subsistence economy, has unique limitations to adaptive capacity (Chapter 3). Among population groups, the poor, the elderly, recent immigrants and Aboriginal peoples tend to face greater challenges in coping with climate changes, often due to limited financial resources, health problems and difficulties accessing technology and institutional services (Chapters 2–9).

Resource-dependent and Aboriginal communities are particularly vulnerable to climate changes. This vulnerability is magnified in the Arctic.

Agriculture, forestry, fishing and hunting are vitally important for the economic well-being of many subregions and communities where land- and resource-based activities remain the foundation of economic life. More than 1600 communities in Canada obtain 30% or more of their employment income from these sectors. The economic impacts of climate change at the community scale can be

TABLE SR-4: General differences in adaptive capacity, which affect vulnerability to climate change, between urban and rural communities (note that these do not apply in all cases; Chapters 3, 6, 7 and 8).

URBAN CENTRES	RURAL COMMUNITIES
Strengths	**Strengths**
• Greater access to financial resources • Diversified economies • Greater access to services (e.g. health care, social services, education) • Higher education levels • Well-developed emergency response capacity • Highly developed institutions	• Strong social capital • Strong social networks • Strong attachments to community • Strong traditional and local knowledge • High rates of volunteerism
Limitations	**Limitations**
• Higher costs of living • More air quality and heat stress issues • Lack of knowledge of climate change impacts and adaptation issues • High dependence on critical, but aging infrastructure • Issues of overlapping jurisdictions that complicate decision-making processes	• Limited economic resources • Less diversified economies • Higher reliance on natural resource sectors • Isolation from services and limited access • Lower proportion of population with technical training

significant (Chapter 2). The vulnerability of resource-dependent communities to climate change reflects the high climate sensitivity of many natural resource–based industries, limited economic diversification, and more restricted access to services (Chapters 2–8).

Aboriginal communities, many of which retain strong linkages to the land for both economic and cultural well-being, are also particularly vulnerable to climate change (Chapters 3–8). The subsistence economy may constitute up to 50% of the total income in these communities (Chapter 2). This vulnerability is magnified in Arctic regions, where rates of warming have been, and are projected to be, the greatest in the world. Changes in snow cover and sea-ice conditions, along with ecosystem impacts, are affecting access to traditional food supplies, while permafrost degradation and coastal erosion are affecting community infrastructure (Chapter 3 and 5). The adaptive capacity of many Aboriginal communities is presently being eroded by social, cultural, political and economic changes taking place in response to a range of stresses (Chapter 3). Significant impacts on traditional ways of life are unavoidable (Chapters 3, 4, 5, 7 and 8).

ADAPTATION

Some adaptation is occurring in Canada, both in response to, and in anticipation of, climate change impacts.

The regional chapters of this assessment note that some adaptation is already taking place in Canada. Adaptation initiatives have been undertaken at scales ranging from individuals and community groups to industry and governments (*see* Table SR-5 for examples). Much of this adaptation has been achieved through informal actions or strategies in response to specific events or circumstances, and where the capacity to take action existed (Chapters 4, 6, 8 and 10). There are also some examples of policy initiatives that provide a more structured approach to adaptation, such as the New Brunswick Coastal Areas Protection Policy (Chapter 4) and British Columbia Future Forests Ecosystem Initiative (Chapter 8).

Several adaptation initiatives address current risks and take into account the likely impacts of future climate change. These include most major new infrastructure development in northern Canada, such as mine sites,

TABLE SR-5: Selected examples of adaptation initiatives undertaken by individuals, community groups, industry and governments in Canada.

Actor	Example	Chapter
Individuals	• northerners are more frequently using insect repellents, bug nets and window screens to deal with the increased proliferation of insects.	3
	• hunters in the Arctic have increased the use of the global positioning systems to assist navigation in unpredictable or challenging weather.	3
	• homes and cottages are being built farther back from the coast.	4
	• residents of remote coastal communities are better prepared for shortages (i.e., power, food, transportation) due to recent experience with inclement weather conditions.	8
Community groups and organizations	• the community of Arctic Bay, NU, has shifted a portion of its narwhal quota from spring to summer hunts to reduce risks associated with ice break-up conditions, and to increase chances of hunting success.	3
	• residents of Pointe-du-Chêne, NB organized an emergency shelter in response to increasing flooding risk, and lobbied elected officials for less vulnerable road access.	4
	• a community group in Annapolis Royal, NS undertook mapping of potential storm surges that has resulted in revision of emergency measures.	4
Industry	• thermosyphons have been used in the construction of several major infrastructure projects in the North to induce artificial cooling of permafrost under warming conditions.	3
	• agricultural producers are purchasing crop insurance to offset losses caused by inclement weather.	6, 7, 8
	• some forestry companies have started using high-flotation tires on their vehicles to help navigate wet or washed-out conditions, allowing them to work in a wider range of weather conditions.	7
	• the forest industry in central BC is seeking to extract as much merchantable timber from forests affected by the mountain pine beetle epidemic as possible. The industry is also attempting to develop alternative markets for beetle killed wood.	8
Governments	• municipalities along the Quebec eastern North Shore have introduced regulations to limit development in zones vulnerable to coastal erosion and flooding.	5
	• Westbank, BC, has included climate change in the Trepanier Landscape Unit Water Management Plan.	8
	• the town of Vanderhoof, BC is engaged in a vulnerability assessment pilot project with the Canadian Forest Service with a specific goal of being able to plan adaptation to climate change.	8
	• water meters have been installed in the Southeast Kelowna Irrigation District and several Canadian cities (e.g. Kelowna, BC; Sudbury, ON; and Moncton, NB) to reduce water consumption.	4, 6, 8
	• Regina, SK has increased urban water conservation efforts.	7
	• smog and heat-health warning systems have been implemented in Toronto, ON, and Montréal, QC.	5, 6
	• Greater Vancouver Regional District is considering the impact of smaller snowpack on city water supplies in planning storage capacity management and upgrades.	8
	• Newfoundland is undertaking a thorough review of emergency management practices and response mechanisms.	4
	• New Brunswick's Coastal Areas Protection Policy establishes set-backs for permanent structures and could facilitate planned retreat	4
	• Alberta's Water for Life Strategy addresses climate change impacts in areas that are currently water-stressed.	7
	• British Columbia's Future Forests Ecosystem Initiative incorporates climate change adaptation into forest management.	8
	• research and networking has been supported through a range of federal, provincial and territorial programs.	10

pipelines and large buildings, where adaptive solutions include the use of thermosyphons to induce artificial cooling of permafrost under warming conditions (Chapter 3). Other examples are the Toronto Hot Weather Response Plan and similar heat-health alert initiatives in other urban areas of Ontario and Quebec (Chapter 5 and 6). The Toronto plan was first developed in response to increasingly hot summers during the 1990s, and the devastating health impacts of heat waves elsewhere in North America. Since its introduction in 1999, the Toronto plan has been continually monitored, evaluated and refined, demonstrating that effective adaptation is a continuing process, which will often involve more than a single action.

Integrating climate change into existing planning processes is an effective approach to adaptation.

Rather than dealing with adaptation in isolation from other factors, integrating (mainstreaming) climate change into ongoing planning and policy decision-making can provide efficiencies in the use of both financial and human resources (Adger et al., 2007; Klein et al., 2007). In such cases, climate change represents one of many factors to be considered in decision-making. Examples of opportunities for mainstreaming, some of which are taking place at a very limited scale, include using recent climate trends and future projections to update building codes and standards to reduce infrastructure vulnerability (Chapter 6), factoring sea-level rise into coastal development planning (Chapter 4), considering the hydrological impacts of climate change on water supply and demand in water and energy conservation initiatives (Chapters 5, 6 and 8) and considering climate change impacts in the environmental assessment process for major development projects (Chapter 3). There are also a large number of programs and policies in the development or review phases dealing with natural resource management, land-use planning, and other climate-sensitive issues that provide ideal opportunities for mainstreaming of climate change adaptation (Chapter 6).

Risk management approaches help decision-makers deal with the uncertainties associated with climate change.

Making decisions regarding adaptation requires dealing with uncertainty. There are uncertainties inherent in projections of future climate, the impacts of these changes and future socioeconomic conditions (which strongly affect adaptive capacity). Risk management provides a means for dealing with these uncertainties in a manner routinely used for non-climatic factors. It offers a practical and credible approach (Figure SR-5) that is well understood by decision-makers for defining measures to achieve

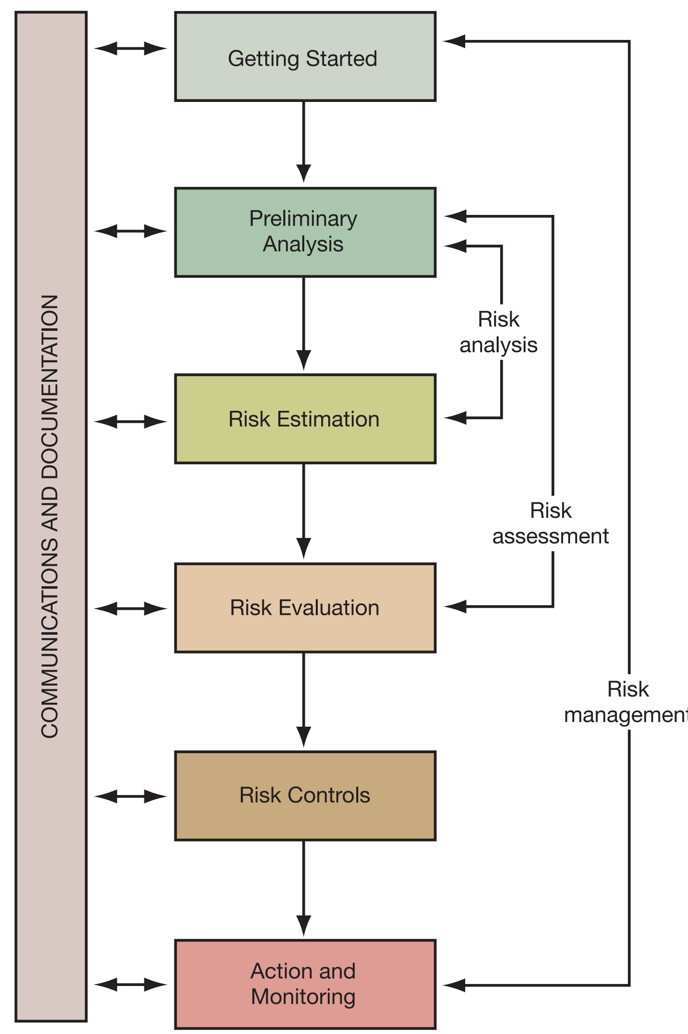


FIGURE SR-5: Steps in the risk management process (Bruce et al., 2006).

acceptable levels of societal risk, and is currently used in many professional fields. Examples of existing risk-based tools to support climate change adaptation include a screening tool for engineered facilities in permafrost terrain that has been used in many northern infrastructure projects since the late 1990s (Chapter 3), and a risk-based guide for supporting adaptation decision-making, which has recently been developed for Ontario municipalities (Chapter 6).

FUTURE DIRECTIONS

Barriers to adaptation action need to be addressed, including limitations in awareness and availability of information and decision-support tools.

Although several examples of recent and ongoing adaptation initiatives are highlighted in this assessment, the number of such actions is small relative to the scope of adaptation needs. As the rate of climate change increases, so does the urgency for adaptation action. Meeting this need will require addressing some of the existing barriers to adaptation actions, such as access to knowledge, data and decision-support tools; specific regulations or legislation that may limit adaptation options; and societal expectations. Some of these barriers to adaptation are jurisdiction or sector specific, involving regulations or application of best practices. Other barriers crosscut regions and sectors. These are best addressed through engagement of industry (including business and professional organizations), community groups, individuals and all orders of government, all of whom can serve as both facilitators and implementers of adaptation actions (Chapter 10). The crosscutting nature of climate change impacts (Figure SR-6) is a challenge in ensuring effective adaptation.

Moving forward on adaptation in Canada will involve building on the momentum established by existing initiatives, and taking new steps to promote and implement adaptation measures. Awareness-raising will be important for overcoming some barriers to action (Chapters 4, 5, 7 and 8). Many decision-makers need a clearer understanding of the risks that climate change presents, and of the local and regional benefits that adaptation provides. Mechanisms to enhance access to, and the sharing of, knowledge and experience contained within industry, academia, government and communities would help to facilitate adaptation decision-making, as would the development of tools to integrate climate change in planning and development processes (Chapters 2 and 10). Strategic approaches to adaptation would help maximize synergies and reduce potential for conflict between and within sectors, industries and regions. In some cases, decision-makers may choose to mandate and regulate consideration of climate change adaptation within their programs and policies (Chapter 10).

Although further research will help to address specific knowledge gaps and adaptation planning needs, existing knowledge is sufficient to start undertaking adaptation activities in most situations.

The chapters of this assessment reveal several research needs to support adaptation decision-making, including:

- quantitative economic analysis, including costs and benefits of impacts and of adaptation options;
- analyses of adaptation processes;
- enhanced climate and socioeconomic scenarios to support more detailed impact assessment and adaptation decision-making, as well as understanding of uncertainty associated with those scenarios;
- improved understanding of thresholds within both natural and human systems, beyond which adaptation is either ineffective or prohibitively expensive; and
- development of methods and tools to assist mainstreaming of climate change adaptation into sectoral planning processes.

The need for more research and the associated scientific uncertainties do not justify inaction. This is demonstrated by the fact that there are numerous examples of anticipatory adaptation in Canada and

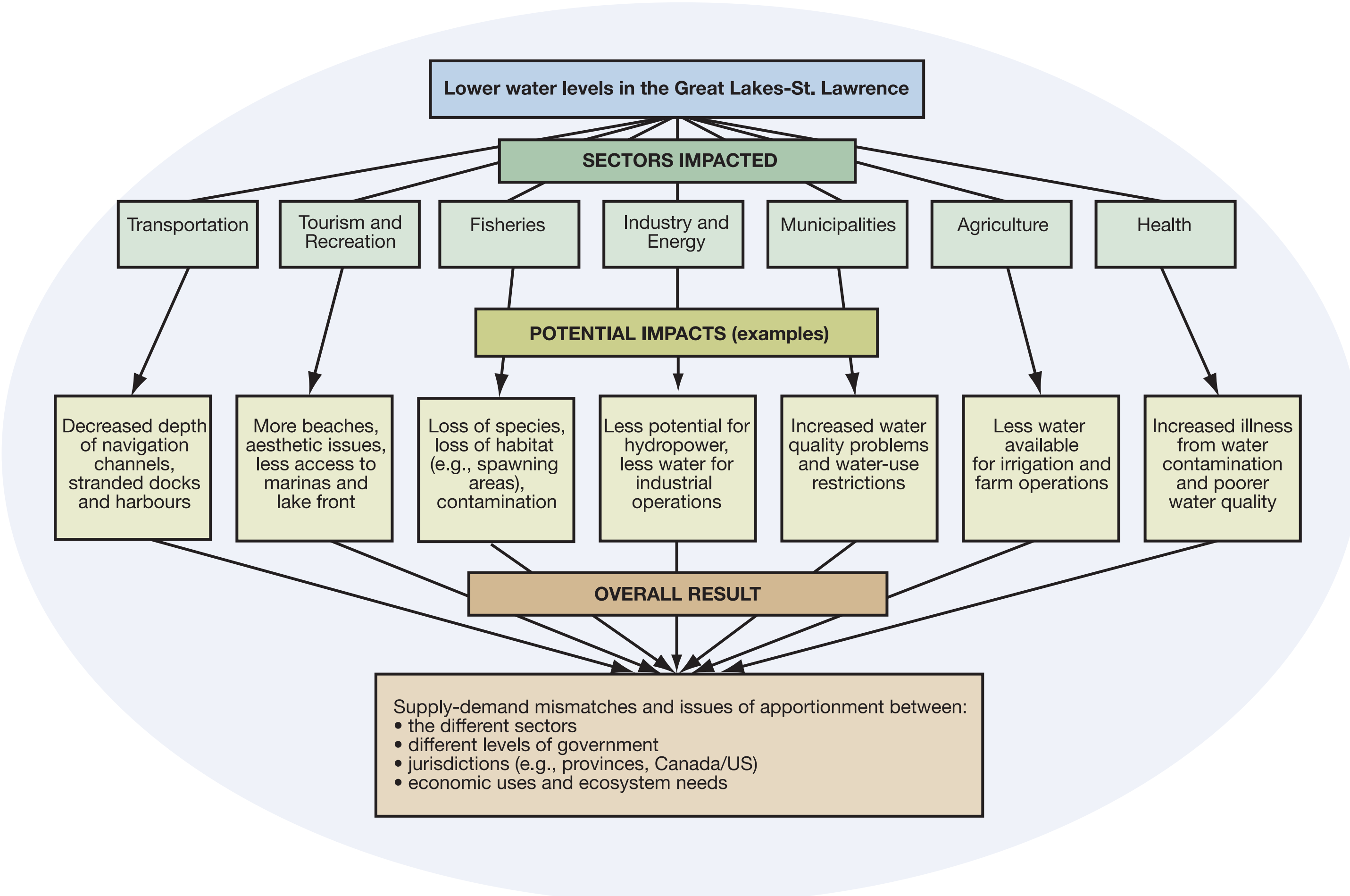


FIGURE SR-6: The crosscutting nature of climate impacts and adaptation, exemplified by lower water levels in the Great Lakes–St. Lawrence basin. Adaptation decisions in one sector will have significant consequences in several other sectors (Lemmen and Warren, 2004).

around the world. Adaptation measures that focus on reducing vulnerability to both current and future climate represent a logical first step that delivers benefits regardless of the rate of future climate changes. For example, adapting building and infrastructure design to reflect both recent climate trends and future projections, implementing water and energy conservation strategies to reduce demand, and reducing reliance on climate-sensitive sectors through economic diversification are actions that will produce both short- and long-term benefits, and enhance the resilience of communities and industry.

Adaptation is an ongoing process that requires greater attention in Canada and globally. In many cases, the responses needed to adapt to changing climate can be accomplished through existing processes and operations. The urgency for action depends on the vulnerability of the system, and the magnitude and life-cycle of investments being made. For example, billions of dollars are invested annually in Canada in climate-sensitive infrastructure that must function effectively and safely for many decades. Similarly, many industries and local governments are engaged in development planning extending 20 to 50 years into the future. Recognition that the climate of the future will differ from that of the present, and designing resilient systems to accommodate ongoing change, will enhance the value of these investments and the sustainability of development efforts.

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CHAPTER 1
Introduction

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INTRODUCTION

"We have options, but the past is not one of them."

(Sauchyn and Kulshreshtha, Chapter 7, this volume)

Recommended Citation:

Lemmen, D.S. and Warren, F.J. (2008): Introduction; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J., Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 21-26.

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The Earth's climate is changing. A growing body of scientific literature provides unequivocal evidence of global warming that is associated with changes in a wide array of other climate parameters, including precipitation patterns and extreme climate events (Intergovernmental Panel on Climate Change, 1995, 2001a, 2007a). These changes in climate are having observable impacts on both natural and human systems (Intergovernmental Panel on Climate Change, 2007b), with significant social, economic and environmental implications. This strong body of science has contributed to the development of a range of policy initiatives, at local to global scales, to address both the causes and the consequences of climate change.

While natural factors and human activity influence global climate, the burning of fossil fuels and changes in land-use patterns have been the dominant causes of climate changes observed since the mid-twentieth century (Intergovernmental Panel on Climate Change, 2007a). These human activities are expected to continue to dominate natural factors through the present century and beyond, leading to rates of global warming that far exceed those experienced in the past several thousand years (Intergovernmental Panel on Climate Change, 2007a). Reduction of greenhouse gas emissions, referred to as mitigation in the climate change literature, is critical to limiting the rate and magnitude of future climate change. However, due to the inertia of the Earth's climate system, we are already committed to some further degree of climate change; temperatures and sea level will continue to rise regardless of global efforts to limit greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2007a). As a result, adaptation is necessary to deal with the current and near-term impacts of climate change (Intergovernmental Panel on Climate Change, 2007b).

Adaptation typically provides local benefits that are realized relatively quickly after implementation, as opposed to mitigation, whose benefits are mostly global in scale and generally characterized by long lag times (Füssel and Klein, 2006), although co-benefits may be realized immediately. Mitigation and adaptation are essential and complementary policy responses to meeting the challenges presented by climate change (Figure 1). The amount and cost of adaptation required are a direct function of the rate and magnitude of climate change. Action on mitigation is necessary to "avoid the worst impacts of climate change" (Stern, 2006) and to enhance the feasibility of effective adaptation.

Adaptation refers to any modification in a system or process made in response to changing climate. Adaptation involves making adjustments in our decisions, activities and thinking because of observed or expected changes in climate, with the goals of moderating harm or taking advantage of new opportunities (Intergovernmental Panel on Climate Change,

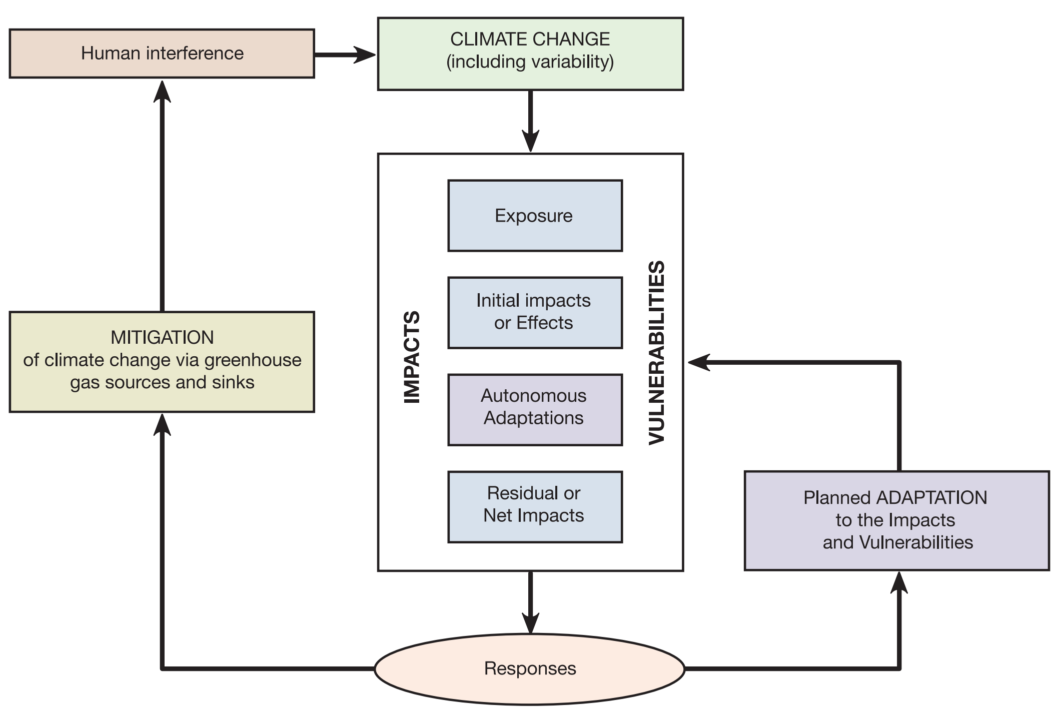

FIGURE 1: Adaptation and mitigation in the context of climate change (from Smit et al., 1999).

Throughout this report, the term 'climate change' refers to any change in climate over time, whether it is the product of natural factors, human activity or both. This usage is the same as that of the Intergovernmental Panel on Climate Change, but it differs from the usage in the United Nations Framework Convention on Climate Change, which restricts the term to climate changes that can be directly or indirectly related to human activity that alters the composition of the atmosphere, and is additional to natural climate variability.

2001b). It is not a new concept: indeed, humans and ecosystems have always adapted to current and changing climates. In natural ecosystems, adaptation occurs spontaneously in response to climate impacts, whereas adaptation in human systems may also be undertaken in anticipation of changes in climate (Smithers and Smit, 1997). While the concept of adaptation is simple, the process of adaptation within human systems is complex. Adaptation actions are tremendously diverse and may involve, for example, behavioural changes; operational modifications; technological interventions; and revised planning and investment practices, regulations and legislation. They entail both monetary and non-monetary costs (cf. Smit et al., 2000; Füssel and Klein, 2006). The most appropriate adaptation actions for any given issue are determined by a wide range of social, economic and environmental factors (*see* Chapter 2). In many cases, adaptation will involve careful planning, guided by both scientific research on climate change and detailed understanding of the systems involved.

A CANADIAN PERSPECTIVE

Climate change will affect most aspects of our lives in Canada. Our economic, social and general well-being are all linked, both directly and indirectly, to climate. For example, climate influences the crops we grow, the productivity of our forests, the spread of disease, the availability of water, the health of ecosystems and the stability of our infrastructure. Changing climate brings many new challenges and, with them, the need to re-examine long-standing practices and assumptions.

Our climate is characterized by high variability, on both seasonal and annual scales. Although our economy, health and infrastructure are generally well adapted to current climate conditions, our vulnerability to climate is clearly evidenced by the impacts resulting from extreme weather and climate events. Losses from recent individual weather-related disasters in Canada are often in the hundreds of millions of dollars. Consider, for example, costs associated with the 2003 summer wildfires in British Columbia and Alberta ($400 million; Public Safety Canada, 2005), the 1991 and 1996 hailstorms in Calgary ($884 million and $305 million, respectively; Public Safety Canada, 2005), the 1997 Red River Flood ($817 million; Public Safety Canada, 2005) and 2003 Hurricane Juan in Halifax ($200 million). Multibillion dollar disasters also occur, including the 1998 ice storm in eastern Canada ($5.4 billion) and the Saguenay flood in 1996 ($1.7 billion; Public Safety Canada, 2005). The 2001–2002 droughts, which were national in scale, resulted in a $5.8 billion reduction in gross domestic product (Wheaton et al., 2005). Extreme weather and climate events impact the health and well-being of Canadians beyond monetary costs, as they frequently involve displacement, injuries and loss of life. For example, the 1998 ice storm led to the greatest number of injuries (945) and 17 800 evacuations (Public Safety Canada, 2005). Unusually heavy rainfall following a period of drought was a contributing factor to the *E. coli* outbreak in Walkerton, Ontario in 2000 that resulted in seven deaths and thousands of people becoming ill (O'Connor, 2002).

Increases in temperature and changes in precipitation have been observed across most of Canada over the past century. During the past 50 years (1948-2006; the period for which data are available for both northern and southern Canada), average national temperature has increased 1.3°C (*see* Chapter 2; Environment Canada, 2006). This is more than double the increase in mean global surface temperature during the same time interval. Canada is projected to continue to experience greater rates of warming than most other regions of the world throughout the present century (*see* also Chapter 2; Environment Canada, 2006). The magnitude of changes in climate will vary across the country, with northern regions and the south-central Prairies warming the

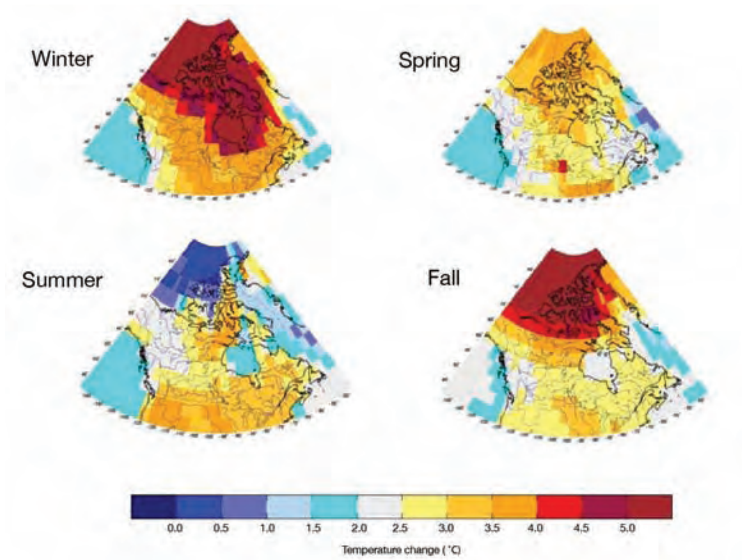

FIGURE 2: Seasonal change in temperature across Canada by 2050 (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the Special Report on Emissions Scenarios (SRES).

most (Figure 2). Average annual precipitation is also projected to rise, although increases in evaporation and transpiration by plants in some regions are expected to more than offset increases in annual precipitation, resulting in increased aridity. More frequent heavy precipitation events, less precipitation during the growing season and more precipitation during the winter are also projected for Canada.

Gradual shifts in average conditions will be accompanied by changes in climate variability and the frequency of extreme weather and climate events (Figure 3). These changes will result in both positive and negative social, economic and environmental impacts. For example, decreases in the frequency of periods of extreme winter cold benefit human health, energy consumption and many aspects of agriculture, but have significant negative impacts on forestry, northern transportation and non-renewable resource exploration. It is generally accepted that the most severe short-term, negative economic impacts will be associated with increased frequency of some extreme climate events, including extreme rainfall, drought and storm surges (Lemmen and Warren, 2004). Longer term economic impacts associated with changes in average conditions will be both positive and negative, and will depend, in part, on our ability to implement effective adaptation measures in a proactive manner (Lemmen and Warren, 2004).

Aggregate analysis at the continental scale suggests that moderate warming may bring net economic benefits to Canada, due to increased agricultural productivity, reduced cold-weather mortality, lowered winter energy demands, and benefits to tourism (e.g. Stern, 2006). However, such analyses rarely include consideration of the impacts of extreme climate events or the ability to adapt. Nor do they generally capture non-monetary consequences, such as impacts on cultural identity or ecosystem services. Most importantly, however, the impacts of a changing climate will not be experienced equally across the country, and some regions and communities are expected to suffer disproportionately, due to increased exposure to climate stress (e.g. northern and coastal communities), less resilience (e.g. due to limited resources or isolation) or a combination of the two.

Factors such as wealth, education level and access to information and technology are often used as indicators of a country's or region's capacity to undertake adaptation. Another equally important factor, although more difficult to quantify, is experience in dealing with a highly variable climate. By almost any measure, Canada is well positioned to address the challenge of climate change adaptation. Nonetheless, as illustrated in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Intergovernmental Panel on Climate Change, 2007b), all countries, even the most developed, have vulnerable regions, communities and sectors. Adaptation needs to be guided by an understanding of our vulnerabilities to current and future climate. This requires assessment of climate sensitivity and resilience; how social, economic and political factors influence our ability to adapt; and the options and processes of adaptation. Through a regional approach, this report *From Impacts to Adaptation: Canada in a Changing Climate, 2007* analyzes these issues for Canada.

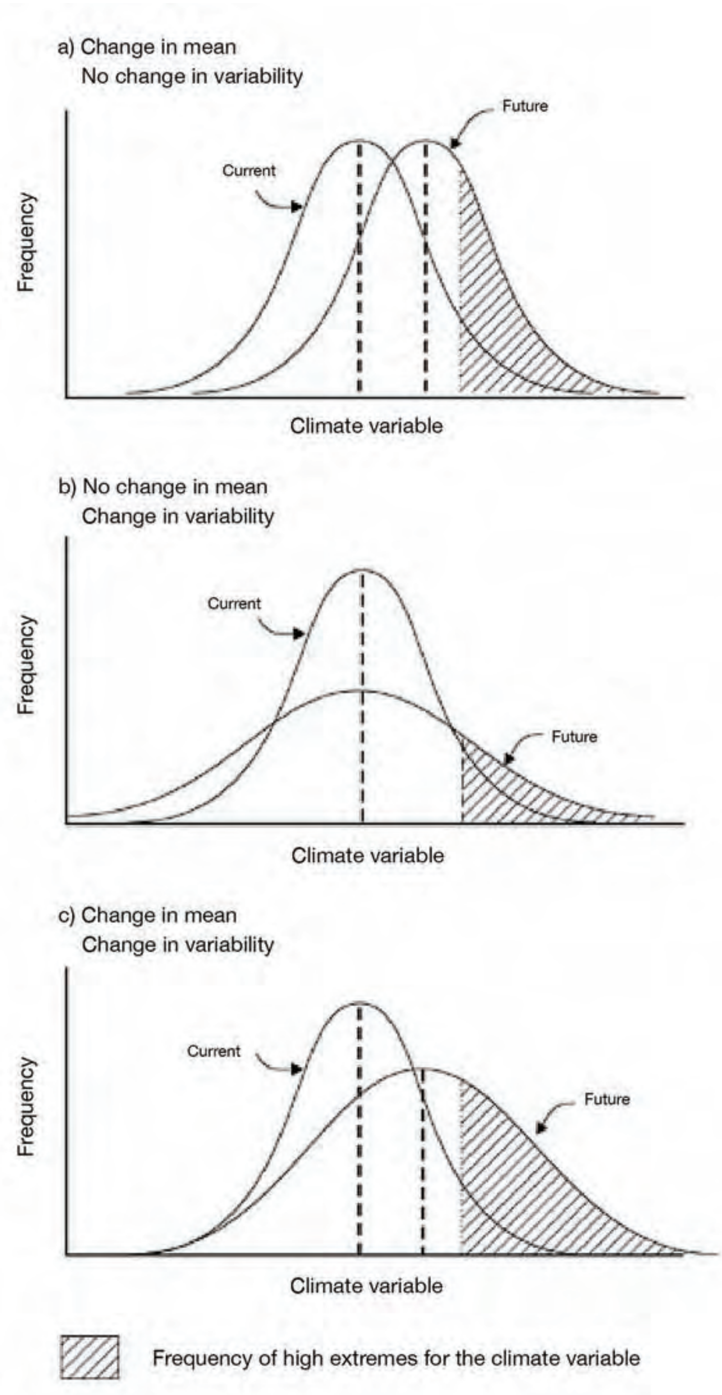

FIGURE 3: Changes in climate means and variability will increase the frequency of climatic extremes (*from* Smit and Pilifosova, 2003).

KNOWLEDGE INTEGRATION AND ASSESSMENTS

There have been significant advances in impacts, adaptation and vulnerability research during the past decade, with levels of interest and the volume of scientific literature growing significantly. These advancements are reflected in the global-scale assessment reports of the Intergovernmental Panel on Climate Change and such multi-country initiatives as the Arctic Climate Impact Assessment (*see* Chapter 3; Arctic Climate Impact Assessment, 2005). The literature increasingly reflects the integrated nature of adaptation issues and the importance of analyses that crosscut both biophysical and social sciences. One of the most important developments is that the value of traditional knowledge in enhancing understanding of climate change impacts and adaptation has been recognized (e.g. Furgal et al., 2006; Nickels et al., 2006; Riewe and Oakes, 2006). Recognition that the local scale of many adaptation issues and applied nature of some research necessitates the early and frequent engagement of practitioners and stakeholders at the community scale also represents noteworthy progress. Despite these major advances, there remain significant shortcomings in the knowledge base, including the scarcity of quantitative analysis of the costs of both impacts and adaptation (*see* Stern, 2006).

Canada's first national-scale assessment of climate change impacts and adaptation, *The Canada Country Study*, was completed in 1998 (Environment Canada, 1998). The resulting eight-volume report (six regional volumes, one national sectoral volume and one volume on crosscutting issues) concluded that the environmental, economic and social costs in Canada related to both the impacts of, and adaptation to, climate change would be large. The accompanying national summary for policy makers also noted that there was a limited understanding of the range and extent of climate change impacts in Canada, and considerable work was required to refine that understanding and develop workable adaptation approaches (Maxwell et al., 1997). In 2004, the report *Climate Change Impacts and Adaptation: a Canadian Perspective* provided an update to *The Canada Country Study* through a sector-based summary of recent studies. Contrasting the knowledge gaps and research needs highlighted in the two reports reflects an increasing appreciation of the need to better understand adaptation (Box 1).

SCOPE AND GOALS OF THIS ASSESSMENT

From Impacts to Adaptation: Canada in a Changing Climate, 2007 reflects the advances made in understanding Canada's vulnerability to climate change during the past decade. Through a primarily regional approach, this assessment discusses current and future risks and opportunities that climate change presents to Canada, with a focus on human and managed systems. It is based on a critical analysis of existing knowledge, drawn both from the published scientific and technical literature (peer-reviewed and grey literature) and from expert (including traditional) knowledge. The current state of understanding is presented, and key knowledge gaps are identified. Authors have highlighted advances in understanding adaptation, as well as examples of recent and ongoing adaptation initiatives. Although emphasis is placed on studies conducted within Canada, international references are incorporated as appropriate. Further details on the approaches used in the assessment are presented in Chapter 2.

This assessment highlights what we know regarding vulnerability and the key issues facing each region of the country, with the goal of being policy relevant. It is a science-based assessment that will serve as an up-to-date, readily accessible source of information on climate change impacts and adaptation, providing a foundation that informs adaptation decision-making and policy development.

BOX 1

Climate change impacts and adaptation in Canada: an evolving issue

Reflecting global trends in research related to climate change impacts and adaptation, Canadian research has become increasingly integrative, with more work crossing disciplines and economic sectors. In recent years, greater emphasis has been placed on understanding vulnerability to both current and future climate, and on understanding the social factors that influence adaptation. This trend is evident in comparing the research needs identified in *The Canada Country Study* (1998) with those of *Climate Change Impacts and Adaptation: a Canadian Perspective (2004)*. While the research needs of *The Canada Country Study* focused primarily on baseline data, modelling capabilities and first-order impacts (Maxwell et al., 1997), the 2004 report highlighted the need to better understand interactive effects (climatic and non-climatic), the linkages between science and policy, and current and future adaptive capacity (Lemmen and Warren, 2004). This evolution reflects the growing involvement of a wide range of disciplines in climate change impacts and adaptation research.

FORMAT OF THIS ASSESSMENT

Including this 'Introduction', there are ten chapters in this volume, as well as an accompanying Synthesis Report.

Chapter 2, 'Background Information', contains reference material relevant to the entire report. The various sections of this chapter provide 1) explanations of key concepts that recur throughout the subsequent chapters; 2) a review of the science related to the evidence for, and causes of, past climate change and variability, as well as projections of future climate change; 3) a broad overview of key factors relevant to understanding climate change impacts and adaptation in Canada, highlighting why these issues are relevant at local to national levels; and 4) a description of the approaches used in this assessment.

Chapters 3 to 8 are regional analyses focused on Northern Canada, Atlantic Canada, Quebec, Ontario, Prairies and British Columbia, and constitute the main body of the assessment. Each regional chapter discusses current and future climate, relevant socioeconomic trends, current sensitivities to climate, and the risks and opportunities presented by climate change (recognizing that there has generally been less research undertaken on opportunities). The regional chapters also discuss adaptation practices, options and planning. In recognition of the significant regional differences in the focus and volume of relevant information, these chapters do not follow a common template; rather, authors have structured each chapter to best capture regional circumstances. For example, considerably more focused information is available for Quebec than for many other regions, in large part due to the activities of the Ouranos Consortium since 2002, whose mandate explicitly includes consideration of adaptation issues (http://www.ouranos.ca/). Similarly, the 'Northern Canada' chapter builds directly on the results of the 2005 Arctic Climate Impact Assessment, which represents a more recent and comprehensive synthesis than is available for the other regions. Similarities in structure between chapters include starting with a concise presentation of key findings that emerge from the main body of the chapter and concluding with a synthesis that focuses on adaptation issues. Case studies are used throughout these chapters to provide additional details regarding key issues, and to highlight recent and ongoing initiatives related to climate change adaptation.

Chapter 9, 'Canada in an International Context', examines the potential implications of climate change impacts outside Canada for our country, as well as how impacts within our borders may affect our international relationships. This involves consideration of a wide range of issues, including trade, international development, immigration, tourism, security and sovereignty. Given the integrated nature of the global market place, the impacts of climate change outside of Canada are likely to have greater economic consequences for some sectors of the Canadian economy than the direct impact of climate change on Canadian operations. Nonetheless, research examining these impacts, and their implications for adaptation, is limited not only with respect to Canada but also for most countries of the world.

Chapter 10, 'Moving Forward', builds on the previous chapters. The regional snapshots capture the state of understanding and readiness to undertake adaptation at one point in time. This concluding chapter examines possible future directions to address the adaptation needs identified both within the regional chapters and in other assessments of climate change impacts and adaptation.

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BACKGROUND

CHAPTER 2
Background Information: Concepts, Overviews and Approaches

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Acknowledgments:
Special thanks are extended to the following individuals for their assistance in strengthening the chapter through their suggestions and input: Alain Bourque, Jim Bruce, Elizabeth Bush, Jacinthe Lacroix, Sharon Smith, Xuebin Zhang and Francis Zwiers.

Recommended Citation:

Warren, F.J. and Egginton, P.A. (2008): Background Information; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 27-56.

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CONTENTS

1 INTRODUCTION

This chapter serves as a reference for the subsequent chapters of the report by discussing key recurrent concepts related to the primary goals of the assessment. It also provides a brief review of the science associated with understanding past and future climate change, and an overview of the broad implications of climate change for Canada. Readers are encouraged to consult the additional sources referred to in this chapter for more detailed explanations. Finally, the chapter includes a description of the approaches used in this assessment, noting where these differ from other recent national- and global-scale assessments.

2 KEY CONCEPTS

Canadians are increasingly aware that climate change represents a fundamental challenge to our health and well-being, environment and economy. The vast majority of discussion at the public-policy level has focused on mitigation, the critically important response of reducing greenhouse gas emissions. Mitigation is essential to slow the rate, and ultimately to limit the magnitude, of climate change. There is, however, less awareness of the fact that, regardless of the success of global mitigation initiatives, further climate change and associated impacts are unavoidable (e.g. Intergovernmental Panel on Climate Change, 2007a). Even if greenhouse gas concentrations were stabilized, warming and sea-level rise would continue for centuries due to the nature of the climate system and feedbacks (Meehl et al., 2006; Intergovernmental Panel on Climate Change, 2007a). This assessment focuses on the need for adaptation in recognition of the reality that Canada's present climate is different from that of the recent past and will continue to change in future.

Adaptation actions undertaken by Canadian governments, industry, communities and individuals are, and will continue to be, based on implicit or explicit understanding of vulnerability. With respect to climate change, this involves considering how climate is likely to change, the probable impacts of these changes and the potential for adaptation. To understand vulnerability, authors of this assessment have drawn from a wide range of disciplines, ranging from the physical, biological and social sciences to economic analysis, and have integrated this information with other sources of knowledge, including local knowledge. Several key concepts that use terminology specific to the field, and convey explicit meanings that extend beyond the basic dictionary definitions, underlie this analysis. Rather than repeating explanations of these key concepts throughout the report, they are discussed in detail here. Note that a more extensive list of key terms in the field of impacts and adaptation is contained in the glossary to this report. For the remainder of Section 2 only, the first occurrence of words in the glossary is in bold italics.

2.1 ADAPTATION

Adaptation refers to any activity that reduces the negative ***impacts*** of ***climate change*** and/or positions us to take advantage of new opportunities that may be presented. Adaptation is needed to address the challenges of climate change, and represents a necessary complement to ***mitigation*** (reduction of ***greenhouse gas*** emissions; Box 1). Both the ***United Nations Framework Convention on Climate Change (UNFCCC)*** and the ***Kyoto Protocol*** include requirements for Parties (i.e. countries) to address adaptation. The goals of adaptation may include 1) alleviating current impacts (Füssel and Klein, 2006); 2) reducing ***sensitivity*** and ***exposure*** to climate-related hazards; and 3) increasing resiliency to climatic and non-climatic stressors (i.e. enhancing ***adaptive capacity***). Successful adaptation does not mean that negative impacts will not occur, only that they will be less severe than would be experienced had no adaptation occurred.

There are many different types of adaptation (Table 2). Adaptation includes activities that are taken before impacts are observed (anticipatory) and after impacts have been felt (reactive). Both anticipatory and reactive adaptation can be planned (i.e. the result of deliberate policy decisions), while reactive adaptation can also occur spontaneously (i.e. autonomous, without planning). Planned adaptation is an iterative process involving four basic steps: information development and awareness-raising; planning and design; implementation; and monitoring and evaluation (Figure 1; Klein

BOX 1

Adaptation and mitigation

There are two categories of response to climate change: mitigation and adaptation. In the climate change literature, these two terms have clear and distinct definitions, and there are fundamental differences between them (*see* Table 1). Mitigation refers to "***anthropogenic*** interventions to reduce the sources or enhance the sinks of greenhouse gases" (Intergovernmental Panel on Climate Change, 2001a). The goal of mitigation is to reduce or prevent changes in the ***climate system*** and, as such, mitigation focuses on the sources of climate change (Schipper, 2006).

TABLE 1: Characteristics of mitigation and adaptation (*compiled from* Füssel and Klein, 2006).

Characteristic	Adaptation to climate change	Mitigation of climate change
Benefited systems	Selected systems	All systems
Scale of effect	Local to regional	Global
Lifetime	Years to centuries	Centuries
Effectiveness	Generally less certain	Certain
Ancilliary Benefits	Mostly	Sometimes
Monitoring	More difficult	Relatively easy

Adaptation, on the other hand, is concerned with addressing the consequences of climate change (Schipper, 2006). Adaptation refers to activities aimed at reducing or preventing the impacts of climate change on human and natural systems.

Although the two terms are distinct, adaptation and mitigation are also codependent. Mitigation, through moderating both the rate and magnitude of changes in the climate system, affects both the demand for, and the potential success of, adaptation options. Greater magnitudes of change will require more extensive adaptation, and greater rates of change make adaptation more challenging. In addition, there are some activities that can be considered both mitigative and adaptive. For example, planting trees in urban areas both increases greenhouse gas sinks (mitigation) and acts to cool surrounding areas (adaptation to increased temperatures). This codependency between adaptation and mitigation indicates the need for climate change policies that address the two responses simultaneously (Mendelsohn, 2006).

While the distinction between adaptation and mitigation is well established in the climate change community, not all disciplines use these terms in this way. The natural hazards community, for example, has long used the term 'mitigation' to refer to activities that reduce the impacts of natural hazards. For example, land-use planning that limits development in floodplains would be considered a mitigation measure in the natural hazards community but an adaptation measure in the context of climate change.

et al., 1999). In most circumstances, anticipatory planned adaptations will incur lower long-term costs and be more effective than reactive adaptations. Nevertheless, there are risks involved in implementing adaptation options to deal with an uncertain future, including opportunity costs (the use of resources that could otherwise be used for competing priorities) and the potential for ***maladaptation*** (*see* Mendelsohn, 2006).

Many different groups, including individuals, organizations, industry and all orders of government, are involved in facilitating adaptation and in the choice and implementation of specific adaptation measures. Such measures are highly diverse, and may involve behavioural changes, operational modifications, technological interventions, and revised planning and investment practices, regulations and legislation. The role of governments includes the provision of information and ***tools***, and the establishment of policy frameworks, that promote adaptation action (Stern, 2006).

Many climate change impact studies provide lists of potential adaptations. Such lists help exemplify the diverse range of adaptation responses, and many examples of these are presented in the regional chapters of this assessment. Nevertheless, they represent only a starting point in analysis. Decisions regarding the most appropriate adaptation response to address a specific impact, or suite of impacts, require understanding of the process of adaptation and the related concepts of ***vulnerability***, adaptive capacity and ***resilience*** (*see* Sections 2.2–2.4). Adaptation will not take place in response to climate change alone, but in consideration of a range of factors with the potential for both synergies and conflicts. Attention must be paid to the feasibility, likelihood and mechanisms for adaptation uptake. Critical questions include the following (Smit and Wandel, 2006): "What can be done practically?", "Who will do it?" and "How will it be implemented?" Research on such questions is currently sparse in the field of climate change (Smit and Wandel, 2006).

2.2 VULNERABILITY

In the climate change literature, vulnerability refers to the degree to which a ***system*** is susceptible to, and unable to cope with, the adverse effects of climate change (Intergovernmental Panel on Climate Change, 2001a). The ***Intergovernmental Panel on***

TABLE 2: Different types of adaptation (*modified from* Smit et al., 1999).

ADAPTATION			
Based on	**Type of adaptation**		
Intent	Spontaneous		Planned
Timing (relative to climate impact)	Reactive	Concurrent	Anticipatory
Temporal scope	Short term		Long term
Spatial scope	Localized		Widespread

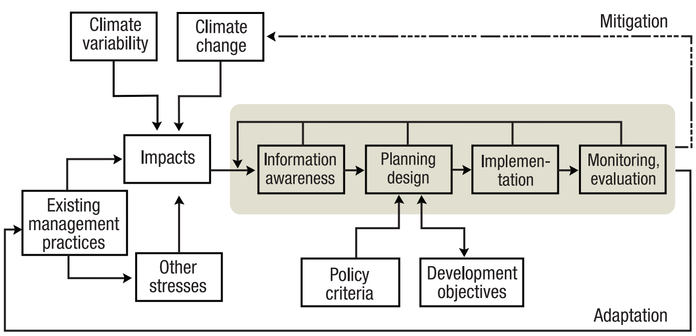

FIGURE 1: Conceptual framework showing (in the shaded area) the steps involved in planned adaptation to climate variability and change (*from* Klein et al., 2006).

Climate Change (2001a) states that "vulnerability is a function of the character, magnitude, and rate of ***climate variation*** to which a system is exposed, its sensitivity, and its adaptive capacity." As such, vulnerability integrates an external dimension, namely exposure to climate, as well as characteristics internal to the system under study (sensitivity and adaptive capacity; Füssel and Klein, 2006). It also necessitates an understanding of both biophysical and socioeconomic processes (Adger, 2006).

As an example, the vulnerability of an agricultural operation to climate change requires understanding of how climate is likely to change (e.g. increased temperatures, more frequent ***droughts***), the sensitivity of the system to that change (e.g. the relationship between crop yield and temperature and/or drought) and the potential for the system to adjust to the change (e.g. planting different crops, irrigation). Although this operation may be highly sensitive to climate change, in that crop yield is strongly controlled by temperature and drought, the system would not be considered highly vulnerable if effective adaptation measures, such as switching to more drought-resistant crops, are easy to implement.

The above example illustrates three other important aspects of vulnerability. First, by definition, vulnerability focuses on negative impacts — the "adverse effects of climate change" (Intergovernmental Panel on Climate Change, 2001a). It is well accepted, however, that climate change will bring benefits as well as negative impacts. In the example provided, increased temperatures may well lead to increased crop yields. Hence, adjusting activities so as to best capitalize on these benefits is also a recognized goal of adaptation. Second, the aspects of climate change most important for informing adaptation decision-making are rarely captured well in terms of the most commonly discussed climate parameters: changes in mean temperature and precipitation. In this example, more important considerations for crop yields may include the timing of precipitation, occurrence of extreme rainfall, growing degree-days and drought severity. Third, and most important, even if the vulnerability of a system is considered relatively low due to a high capacity to adapt, it may still incur significant impacts if adaptation actions are not implemented. In the example provided, if the operator continued to plant the same crop and made no other adjustments in the operation, they could experience severe negative impacts or would fail to benefit from new opportunities.

Recognition of the need to consider the ability of systems to adapt is what distinguishes vulnerability from sensitivity. Sensitivity does not account for the moderating effect of adaptation, whereas vulnerability can be viewed as the impacts that remain after adaptation has been taken into account. Although many early climate change impact studies focused primarily on sensitivity, it is now accepted that adaptation will strongly influence the magnitude of climate change impacts. Indeed, researchers have noted that "it is meaningless to study the consequences of climate change, without considering the ranges of adaptive responses" (Adger and Kelly, 1999). Most of the more recent climate change impact studies focus on assessing vulnerability, rather than sensitivity.

Assessing vulnerability requires consideration of the main stressors, both climatic and non-climatic, on a system or region, as well as the socioeconomic influences on adaptive capacity (see Section 2.3; Füssel and Klein, 2006). It is widely recognized that engagement of ***stakeholders*** represents a critical first step in assessing vulnerability (Lim et al., 2005). While impacts are frequently expressed quantitatively (e.g. percentage increase in productivity, dollar loss in revenue), vulnerability studies focus more on understanding the processes involved and influencing factors. The social and biophysical influences on vulnerability change readily over time and space (Adger, 2006). As a result, vulnerability is generally characterized, rather than measured, although advances in quantifying the concept are ongoing (*see* Adger, 2006).

2.3 ADAPTIVE CAPACITY

In the context of climate change, adaptive capacity is defined as the "potential, capability or ability of a system to adapt to climate change stimuli or their effects or impacts" (Intergovernmental Panel on Climate Change, 2001a). A system is a broad term, which encompasses all scales and types of units, including regions, communities, economic sectors, ***institutions*** and private businesses.

Adaptive capacity is a relatively new term in climate change research, first appearing in the scientific literature in about 1999 and not being cited frequently until 2003. The uptake and use of the term was likely spurred by the publication of the *Third Assessment Report of the Intergovernmental Panel on Climate Change* (2001), in which Chapter 18 ('Adaptation in the Context of Sustainable Development and Equity'; Smit et al., 2001) discussed the concept in detail. Adaptation and adaptive capacity are closely linked (Box 2), and enhancing adaptive capacity is a ***'no-regrets'*** adaptation option that brings benefits regardless of the changes in climate. As such, adaptation approaches that focus on enhancing adaptive capacity are an effective way of taking action, despite the uncertainties inherent in projections of future climate (Smit and Pilifosova, 2003). By increasing adaptive capacity, vulnerability to current climate, future climate and oftentimes other stressors are reduced.

To address adaptive capacity, two key questions must be considered: "Adaptive capacity of what?" and "Adaptive capacity to what?" (Smit et al.,1999). One may, for example, consider the adaptive capacity of a farm (system) to increased aridity (climate change), or the adaptive capacity of a community (system) to more frequent heat waves (climate change). Adaptive capacity is influenced by a number of location-specific determinants, which depend upon the social, economic and institutional state of the system or region being studied (Figure 2). These determinants act to either constrain or enhance ability to adapt (Kelly and Adger, 2000), and vary in both space and time (Smit et al., 2001).

Past experience clearly influences adaptive capacity. Canada's highly variable climate contributes positively to the capacity of Canadians to adapt to climate change. Single events can impact adaptive capacity both positively and negatively (Smit et al., 2001).

For example, lessons learned from a recent ***storm surge*** should lead to improved preparedness for future storms, thereby enhancing adaptive capacity. However, if recovery from that same event exhausted financial resources available to assist flood victims, adaptive capacity could be diminished until those resources are replenished. Past events also influence perception of ***risk*** at the individual and institutional levels, which in turn affects the likelihood of proactive adaptation (Grothmann and Patt, 2005).

Adaptive capacity is difficult to measure. Proxy indicators, such as per capita income, education level and population density, have been used for some of the determinants (Yohe and Tol, 2002), but others are more difficult to assess. In addition, although adaptive capacity is most meaningful as a local characteristic, data availability frequently means that it can only be assessed at the national or regional level (Yohe and Tol, 2002).

For this assessment, authors focused on characterizing the factors that influence adaptive capacity within their region, in some

BOX 2

Contrasting adaptation and adaptive capacity

Adaptive capacity and adaptation, although related, are distinct terms in the climate change literature. Adaptive capacity is an attribute of a system, which provides an indication of its 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. Adaptation, on the other hand, refers to a process and/or specific action.

Building adaptive capacity is a component of adaptation strategies (Brooks et al., 2005), and a system with many adaptation options generally has a higher adaptive capacity than a system with few or none (Yohe and Tol, 2002). Some suggest that adaptive capacity can be viewed as the potential for adaptation and, when adaptive capacity is used to adapt, vulnerability is reduced (Brooks, 2003).

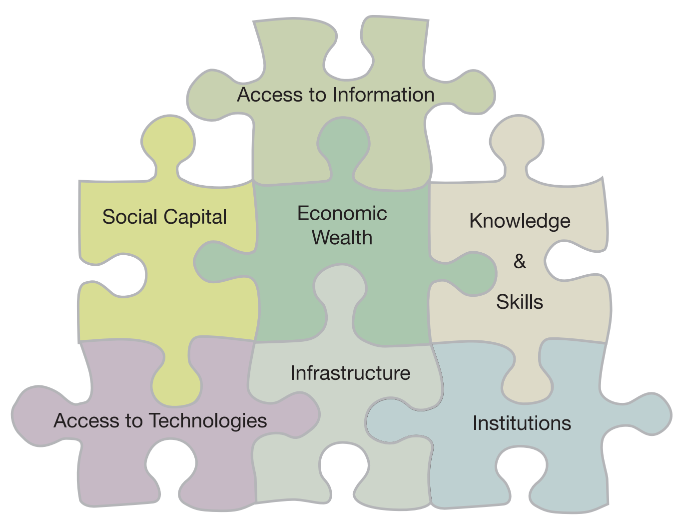

FIGURE 2: Determinants of adaptive capacity (*adapted from* Smith et al., 2003).

instances extending this characterization to the system level (subregions or sectors). Although discussion of adaptive capacity at the local level is rare in the climate change literature, there is considerable potential to learn lessons from analyses of other disciplines, including emergency preparedness, economic development/diversification and ***food security***. While generally beyond the scope of this assessment, such analysis represents a profitable direction for future impacts and adaptation research (*see* Chapter 10).

2.4 RESILIENCE

Resilience is defined as the "amount of change a system can undergo without changing state" (Intergovernmental Panel on Climate Change, 2001a). The term 'resilience' is not as commonly used in the climate change literature as 'adaptive capacity' or 'vulnerability'. Studies that do use the term tend to focus more on natural systems, rather than human systems, likely due to the term's roots in the field of ecology. Some researchers have modified the terminology for specific use in climate change studies, and now refer to 'eco-social resilience' or 'social-ecological resilience' (e.g. Adger, 2006).

As noted above, much of the terminology around impacts and adaptation continues to evolve. At times, 'resilience' has been used interchangeably with 'adaptive capacity'. Each term refers to an attribute of a system that relates to its ability to deal with external stressors, and both can be either constrained or enhanced by internal and external factors. However, as the definition of resilience implies an inherent characteristic of systems to remain at their current state and to provide the same function and structure (Walker et al., 2004), it does not necessarily align well with the goals of adaptation, where change is viewed as a necessary consequence of changing climate.

The definition of 'resilience' introduces two related concepts that are important for adaptation: ***'coping ranges'*** and ***'thresholds'***. 'Coping range' refers to the variation in climate that a system can absorb without incurring significant impacts. Adaptation actions will adjust the coping range, and similarly affect resilience (Figure 3). A 'threshold' is the point at which significant impacts are incurred (i.e. the coping range is exceeded) or the system undergoes a change of state (i.e. resilience is overwhelmed). Defining thresholds within natural systems is a key objective of many climate change impact studies (International Scientific Steering Committee, 2005), while understanding thresholds in human systems can be key to guiding adaptation decisions. Walker and Meyers (2004), however, have questioned whether thresholds can be defined before they are crossed, and found no examples in the published literature of thresholds being predicted before occurrence.

2.5 TECHNOLOGIES FOR ADAPTATION

Technology is frequently cited as a vital solution for the challenges presented by climate change. This is particularly true for mitigation, where a range of innovative new and developing technologies hold promise for providing alternative sources of

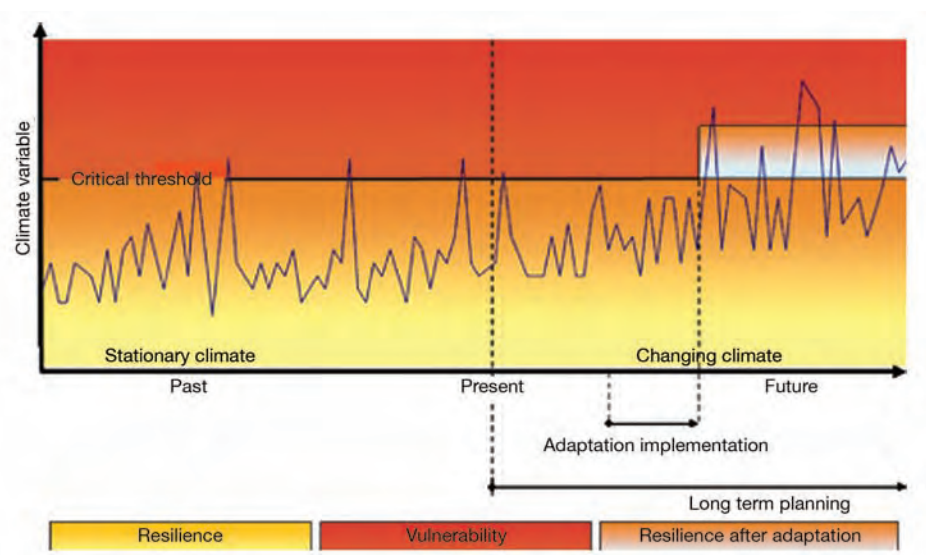

FIGURE 3: Adaptation will increase the coping range, making systems more resilient, and therefore less vulnerable, to climate change (*adapted from* Smit et al., 1999).

energy, enabling sequestration of greenhouse gases and enhancing energy efficiency. Technology will also play a role in adaptation (United Kingdom Climate Impacts Programme, 2005). Access to, and use of, technology is commonly cited as a determinant of adaptive capacity. For example, use of water conservation technologies may improve capacity to address climate change impacts on water supply (*see* Chapter 7). The goals of technologies for adaptation include improved resilience and flexibility, prevention of additional damage and reduction of costs.

Although relatively little research has focused on the actual role of technology in climate change adaptation, the concept of ***'technologies for adaptation'*** is explored in a comprehensive manner by Klein et al. (2006). The term itself (as opposed to 'adaptation technologies') indicates that many of the technologies that may be implemented for climate change adaptation represent existing technologies developed to address issues not directly related to climate change. While the focus in mitigation has been on the development of new technologies, greater emphasis in adaptation will likely be placed on the transfer of existing technologies that are then customized to meet local requirements. In the climate change literature, technology tends to be given a very broad definition, such as "a piece of equipment, technique, practical knowledge or skills for performing a particular task" (Metz et al., 2000), hence encompassing virtually every conceivable adaptation option. A distinction is generally made between hard and soft technologies, the former referring to physical products and the latter to practices and planning. Successful adaptation strategies will generally include both hard and soft technologies (Klein et al., 2006). Further distinctions can be made between traditional, modern, high and future technologies (Klein et al., 2006). In this assessment, the term 'technology' is generally limited to hard technologies.

2.6 SCENARIOS

Scenarios are "a coherent, internally consistent and plausible description of a possible future state of the world" (Parry and Carter, 1998). A scenario is not a prediction, since use of the term 'prediction' or 'forecast' implies that a particular outcome is most likely to occur. Rather, a scenario represents one of any number of possible futures. Both climate and socioeconomic scenarios provide input to analyses of impacts, vulnerability and adaptation measures. They provide a foundation to guide and explore the implications of adaptation and mitigation decisions, and to raise awareness of climate change issues. Scenarios define a range of possible futures that facilitate consideration of the ***uncertainty*** relating to different development pathways, with implications for future climate, social, economic and environmental change. For national and regional scenarios extending more than about 30 years into the future, significant attention has been paid to the development of ***climate scenarios***, whereas socioeconomic scenarios remain poorly developed despite the direct linkages between the two.

Climate Scenarios

Most climate scenarios are derived from ***climate model*** output, usually from ***Atmosphere-Ocean General Circulation Models*** (AOGCMs; *see* Box 3). Current standard practice in scenario development is to calculate the change between 30-year average AOGCM representations of the future (e.g. 2040–2069) and ***baseline*** (currently 1961–1990) conditions, and to apply these changes to observational data. These changes are generally expressed as simple differences for temperature, and in percentage differences for precipitation. Model output is averaged over thirty years for both the baseline and future time periods to ensure that the longer term climate change trend is captured. The AOGCM-derived changes are referred to as climate change scenarios, or sometimes as change fields. A climate scenario refers to the data that result from applying these change fields to observed climate data, and represents climate information for the future time period (e.g. the 2050s).

Owing to uncertainties involved in the projection of future climate (*see* Box 3), it is important that impacts and adaptation studies consider a range of climate change scenarios. The use of climate scenarios in this assessment is discussed in Section 5.3. Further information concerning scenarios can be found in Intergovernmental Panel on Climate Change Task Group on Scenarios for Climate Impact Assessment (1999).

Socioeconomic Scenarios

Social and economic conditions will not remain static as climate changes, and understanding the likely nature of these socioeconomic changes is important in characterizing vulnerability to climate change. Socioeconomic scenarios, which include information concerning population and human development, economic conditions, land cover and land use, and energy consumption, provide important information for understanding adaptive capacity. Global-scale socioeconomic scenarios extending to 2100 are the foundation of the emissions scenarios in the *Special Report on Emissions Scenarios* (SRES) of the Intergovernmental Panel on Climate Change (IPCC; *see* Box 3; Carter et al., 2001). It is unclear, however, whether these scenarios can be meaningfully downscaled for the purpose of impacts and adaptation studies. Socioeconomic forecasts at the national and regional scales may be more relevant for use in impacts and adaptation studies.

BOX 3

Climate modelling

Atmosphere-Ocean General Circulation Models (AOGCMs)[2]

The extreme complexity of the Earth's climate system, involving dynamic interactions between the atmosphere, the oceans, the ***cryosphere***, land surfaces and the biosphere, necessitates the use of sophisticated AOGCMs to project future climate change. These AOGCMs are three-dimensional mathematical representations of the large-scale physical processes of the Earth-atmosphere-ocean-land system, and provide a comprehensive and internally consistent view of future climate change. In AOGCMs, the Earth's climate system is divided into a gridded network of interconnected boxes, and the physical processes that control this system are represented by series of fundamental mathematical equations describing the conservation of momentum, mass and energy. ***Feedback*** effects in the climate system, such as those between snow and ice and the reflectivity of the Earth's surface ***(albedo)***, are included in the models, although some of these processes are incompletely specified and poorly quantified.

To project future climate, AOGCMs must be provided with information about future atmospheric composition. Future levels of greenhouse gas and aerosol emissions are dependent on a range of factors, including population growth, economic activity and use of energy and technology, so there is a wide range of possible emissions futures, referred to as ***emissions scenarios***. For its Third Assessment Report, the Intergovernmental Panel on Climate Change commissioned a Special Report on Emissions Scenarios (SRES), which describes about forty different emissions scenarios (Carter et al., 2001). Six of the ***SRES scenarios*** have been identified as 'marker scenarios' and are recommended for use by the climate modelling community, namely A1FI, A2, A1B, B2, A1T and B1 (presented in order of descending radiative forcing by 2100). At the extremes, the A1FI storyline describes a fossil-fuel-intensive world with very rapid economic growth, global population that peaks around 2050 and rapid introduction of new technologies. The B1 storyline describes a convergent world in which population also peaks about 2050, but with rapid economic changes towards a service and information economy and the introduction of clean and resource-efficient technologies (Carter et al., 2001). Best estimates and likely ranges of globally averaged temperature changes and ***sea-level rise*** for each of these marker scenarios are shown in Table 3.

Uncertainty in projections of future climate increases with time. Emission scenarios represent one source of uncertainty related to future development pathways. Although this uncertainty cannot be avoided, it is noteworthy that emission scenarios only become an important source of uncertainty after about 2030 (Intergovernmental Panel on Climate Change, 2007a). A second source of uncertainty relates to differences between AOGCMs in the way physical processes and feedbacks are simulated. These differences result in the different AOGCMs simulating different global warming values per unit change of radiative forcing. New methods for dealing with this uncertainty have emerged since 2001 (Solomon et al., 2007).

TABLE 3: Influence of the scenario used on projected temperature change and sea-level rise. *Source*: Intergovernmental Panel on Climate Change (2007a).

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise[b] (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[c]	0.6	0.3 - 0.9	NA
B1 scenario	1.8	1.1 - 2.9	0.18 - 0.38
A1T scenario	2.4	1.4 - 3.8	0.20 - 0.45
B2 scenario	2.4	1.4 - 3.8	0.20 - 0.43
A1B scenario	2.8	1.7 - 4.4	0.21 - 0.48
A2 scenario	3.4	2.0 - 5.4	0.23 - 0.51
A1FI scenario	4.0	2.4 - 6.4	0.26 - 0.59

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulation Models (AOGCMs).

[b] Sea-level-rise estimates are based on observed flow rates from Greenland and Antarctica for 1993–2003. These rates may increase or decrease in the future. If they were to increase linearly with global mean temperature rise, the upper ranges shown in the table would increase by 0.1–0.2 m.

[c] Year 2000 constant composition is derived from AOGCMs only.

Regional Climate Models (RCMs)

Regional Climate Models provide higher spatial resolution (i.e. more detailed) data than AOGCMs by nesting a high-resolution RCM within a lower resolution AOGCM. This means that RCMs are susceptible to any systematic errors present in the AOGCM used (Canadian Institute for Climate Studies, 2002). An advantage of RCMs is their ability to provide information that is more spatially detailed, and hence at a more appropriate scale for climate impact studies (Laprise et al., 1998). At present, however, RCM data are only available for a limited combination of AOGCMs and emission scenarios, and generally do not encompass a full range of plausible futures. Nevertheless, work in this field is evolving rapidly, with analysis and quantification of the confidence and uncertainty associated with RCMs a major area of research (cf. Caya, 2004; Déqué et al., 2005, Plummer et al., 2006).

In Canada, researchers have access to RCM data from the Canadian Regional Climate Model (CRCM) through the Canadian Centre for Climate Modelling and Analysis (CCCma; see http://www.cccma.ec.gc.ca/models/crcm.shtml); refer to Laprise et al. (2003) and Plummer et al. (2006) for discussions of model sensitivity and validation. The Ouranos Consortium provides support for the development of the CRCM and has utilized scenarios based on RCMs for analysis of climate change impacts (*see* Chapter 5).

[2]Also commonly referred to as Global Climate Models or General Circulation Models (GCMs).

3 CLIMATE SCIENCE

Climate science is an intrinsic and important aspect of addressing vulnerability. Understanding why and how the climate is changing is critical to dealing with climate change. Each regional chapter of this assessment discusses the region's current climate, recent climate trends and future projections as input into analyses of sensitivity and vulnerability. This section complements material in the regional chapters by providing an overview of the causes of climate change, evidence for recent global climate change, and future changes in global climate. Climate change in Canada is discussed in Section 4.3. For more detailed information, readers are referred to the report *An Introduction to Climate Change: A Canadian Perspective* (Hengeveld et al., 2005), as well as the more technical reports prepared by Working Group I of the Intergovernmental Panel on Climate Change (2001c, 2007a).

3.1 CLIMATE CHANGE DRIVERS

Climate change drivers comprise both natural factors, such as solar orbit, sunspot cycles and volcanic eruptions, and anthropogenic factors, including emissions of greenhouse gases. These drivers influence the amount of energy that the Earth receives from the sun and the amount that is retained within the atmosphere and oceans, resulting in changes in all elements of climate, such as temperature, precipitation and atmospheric circulation.

Climate change drivers operate on a range of time scales, with changes in some factors (e.g. the orbit of the Earth around the sun) operating over tens to hundreds of thousands of years, whereas changes in others (e.g. atmospheric concentrations of greenhouse gases and volcanic aerosols) operate on shorter time scales. At timescales of decades to centuries, long-term drivers such as orbital variation are not as relevant. That is because, despite the large magnitude of related changes in climate when accumulated over many millennia, the rate of change on a century time scale is very small, on the order of 0.1°C/century or less.

Since the mid–twentieth century, human activities, including the burning of fossil fuels and changes in land-use patterns, have been the dominant cause of climate change (Intergovernmental Panel on Climate Change, 2007a). This trend is expected to continue through the present century and beyond, leading to rates of global warming that will exceed any experienced during the past several thousand years (Intergovernmental Panel on Climate Change, 2007a).

Paleoclimatic Change

During the past two and a half million years, the Earth's climate has been dominated by large fluctuations between glacial and interglacial conditions. Although average global surface temperatures during glacial periods were only about 4 to 6°C colder than during the warm interglacial periods, these changes were enough to alter Canada's landscape from one almost entirely covered with thick ice sheets to the hospitable biome of today. The last global deglaciation began about 20 000 years ago, and full interglacial conditions have dominated the Earth's climate for the past 10 000 years. The best analogue for the current interglacial, in terms of both climate forcing and the pattern of paleogeographic changes, may be the interglacial that took place some 400 000 years ago (European Project for Ice Coring in Antarctica community members, 2004). A comparison of the two periods suggests that the Earth's present climate, if allowed to evolve naturally, might last an additional 20 000 years or so before the conditions begin to slide back into the glacial part of the cycle.

Changes in solar insolation due to variations in the Earth's orbit around the sun are thought to be the primary driver of climate change across glacial-interglacial cycles. These variations include the 100 000 year cycle in the shape (eccentricity) of the Earth's orbit (from ellipse to circle and back again), the 42 000 year cycle in the angle (obliquity) of its axis of rotation with respect to the orbit, and the 22 000 and 19 000 year cycles in its wobble (precession). Reconstruction of past changes in atmospheric composition during the past 650 000 years from ice cores extracted from polar ice sheets indicates that the responsive changes in atmospheric concentrations of carbon dioxide, methane and nitrous oxide, three key natural greenhouse gases, significantly amplified the climatic effects of changes in solar insolation (Hutterli et al., 2005; Spahni et al., 2005).

Analyses of various proxy climate records extracted from polar ice cores, ocean sediments and other sources suggest that global temperatures have been remarkably stable during the past 10 000 years, a period referred to as the Holocene. These data also indicate, however, that this period has experienced some pronounced changes in regional climates, likely due to natural, internal climate variability. Such events involved a redistribution of heat within the climate system rather than a change in the total energy of the system (as in the case of the enhanced greenhouse effect).

Anthropogenic Forcings

Human activities, including greenhouse gas emissions (e.g. of carbon dioxide, methane and nitrous oxide), aerosol emissions (e.g. sulphate, carbon, nitrate and dust) and land-use change (e.g. deforestation, land development) are increasingly affecting global climate. Although natural factors can explain much of the global climate change that occurred during the first part of the twentieth century, the warming observed in the late twentieth century is primarily due to human activities that have led to increased atmospheric concentrations of greenhouse gases (Intergovernmental Panel on Climate Change, 2001c, 2007a; *see* Table 4). The effect of this anthropogenic radiative forcing on climate since 1950 has been approximately five times greater than the influence of solar output changes (Intergovernmental Panel on Climate Change 2007a; *see* Figure 4).

Although the rate of increase in the concentrations of human-induced nitrous oxide and methane are currently stable or declining, the rate of increase in carbon dioxide (the most important greenhouse gas with significant anthropogenic influence) emissions continues to rise (Intergovernmental Panel on Climate Change, 2007a). The predominant sources of carbon dioxide emissions are fossil fuels (production, distribution and consumption), cement production and land-use changes associated with forestry and agriculture.

TABLE 4: Current and pre-industrial concentrations of the main greenhouse gases (*compiled from* Intergovernmental Panel on Climate Change, 2007a).

Greenhouse gas	2005 concentration	Pre-industrial concentration
Carbon dioxide	379 ppm	~ 280 ppm
Methane	1774 ppb	~715 ppb
Nitrous oxide	319 ppb	~270 ppb

Atmospheric aerosols emitted by human activities also affect climate, both directly (by reflecting sunlight back to space) and indirectly (through effects on cloud properties). Although their effects are short lived (as they are removed by gravity and precipitation), they significantly affect radiative forcing at the continental to global scale. Aerosols have a negative radiative forcing (cooling effect) and are likely to have offset some of the warming during the twentieth century that would otherwise have been induced by greenhouse gases (Intergovernmental Panel on Climate Change, 2007a).

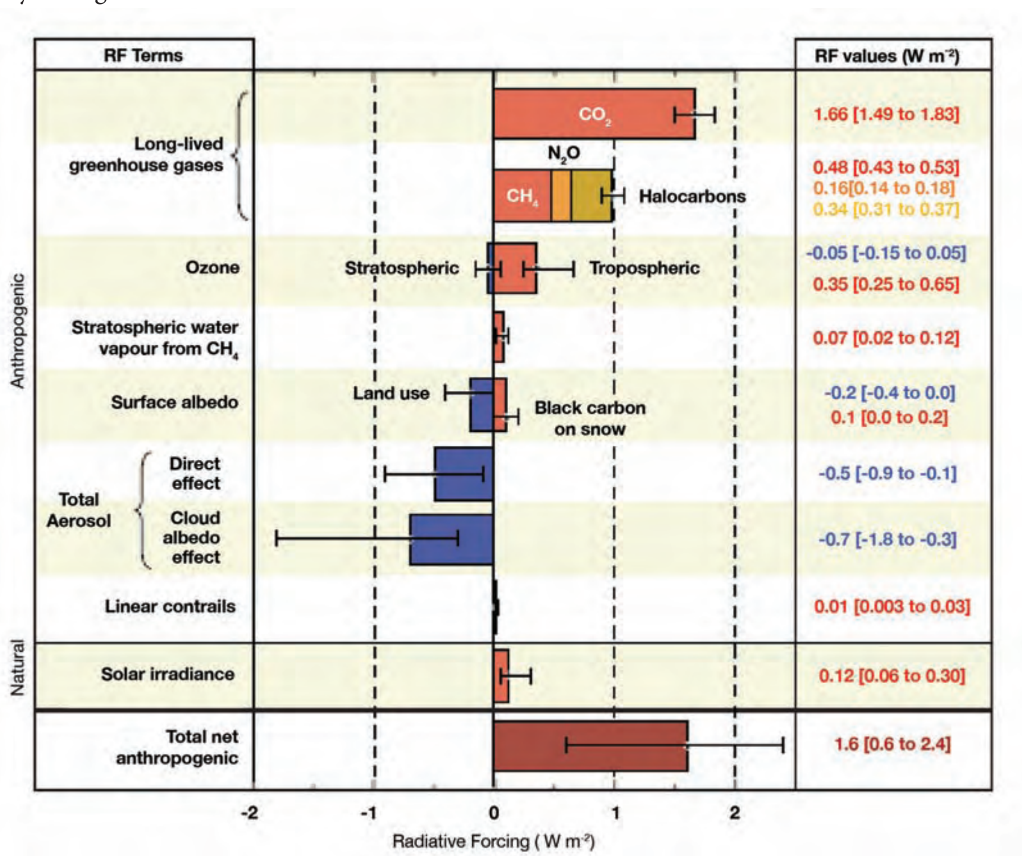

FIGURE 4: Global-average (2005) radiative forcing components of important agents and mechanisms. *Modified from* Intergovernmental Panel on Climate Change (2007a).

Feedbacks and Interactions

In addition to these primary drivers of climate change, there are numerous complex interactions and feedbacks in the climate system, at a variety of spatial and temporal scales, that either enhance or moderate climate change. Some of these feedbacks are positive (i.e. they amplify the magnitude of the original change) and others are negative (i.e. they moderate the original change). Particularly important feedbacks are the role of atmospheric water vapour (which also functions as a greenhouse gas) and clouds (which both reflect sunlight and absorb outgoing heat radiation). Rising temperatures increase both the rate of surface evaporation of water and the atmosphere's capacity to hold water vapour (a positive feedback). More water vapour also affects the distribution and properties of clouds in complex ways, providing both positive and negative feedbacks. Another important feedback is the change in the reflectivity of Earth's surface (albedo) that results from changes in the extent of snow and ice cover. The potential for release of large volumes of methane as a result of permafrost degradation, and subsequent decomposition of previously frozen organic material, is another example of a positive feedback that would enhance climate change (cf. Hyndman and Dallimore, 2001). A negative feedback is the potential for reduced Arctic sea-ice cover to allow arctic marine waters to absorb additional CO_2 from the atmosphere (Bates et al., 2006).

3.2 CLIMATE VARIABILITY

Interactions between the ocean and the atmosphere, and changes in associated circulation patterns, are the primary cause of climate variability. These changes are not directly related to changes in the global energy balance, although indirect interactions are likely. Much of this variability is natural, reoccurring at time scales that vary from months to decades and even longer. Because these oscillations change the flow of warm and cold air masses and alter storm tracks, they often cause trends in one region or location opposite to those in another, resulting in relatively small changes in large-scale climate. Nevertheless, their impact on regional climate in different parts of Canada can be quite significant.

Climate variations of particular importance to Canada include the following:

El Niño–Southern Oscillation (ENSO):

This well-known pattern of variability causes surface temperatures of the tropical Pacific Ocean to vary from El Niño conditions (abnormally warm temperatures in the eastern tropical Pacific) to La Niña conditions (much colder surface waters in the tropical Pacific) and back again about once every 3 to 7 years. In transition years, neither condition dominates.

The strength of the easterly trade winds in the tropics is closely related to ENSO behaviour. Strong El Niño and La Niña events, however, can also dramatically affect the flow pattern of winds and storm tracks over Canada, and hence temperature and precipitation patterns. These impacts are most evident in British Columbia, where El Niño events bring warmer and drier conditions than La Niña events (*see* Chapter 8). The impacts of ENSO are strongest in winter and spring, and are a significant factor in the country's year-to-year climate variability.

Pacific Decadal Oscillation (PDO):

This pattern of variability is most prominent in the North Pacific, and therefore has a large influence on the mid-latitude climates of North America, particularly that of western Canada. Its cause is not well understood, but it is likely linked to ocean circulation processes. Although the record is too short to determine whether the PDO is a persistent mode of variability, there have been two full cycles during the past century. The positive (warm) PDO phase is characterized by warmer coastal waters in the northeastern Pacific. In British Columbia, the positive PDO is associated with slightly higher winter and spring temperatures, and variable effects on precipitation, whereas the negative PDO phase is associated with cooler and wetter conditions (*see* Chapter 8). Hence this oscillation has been a significant influence on climate variability over much of Canada on multi-decadal time scales.

Arctic and North Atlantic Oscillations (AO and NAO):

The North Atlantic Oscillation is an indicator of atmospheric pressure differences between high and temperate latitudes of the North Atlantic Ocean. It is related to variations in the behaviour of the westerly winds of the Northern Hemisphere, so variations in the NAO affect the entire hemisphere. Alternatively, the Arctic Oscillation index (also known as the Northern Annular Mode, or NAM) describes variation in pressure patterns around the North Pole. The two appear to be closely linked. Variations in the NAO-AO significantly influence the monthly and annual variability of Northern Hemisphere climates, but also show significant long-term trends. There are indications that the anomalous behaviour evident in both indices during the 1990s may reflect human influences on the global climate circulation system (Hegerl et al., 2007).

3.3 OBSERVED AND PROJECTED CHANGES IN CLIMATE (GLOBAL[3])

Observed Changes

"*Warming of the climate system is unequivocal.*" (Intergovernmental Panel on Climate Change, 2007a)

During the past century, the world has become warmer. This is evidenced by the increase in global average air and ocean temperatures, the rise in sea level and the decline in snow (Figure 5) and ice cover. Increased temperatures have been accompanied by a number of other observed changes in global climate (Table 5). For example, global sea level has risen an estimated 0.17 m (range 0.12–0.22 m) over the past century, with the rate of increase accelerating during the past decade (1993–2003; Intergovernmental Panel on Climate Change, 2007a).

Shifts in precipitation patterns have also been observed. Some regions have seen increases in precipitation (e.g. northern Europe, northern and central Asia, and northern North America), while others have experienced declines (e.g. the sub-Saharan grasslands and southeastern Africa). In general, precipitation has increased at high latitudes and in the tropics, but decreased in the subtropics. Of greater concern than changes in annual precipitation for many regions is the increased frequency of heavy precipitation events that overload drainage systems, cause extensive flooding, trigger landslides and compromise drinking water and sewage systems, resulting in loss of lives and severe health and economic impacts (*see* Chapter 9).

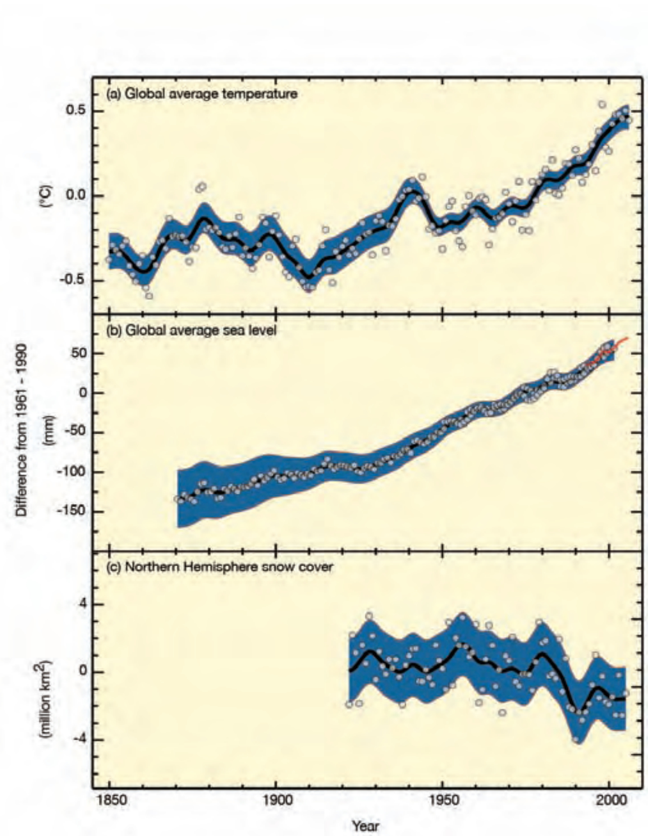

FIGURE 5: Observed changes (relative to 1961–1990) in global average surface temperature, sea level and Northern Hemisphere snow cover (Intergovernmental Panel on Climate Change, 2007a).

Climate Projections

Projections of climate are derived from climate modelling experiments (*see* Box 3) In many cases, future changes will involve a continuation, and often acceleration in the rate, of the observed trends of the twentieth century. The fourth assessment report of Working Group I of the Intergovernmental Panel on Climate Change (2007a; Meehl et al., 2007) discusses the key changes projected during the twenty-first century (Table 6). Significant advances in this report relative to previous IPCC assessments include greater confidence in model projections, improved projections of extreme events and stronger attribution of observed changes to anthropogenic forcing, all due to the advances in climate science and computer capacity, and longer observational periods.

TABLE 5: Observed changes in climate and weather indicators (*compiled from* Intergovernmental Panel on Climate Change, 2007a).

Indicator	Change	Comments
Air temperature	Increased 0.74°C Increased 0.13°C per decade	1906–2005 Rate (last 50 years)
Ocean temperature	Increased to depths of 3000 m	
Sea level	Rose 1.8 mm/a Rose 0.17 m	Rate (1961–2003) Total (1900–2000)
Snow cover	Declined	Northern Hemisphere
Mountain glaciers	Widespread retreat	Since 1900
Arctic sea-ice extent	Decreased 2.7% per decade	Rate (1978–2005)
Permafrost extent	Decreased by ~7%	Since 1900
Heavy precipitation events	Increased in frequency	
Droughts	Increased in intensity and duration	Since 1970s
Heat waves	Increased in frequency	
Tropical cyclones	Increased in intensity	Since 1970s

[3] Observed and projected changes in Canada are presented in Section 4.3.

During the next two decades, IPCC-derived best estimates are that average global temperature will increase by 0.2°C/decade. Even if atmospheric concentrations of greenhouse gases were kept constant at year 2000 levels, global mean temperature would continue to increase by 0.1°C/decade (Intergovernmental Panel on Climate Change, 2007a) for the next two decades. Geographic variation in amount of warming is projected, with the greatest warming occurring over land and at high northern latitudes. Precipitation is also projected to increase more at high latitudes, and to decrease most in subtropical land regions. Sea level is projected to rise 0.18 to 0.59 m by 2100, depending on the scenario used (*see* Table 3).

Higher temperatures will be accompanied by continued reductions in snow cover, reduced extent and duration of Arctic sea ice, and an increase in the depth of permafrost thaw (Intergovernmental Panel on Climate Change, 2007a). Over longer time scales, the magnitudes of projected global temperature increase and sea-level rise are dependent on the assumptions inherent in the scenario used (Table 3), but it is important to note that the directions of such changes are consistent among the emission scenarios.

Changes in extreme weather, including hot days, cold days and heavy precipitation events, will accompany gradual warming (Kharin et al., 2007). Based on outputs of multimodel runs (12–14 models), Kharin et al. (2007) have projected that days of extreme heat in the summer will become hotter, winter cold extremes will warm substantially and heavy precipitation events will occur more frequently. Other studies suggest that tropical and winter cyclones may become more intense in the future due to rising sea-surface temperatures (Webster et al., 2005; Lambert and Fyfe, 2006).

Researchers acknowledge that there is also a real and finite risk of large and potentially cataclysmic surprises that are not captured by model simulations (Intergovernmental Panel on Climate Change, 2007a) but could have dire consequences. These include 1) the potential sudden reduction or shutdown of the Atlantic meridional overturning circulation that transports large quantities of heat from the equator to the North Atlantic, and without which Europe's annual temperature would be much cooler; 2) the disintegration of the west Antarctic ice sheet, which could cause global sea level to rise by 5 m; and 3) the abrupt release of large quantities of methane from frozen gas hydrates below the ocean floor, which would cause methane concentrations in the atmosphere to rise rapidly, resulting in further and more pronounced global warming. Although it appears very unlikely that such surprises will be fully realized within the next century, the irreversible processes that ultimately lead to them could be triggered before 2100. Paleoclimate records show that such surprises have occurred in the past, particularly during periods of rapid climate transition.

TABLE 6: Projected changes in climate (*compiled from* Intergovernmental Panel on Climate Change, 2007a).

Indicator	Change	Likelihood
Cold days and nights	Warmer and fewer	Virtually certain
Hot days and nights	Warmer and more frequent	Virtually certain
Heat waves	More frequent	Very likely
Hot extremes	More frequent	Very likely
Heavy precipitation events	More frequent	Very likely
Meridional overturning circulation of Atlantic Ocean	Slowdown (by 25%)	Very likely
Droughts	Increase in area affected	Likely
Tropical cyclones	More intense	Likely

4 OVERVIEW OF CLIMATE CHANGE IN CANADA

As outlined in Section 2, understanding the risks and opportunities that climate change presents for Canada requires knowledge of not only changes in climate but also the climate sensitivity of key aspects of the Canadian economy and social fabric, and the ability of Canadian governments, industry and individuals to undertake adaptation actions.

Canada is a vast country with great variability between and within regions in terms of climate, landscapes, communities and economy. This diversity is highlighted by contrasting the various regional chapters of this assessment. National-scale trends and projections provide important context for these regional analyses. Over the past half century, changes in climate have resulted in increased temperatures throughout much of Canada, altered precipitation patterns, reduced sea-ice cover, shifting hydrological conditions and changes in some extreme weather events. At the same time, Canada's economy has become dominated by the services sector, while the population has aged and become increasingly urban. In all cases, these trends are expected to continue, with implications for future vulnerability. For example, the services sector is likely less sensitive to changes in climate than the primary resource sector, and the elderly generally have a lower capacity to deal with extreme weather events, such as heat waves. Stronger economies also have more options for adaptation, and are therefore considered better able to adapt.

This section provides an overview of what climate change means for Canada, by examining current conditions, observed trends, and projections for our economy, demographics and climate. A recurrent theme is the importance of scale in assessing vulnerability to climate change. It highlights the fact that aggregate analyses at the national and global scale will inevitably understate the magnitude of the economic and social impacts that will be experienced at regional and local levels.

4.1 THE CANADIAN ECONOMY

Current State

The Canadian economy is large and diversified, with a national GDP of more than $1 trillion. It is mainly a tertiary economy: the services sector represents nearly 70% of GDP, whereas goods-producing industries make up about 30% (*see* Table 7). In the services sector, finance and insurance are main contributors, along with wholesale and retail trade, health care and public administration. Among the goods-producing industries, manufacturing (e.g. of automobiles, aircraft and pharmaceuticals) accounts for the largest share. Although natural resource–based industries, such as mining, agriculture, forestry, fishing and hunting, make up only a small percentage of GDP at the national scale (*see* Table 7), they remain a key component of Canada's economy. Historically, these industries played a large role in the development of the country and are still major contributors to foreign trade and the basis of Canadian wealth.

Trends and Projections

The strength of the Canadian economy during the past decade translated into continuous growth of production per capita through both a rising employment rate and growing labour productivity. This increase in productivity, largely attributed to technological development and capital building, should continue in the near and mid-future. Based on present trends, it is reasonable to foresee a sustained growth of the Canadian GDP and an increase in Canada's wealth.

TABLE 7: Gross domestic product at basic prices, by industry (Statistics Canada, 2007a).

	Millions of constant dollars (1997)				
	2002	2003	2004	2005	2006
Goods-producing industries:					
Agriculture, forestry, fishing and hunting	19 721	21 632	23 047	23 777	23 373
Mining and oil and gas extraction	36 345	38 287	39 469	39 750	40 157
Manufacturing	172 130	171 499	174 992	176 497	174 992
Construction industries	54 620	56 274	59 764	63 108	67 618
Utilities	26 982	27 221	27 366	28 562	28 042
Services-producing industries:					
Transportation and warehousing	46 638	47 176	49 494	51 403	52 792
Information and cultural industries	41 017	41 924	42 534	44 258	45 315
Wholesale trade	57 846	60 252	63 510	68 040	73 510
Retail trade	56 771	58 533	60 732	63 627	67 273
Finance and insurance, real estate, and renting, leasing and management of companies and enterprises	193 595	197 828	205 480	212 385	220 507
Professional, scientific and technical services	43 729	45 610	46 838	48 284	49 728
Administrative and support, waste management and remediation services	21 799	22 531	23 351	24 187	25 664
Public administration	56 346	57 882	59 084	59 902	61 527
Educational services	44 712	45 252	46 293	47 055	47 959
Health care and social assistance	56 933	58 369	59 477	60 305	61 572
Arts, entertainment and recreation	9 130	9 117	9 223	9 283	9 529
Accommodation and food services	23 063	22 533	22 983	23 223	24 143
Other services (except public administration)	24 496	25 065	25 529	26 015	26 628
All industries[1]	985 873	1 006 985	1 039 166	1 069 661	1 100 329

[1] North American Industry Classification Standard

Climate change will impact a rapidly evolving Canadian economy, in which demographic, commercial and technological changes will exert strong influences on future outcomes. The magnitude of the impacts of climate change on the Canadian economy is thus difficult to predict. Impact modelling suggests that, although overall economic impacts may be slightly positive in the short term at moderate degrees of warming, further warming and associated changes in climate will overwhelm systems, causing net economic losses (Stern, 2006). It must also be stressed that much of the research to date on the economic impacts of climate change considers only changes in mean conditions, rather than extreme events, despite the fact that natural disasters associated with extreme weather events frequently incur significant short- and longer term costs. Losses to regional and local economies from both extreme weather events and gradual, longer term changes in climate could be severe. At the local scale, communities that are reliant on climate-sensitive natural resources may be particularly vulnerable to climate change (*see* Box 4; Intergovernmental Panel on Climate Change, 2007b).

National-scale roll-ups, where losses or gains are expressed in terms of national GDP, tend to obscure the impacts in smaller provinces and territories. Consider, for example, the collapse of the northern cod fishery in Newfoundland in 1992. This had extreme provincial- and community-level repercussions, including the loss of up to 40 000 jobs (Mason, 2002), and yet was hardly reflected at the scale of national GDP.

Some of the key ways in which climate change will impact the Canadian economy are categorized as follows:

- **Impacts from extreme events and natural disturbances:** Economic losses from such events in Canada are often in the hundreds of millions of dollars (e.g. Hurricane Juan, Alberta hailstorms, British Columbia wildfires), and even in the billions (1998 Ice Storm, 1996 Saguenay flood; 2001–2002 national-scale drought). Insect damage to forests and crops may also be significant.
- **Impacts on buildings and infrastructure:** Included in this category are increased maintenance and protection costs, total loss or replacement costs, and loss of assets. Winter roads (*see* Chapters 3 and 7), coastal erosion (*see* Chapters 3, 4, 5 and 8) and permafrost degradation (*see* Chapters 3 and 5) are key concerns in Canada.
- **Impacts on the production and prices of, and the demand for, goods and services:** These costs will be manifest both within Canada and internationally (*see* Chapter 9), and will be both positive and negative.
- **Costs related to the impacts on public safety, health and welfare of populations:** These costs, although difficult to quantify and predict, may be high. Examples include the effect of vector-borne diseases, the long-term effects of flooding (e.g. mental health, mould issues and financial hardship), and impacts of changing climate on culture and traditional ways of life. Potential benefits may result from less extreme winter weather.
- **Impacts resulting from hydrological changes in lakes and streams:** Several economic sectors, including energy (e.g. hydroelectricity), tourism and recreation, freshwater fisheries, and transportation will be affected by changing water levels and supply.

Limited data are available on the sensitivity or vulnerability of the services sector in Canada, which now dominates our economy. In the short term, however, it is likely to be less sensitive to slow and/or moderate climate change than the renewable resources sector. For all sectors, continuing climate change means

BOX 4

Resource-dependent communities

Although agriculture, forestry, fishing and hunting account for only about 2% of national GDP (*see* Table 7), and a maximum of 7% of provincial GDP (Saskatchewan), they are vitally important for the economic well-being of many subregions and communities, where land- and resource-based activities are still the basis of economic life. For instance, more than 1600 Canadian communities are more than 30% reliant on one or more of these industries for their economic well-being (i.e. obtain 30% or more of their employment income from employment in these sectors; Natural Resources Canada, 2006). Of these, 808 communities are reliant on agriculture, 651 on forestry and about 200 on fishing. Note that these estimates do not capture smaller (population <250 people) resource-dependent communities.

Natural resources are also integral to many Aboriginal communities in Canada. The subsistence economy may constitute one-half to one-quarter of the total economy of these communities and be worth about $15 000 per household in the Arctic and half of that in the sub-Arctic (Berkes and Fast 1996; Centre for Indigenous Environmental Resources, 2006). These values, however, are not easily reflected in traditional economic accounting.

Several factors heighten the vulnerability of resource-dependent communities to climate change. These include the high climate sensitivity of many natural resources (agriculture, forestry and fisheries), as well as many factors related to lower adaptive capacity, including limited economic diversification, fewer economic resources available for adaptation, an aging population, and generally more restricted access to services (e.g. greater degree of isolation).

Overall, economic impacts at the community scale can be significant. Aggregate analysis tends to hide critical local impacts and imposed hardships.

increasing risk that critical thresholds will be reached, triggering long-term future feedbacks (Schneider, 2004) and catastrophic events that would be extremely costly (Stern, 2006).

4.2 POPULATION AND DEMOGRAPHICS

Current State

Canada has a population of 32.6 million (Statistics Canada, 2006), with a population density of 3.5 people/km^2, among the lowest in the world (Statistics Canada, 2007d). This number, however, is not representative of the regions where most people reside, since more than half of Canada's population lives in the densely populated Quebec City–Windsor corridor.

Trends and Projections[4]

Canada's population grew from 24.3 million in 1981 to 32.6 million in 2006 (Statistics Canada, 2006, 2007e). Two key trends have accompanied this population growth: urbanization and aging. Both of these trends are expected to continue into the future.

In 2001, approximately 80% of the Canadian population lived in cities, with the number of urban dwellers growing by about 50% since 1971. Urban population expansion has resulted both from cities being the preferential location for new immigrants and from the migration of rural residents to take advantage of job opportunities. This demographic is associated with growth in secondary and tertiary industries, but has also been accompanied by an expansion of the urban areas themselves. In 2001, the bulk of the urban areas in Canada were still found in Ontario and Quebec. Rapid expansion of urban areas is also occurring in Alberta and British Columbia.

The elderly are commonly identified as being among the most vulnerable to climate change, especially with respect to health-related impacts. The proportion of elderly persons (age 65 and over) in Canada increased 3% between 1981 and 2005 (from 10 to 13%), and will continue to increase until 2056 under all projection scenarios (Statistics Canada, 2005). Under medium-growth scenarios, the proportion of elderly is projected to almost double in the next 25 years and, by 2056, half the Canadian population would be over 47 years of age. The proportion of the oldest seniors (80 years and over) also increases sharply in every projection scenario. For example, in the medium-growth scenario, about one in 10 Canadians will be 80 years and over by 2056, compared with about one in 30 in 2005. Other populations considered more vulnerable to climate change include children, Aboriginal people, people with pre-existing health conditions and the poor (Health Canada, 2005).

Canada's population will continue to grow between now and 2056 under most scenarios analyzed by Statistics Canada (*see* Figure 6; Table 8). The medium-growth scenario would bring a 30% increase in the size of the Canadian population by 2056, whereas the high-growth scenario would yield a 53% increase from present. The low-growth scenario projects an increase to 2039, then a gradual decline to 2056. In all the scenarios considered, natural increase would become negative in the medium or long term and migration would become Canada's only source of population growth.

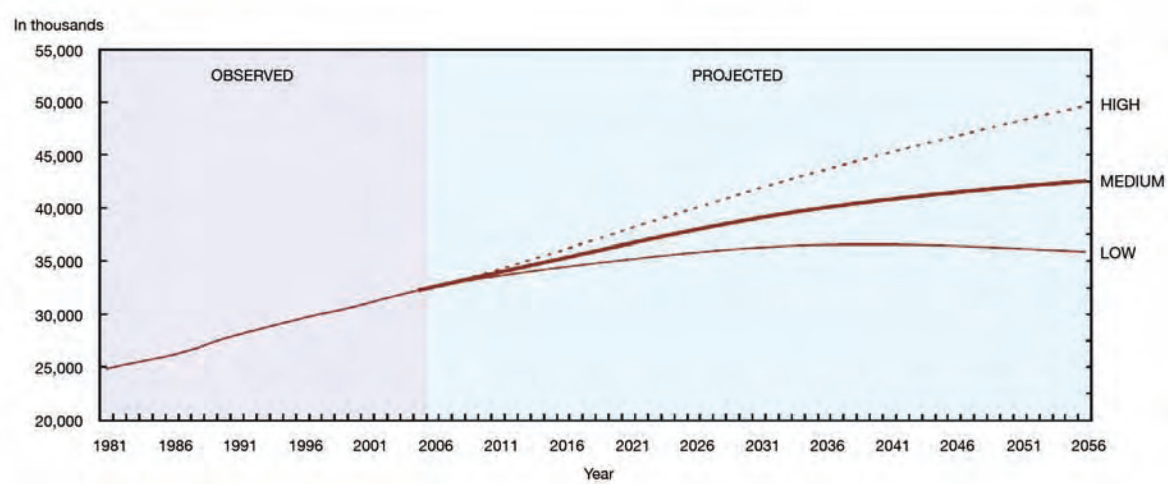

FIGURE 6: Observed (1981–2005) and projected (2006–2056) population of Canada according to three scenarios (Statistics Canada, 2005).

[4] Further description of the projections presented in this section can be found in Statistics Canada (2005).

TABLE 8: Population projections for Canada under low-, -medium- and high-growth scenarios to 2031 and 2056 (*compiled from* Statistics Canada, 2005).

Scenario	2031	2056
Low growth	36.3 million	35.9 million
Medium growth	39 million	42.5 million
High growth	41.8 million	49.7 million

Current population (2006): 32.6 million

The greatest rate of mean annual population growth is projected for British Columbia, followed by Ontario and Alberta (*see* Table 9). Certain provinces, namely Saskatchewan and Newfoundland and Labrador, are projected to see small declines in population. Population increases are projected to be concentrated largely in the major urban areas of the most populous provinces of Ontario, British Columbia, Alberta and Quebec. Further discussion of provincial and territorial trends is found in the regional chapters of this report. The projection results are more uncertain at the provincial/territorial level than at the national level due to interprovincial migration, which has been highly volatile in the past.

TABLE 9: Provincial growth projections for 2031 under a medium-growth, medium-migration trends scenario (*compiled from* Statistics Canada, 2005).

Province	Population (thousands)		Mean annual growth rate (rate per thousand)
	2005	2031	
British Columbia	4 254.5	5 502.9	9.9
Alberta	3 256.8	4 144.9	9.3
Saskatchewan	994.1	975.8	-0.7
Manitoba	1 177.6	1 355.7	5.4
Ontario	12 541.4	16 130.4	9.7
Quebec	7 598.1	8 396.4	3.8
Newfoundland and Labrador	516.0	505.6	-0.8
Prince Edward Island	138.1	149.5	3.1
Nova Scotia	937.9	979.4	1.7
New Brunswick	752.0	767.2	0.8
Yukon	31.0	34.0	3.6
Northwest Territories	43.0	54.4	9.1
Nunavut	30.0	33.3	4.0

4.3 CLIMATE TRENDS AND PROJECTIONS

Observed Trends — Temperature and Precipitation

The influence of anthropogenic climate change on Canada is evident in observed trends and temperatures simulated by global climate models (Zhang et al., 2006). These changes are already impacting human and natural systems (cf. Gillett et al., 2004). Observational data have been collected in southern Canada for more than a century and in other parts of Canada since the mid–twentieth century. These data, together with satellite data from the past 25 years or so, provide a detailed picture of how Canadian climate and associated biophysical variables have changed in recent decades. This section provides an overview of the observed changes; for more detailed discussion, readers are referred to Barrow et al. (2004) and Hengeveld et al. (2005).

On average, Canada has warmed by more than 1.3°C since 1948 (Figure 7), a rate of warming that is about twice the global average. During this time period, the greatest temperature increases have been observed in the Yukon and Northwest Territories. All regions of the country have experienced warming during more recent years (1966–2003; McBean et al., 2005), including the eastern Arctic, where there has been a reversal from a cooling trend to a warming one, starting in the early 1990s (Huntington et al., 2005a; Nickels et al., 2006).

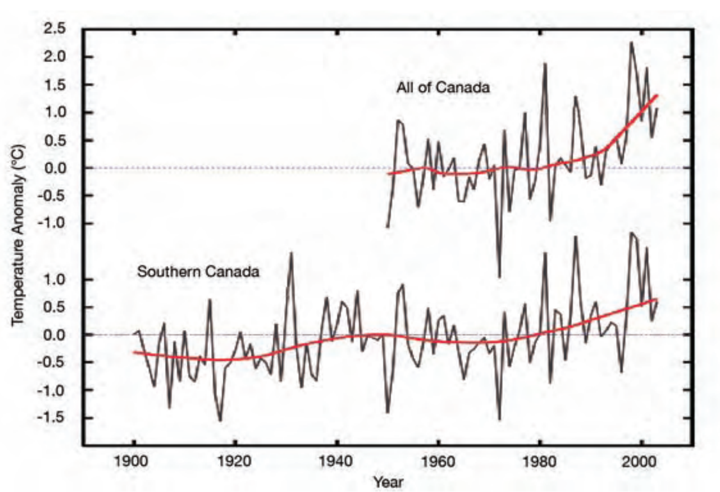

FIGURE 7: Annual national temperature departures and long-term trend, 1948 to 2006 (Environment Canada, 2006).

On a seasonal basis (Figure 8), temperature increases have been greater and more spatially variable during the winter and spring months. In northwestern Canada, winter temperatures increased more than 3°C between 1948 and 2003. During the same period, winter and spring cooling trends (up to –2.5°C) were observed in parts of the eastern Arctic. Summer warming has been both more modest and more uniform in space, whereas warming in the autumn period has been largely confined to Arctic regions and British Columbia (Figure 8).

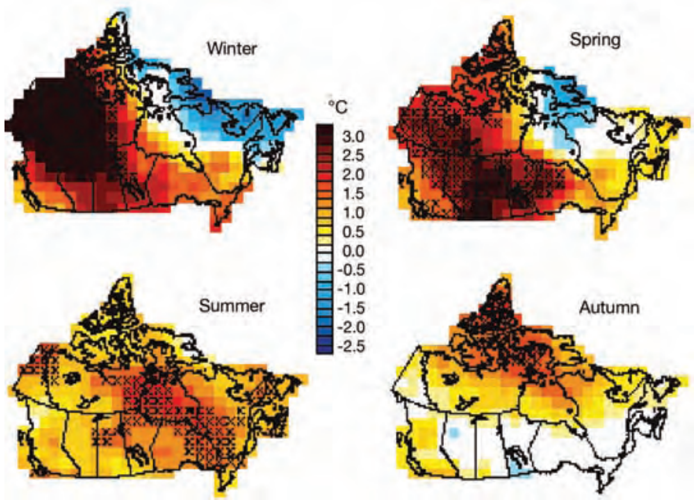

FIGURE 8: Regional distribution of linear temperature trends (°C) observed across Canada between 1948 and 2003, by season. The 'X' symbols indicate areas where the trends are statistically significant. *Source*: Hengeveld et al. (2005).

National trends in precipitation (Figure 9) are more difficult to assess, primarily because of the discontinuous nature of precipitation and its various states (rain, snow and freezing rain). Nevertheless, Canada has, on average, become wetter during the past half century, with mean precipitation across the country increasing by about 12 % (Environment Canada, 2003).

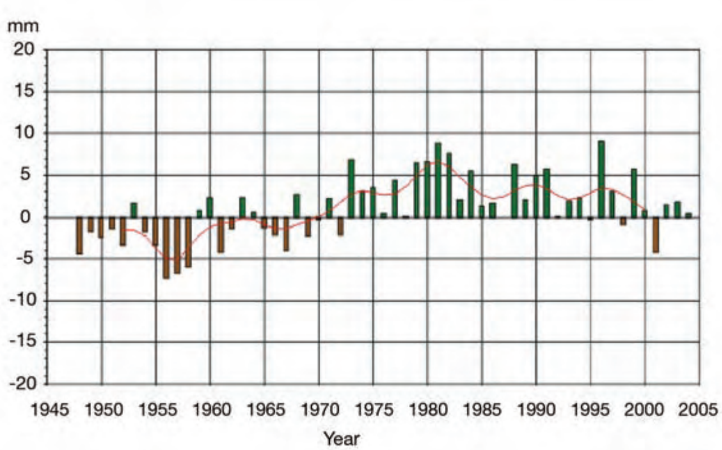

FIGURE 9: Trends in annual departures of average annual precipitation across Canada from the 1951 to 1980 normals, with weighted running mean. *Source*: Environment Canada.

Changes in precipitation have also varied by region and season (Figures 10, 11) since 1950. Annually averaged, the largest percentage increase in precipitation has occurred in the high Arctic, while parts of southern Canada (particularly the Prairies) have seen little change or even a decrease (Figure 10). For example, over most of Nunavut, annual precipitation has increased by 25 to 45%, whereas the average increase in southern Canada has been 5 to 35% (Environment Canada, 2003).

FIGURE 10: Regional distribution of linear annual precipitation trends (% change) observed across Canada between 1948 and 2003. The 'X' symbols indicate areas where the trends are statistically significant *Source*: Zhang et al. (2000), updated in 2005.

Seasonal trends since 1950 indicate that most of the Arctic has become wetter in all seasons. Southern British Columbia and southeastern Canada also show regions with significant increases in precipitation in spring and autumn. In contrast, most of southern Canada except the western part of southern Ontario, which has seen increased lake effect snow (*see* Chapter 6), has experienced a significant decline in winter precipitation.

Changes in the frequency of extreme temperature and precipitation events have been observed in Canada from 1950 to 2003, including (from Vincent and Mekis, 2006):

- fewer extreme cold nights,
- fewer extreme cold days,
- fewer frost days,
- more extreme warm nights,
- more extreme warm days,
- more days with precipitation,
- decrease in mean amount of daily precipitation,
- decrease in maximum number of consecutive dry days,
- decrease in annual total snowfall (southern Canada), and
- increase in annual total snowfall (northern and northeastern Canada).

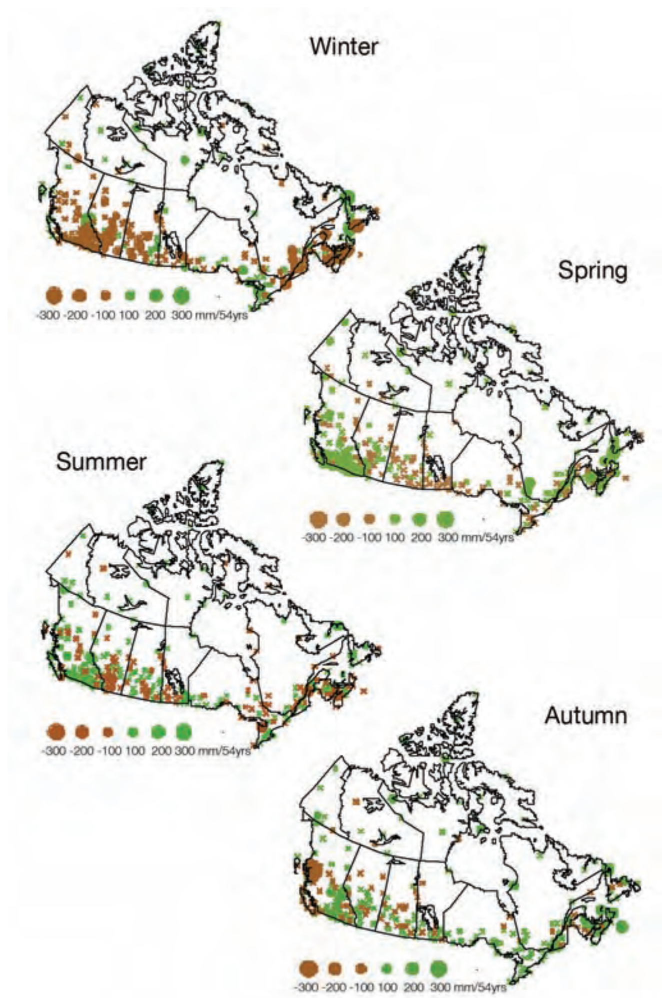

FIGURE 11: Changes in precipitation since 1950, by season. Data are presented as total change over the full 54 years of data, expressed in mm. The magnitude of change is indicated by the size of the circle, with green indicating an increase and brown a decrease. The crosses denote areas where trends are not statistically significant.
Source: Environment Canada.

Accompanying these changes has been a significant decline in the number of heating-degree days. There are also significant changes at the regional scale in the numbers of intense precipitation events. On average, the fraction of precipitation falling as intense events (the upper 10%) has been decreasing in southern Canada but increasing in northern Canada, particularly in the northeast. Also, more of the precipitation is falling as rain rather than snow.

Other Observed Changes

Changes in temperature and precipitation during the past 50 to 100 years have led to changes in other variables, including sea ice, snow cover, permafrost, evaporation and sea level. These changes, as well as their implications for the environment, the economy and society, are discussed in detail in the regional chapters of this report. This section simply highlights key observations.

The cryosphere has responded to observed warming. For example, the extent of Arctic sea ice during the late summer season has decreased by 8% since 1979 (Figure 12). Snow-cover duration, on average, has decreased by about 20 days in the Arctic since 1950 (Figure 13). Annual total snow amount has increased in some Arctic regions (Taylor et al., 2006), however, because

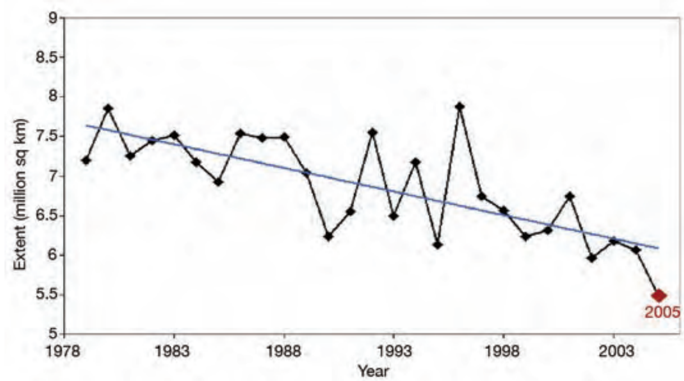

FIGURE 12: Trends in minimum (September) Arctic sea-ice extent from 1978 to 2005, as recorded by NASA satellites. The trend from 1979 to 2005, now showing a decline of more than 8% percent, is shown with a straight blue line. *Source*: National Snow and Ice Data Center (2005).

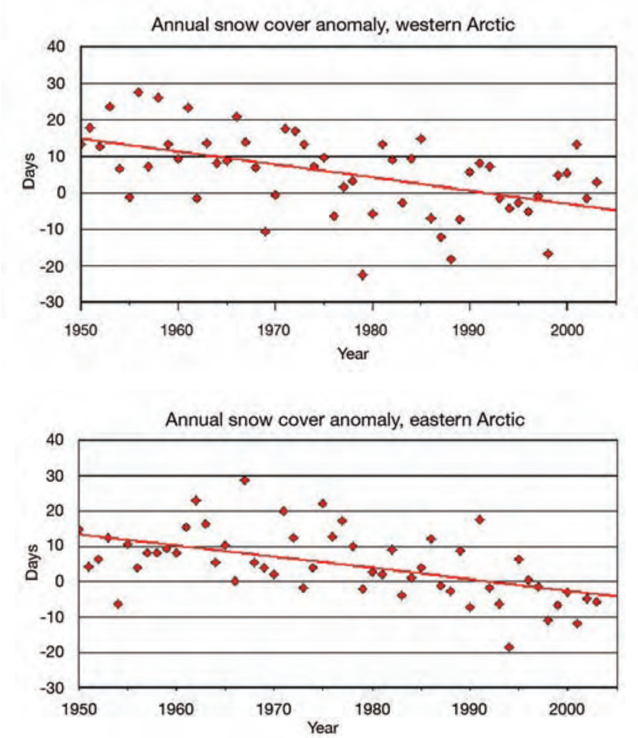

FIGURE 13: Trends in Canadian Arctic snow-cover duration, measured as change in days relative to 1990. *Source*: Ross Brown, Environment Canada, pers. comm., 2007.

higher temperatures induce higher humidity, which results in more precipitation. A general increase in thaw depth was observed through the 1990s across the Canadian permafrost regions (e.g. Brown et al., 2000; Nixon et al., 2003; Smith et al., 2005). Shallow permafrost temperatures increased during the last two to three decades of the twentieth century by 0.3 to 0.5°C per decade in the Canadian high Arctic (Taylor et al., 2006), and ranged from no change to almost 1°C per decade in the western Arctic (Smith et al., 2005).

Recent declines in the volume of glacial meltwater in western Canada (Demuth et al., 2002), and precipitation changes and increased evaporation elsewhere (linked to higher temperatures), have altered water resources across much of Canada (Shabbar and Skinner, 2004). Actual evapotranspiration rates (AET) have, on average, increased in most regions of the country during the last 40 years (Table 10), although the trend is weak or inconsistent in some areas (Fernandes et al., 2007) due to limited availability of water to evaporate. For example, evapotranspiration rates have decreased slightly in the dry regions of the Prairies, where water (to evaporate) is already limited throughout much of the year (Huntington, 2006; Fernandes et al., 2007). Although many areas of the country are expected to experience an increase in precipitation (*see* Figure 14), this may not be sufficient to offset the AET increase due to temperature rise. In the Great Lakes area, for example, a 1°C increase in mean annual temperature was associated with a 7 to 8% increase in AET (*see* Fernandes et al., 2007), resulting in a decrease in water availability.

Water levels in lakes across Canada have varied considerably over time, and recent trends toward lower levels in the upper Great Lakes, in association with higher temperatures, have been quite dramatic (Mortsch et al., 2006). Water levels in the Great Lakes are generally projected to continue to drop in the future (*see also* Chapter 6; Moulton and Cuthbert, 2000; Mortsch et al., 2006; Figure 15).

During the past century, global ocean levels have risen an estimated 0.17 m (range 0.12–0.22 m; Intergovernmental Panel on Climate Change, 2007a). The magnitude of relative sea-level rise along Canadian coastlines depends upon whether the coast is experiencing crustal (glacioisostatic) rebound or subsidence as a result of the deglaciation that took place thousands of years ago. For example, in some parts of Canada, such as around Hudson Bay, land has continued to emerge despite increasing global sea levels. However, regional land subsidence in other regions, including most of the Atlantic coastline, has doubled the rate of

TABLE 10: Trends and changes in actual annual evapotranspiration rates over 40 years by Canadian climate zone (*data from* Fernandes et al., 2007).

Region	ET trend	ET change
	mm/yr	mm over 40 yrs
Pacific Coast	1.16	46.40
South BC	1.24	49.68
Yukon	0.06	2.24
Prairies	0.03	1.12
Mackenzie	0.24	9.80
Northwest forest	0.22	8.80
Northeast	0.75	30.00
Great Lakes	0.69	27.56
Atlantic	1.04	41.48
Tundra	0.16	6.48

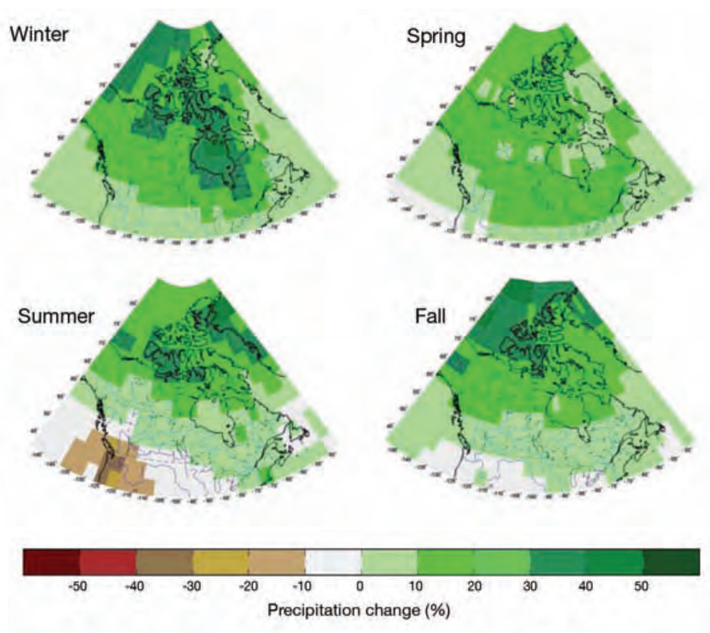

FIGURE 14: Seasonal change in precipitation by the 2050s (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

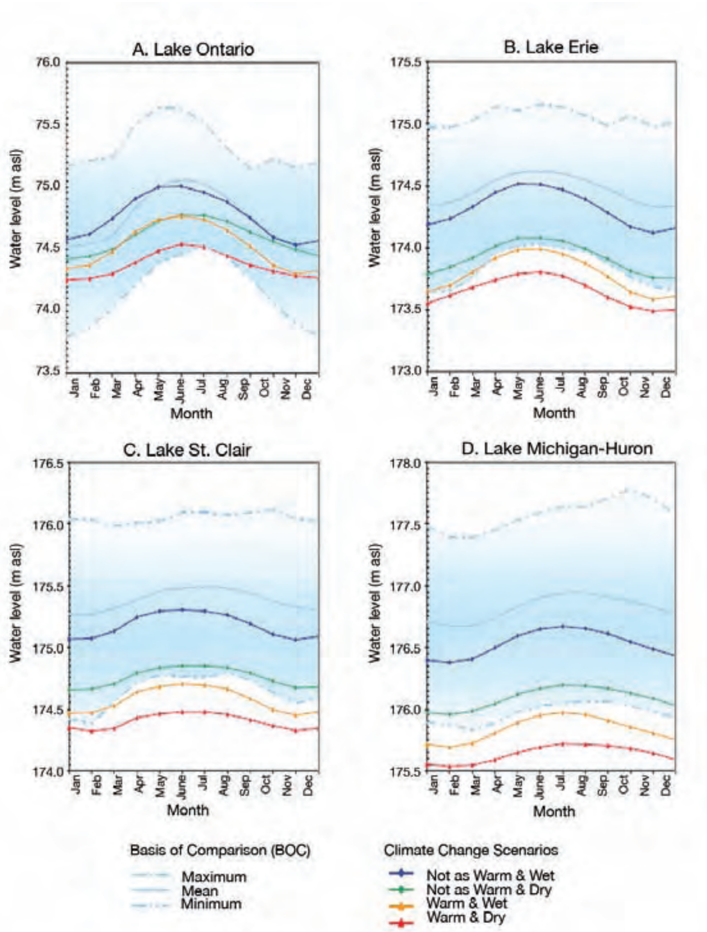

FIGURE 15: Projected changes in water levels for the Great Lakes (Mortsch et al., 2006).

local sea-level rise in some areas (McCulloch et al., 2002). In Charlottetown, for instance, relative sea level rose 32 cm over the twentieth century (Forbes et al., 2004). Additional geophysical factors influencing relative sea-level changes in Canada include tectonic activity along the Pacific coast and subsidence due to extensive sediment deposition, particularly in the Fraser River and Mackenzie River deltas. Along the west coast, relative sea-level change has been lower, with sea level rising by 4 cm in Vancouver, 8 cm in Victoria, 12 cm in Prince Rupert and dropping by 13 cm in Tofino over the twentieth century (British Columbia Ministry of Water, Land and Air Protection, 2002). In the north, the Yukon coast and the directly adjacent Northwest Territories coast are subsiding, making relative sea-level rise in these regions greater than along most of the Arctic coast (Barrow et al., 2004).

Projections — Temperature and Precipitation[5]

All of Canada, with the possible exception of the Atlantic offshore area, is projected to warm during the next 80 years. In most cases, future changes in climate will involve a continuation of the patterns, and often an acceleration of the trends, discussed above. Therefore, amounts of warming will not be uniform across the country (*see* Figure 16). During the present century, temperature increases will be greatest in the high Arctic, and greater in the central portions of the country than along the east and west coasts (Figure 16). Regional differences in temperature projections are also illustrated in Figure 17, which shows historical and projected change in temperature for six cities across Canada.

On a seasonal basis, warming is expected to be greatest during the winter months (Figure 16), due in part to the feedback effect that reduced snow and ice cover has on land-surface albedo. Winter warming by the 2050s is expected to be most pronounced in the Hudson Bay and high Arctic areas, and least in southwestern British Columbia and the southern Atlantic region. A decrease in the winter diurnal temperature range across the country indicates that winter nights will likely warm more than winter days (Barrow et al., 2004). This pattern was not found for the other seasons. Rates of warming will be lower in the summer and fall, and summer warming is projected to be more uniform

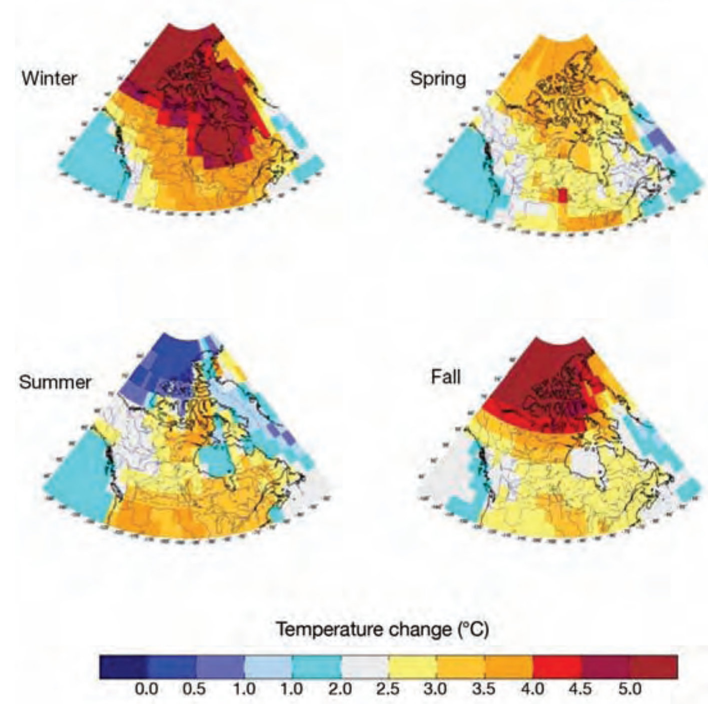

FIGURE 16: Seasonal change in temperature across Canada by 2050 (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

[5] Much of the material in this section is abstracted from the Barrow et al. (2004) report *Climate Variability and Change in Canada: Past, Present and Future.*

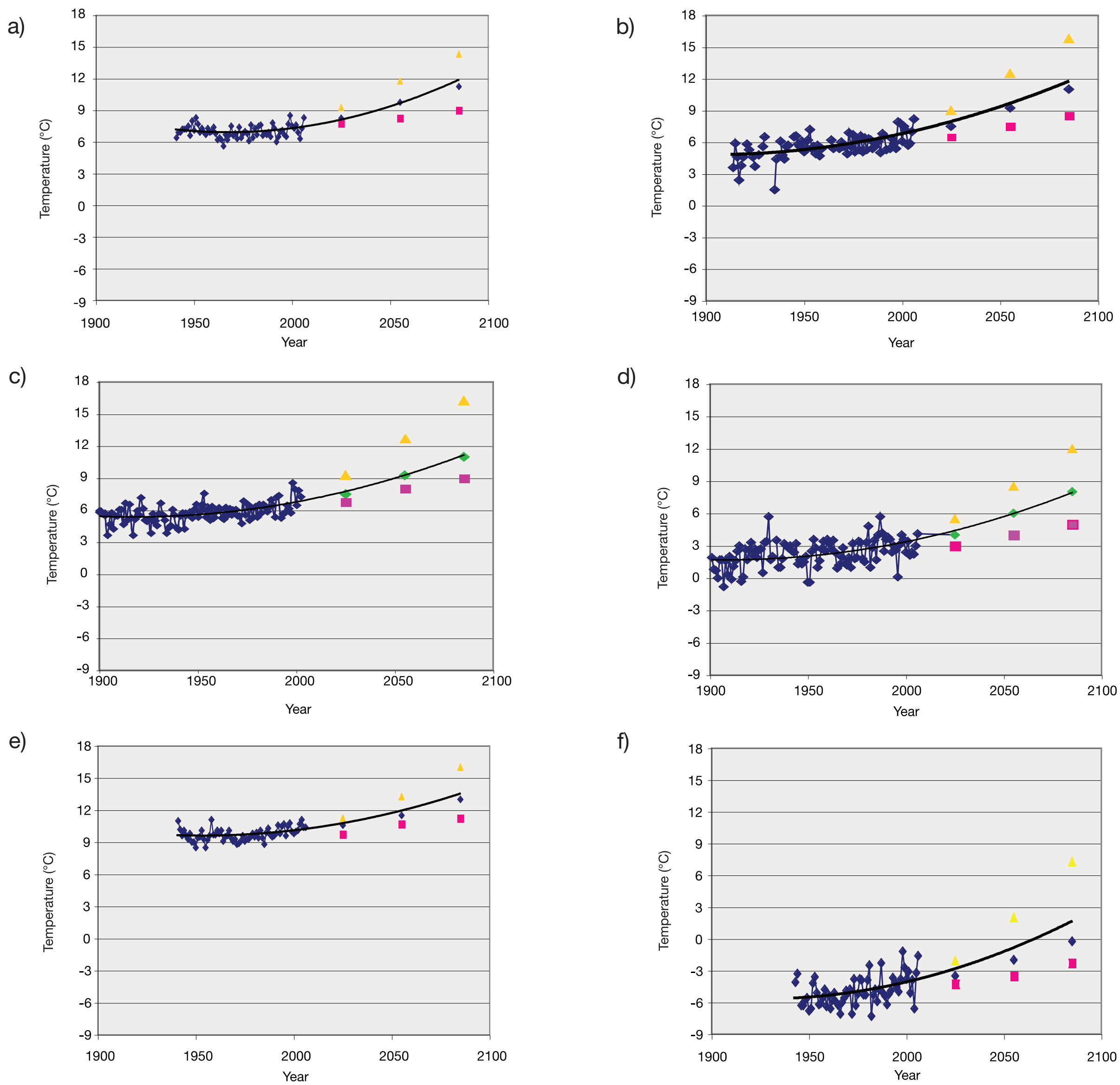

FIGURE 17: Historical trends (blue diamond) and projected maximum (yellow triangle), median (green diamond) and minimum (pink square) annual mean temperature scenarios for the 2020s, 2050s and 2080s for six cities across Canada: a) Yarmouth, NS; b) Drummondville, QC; c) Ottawa, ON; d) Regina, SK; e) Victoria, BC; and f) Yellowknife, NT. Note historical data presented are limited by data availability, and projected changes are derived from a range of global climate models using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

across the country. These patterns are consistent with the observed trends presented above.

The frequency of extreme warm summer temperatures (exceeding 30°C) is expected to increase across Canada (*see* Figure 18; Kharin et al., 2007). Heat waves are projected to become more intense and more frequent. The health impacts of extreme heat, as well as effective adaptation measures to deal with heat waves, are discussed in several of the regional chapters (e.g. Chapters 5, 6 and 7). At the same time, extreme cold days are projected to decline significantly (Kharin et al., 2007), resulting in an overall reduction in the climate severity index (Barrow et al., 2004).

Future precipitation is more difficult to project, and changes are generally of lower statistical significance, than changes in temperature (Barrow et al., 2004). This is reflected in the wide range in model results for projected precipitation (*see* Figure 19). Annual total precipitation is projected to increase across the country during the current century. By the 2080s, projected

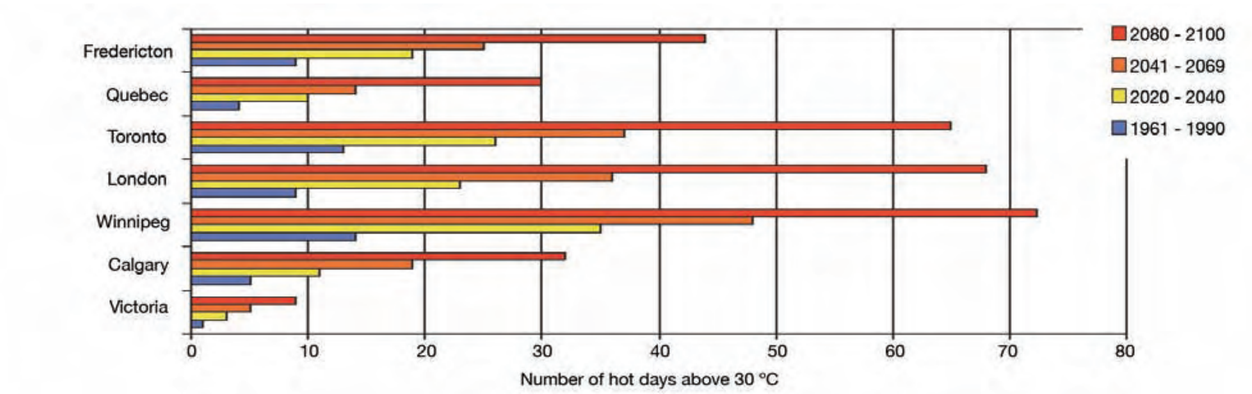

FIGURE 18: Number of days with temperatures exceeding 30ºC, during observed (1961–1990) and future (2020–2040; 2041–2069; and 2080–2100) time periods (Hengeveld et al., 2005).

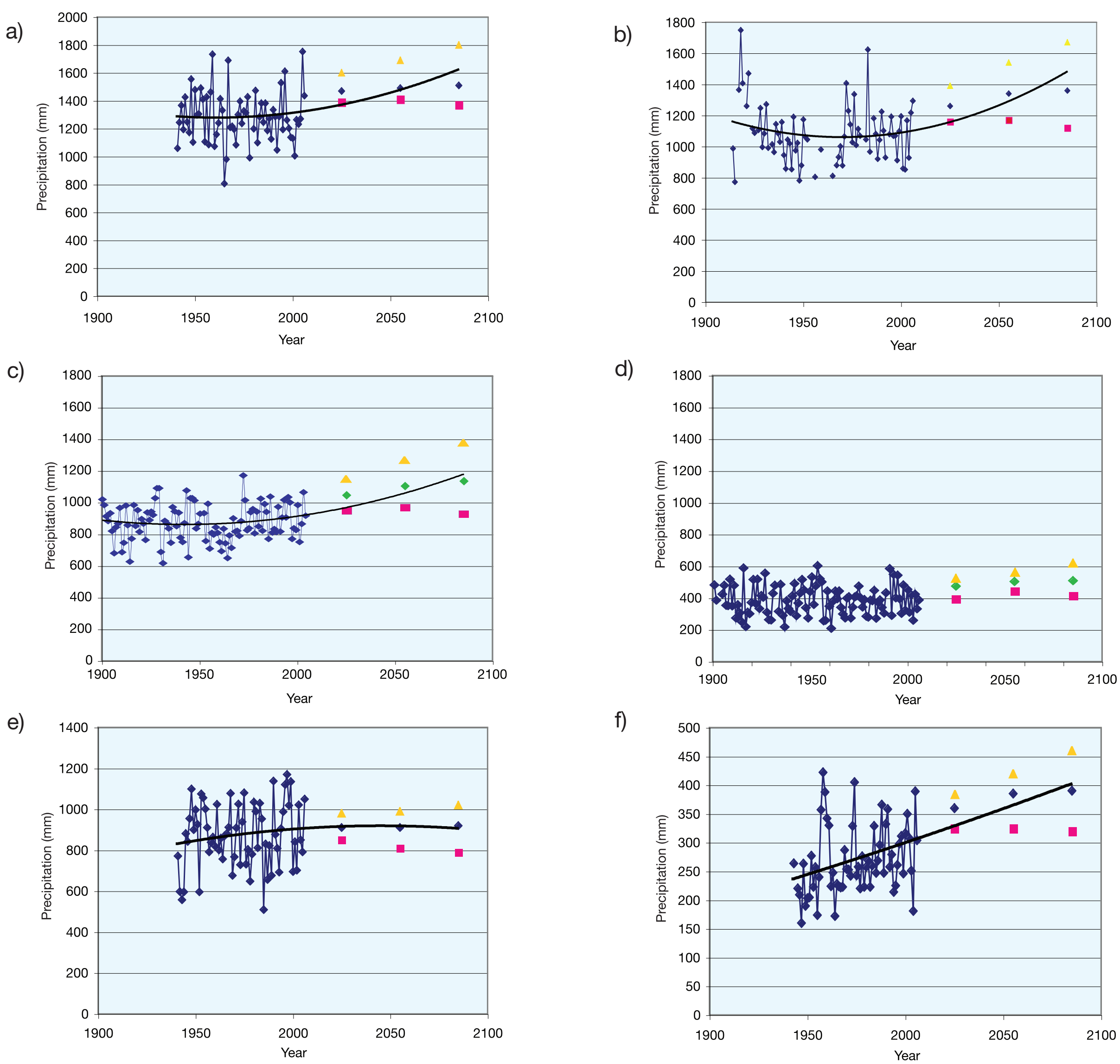

FIGURE 19: Historical trends (blue diamond) and projected maximum (yellow triangle), median (green diamond) and minimum (pink square) total annual precipitation scenarios for 2020s, 2050s and 2080s for six cities across Canada: a) Yarmouth, NS; b) Drummondville, QC; c) Ottawa, ON; d) Regina, SK; e) Victoria, BC; and f) Yellowknife, NT. Note historical data presented are limited by data availability, and projected changes are derived from a range of global climate models using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

precipitation increases range from 0 to 10% in the far south up to 40 to 50% in the high Arctic. Due to enhanced evapotranspiration, driven by higher temperatures, many regions will experience a moisture deficit despite greater amounts of precipitation.

Seasonal changes in precipitation will generally have greater regional-scale impacts than the annual totals. Throughout most of southern Canada, precipitation increases are projected to be low (0–10% by the 2050s) during the summer and fall months. In some regions, especially the south-central Prairies and southwestern British Columbia, precipitation is even expected to decline in the summer (Figure 14). This means less available precipitation during the growing season in important agricultural regions. Other important changes in precipitation include an increase in the percentage of precipitation falling as rain rather than snow, and an increase in extreme daily precipitation (Figure 20; Kharin and Zwiers, 2000).

Other Projected Changes

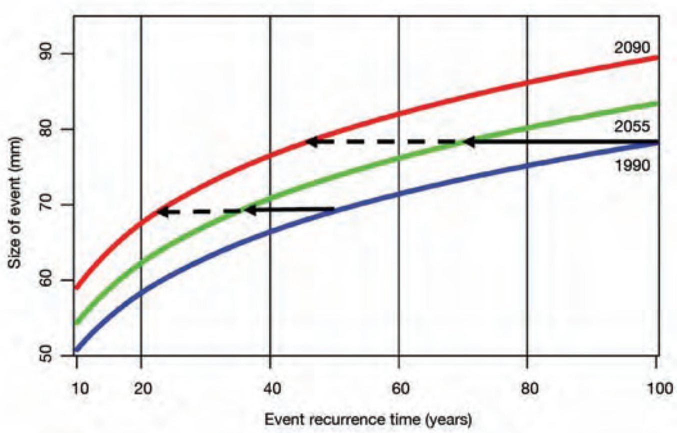

FIGURE 20: Projected changes in extreme 24-hour precipitation events, North America between latitudes 25°N and 65°N (based on Kharin and Zwiers, 2000). *Source*: Environment Canada.

Sea level will continue to rise during the current century, with global projections of 0.18 to 0.59 m by 2100 (Intergovernmental Panel on Climate Change, 2007a). Relative sea-level changes in Canada will continue to exhibit similar patterns to those observed during the twentieth century. Therefore, regions of rebound (e.g. Hudson Bay, parts of the British Columbia coast and the Labrador coast) will generally experience lesser impacts as a result of sea-level change than areas that are currently subsiding (e.g. Beaufort Sea coast, much of the Atlantic coast and the Fraser River delta). The influence of sea-level rise on coastal communities and activities such as shipping and tourism are discussed in detail in Chapters 3, 4, 5 and 8.

As sea level rises, the risk of storm-surge flooding increases. Such flooding will likely occur more frequently in the future, particularly in areas already impacted by these events. For example, storm-surge flooding in Charlottetown, which occurred six times between 1911 and 1998, is likely to occur every year by 2100 unless significant adaptation measures are implemented to protect the city (McCulloch et al., 2002).

There is not a simple direct relationship between sea ice and temperature because complex interactions, associated with changes in atmospheric and ocean circulation patterns (e.g. the Arctic and North Atlantic oscillations), strongly influence sea-ice patterns (Barrow et al., 2004). Patterns of sea-ice reduction will therefore continue to vary locally and regionally, as they have during the past century (Barrow et al., 2004). Arctic sea-ice extent will, however, decrease during the twenty-first century, and summer ice extent will change more than winter ice extent (Intergovernmental Panel on Climate Change 2007a; Anisimov et al., 2007). Although climate models vary in estimating the rate of ice decline (*see* Chapter 3), several scenarios indicate that large areas of the Arctic Ocean will be seasonally ice free before the end of the twenty-first century (Solomon et al., 2007).

Sea-level rise, storms and decreases in sea ice will all increase the rate of coastal erosion (*see also* Chapters 3 and 4; Manson et al., 2005). In northern regions, permafrost degradation will make coastal areas further susceptible to erosion.

4.4 CONCLUSIONS

Canada's climate is changing, and projections show that it will continue to change in the future. In addition to gradual shifts in average temperature and precipitation, changes in temperature and precipitation extremes, sea level, storm surges, sea ice and other climate and climate-related parameters have been both observed and projected. These changes will continue to occur across a backdrop of social and economic changes, which will greatly influence net impacts. Regional differences in projected climate, sensitivity and factors influencing adaptive capacity (e.g. access to economic resources, population demographics) mean that vulnerability varies greatly across the country, both within and between regions. These differences are highlighted throughout the regional chapters of the report.

5 APPROACHES USED IN THIS ASSESSMENT

5.1 SYNTHESIS

This assessment is a critical analysis of the existing body of knowledge concerning the risks and opportunities that climate change presents for Canada. This process required consideration of historical climate trends, projected climate change, climatic sensitivity of key systems, and current and future adaptive capacity. New studies and research were not commissioned for the purposes of the assessment.

Authors were directed to draw from three main sources:

1) **Peer-reviewed published literature**: Peer-reviewed published literature was the primary source of material for the assessment. There is a large and growing body of climate change literature focused specifically on Canada, and international papers of relevance to understanding Canada's vulnerability. In addition, there is a wealth of peer-reviewed information relevant to climate change impacts and adaptation outside climate change journals. The authors were therefore encouraged to draw from other fields of research, such as natural disasters, land-use management, political economics and planning.

2) **Grey literature**: Grey literature, including government reports, non–peer-reviewed papers in a variety of publications, workshop reports and consultant reports was also used as reference material. Such sources contribute significantly to understanding vulnerability to climate change, and often are the only place to access the most recent and locally relevant information. Authors' discretion was used to evaluate the quality and suitability of the grey literature.

3) **Local/practitioner knowledge**: This assessment recognizes that local knowledge, frequently obtained through communication with practitioners, complements that obtained from scientific sources. Given the applied nature and local scale of many adaptation measures, direct experience is rarely captured in the scientific literature. For this reason, the report occasionally cites personal communications to capture and attribute this knowledge.

As noted in Chapter 1, the scientific information presented in this assessment includes traditional (Aboriginal) knowledge. This knowledge is captured in all three sources described above. Material included in each chapter broadly reflects the scope of information available through the sources noted above. The volume of material available on a specific topic, however, does not necessarily reflect the relative significance of that issue at a regional or national level. Indeed, there is only very limited information available on some important aspects of impacts and adaptation, such as economic analyses. Hence, assessment of the significance of available knowledge reflects the expert judgement of the lead and contributing authors of each chapter, in their areas of specialization. The authors were also asked to identify key knowledge gaps. General guidance documents addressing scope, goals and key concepts were provided to the writing teams, but decisions on how information on any given region could be most effectively presented was left to the authors. Peer review by both science and policy experts in academia and government helped to guide the final version of this report.

5.2 LIKELIHOOD AND CONFIDENCE

Uncertainty is an inherent component of any climate change analysis. While it may be possible to identify the major sources of uncertainty (e.g. in climate change projections), full quantification is rarely possible. This is particularly true for impacts and adaptation studies, which typically involve multiple steps, each introducing uncertainties that are propagated through the study (i.e. cascading uncertainties). Uncertainties related to socioeconomic factors, which influence both future emission pathways and adaptive capacity, are especially difficult to assess (Manning et al., 2004). These uncertainties make it challenging to reach strong conclusions on the likelihood of an outcome being realized, or to determine the confidence that should be associated with a particular statement.

Many science assessments, including the Arctic Climate Impact Assessment (ACIA) and those of the Intergovernmental Panel on Climate Change (IPCC), adopt a probability-based nomenclature for expressing likelihood and/or confidence. Assignment of a particular term (e.g. likely, very likely) is based upon expert evaluation of the volume and agreement of the scientific literature, drawing from multiple lines of evidence that include observed trends, experiments, model simulations and theory (Huntington et al., 2005b).

For this assessment, it was deemed neither practical nor meaningful to adopt a probability-based terminology. When undertaking analysis at the regional or sub-regional level, the generally small volume of information available on any specific topic dictates that statements of likelihood and confidence will dominantly reflect expert judgement, and are necessarily qualitative. Authors were encouraged to focus on communicating both the likelihood and confidence of their conclusions using common-sense language rather than prescribed expressions. Authors were generally able to express greater confidence when the quantity and quality of research available on the issue was high. Expressions of likelihood are strongest where projections are consistent with historical trends and/or well-established climate-system relationships, and supported by independent modelling analysis.

5.3 USE OF SCENARIOS

Climate Scenarios

This assessment does not focus on any particular climate scenario or set of scenarios in the discussion of future climate change. As an integration and analysis of previous studies that took different approaches to the issue of climate scenarios and related assumptions, it tries to place the results of those studies in the context of a complete range of plausible climate futures.

Each regional chapter includes a section describing projected climate change for the region, which have been derived from climate change experiments undertaken with seven global climate models (GCMs), using an illustrative scenario from each of the six emissions scenario groups in the *Special Report on Emissions Scenarios* (SRES). These were the most recent scenarios available at the start of this assessment process (2005), and have been constructed in accordance with the recommendations of the IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (IPCC-TGICA). The GCMs selected for use conform to this group's recommendations, and the scenarios indicate the climate changes (with respect to 1961–1990) for the 2020s, 2050s and 2080s, the three future time periods recommended for study. Scenario results were provided to the authors of each chapter as scatterplots, maps and box-and-whisker plots (Appendix 1). The decision regarding which of these graphic formats appear in the published chapters was left to the lead authors. Some chapters present additional climate scenario information, in which case the models and emission scenarios used are specified.

Socioeconomic Scenarios

Long-term socioeconomic scenarios suitable for climate change impacts and adaptation studies do not exist for all regions of Canada. As a result, authors of each chapter were encouraged to use whatever relevant data was available. Extensive data on demographic and socioeconomic historical trends are available from Statistics Canada at various scales (e.g. national, provincial, census metropolitan area). Examples of trends of relevance to vulnerability assessment include rural to urban migration, changing age distributions, and trends in income level and gross domestic product (*see* http://www41.statcan.ca/ceb_r000_e.htm). Statistics Canada also provides projections of future population totals and age distributions by sex for the years 2011, 2016, 2021, 2026 and 2031. Other sources of socioeconomic data are referenced in individual chapters of this assessment.

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GRAPHICAL PRESENTATION OF CLIMATE SCENARIOS

Scatterplots (Figure A-1)

The scatterplots provide a quick visual summary of changes in mean temperature and precipitation averaged over the study region. The number of grid boxes contained within an individual chapter region is GCM-dependent, since the spatial resolution varies between climate models. Each coloured symbol represents a different climate change scenario, identified in the associated legend. Also illustrated on the scatterplots are grey squares that indicate the representation of 'natural' climate variability by the second-generation coupled global climate model (CGCM2) of the Canadian Centre for Climate Modelling and Analysis. This has been derived from a long control run undertaken with this GCM in which there is no change in forcing over time.

Where there is overlap between the coloured symbols and the grey boxes, the scenarios concerned lie within the range of 'natural' climate variability. No overlap indicates that the scenarios lie outside of this range and potentially represent conditions that have not previously been experienced.

The blue lines on the scatterplot represent median changes in mean temperature and precipitation, derived from the suite of climate change scenarios illustrated on the scatterplot. These lines effectively divide the plot into four quadrants, allowing the identification of those scenarios that exhibit cooler, warmer, drier or wetter conditions than are indicated by the majority of scenarios. Thus, it also provides a means of identifying those scenarios that exhibit the most 'extreme' changes.

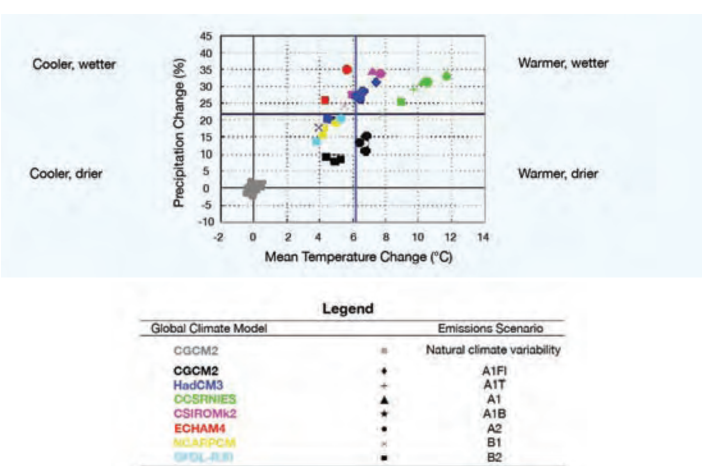

FIGURE A-1: Example of a scatterplot and the legend for the scatterplots presented in this report. The colours represent the global climate model, and the symbols represent the emissions scenarios.

Scenario Maps (Figure A-2)

The scenario maps summarize all the GCM-derived scenarios of climate change illustrated on the scatterplots. All scenarios have been interpolated onto the CGCM2 grid and then the minimum, median and maximum changes have been calculated and plotted. Hence, the values in each grid box are not necessarily from the same scenario.

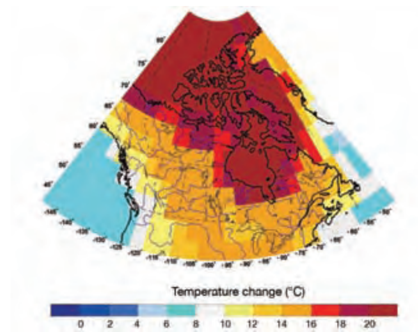

FIGURE A-2: Example of a scenario map for an ensemble scenario. This is the maximum annual temperature change projected for Canada by the 2080s.

Box-and-Whisker Plots (Figure A-3)

A box-and-whisker plot is a means of providing summary information about a data sample. The box has lines at the lower quartile, median and upper quartile values, and the whiskers are lines extending from each end of the box to show the extent of the rest of the data. The box represents the central 50% of the data sample. The whiskers indicate the maximum and minimum data values if there is a dot located on the lower whisker. If there are outliers in the data, indicated by '+' symbols, then the whisker length is 1.5 times the interquartile range. The box-and-whisker plot illustrated in Figure A-3 indicates that, for the 2050s and 2080s, the whiskers represent the maximum and minimum data values. For the 2020s there is an outlier at the upper end of the data values, indicated by the '+' symbol. In this case, the whisker represents 1.5 times the interquartile range.

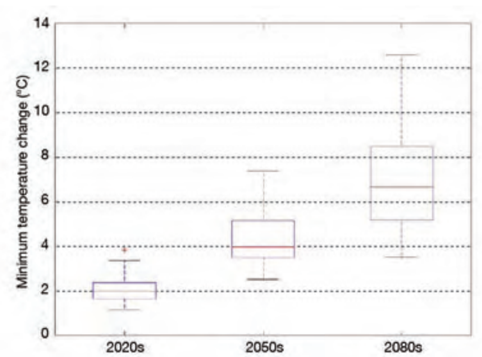

FIGURE A-3: Example of a box-and-whisker plot.

CHAPTER 3
Northern Canada

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NORTHERN CANADA

Recommended Citation:

Furgal, C., and Prowse, T.D. (2008): Northern Canada; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 57-118.

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CONTENTS

KEY FINDINGS

The climate of the Arctic has shown an unprecedented rate of change during the past 50 years. Over the last half century, the Canadian Arctic has experienced significant increases in both temperature and precipitation, consistent with trends in other circumpolar regions. Increases in air temperature have resulted in many of the most extreme warm years throughout the entire Canadian North being recorded in the last decade, with the greatest temperature increases observed over the western Arctic. All global climate models project continued increases in temperature and precipitation over the Canadian Arctic, with greatest temperature changes at higher latitudes. As a result, there will continue to be significant changes in the physical environment, particularly in the cryosphere (snow, glaciers, permafrost and river/lake/sea ice).

There is increasing evidence that changes in climate are already having impacts on ecological, economic and human systems in northern regions, and that some individuals, communities and institutions are already taking action to reduce harmful impacts. Current levels of exposure to climate-related changes and sensitivities, as well as limitations in adaptive capacity, make some northern systems and populations particularly vulnerable to the effects of climate change. Key findings include the following:

- **Climate-induced changes in the cryosphere (permafrost, sea ice, lake ice and snow) have important implications for infrastructure maintenance and design.** Much of the infrastructure in the North is dependent upon the cryosphere to, for example, provide stable surfaces for buildings and pipelines, contain wastes, stabilize shorelines and provide access to remote communities in the winter. Permafrost warming and thaw may require remedial action or further engineering modifications to existing infrastructure. Waste retention ponds and lakes that rely on the impervious nature of permafrost to retain environmentally hazardous materials are a particular concern. Climate change is already being considered in the design of most major projects in the North, including tailings containment structures, pipelines and roads, and large buildings. In the longer term, marine and freshwater transportation will need to shift its reliance from ice routes to open-water or land-based transport systems. Coastal areas and communities will also become more vulnerable to erosion due to loss of sea ice compounded by increased storminess and rising sea levels. Changes in the timing of river flows will require modifications to the infrastructure and flow strategies used in generating hydroelectricity.

- **As the climate continues to change, there will be consequences for biodiversity shifts and the ranges and distribution of many species, with resulting impacts on availability, accessibility and quality of resources upon which human populations rely.** This has implications for the protection and management of wildlife, fisheries and forests. The northward migration of species, and disruption and competition from invading species, are already occurring and will continue to alter terrestrial and aquatic communities. Shifting environmental conditions will likely introduce new animal-transmitted diseases and redistribute some existing diseases, affecting key economic resources and some human populations. Stress on populations of iconic wildlife species, such as the polar bear, at the southern limit of their distribution will continue as a result of changes to critical sea-ice habitat. Where these stresses affect economically or culturally important species, they will have significant impacts on people and regional economies. Widespread proactive adaptation to these changes will be required in natural resource management sectors.

- **Increased navigability of Arctic marine waters and expansion of land- and fresh water–based transportation networks will lead to a less 'remote' northern Canada, bringing both opportunities for growth in a range of economic sectors and challenges associated with culture, security and the environment.** Diminishing sea ice, particularly in Hudson Bay and the Beaufort Sea, and a lengthened summertime shipping season associated with warming, will increase opportunities for shipping and passage within Canadian Arctic waters. It is likely that adaptations in the form of increased surveillance and policing will be required. Loss of sea ice and fresh ice will also lead to the development of marine ports and all-season road networks to interior portions of the northern mainland and Arctic islands, particularly to access natural resources whose development has previously been uneconomic. Socioeconomic and cultural impacts on Arctic communities from increased economic activity, including increased marine traffic and access associated with the opening of the Northwest Passage, may be far reaching.

- **While maintaining and protecting aspects of traditional and subsistence ways of life in many Arctic Aboriginal communities may become more difficult in a changing climate, new opportunities will also be presented.** Young and elderly Aboriginal residents, in particular those pursuing aspects of traditional and subsistence-based ways of life in more remote communities, are the most vulnerable to the impacts of climate change in the North. An erosion of their adaptive capacity via the social, cultural, political and economic changes taking place in many communities today will further challenge their abilities to adapt to changing environmental conditions. However, enhanced economic opportunities may provide significant benefits to communities, making the net impacts on human and institutional vulnerability difficult to predict.

1 INTRODUCTION

There is strong evidence from scientists and local residents that Canada's North is already experiencing changes in its climate (e.g. Ouranos, 2004; Huntington et al., 2005; McBean et al., 2005; Overpeck et al., 2005; Bonsal and Prowse, 2006). The western and central Canadian Arctic experienced a general warming during the past 50 years of approximately 2 to 3°C (Zhang et al., 2000). In the eastern Canadian Arctic, cooling of approximately 1 to 1.5°C occurred during the same period (Zhang et al., 2000), but with warming reported in the last 15 years. Local Aboriginal hunters and elders have reported significant warming throughout the region in recent decades, which corroborates the scientific observations (e.g. Huntington et al., 2005; Nickels et al., 2006). These climatic changes have resulted in significant decreases in the extent and thickness of sea ice in some parts of the Arctic, thawing and destabilization of permafrost terrain, increased coastal erosion, and shifts in the distribution and migratory behaviour of Arctic wildlife species (Arctic Climate Impact Assessment, 2004, 2005). Climate model projections suggest that these recently observed changes across the North will continue (Kattsov et al., 2005; Bonsal and Prowse, 2006), with a myriad of implications for human and wildlife populations and future regional development (Arctic Climate Impact Assessment, 2004, 2005; Ford et al., 2006b; Furgal and Seguin, 2006).

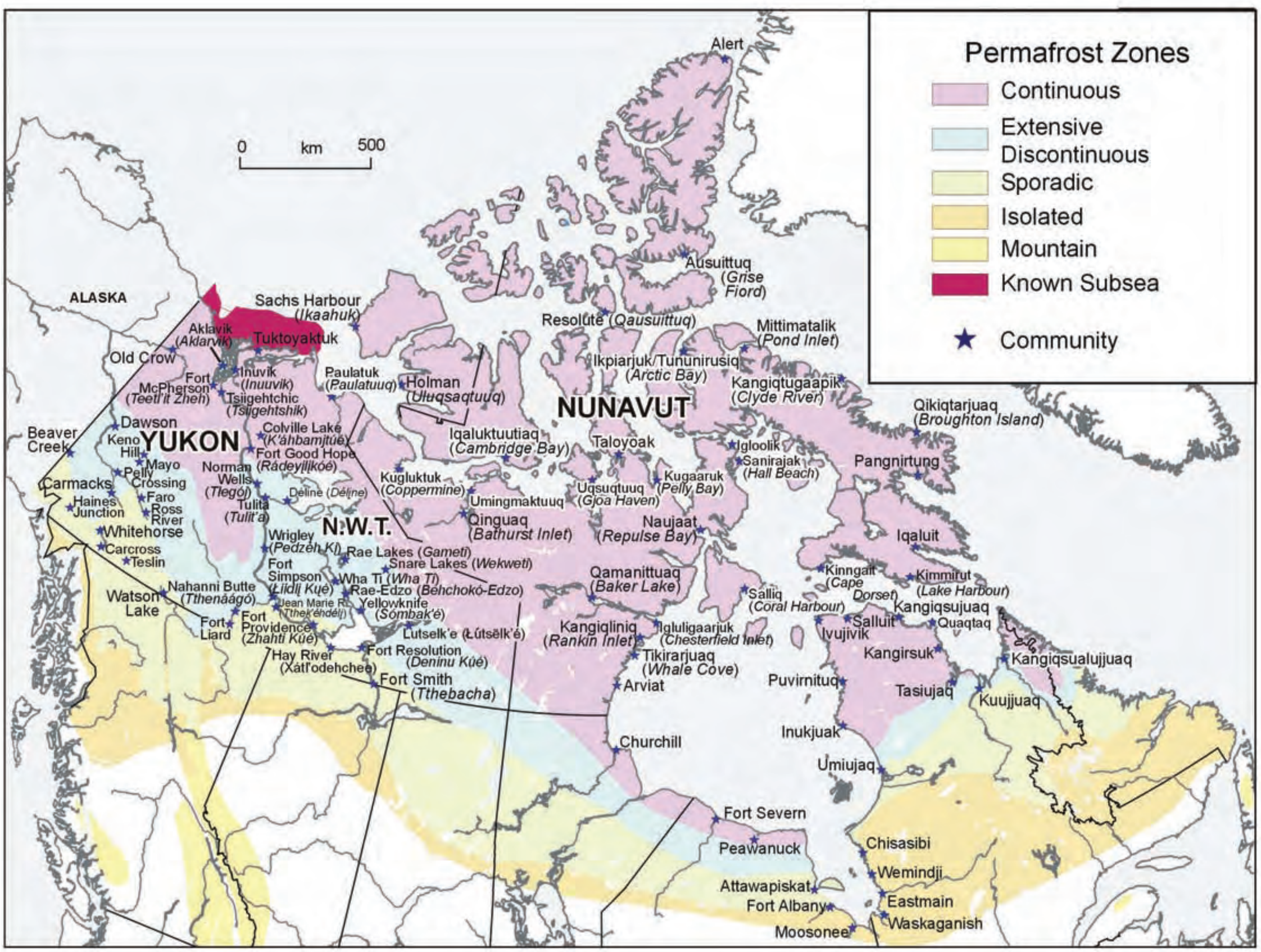


FIGURE 1: Political boundaries and communities of the Canadian North, superimposed on a map of permafrost zones (*derived from* Heginbottom et al., 1995; Furgal et al., 2003).

A number of recent scientific assessments have examined changes in climate and in socioeconomic, environmental and political conditions, and the impacts of these changes on Arctic regions (e.g. Intergovernmental Panel on Climate Change, 2001a, b, 2007a, b; Arctic Monitoring and Assessment Program, 2002; Arctic Climate Impact Assessment, 2004, 2005; Einarsson et al., 2004; Chapin et al., 2005). These works provide a strong foundation for evaluating the impacts of climate change on the services that the Arctic environment provides to local, regional and national populations and economies, and the vulnerabilities of human systems to change. This chapter builds on these previous assessments and adopts aspects of a vulnerability approach to climate assessment, primarily through a review of existing and projected exposures and adaptive capacity (*see* Chapter 2). In so doing, it moves towards a more comprehensive understanding of climate impacts and adaptation across the northern regions of the country.

In the context of this chapter, Northern Canada refers to the three territorial administrative regions (Yukon, Northwest Territories and Nunavut) north of latitude 60°N in Canada. Although these areas share many biogeographic characteristics, each has unique environmental, socioeconomic, cultural and political characteristics. Together, they form a vast region encompassing nearly 60% of Canada's landmass and many ecological zones, and feature nearly 100 communities of diverse languages and cultures (Figure 1).

Sections 1 and 2 of this chapter provide an introduction to climate change in the Canadian Arctic, a review of past and current conditions, and projections for future climate in the North. Section 3 discusses the impacts that climate change is expected to have on key components of the Arctic environment, many of which are the basis for livelihoods in northern communities. Section 4 discusses the implications of these changes for regional and national services, with a focus on identifying specific vulnerabilities of various sectors and systems. Section 5 then addresses implications for large and small northern communities, and provides perspectives from potentially vulnerable populations, such as Arctic Aboriginal groups. Finally, key conclusions are presented in Section 6.

This chapter draws on a number of different sources and methods to assess the current and potential future impacts of climate change across Northern Canada (*see also* Chapter 2). For topics presented in Sections 1 to 3, the chapter relies primarily on review and assessment of the published scientific literature. Where appropriate, authors have drawn on government reports and other 'grey' literature sources. For many of the topics presented in Sections 4 and 5, scientific research in the Arctic is still underway or just in its initial stages. As a result, these sections rely more heavily on grey literature and on documentation of local observations and traditional knowledge, and on the expert judgement of the assessment team.

2 REGIONAL OVERVIEW

2.1 PHYSICAL GEOGRAPHY

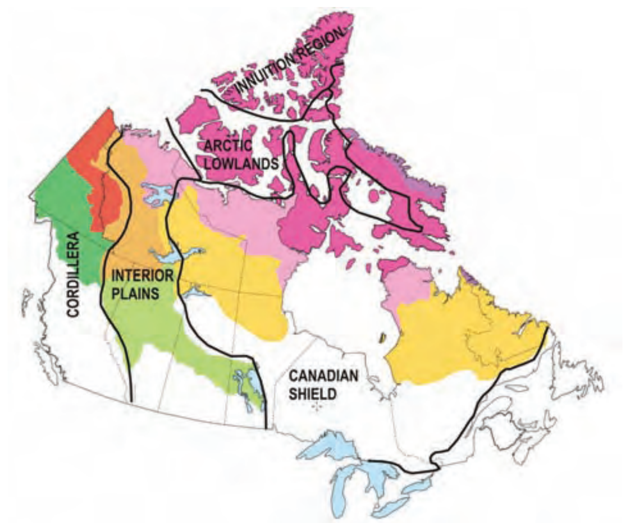
Physiography

Northern Canada includes five major physiographic regions: Canadian Shield, Interior Plains, Arctic Lowlands, Cordillera and Innuitian Region (Figure 2; Fulton, 1989). The Canadian Shield dominates the eastern and central portions of the Arctic mainland, and the eastern portions of the Arctic Archipelago. Rolling terrain contains a maze of lakes and rivers and a high proportion of exposed bedrock, while the mountainous terrain of Baffin Island features glaciers and ice fields. The Interior Plains lie to the west of the Canadian Shield and comprise a series of low-lying plateaus and extensive wetlands. The Arctic Lowlands, which form part of the Arctic Archipelago, lie between the Canadian Shield and the Innuitian Region. This region contains lowland plains with glacial moraines in the west and uplands with plateaus and rocky hills in the east. The complex terrain of the Cordillera lies immediately west of the Interior Plains and encompasses steep mountainous terrain with narrow valleys, plateaus and plains. Extensive ice fields and many of the highest peaks in North America are found in the St. Elias Mountains on the Yukon Pacific coast (Prowse, 1990; French and Slaymaker, 1993). The Innuitian Region encompasses the Queen Elizabeth Islands, the most northern and remote area of the country.

Consideration of physiography, together with regional differences in climate, vegetation and wildlife, allow definition of eight ecoregions in the North (Furgal et al., 2003), which are depicted and described in Figure 2.

Climate

Northern Canada is characterized by long cold winters interrupted by short cool summers. Precipitation is light and concentrated in the warmer months. Mean annual temperatures (1971–2000) range from approximately –1 to –5°C in more southerly regions of the Canadian Arctic to near –18°C in the



Ecozone	Landforms	Climate	Vegetation	Wildlife
Arctic Cordillera	Massive icefields and glaciers cap the rugged mountains	Very cold and arid	Largely absent due to permanent ice and snow	Polar bear, walrus, seals, narwhal, whales
Northern Arctic	Lowland plains with glacial moraines in the West, and uplands with plateaus and rock hills in the East	Very dry and cold	Dominated by herbs and lichen	Caribou, muskox, wolf, arctic hare, lemmings
Southern Arctic	Broadly rolling upland and lowland plains	Long, cold winters and short cool summers	Dwarf shrubs that decrease in size in the North	Muskox, wolf, arctic fox, grizzly and polar bear, caribou
Taiga Plains	Broad lowlands and plateaus, incised by major rivers	Semi-arid and cold	Dwarf birch, labrador tea, willows and mosses	Moose, woodland caribou, wolf, black bear, marten
Taiga Shield	Rolling terrain with uplands, wetlands and innumerable lakes	Subarctic continental climate, with low precipitation	Open forests and arctic tundra	Caribou, moose, wolf, snowshoe hare, black and grizzly bears
Taiga Cordillera	Steep, mountainous topography with sharp ridges and narrow valleys	Dry, cold winters and short, cool summers	Shrubs, mosses, lichens, dwarf birches, willows	Dall's sheep, caribou, lynx, wolverine
Boreal Plains	Level to gently rolling plains	Moist climate with cold winters and warm moderately summers	Spruce, tamarack, jack pine, white birch, balsam, poplar	Woodland caribou, mule deer, coyote, boreal owl
Boreal Cordillera	Mountain ranges with high peaks and extensive plateaus	Long, cold, dry winters and short, warm summers	Spruce, alpine fir, trembling aspen, white birch	Woodland caribou, Dall's sheep, mountain goat, marten, ptarmigan

FIGURE 2: Physiographic regions (*from* Fulton, 1989) and ecoregions of the Canadian North (Furgal et al., 2003).

islands of the high Arctic. On a seasonal basis, average winter temperatures range from around –37°C in the north to –18°C in the south, and summer values from +6 to +16°C (Environment Canada, 2006). Within these averages, there exists a high degree of variability on intraseasonal, interannual and interdecadal scales (Bonsal et al., 2001a).

Northern Canada receives relatively low amounts of precipitation, particularly at very high latitudes. Annual values typically range from 100 to 200 mm over the islands of the high Arctic to nearly 450 mm in the southern Northwest Territories. Higher precipitation occurs over the east coast of Baffin Island (600 mm/a) and the Yukon, where annual amounts can range from approximately 400 to 500 mm in southeastern areas to more than 1000 mm in the extreme southwest (Phillips, 1990).

Mean annual evaporation decreases from approximately 250 to 400 mm at latitude 60°N to less than 100 mm in the central portions of the Arctic Archipelago (den Hartog and Ferguson, 1978). Evaporation is greatest during the summer, especially in areas of low relief characterized by numerous bogs and lakes. On large deep bodies of water, such as Great Slave Lake, heat stored from the summer months continues to produce significant evaporation during the fall (Oswald and Rouse, 2004). North of the wetland and forested zones, transpiration decreases because of the lower vegetation density and the increasing proportion of mosses and lichens. However, the relative importance of evapotranspiration in the overall water balance tends to increase northward because of the more rapid decrease in precipitation. Moisture loss to the atmosphere also occurs through sublimation of snow and ice (Pomeroy et al., 1998).

Permafrost

The term 'permafrost' refers to earth materials that remain below 0°C for two consecutive summers. The permafrost region covers about half of the Canadian landmass (Figure 1). In more northerly areas, permafrost is continuous and may be several hundred metres thick (Heginbottom et al., 1995; Smith et al., 2001a). Southward, its distribution becomes discontinuous and patchy, and it is only a few metres thick at the southern fringe of the permafrost region. Subsea permafrost is also found offshore in parts of the Canadian Arctic.

The presence of permafrost and associated ground ice strongly influence the properties and performance of earth materials, landscape processes and surface and subsurface hydrology, and also control much land and property development. Permafrost restricts infiltration of water and has led to the formation of extensive wetlands and peatlands in areas of low relief (e.g. Brown et al., 2004; Mackenzie River Basin Board, 2004). Differential thawing of ice-rich permafrost results in hummocky or thermokarst topography. Runoff response in permafrost regions is controlled by the depth of the seasonal thaw (active) layer, which may exist for as little as 2 months.

Water

Eighteen per cent of Canada's fresh water is found north of latitude 60°N, primarily in lakes (e.g. Great Bear and Great Slave lakes) on the mainland Canadian Shield of the Northwest Territories and Nunavut (Prowse, 1990). This percentage does not include the extensive glacierized areas that total in excess of 150 000 km^2 on the islands of the Arctic Archipelago and 15 000 km^2 on the territorial mainland. Twenty per cent of

Canada's wetland area is found in the Arctic (Hebert, 2002). Runoff in the North is strongly influenced by snowmelt and/or glacier ablation (Woo, 1993).

Freshwater ice seasonally covers all lakes and rivers in the Northern Canada, with mean thickness in excess of 2 m on lakes at the highest latitudes. Duration of river-ice coverage is less than that of lake ice because rivers freeze up later in the year and are first to break up in the spring. Complete clearance of lake ice does not always occur in the far North, and multi-year ice develops on some lakes because of the brevity of the melt season. Multi-year ice accretions can also be found in the extreme North, where groundwater flow has contributed to the development of exceedingly thick surface ice.

Northern rivers are a major source of fresh water to the Arctic Ocean and contribute to the thermohaline circulation of the world's oceans, a regulator of global climate (Carmack, 2000). The dominant hydrological system in the North is the Mackenzie River, the largest river basin in Canada (1 805 200 km^2). The Yukon River drains approximately three-quarters of the Yukon as it flows northwest into Alaska (Prowse, 1990).

Marine Environment

Canada's northern seas consist of the Arctic Ocean, Beaufort Sea, Hudson Bay, Foxe Basin, Baffin Bay and various channels and straits between the islands of the Arctic Archipelago. The most striking characteristic of these waters is the seasonal to multi-year cover of sea ice, often several metres thick. Permanent pack ice occurs in the central Arctic Ocean. Open water develops in the late summer off the west coast of Banks Island and in the Beaufort Sea. Farther south, Hudson Bay freezes by the end of December and begins to clear in July. Overall, the distribution and thickness of sea ice are extremely variable. Of ecological importance are open-water areas during the winter, called polynas, that occur in the Beaufort Sea, Arctic Archipelago and northern Baffin Bay (Barry, 1993).

The Arctic Ocean is connected to the Atlantic Ocean via the Greenland and Norwegian seas, as well as by numerous channels through the Arctic Archipelago to Baffin Bay and the Labrador Sea. A dominant influence on the circulation of the Arctic Ocean and pack-ice cover is the Beaufort Gyre, which results in clockwise circulation and ice movement in the Canada Basin of the Arctic Ocean. Apart from landfast ice within archipelagos and along coastlines, the sea ice is in constant motion. The movement of the marine waters and presence of extensive ice packs exert a strong influence on the climate of Canada's northern landmass (Serreze and Barry, 2005).

2.2 SOCIOECONOMIC, HEALTH AND DEMOGRAPHIC CONDITIONS AND TRENDS

Population

A little more than 100 000 people live in Northern Canada. Nearly two-thirds of northern communities are located along coastlines. The majority of Arctic communities (inland and coastal) have less than 500 residents, and these small communities together represent only 11% of the total northern population (Bogoyavlenskiy and Siggner, 2004). Only the three territorial capitals, Whitehorse, Yellowknife and Iqaluit, have populations exceeding 5000. Although Whitehorse (population 23 511 in 2005) accounts for approximately 73% of the total population of the Yukon, more than two-thirds of people in Nunavut live in communities of less than 1000 people.

The region has experienced significant demographic, social, economic and political change in recent decades, with maximum growth associated with an increase in the non-Aboriginal population, related primarily to resource development and the increase in public administration (Bogoyavlenskiy and Siggner, 2004; Chapin et al., 2005). Most growth since the establishment of communities has occurred in the three main urban centres (Einarsson et al., 2004). Over the next 25 years, greatest growth is projected in the Northwest Territories (Table 1), partly as a result of industrial development associated with the Mackenzie Valley pipeline project and new mining developments.

The average age of northern residents is younger than for Canada as a whole (Table 2), and more than 50% of residents in Nunavut are less than 15 years old. Projections for the next 25 years indicate that the population in Northern Canada will remain

TABLE 1: Current (2005) and projected (2031) populations (thousands) for Canadian northern territories under a moderate population growth scenario (Statistics Canada, 2005b).

	2005 population (thousands)	Projected population in 2031[1] (thousands)	Mean annual growth rate[1] (rate per thousand)
Canada	32 270.5	39 024.4	7.3
Nunavut	30.0	33.3	4.0
Northwest Territories	43.0	54.4	9.1
Yukon	31.0	34.0	3.6

[1] The population growth scenario assumes medium growth and medium migration rates with medium fertility, life expectancy, immigration and interprovincial migration (*see* scenario 3 in Statistics Canada, 2005b).

TABLE 2: Current (2005) and projected (2031) median age and population dependency ratios for Canadian northern territories under a moderate population growth scenario (Statistics Canada, 2005b).[1]

Indicator	Canada current (projected)	Yukon current (projected)	Northwest Territories current (projected)	Nunavut current (projected)
Median age	38.8 (44.3)	37.6 (40.7)	30.8 (35.7)	23.0 (24.5)
Percentage aged 0–14	24.9 (23.5)	23.9 (25.0)	33.7 (31.3)	54.3 (50.9)
Percentage aged 65 and over	19.0 (37.7)	9.8 (30.8)	6.9 (23.5)	4.4 (9.1)
Total dependency ratio	43.9 (61.3)	33.6 (55.8)	40.6 (54.8)	58.7 (60.0)

[1] The population growth scenario assumes medium growth and medium migration rates with medium fertility, life expectancy, immigration and interprovincial migration (*see* scenario 3 in Statistics Canada, 2005b).

young, but have a growing proportion of people over the age of 65, increasing dependency ratios across the territories (Table 2).

Just over half of northern residents are Aboriginal and represent diverse cultural and language groups, from the fourteen Yukon First Nations in the west to the Inuit of Nunavut in the east, many of whom have been in these regions for thousands of years. Non-Aboriginal residents account for 15 and 78% of the total population in Nunavut and the Yukon, respectively (Table 3; Statistics Canada, 2001). The majority of small communities are predominantly Aboriginal in composition and are places where various aspects of traditional ways are still strong components of daily life.

Health Status

The health status of northern Canadians is lower than the national average, as measured by a number of health indicators (Table 4; Statistics Canada, 2001). All territories report lower life expectancy and higher infant mortality rates than the national averages, and these disparities are particularly pronounced in Nunavut (Table 4). The health status of Aboriginal northerners is, for many indicators, significantly below that of non-Aboriginal northern residents and the national average. Higher rates of mortality from suicide, lung cancer, drowning and unintentional injuries (i.e. accidents) associated with motor vehicle accidents occur in the North relative to the rest of the country (Table 5; Statistics Canada, 2001). Accidental deaths and injuries are likely associated, in part, with the increased exposure associated with the amount of time spent 'on the land' and the high level of dependence on various modes of transport for hunting, fishing and collection of other resources, which are a strong part of livelihoods and life in the North.

TABLE 3: Population characteristics of Canadian northern territories (Statistics Canada, 2001).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
Population density (per km^2)	3.33	0.06	0.03	0.01
Percentage of population that is urban[1]	79.6	58.7	58.3	32.4
Percentage of population that is Aboriginal[2]	3.4	22.9	50.5	85.2

[1] Urban areas are those continuously built-up areas having a population concentration of 1000 or more and a population density of 400 or more per square kilometre based on the previous census; rural areas have concentrations or densities below these thresholds.

[2] Aboriginal people are those persons who reported identifying with at least one Aboriginal group (e.g., North American Indian, Métis or Inuit) and/or those who reported being a Treaty Indian or a Registered Indian as defined by the Indian Act and/or those who were members of an Indian Band or First Nation.

Socioeconomic Status

The economies of many northern communities are a mix of traditional land-based renewable resource–subsistence activities and formal wage-earning activities. Estimates of Nunavut's land-based economy are between $40 and 60 million per year, with an estimated $30 million attributed to all food-oriented economic activity (Conference Board of Canada, 2005). However, the true value of such activities is difficult to measure, as they are significant contributions to the social fabric of communities and provide more than monetary benefits. The traditional economy is similarly important in other northern regions (Duhaime et al., 2004). For example, more than 70% of northern Aboriginal adults reported harvesting natural resources via hunting and fishing and, of those, more than 96% did so for subsistence purposes (Statistics Canada, 2001).

Wage-earning activities are often tied to non-renewable resource extraction or to public administration, which is the largest economic sector in many regions (e.g. 22% of territorial gross domestic product in the Yukon). Large-scale extraction of mineral and hydrocarbon resources is a significant component of the economy in some regions (Duhaime et al., 2004). Although only a fraction of the revenue from these resources remains in the regions where the activities are conducted, it nonetheless

TABLE 4: Selected health status indicators for Canada and its northern territories, 2001 (Statistics Canada, 2002).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
Public health spending per capita ($)	2535	4063	5862	7049
Life expectancy at birth (males, 2002)	75.4	73.9	73.2	67.2
Life expectancy at birth (females, 2002)	81.2	80.3	79.6	69.6
Life expectancy at age 65 (males, 2002)	17.1	15.6	14.5	16.3
Life expectancy at age 65 (females, 2002)	20.6	19.5	19.2	11.4
Infant mortality rate (per 1000 live births, 500 g or more, 2001)	4.4	8.7	4.9	15.6
Low birth weight rate (% of births less than 2500 g)	5.5	4.7	4.7	7.6
Potential years of life lost due to unintentional injury (deaths per 100 000)	628	1066	1878	2128
Self-reported health (percentage aged 12 and over reporting very good or excellent health)[1]	59.6	54	54	51
Physical activity (% aged 12 and over reporting physically active or moderately active)[1]	42.6	57.9	38.4	42.9

[1] Population aged 12 and over reporting level of physical activity, based on their responses to questions about the frequency, duration and intensity of their participation in leisure-time physical activity.

TABLE 5: Selected crude mortality rates (per 100,000 population) for Canada and its northern territories, 2001 (Statistics Canada, 2006).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
Major cardiovascular diseases	233.2	111.3	118.5	78.9
Acute myocardial infarction	58.9	6.5	35.5	10.3
Heart attacks	52.1	37.1	28	3.7
Lung cancer	48.2	73.2	61	209.5
Accidents, unintentional injuries	28.6	65.5	59.2	30.9
Transport accidents (motor vehicle, other land transport, water, air and unspecified)	9.9	19.6	16.6	27.5
Accidental drowning	0.8	9.8	7.1	<0.5
Intentional self-harm (suicide)	11.9	19.6	23.7	106.4

represents significant benefits in terms of wage-earning employment, significantly increasing average personal incomes. As a result, there are strong disparities in social and economic status between and within regions of the North (Table 6).

Food insecurity in Canada is highest in the three territories, where there are significantly higher numbers of female single parent households (Table 6; Statistics Canada, 2001, 2005a) and the cost of a standard list of grocery items can be up to three times higher than in southern Canada (Table 7; Statistics Canada, 2005a). In communities not accessible by road (e.g. Nunavut, Nunavik and Nunatsiavut and some smaller regions and communities in the Northwest Territories and Yukon), access to market food items is reliant upon shipment via air or sea, which significantly increases the price. Data from 2001 show that 68% of households in Nunavut, 49% of those in the Northwest Territories and 30% of those in the Yukon had at least one occasion in the previous year when they did not have the financial resources for sufficient food.

Chapin et al. (2005) reported that, despite the physical, economic and administrative challenges to health for some residents in the North, the deterioration of cultural ties to land-based and subsistence activities among Aboriginal people is the most serious cause of decline in well-being within circumpolar regions. The loss of connection to the land through changes in ways of life, loss of language and dominance of non-Aboriginal education systems are impacting health and well-being in various and long-lasting ways.

TABLE 6: Selected social and economic indicators for Canada and its northern territories (Statistics Canada, 2001, 2002).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
High social support[1]	-	78.0	74.5	58.1
Sense of belonging to local community (very strong or somewhat strong)	62.3	69.3	72.3	80.9
Proportion of census families that are lone female parent families	15.7	19.8	21.0	25.7
Personal average income (in dollars), 2000	29 769	31 917	35 012	26 924
Government transfer income as proportion of total, 2000	11.6	8.6	7.3	12.9
Percentage of long-term unemployed (labour force aged 15 and over)[2]	3.7	6.0	4.8	11.2
Percentage of population aged 25–29 that are high school graduates	85.3	85.4	77.5	64.7

[1] Level of perceived social support reported by population aged 12 and over, based on their responses to eight questions about having someone to confide in, someone they can count on in a crisis, someone they can count on for advice, and someone with whom they can share worries and concerns.

[2] Labour force aged 15 and over who did not have a job any time during the current or previous year.

TABLE 7: Cost ($) of Northern Food Basket[1] in 2006[2] for selected northern and southern locations (Indian and Northern Affairs Canada, 2007).

Location	Perishables	Nonperishables	Total food basket
Nunavut			
Iqaluit (2005)	114	161	275
Pangnirtung (Baffin) (2005)	127	165	292
Rankin Inlet (Kivalliq)	153	165	318
Kugaaruk (Kitikmeot)	135	187	322
Northwest Territories			
Yellowknife	65	94	159
Deline	148	161	309
Tuktoyaktuk	129	154	282
Paulatuk	180	167	343
Yukon			
Whitehorse (2005)	64	99	163
Old Crowe	169	219	388
Selected southern cities			
St. John's, NF (2003)	66	78	144
Montreal, QC (2005)	64	90	155
Ottawa, ON	72	93	166
Edmonton, AB	65	108	173

[1] The Northern Food Basket (NFB) consists of 46 items based on Agriculture Canada's Thrifty Nutritious Food Basket, which is used to monitor the cost of a nutritious diet for a lower income reference family of four (a girl age 7–9 years, a boy age 13–15 years, and a man and woman age 25–49 years). For a listing of NFB items go to <http://www.inac.gc.ca/ps/nap/air/Fruijui/NFB/nfb_e.html>.

[2] Unless otherwise identified

2.3 CLIMATIC CONDITIONS, PAST AND FUTURE

2.3.1 Past Climate

The high natural climate variability of the Arctic, together with the relatively sparse observational data sets, make it difficult to distinguish with confidence a climate change signal in the trends observed in the instrumental period of record (McBean et al., 2005). As few stations have data prior to 1950, estimates of trends and variability are limited to the second half of the twentieth century. For the period 1950 to 1998, there is a west to east gradient in mean annual temperature trends, with significant warming of 1.5°C to 2.0°C in the western Arctic and significant cooling (−1.0°C to −1.5°C) in the extreme northeast (Zhang et al., 2000). During more recent periods, all regions show warming . Trends were strongest in winter and spring. Annual and winter temperature anomalies and annual precipitation departures over four northern regions from 1948 to 2005 (Figure 3) show greatest warming in the Yukon and Mackenzie District (2.2°C and 2.0°C, respectively). In comparison, temperatures throughout Canada as a whole increased by 1.2°C over this same period (Figure 3a; all trends are significant at the 0.05 level). Many of the extreme warm winters in these regions have occurred during the latter part of the record, including 2006. For northwestern Canada in general, the period 1950 to 1998 exhibited a trend towards fewer days with extreme low temperature and more days with extreme high temperature during winter, spring and summer (Bonsal et al., 2001b).

Annual precipitation totals (1948–2005) increased throughout all of northern Canada, with the largest increases over the more northerly Arctic Tundra (+25%) and Arctic Mountain (+16%) regions (Figure 3c). The increase in high Arctic regions is evident during all seasons, with strongest trends in fall, winter and spring (*see also* Zhang et al., 2000). The magnitude of heavy precipitation

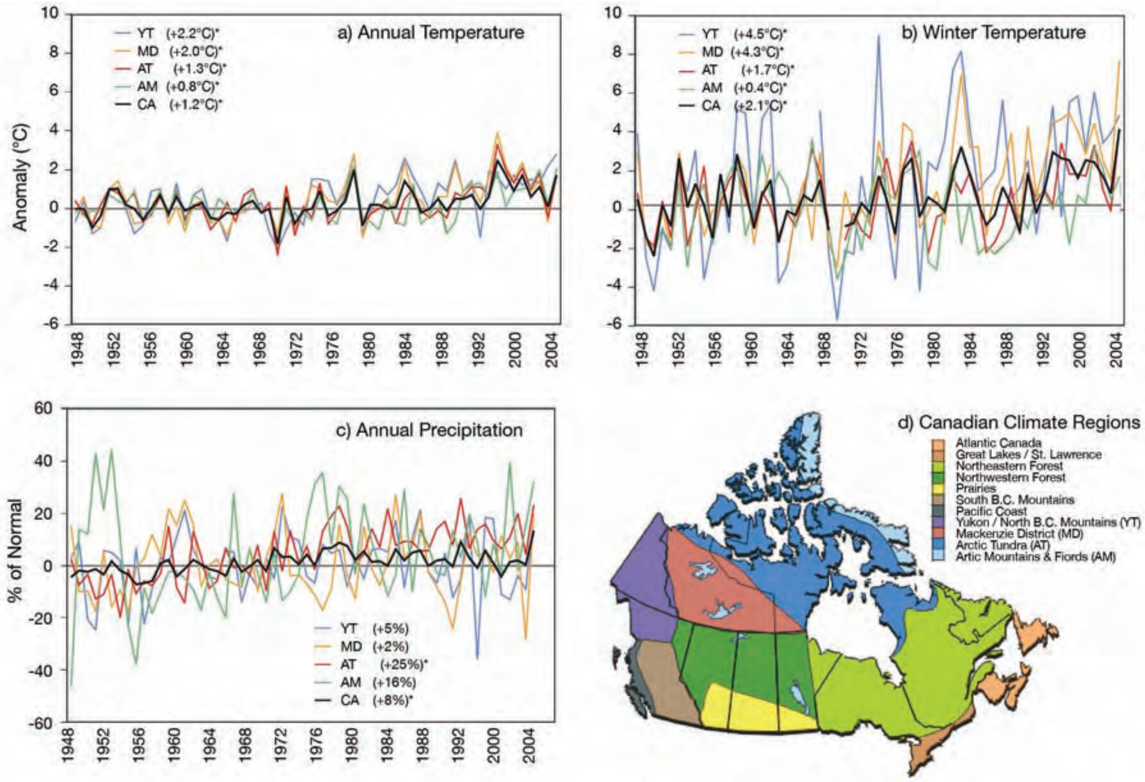


FIGURE 3: Regional temperature anomalies and precipitation departures from normal in the Canadian North: a) annual temperature; b) winter temperature; c) annual precipitation; d) Canadian climate regions. Linear trends over the period of record are given in parentheses. Asterisks signify significant trends at the 0.05 level. Data were obtained from Environment Canada's Climate Trends and Variations Bulletin.

events increased during the period of record (Mekis and Hogg, 1999), and there has been a marked decadal increase in heavy snowfall events in northern Canada (Zhang et al., 2001b).

The observed trends and variability in temperature and precipitation over northern Canada are consistent with those for the entire Arctic (McBean et al., 2005). Throughout the circumpolar Arctic (north of lat. 60ºN), annual air temperatures during the twentieth century increased by 0.09ºC per decade. This included a general increase from 1900 to the mid-1940s, then decreases until the mid-1960s and accelerated increases thereafter. Although most pronounced in winter and spring, all seasons exhibited an increase in temperature during the past several decades. In terms of precipitation, the entire Arctic has shown a significant positive trend of 1.4% per decade for the period 1900 to 2003. Largest increases generally occurred in fall and winter. Some studies have also suggested that the fraction of annual precipitation falling as snow has diminished, which is consistent with widespread temperature increases (McBean et al., 2005).

The pre-instrumental climate history of northern Canada is known from various natural archives, including tree rings, lake and marine sediments and glacier ice, and from the mapping and dating of glacial moraines and other geomorphic features (McBean et al., 2005). The climate of the North during the last 10 000 years has been characterized by relative warmth and remarkable stability (Figure 4). In the last 2000 years, climate has been characterized by multi-centennial oscillations ranging from mild conditions (similar to the modern era) to widespread persistence of relatively cool conditions (Figure 5). The general pattern of variability is believed to reflect primarily long-term natural fluctuations in circumpolar atmospheric circulation, expressed during the Little Ice Age (ca. AD 1500–1800) by increased southward penetration of cold Arctic air due to intensified meridional circulation (Kreutz et al., 1997).

Climate of the last 400 years has been characterized by warming and related changes over most of the Arctic, including retreat of glaciers, reduction in sea-ice extent, permafrost melting, and alteration of terrestrial and aquatic ecosystems (Overpeck et al., 1997). During the past approximately 150 years, however, it is evident that the rate and nature of change are unprecedented since the abrupt warming at the onset of the current interglacial period more than 10 000 years ago. This rapid acceleration in temperature increase over the Arctic is projected to continue throughout the twenty-first century (Kattsov et al., 2005).

2.3.2 Future Climate

Comparisons of the ability of seven Atmosphere-Ocean General Circulation Models (AOGCMs, *see* Chapter 2) to simulate the mean values and spatial variability of current (1961–1990) temperature and precipitation over four regions spanning Northern Canada revealed considerable inter-regional and

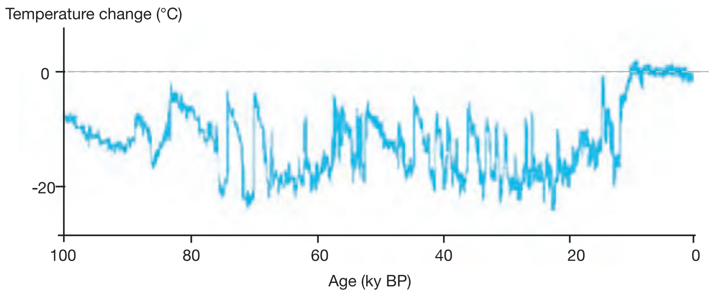


FIGURE 4: Temperature change (departure from present) during the past 100,000 years reconstructed from Greenland ice core (Ganopolski and Rahmstorf, 2001).

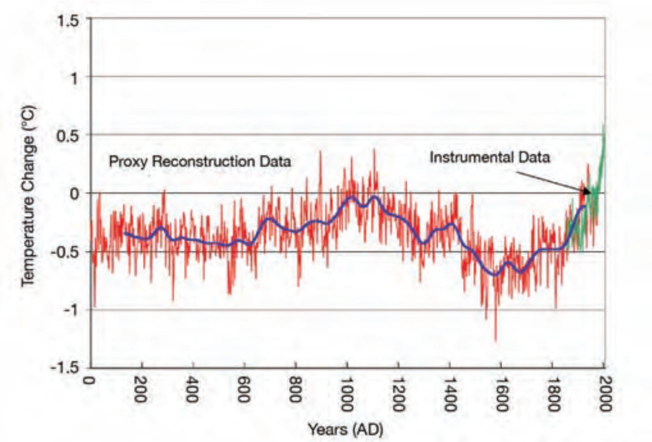


FIGURE 5: Reconstruction of northern hemisphere mean annual temperature, expressed as departures from the 20th century mean (Moberg et al., 2005).

seasonal variability, with temperature being more accurately simulated than precipitation (Bonsal and Prowse, 2006; *see also* Kattsov et al., 2005). The British Hadley Centre for Climate Prediction and Research (HadCM3), the German Max Planck Institut für Meteorologie (ECHAM4) and the Japanese Centre for Climate Research Studies (CCSRNIES) models best replicated annual and seasonal temperature values over all subregions, with the Canadian Centre for Climate Modelling and Analysis (CGCM2) and American National Centre for Atmospheric Research (NCAR-PCM) models having intermediate accuracy and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIROMk2) and American Geophysical Fluid Dynamics Laboratory (GFDL-R30) models being least representative. Collectively, the AOGCM temperature simulations displayed a similar degree of accuracy over all subregions. Conversely, precipitation was only accurately simulated by the majority of models over northern Quebec and Labrador. Annual and seasonal precipitation amounts were substantially overestimated by all AOGCMs in the western and central Canadian Arctic.

Climate Change Projections for the Canadian North

Scenarios of climate change with respect to the 1961–1990 baseline for the 30-year periods centred on the 2020s (2010–2039), 2050s (2040–2069) and 2080s (2070–2099) are presented in scatterplot and map format (*see* Appendix 1 of Chapter 2 for descriptions).

Scatterplots for the western and eastern regions of the North, divided at longitude 102°W, reveal little difference in projections between the two regions (Figure 6). For the 2020s, both western and eastern regions exhibit mean annual temperature changes concentrated near +2.0°C and precipitation increases ranging from 5 to 8%. Intermodel variability is greatest during the 2080s: median temperature changes for the western region are near +6.0°C but range from +3.5°C (NCAR-PCM B2 scenario) to +12.5°C (CCSRNIES A1FI scenario); most scenarios project a 15 to 30% increase in annual precipitation. Note that projections during all periods fall outside the range of modelled natural variability indicated by the grey squares in Figure 6.

Insights into projected seasonal climate change are evident in scatterplots for the 2050s (Figure 7). Despite considerable intermodel variability, the greatest temperature changes are projected to occur during winter. The eastern Canadian Arctic exhibits slightly higher projections of winter temperature than the west. Summer has the lowest projected temperature increases and the least amount of intermodel scatter. With respect to precipitation changes, values during winter range from near 0% over both regions to more than 40% in the east, with most scenarios projecting winter precipitation increases of 20 to 30%. During summer, all models project increases between 5 and 20%, with median values of 10%.

Spatial characteristics of annual and seasonal projected temperature changes over northern Canada indicate that the greatest temperature changes will occur at higher latitudes, particularly in the extreme northwest (Figures 8 and 9). Seasonally, the greatest temperature changes over the entire region are projected to occur during winter and fall. Annual and seasonal precipitation changes show considerable spatial variability in the Canadian Arctic, with the greatest annual percentage increases projected over more northerly regions (Figures 10 and 11). Seasonal maps for the 2050s show even higher variability, with minimum changes associated with decreases in precipitation over parts of the region during all seasons. The median projections tend to show greatest increases during winter and fall, particularly in more northerly regions.

The high degree of variability inherent in Arctic climate increases the uncertainty of projected changes in temperature and precipitation. Given the findings of Bonsal and Prowse (2006), it is recommended that a range of future climate projections be used when examining potential impacts across the North (*see also* Chapter 2). Individual model outliers, such as the CGCM2 low precipitation projections and the CCRSNIES high temperature increases (Figure 8), should be used with caution due to their inconsistency with other model projections.

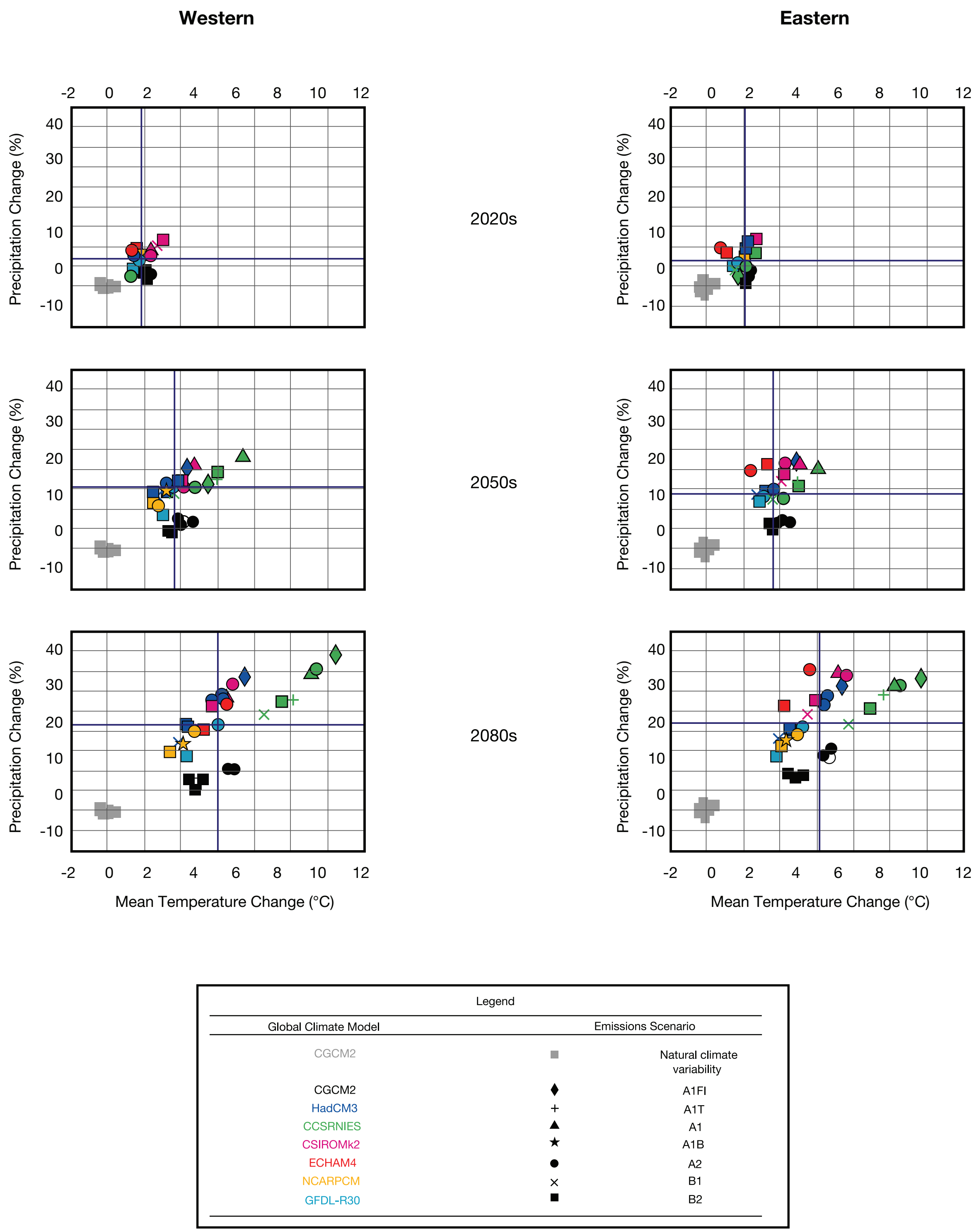


FIGURE 6: Scatterplots of projected mean annual temperature and precipitation changes in eastern (right) and western (left) regions of Northern Canada. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot (*see* Appendix 1 of Chapter 2 for details).

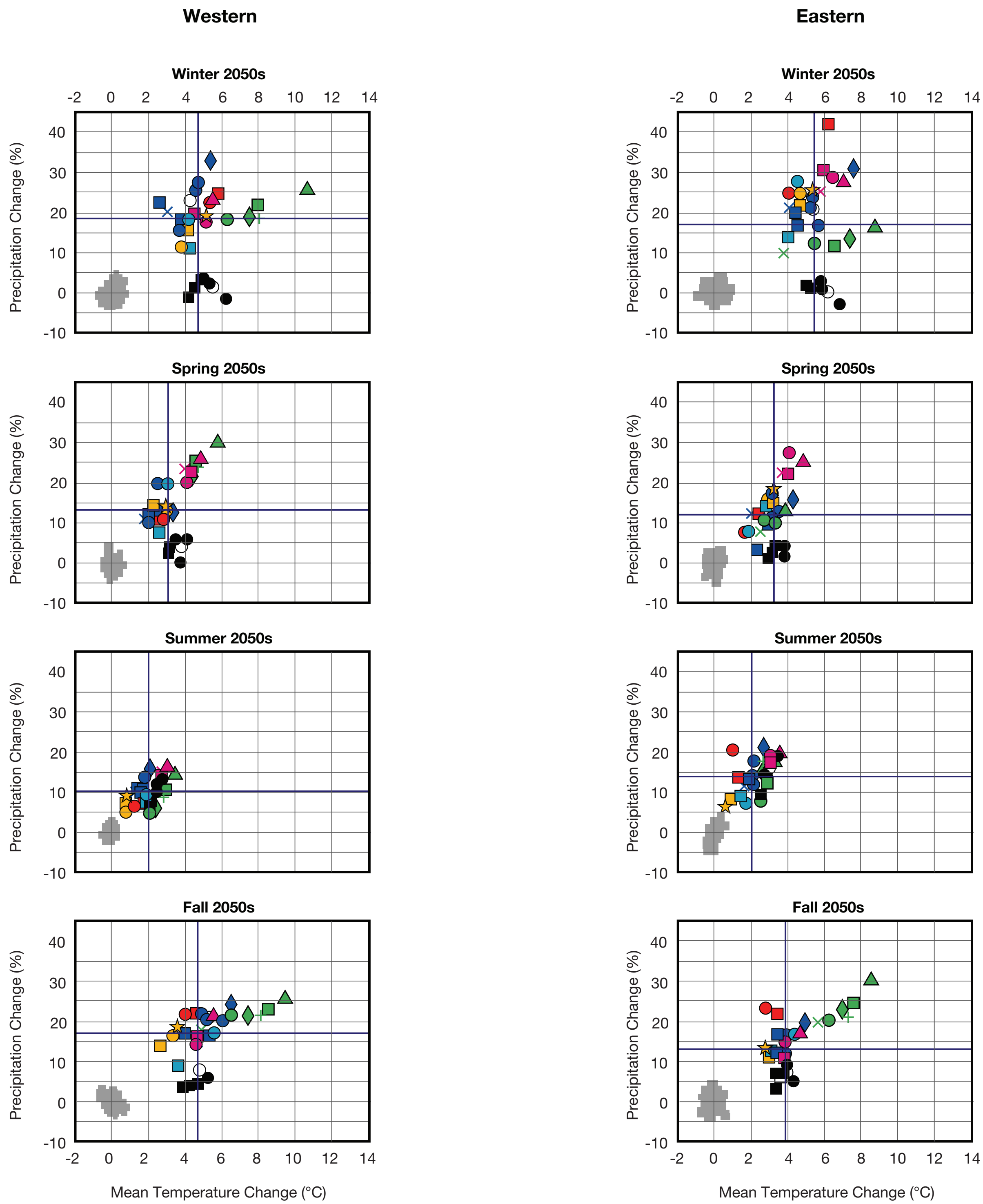


FIGURE 7: Scatterplots of projected seasonal temperature and precipitation changes for the 30 year period centred on the 2050s over eastern (right) and western (left) regions of Northern Canada. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot (*see* Appendix 1 of Chapter 2 for details).

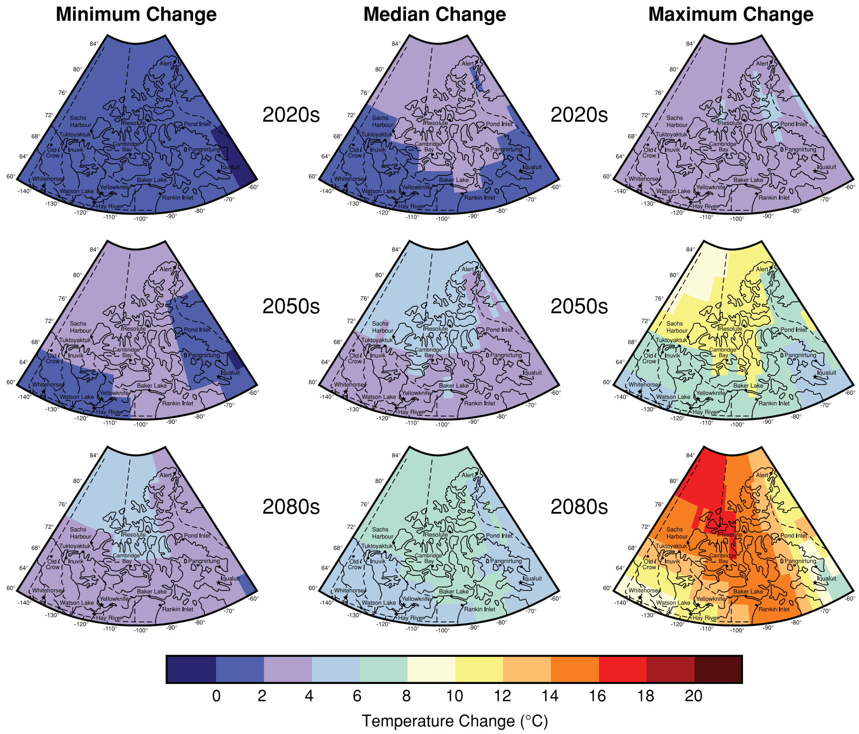


FIGURE 8: Maps of projected changes in mean annual temperature over Northern Canada.

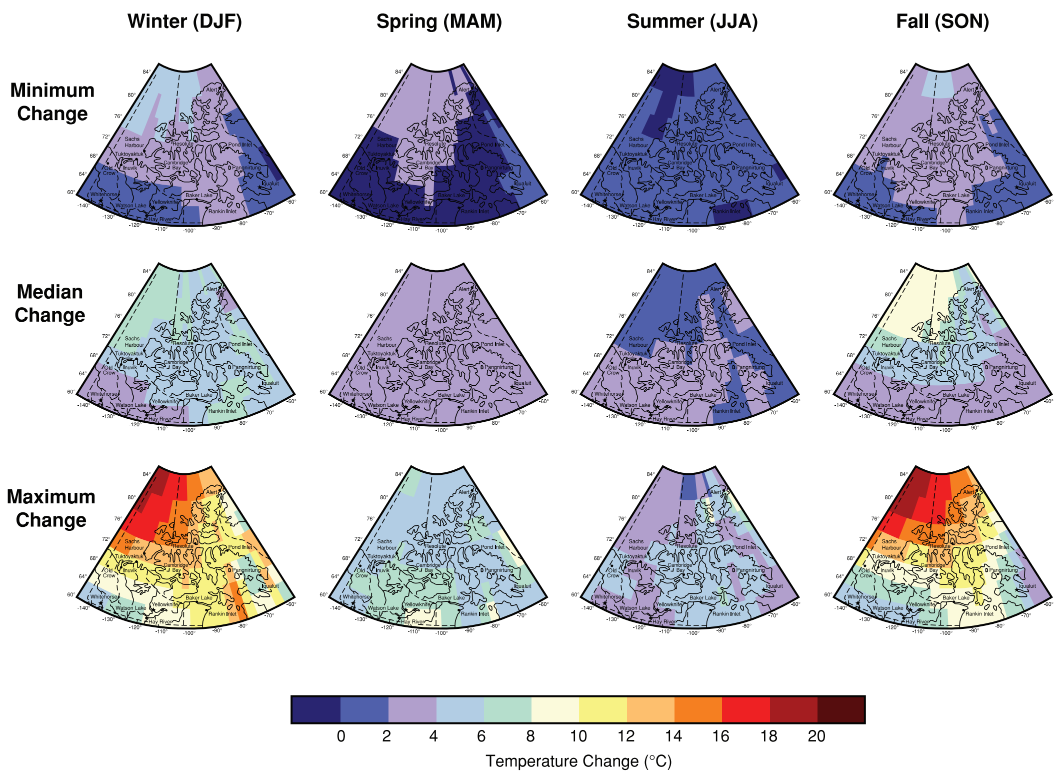


FIGURE 9: Maps of projected seasonal changes in temperatures for the 30-year period centred on the 2050s over Northern Canada.

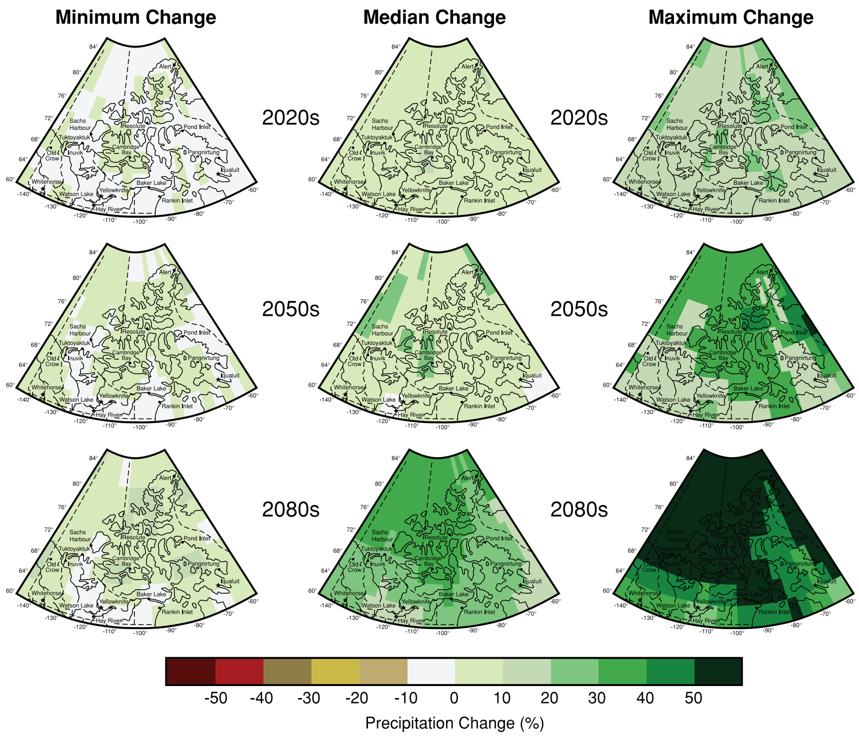


FIGURE 10: Maps of projected changes in mean annual precipitation over Northern Canada.

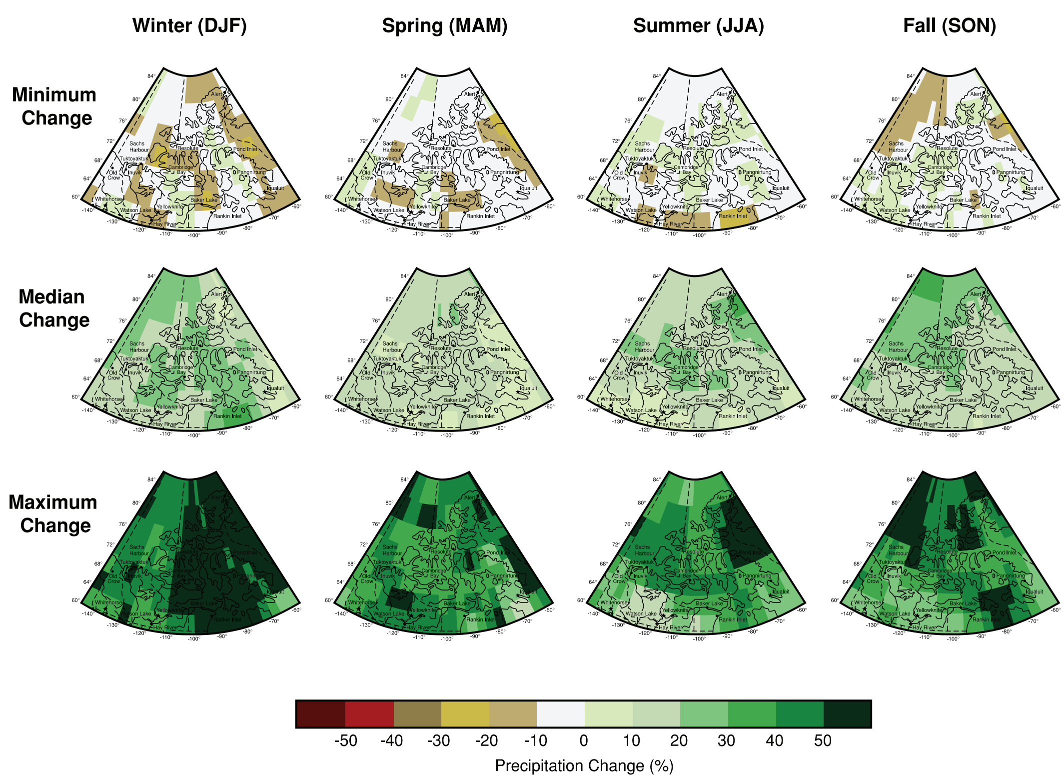


FIGURE 11: Maps of projected seasonal changes in precipitation for the 30-year period centred on the 2050s over Northern Canada.

3 IMPLICATIONS OF CHANGING CLIMATE FOR THE ARCTIC ENVIRONMENT

Of the many components that constitute the Arctic environment, the cryosphere is the most sensitive to the effects of changing climate. The cryosphere includes sea ice, seasonal snow cover, glaciers and ice caps, permafrost, and river and lake ice. All of these are effective indicators of climatic trends and important in various climate feedbacks through changes in energy, moisture and gas fluxes (e.g. Intergovernmental Panel on Climate Change, 2007a; Anisimov et al., 2007; Lemke et al., 2007; Trenberth et al., 2007). Terrestrial, freshwater and marine ecosystems will be impacted by changes in the cryosphere and by other aspects of climate change (Arctic Climate Impact Assessment, 2004, 2005). The following summary of several of the most important changes to the cryosphere and related ecosystems draws extensively on relevant chapters of the Arctic Climate Impact Assessment (Callaghan et al., 2005; Walsh et al., 2005; Wrona et al., 2005).

3.1 SEA ICE

Sea-ice areal coverage varies generally from 5 to 6 million km^2 at the end of the summer to 14 million km^2 at the end of the winter (Parkinson et al., 1999). Sea-ice thickness increases along the path of sea-ice drift and convergence from west to east (from the Siberian side of the Arctic to the Canadian Arctic Archipelago). The annual averaged area of sea ice in the Northern Hemisphere has decreased by 7.4% (3% per decade) between 1978 and 2003 (Johannessen et al., 2004). The annual maximum ice area has shrunk less rapidly, at about 2% per decade, whereas the annual minimum has declined more rapidly, at about 5.6% per decade. Much of the decrease in annual minimum ice area is a consequence of decline in the area occupied by multi-year ice, about 14% (6.7% per decade) between 1978 and 1999 (Johannessen et al., 1999). The loss of thick old floes from the polar pack has caused an obvious decrease in ice thickness in the central Arctic Ocean (Rothrock et al., 1999; Holloway and Sou, 2002).

The primary cause of reductions in ice thickness and in late summer ice extent has been an increased export of multi-year ice from the Arctic via Fram Strait during 1989–2003, not atmospheric warming (Rigor et al., 2002; Fowler et al., 2004; Rigor and Wallace, 2004; Belchansky et al., 2005). Data from Siberia and northern Canada during the second half of the twentieth century revealed no significant change in the thickness of first-year ice (Brown and Coté, 1992; Polyakov et al., 2003). Although the rate of decrease in late summer ice extent is consistent with the trend in multi-year sea ice (Comiso, 2002), this decrease has been especially large north of the Russian and Alaskan coasts, and considerably less within Canadian waters (Walsh et al., 2005). Even in the much cooler mid–nineteenth century, the extent of summer sea ice in the Canadian Archipelago, insofar as it is shown from ship tracks and the logbooks of explorers, was similar to the present (Wood and Overland, 2003).

All AOGCMs project decreases in sea-ice extent during the twenty-first century. Projections from the CGCM2 model indicate an ice-free Arctic during September by the mid–twenty-first century, whereas other models project ice-free summers in the Arctic by 2100. Therefore, although models differ in their projections of when ice-free Arctic summers can be expected, they agree in projecting that such conditions will eventually develop. By the year 2100, model projections of decreases in annual sea-ice extent vary from about 2 to 4 million km^2, and none of the model projections is close to ice free for the month of March. A modest future retreat of pack ice in winter is anticipated where it meets temperate oceans (i.e., in the Labrador, Greenland, Barents, Okhotsk and Bering seas).

Atmosphere-Ocean General Circulation Models have limitations when projecting future changes in sea ice. Scientific understanding of sea-ice dynamics is incomplete and the representation of the Arctic atmosphere-ice-ocean system in global climate models is relatively primitive. Also, the modelling of sea-ice climate is very sensitive to positive feedbacks between sea ice and climate, and small errors in representing this feedback can have large implications (Walsh et al., 2005). For example, the spatial grid of the modelled ocean is generally too coarse to represent the Canadian Arctic Archipelago (*see* Kattsov et al., 2005, Table 4.1). Therefore, the observational record of sea-ice extent in Canadian Arctic waters, and an understanding of the physical processes involved, become particularly important in projecting future changes in sea-ice regime.

3.2 SNOW COVER

In the Arctic regions, snow can account for up to 80% of annual precipitation. Snow insulates the ground, affecting the ground thermal regime and permafrost distribution (Marsh, 1990). Snow also influences surface radiation balances and water budgets (Gray and Prowse, 1993), and affects the habitat of terrestrial and aquatic biota (e.g. Adams, 1981).

From 1972 to 2003, average annual snow-cover extent in the Northern Hemisphere decreased by about 10%. The largest decreases occurred during spring and summer, which correlated with a large spring warming over northern land areas (Brown, 2000; Walsh et al., 2005). The largest changes in snow depth in northern Canada for the period 1946 to 1995 were decreases observed for the Mackenzie River basin (Brown and Braaten, 1998), although even more recent records (1955–1956 to 2002–2003) have also shown significant decreases in the mean and maximum depths of snow cover for the eastern and western Arctic stations (Environment Canada, 2007). Decreases in snow depth have been accompanied by reductions in spring and summer snow-cover duration and extensive reductions in spring snow-covered area (Brown et al., 2004).

Projected increases in temperature will decrease the length of time available for accumulation of a winter snowpack, thereby affecting the magnitude of the spring snowmelt, the major hydrological event of the year in most northern systems (Marsh, 1990). Although changes in mean annual snow cover are generally not expected to be very large for the present century, even for the period 2071 to 2090 when the projected changes vary from –9 to –18% (Walsh et al., 2005), the most pronounced changes in snow extent are expected in the shoulder seasons, November and April, the latter being most influential for spring runoff.

3.3 GLACIERS AND ICE SHEETS

The estimated total volume of land ice in the circumpolar Arctic is approximately 3.1 million km^3, which is equivalent to about 8 m of sea level (Dowdeswell and Hagen, 2004). Although the majority of this is contained on Greenland, Canada has major glaciers and ice caps in the high Arctic and Yukon. In general, glaciers and ice caps across the Arctic (apart from the Greenland Ice Sheet) show a retreat in glacier fronts and volume decreases since about 1920, although there are large regional variations (Walsh et al., 2005). For the Canadian high Arctic (data since about the 1960s), the monitored glaciers and ice caps on the Queen Elizabeth Islands (except the Meighen Ice Cap, which may be cooled from an increasingly open ocean nearby) show a weak but significant trend towards increasingly negative mass balances, primarily due to slight summer warming (Koerner, 2005).

The mass balance for all ice caps in the Canadian Arctic Archipelago over a five-year period at the end of the last century is estimated to be –25 km^3/a of ice, which corresponds to a global sea-level rise of 0.064 mm/a (Abdalati et al., 2004). Although this is significant, more pronounced ablation has been recorded for the Yukon-Alaska glacier network, where accelerated melting of 1.5 ± 0.5 mm/a has contributed almost 9% of the observed global sea-level rise during the past 50 years, and possibly as much as 3.2 mm/a during the past decade or so (Arendt et al., 2002). From the mid-1990s to 2000–2001, enhanced thinning of Yukon-Alaska glaciers likely equates to a sea-level rise almost double that estimated for the Greenland Ice Sheet during the same period (Rignot and Thomas, 2002).

Over the long term, the Greenland Ice Sheet is projected to make the largest contribution to future sea-level changes, but meltwater from glaciers in Alaska-Yukon are also projected to make a significant addition (Arendt et al., 2002; Meier and Dyurgerov, 2002). Future contributions from the high Arctic remain to be quantified but could also be significant (Abdalati et al., 2004). Glacier ablation also affects the magnitude and timing of river flows and drainage patterns (e.g. Clague et al., 2006).

3.4 PERMAFROST

Active layer and permafrost thermal-monitoring activities during the last two to three decades indicate that recent warming of permafrost has occurred in many regions of the Canadian permafrost zone (e.g. Broll et al., 2003; Couture et al., 2003; Kershaw, 2003; Smith et al., 2003, 2005), and that summer thaw penetration has increased in the 1990s (e.g. Smith et al., 2001b, 2005; Mackay and Burn, 2002; Nixon et al., 2003; Tarnocai et al., 2004). The magnitude of permafrost warming has varied both regionally (Smith et al., 2005) and temporally, with generally greater warming occurring in the western Arctic and later warming occurring in the eastern and high Arctic (Brown et al., 2000; Smith et al., 2005). The response of the active layer to extreme warm conditions, such as those of 1998 (e.g. Smith et al., 2001b), is consistent with that observed for other components of the cryosphere (Atkinson et al., 2006).

Approximately half of the area underlain by permafrost in Canada contains permafrost warmer than –2°C that could ultimately disappear under projected climate warming (Smith and Burgess, 2004; Figure 12). Where permafrost is thicker and colder, thickening of the active layer and warming and thinning of permafrost will likely occur. Projections of increases in the active-layer depth range from 0% to more than 50% during the next 50 years (Walsh et al., 2005). The largest percentage increases in Canada are projected for the Yukon. Degradation of continuous permafrost to discontinuous permafrost, and disappearance of discontinuous permafrost, are projected to occur at the southern boundaries of these permafrost zones. Thawing of permafrost has the potential to release large pools of carbon, which can act as feedback to the climate system (e.g. Tarnocai, 2006; Callaghan et al., 2005; Zimov et al., 2006).

Thaw sensitivity and settlement of permafrost have important implications for landscape stability and the performance of any overlying infrastructure. National-scale mapping by Smith and Burgess (2004; Figure 13) demonstrated that thaw sensitivity is moderate to high in about 50% of the present permafrost zones (excluding areas where massive ice is present and where thaw sensitivity may be higher than indicated). Regions where frozen soils are thaw sensitive include the silty clay and organic terrain in

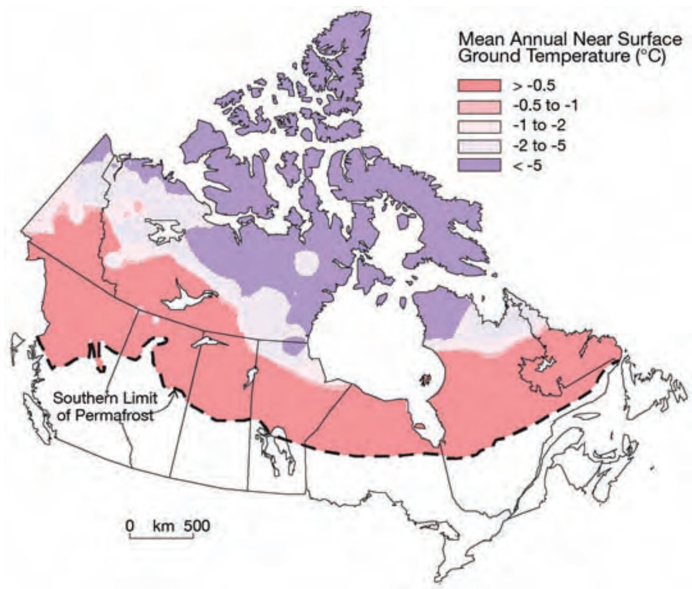


Figure 12: Variation in mean annual near surface ground temperature for the Canadian permafrost zone (Smith and Burgess, 2004).

the Mackenzie region and the peatlands of the northern Prairies and Hudson Bay Lowlands.

Frozen ground plays an important role in northern hydrology through its influence on infiltration, runoff and groundwater storage and flow. The implications of climate-induced changes in permafrost for northern hydrology have been summarized by Woo et al. (1992), Michel and van Everdingen (1994), Brown et al. (2004), Mackenzie River Basin Board (2004) and Smith and Burgess (2004). Active-layer thickening and permafrost degradation in response to climate warming can lead to increased infiltration, greater groundwater storage, lower spring runoff and increase in base flow (Woo et al., 1992). As a result, groundwater will play a greater role in future streamflow, with implications for surface-water quality (Michel and van Everdingen, 1994). As ground ice thaws, differential settlement and ponding may occur, leading to changes in drainage and the distribution of surface water. Thawing of ice-rich permafrost may also cause some lakes and wetlands to drain, leading to loss of fish and wildlife habitat (Labrecque and Duguay, 2001; Marsh and Neumann, 2001).

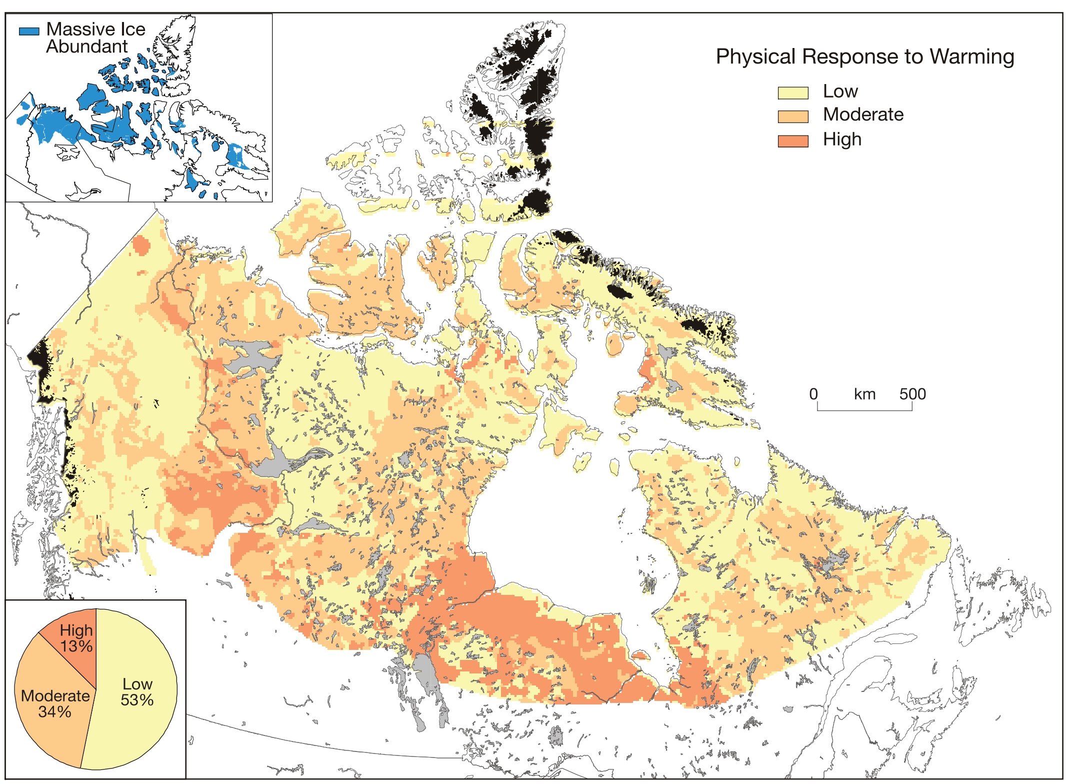


FIGURE 13: The relative physical response (thaw sensitivity) of permafrost to climate warming (Smith and Burgess, 2004).

3.5 RIVER AND LAKE ICE

Freshwater ice is responsible for the timing and severity of many hydrological extremes in northern systems, such as low flows and floods that are experienced during freeze-up and break-up periods (e.g. Beltaos and Prowse, 2001; Prowse and Carter, 2002). River ice is also a major factor in river ecology (Prowse and Culp, 2003), particularly in the Mackenzie Delta (Marsh and Lesack, 1996).

From 1846 to 1995, freeze-up and break-up trends for lakes and rivers in the Northern Hemisphere, including a long-term site on the Mackenzie River, show an average delay of 5.8 days per century in freeze-up dates and an average advance of 6.3 days per century in break-up dates (Magnuson et al., 2000). Canadian data for the period 1947–1996 show that western sites have a predominant trend towards earlier break-up dates, and that there has been a nationwide trend towards earlier freeze-up dates (Zhang et al., 2001a). Break-up–freeze-up trends are complex, however, and depend on the interval considered, but generally reflect trends in fall and spring air temperatures (e.g., Lacroix et al., 2005; Duguay et al., 2006).

Prowse and Beltaos (2002) outlined the complexities of freshwater-ice responses to changing climate. Although changes are difficult to predict (Bonsal and Prowse, 2003), future warming will likely lead to a shortened ice season and thinner lake- and river-ice covers, and cover composition (i.e. proportion of white ice) might be altered by increases in winter snowfall. Changes in winter snowfall will be a major factor in determining whether the severity of river-ice events, such as ice-jam flooding, increase or decrease (Walsh et al., 2005).

3.6 FRESHWATER DISCHARGE

Rivers flowing into the Arctic Ocean have low winter runoff, high spring flow rates (driven by snowmelt) and rain-induced floods in the summer and autumn. Snowmelt accounts for most of the flow in high-Arctic rivers and streams (Woo, 1990). Flow of large rivers, such as the Mackenzie, is strongly influenced by the hydrological regimes in their non-Arctic southern headwaters (Prowse et al., 2006).

Observed trends in river discharge vary regionally, with studies documenting both increases and decreases in flow since the 1960s. From 1964 to 2003, the total annual river discharge for 64 rivers draining into the Labrador Sea, Hudson Bay, Arctic Ocean and Bering Strait decreased by 10% (Dery et al., 2005). Between 1967 and 1996, Zhang et al. (2001a) found a trend towards increasing streamflow discharge for Chesterfield Inlet, whereas rivers in northern Ontario and Quebec showed a decrease in discharge. No significant trend was found in discharge from the Yukon River for the period 1964–2000 (McClelland et al., 2006).

Future projections, based on model scenarios for 2050, suggest increases in discharge. For example, Arnell (1999) concluded that annual discharge could increase between 12 and 20% relative to the 1961–1990 baseline for the Mackenzie River, and between 20 and 30% for the Yukon River. Broadly speaking, projections of future climate suggest that total annual discharge to the Arctic Ocean from Arctic land areas could increase between 10 and 20% by about 2050, with winter discharge likely to increase between 50 and 80%. It is also expected that 55 to 60% of annual discharge will enter the Arctic Ocean between April and July (peak runoff season; Arnell, 1999; Arora and Boer, 2001).

3.7 SEA-LEVEL RISE AND COASTAL STABILITY

Climate change will lead to rising sea levels in the Arctic Ocean (Proshutinsky et al., 2001) and other northern seas. Climate warming affects global sea level through ocean thermal expansion and additional water transfers to the ocean basins from melting glaciers and ice sheets. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007a) has projected a rise in global mean sea level (MSL) of between 0.18 and 0.59 m by 2100 (2090–2099 MSL relative to 1980–1999 MSL). The rise in sea level will not be uniform throughout the globe and some areas, including parts of the Arctic, may be subject to more rapid rates. In addition, the relative sea-level change along any coast (the trend measured by a tide gauge) is a combination of sea-level change and any vertical motion of the land surface. Vertical motion in the Arctic is dominated by ongoing postglacial isostatic rebound, with uplift in some places being as high as about 1 m per century. Other areas around the margins of the former ice sheets (the Beaufort Sea coast, the western margin of the Canadian Arctic Archipelago and a narrow band on eastern Devon Island and the east coast of Baffin Island) are subsiding (Forbes et al., 2004).

Sea-level rise increases the risk of flooding and erosion on Arctic coasts and may exacerbate other coastal hazards, such as ice ride-up and pile-up. In the western Arctic, sea-level rise and coastal erosion threaten cultural heritage sites (e.g. former habitations and burial sites) on the Yukon coast (e.g. Herschel Island), seasonal settlements (e.g. Shingle Point, YT) and coastal communities (e.g. Tuktoyaktuk, NT; e.g. Colette, 2007). Coastal erosion is a concern at other communities in the western Arctic, including Sachs Harbour and, to a lesser extent, Ulukhaktok, NT (Manson et al., 2005), while high water levels have been noted as an issue in Cambridge Bay, NU (Shirley, 2006). In the eastern Arctic, high-water and erosion concerns have been noted at Hall Beach, Iqaluit, Pond Inlet and Arctic Bay, NU, prompting discussions about adaptation options (Shirley, 2006; Ford et al., 2006a; Bhabesh Roy, Regional Engineer, Government of Nunavut, pers. comm., March 14, 2007). With the exception of Hall Beach, the affected communities are in areas of nearly stable or subsiding crust, where sea-level rise may overwhelm residual uplift or add to the rate of subsidence. Reduced sea ice, more open water and more energetic waves may be important in a number of places, including Hall Beach, where postglacial uplift and coastal emergence are ongoing.

The most severe flooding risks in low-lying communities, such as Tuktoyaktuk, are associated with large storm surges, which may reach more than 2 m above MSL (Manson et al., 2005). Storm waves during severe surges can cause rapid coastal retreat of 10 m or more in a single event. Sea-level rise will increase the upper limit of potential storm-surge flooding, and also increase the frequency of flooding at lower levels. Storm frequency in the Canadian Arctic shows no clear trends during the past 50 years (Atkinson, 2005). Erosion rates may be accentuated by warmer ground temperatures, deeper summer thaw and volume loss on melting of excess and massive ground ice where exposed in coastal cliffs (Forbes, 2005). Despite some suggestions of increased erosion rates in the western Arctic, including the Yukon and Alaska coast, a regional analysis for the southern Beaufort Sea detected no significant trend in areas of rapid erosion for the 1972–2000 time interval (Solomon, 2005). However, further warming, combined with sea-level rise and reduced sea ice, can be expected to maintain or increase the already rapid rates of coastal retreat along this coast.

3.8 TERRESTRIAL VEGETATION ZONES AND BIODIVERSITY

The extreme temperature gradients of the Arctic mean that plant communities will likely show a quick and strong response to temperature change. For currently widespread grass, sedge and flowering species, such as *Carex bigelowii/arctisibirica*, *C. stans*, *Dryas octopetala/punctata*, *Cassiope tetragonal* and the moss *Tomentypnum nitens*, continued temperature increase will result in higher productivity and abundance, and an expansion in range to the north. Other species found exclusively (hyperarctic; e.g. grasses — *Poa abbreviate*) or primarily (euarctic; e.g. polar willow — *Salix polaris*) at high northern latitudes, on the other hand, will likely respond to climate warming with a narrowing of their ecological niche (Callaghan et al., 2005).

Latitude and light regimes currently limit the distribution of some plant species, so these will not be able to migrate northward in response to increasing temperatures. Other important factors to be considered when projecting a whole-system response to climate change include: 1) the importance of carbon-nutrient interactions; 2) the interactions of carbon and nutrient cycles with temperature, water and snow cover; 3) the magnitude of dissolved organic and inorganic carbon losses in soil water; and 4) the magnitude and role of wintertime processes. The cumulative impacts of climate change on these factors will likely result in new communities, with different structures and species composition (Callaghan et al., 2005).

Vegetation-model projections for the present century indicate that, depending on location, the boreal forest will displace between 11 and 50% of all Arctic tundra (Harding et al., 2002; Skre et al., 2002). However, recent observations of the latitudinal treeline show a southward displacement, suggesting that a northward displacement, projected on the basis of changing climatic conditions alone, is unlikely (Callaghan et al., 2005). Increased disturbances, such as pest outbreaks and fire, will locally affect the direction of treeline response. In general, the treeline will show many different responses depending on the magnitude of temperature change, as well as changes in precipitation, permafrost conditions, forest composition and land use.

3.9 FRESHWATER ECOSYSTEMS

Climate change will affect the structure and function of Arctic freshwater ecosystems. Community and ecosystem attributes, including species richness, biodiversity, range and distribution, will be affected by changes in physical and chemical environmental parameters, and will consequently affect food-web structures and production levels (Rouse et al., 1997; Vincent and Hobbie, 2000; Poff et al., 2002; Wrona et al., 2006a).

The northern freshwater fish fauna of Canada consist of approximately 35 species, with another 15 anadromous species present (Richardson et al., 2001; Evans et al., 2002; Coad and Reist, 2004; Reist et al., 2006b). Relative to the South, low biological productivity is pervasive in aquatic ecosystems of the North, which is partly a result of low energy inputs. General knowledge of the biology of aquatic biota is low, particularly with respect to understanding potential connections with climate drivers and ecosystem structural and functional responses (Wrona et al., 2006a). Although large uncertainties remain in projecting species- and system-specific responses, it is likely that locally adapted Arctic species will disappear from certain areas when environmental conditions begin to exceed their physiological tolerances and/or ecological optima. The most vulnerable species are those with limited climatic ranges. Extinctions of Arctic species across their entire range are not expected, although some species will be marginalized geographically and/or ecologically (Wrona et al., 2006b).

Changing climate will also result in alterations to the geographic ranges of freshwater species due to loss of optimal habitat for 'native' Arctic species and the northward expansion of more southerly species (Wrona et al., 2006b). Ecological observations by trappers on the Peace-Athabasca Delta of the Mackenzie River system indicate that muskrat abundance is likely to increase in high-latitude lakes, ponds and wetlands due to the expected increases in the abundance of aquatic vegetation (Thorpe, 1986). Projected impacts and changes among marine species are discussed in Section 4.8.

4 IMPLICATIONS FOR ECONOMIC DEVELOPMENT AND ADAPTATION WITHIN KEY SECTORS

4.1 HYDROELECTRIC DEVELOPMENT

Demand for electricity is rising in all three territories, due to increasing population and heavy industry, such as diamond mines in the Northwest Territories and Nunavut. Alternative renewable energy sources, such as solar, wind, wood and even geothermal power, could help to meet some of the increasing demands for electricity, and territorial government agencies have indicated that they are committed to increasing renewable energy supply. There is already a significant dependence on hydroelectric generation, with seven large (>10 m in height) hydroelectric dams operating in the Yukon and Northwest Territories (Canadian Dam Association, 2003), along with a range of small, often privately owned, micro-hydro facilities. Further expansion of micro-hydro facilities is under consideration, but the major northern rivers still offer some of the largest potential (Prowse et al., 2004).

Changing climate will affect the capacity and operations of current and future hydroelectric developments, as well as affecting the demand for electricity. Projected increases in winter runoff from rainfall and enhanced winter snowmelt will lead to a decline in winter snow storage. Reservoir capacities on current and future developments may need to be expanded to offset this loss in natural storage. For some sites, this could be achieved by raising the height of the retention dam, thereby increasing storage area and volume. Where the landscape (e.g. relatively low relief) or operations (e.g. run-of-river power plants) preclude such an approach, adaptation measures may involve the construction of additional storage or facilities in other locations. The gradual loss of meltwater contributions from glaciers as they ablate and retreat will also need to be factored into future calculations of capacity.

Changes in the magnitude and seasonality of flows will also necessitate an increased focus on the safety of existing dam structures (World Commission on Dams, 2000). Of particular importance is a need to redefine the Inflow Design Flood (IDF: volume, peak, duration, shape and timing), commonly defined as the most severe inflow flood for which a dam and its associated facilities are designed (Zielinski, 2001). Concern that changing hydrological conditions will require reassessment of IDFs has already been noted for hydroelectric operations on the Snare River (Bruce et al., 2000). Changes in river-ice regimes will alter threats from downstream ice jamming (Prowse and Beltaos, 2002). Fuller assessment of the risks to hydroelectric facilities under a changing climate, however, requires hydrological models capable of predicting flow in northern regions that often lack flow gauges (e.g. Spence et al., 2005).

4.2 OIL AND GAS

The oil and gas industry involves exploration, extraction, production and delivery. Although changes in climate need to be considered for all four, exploration activities are likely to be most affected. In 2006, there were active and potential exploration activities in the Eagle Plains area of the Yukon and in the Cameron Hills, Fort Liard and Mackenzie Delta areas of the Northwest Territories. Some of the largest future potential reserves exist within the Canadian Arctic Archipelago (e.g. Drummond, 2006), and projected decreases in sea-ice cover may result in this area becoming a focus of additional exploration activity.

Thawing of permafrost and changes in snow cover will necessitate an increased focus on low-impact vehicles and/or changes in seasonal scheduling of exploration activities. The unpredictability of the winter season and the winter ice-road system will necessitate greater flexibility in scheduling of exploration and extraction activities. The greatest impact of changing climate on exploration, however, may relate to the use of in-ground sumps for drilling wastes. Disposal in sumps relies on the presence of permafrost to prevent subsurface movement of drilling wastes into the surrounding environment (French, 1980; Dyke, 2001). Increased ground temperatures resulting from increases in air temperature and/or snow depth (Jenkins et al., 2005) will increase the likelihood of contaminant transport. Alternate drilling-waste practices, including remote sumps, central processing facilities, down-hole injection or transportation of waste to outside the territories (e.g. Environmental Studies Research Funds, 2004), represent potential adaptations to climate change.

Offshore exploration drilling, such as that recently conducted by Devon Canada Corporation in the Beaufort Sea, will be affected by decreasing sea-ice cover. Future development may require design changes to drilling platforms to counter the effects of increased wave action and storm surges. One possible adaptation would be to increase the use of exploration drill ships (Croasdale, 1993).

Processing plants, one of the largest infrastructure components of production, must maintain their structural integrity over the multi-decade lifetime of a project. Design of production facilities needs to consider the effects of climate change on permafrost and ground stability. For facilities located on river channels or coasts, such as in the Mackenzie Delta region, additional factors such as river-ice break-up and ice-jam flooding, coastal erosion and sea-level rise must be considered. One recently proposed method to avoid some potential impacts involved using a barge for production facilities, rather than a land-based facility.

Oil and gas are delivered to markets through pipelines that are designed according to environmental conditions, many of which are influenced by climate. Currently there are three small pipelines operating in the North, but Imperial Oil Resources Ventures Limited Canada (Imperial Oil Resources Ventures Limited, 2004) submitted an application in 2004, as part of the Mackenzie Gas Project, to construct a large diameter (30-inch), high-pressure chilled pipeline to deliver natural gas from three fields in the Mackenzie Delta to northern Alberta. If approved, the Mackenzie Gas Project would be the largest industrial development in the Canadian Arctic. A number of geotechnical–climate change issues need to be addressed when constructing pipelines in permafrost zones, such as changes in the ground thermal regime, drainage and terrain stability, all of which may result from a warming climate over the lifetime of such a project (*see* Section 4.4). Experience from the Norman Wells pipeline illustrates the need to closely monitor the performance of both pipeline and right-of-way to determine if actions are required to maintain pipeline integrity and to minimize environmental impacts (e.g. Agra Earth and Environmental Limited and Nixon Geotech Ltd., 1999; Nixon and Burgess, 1999; Oswell, 2002). Adaptation, such as adding insulation or using thermosyphons to induce artificial cooling, may be required, especially along sensitive slopes.

4.3 MINING

There are currently three major mines operating in the northern territories: two diamond mines in the Northwest Territories and one diamond mine in Nunavut. Other projects have recently been approved or are in the advanced stages of environmental assessment and regulatory process in all three territories. Moreover, development of integrated land and marine transportation networks in response to projected declines in sea-ice cover is likely to stimulate further mine exploration and development (*see* Case Study 1). The principal mineral deposits include diamonds, gold, tungsten, silver, lead, iron, copper, zinc, nickel, coal, tantalum, niobium, lithium, cobalt, bismuth, uranium, beryllium and barium.

Resupply of existing mines is generally limited to winter periods and the availability of ice roads, whereas exploration activities are usually restricted to short summer periods, with access by air. Climate-change should be considered in the engineering design, during operations and in final closure and abandonment of mines, a planning process termed "designing for closure" (Milburn and Brodie, 2003). Of particular concern for mine access is the expected reduction in the availability of ice roads, which may necessitate development of all-season roads and/or water-based transportation systems (*see* Section 4.5.2). Another concern is the impact of climate change on permafrost and ground stability (*see* Section 4.4). The stability of waste-rock piles, tailings piles and tailings-containment impoundments often depends on maintenance of frozen conditions to ensure that contaminants and acid-metal leachate (or acid-rock drainage) are not discharged to the environment (Mine Environmental Neutral Drainage Program, 1997).

4.4 INFRASTRUCTURE

Permafrost and the ground ice it contains present challenges for the design, construction and operation of infrastructure in northern Canada (e.g. Smith et al., 2001a; Couture et al., 2003) and throughout the circumpolar region (Instanes et al., 2005). Although ice-bonded frozen ground can provide a strong foundation for infrastructure, thawing of the ground leads to loss of strength, as well as to settlement and instability. The removal of insulating vegetation/organic cover and other disturbances of the ground surface that generally accompany construction can significantly alter the ground thermal regime, resulting in warming and thawing of permafrost. Additional warming may occur due to heat generated by the structure itself (e.g. heated buildings and buried water, sewage or hydrocarbon pipelines). For larger structures, particularly such linear structures as runways, roads and pipelines that cover large distances, concerns include differential settlement due to spatial variations in soil characteristics and ice content, and slope instability resulting from permafrost thawing.

Climate warming presents an additional challenge for northern development and infrastructure design. In the short term (years), the impacts associated with ground disturbance and construction will be of far greater significance than those related to climate. The impacts of changing climate become increasingly significant over longer time scales (decades). For example, permafrost monitoring along the Norman Wells pipeline corridor has shown that the climate signal is largely obscured by the effect of disturbance of the ground surface related to right-of-way clearing (Burgess and Smith, 2003). This was especially true in the first 5 to 10 years following the disturbance, when permafrost was responding to an abrupt change in ground-surface temperature of 2 to 4°C, and large increases in thaw depth occurred. In contrast, changes in ground thermal regimes related to climate occur much more slowly, with changes in ground-surface temperature on the order of 2 to 4°C occurring gradually over a period of several decades.

Failure to take proper precautions in the engineering design of infrastructure in permafrost regions can have serious consequences. This was the case in the Yukon in the 1890s, when

CASE STUDY 1

Opportunities for Growth in the Mining and Transportation Sectors

Reductions in the duration and extent of sea-ice cover as a result of changing climate present new opportunities for marine transport in the Canadian Arctic (*see* Case Study 2). These opportunities, in turn, will potentially increase the competitiveness of both existing and planned resource development. Recent expansion of large-scale gold, base metal and diamond projects in the Slave geological province of the Northwest Territories and Nunavut, in concert with the prospect of a longer shipping season, greatly enhance the economic rationale for construction of a deep-water port along Canada's northern coastline. Such a port would ideally be fed by an all-weather road network, linking it with the inland mine sites.

One proposal currently under consideration calls for development of a port at the southern end of Bathurst Inlet, NU, capable of handling 50 000-ton vessels and smaller barges serving western Nunavut (Kitikmeot) communities (Figure 14; Kunuk and Stephens, 2003). The port development would be augmented by 211 km of all-weather gravel roads connecting Bathurst to Contwoyto (Figure 14). The economic benefits of such mining activities could be substantial (Kunuk and Stephens, 2003). Moreover, development of the port and road infrastructure would likely stimulate additional development at known mineral deposits along the transportation corridor, attract new mineral exploration and link Nunavut communities to an enhanced Arctic Ocean marine traffic system.

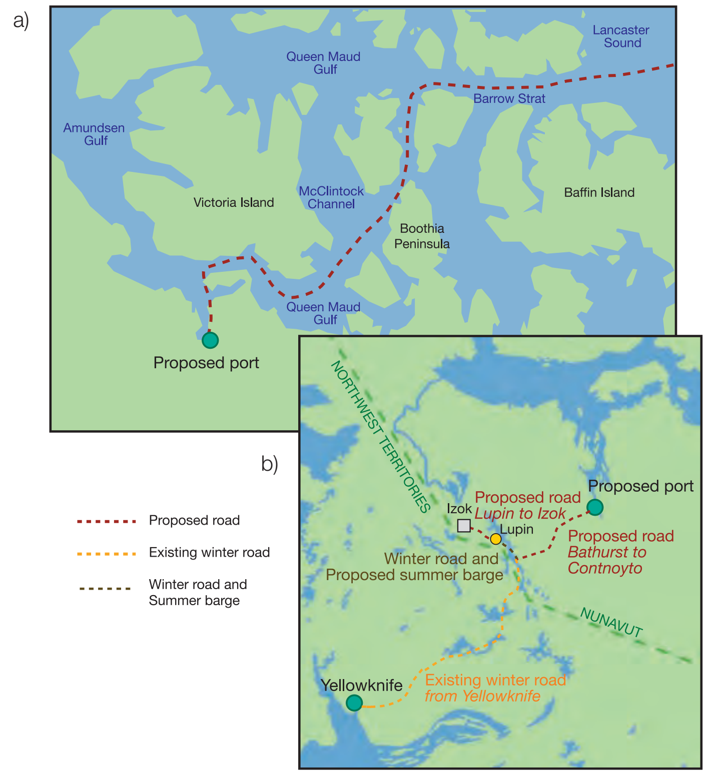


FIGURE 14: Proposed marine and land transportation network in northern Canada, consisting of a) shipping route to new port at Bathurst Inlet, showing average date of ice break-up; b) road network linking the port to resource developments in Nunavut (Bathurst Inlet Port and Road Joint Venture Ltd., 2003, 2007).

construction in Dawson proceeded with no consideration for the ice-rich alluvial sediments that underlay the site (Hughes, 1989). Subsequent thawing of ground ice and associated settlement damaged buildings, causing many to become uninhabitable, and made many roads impassable. Until the middle of the twentieth century, the presence of permafrost was often not recognized. Current engineering practices, however, have the objective of minimizing both disturbance to the terrain and the impacts on structures. Locations are generally chosen to avoid thaw-sensitive soils, and modern infrastructure is designed to preserve thaw-sensitive permafrost, limit thaw settlement and withstand thaw settlement where it does occur.

In the past, climate warming was not considered in engineering design, even for such large projects as the Norman Wells pipeline, which was designed in the early 1980s. Climate warming, however, has increasingly been recognized as a critical factor over the lifetime of major infrastructure projects in northern Canada, and has been incorporated in the engineering design and environmental impact assessments of such developments since the late 1990s. A risk-based project screening tool has been developed for considering climate change in engineered facilities and for gauging the level of analysis required for a particular facility (Environment Canada, 1998). A key factor in the screening process is the consequence of failure, so that the level of analysis is higher where the potential consequences of failure are greater (e.g. for a waste-containment facility).

For significant recent projects, such as water-retention or tailings-containment structures, large buildings and linear infrastructure such as pipelines and roads, climate change has been considered in the design phase. Indeed, such consideration is a requirement of the Canadian environmental assessment process (e.g. Lee, 2000; Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment, 2003). For example, climate warming was recognized as a concern over the lifetime of the Ekati diamond mine, which opened in 1998, and the potential impacts were considered in the design of the mine's frozen-core tailings dams (EBA Engineering Consultants Ltd., 1995). Other recent mining projects in the Northwest Territories and Nunavut, as well as the proposed Mackenzie Gas Pipeline, have considered climate warming in both their engineering design and environmental-impact assessment. Design of recently constructed large buildings, such as the Inuvik Regional Health Centre, has considered the impact of climate warming on the underlying permafrost (Hayley, 2004).

For structures built prior to the late 1990s, climate change may cause increased thaw depth and settlement beyond the original design values, potentially resulting in increased maintenance costs and remedial work to ensure structural integrity. Concerns about thaw settlement will be less where soils have low ice content, structures are founded on bedrock or constructed on deep foundations, and for smaller structures built on adjustable foundations. Structures on thaw-sensitive soils built on shallow foundations are at greatest risk. A pilot study of Norman Wells and Tuktoyaktuk, NT compiled digital databases of all available borehole geotechnical data and an inventory of infrastructure and foundation systems, to identify those structures where impacts of climate warming may be of concern (Couture et al., 2000, 2001; Chartrand et al., 2002). Similar databases could be compiled for other communities to aid climate change adaptation planning for existing structures, and to facilitate future land-use planning.

Of greatest concern in the context of changing climate are structures that need to maintain their integrity over periods of many decades to centuries, and/or have significant consequences associated with failure. Waste-containment facilities present a particular challenge, as facilities constructed several decades ago were not designed for the warmer conditions presently being experienced, and certainly did not consider the warmer conditions projected for the future. Failure of frozen-core dams on tailings ponds due to thawing and differential settlement, or thawing of tailings piles associated with climate warming, could result in contaminants being released into the surrounding environment, with subsequent impacts on ecosystems and human health. Remedial action may be required at these older sites, possibly including the use of thermosyphons to ensure the maintenance of frozen conditions, or modification to covers of land-based tailings piles to ensure that the tailings remain encapsulated in permafrost (e.g. BGC Engineering Ltd., 2003; Mine Environmental Neutral Drainage Program, 2004). New containment structures in the southern part of the continuous permafrost zone may need to consider techniques presently used in the discontinuous permafrost zone or in non-permafrost areas, such as the use of impermeable liners.

Adaptation of northern infrastructure to climate change will largely involve approaches already in use to reduce the impacts of ground disturbance. These include the use of pile foundations (that may need to be deeper to account for climate change), insulation of the surface (which may require thicker gravel pads), clearance of snow (to promote colder winter ground temperatures), adjustable foundations for smaller structures, and increased use of artificial cooling to ensure that foundation soils remain frozen (Couture et al., 2003). Recently developed techniques, such as air-convection embankments (Goering, 1998, 2003), may also be utilized. Where permafrost is thin, frozen ice-rich material may be excavated and replaced with thaw-stable material, or intentionally thawed by clearing vegetation and postponing construction for several years until the permafrost has completely degraded and the ground has settled (cf. Brown, 1970).

Finally, an important element of any adaptive response will be monitoring to: 1) evaluate infrastructure performance; 2) determine if changes in permafrost conditions deviate from those predicted; and 3) decide whether additional adaptation measures are required.

4.5 TRANSPORTATION

4.5.1 Marine Traffic

The many different types of sea ice and glacier ice in Arctic marine environments, in addition to such conventional factors as storm waves and shoals, present unique risks to transport. In turn, marine transport presents potential risks to the Arctic environment, including the possibility of fuel and cargo spills, disturbance of wildlife via vessel presence and underwater and airborne noise, and destabilization of fast ice that can disrupt both animal and human travel. The Canadian Arctic provides three routes for marine shipping: to the port of Churchill and other communities in Hudson Bay via Hudson Strait; to the Beaufort Sea via Bering Strait or the Mackenzie River; and through the Arctic Archipelago via the Northwest Passage. The Northwest Passage extends from Baffin Bay through Lancaster Sound to the Beaufort Sea via a number of alternative waterways (Figure 15; Case Study 2), including:

- the Viscount Melville Sound–M'Clure Strait route, which is the most heavily choked with ice;
- the Viscount Melville Sound–Prince of Wales Strait route, which is the next most difficult, but would be the preferred route for deep-draft vessels; this is the route that was taken by the SS Manhattan and the USCGC Polar Star; and
- the Prince Regent Inlet–Larsen Sound–Victoria Strait–Coronation Gulf route, which is the one most commonly used by Canadian Coast Guard icebreakers, commercial ships and smaller vessels, despite the somewhat narrow and difficult passage through Bellot Strait and the generally shallower waters; the route via Pell Sound to Larsen Sound provides an alternative should Prince Regent Inlet be ice bound; the most challenging ice conditions along either of these routes are usually found in Victoria Strait.

Another route through the Arctic Archipelago, not normally considered to be part of the NWP, is through Hudson Strait, Foxe Basin, Gulf of Boothia and Bellot Strait to Larsen Sound.

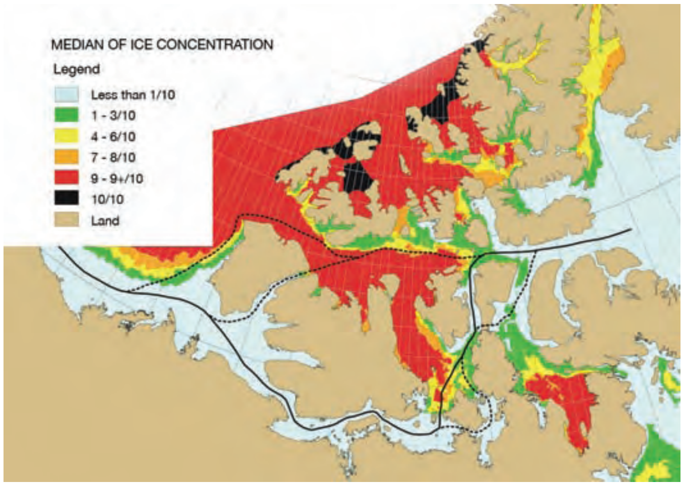


FIGURE 15: Typical routes for the Northwest Passage, superimposed on charted median ice concentration (1971-2000) for September 3. Colour indicates ice concentration in tenths (*courtesy of* Humfrey Melling, Fisheries and Oceans Canada).

Although strong tidal currents present navigational challenges in Fury and Hecla Strait, reduced ice in Foxe Basin and the much shorter sailing distance from the central Arctic to the south have made this an attractive route in recent years (J. Falkingham, Environment Canada, pers. comm, March 20, 2007).

Arctic seaways are used for the resupply of communities, export of raw materials and cruises for sovereignty, tourism or science. Resupply of communities generates the most predictable traffic. Ocean-going ships are generally used for the eastern sea-lift, while tugs and barges are better suited to the shallow waters of the western Canadian Arctic. Raw materials have been exported at times during the last 25 years. Although this type of use is presently dormant, there are expectations that at least two high-grade iron mines could start production and export of concentrate in the next few years. Scientific cruises to the Arctic have increased dramatically since 1990, and are frequently multitasked on Canadian Coast Guard (CCG) icebreakers that simultaneously serve other roles, such as navigational support and maintaining a Canadian government presence. In 2004, the CCGS Amundsen was outfitted specifically to support research on the impacts of climate change in the coastal Canadian Arctic, as part of the ArcticNet Network Centre of Excellence (ArcticNet, 2007), and now regularly traverses the Northwest Passage. Similarly, tourist cruises through the passage are becoming increasingly common. Although international shipping represents another usage of marine waterways, initiatives by the tanker Manhattan in 1969 and 1970 revealed the serious challenges to safe, cost-effective and predictable transshipment through the Northwest Passage.

Arctic Canada has never seen year-round shipping, nor is it expected to for decades to come (Wilson et al., 2004). Resupply presently begins in July and ends in October, and frequently requires support from Canadian Coast Guard icebreakers even within that window. Winter shipping is difficult relative to summer shipping due to that fact that winter ice is colder, and therefore stronger, than summer ice. In addition, winter ice is consolidated from shore to shore, without the cracks (leads) that make it easier for a ship to pass through. Additionally, near-total darkness and bitter cold make winter navigation exceedingly hazardous. Multi-year ice, which does not soften much in summer, is a serious hazard to ships year round. At high concentrations, multi-year ice is a barrier to all but the most powerful icebreakers, even in summer. In winter, it is effectively impenetrable.

The most obvious impact of changing climate on Arctic marine transportation will be an increase in the length of the summer shipping season, with sea-ice duration expected to be 10 days shorter by 2020 and 20–30 days shorter by 2080 (Table 8; Loeng et al., 2005), although there is no expectation of an ice-free Arctic in winter. Even though a longer shipping season appears beneficial, ice conditions in all areas of the Canadian Arctic are highly variable from year to year and will likely remain that way. Hence, there will continue to be summers with ice conditions either more benign or far worse in the future.

Future trends in the sea-ice environment of northern Canada will likely differ somewhat from those outlined in Section 3.1 for the Arctic as a whole. The persistent and preferential occurrence of multi-year ice on the Canadian side of the Arctic (Rigor and Wallace, 2004) is likely to present challenges to northern shipping for at least several decades. At present, much of the ice cover of the Canadian Arctic Archipelago is land-locked for up to 10 months each year, and drifts slowly southward from the Arctic Ocean to the Northwest Passage (Melling, 2002). The longer thaw season of a warmer climate will promote a longer period of weakness in the pack, resulting in more rapid drift of Arctic Ocean multi-year ice through the Arctic Archipelago and into the Northwest Passage. This will tend to maintain, or even increase, the hazard to shipping in the Northwest Passage as long as there is a supply of ice from the Arctic Ocean.

Hudson Bay and the Beaufort Sea, because of their very different ice regimes, are both likely to see increased numbers of transits by large ships. A longer summer shipping season will likely encourage shipping through the port of Churchill on Hudson Bay; in the Beaufort Sea, it will increase the appeal of offshore hydrocarbon development and of shipping oil and gas in large ships westward and through Bering Strait. Increased wind fetch will increase risks from waves and surges to barge traffic, coastal infrastructure and small-boat use by northern residents. The increase in marine traffic and some hazards are likely to increase demands for:

- updated navigational charts;
- marine-weather forecasting, including storm waves and surges;
- ice reconnaissance and forecasting;

CASE STUDY 2

The Future of the Northwest Passage

The Northwest Passage is a series of seven major channels running through the islands of Canada's Arctic Archipelago (Figure 15). Considerable debate has emerged during the past two decades regarding the future of the Northwest Passage, mainly because of the projection of future reductions in sea-ice cover. Historically, multi-year sea ice has entered the archipelago via the small channels along the northwestern side of the Queen Elizabeth Islands and has grown in situ in Viscount Melville Sound, to be exported eastwards and westwards (Figure 15; Melling, 2002). In heavy ice years, multi-year pack ice extends southward to the Tuktoyaktuk Peninsula.

An ice-free Northwest Passage would create a significant economic opportunity for shipping companies, as it provides a route that is about 7000 km shorter for travel between Tokyo and London than using the Panama Canal. It also offers the advantage of allowing passage of ships that cannot fit through the canal systems and, for example, are forced to travel around Cape Horn. The capacity to accommodate even supertankers was demonstrated with the 1969 passage of the SS Manhattan (modified for ice breaking service) between the oilfields of Prudhoe Bay and the east coast of the United States. In some instances, the shelter from storms provided by the archipelago, compared to the open Pacific shipping routes, is another advantage of the Northwest Passage, as evidenced by the successful 1999 towing of a dry dock from Vladivostok, Russia eastward through the passage en route to its final destination of Bermuda (Huebert, 2001).

An alternative for cross-Arctic transit, the northern coast of Eurasia, is expected to open before the Northwest Passage, since the remnant ice pack will tend to shift towards North America. Furthermore, significant variability in ice conditions and resulting shipping hazards will likely persist in the Northwest Passage, even in the warmest summers. The persistence of such hazards might reduce interest in use of the Northwest Passage for commercial shipping (e.g. Griffiths, 2003).

While international disputes about Canada's claims to the lands and islands in the Arctic Archipelago were largely resolved in the 1930s, the Northwest Passage remains the focus of international discussion. The two opposing views are that: 1) the Northwest Passage is part of Canada's 'historic internal waters' found within straight baselines enclosing the archipelago, giving the country unfettered authority to establish controls and conditions to protect its safety, security, environmental and Inuit interests; and 2) the Passage is an international strait through Canadian territorial waters where the right to regulate is subject to some limitations. As summarized by Pharand (2007), Canada has exercised jurisdiction over shipping in the Passage through the creation of an arctic shipping regime consisting of a number of laws and regulations (18 in the case of passenger vessels), including the oldest of these laws, the Arctic Waters Pollution Prevention Act (AWPPA) of 1970. Canada led the effort for the inclusion of Article 234, known as the 'Arctic Exception', in the 1982 United Nations Convention of the Law of the Sea (UNCLOS). Article 234 allows coastal states to enforce laws relating to maritime pollution out to 200 nautical miles when virtually year-round ice creates exceptional navigational hazards (Charron, 2005; Barber et al., 2006), and legitimized Canada's authority to enforce a very strict anti-pollution regime. As customary international law developed, Canada also amended its legislation to extend the definition of the territorial sea (and hence coastal state rights) from 3 to 12 nautical miles (Killaby, 2006). This is significant, given that the narrowest point of the Northwest Passage is less than 24 nautical miles across (*see also* Barber et al., 2006).

As long as ice conditions remain hazardous and unattractive to commercial shipping, there is little incentive for any country to challenge the Canadian position. However, changing climate and associated changes in sea-ice regimes may increase pressure to designate the Northwest Passage an international strait. Enhanced marine traffic through the Northwest Passage is likely to lead to a number of additional issues that will need to be addressed by Canada and northerners. These include the use of northern coastlines for illegal activities (e.g. smuggling), spread of new and exotic species and diseases, and increased marine-traffic accidents and related threats from pollution (e.g. Kelmelis et al., 2005). Adaptive responses to such issues may include increased Arctic surveillance and policing, and additional enforcement of environmental standards and regulations (e.g. Huebert, 2003; Charron, 2005; Barber et al., 2006). The reduction in sea ice and increased marine traffic would have significant negative impacts on the traditional ways of life of northern residents, but also offer opportunities for economic diversification in new service sectors supporting marine shipping. It has even been envisaged that some settlements, such as Tuktoyaktuk and Iqaluit, could become important ports of call in the future (Huebert, 2001), leading to significant socioeconomic changes in these communities.

TABLE 8: Summary of projected changes in ocean conditions (Loeng et al., 2005).

	2020	2050	2080
Sea ice:			
Duration	Shorter by 10 days	Shorter by 15–20 days	Shorter by 20–30 days
Winter extent	6–10% reduction	15–20% reduction	Probable open areas in high Arctic (Barents Sea and possibly Nansen Basin)
Summer extent	Shelves likely to be ice free	30–50% reduction from present	50–100% reduction from present
Export to North Atlantic	No change	Reduction beginning	Strongly reduced
Type	Some reduction in multi-year ice, especially on shelves	Significant loss of multi-year ice, with no multi-year ice on shelves	Little or no multi-year ice
Landfast ice:			
Type	Possible thinning and a retreat in southern regions	Probable thinning and further retreat in southern regions	Possible thinning and reduction in extent in all Arctic marine areas

- icebreaking support services and search-and-rescue capability;
- marine-traffic surveillance, control and enforcement;
- coastal facilities for fuelling and loading cargo;
- ice-class vessels for new sea conditions and cargos (e.g. barges, tugs, tankers and bulk carriers); and
- specialized crews for the Arctic trade.

Climate change is also expected to change the nature of the risks to shipping traffic in many areas of the Arctic. Rather than being confronted with extensive ice pack that necessitates icebreaker escort, ships in the future will see easier navigating conditions in general, punctuated by frequent occurrences of ice pressure in congested straits, multi-year ice in low concentrations that is difficult to detect, and extreme variability of conditions from one year to the next. As such, there will be a need for continued, if not increased, icebreaking support for increased and more broadly dispersed shipping activities.

4.5.2 Freshwater Transport

Historically, open-water transport on rivers and lakes was the main method of transporting goods to northern communities using, for example, the main stem and major tributaries of the Yukon and Mackenzie river systems. The Mackenzie remains a major freshwater transportation system, with goods (largely bulk fuel, equipment and general cargo) that originate from the northern railhead at Hay River being transported via barge–tug boat trains across Great Slave Lake to riverside communities and ultimately to Tuktoyaktuk. Here, barges are uncoupled and transported by ocean-going tugboats to as far east as Taloyoak on the Boothia Peninsula and as far west as Barrow, Alaska.

An increase in the river ice-free season as a result of climate warming will expand the potential period of operation for Mackenzie barges from its current four-month season between mid-June and mid-October. Lonergan et al. (1993), for example, projected that a 6 to 9 week reduction in the ice season could result in a 50% increase in the use of barge-based transport along the Mackenzie, although this figure pales compared to the 600% increase in transport forecast to occur in the next few years as a result of the Mackenzie Gas Project in the Mackenzie Delta (Neudorf, 2005; *see* Section 4.2). However, these forecasts do not include consideration of how climate-related changes in lake and river levels (cf. Kerr, 1997; Blanken et al., 2000; Rouse et al., 2003) could affect the use of flat-bottomed barges in an already relatively shallow river system, particularly during late summer low-lake and low-flow periods. Upstream flow regulation is another factor influencing low-flow levels and has contributed to increasingly difficult river navigation during the last half century (e.g. Gibson et al., 2006).

Dredging selected portions of the channel may offer localized, short-term solutions to decreased water levels but is unlikely to be a practical long-term adaptive measure, given the rapidly changing bed morphology of the Mackenzie and other northern river systems (e.g. Prowse, 2001). Upstream flow regulation could be used to increase late-summer flows but would, in turn, negatively impact hydroelectric-generating potential. The most obvious adaptation measure to increasingly difficult river transport is an increase in all-season road networks, although there would be significant engineering challenges in constructing and maintaining such roads in permafrost terrain (*see* Section 4.4).

4.5.3 Winter Roads

Although lake and river ice have historically served as natural transportation routes, and modern engineering has led to increasingly sophisticated methods of winter-road construction and expansion, little scientific literature exists about the effects of climate on these systems. The most relevant information, even about the basic winter-road network, is contained only within consultant and local government reports or news media. Since the 1950s, the seasonal road network has evolved into a large suite of private and public lake and river crossings linking northern communities and all-season road systems. Ice roads and ice bridges that are constructed and maintained each winter provide a relatively inexpensive way to supply northern communities and industry, particularly the rapidly expanding mining sector that relies on ice roads to move heavy equipment, materials and fuel for the remainder of the year. Additionally, they form critical travel routes connecting communities and facilitating the ability to continue social and cultural activities during winter months.

Although minor on-ice travel occurs in the Yukon (e.g. Dawson City ice crossing, mine access roads and an occasional ice road to Old Crow), the primary ice-road networks are found in the Northwest Territories and Nunavut, the latter having no long-distance all-season highways. Extensive winter-road networks are also found in the northern parts of several provinces (*see* Chapters 6 and 7). The longest winter road, the 'Tibbitt to Contwoyto Winter Road' (TCWR), is 600 km long, with 495 km located on frozen lakes (EBA Engineering Consultants Ltd., 2001). It is the main supply road for the Ekati and Diavik diamond mines, the Lupin gold mine (currently inactive), the Snap Lake and Jericho mine developments and several other mineral exploration projects. The TCWR is currently licensed and operated by the Winter Road Joint Venture (WRJV), a private-sector partnership between BHP Billiton, Diavik Diamond Mines and Echo Bay Mines, who share the cost based on use, while other companies using the road pay a tonne/kilometre charge. The TCWR typically operates for two months each year, February and March, at an approximate annual cost of $10 million, with trucks running almost 24 hours/day and convoys leaving at approximately 20 minute intervals. Between 1997 and 2003, it carried up to 8000 truck loads per year, each weighing an average 30 tonnes (t), with the load capacity rising as the ice thickens and increases in bearing strength. The economic importance of the TCWR is projected to continue for many years (Figure 16; EBA Engineering Consultants Ltd., 2001).

The main ice-only road in the Canadian North forms a 150 km winter link between the communities of Inuvik and Tuktoyaktuk, and is constructed and maintained by the Government of the Northwest Territories. Numerous smaller winter roads and ice bridges are found throughout the northern territories, with the Northwest Territories public road system almost doubling in length during the winter (approximately 1400 km in total). Operating windows vary by location and year, but typically extend from November – December until March – April.

Methods of ice-road construction vary by use, and some also involve tandem development with winter road construction on land. The more formalized road and bridge networks enhance the load-bearing capacity through snow removal or snow compaction to reduce its insulating effects. Rapid ice thickness can be achieved by surface flooding or by spray-ice techniques similar to snow-making. In both cases, the ice thickness can be increased beyond that possible due to normal ice growth for a given set of climatic conditions. Melt events can reduce surface usability even when the load-bearing capacity is high (Figure 17). Large

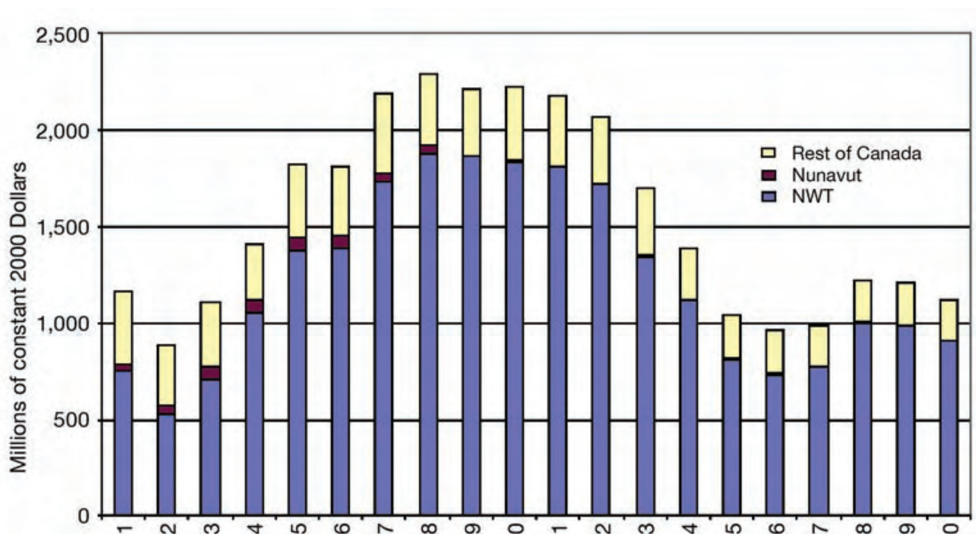


FIGURE 16: Annual contribution of the Tibbitt to Contwoyto Winter Road and associated projects to gross domestic product in the Northwest Territories (NWT), Nunavut and rest of Canada, 2001-2020 (EBA Engineering Consultants, 2001).

FIGURE 17: Transport truck crossing deteriorating ice road, Liard Ferry crossing near Fort Simpson, Liard River, NT (Terry D. Prowse).

snowfalls near the start of the season can cause a significant delay in ice growth and development of load-bearing capacity.

Although regular records are kept regarding the opening and closing of ice roads/crossings, no comprehensive trend analysis of such dates has been conducted. However, observations for the Mackenzie River Crossing Ice Road show that the average opening date for light traffic has been delayed by more than 3 weeks since 1996, whereas it had remained relatively constant (between December 8 and 19) during the previous 30 years or more (Northern Climate Exchange, 2006). Reductions in ice thickness associated with climate warming reduce the maximum loads that can be safely transported. Initially, modifications in ice-road construction (as described previously) may serve as an effective adaptation. At locations where transport capacity is not already maximized, it is possible to modify transport schedules to concentrate shipping into the core portion of the winter when ice thickness is maximized. A possibility also exists for transporting heavy loads over ice with the assistance of balloons, as suggested for the movement of oilfield equipment in Alaska and the Canadian Arctic (cf. Prentice and Turriff, 2002). This combination of impacts associated with decreased length of the ice-road season and reduced ice thickness translates into increased difficulties in resupplying northern communities and industrial sites during winter months.

Where and when the use of winter roads becomes impractical, there will be a need to provide alternative transportation routes. Where an open-water network is viable, increased use of barge transport might be possible. In land-locked locations, such as those currently serviced by the TCWR, construction of land-based roads is likely the only viable option to carry the enormous total annual loads of freight (*see* Case Study 1). All-weather roads are significantly more costly than winter roads to build and maintain. Costs vary but, as an example, Dore and Burton (2001) cited costs of at least $85 000 per km for all-weather roads to be constructed in northern Ontario, plus costs of between $64 000 and $150 000 per bridge.

4.6 FORESTRY

Significant areas of the Yukon (22.79 million ha) and the Northwest Territories (33.35 million ha) are covered by boreal forest, together constituting about 13% of Canada's total forest cover. The cultural, spiritual, social and economic well-being of many First Nations is dependent on a healthy forest ecosystem. Gathering of food and the exercise of cultural practices are important uses of forest land in the Yukon and Northwest Territories. Less than 30% of the Yukon forest cover is of a species or size that might support timber-harvesting activities (Government of Yukon, 2006), with the majority of merchantable forests located south of latitude 61°N. Farther north, Yukon forests are more affected by cold soils, poor drainage and aggressive fire regimes.

The Yukon is moving towards a legislative framework and more regulated practices for forestry activities, including the development of a *Yukon Forest Resources Stewardship Act*. Responsibilities for forest management are shared by the Government of Yukon, First Nation governments and renewable resource councils. The first strategic forest management plan in the Yukon was adopted in December 2004 for the Champagne and Aishihik Traditional Territory (Case Study 3).

Salvage harvest opportunities are currently driving the forest industry in the Yukon in response to recent expansive forest disturbance. In 2005, more than 300 000 m^3 in timber permits were issued to salvage wood from areas that were burned during the record fire season of 2004 (e.g. Green, 2004). The 2004 fires also created the opportunity for a large mushroom harvest, a lucrative post-fire non-timber forest product. In 2006, a request for proposals for 1 000 000 m^3 in timber permits was issued to salvage wood from the spruce bark beetle infestation in the Champagne and Aishihik Traditional Territory of southwestern Yukon (*see* Case Study 3). The contribution of harvested wood products to the Yukon economy in 2004 was estimated at a million dollars, and is poised to increase because of the salvage operations. In contrast, the estimated contribution of forest products to the Northwest Territories economy in 2004 was only $70 000 (Table 9).

The mounting evidence of local ecological responses to recent climate change demonstrates the sensitivity of northern forested ecosystems to climate change (Parmesan and Yohe, 2003; Juday et al., 2005; Ogden, 2006; Scholze et al., 2006). Indeed, many of the projected impacts of changing climate on the northern forest sector (Table 10) are already visible. Increased forest disturbances due to insect outbreaks are almost certain to result from continued climate warming (Juday et al., 2005). The spruce bark beetle infestation of southwestern Yukon, which has led to

CASE STUDY 3

Building the Foundation for Forest Management in a Changing Climate

There is accumulating evidence that climate change is affecting the Champagne and Aishihik Traditional Territory of the southwestern Yukon. During the past 40 years, average annual temperatures have been increasing and winters have had fewer periods of prolonged severe cold. There has been a decrease in average summer precipitation. One result of these warmer winters and warmer and drier summers has been a severe outbreak of spruce bark beetle (*Dendroctonus rufipennis*), causing widespread mortality of white spruce. This mortality has also led to the loss of merchantable timber and significant changes to the regional ecology. The spruce beetle infestation has also increased quantity, flammability and extent of forest fuels, thereby increasing the fire hazard.

The spruce bark beetle outbreak is driving forest management and planning efforts in the southwestern Yukon. In November 2004, the Government of Yukon and the Champagne and Aishihik First Nation approved the first community-directed forest management plan that identifies reduction of fire hazard, forest renewal, economic benefits and preservation of wildlife habitat as forest management and planning priorities. The plan also explicitly incorporates an adaptive management framework, considered to be an essential response to climate change.

Examination of forest management actions that could be undertaken to reduce the vulnerability of forest ecosystems, and the people and economies that depend on them, to climate change was undertaken by the Northern Climate Exchange (Ogden, 2006). Activities included a workshop on 'Our Changing Boreal Forest', hosted by the Champagne and Aishihik First Nation and the Alsek Renewable Resource Council, and involving local residents, governments and management agencies, and researchers. The workshop outcomes provided a foundation for a preliminary research framework to support forest management decision-making in the changing climate of southwestern Yukon.

The region has been designated a Special Project Area of the Canadian Model Forest Program, securing funding for the Champagne and Aishihik First Nation to do additional research on issues of community sustainability. Future work will include seeking the perspective of community members on the applicability of various adaptation management actions in the local context, conducting a scenario planning exercise to examine the effectiveness of forest management options under possible future climates, and incorporating traditional and local knowledge into the adaptive management framework.

widespread mortality of white spruce, is the largest and most intense outbreak to affect Canadian trees and is a notable example of ecosystem response to recent warming (Table 11; Figure 18; *see* Case Study 3; Juday et al., 2005). Climate change is also projected to increase the frequency, extent and severity of forest fires, thereby reducing mean fire return intervals, shifting age class distributions toward younger forests, triggering more frequent shifts from conifer- to deciduous-dominated successional trajectories, and decreasing the amount of terrestrial carbon stored in the boreal forest (Flannigan et al., 2000; Stocks et al., 2000; Juday et al., 2005; McCoy and Burn, 2005; Johnstone and Chapin, 2006).

Depending on species, site type and region, warmer temperatures in the last several decades have either improved or decreased tree growth. In some areas where declines have been observed, drought stress has been identified as the cause, whereas declines in other areas remain unexplained (Juday et al., 2005). Drought stress is also impeding the re-establishment of spruce forests following fire in some areas of southwestern and south-central Yukon, which are highly vulnerable to climate change if trends towards drier conditions continue (Hogg and Wein, 2005). Most projections of future climate result in conditions that are very likely to limit the growth of commercially valuable white spruce types and widespread black spruce types in large parts of Alaska and probably the western boreal forest of Canada (Barber et al., 2000; Hogg and Wein, 2005; Juday and Barber 2005; Juday et al., 2005). Climate-related changes in forest productivity will likely have significant impacts on northern forest-dependent communities (Hauer et al., 2001; Davidson et al., 2003).

The principles and practice of sustainable forest management embody many of the activities that will be required to respond to the effects of climate change (Spittlehouse and Stewart, 2003). Of those forestry practitioners in the Yukon and Northwest Territories who were surveyed about the likely impacts of climate change on forest sector sustainability and potential adaptation options, 71% agreed that the seven criteria of sustainable forest management[3] could also serve as goals for climate change adaptation in the forest sector (Ogden and Innes, in 2007b). The three impacts most frequently identified as already having affected sustainability were changes in the intensity, severity or magnitude of forest insect outbreaks; changes in extreme weather events; and changes in the intensity, severity or magnitude of forest fires (Table 12; Ogden and Innes, in 2007b). However, more than half of the respondents indicated that commodity prices, availability of timber, trade policies, environmental regulations and the ability to secure needed capital presently have more of a negative impact on sustainability than climate change (Table 13; Ogden and Innes, in 2007b).

[3] Criteria outlined in the 1995 Santiago Declaration are: 1) conservation of biological diversity; 2) maintenance of productive capacity of forest ecosystems; 3) maintenance of forest ecosystem health and vitality; 4) conservation and maintenance of soil and water resources; 5) maintenance of forest contribution to global carbon cycles; 6) maintenance and enhancement of long-term socioeconomic benefits to meet the needs of societies; and 7) legal, institutional and economic framework for forest conservation and sustainable management.

TABLE 9: Profile of Canada's Northern Forest Sector (Natural Resources Canada, 2005).

	Canada	Yukon Territory	Northwest Territories	Nunavut
PROFILE				
Population[1]	32 100 000	31 227	42 944	29 6583
Land area (ha)	979 100 000	48 490 000	128 120 000	200 600 000
Forest and other wooded land	402 100 000	22 790 000	33 000 000	940 000
Parks	26 500 000	not available	13 363	not available
RESOURCES				
Ownership[2]				
Federal	16%	100%	100%	100%
Provincial/Territorial	77%	0%	0%	0%
Private	7%	0%	0%	0%
Forest type[2]				
Softwood	66%	79%	53%	52%
Hardwood	12%	2%	47%	48%
Mixedwood	22%	19%	0%	0%
Potential harvest (m^3)[3]	238 800 000	238 000	not applicable	
Harvest (volume) – industrial roundwood (m^3)[3]	193 700 000	7 000	6 000	
Harvest (area) – industrial roundwood (ha)[3]	974 472	44	31	
Area planted (ha)[4]	427 051	310	112	
Area seeded (ha)[4]	18 906	not available	not available	
Area defoliated by insects and beetle-killed trees (ha)[3]	19 200 000	41 640	not available	
Number of fires[2]	6634	282	297	
Area burned (ha)[2]	3 300 000	1 800 000	515 621	
Industry				
Value of exports[2]	$44 600 000 000	$961 842	$69 954	
Softwood lumber	24.71%	1.5%	17.61%	
Major export markets[2]				
United States	80%	100%	37.38%	
European Union	6%	0%	62.62%	
Japan	5%	0%	0%	

Source: Natural Resources Canada (2005); data reported are from Statistics Canada

[1] for 2005 [2] for 2004 [3] for 2003 [4] for 2002

TABLE 10: Examples of the impacts of climate change on the northern forest sector (*modified from* Lemmen and Warren, 2004).

Biophysical impact	Socioeconomic impacts
Changes in forest productivity	Changes in timber supply and rent value
Increased atmospheric greenhouse gases	Introduction of carbon credit-permit mitigation policies that create a carbon sequestration market
Increased disturbances	Loss of forest stock and non-market goods
Northward shift of ecozones	Change in land values and land-use options
Change in climate and ecosystems	Economic restructuring leading to social and individual stresses
Ecosystem and specialist species changes	Changes in non-market values
Ecosystem changes	Dislocation of parks and natural areas, increased land-use conflicts

TABLE 11: Climate Change and the Spruce Bark Beetle (Juday et al., 2005).

Direct controls on insect populations:	Two successive cold winters depress the survival rate of the bark beetle
	Abnormally warm summers enable the beetle to complete its life cycle in one year, thus dramatically increasing its population
Indirect control on tree resistance:	Drought stress reduces ability of trees to resist beetle attacks
'Fingerprint' of climate warming:	Greater frequency of insect outbreaks
	More extensive areas of tree mortality during outbreaks
	Greater intensity of insect attack, resulting in higher tree mortality rates in outbreak areas

Despite not perceiving climate change as the most important influence on forest sector sustainability (Ogden and Innes, 2007b), northern forest managers are already adapting reactively to the impacts of changing climate, most notably in response to the spruce bark beetle infestation in southwestern Yukon (*see* Case Study 3; Alsek Renewable Resource Council, 2004). Possible proactive adaptations include targeted regeneration, silviculture or protection strategies to address long-term shifts in forest disturbance patterns (Ohlson et al., 2005). Proactive adaptation is more likely to avoid or reduce damage than reactive responses (Easterling et al., 2004). The perspectives of forest practitioners on the importance of adaptation options that may be considered to meet the goals of sustainable forest management were explored. The options assessed are presented in Table 14 (Ogden and Innes, 2007b). Practitioners also identified what they felt were the most important research needs to assist decision-making. These include understanding the impacts of climate change on the intensity, severity and magnitude of forest insect outbreaks and forest fires, as well as net impacts on forest growth and productivity (Ogden and Innes, 2007b).

TABLE 12: Percentage of forestry practitioners surveyed who perceive that the following climate change impacts have had a very significant or quite significant effect on the sustainability of the forest-sector or forest-dependent communities in the northern territories (Ogden and Innes, 2007b).

Climate change impact	Respondents (%)
Intensity, severity or magnitude of forest insect outbreaks	66
Extreme weather events	47
Intensity, severity or magnitude of forest fires	44
Lifestyles	34
Land values and land-use options	31
Length of winter road season	31
Economic opportunities	25
Forest carbon budget	22
Phenology	22
Timber supply	22
Species abundance, movement and ranges, including invasive species	19
Forest cover type	19
Forest growth and productivity	16
Location of treeline	16
Availability of non-timber forest products	9

TABLE 13: Percentage of forestry practitioners surveyed who perceive that the following factors presently have more of a negative impact than climate change on the sustainability of the northern forest sector or forest-dependent communities (Ogden and Innes, 2007b).

Influence on sustainability is presently more important than that of climate change	Respondents (%)
Commodity prices	56
Availability of timber	53
Trade policies	50
Environmental regulations	50
Ability to secure needed capital	50
Competitiveness	47
Oil and gas	41
Habitat fragmentation	41
Aboriginal involvement and governance	35
Public participation in forest management and planning	35
Minerals	35
Tourism	35
Community health and well-being	35
Invasive species	29
Unemployment	29
Contaminants	26
Participation in traditional lifestyles	21
Availability and security of traditional food supplies	18
Availability of recreational opportunities	15
Ozone depletion	6

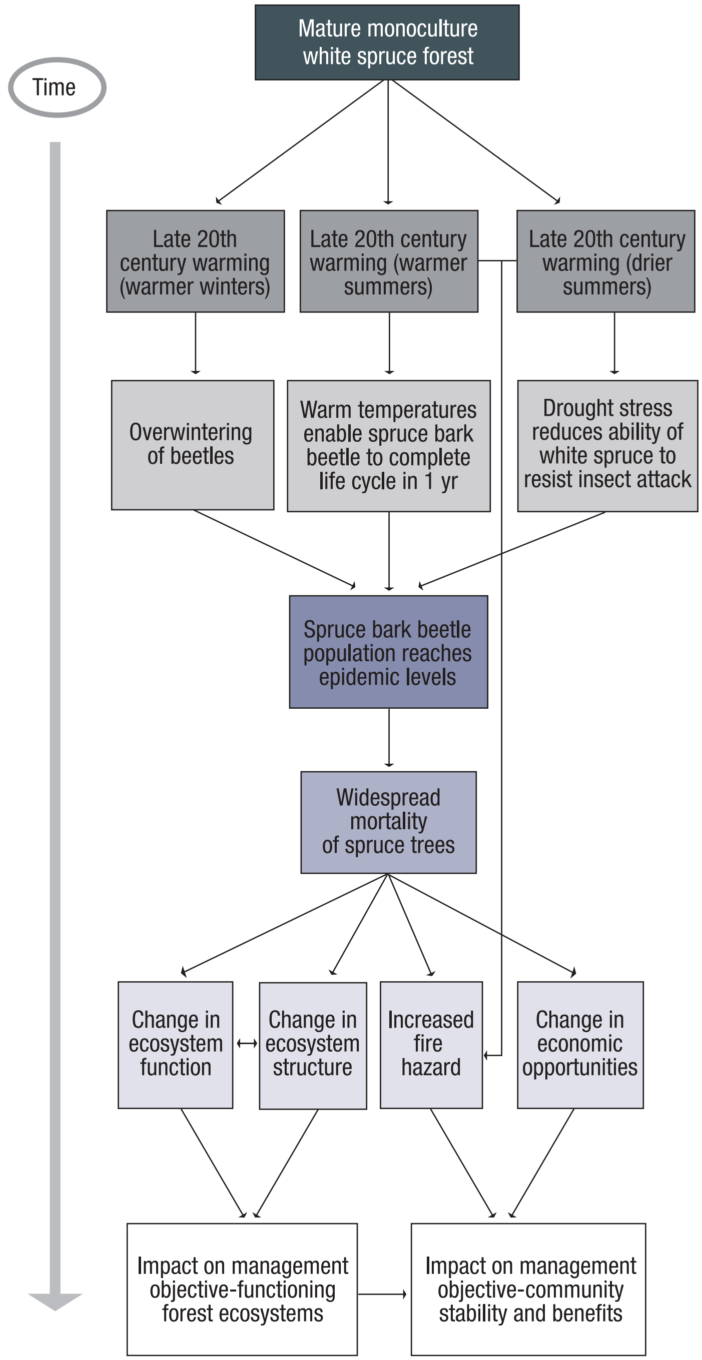


FIGURE 18: Influence of climate warming on spruce bark beetle populations in the southwest Yukon (Ogden, 2006).

TABLE 14: Strategic and operational-level climate change adaptation options that may be considered to meet the goals of sustainable forest management, as defined by the Montreal Process (*Source* Ogden and Innes, 2007a).

Adaptation goals	Conserve biological diversity	Maintain productive capacity of forest ecosystems	Maintain forest ecosystem health and vitality	Conserve and maintain soil and water resources
Strategic-level adaptation options	• Minimize fragmentation of habitat and maintain connectivity • Maintain representative forest types across environmental gradients in reserves • Protect climate refugia at multiple scales • Identify and protect functional groups and keystone species • Maintain natural fire regimes • Provide buffer zones for adjustment of reserve boundaries • Create artificial reserves or arboreta to preserve rare species • Protect most highly threatened species *ex situ* • Maintain natural fire regimes • Develop a gene management program to maintain diverse gene pools	• Practice high-intensity plantation forestry in selected areas to promote the growth of commercial tree species, especially in areas where an increase in disturbance is anticipated • Enhance and minimize disturbance to forest soils	• Breed for pest resistance and for wider tolerance to a range of climate stresses and extremes in specific genotypes • Reduce non-climatic stresses to enhance ability of ecosystems to respond to climate change by managing tourism, recreation and grazing impacts • Reduce non-climatic stresses to enhance ability of ecosystems to respond to climate change by regulating atmospheric pollutants • Reduce non-climatic stresses to enhance ability of ecosystems to respond to climate change by restoring degraded areas to maintain genetic diversity and promote ecosystem health • Adjust harvest schedules to harvest stands most vulnerable to insect outbreaks	• Avoid constructing roads in landslide-prone terrain where increased precipitation and melting of permafrost may increase hazard of slope failure • Enhance and minimize disturbance to forest soils
Operational-level adaptation options	• Allow forests to regenerate naturally following disturbance, favouring natural regeneration wherever appropriate • Control invasive species • Practice low-intensity forestry and prevent conversion to plantations • Assist changes in the distribution of species by introducing them to new areas	• Assist in tree regeneration • Employ vegetation control techniques to offset drought • Plant genetically modified species and identify more suitable genotypes • Enhance forest growth through forest fertilization • Actively manage forest pests • Underplant with other species or genotypes where the current advanced regeneration is unacceptable as a source for the future forest • Selectively remove suppressed, damaged or poor-quality individuals to increase resource availability to the remaining trees (pre-commercial thinning) • Reduce the rotation age followed by planting to speed the establishment of better-adapted forest types • Control those undesirable plant species that will become more competitive in a changed climate • Relax rules governing the movement of seed stocks from one area to another • Include climate variables in growth and yield models in order to have more specific predictions on the future development of forests • Design and establish a long-term multi-species seed-lot trial to test improved genotypes across a diverse array of climatic and latitudinal environments	• Plant genotypes that are tolerant of drought, insects and/or disease • Reduce disease losses through sanitation cuts that remove infected trees • Used prescribed burning to reduce fire risk and reduce forest vulnerability to insect outbreaks • Employ silvicultural techniques to promote forest productivity, and increase stand vigour (i.e. partial cutting or thinning) by lowering susceptibility to insect attack • Shorten the rotation length to decrease the period of stand vulnerability to damaging insects and diseases and to facilitate change to more suitable species	• Maintain, decommission and rehabilitate roads to minimize sediment runoff due to increased precipitation and melting of permafrost • Minimize the impacts on infrastructure, fish and potable water of changes in the timing of peak flow and volume in streams resulting from more/earlier snow melt

TABLE 14: *Continued*

Adaptation goals	Maintain forest contribution to global carbon cycles	Maintain and enhance long-term multiple socioeconomic benefits	Legal, institutional and economic framework for forest conservation and sustainable management
Strategic-level adaptation options	• Mitigate climate change through forest carbon management • Increase forested area through afforestation • Reduce forest degradation and avoid deforestation • Enhance and minimize disturbance to forest soils	• Anticipate variability, and change and conduct vulnerability assessments at a regional scale • Enhance capacity to undertake integrated assessments of system vulnerabilities at various scales • Foster learning and innovation, and conduct research to determine when and where to implement adaptive responses • Diversify forest economy (e.g., explore dead-wood product markets, value-added products) • Diversify regional economy (non-forest based) • Enhance dialogue among stakeholder groups to establish priorities for action on climate adaptation in the forest sector • Develop technology to use altered wood quality and tree species composition, and modify wood-processing technology • Make choice about preferred tree species composition for the future; establish objectives for the future forest under climate change • Include risk management in management rules and forest plans, and develop an enhanced capacity for risk management • Conduct an assessment of greenhouse gas emissions produced by internal operations • Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions regarding fuels management and community protection	• Provide long-term tenures • Relax rules governing movement of seed stocks from one area to another • Provide incentives and remove barriers for enhancing carbon sinks and reducing greenhouse gas emissions • Provide opportunities for forest management activities to be included in carbon-trading systems (as outlined in Article 3.4 of the Kyoto Protocol) • Practice adaptive management (a management approach that rigorously combines management, research, monitoring and means of changing practices so that credible information is gained and management activities are modified by experience) • Measure, monitor and report on indicators of climate change and sustainable forest management to determine the state of the forest and identify when critical thresholds are reached • Evaluate the adequacy of existing environmental and biological monitoring networks for tracking the impacts of climate change on forest ecosystems, identify inadequacies and gaps in these networks and identify options to address them • Support research on climate change, climate impacts and climate adaptations • Support knowledge exchange, technology transfer, capacity-building and information-sharing on climate change • Incorporate new knowledge about the future climate and forest vulnerability into forest management plans and policies • Involve the public in an assessment of forest management adaptation options
Operational-level adaptation options	• Allow forests to regenerate naturally following disturbance, favouring natural regeneration wherever appropriate • Control invasive species • Practice low-intensity forestry and prevent conversion to plantations • Assist changes in the distribution of species by introducing them to new areas	• Protect higher-value areas from fire through ‘firesmart’ techniques • Increase amount of timber from salvage logging of fire- or insect-disturbed stands	

Sources listed in Ogden and Innes, 2007a.

4.7 FISHERIES

The northern fish fauna of Canada consist of an estimated 240 species (190 marine, approx. 15 anadromous, and approx. 35 freshwater forms; Richardson et al., 2001; Evans et al., 2002; Coad and Reist, 2004). Additional fish species, not yet recorded due to poor sampling coverage, likely also occur in northern, particularly marine, waters. Adjacent regions contain additional species that may eventually be found in the North. Of the endemic species, northern fisheries target relatively few (approx. 11 species), most of which are salmonids (e.g. salmon, chars, whitefishes, grayling) captured in fresh, estuarine or nearshore waters. About five freshwater species are targeted (e.g. burbot, northern pike, suckers and perches). A further limited number (2–3) of marine fish species (e.g. Greenland halibut, Arctic cod) and a few (3–6) invertebrate species (e.g. shrimps, clams, mussels and urchins) complete the suite of exploited taxa (Nunavut Wildlife Management Board, 2004; Government of Nunavut and Nunavut

Tuungavik Incorporated, 2005; Reist et al., 2006a). Some additional species may be fished locally and/or captured as by-catch in fisheries and either discarded or used for bait or dog food.

The number of species present in the region is likely to rise as climate changes, especially along the southern margin of the North. Several southern species are known to occur as vagrants in the North, including three species of Pacific salmon in the western Arctic and Atlantic salmon in the east. Colonization could result in new opportunities for fisheries, but could also add to existing stressors as ecosystems restructure, new predators appear, competition ensues and/or parasites are introduced by the colonizing species (Reist et al., 2006b, c; Wrona et al., 2006a). Experience with the vagrants in local fisheries enhances interest in future potential for fisheries based upon those species.

Freshwater and anadromous species can be divided into three groups, based on thermal associations and preferences (*see* Wrona et al., 2005; Reist et al., 2006a):

- Arctic (thermal tolerance <10°C): species that are wholly or primarily distributed in the north (e.g. broad whitefish, an anadromous fish of the western Arctic)
- northern cold-water–adapted (11–15°C): species that reach their limits of distribution somewhere in the North
- southern cool-water–adapted (21–25°C): many of these species (e.g. Atlantic salmon) reach the northern limit of their distribution near the extreme southern margin of the North

Changing climate will affect these three groups, and associated fisheries, differently. Arctic species will likely experience declining productivity, local extirpation along the southern margin of their distribution and overall range contraction as local conditions exceed thresholds and southern species colonize and compete with or prey upon them. Both northern cold-water and southern cool-water species will likely increase in abundance and local productivity, and perhaps also extend their geographic range farther northward as conditions allow.

Particular fish species are either stenothermal (i.e. adapted to a narrow range of temperatures) or eurythermal (i.e. adapted to wide thermal ranges; e.g. Wrona et al., 2005; Reist et al., 2006a). These species are often captured together in the same fishery. In many cases throughout the North, local climate change may be positive for one species and negative for another. Such variability in the response will substantially affect fishery structure, output and sustainability, and present challenges to those fishery managers who rely primarily upon single-species management approaches. Management structures and approaches that focus on the ecosystem level are likely to be more highly responsive to climate change impacts. An ecosystem approach involves attaching differential values to local species and enabling the setting of attainable goals for sustainable fisheries and their management.

Northern fisheries can be classified into three types, household, commercial and recreational, based upon the final disposition of the catch (Clarke, 1993). Household fisheries include traditional and subsistence food fisheries conducted by Aboriginal people, as well as licensed domestic fisheries conducted by non-Aboriginal northerners. Commercial fisheries are licensed activities in which the product is sold either locally or in distant markets. Recreational or sport fisheries are licensed individual fisheries by non-Aboriginal persons. Each type of fishery and area will be affected differently by climate change, making the development of generalizations that are applicable to fisheries throughout the North difficult. Although detailed assessment of all northern fisheries is beyond the scope of this chapter, many of the issues and challenges are developed further in Case Study 4.

Commercial fisheries (*see* Case Study 4), and the very limited aquaculture occurring in the North, are generally small and widely dispersed, and conducted on small water bodies by local residents for both food and income. This results in limited economic potential measured in such typical terms as commercial cash income; however, valuation of these numerous widely dispersed fisheries must also include estimates of protein replacement and social and cultural value. In Nunavut, fisheries are estimated to contribute between $12 and 14 million annually to the economy (Government of Nunavut and Nunavut Tuungavik Incorporated, 2005). Of this, $5.8 million is estimated to accrue from Arctic char, of which $1.4 million comes from commercial sales of 800–1000 t annually and $4.4 million from the food value for subsistence use.

Inshore coastal marine and lake-based commercial fisheries and aquaculture operations are likely to face significant adaptation challenges as a result of changing climate. In addition to fairly intensive capitalization of the fishing fleet, these fisheries are supported by harbour facilities and onshore fish-processing facilities that require significant capital expenditures and regular inspection and maintenance to maintain standards for processing commercial fish products. In the North, long-term, relatively stable production is required to recoup initial investments. Current views of such activities in the North being a major contributor to economic development in the future (e.g. Government of Nunavut and Nunavut Tuungavik Incorporated, 2005) may have to be adjusted in view of the consequences of changing climate.

Inherent adaptive ways of life and resiliency of northern Aboriginal peoples will aid the process of adjusting traditional and subsistence fisheries to changing climate. By their nature, recreational fisheries are highly adaptable with respect to harvest levels, gear used and location of fishing. Thus, sport fisheries will likely be readily able to accommodate the impacts of climate change, the possible exception being where there is widespread loss of a species over a large area, in which case reprofiling such fisheries to 'new' species might be possible.

CASE STUDY 4

Commercial and Subsistence Arctic Fisheries

This case study describes and contrasts three different northern fisheries to illustrate the challenges that changing climate presents to resource management.

Nunavut Commercial Fisheries on Greenland Halibut

Both inshore and offshore commercial fisheries for Greenland halibut have been developed in Nunavut. Greenland halibut is a flatfish typically found near the bottom in deep waters of Baffin Bay and Davis Strait, as well as inshore in deeper fjords.

The inshore fishery is typically conducted through landfast ice on Cumberland Sound from December to March (Figure 19), with a quota presently set at 500 t. This fishery has been operating since 1987, with harvests varying from 4 to 430 t, 6 to 115 fishers involved annually and a season of 9 to 21 weeks duration. Recent high variability in sea-ice formation has affected the ease of travel and safety of fishers accessing the fishing grounds. In some years, ice formation has been quite distant from the best locations, resulting in low success of the fishery. This discourages entry and continued participation in the fishery, which in turn causes decreased employment at the processing plant and decreased local economic benefit.

FIGURE 19: Hauling long-lines; inshore ice fishery. Photograph courtesy of Nunavut Government.

The projected impacts of climate change on sea-ice conditions will have a significant effect on this inshore fishery. One possible adaptive response would be to diversify the inshore fishery to encompass a wider resource base, thereby increasing the resilience of the community to perturbation from climate or other factors. More extensive use of the existing Exploratory Fisheries Program could foster such diversification. The economic, social and societal benefits of diverse local fisheries have been documented for Greenland and other North Atlantic fishing communities (e.g. Hamilton and Otterstad, 1998; Hamilton et al., 2000).

The offshore fisheries in this area are also significant, accounting for 550 t of the total Canadian quota. It is a deep-water, bottom-trawl fishery involving large vessels during open-water season. Although subject to minor interannual variability due to seasonal ice conditions, access to the fishing grounds will be either unaffected or improved as a result of changing climate, although ice hazard risks may be similar to or greater than those at present. Little is known about how shifts in freshwater budgets will affect Greenland halibut production. Loeng et al. (2005) indicated that substantive restructuring of marine ecosystems will occur under changing climate, with Greenland halibut likely moving from deeper waters to shelf areas, affecting where and how fisheries could be conducted. This will necessitate adaptation (e.g. shift in gear type and possibly in vessel size) on the part of the existing fishery fleet.

Great Slave Lake Fisheries, Northwest Territories

Great Slave Lake, the eleventh largest lake in the world, supports commercial fisheries with an annual recent catch of approximately 1200 t. The principal species fished are lake whitefish, northern pike and inconnu (Figure 20). The East Arm of Great Slave Lake supports trophy sport fisheries, primarily for lake trout. Household fisheries occur in nearshore areas and local tributaries. All fishery types target multiple species. To minimize conflicts and maximize conservation and the value and sustainability of the various fisheries, fisheries managers use a system of area closures, quota limits and gear restrictions to limit both commercial and recreational activities. These same actions will likely be important tools for dealing with the impacts of changing climate.

Projected impacts of changing climate include a potential 50% increase in the number of ‘optimal growing season’ days for cold-water fish, such as lake trout, in the East Arm (McLain et al., 1994). In the relatively shallow west basin of Great Slave Lake, climate-related changes are likely to stress lake trout populations, but species with higher upper thermal tolerances, such as lake whitefish, will likely be positively impacted in terms of increased growth. Structural shifts in the lake ecosystem will likely occur as more southerly species from Alberta river systems, which are currently limited by climate, colonize and/or increase in abundance in the lake. Individual and cumulative effects of these impacts cannot be estimated with confidence because of a lack of baseline information. Adaptive management of the lake ecosystem needs to be done in the context of cumulative effects, including non-climate stresses.

(continued next page)

FIGURE 20: Lifting whitefish nets on Great Slave Lake. Photo courtesy of George Low (Fisheries and Oceans Canada).

CASE STUDY 4 Continued

Arctic Char Subsistence Fisheries

Traditional and subsistence fisheries for Arctic char and related char species are conducted wherever these fish occur, particularly in the coastal western Arctic and throughout Nunavut. Data from the harvest study conducted by the Nunavut Wildlife Management Board (2004) indicate that this species constitutes 45% (by number caught) of the top 15 harvested species reported from 1996–2001 (Figure 21). Other estimates indicate annual harvests of 1200–1500 t (Government of Nunavut and Nunavut Tuungavik Incorporated, 2005), with a high value to local economies and ways of life. All Nunavut, and most Inuvialuit and Gwich'in communities report harvests of either Arctic char or Dolly Varden. Traditional subsistence fisheries have tended to operate in a conservative fashion and are small, widely dispersed and usually short term, with low overall impact. Increases in Aboriginal populations and centralization in settlements, however, have recently limited the efficacy of this approach to northern subsistence fisheries. Where char are exploited by multiple fisheries (subsistence/household, commercial and recreational), current northern fishery management ranks traditional and subsistence fisheries as the most valued (Clarke, 1993).

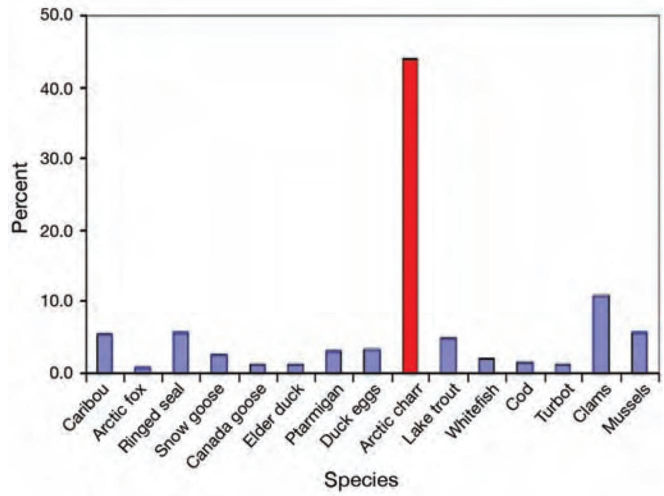


FIGURE 21: The frequency of Arctic char reported as harvested in subsistence fisheries in Nunvaut as overall counts of the top 15 harvested organisms reported in the Nunavut Harvest Study from 1996-2001 (Nunavut Wildlife Management Board, 2004). *Figure compiled by* B. Dempson, Fisheries and Oceans Canada.

Projected effects of changing climate on char will involve shifts in productivity and biodiversity, including changes from predominantly anadromous to resident life histories, complete extirpation in some areas and local declines in abundance in other areas (Wrona et al., 2005; Reist et al., 2006a). These shifts in the biological base of the fishery will have cascading ramifications. They will necessitate a variety of local adaptive responses on the part of the fishers and fishery managers, including shifting places, times or methods of capture; switching to alternative species (or life history types); adjusting levels of exploitation; and, in some cases, altering expectations and value associated with fishery resources (Reist et al., 2006c). Another key consideration is the interaction of climate change with contaminant dynamics that affect fish productivity and quality (Wrona et al., 2005), and hence fish suitability for human consumption. Monitoring of such effects, and of human health impacts, should be part of general approaches to northern fisheries.

An effective generalized approach to climate change adaptation involves comprehensive management and understanding of all human activities that impact northern aquatic ecosystems. For pervasive impacts in the North, such as contaminant loading, climate change, ozone depletion and increased incident ultraviolet radiation, virtually no quantification of the effects on fish populations is available. As a result, adaptive strategies should incorporate a wide buffer to enhance resiliency in the system. For fisheries, this likely means revising 'sustainable' strategies to levels below what is assumed or known to represent the 'maximum sustainable level' or 'total allowable harvest', as this most often will be the only factor that can be managed. Priority might be placed on ecosystems undergoing, or projected to undergo, the greatest changes from all stressors. It presently appears that aquatic systems in the western Arctic, particularly in the southern portion of the Yukon, along the Mackenzie Valley to the delta and along the Beaufort Sea coast, are undergoing significant shifts (e.g. Prowse et al., 2006) and are therefore at greatest overall risk.

4.8 WILDLIFE, BIODIVERSITY AND PROTECTED AREAS

A diverse range of wildlife has been critically important for Aboriginal people in the Canadian North for thousands of years. Today, wildlife continues to play a vital role in the diet, traditions and cultures of Aboriginal people, and also forms important components of local and regional economies (Nuttall et al., 2005). Many Arctic terrestrial and marine mammals and bird species have narrow habitat and niche requirements that make them particularly sensitive to climate change (Conservation of Arctic Flora and Fauna, 2001). Range-restricted wildlife species that occur near their ecological limit have been some of the first to exhibit impacts from changing climate (Parmesan, 2006). Previous assessments of projected climate change on circumpolar Arctic wildlife highlight changes in mortality rates, reduced reproductive capacity, increased competition for resources due to northward extension of southern species, and the emergence of new zoonotic diseases (Berner et al., 2005; Chapin et al., 2006).

Such changes will impact key traditional, subsistence and economic species in some regions, and their effects could be reduced by means of proactive adaptation to reduce the implications for human populations relying on these resources.

Terrestrial Species

Projected warming and shifts towards a wetter Arctic are expected to affect the diversity and accessibility of vegetation critical to several foraging mammals, such as woodland and barren ground caribou (*Rangifer tarandus*) and muskox (*Ovibos moschatus*). Changes in ultraviolet radiation, precipitation and temperature will directly affect the nutritive content of forage (Lenart et al., 2002), while changes in the composition of flora communities may result in the loss of nutritionally important plant species, which are chosen by caribou during important reproductive stages (White and Trudell, 1980). Projected increases in winter temperature and precipitation will likely result in an increase in energy expended by caribou to dig for food through deeper snow pack (Russell et al., 1993).

Some barren ground caribou in the western and central Arctic, including the Bluenose East and West, Cape Bathurst and Porcupine herds, have experienced significant declines in recent years, at least partly attributable to changes in climate. Declines have been associated with difficulties in obtaining appropriate forage and increased harassment by insects that interrupts summer feeding, resulting in poorer animal condition and a subsequent reduction in reproduction and recruitment (Russell, 1993). Similarly, recent declines of caribou and muskox occupying the islands of the south-central Arctic Archipelago (Prince of Wales, Somerset and Russell) are partly attributable to large-scale winter die-offs of both species associated with decreased access to forage due to harsh winter weather, including heavy snow events and increased icing (Miller and Gunn, 2003; Harding, 2004; Gunn et al., 2006; Tesar, 2007). Similar conditions on the western islands of the high Arctic are reported to be the cause of decline among Peary caribou, currently listed as a 'threatened' species. Additional factors involved in the decline of some herds include increased competition between caribou and muskox occupying the same habitat, increased incidence of parasitic infection, emigration to adjacent areas, wolf predation and hunting (Gunn et al., 2006). Similar impacts were projected by Brotton and Wall (1997) for the Bathurst caribou herd using four future climate scenarios.

Caribou are a key traditional and subsistence species for Aboriginal peoples of the Canadian Arctic, including Gwich'in, Tli cho, Denesuline and Inuit, and play an important role in local nutrition, economies, cultures and spirituality. The climate sensitivity of caribou highlights the need to monitor and better understand changes in small and genetically unique groups of animals, and to adjust wildlife management strategies accordingly (Miller et al., 2005; Gunn et al., 2006). Adaptation measures will need to limit the chance of undetected large-scale herd die-offs and harvesting above sustainable levels, in order to protect species from declines to levels from which they cannot recover (Brotton and Wall, 1997; Klein et al., 2005). Wildlife management boards in the Northwest Territories are currently considering implementing measures to reduce the non-resident and non-Aboriginal harvest of caribou (Tesar, 2007). Adaptive co-management strategies, involving local Aboriginal harvesters and bringing together scientific and traditional knowledge, are becoming increasingly important (Klein et al., 2005; Parlee et al., 2005).

Marine Species

The Arctic marine environment is home to a variety of large mammal species that have adapted to the unique conditions of this ecosystem. Ringed sea (*Phoca hispida*), walrus (*Odobenus rosmarus*), narwhal (*Monodon monocerus*), polar bear (*Ursus maritimus*) and beluga whale (*Delphinapterus leucas*) are widely found throughout Northern Canada and are commonly harvested by coastal Aboriginal populations (Nuttall et al., 2005), conveying important health, economic and cultural benefits (Van Oostdam et al., 2005). Many of these species are also central to important Arctic tourism and sport-hunting ventures. Changes in the distribution, stability and annual duration of sea ice and snow availability will have significant impacts on the populations of these mammals. Some species dependent on sea ice as a suitable platform for resting, pupping, moulting or feeding are already showing stress at their southern limits (Learmonth et al., 2006). Species that rely on the ice-edge environment, such as beluga, narwhal and walrus, are most vulnerable to the effects of projected decreases in sea-ice cover (Learmonth et al., 2006).

Decreased snow depth and earlier ice break-up in the spring have been shown to affect the survival and recruitment of ringed seal (*Phoca hispida*) pups in western Hudson Bay, while early spring warming and rainfall have been linked to the melting and destruction of ringed seal lairs in southeastern Baffin Island (Stirling and Smith, 2004; Ferguson et al., 2005). A review of changes in sea-ice conditions and suitability of habitat for ringed seals in M'Clintock Channel and the Gulf of Boothia by Barber and Iacozza (2004) showed large interannual variability, yet negative impacts on ringed seal habitat were evident between 1997 and 2001. For some other seal species, including harbour seals and grey seals, climate warming and decreases in sea-ice cover will mean a northward expansion of their distributions and an increase in their prevalence in Arctic waters.

The distribution of polar bears (*Ursus maritimus*) is partly a function of the ice conditions that allow them to most efficiently hunt and travel. This relationship is particularly strong in areas of moving ice, between foraging grounds and where they give birth to and rear their young (Learmonth et al., 2006). As polar bears feed almost exclusively on ringed seals, changes in ice distribution and extent that impact seal populations will also affect polar bear distribution and foraging success. A significant decline in the numbers and condition of southern populations of adult bears has been documented in western Hudson Bay, and is associated with changes in sea-ice conditions and seal populations (Stirling et al., 1999; Ferguson et al., 2005). Such changes require bears to travel longer distances in search of seals, and to diversify their diet when possible, expending more energy and depleting adipose stores. Ultimately, this can lead to reproductive impairment in females and decreased health of cubs, as mothers have less fat stores during winter months (Derocher et al., 2004). Changes in the proportions of different seal species in the diet of polar bears in Hudson Bay are further evidence of the cascading effects that changing climate and other stressors are likely having on bears in this region (Stirling, 2005). It has also been suggested that changes in ice conditions, as well as specific intraspecies and interspecies competition, have resulted in some bear mortalities in the Beaufort Sea (Amstrup et al., 2006; Monnett and Gleason, 2006).

Projected climate change is likely to lead to improved habitat conditions for both seals and bears at higher latitudes in the near future, as multi-year ice is replaced with annual ice and more leads and pressure ridges are created. In the longer term, however, it is likely that impacts similar to those currently seen in Hudson Bay will also be experienced in high-latitude areas (Derocher et al., 2004).

The iconic nature of the polar bear as a symbol of the Canadian North has elevated discussion of its fate. Not only are polar bears an important component of the Arctic ecosystem, but they are also a key attraction for many visitors to the North each year, and play a significant role in the culture and economies of many Aboriginal communities. Their economic value in regions where high success is achieved in sport hunts, such as western Hudson Bay and Lancaster Sound, is significant for Nunavut communities, where a tag alone can attract as much as $20 000 from a non-resident hunter, with additional income obtained from guiding and outfitting fees garnered by residents in the community (Wenzel, 2005; Freeman and Wenzel, 2006). Thus, the impacts on bears of shifting climate regimes also have implications for tourism, culture and local economies in many regions.

The potential effects of climate change on Arctic whale species are less well understood than for other large marine mammals (Loeng et al., 2005). It is expected that changes in the distribution and extent of ice cover, and the formation and location of polynyas will influence prey species, and thus affect the distribution and range of many northern cetaceans. In general, warming will cause shifts in species composition, with a tendency for northward movement in community structures and the potential loss of some polar species (Tynan and DeMaster, 1997). For example, Moshenko et al. (2003) ranked climate change as a 'high' threat to bowhead whales (*Balaena mysticetus*).

Bird Species

Many sea birds and other migratory avian species are consumed by Aboriginal residents of the North and provide local-scale economic resources in some regions (e.g. eider down). Warming waters and changes in ice distribution and prey productivity are already impacting some northern bird species. The ivory gull (*Pagophila eburnea*), whose distribution is linked to sea ice, has undergone population reductions and further reductions are projected in the future (Mallory et al., 2003). Studies of Brunnich's guillemot (*Uria lomvia*) have shown changes in the timing of breeding at both the northern and southern limits of its range and an advancement of egg-laying dates, yet lower chick growth rates and adult body mass at its southern limits and reduced reproductive success in years of late freeze-up in the north. Gilchrist and Robertson (2000) showed the importance of small recurring polynyas and ice floe edges as wintering habitat for species such as old squaw (*Clangula hyemalus*) and king eider ducks (*Somateria spectabilis*) in Hudson Bay. Throughout the North, Aboriginal hunters have reported changes in migration routes, timing, breeding and reproductive behaviour of birds, as well as the appearance of previously unseen species (e.g. Huntington et al., 2005; Nuttall et al., 2005; Nickels et al., 2006). Together, these results show that warming in the Canadian Arctic in the near future should continue to positively affect some bird species at their northern limits, while having negative impacts at their southern extremes (Gaston et al., 2005).

Conservation and protection of migratory bird resources in the face of changing climate will be challenging in the Arctic, particularly in areas where industrial activity, tourism and increases in local human population provide additional stressors. Protecting key marine areas could play an important role in maintaining ecosystem integrity and thus protecting sea bird populations (Dickson and Gilchrist, 2002). Management strategies involving resource users (Aboriginal residents and others) and industry representatives will have to consider the many stresses on bird populations.

Contaminants and Wildlife

Climate-related changes that have already been observed in the North also influence wildlife exposure to, and intake of, environmental contaminants (Macdonald, 2005; Macdonald et al., 2005). Many environmental contaminants are transported towards polar regions via air and water currents, and changing climate is altering these contaminant pathways (Arctic Monitoring and Assessment Programme, 2003b). For the metals lead, cadmium and zinc, the Arctic is likely to become a more effective 'sink' because of projected increases in precipitation. Mercury appears to be increasing in some northern aquatic systems, related partly to changes in ice cover and permafrost melting. Migratory species represent a form of biotransport, changing the distribution of contaminants they contain. Areas seeing the appearance of new species are most vulnerable to negative changes in contaminant loads in the future. Finally, hydrocarbons will be affected by changes in sea-ice distribution and drift tracks (Macdonald et al., 2005). The largest change in contaminant movement into or within the Arctic may occur as the Arctic Ocean becomes increasingly open to transportation, tourism and mineral exploration.

Changes in contaminant composition and levels in key wildlife species that are consumed by northern residents are significant for human heath and well-being (Kraemer et al., 2005; *see* Section 5). To more accurately track trends of contaminants in key wildlife species in the future, and ascertain the effects of climate on their levels, there is a need to concurrently collect data in both biotic and abiotic media (Macdonald et al., 2005).

Biodiversity and Protected Areas

Climate change is expected to affect Arctic biodiversity through changes in the distribution of ranges and habitats of species, the abundance of species, the genetic diversity and behaviour of migratory species, and the introduction of non-native species (Usher et al., 2005). Current plans for parks and protected areas adopt a natural region or ecoregion representation approach, designed to protect specific natural features, species and communities of a site. These plans generally do not consider the landscape-level shifts in ecosystem distribution and structure that are likely to result from changing climate (Lemieux and Scott, 2005).

Using two global vegetation models and a number of climate models, Lemieux and Scott (2005) projected a decline of more than 50% in conservation lands from each of the three northern biomes (tundra, taiga/tundra, boreal) under a scenario of doubled atmospheric concentrations of carbon dioxide. Such projections raise concerns about the adequacy of existing plans to continue protecting representative samples of Canadian Arctic ecosystems, and ultimately Arctic biodiversity. Usher et al. (2005) concluded that there is an immediate need to develop and adopt new approaches to managing Arctic biodiversity. Adaptive conservation and protected area plans should consider projected changes in phenology and the movements of individual species in response to changing climate, as well as potential changes in biological communities. Disruption of competitive or predator-prey interactions could jeopardize sustainability of ecosystem services on which humans rely (e.g. Root and Schneider 1993; Millennium Ecosystem Assessment, 2005). This is particularly important for species in areas projected to incur cumulative stresses related to climate change, increased development and other human activities.

4.9 TOURISM

The Arctic has seen increased interest and visitation by tourists in recent years (Stewart et al., 2005). Although standardized tourism statistics are lacking for the region as a whole (Pagnan, 2003), some indicators of the level of visitation and the importance of these visitors to local and regional economies are available. The Yukon sees the greatest economic benefits from tourism, with approximately 32 000 tourists in 2002 generating approximately $164 million in economic value (Pagan, 2003). Although hunting and fishing visitors account for only 14% of all visits in the Northwest Territories, they generate approximately 45% of annual spending by tourists in the territory. Tourism is the fourth largest economic sector in Nunavut, with 18 000 visitors entering Canada's newest territory in 2003.

Economic development has long been the driving force behind tourism in the North (Stewart et al., 2005). Although there are obvious benefits to economic diversification, there are also concerns regarding the impacts of tourism on northern communities and local businesses. Inuit in Clyde River, NU, for example, have expressed interest in opportunities associated with tourism as long as the development of these activities is gradual and the community maintains control (Nickels et al., 1991; Stewart et al., 2005).

Challenges facing the tourism industry in the Arctic include a short travel season, transportation difficulties, costs of infrastructure and dependence on nature. Potential positive impacts of changing climate for the tourism industry are associated with increased access and longer travel seasons. An increasingly navigable Northwest Passage could increase tourism opportunities for cruise ships through this relatively unseen wilderness (Stewart et al., 2005), although ice hazards are likely to remain high for several decades (*see* Sections 3.1 and 4.5.1).

5 COMMUNITIES, HEALTH AND WELL-BEING

Communities throughout the North are already reporting impacts and challenges associated with climate change and variability (e.g. Krupnik and Jolly, 2002; Canadian Climate Impacts and Adaptation Research Network (C-CIARN) North, 2006a–c; Ford et al., 2006b; Nickels et al., 2006). The distribution of economic, health, cultural and social impacts associated with changing climate will vary across regions and among segments of the population (Arctic Climate Impact Assessment, 2004, 2005). Furthermore, climate is only one of several factors whose changes are influencing the nature of settlements and populations in the three Canadian territories (*see* Section 2.2). It is the interactions and effects of ongoing changes in human, economic and biophysical systems, exacerbated by changes in regional and local climate, that are disproportionately influencing the health and well-being of northern residents (Chapin et al., 2005).

The majority of research conducted to date on climate impacts in Arctic human systems has been focused on the individual or subpopulation (e.g. hunters within a community) scale. Community case studies, such as those conducted by Ford et al. (2006b), have focused primarily on small remote Aboriginal populations and provide insights into the vulnerability of some northern residents. The challenge in understanding vulnerability throughout the North is complicated by the diversity of community types and their dynamic nature. The factors that influence community vulnerability (*see* Chapter 2) vary significantly between small, remote, predominantly Aboriginal communities, regional centres and larger northern municipalities.

Workshops (e.g. Council of Yukon First Nations and Arctic Athabaskan Council, 2003; Anonymous, 2006; Nickels et al., 2006) have identified a series of local impacts and future concerns throughout the northern territories. At one of the few workshops focused on larger municipalities, impacts and concerns raised by Yellowknife residents included, but were not limited to, municipal water and sanitation, municipal roads and related infrastructure, power sources, and adaptation strategies and planning (Anonymous, 2006). Although there has been little study on how climate change is being considered or integrated in municipal- and regional-level planning and other decision-making processes, some Northwest Territories communities have developed integrated planning processes that consider both the reduction of greenhouse gases and the development of long-term adaptive capacity (Bromley et al., 2004). In Nunavut, one regional workshop has taken place and others are planned that focus on adaptation planning for climate change, and specific community-based projects have begun as a result of this initial meeting (Government of Nunavut, 2006). Concerns shared by small, more remote settlements, in addition to effects on infrastructure from melting permafrost and coastal erosion, include the impacts that changing climate is already having on their relationship with the local environment, the services it provides (e.g. country/traditional foods, raw water, aspects of health and well-being) and the environment's place in local culture, tradition and identity (e.g. Council of Yukon First Nations and Arctic Athabaskan Council, 2003; Nickels et al., 2006).

The effects of climate change on northern biophysical and economic systems (*see* Sections 3 and 4), interacting with non-climatic stressors, have both direct and indirect influences on residents, their health and well-being. The distribution and significance of these impacts is a function of existing vulnerabilities and the characteristics of adaptive capacity at individual and collective scales (Ford and Smit, 2004).

5.1 DIRECT IMPACTS ON HEALTH AND WELL-BEING

The direct influences of climate on human health and well-being in northern communities are primarily related to extreme weather and temperatures, and natural hazards (Table 15). A more detailed discussion of human health vulnerabilities to climate in the Canadian North is provided in Furgal et al. (in press). The effects on northern residents of changes in levels of ultraviolet-B exposure are discussed elsewhere (e.g. Berner et al., 2005).

Residents of small, predominantly Aboriginal communities in all regions of the Canadian Arctic have reported that the weather has become less predictable and, in some cases, that storm events progress more quickly today than in previous memory (e.g. Huntington et al., 2005; Ford et al., 2006b; Nickels et al., 2006). This unpredictability limits participation in land-based and subsistence activities and travel, and increases the risks of being stranded or involved in accidents on the land (Ford and Smit, 2004; Ford et al., 2006b; Nickels et al., 2006). Residents of Arctic Bay, NU have reported that "increased storminess" increases the danger of summer boating and decreases access to some hunting grounds (Ford et al., 2006b). These changes have economic implications for individuals and households in terms of damage to equipment and decreased or lost country/traditional food catches. Extremes of temperature, both cold and heat, influence health directly. The Council of Yukon First Nations has reported that 7% of injuries among youth are cold related, such as hypothermia and frostbite (Council of Yukon First Nations, 2006), and reports of heat-related stress are being recorded, predominantly among elderly residents, in a number of regions (e.g. Communities of Labrador et al., 2005; Communities of the Inuvialuit Settlement Region et al., 2005). Qualitative data suggest that the incidence of accident-related injuries attributable to weather conditions is increasing in smaller coastal communities throughout the North (Nickels et al., 2006). Although preliminary analysis (Noonan et al., 2005) shows increased daily variability of weather in Nunavut, and climate models project an increase in the frequency and severity of extreme events (storms, floods, icing of snow layers, drought), the impacts of such events on health remain difficult to project (Berner et al., 2005).

In response to changing weather conditions, northern residents identified the need for improved infrastructure to communicate weather information, including cellular and improved citizens band radio (CB) service, and the need to construct more permanent shelters on the land as refuges from storms (Communities of the Inuvialuit Settlement Region et al., 2005). In the Nunavut communities of Repulse Bay and Arctic Bay, residents reported taking more supplies than has typically been the norm, such as additional warm clothing, lighters and extra food, when going hunting or travelling on the land, in order to be better prepared for uncharacteristic weather events (Community

TABLE 15: Summary of potential, direct, climate related health impacts in northern regions (*adapted from* Furgal et al., 2002).

Identified climate-related change	Potential direct health impacts
Increase in temperature extremes (magnitude and frequency)	Increased heat- and cold-related morbidity and mortality
Increase in frequency and intensity of extreme weather events (e.g. storms, etc.) Increase in uncharacteristic weather patterns	Increased frequency and severity of accidents while hunting and travelling, resulting in injuries, death and psychosocial stress
Increase in ultraviolet-B exposure	Increased risk of skin cancers, burns, infectious diseases, eye damage (cataracts), immunosuppression

of Repulse Bay et al., 2005; Ford et al., 2006b). People are also becoming more risk averse, with some residents curtailing hunting and travelling activities to avoid storms. Increased use of global positioning systems (GPS) for navigation, and of larger or faster vehicles, was reported among hunters in several communities to compensate for unpredictable or challenging weather. However, these adaptations can also increase exposure to risk by raising the sense of security among hunters and increasing the amount of travel in dangerous circumstances.

Documentation of experience with weather-related natural hazards, such as avalanches, is limited in northern regions. Fatal avalanches and property damage have been recorded in Nunavik (Arctic Quebec), Nunavut, the Northwest Territories and the Yukon, but they are far less common than in British Columbia and Alberta. Events such as the avalanche in Kangiqsualujjuaq, Nunavik in 1999, which killed 9 and injured 25, demonstrate local northern vulnerability. Increased frequency of midwinter thaw-freeze events, creating conditions conducive to snow slides and avalanches, have been reported by residents mainly in eastern Arctic regions in recent years (Nickels et al., 2006). Parts of the western Arctic (e.g. communities within the mountainous regions of the Yukon), where significant winter warming has already been recorded, are particularly vulnerable to avalanche hazards. Landslides associated with heavy rainfall and/or permafrost melt represent another climate-related natural hazard. Communities in the Inuvialuit Settlement Region and in Arctic Bay, NU have reported observations of such events for the first time in recent decades (Ford et al., 2006b; Nickels et al., 2006), and a resulting increase in dangerous travelling conditions (Ford and Smit, 2004; Community of Arctic Bay et al., 2006).

There has been little research that considers the risks associated with changing climate on hazard zonation and adaptation for northern communities (Lied and Domaas, 2000). Newton et al. (2005) recommended that such applied research be conducted in co-operation with northern communities and Aboriginal groups, in order to include local understanding and knowledge of such conditions. Some northern communities in mountainous regions have noted the increasing importance of adequate staffing and training of search-and-rescue personnel because of the increasing possibility of weather-related natural hazards (e.g. Communities of Labrador et al., 2005).

5.2 INDIRECT IMPACTS ON HEALTH AND WELL-BEING

Indirect influences of changing climate on northern communities and residents' health and well-being result from shifts in ice conditions, changes in exposure to emerging diseases, changes and impacts to aspects of food security, implications of permafrost melting for community infrastructure, and the combined effects of environmental and other forms of change on northern residents. Furgal et al. (in press) have provided a detailed discussion of human health vulnerabilities associated with indirect relationships to climate (Table 16). The following is a general discussion of human impacts associated with climate-related changes in northern territories.

Ice Conditions and Safety

Scientific studies and local Aboriginal observations have reported an increasing length of the ice-free season and decreasing ice thickness and extent of sea-ice cover (*see* Section 3.1; Huntington et al., 2005; Walsh et al., 2005; Ford et al., 2006b; Gearheard et al., 2006; Nickels et al., 2006). Models project a continuation of these recent trends through the twenty-first century, with summer sea-ice loss expected to be greatest in the Beaufort Sea (Walsh et al., 2005). Flato and Brown (1996) estimated that continued warming will decrease landfast ice thickness and duration of cover by approximately 0.06 m and 7.5 days/°C, respectively. This would translate into a decrease in thickness of 50 cm and duration of coverage by 2 months by 2080–2100 for a community such as Arctic Bay, NU (Ford et al., 2006b).

In addition to the implications of changes in ice conditions reported in Sections 3 and 4, such changes are also important for many traditional and subsistence activities. Sea-ice provides a stable travelling and hunting platform for northern residents and is critical to the reproduction and survival of several Arctic marine species (*see* Section 4.8). Inuit residents have reported recent changes in ice characteristics, increasing danger and decreasing access to hunting areas and country/traditional foods throughout the territories (Riedlinger and Berkes, 2001; Huntington et al., 2005; Ford et al., 2006b; Nickels et al., 2006). A perceived increase in the number of accidents and drownings associated with ice conditions (Lafortune et al., 2004; Barron,

TABLE 16: Summary of potential indirect climate-related health impacts in northern regions (*adapted from* Furgal et al., 2002).

Identified climate related change	Potential indirect health impacts
Increase in temperature extremes (magnitude and frequency)	Increased incidence and transmission of infectious disease, psychosocial disruption
Decrease in ice distribution, stability and duration of coverage	Increased frequency and severity of accidents while hunting and traveling, resulting in injuries, death and psychosocial stress Decreased access to country food items, decreased food security, erosion of social and cultural values associated with country foods preparation, sharing and consumption
Change in snow composition (decrease in quality of snow for igloo construction with increased humidity)	Challenges to building shelters (igloo) for safety while on the land
Increase in range and activity of existing and new infective agents (e.g. biting flies)	Increased exposure to existing and new vector-borne diseases
Change in local ecology of water and food-borne infective agents (introduction of new parasites and perceived decrease in quality of natural sources)	Increased incidence of diarrheal and other infectious diseases Emergence of new diseases
Increase in permafrost melting, decrease in land surface stability	Negative impacts on stability of public health, housing and transportation infrastructure Psychosocial disruption associated with community relocation (partial or complete)
Sea-level rise	Psychosocial disruption associated with infrastructure damage and community relocation (partial or complete)
Changes in air pollution (contaminants, pollens and spores)	Increased incidence of respiratory and cardiovascular diseases, increased exposure to environmental contaminants and subsequent impacts

2006) may be reflected in statistics showing a higher incidence of accidental deaths and injuries in smaller settlements of the Northwest Territories (Government of the Northwest Territories, 2004). Increased velocity and volume of spring run-off from melting ice and snow create hazardous conditions for young children in northern communities. Economic impacts arising from changes in ice conditions include lost earnings from reduced seal or narwhal harvests, damage to equipment and loss of access to wildlife food resources (Ford et al., 2006b). These changes also have a negative impact on social cohesion and mental well-being by disrupting the traditional cycle of land-based practices (e.g. Furgal et al., 2002; Berner et al., 2005). Similar changes have been reported for freshwater ice and access to fish resources that are important for many Aboriginal and non-Aboriginal populations across the North (*see* Section 4.7).

Adaptation to changes in ice conditions has involved shifts in individual behaviours and the adoption of new technologies. Shifts in hunting activities in response to changes in sea-, lake- or river-ice conditions have been reported by many communities. In Arctic Bay, NU, a portion of the narwhal quota for that community has been shifted from the spring to summer hunt to reduce safety risks associated with earlier and less predictable break-up conditions, and to increase chances of hunting success (Armitage, 2005; Community of Arctic Bay et al., 2006). Some hunters now take small boats with them in case they are stranded on drifting ice (Ford et al., 2006b). Inuit hunters in coastal communities report using new land-based or nearshore routes to access areas previously reached via sea-ice trails (Tremblay et al., 2006). Some residents now consult Internet-based satellite imagery of sea-ice conditions prior to travelling to the floe edge, and many carry GPS units to increase travel and hunting efficacy and decrease risks (Communities of Nunavut et al., 2005; Ford et al., 2006b; Gearheard et al., 2006).

Warming Temperatures and Emerging Diseases

Many zoonotic diseases currently exist in Arctic host species (e.g. *trichinella* in walrus and polar bear, and *cryptosporidium* in both marine and terrestrial mammals), and some regions have reported significant cases of zoonotic diseases in humans in the past (Proulx et al., 2000). A relationship between zoonotic diseases and temperature is evidenced by increased illness and parasitic infection in terrestrial mammals, marine mammals, birds, fish and shellfish in Arctic regions associated with past warm years related to El Niño Southern Oscillation events (Kutz et al., 2004). It is likely that longer warm seasons resulting from changing climate will be associated with a change in the type and incidence of disease in these species, which can be transmitted to northern residents (Bradley et al., 2005). Changes in the spatial occurrence of these diseases is also likely.

The most common forms of food- and water-borne diseases in the Northwest Territories are giardia (from drinking contaminated water), and *salmonella* and *campylobacter* (from eating typically raw or poorly cooked contaminated foods; Government of the Northwest Territories, 2005). Despite the consumption of some foods that are traditionally eaten raw in Aboriginal communities, the rates for *campylobacter* and *salmonella* have declined in recent years in the Northwest Territories (Government of the Northwest Territories, 2005). Communities in the central and eastern Arctic, however, have identified an increase in parasites in caribou over recent years, an observation that has been corroborated by studies of muskox

(Kutz et al., 2004), and have expressed concerns about whether this meat is safe for consumption (Nickels et al., 2006).

Overwintering survival and distribution of some insect species are positively impacted by warming temperatures, leading to increased risk from human and animal vector-borne diseases already present in the region, as well as opportunities for the introduction of new diseases into Arctic regions (Parkinson and Butler, 2005). In the western Arctic, Inuvialuit residents have reported seeing increased numbers of insects and species not observed there previously, including biting flies and bees (Communities of the Inuvialuit Settlement Region, 2005).

Food Security

The diet of many northern residents is a combination of imported foodstuffs and locally harvested foods (country/traditional foods). These foods from the land and sea, including animal and plant species, contribute significant amounts of energy and protein to the total diet, help individuals meet or exceed daily requirements for several vitamins and essential elements, and provide protection from some forms of cardiovascular disease and, potentially, contaminant toxicity (Blanchet et al., 2000; Kuhnlein et al., 2000; Van Oostdam et al., 2005). The proportion of the total diet consisting of country/traditional foods is significantly higher among Aboriginal residents and older age groups (Kuhnlein et al., 2000; Van Oostdam et al., 2005).

Hunting, fishing and gathering also figure prominently in the cash economy of northern communities, and are important for maintaining social relationships and cultural identity among Aboriginal populations (Nuttall et al., 2005). The dependence on country/traditional foods is greater in more remote communities, where access to affordable, fresh market foods is significantly less (*see* Section 2.2, Table 7). Despite their importance, there has been a shift away from country/traditional foods and an increase in the amount of store-bought foodstuffs in the diet of northern populations, especially among younger ages and residents of those communities with greater access to store foods (Receveur et al., 1997).

Shifts in animal distributions and local ecology, and changes in northerners' access to country/traditional food species as a result of changing climate have significant implications for food security (Furgal et al., 2002; Ford et al, 2006b; Guyot et al., 2006; Pratley, 2006). Climate-related changes in terrestrial and marine species, as outlined in Section 4.8, are reported to be affecting harvests of wildlife in some regions. For example, Inuvialuit residents have reported changes in fish and wildlife distributions in addition to the severe storms and changes in sea-ice and permafrost stability, all of which make harvesting more difficult (Riedlinger, 2001). Many other northern communities have also reported impacts on country/traditional food security as a result of changing environmental conditions (e.g. Berkes and Jolly, 2002; Huntington et al., 2005; Ford et al., 2006b; Nickels et al., 2006). These challenges are not limited to coastal communities. For example, residents in Beaver Creek, YT and the Deh Gah Got'ie First Nation in Fort Providence, NT have also witnessed changes in climate that are affecting aspects of their country food harvest (Guyot et al., 2006). The discussion of the impact of climate change on livelihoods of Aboriginal peoples is about sustaining relationships between humans and their food resources, as well as being aware that this impact poses the threat of irreversible social change (Nuttall et al., 2005).

Country/traditional food items are also the largest source of exposure to environmental contaminants for northern residents (Van Oostdam et al., 2005). Climate change will likely enhance transport, deposition and uptake into Arctic wildlife of contaminants, thereby influencing human exposures (*see* Section 4.8; Kraemer et al., 2005). These chemicals are known to adversely affect immune and neuromotor functioning in children (Arctic Monitoring and Assessment Program, 2003a; Després et al., 2005). Current levels of exposure to mercury and organochlorine contaminants among some segments of the population in Nunavut already exceed recommended safety guidelines (Van Oostdam et al., 2005).

Increased temperatures and lengthening growing seasons present opportunities for the development and enhancement of small-scale northern agriculture, particularly in the western Arctic. Such opportunities would create additional and more cost-effective local sources of some food items. Increased warming will also lengthen the ice-free seasons and increase navigability of northern waters (see Section 4.5), and could therefore increase the frequency of transport to communities and reduce costs associated with some market items.

Individual adaptations to changes in country/traditional food access have included shifting times of hunting activities and the use of different forms of transportation (e.g. all-terrain vehicles rather than snowmobiles) to access some hunting and fishing grounds. Residents in all northern regions have reported species that are more difficult to locate and catch today, and are replacing them in the regular hunting schedule with species that are more readily accessible. In the community of Kugaaruk, NU, residents reported that, when the ice is dangerous for travel, people have started to go fishing instead of travelling on the ice to go seal hunting. Some regions have reported a greater need for the community freezer program (Communities of Nunavik et al., 2005; Communities of the Inuvialuit Settlement Region et al., 2005) or the development of intercommunity trade programs (e.g. Communities of Nunavik et al., 2005; Community of Arctic Bay et al., 2006). Increased costs associated with some responses (e.g. purchase of larger boats, use of more fuel to travel farther and access caribou whose migration route has changed) have implications for household budgets, but have not yet been evaluated.

Water Quality

There are significant concerns about access to, and quality of, freshwater resources in many northern communities (Box 1). In the Yukon, 25% of First Nations residents reported that their water was unsafe for consumption (Council of Yukon First Nations, 2006). Approximately 2% of Yukon First Nations residents use untreated water directly from a natural source for daily household use (Council of Yukon First Nations, 2006). Climate-related impacts on the quantity, quality and accessibility of drinking water resources are expected to affect mainly smaller, remote northern communities, some of which face challenges in effectively utilizing municipal treatment systems (Moquin, 2005). Increasing temperatures in the western Arctic have resulted in increased algal and plant growth, making untreated water sources less desirable.

BOX 1

Local observations of changing water resources

"Freshwater is not as good anymore. It tastes swampy because it is not moving as it should. The water flow in creeks is much less now…Some drinking water sources are not there now." (Tuktoyaktuk resident; Community of Tuktoyaktuk et al., 2005)

"The glaciers, which used to reach right into the sea, have all receded, some to the point that you can no longer see them. Permanent snow, which used to remain in the shady areas have started to melt and are no longer available for water in the summer…the Inuit really depend on this water for their tea." (Pijamini; Nunavut Tunngavik Incorporated Elders Conference, 2001)

Decreases in water quality and accessibility have resulted in northern residents becoming increasingly reliant on bottled water when hunting and fishing away from the community (Nickels et al., 2006). Several communities have reported the need for more frequent water-quality testing of both municipal systems and untreated water sources to ensure safety and confidence in drinking water.

Community Infrastructure

Changes in permafrost may have significant implications for a variety of public infrastructure in northern settlements, including waste-water treatment and distribution, water distribution systems relying on pipes, housing and other buildings, and transportation access routes (Warren et al., 2005). Current issues of overcrowding and the quality and affordability of housing faced by many northern residents complicate these challenges. As of 2001, 54% of residents in Nunavut, 35% in the Inuvialuit Settlement Region of the Northwest Territories and 43% in the Yukon lived in overcrowded homes (Statistics Canada, 2001; Council of Yukon First Nations, 2006). Moreover, 16% of homes in the Northwest Territories and 33% of those in the Yukon required major repairs, as compared with the national average of 8% (Statistics Canada, 2001; Government of the Northwest Territories, 2005; Council of Yukon First Nations, 2006). These issues are of greatest concern in small communities (Government of the Northwest Territories, 2005).

Low-lying coastal communities in areas of high risk of permafrost melting (i.e. areas with significant massive ground ice) are most vulnerable to infrastructure damage (cf. Smith and Burgess, 2004). Some communities in these regions are already reporting damage to community buildings from the combined forces of coastal erosion and permafrost degradation (Community of Aklavik et al., 2005; Community of Tuktoyaktuk et al., 2005; *see* also Section 3.7).

Permafrost degradation and coastal erosion are also damaging important cultural sites (Colette, 2007), and may mean partial or complete relocation of communities in the future (Barrow et al., 2004). Although the shoreline in some communities, such as Tuktoyaktuk, has been reinforced to reduce coastal erosion associated with increased storm surges, decreasing sea-ice cover and increasing water levels, this is only a temporary solution. In Tuktoyaktuk, the community has undertaken consultations on potential relocation plans for portions of the community (Community of Tuktoyaktuk et al., 2005). In many communities, residents are moving buildings back from the shoreline in response to erosion (Communities of the Inuvialuit Settlement Region et al., 2005).

In one of the few studies to estimate costs of infrastructure adaptation, Hoeve et al. (2006) developed an inventory of building foundations in six Northwest Territories communities and conducted a scenario-based approach to estimating costs of adaptation for the territory. Assuming these communities were representative of others in the Northwest Territories, preliminary cost estimates of adaptation could be up to $420 million ('worst case' scenario if all foundations require rehabilitation).

Multiple Stressors and Impacts

Changes in environmental conditions also influence the mental health and well-being of many northern residents whose livelihood and ways of life are strongly connected to the local environment. This is especially the case for the approximately half of Arctic residents whose culture, language and identity are tied inextricably to the land and sea via their Aboriginal heritage and identity (*see* Boxes 2–4). Disruption of traditional hunting cycles and patterns (Ford et al., 2006b; Nickels et al., 2006), reduced ability of elders to predict weather and provide information to others in the community, and concern over losses of cemeteries and homes due to coastal erosion (Community of Tuktoyaktuk et al., 2005) all represent forms of social disruption in communities already undergoing significant change as a result of both internal and external forces. The stresses resulting from these multiple changes have been associated with symptoms of psychosocial, mental and social distress, such as alcohol abuse, violence and suicide (Berner et al., 2005; Curtis et al., 2005).

Each region in Northern Canada is unique with regards to the environmental, social, cultural, economic and political forces that influence change at the local and regional scales. This is very important for regions or communities undergoing various forms of rapid change in many sectors at the same time (Chapin et al., 2005). For example, the increased growth of the wage economy in many regions has reduced both the necessity for, and time available for, hunting, fishing and gathering. This, in turn, has reduced the generation and transmission of traditional knowledge and environmental respect to younger generations, as well as diminishing the health benefits from the consumption of local foods. However, access to the cash economy provides resources for adaptation via the purchase of hunting equipment (e.g. boats, ATVs, snowmobiles) that, in turn, permits individuals to hunt more species over a larger geographic area. Dominant driving forces of change in any one community or region may be enhanced, reduced or altered by aspects of a changing climate (McCarthy et al., 2005). After reviewing key forces and their interactions, Chapin et al. (2005) reported that the deterioration of cultural ties to traditional and subsistence activities, and all they represent, is the most serious cause of decline in well-being among Aboriginal people in circumpolar Arctic regions today (Chapin et al., 2005).

5.3 ADAPTIVE CAPACITY

Adaptation occurs at the individual, collective or systems level, and at local, regional or national scales (Government of Canada, 2001, *see* Chapter 10). For many issues, adaptations will be most effective and sustainable when they are developed at the local

BOX 2

Aboriginal perspectives on climate change impacts and adaptation: Inuit concerns and priorities (prepared by Inuit Tapiriit Kanatami)

The Inuit of Canada are approximately 53 400 in number, inhabiting the Inuvialuit Settlement Region on the Beaufort Sea; the Kitikmeot, Kivalliq and Qikiqtani regions in Nunavut; Nunavik, in northern Quebec; and Nunatsiavut, in northern Labrador (Statistics Canada, 2001). Inuit communities have several common characteristics that make them distinct from other northern Aboriginal populations and southern populations within Canada and strongly influence their vulnerability to changing climate.

Nearly all Inuit communities were established in the last 50 to 60 years, are located on the Arctic or Atlantic coasts, have no road access and depend upon the health and management of the land and oceans to support and sustain a way of life that is based largely on marine activities and resources. Prior to the formation of communities, Inuit were largely nomadic, living throughout the Arctic in dispersed hunting camps and following migratory wildlife. Today, communities are trying to find ways to provide adequate infrastructure and services to meet existing needs, while anticipating further pressures on a young and rapidly growing population. Like other Aboriginal peoples in Canada, Inuit have experienced fundamental and rapid change to their society, language and culture since contact, and these changes continue today. Significant gaps exist between Inuit and other Canadians in areas such as human health, level of secondary and post-secondary education, housing needs, access to early childhood development initiatives, rates of incarceration, and employment rates and income.

Innovative political and administrative institutions established by Inuit, in the form of the four land claim agreements for traditional Inuit territories, play a key role in addressing the challenges and opportunities associated with climate change. Inuit Nunaat (Inuit homelands encompassed by the four agreements) make up approximately 40% of Canada's land mass and an even larger proportion of Canada's total land and marine areas. It includes nearly half of Canada's coastlines and forms virtually all of one territory (Nunavut) and portions of two other territories (Northwest Territories and Yukon) and two provinces (Quebec and Newfoundland and Labrador). As land owners of some of the most sensitive and vulnerable regions in the country to the impacts of climate change, Inuit play a key role in addressing this very important issue.

Through their regional, national and international organizations, Inuit have taken steps to identify the impacts of climate variability and change that are of particular significance for their populations; these priorities are outlined in Table 17. A Partnership Accord, signed by the Inuit of Canada and the federal government on May 31, 2005, includes an Inuit Action Plan that identifies activities and initiatives to be conducted over a three-year period. One of the most important issues in this plan is climate variability and change. In this regard, the plan calls for: 1) a policy process that involves Inuit knowledge alongside science; 2) establishment of an Inuit-driven process to deal with Inuit-specific concerns; 3) increasing Inuit involvement with the Government of Canada to address climate change mitigation and adaptation, both domestically and internationally; 4) a process to follow up on the recommendations of the Arctic Climate Impact Assessment; 5) development of sustainable capacity-building tools supporting Inuit efforts in impacts and adaptations research and planning; and 6) the establishment of a Canadian Arctic Climate Change Strategy that addresses both mitigation and adaptation. The Action Plan also stresses the need for co-operation on key international activities related to climate change, such as those under the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the North American Commission for Environmental Co-operation, and the Arctic Council.

BOX 2 *Continued*

TABLE 17: Priority issues around climate change impacts and adaptation for the Inuit of Canada.

Key issue	Importance for Inuit
Wildlife	Wildlife is more than subsistence and nutrition to Inuit. It plays a role in preservation and promotion of language, culture and traditional knowledge. Hunting is a social process of learning and knowledge transmission in communities, even today. Some key species (e.g. polar bear) require attention to balance interests between conservation and management for wise use by Inuit in the future.
Infrastructure	Inuit communities are located in predominantly low-lying coastal zones, and many are already having to take actions to protect shorelines and buildings, and to consider future relocation as a result of encroaching erosion and existing damage.
Human health	Health impacts of climate change are already reported in many Inuit communities today. Inuit health status is already challenged and climate will influence existing vulnerabilities (social, physical and mental). Ability to adapt is limited by such things as access to medical and emergency services, which are already significantly less in Inuit communities than in other parts of the country.
Food security and contaminants	Reports of impacts on Inuit food security already exist and will combine with the influence of contaminants currently recognized in country foods. Adaptation in response to contaminants is dependent on outside information delivery and education. Current monitoring and research capacity to support informed decision-making is limited. Current economic access to alternatives (healthy market foods) is limited.
Traditional knowledge	Traditional knowledge of the environment (seasonal rhythms, weather prediction, animal migration, and quality and quantity of sea ice) is an important part of Inuit culture. Inuit knowledge plays an important role in development of northern policy, and wildlife management and endangered species regulations. Climate change, along with other forms of change in communities, is threatening and eroding Inuit traditional knowledge. However, its role in adaptive capacity is raising awareness of its value and importance for the future.
Economies	Changing climate is impacting the ability of Inuit to earn income and, at the same time, increasing their expenditures. Inuit have already started to adapt, with individual households bearing the brunt of economic impacts, which are expected to rise.
Emergency management	Emergency preparedness is most critical for small remote communities, such as those in which many Inuit live. Increasing and changing environmental hazards are putting more young Inuit at risk while on the land. Search-and-rescue efforts are becoming more frequent and also more dangerous. Increasing potential risks to health call for enhanced emergency response capability, plans and disaster recovery strategies.
Security and sovereignty	Inuit traditional lands include extensive Arctic coastline, and nearly all communities are coastal. Increased shipping and the opening of Arctic ports will mean significant changes for Inuit communities, including potential risks associated with environmental disasters (spills) and sociocultural change, and benefits (increased opportunities for wage employment).

BOX 3

Aboriginal perspectives on climate change impacts and adaptation: Yukon First Nation communities (prepared by Council of Yukon First Nations)

The Council of Yukon First Nations (CYFN) represents 11 of the 14 First Nations in the Yukon, as well as four Gwich'in First Nations in the Mackenzie Delta region. The CYFN is committed to the promotion of responsible management of the human and natural resources within all its member First Nation traditional territories. The effects of a changing climate on ecosystems are already evident, having been reported by elders and other First Nation members. They include such things as altered seasonal river discharges, insect infestations and changes in forest composition. In partnership with the Arctic Athabaskan Council, CYFN participated in the development of the Arctic Climate Impact Assessment and supports the implementation of its central recommendations. The CYFN has built its own climate change strategy around these objectives. The organization's response is organized around three primary themes:

- core capacity to co-ordinate and manage Yukon First Nation responses to climate change impacts
- support for directed community research
- communication, public education and partnership development

Community-based research and monitoring are viewed as important for developing an overall understanding of potential adaptation. The CYFN argues that such research and monitoring would illustrate the importance of accumulating detailed knowledge of local perspectives and understanding of climate change, and the need for the exchange of information among a diverse group of individuals, including communities, scientists and policy makers. The concerns and priorities of the communities have been documented through workshops and conferences undertaken by CYFN over the past few years. They identify community concerns about the potential impacts of climate change on traditional and non-traditional aspects of society; community social and cultural interactions; and local- and regional-scale economic activities. They describe the problems communities believe they are either already dealing with or are likely to face in the future, and how they might organize themselves to take advantage of opportunities through effective adaptation. Key research themes identified in consultation with First Nations communities are presented in Table 18.

The focus of the CYFN's approach to enhancing adaptive capacity of communities is to provide the right information to the right people at the appropriate time. Drawing upon the findings of the latest research and assessments, it is argued that the promotion of, and support for, sustaining the livelihoods and cultural traditions of Aboriginal peoples and communities requires getting this information out to decision-makers at various levels to support the proactive development and implementation of policies and actions. Yukon First Nation elders have established the Elders Panel on Climate Change and have participated and assisted in directing the work for CYFN on climate change issues. The elders believe that sharing their knowledge will break new ground in contributing an understanding needed to formulate national and circumpolar strategies to investigate and address the issue. Engaging CYFN communities and assisting them in understanding and developing their own adaptive capacities and addressing conflicts in the face of climate change impacts is the primary goal of CYFN efforts in the near term.

TABLE 18: Priority themes for research related to climate change, identified by the Council of Yukon First Nations in consultation with Yukon First Nation communities.

Key issue	Importance for Council of Yukon First Nations communities
Food security	Traditional resource practices of hunting, herding, fishing and gathering remain critically important for local economies, cultures and health of Yukon First Nation members. Characteristic environmental conditions over centuries have enabled communities and peoples to develop skills and knowledge and pass these down between generations. Conditions are changing, and impacts on resource practices are already occurring. Access and legal right to harvest fish and wildlife are protected for Yukon First Nations under existing agreements, yet these institutions may be challenged by changes in climate. Thus, there are political implications for food security that require better understanding to protect these resources for First Nations members.
Community health and well-being	The potential introduction of new diseases into the Yukon is a direct threat to First Nation communities. The combined effects of the biophysical (climate), social, economic and cultural change taking place have significant potential to negatively impact health, which is already stressed on many fronts. Potential impacts on the sustainability of traditional Yukon economies and indirect influences on health and well-being are significant but poorly understood.
Resource-use conflicts	Because of strong involvement in both wage and traditional economies, and potential impacts to both via climate change, there is a need to better understand conflicts arising as a result of impacts and competition between economic sectors (traditional and wage based). There is a need to understand cumulative impacts, including climate, associated with large-scale developments in the Yukon.
Emergency preparedness	There is currently a lack of understanding of the level of First Nations community emergency preparedness in the Yukon to deal with increased risks of extreme weather events and variability and associated natural disasters, such as forest fires, and the potential impacts of climate on remote communities.

BOX 4

Aboriginal perspectives on climate change impacts and adaptation: the Dene Nation (*from* Paci et al., 2005)

The Dene Nation is the Aboriginal political organization mandated to represent the interests and beliefs in Denendeh, which includes more than 25 000 residents living in 29 communities across five culturally and geographically distinct areas. As in other Arctic regions, Dene are experiencing and reporting changes in climate and the environment that are unique to the people of that land. The Denendeh Environmental Working Group (DEWG) brings together Dene and invited guests from government, universities and non-governmental organizations, and has held workshops on climate change knowledge and observations. Workshops have discussed the themes of climate change and impacts on forests, water and fish. Four central questions have shaped much of the DEWG discussion on climate to date (Paci et al., 2005, p. 80):

- Is there a difference today in Denendeh and is climate change having a role in these changes? What else might be causing it?
- What climate change programs are there, and how can our communities be more involved in research and communication about these changes?
- If it is important to document Dene climate change views/knowledge, how should we communicate this knowledge with each other and policy-makers, governments and others outside the North?
- Is the DEWG a good mechanism to discuss climate change? What should we be talking about and what else do we need to do?

A more comprehensive description of Dene observations of climate change and climate impacts in Denendeh is reported in the Arctic Climate Impact Assessment (Paci et al., 2005).

scale and directly involve the individuals affected (Clark, 2006; Furgal and Seguin, 2006). Institutions that facilitate connections across scales help to enhance resilience to change (Berkes et al., 2005). With respect to Northern Canada, studies to date on adaptation have focused mainly on remote communities made up of predominantly Aboriginal residents (e.g. Berkes and Jolly, 2002, and chapters contained therein; Nickels et al., 2002; Ford et al., 2006b). Comparatively less attention has been given in the academic literature to impacts of changing climate on non-Aboriginal residents or adaptation in large municipalities. However, issues such as impacts and vulnerabilities of municipal infrastructure and transportation have been recognized for their significance, and some governments have been working to address them in recent years (e.g. Government of Nunavut, 2006).

Workshops and research projects conducted throughout the North have reported that individuals are already adapting to reduce the impacts of climate change on aspects of their lives and livelihoods, primarily in a reactive manner (*see* examples in previous sections of this chapter). The ability to adapt is influenced by factors such as access to economic resources, technology, information and skills, institutional arrangements, equity among members of a group, risk perception and health status (*see* Chapter 2; e.g. Kovats et al., 2003; Smit and Pilifosova, 2003). As outlined in Section 2.2, many of these factors vary significantly between regions and also within regions between smaller remote communities and larger regional centres and municipalities. Consequently, the adaptive capacity and resilience of individuals and communities to climate and other forms of change vary by geography, sociodemography, economic status and culture. Nonetheless, it is possible to identify some sources of social and economic resilience and vulnerability, and associated opportunities for adaptation, that are common to many Arctic societies (Table 19; Chapin et al., 2006).

Erosion of Traditional Capacities

The Arctic has experienced significant climate change in the past. The archeological record, ethnohistorical accounts and memories of Aboriginal elders provide detailed accounts of how periodic, irregular and often dramatic ecosystem changes, triggered by periods of warming or cooling and extreme weather events, have been a dominating influence on human life in the Arctic. The successful long-term habitation of the Arctic by Aboriginal peoples has been possible because of the capacity of their social, economic and cultural practices to adjust to climate variation and change. For millennia, Arctic populations adapted to gradual or even rapid environmental change by resettling amid favourable environments and along the paths of animal migration routes (Nuttall et al., 2005). The massive social, cultural and economic changes that have occurred since Aboriginal peoples have settled in permanent communities, predominantly over the last 50 to 60 years, have significantly eroded the traditional aspects of their socioecological resilience and adaptive capacity (Berkes and Jolly, 2002). New economic opportunities that could be presented as a result of climate change should result in increased wage employment. This, in turn, is likely to further reduce opportunities for individuals to gain the land-based skills and traditional knowledge necessary to continue aspects of subsistence and traditional livelihoods.

Economic Resources

Northern communities, however remote or small, are tied economically and politically to the national mainstream. Trade barriers, wildlife management regimes, globalization, and political, legal and conservation interests all affect the abilities of northerners to meet the challenges posed by changing climate. Several northern issues are unique within Canada. For example, even though the Government of Nunavut estimates that it would cost approximately CDN$35 million annually to replace food secured through traditional and subsistence activities, virtually

TABLE 19: Sources of social and economic resilience and vulnerability that characterize many Arctic systems (*from* Chapin et al., 2006).

Arctic characteristics	Sources of resilience	Sources of vulnerability	Opportunities for adaptation
Social and institutional properties	Sharing of resources and risks across kinship networks Multiple jobs and job skills held by an individual ('jack of all trades')	Inadequate educational infrastructure to plan for future change Relatively unskilled labour force	Learning and innovation fostered by high cultural diversity
Land tenure and use rights are regionally variable; where strong there is flexibility for adaptation			
Economic properties	Flexibility to adjust to change in mixed wage-subsistence economy	Decoupling of incentives driving climatic change from economic consequences Non-diverse extractive economy: boom-bust cycles Infrastructure and political barriers to relocation in response to climate change	Substitution of local resources for expensive imports (food, fuel) National wealth sufficient to invest in adaptation
Retention of rents from development are regionally variable; where present, they can build infrastructure and social capital that allow adaptation and diversification			

none of this traditional wealth can be converted into the money needed to purchase, operate and maintain the equipment that hunters use. Abandoning hunting for imported food would not only be less healthy than continued use of country/traditional foods, but would also be immensely costly (Nuttall et al., 2005).

The natural resource extraction economy of many northern regions provides an economic base to support various adaptations to environment change. As a result, some regions have a far greater capacity to adapt in the short term if they are able to benefit from these activities. However, as noted by Justice Berger (Berger, 2006), Inuit (and all northerners, for that matter) must be educated and ready to take part in the economic opportunities that future changes may create in the North, such as enhanced oil and gas exploration and development, intensive development of mineral resources, enhanced navigation, and port and other infrastructure development. Current levels of skilled labour and formal education often limit the abilities of northerners to take advantage of such opportunities.

Information and Technology

Ford et al. (2006b) discussed the importance of traditional skills and knowledge, social networks and flexibility towards resource use in their analyses of vulnerability to climate change, primarily among hunters. Many other studies have noted the importance of combining scientific knowledge and traditional knowledge in the effort to understand aspects of climate change, impacts and local-scale responses (e.g. Parlee et al., 2005; Furgal et al., 2006; Gearheard et al., 2006; Laidler, 2006;). Traditional knowledge systems and skills are central components to many individual responses to environmental change, yet are being challenged and, in some cases, eroded by the combined forces of environmental and social change in northern communities (Nuttall et al., 2005; Ford et al., 2006b; Lacroix, 2006). This erosion is particularly acute among younger Aboriginal residents engaged in full-time wage-earning employment. Nevertheless, at the same time that their adaptive capacity in response to environmental change is diminishing in one respect, it is also enhanced as a result of increased access to economic resources and technology. As a result, it is difficult to project the net impact of all combined forces of change very far into the future.

Policies and Institutional Capacity

Chapin et al. (2006) and Ford et al. (2007) recommended adaptation policies aimed at supporting aspects of resilience in northern communities and sectors. These include such things as ensuring flexibility in resource management regimes (e.g. Adger, 2003), support for formalized teaching of traditional skills and knowledge, and economic support for the pursuit of traditional and subsistence ways of life (e.g. Ford et al., 2007). They also place emphasis on skills training and development so that northerners are better prepared to adapt to, and derive benefits from, the rapidly changing northern social, economic and physical environment (e.g. Berger, 2006).

The development and implementation of such policies requires institutional awareness and vision. Of particular importance is the manner in which organizations and individuals interact — in the public sector, across government and non-governmental organizations, and within society (Adger, 2003; Willems and Baumert, 2003; Berkes et al., 2005). There are some examples of institutional capacity in the North to address climate change. Where government departments and organizations have developed and implemented adaptation plans, or where groups engaging Aboriginal organizations, government representatives and the general public have convened to identify common challenges and how to address them, there is evidence of the effect that mobilizing the existing local, territorial and regional capacity can have. Nevertheless, the effective implementation of policies and measures will require maintenance and strengthening of climate-related expertise and perhaps the creation of new institutional arrangements for a variety of policy areas in the North, particularly related to public safety and economic development. Use of existing institutional capacity to integrate (mainstream) climate concerns into existing policy and program areas is an important goal.

6 CONCLUSIONS

Canada's Arctic has already experienced significant changes to its climate that are producing cascading effects on physical, biological, economic and social systems. The sensitivity of these systems to climate change is relatively high because of their dependence on the predictability and characteristic stability of the cryosphere (snow, glaciers, freshwater/sea ice and permafrost). Current climate trends are likely to continue and intensify, creating unique conditions, challenges and/or opportunities for natural and human adaptation.

Major changes are expected in a variety of resource sectors, including hydroelectric generation, oil and gas, mining, forestry and fisheries. Locally, hydroelectric facilities and operations will need to be adapted to changing flow regimes associated with an altered timing and magnitude of snowmelt runoff. Perhaps more important, however, will be a need to consider the implications of future impoundments as the needs for additional and renewable energy increase, particularly on the northward-flowing Mackenzie River system. Where older infrastructure in the Arctic overlies thaw-sensitive permafrost, some form of structural or operational adaptation may be needed to deal with permafrost thawing, and there is evidence that some adaptive measures are already being undertaken (Section 4.4). An important issue for the mining industry is the containment of wastes. Historically, the industry has relied on the impervious nature of permafrost to ensure long-term storage, but future permafrost thaw could eliminate the option of such surface-storage approaches and require remediation of older storage sites. In the case of the oil and gas industry, changing climate will affect exploration, production and delivery. Projected reductions in sea-ice cover, for example, are likely to be beneficial to exploration and development in both the energy and mining sectors, leading to further economic development.

Reductions in the thickness and seasonal extent of river, lake and sea ice will require adaptation of marine and freshwater transportation activities. These will vary from changes in the types of vessels used and the routes followed to a shift to more barge- and land-based traffic as ice roads and crossings become less viable. For the marine system, increases in navigability also raise important issues about the international use of the Northwest Passage. Expansion of marine and land-based transportation would have synergistic effects on resource exploration, as previously remote resources would become more accessible and economically viable to exploit. These changes will introduce new risks and opportunities for human settlements. The influx of wage employment may enhance adaptive capacity to some climate impacts; however, greater involvement in full time jobs will continue to be associated with current trends of social and cultural erosion.

Changes in habitat quality and quantity in the fisheries and forestry sectors will require adaptation ranging from shifts in management strategies to alterations in the equipment used. For both sectors, there are also concerns about how to deal with invading species and changes in biodiversity. Modified sustainable management plans will be required for both sectors to deal with future changes in climate. Key Arctic wildlife species at their southern limits are already being affected by changing climate, and alterations in management regimes and potential changes in boundaries of protective areas may be required. Actions to better understand and protect genetically unique and sensitive species that have undergone recent significant declines, such as the caribou herds of the central and western Arctic, will help support the health and cultural well-being of Aboriginal Arctic populations.

The direct health impacts of climate extremes and natural disasters are most significant for communities and individuals living in more environmentally exposed locations (e.g. remote, low-lying coastal areas and isolated mountainous regions), which are situated farther from emergency health services and with less developed emergency preparedness plans. Elders and those individuals with an already challenged health status are most vulnerable to temperature extremes. Many of the populations most highly exposed to the indirect impacts of climate change are already under stress from other forms of change, so the specific role of climate is often difficult to isolate. Based on increased exposure to untreated water sources and challenges in the effective use of municipal treatment systems in some small communities, these settlements are more vulnerable to the effects of warming on drinking water quality. However, large communities also face risks to water quality and supply because the access, treatment and distribution of drinking water is generally dependent upon a stable platform of permafrost for pond or lake retention, a situation that is currently changing.

Communities and households most vulnerable to the effects of climate change on food security are those that depend on a limited number of country/traditional food species, are high consumers of country/traditional foods, are located farther from regional centres and have limited access to market foods. Many of these communities also lack the economic resources to purchase new and more powerful hunting and transportation equipment to adapt to changing environmental conditions. Adaptation measures in the form of intercommunity trade programs, community freezers and a variety of individual behavioural changes have been developed by some communities to reduce the impacts already being experienced.

The political, cultural and economic diversity of northern Canada means that communities are affected by, and respond to, environmental change in different ways. For many of the currently identified climate-related impacts, it appears that the larger municipalities and their residents are less vulnerable than smaller, more remote communities. Larger municipalities are generally less exposed to climate risks, and have greater capacity to adapt (e.g. greater access to economic resources, technology, infrastructure and health services). At the same time, however, groups and individuals residing within regional centres are dependent upon municipal infrastructure, which is sensitive to climatic change. Within the smaller, predominantly Aboriginal communities, many other factors influencing adaptive capacity are stronger, including traditional knowledge and skills, social capital, and risk perception and awareness. As vulnerability is a function of exposure and the ability to adapt, and these concepts vary within and between communities for particular climate-related impacts and opportunities, it is not possible to generalize climate change vulnerability across the Canadian North.

It is evident that the Canadian Arctic is already undergoing significant changes in climate, and that these changes are affecting almost every aspect of the northern environment and population. Many communities have already begun adapting. However, knowledge gaps remain regarding the thresholds at which impacts occur, how best to support ongoing adaptation efforts, where adaptation is not possible, and what the limits to adaptation strategies are for various locations and groups. Strengthening understanding in these areas will support more informed decision-making on these issues in future.

7 ACKNOWLEDGEMENTS

The authors would like to thank Ross Mackay (Environment Canada, National Hydrology Research Centre, Saskatoon) for acquisition and processing of data and Elaine Barrow for creation of future climate-scenario projections. Also, the authors gratefully acknowledge the extensive proof-reading conducted by Steve Deschênes, Jane Drengson and Simon Van de Wall (Water and Climate Impacts Research Centre, Environment Canada/University of Victoria). Margaret Treble and Brian Dempson (both of Fisheries and Oceans Canada) are acknowledged for their contributions to the fisheries section of the chapter.

The authors also thank the following people for providing input to development of the Northern Canada chapter by participating in regional workshops:

Rick Armstrong, David Black, Jackie Bourgeois, Bob Bromley, Lilian Chau, Yanie Chauret, Rebecca Chouinard, Shirley Cook, Paul Crowley, Pauline Deehan, Cindy Dickson, Michelle Edwards, Karen Felker, Aleta Fowler, Savanna Hayes, Jenny Ipirq, Stanley James, Mary Jane Johnson, Tom Livingston, Hugh Lloyd, John MacDonald, Johanna Martin, Steve Matthews, David Milbourne, Scott Milton, Lorne Napier, Marie-Eve Neron, Mike Nitsiza, Aynslie Ogden, Bruce Rigby, Doug Ritchie, Julie Roberge, June Shappa, Jamal Shirley, John Streicker, Mary Tapsell, Jessica Thiessen, Mary-Ellen Thomas, Dan Utting, Jody Butler Walker, Laurie Anne White, Michael Westlake, Richard Zieba.

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CHAPTER 4
Atlantic Canada

ATLANTIC CANADA

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Recommended Citation:

Vasseur, L. and Catto, N. (2008): Atlantic Canada; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 119-170.

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KEY FINDINGS

Atlantic Canada will experience more storm events, increasing storm intensity, rising sea level, storm surges, coastal erosion and flooding. Coastal communities and their infrastructure and industries, including fisheries and tourism, are vulnerable to these changes. Impacts on coastal infrastructure, such as bridges, roads and energy facilities, have already affected trade and tourism in the region, and some coastal communities have started experiencing saltwater intrusion in their groundwater supply. Future disruptions to transportation, electricity transmission and communications will have widespread implications, including increasing the susceptibility of some communities to isolation.

Water resources will come under pressure as conditions shift and needs change. Seasonal and yearly variations in precipitation will combine with higher evapotranspiration to induce drier summer conditions, especially in Maritime Canada. Limited water resources would affect municipal water supplies and challenge a range of sectors, including agriculture, fisheries, tourism and energy.

For marine fisheries, impacts will extend beyond fish species to include numerous aspects of fishery operations, including transportation, marketing, occupational health and safety, and community health. Harvesters of wild marine resources are constrained in their potential responses to climate change by the existing regulatory regimes. Integration of climate change into assessments and policy development would allow more effective management of marine resources.

Although higher temperatures and longer growing seasons could benefit agriculture and forestry, associated increases in disturbances and moisture stress pose concerns. Changes in climate have implications for management of agricultural production and farm water usage. Re-examination of cropping systems and improved water management would help the agricultural sector to adapt, although non-climatic factors, such as socioeconomic and demographic trends, may limit adaptive responses. In some areas of the Maritimes, forested areas will be affected by drier summers, potentially leading to reduction or loss of species that prefer cooler and wetter climates. Options for short-term adaptation, although limited in the forestry sector, are likely to focus on minimizing other stresses and preserving genetic diversity.

Vulnerability to climate change in the Atlantic region can be reduced through adaptation efforts focused on limiting exposure and through careful planning. Identifying vulnerable infrastructure, incorporating river and coastal flooding in land-use policies, revising emergency response measures, and accounting for sea-level rise when planning and building infrastructure would reduce damage to infrastructure and the environment, and lessen the risk to human health and well-being. Other effective adaptation measures include managing development in coastal areas, preventing construction in areas of known vulnerability, and protecting coastlines around significant sites. In some communities, low adaptive capacity due to aging populations and average annual incomes lower than the national average will make adaptation challenging to implement.

1 INTRODUCTION

Atlantic Canada includes the provinces of New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island (Figure 1a, b). Newfoundland and Labrador has the largest area of the four provinces, more than three times the land area of the three Maritime Provinces combined, and extends from latitude 60°23'N (Cape Chidley) to latitude 46°37'N (Cape Pine). Of the three Maritime Provinces, New Brunswick is the largest and Prince Edward Island the smallest. The southernmost point in Atlantic Canada is Cape Sable, NS (43°28'N). With the exceptions of Churchill Falls, Labrador City and Wabush, NL, no community is more than 200 km from the nearest marine shoreline.

Atlantic Canada includes the entire region — the provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador.

Maritime Canada (or the Maritimes) includes New Brunswick, Nova Scotia, and Prince Edward Island, but not Newfoundland and Labrador.

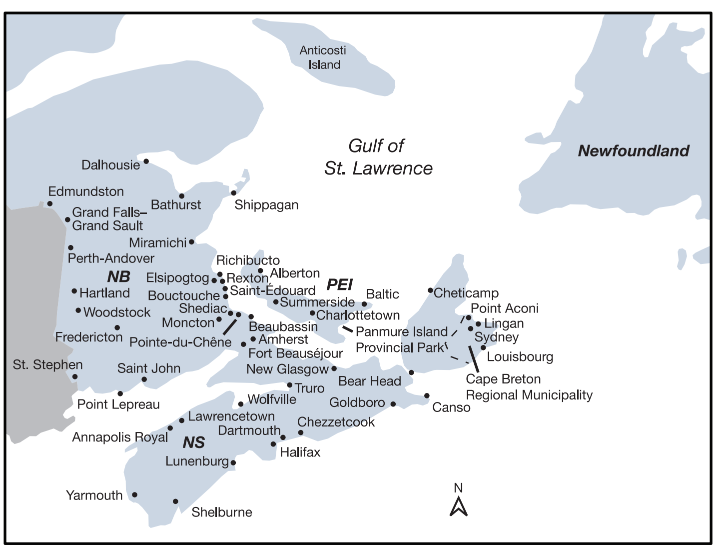
1.1 DEMOGRAPHIC PROFILE

The total population of the four Atlantic Provinces was 2.34 million in 2005 (Statistics Canada, 2005a, b), virtually unchanged from 2004. While Newfoundland and Labrador and New Brunswick experienced a decline in population, Prince Edward Island and Nova Scotia showed an increase in population during the same period (Table 1). Considering that most communities of the region are aging (Table 1) and have average annual incomes below the national average, any impacts due to climate change will represent an additional challenge to these provinces.

1.2 ECONOMY

Atlantic Canada includes numerous rural communities, along with urban centres such as the Halifax Regional Municipality, Cape Breton Regional Municipality, Moncton, Saint John, Fredericton, Charlottetown and St. John's. Substantial discrepancies exist between rural and urban areas, with rural communities generally marked by populations with fewer economic resources, leading to the out-migration phenomenon observed in rural Atlantic Canada. Population growth rates in Halifax (+4.6%) and Moncton (+3.6%) between 1996 and 2001 are in contrast to losses in rural areas (Statistics Canada, 2001b). Of the twenty regional economic zones throughout Newfoundland and Labrador, only five are projected to have population increases between 2006 and 2019 (Newfoundland and Labrador Department of Finance, 2007).

a)



b)

FIGURE 1: Communities in the Atlantic provinces: a) New Brunswick, Nova Scotia, and Prince Edward Island; and b) Newfoundland and Labrador.

TABLE 1: Demographic parameters for the Atlantic provinces (*from* Statistics Canada, 2005a, b).

	New Brunswick	Newfoundland and Labrador	Nova Scotia	Prince Edward Island	Canada
Population, 2005	752 000	516 000	937 900	138 100	32 270 500
Population change, 2004–2005 (%)	–0.01	–0.25	+0.04	+0.14	+0.9
Net interprovincial migration, 2004–2005[(1)]	–1650	–1875	–473	–222	N/A
Population density, 2005 (persons/km^2)	10.3	1.27[2]	17.0	24.4	3.2
Urban (%)[(3)]	50	58	56	45	80
Ages 0–14 (%)	16.1	15.7	16.2	17.7	17.6
Ages 15–64 (%)	69.9	71.2	69.5	68.2	69.3
Ages 65+ (%)	13.9	13.1	14.2	14.1	13.1
Projected population by 2030	742 600 (–1.3%)	490 000 (–5.3%)	940 100 (+0.02%)	141 500 (+2.1%)	36 182 300 (+11.1%)

[1] includes migration between Canadian provinces, both within and outside Atlantic Canada; for all four provinces, the dominant destinations were Alberta and Ontario (Statistics Canada, 2005a, b)
[2] Newfoundland 4.38 persons/km^2; Labrador 0.95 persons/km^2
[3] 2001 census

Socioeconomic differences between rural and urban areas can lead to differences in community vulnerability to the impacts of extreme weather events and climate change (Morrow, 1999; Alchorn and Blanchard, 2004; Catto and Hickman, 2004). Historically, a large part of the population of Atlantic Canada relied on natural resources, including fisheries, agriculture, forestry and mining. With globalization and changing demographics, however, Atlantic Canada has experienced a significant reduction of jobs in communities relying on a single resource-based industry (e.g. industrial Cape Breton, NS; Shippagan, NB; Stephenville and Harbour Breton, NL). Burgeo, NL is typical of many fishery-dependent communities: in May 2001, the employment rate for people aged 18 to 64 was 35%, in contrast to the provincial rate of 55% (Government of Newfoundland and Labrador, 2006). The urbanized areas of Atlantic Canada have been the main focus of the local economy, and have seen greater opportunities in the global market.

This divergent regional development has produced a gap between rural and urban regions. The labour market has been transformed during the past several decades from having an important rural component, with a resource-based economy, to a labour force that relies mainly on technology and advanced knowledge to compete at the global market level. The workers with better skills can get new jobs, mostly in services and entrepreneurship. Many are now self-employed workers, bringing business and the economy of the Atlantic Provinces to national and international markets. Simultaneously, the resource-based rural and smaller communities are facing international competition, particularly in fish processing and paper manufacturing, as well as domestic competition, predominantly with potatoes and other agricultural products. In many rural areas, the response of some workers has been to leave Atlantic Canada in search of employment, or to accept positions in western Canada while maintaining permanent residences and leaving immediate family in Atlantic Canada.

Both rural and urban economies are sensitive to changes in the global market. Job maintenance and creation are highly dependent on the competitiveness and productivity of businesses, and on intergovernmental and foreign policies. Access to marine transportation has helped this region contribute to Canada's trade balance. With future climate change, this heavy reliance on marine and coastal systems and communities may increase vulnerability, especially if transportation and infrastructure are disrupted by storm events.

1.3 ABORIGINAL COMMUNITIES

Aboriginal communities, including Innu, Inuit and Migmag among others, have a distinctive set of socioeconomic conditions. Characteristically, these communities have higher proportions of young citizens (e.g. 43.1% of the population of Nain in 2001 was 19 years of age or younger; Government of Newfoundland and Labrador, 2006). Per capita earnings and incomes are lower than for the general populations of the region (e.g. for Lennox Island, PE, the median total income for persons 15 and over was $12 272 in 2001, compared with a provincial average of $18 880; Statistics Canada, 2001b). Education levels are generally lower as well (e.g. at Whycocomagh, NS, 29.4% of the population between ages 20 and 34 have not graduated from high school, compared with 16.1% of the general population of Nova Scotia; Statistics Canada, 2001b).

BOX 1

Addressing climate change in Elsipogtog

Migmag communities of the New Brunswick eastern coast are concerned about the impacts of climate change on the sustainability of their traditions and access to natural resources. This is especially important for the traditional food and medicines found in salt marshes. The protection of traditional knowledge and resources is an important way for the Migmag to protect their culture.

A survey of traditional plants was completed in collaboration with the Elsipogtog Community to understand the potential impacts of climate change on their traditional resources. Field data were then combined into a digital elevation model (DEM), built using laser imaging detection and ranging (LIDAR) data. Several flooding scenarios integrating projections of sea-level rise and terrestrial subsidence (e.g. Carrera and Vaníček, 1988) were developed to evaluate the impacts of sea-level rise on the existing populations of sweetgrass and other medicinal plants located in salt marshes.

Sweetgrass
(*Hierochloa odorata*)

Sweetgrass is a very important plant for Aboriginal communities. It is used in ceremonies as incense, to weave baskets, as ornaments and in teas. The modelling is an extension and new application of the Thompson et al. (2001) methodology, and based on the reconstruction of the model of the storm-surge events of January 21, 2000. Results show that, even under the most optimistic scenario, the flood line reached the forest, flooding all the salt marshes.

Planning is now the main focus of the community. Historically, Aboriginal people did not build permanent housing along the coast, as this habitat is very fragile and sensitive to human influence. With establishment of reserves, coastal infrastructure became more common. Under the current conditions, moving structures from the coast would require the community to acquire new lands farther inland, as the current reserve is a very narrow strip along the coast. Any acquisition of land would mean changes in the planning and land development of the adjacent communities, such as Richibucto.

Other approaches for adapting to climate change and sustaining the traditional use of resources, which were suggested in community discussions, included the following:

- Maintain the status quo (i.e. let everything stay as is and nature will take its course).
- Move some or all of the existing infrastructure currently located near marshes farther inland.
- Protect zones for the future, rehabilitate marshes that were destroyed and protect remnants of marshes.
- Plant sweetgrass in areas that are suitable for growth.
- Involve the community in all these actions, including education.

Through these discussions and actions, Elsipogtog has initiated its own journey to adapt to projected climate change.

Aboriginal communities have observed changes in their environments due to climate change (Gosselin, 2004). The coastal locations of many communities put them more at risk to climate change. Traditionally, many Aboriginal communities practiced seasonal migration, an adaptation to changing environments. Modern settled communities, however, are vulnerable to loss of coastal land (*see* Box 1). Lower education levels, lower incomes and substandard infrastructure relative to national averages can impose additional difficulties for Aboriginal communities.

Another climatically sensitive aspect of Aboriginal life centres on the importance of country foods. Seal, salmon, caribou, rabbit, partridge, ducks, berries and other foods offered by the land and sea all form part of the diet of Aboriginal communities (Degnen, 1996; Hanrahan, 2000). Changes in climate and habitats that may alter the quality and quantity of these resources pose further problems. Country foods add important nutrients, particularly in Labrador where purchased food is very expensive. The spiritual and cultural health of many communities depends upon food procurement activities. For example, Mukushan, a communal meal celebrated by Innu after a successful caribou hunt to honour the spirit of the caribou, is an important part of Innu culture. Communal trips into the country, where families spend two or three months hunting, fishing and gathering food supplies, are a significant cultural activity for Sheshatshiu and Natuashish (Degnen, 1996; Matthews and Sutton, 2003). Traditional knowledge is maintained by participating in such activities and by passing the knowledge on to younger generations. Changes in the availability of country food could jeopardize this process of cultural continuance. Although climate change is just one of many concerns facing Aboriginal populations, the importance placed on protecting sources of traditional foods and medicine, and the sacred value of water, can rapidly become a priority.

1.4 ECOZONES

The ecological diversity of Atlantic Canada is demonstrated by the number of terrestrial ecozones (Figure 2; Environment Canada, 2005b) and ecoregions (Sabine and Morrison, 2002). Climate regions range from cool humid-continental through subarctic to arctic tundra, with the influence of the warm Gulf Stream in the south giving way to that of the cold Labrador Current in the north. Seasonal conditions reflect competing tropical and polar, continental and maritime influences. Along the Atlantic Ocean coastline, multi-decadal variability in weather systems and their effects, particularly in winter, are associated with the North Atlantic Oscillation (NAO; Marshall et al., 2001).

The **Atlantic Maritime** ecozone consists of Nova Scotia, Prince Edward Island, New Brunswick and the Gaspé region of Quebec (Figure 3a, b). The Gulf of St. Lawrence coast of New Brunswick forms a plain that slopes gently eastward, with long shallow

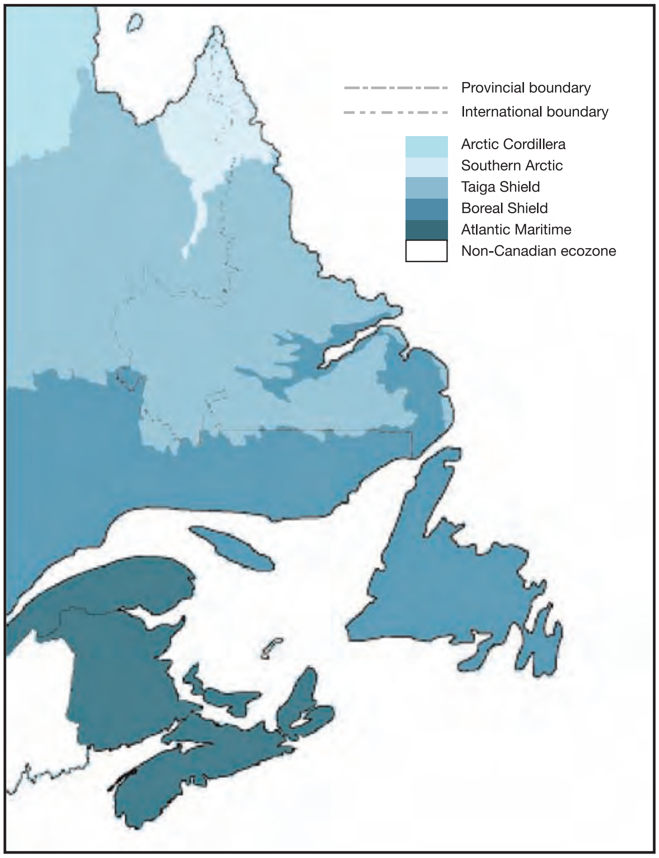


FIGURE 2: Terrestrial ecozones of Atlantic Canada. (*after*: Agriculture and Agri-Food Canada).

embayments and salt marshes. Rolling to rugged uplands, with much terrain more than 200 m above sea level, characterizes western New Brunswick, the margins of the Bay of Fundy and most of Nova Scotia. Coastlines are deeply indented, dominated by cliffs and gravel beaches, and characterized by steep offshore bathymetry. The Nova Scotia coast of the Bay of Fundy has steep cliffs flanking the shoreline. Inland is a steep escarpment 120 to 150 m high. The topography of the low-lying plain of the Annapolis Valley, and the rolling hills of the Nova Scotia Uplands, trend northeast. Cape Breton Island has irregular hills, steep escarpments and flat-topped to rolling plateaus, dissected by short steep streams with numerous cataracts and waterfalls. Prince Edward Island is an undulating plain of low relief with well-developed sand dune and beach systems.

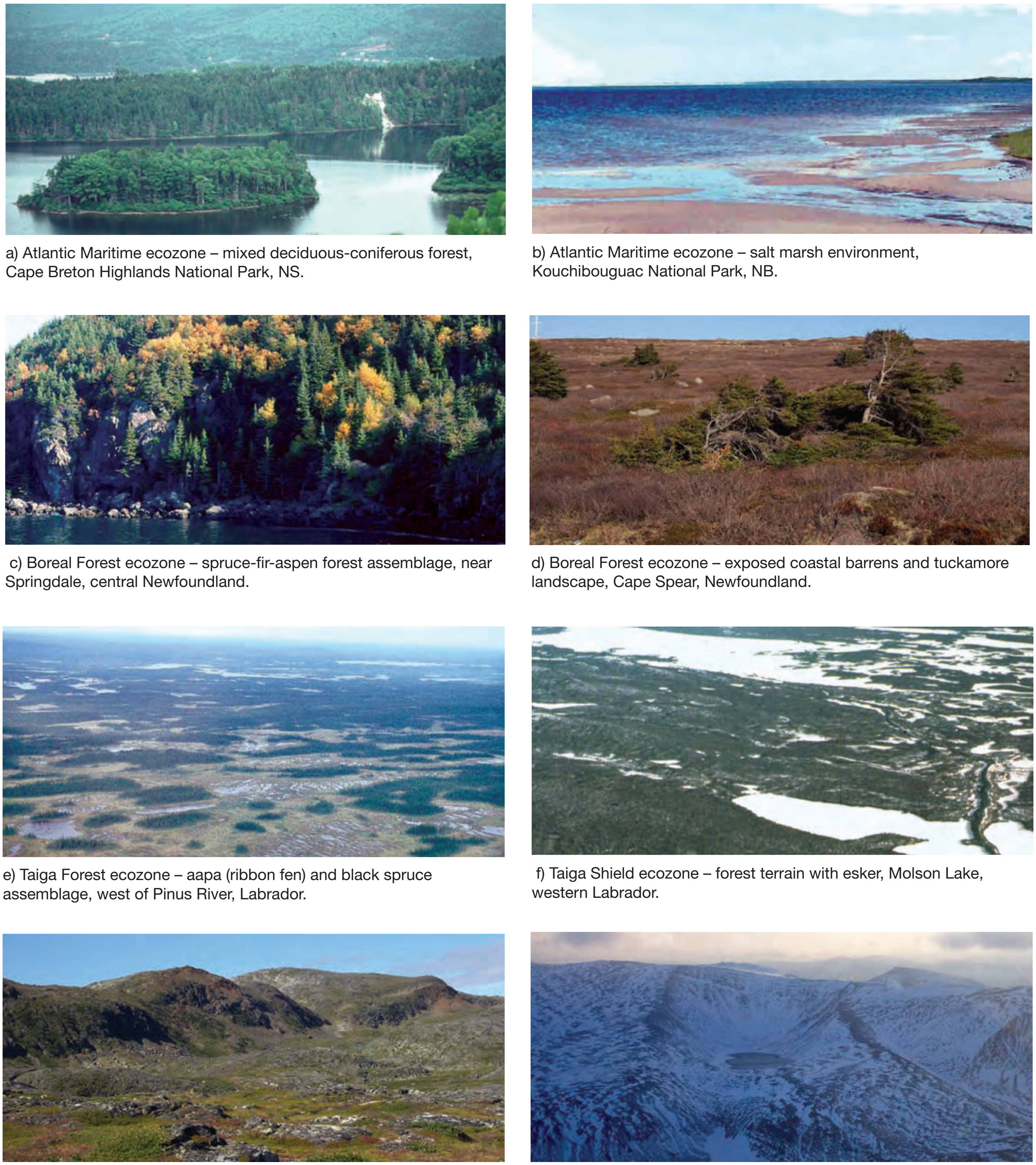
The Atlantic Maritime ecozone is the warmest in Atlantic Canada, with southern to mid-boreal climates. Mean winter temperatures range from −8 to −2°C (Environment Canada, 2005a). Mean summer temperatures vary regionally between 13 and 15.5°C. Mean annual precipitation ranges between 800 and 1500 mm. The New Brunswick climate varies with distance from the Gulf of St. Lawrence coastline, as both moist Atlantic air from the Bay of Fundy and humid winds blowing from the New England and Great Lakes–St. Lawrence Lowland regions influence the region. Interior areas have a more continental climate, whereas regions along the Bay of Fundy have cool summers and mild winters. Fog is common in exposed coastal areas. Nova Scotia is constantly influenced by the ocean, but coastal regions of the province still have cooler springs and summers and milder winters than interior sites. Ice cover on the Gulf of St. Lawrence during winter brings cooler temperatures and a later spring. Prince Edward Island receives the strongest maritime influence of the three provinces, and has mild winters, late cool springs and moderate windy summers.

Mixed-wood forests are the primary vegetation in this ecozone. Red spruce, balsam fir, yellow birch and sugar maple are the main species, with significant numbers of red and white pine, and eastern hemlock. Acadian Forest assemblages were the pre–European settlement vegetation in most of Prince Edward Island, southeastern New Brunswick and sheltered areas of mainland Nova Scotia. Boreal species, such as white birch and black and white spruce, are also present. Shrubs in the ecozone consist of willow, pin cherry, speckled alder and blueberry. In terms of a natural resource–based economy, forest industries represent a major economic component of this ecozone, together with fisheries (mostly lobster, finfish and aquaculture) and local mining.

The island of Newfoundland, the southeastern corner of Labrador, and the shoreline of Lake Melville are part of the **Boreal Shield** ecozone (Figure 3c, d). The island of Newfoundland features diverse topography. The Avalon Peninsula has rolling uplands interspersed with small plateau regions, embayments, short rivers with steep-gradients and cliffs up to 65 m high. The central part of the island includes ridges interspersed with undulating terrain and small plateaus. Relief is generally less than 200 m. The coastline is ragged, marked by deep indentations, cliffed headlands and numerous islands and skerries. Locally, cliffs rise in excess of 100 m. Beaches are restricted to sheltered coves and are dominated by cobbles and pebbles. The western coast is a region of rugged topography, grading eastwards into rolling plateaus. Relief exceeds 800 m. A narrow costal plain discontinuously borders the western margin of the island.

Southeastern Labrador is rough and undulating, with isolated patches of permafrost. Elevation rises rapidly from the coast to 365 m above sea level. The area around Lake Melville is coastal lowland. To the south and west of the Lake Melville Plain, the terrain is dissected by river valleys, with some hills reaching 500 m.

Precipitation in this mid-boreal climate ranges from 900 to 2000 mm annually (Environment Canada, 1993, 2005a). Mean temperatures in the summer vary from 8.5 to 12.5°C, whereas



a) Atlantic Maritime ecozone – mixed deciduous-coniferous forest, Cape Breton Highlands National Park, NS.

b) Atlantic Maritime ecozone – salt marsh environment, Kouchibouguac National Park, NB.

c) Boreal Forest ecozone – spruce-fir-aspen forest assemblage, near Springdale, central Newfoundland.

d) Boreal Forest ecozone – exposed coastal barrens and tuckamore landscape, Cape Spear, Newfoundland.

e) Taiga Forest ecozone – aapa (ribbon fen) and black spruce assemblage, west of Pinus River, Labrador.

f) Taiga Shield ecozone – forest terrain with esker, Molson Lake, western Labrador.

g) Arctic Cordilleran ecozone – tundra landscape and vegetation, Hebron, Labrador.

h) Arctic Cordilleran ecozone – glacial cirques, Torngat Mountains, Labrador.

FIGURE 3: Examples of Atlantic Canada's terrestrial ecozones.

the winter range is –20 to –1°C. The topography causes storm systems to diverge, either along the west coast or across the Burin and Avalon peninsulas. Spring and summer are cool. Moderating ocean influences are most evident along the west and south coasts, which are washed by the Gulf of St. Lawrence and Gulf Stream, but are less apparent along the northeast coastline, which is influenced by the Labrador Current and the NAO. Interior sites have warmer summers and cooler winters than do adjacent coastal regions.

This ecozone is mostly forested, with black and white spruce, balsam fir, larch (tamarack), white birch and aspen poplar being the dominant species. Lichens and shrubs grow in areas of exposed bedrock. Although forestry is important in some parts of this ecozone, fisheries and mineral exploration are the main components of the resource-based economy.

The **Taiga Shield** ecozone encompasses most of Labrador (Figure 3e, f). It is marked by rolling topography, with generally less than 200 m of elevation difference between the deepest valleys and the adjacent summits in western Labrador. In contrast, the Mealy Mountains have rugged terrain. Elevations of the summits reach 1190 m, and areas of permafrost occur locally.

A northern boreal climate characterizes the Taiga Shield ecozone. The prevailing westerly winds bring dry air from northern Quebec, producing cold dry winters with calm days and minimal humidity in interior locations. Summers are short and cool with long days. Coastal locations are influenced by the Labrador Current, and have cooler summer conditions. Annual precipitation ranges from 800 mm in western regions to more than 1000 mm in areas along the coast (Environment Canada, 2005a). Mean winter temperatures vary from –25 to –10°C; summer means are between 6.5 and 10°C.

Vegetation varies from forests of black and white spruce and balsam fir to shrublands and meadows. Fens and bogs have alder, willow and larch (tamarack) in addition to the conifer species. Riverbanks and upland sites support white spruce, trembling aspen, balsam poplar and white birch. Mineral resources and hydroelectric power generation are the main economic activities.

The southernmost portion of the **Arctic Cordillera** ecozone contains the Torngat Mountains of northern Labrador (Figure 3g, h). The tundra climate in the Torngat Mountains is cold and humid with short, cool, moist summers and long, cold winters. Coastal ice may persist into July. Mean annual precipitation ranges from 400 to 700 mm, with higher values in central areas of high elevation. The mean winter temperature is –16.5°C and the summer mean is 4°C. Sheltered, south-facing valley slopes support patches of arctic mixed evergreen and deciduous shrubs, while other areas are sparsely covered with moss, lichen and sedges.

2 CLIMATE AND CLIMATE-RELATED TRENDS AND PROJECTIONS

2.1 TEMPERATURE AND PRECIPITATION

Regional trends in seasonal temperatures for Atlantic Canada show an overall warming of 0.3°C from 1948 to 2005 (Lewis, 1997; Lines et al., 2003; Environment Canada, 2005c), with summers showing the greatest increase in temperature (+0.8°C mean). Warming characterizes springs (+0.4°C) and autumns (+0.1°C), whereas winters have become colder (–1.0°C). Daily minimum temperatures show a slight increase (+0.3°C), but daily maximums have decreased more (–0.8°C). During the past 10 years, temperature trends in the northern North Atlantic region have become more similar to those of interior North America, showing increases.

Precipitation increased in Atlantic Canada by approximately 10% between 1948 and 1995 (Lewis, 1997), a trend that continued through the 1990s (Jacobs and Banfield, 2000; Lines et al., 2003). These average values, however, include much variation throughout the region.

Lines et al. (2003) and Lines and Pancura (2005) have analyzed projections of temperature and precipitation changes, using downscaling techniques for the Atlantic regions and ecozones. Recent analyses in support of this assessment were also conducted (*see* Figures 4, 5). These analyses indicate that anticipated change varies across the region, and that future diversity mirrors the present differences in climate among the ecozones, ecoregions and individual locations in the region.

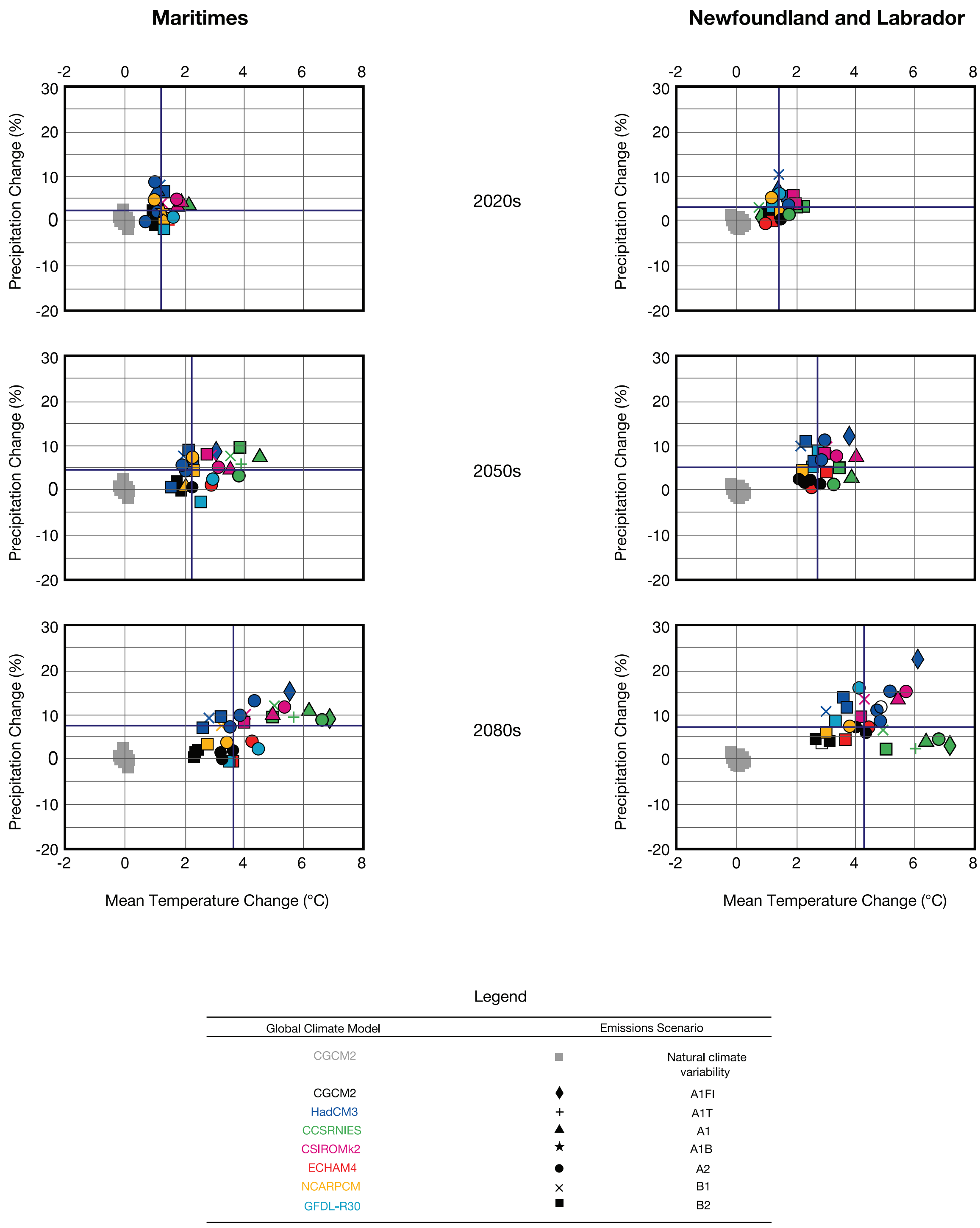


FIGURE 4a: Scatterplots of annual change in mean temperature and precipitation for the Maritimes (left) and Newfoundland and Labrador (right), as projected by a suite of climate models for the 2020s, 2050s and 2080s. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot.

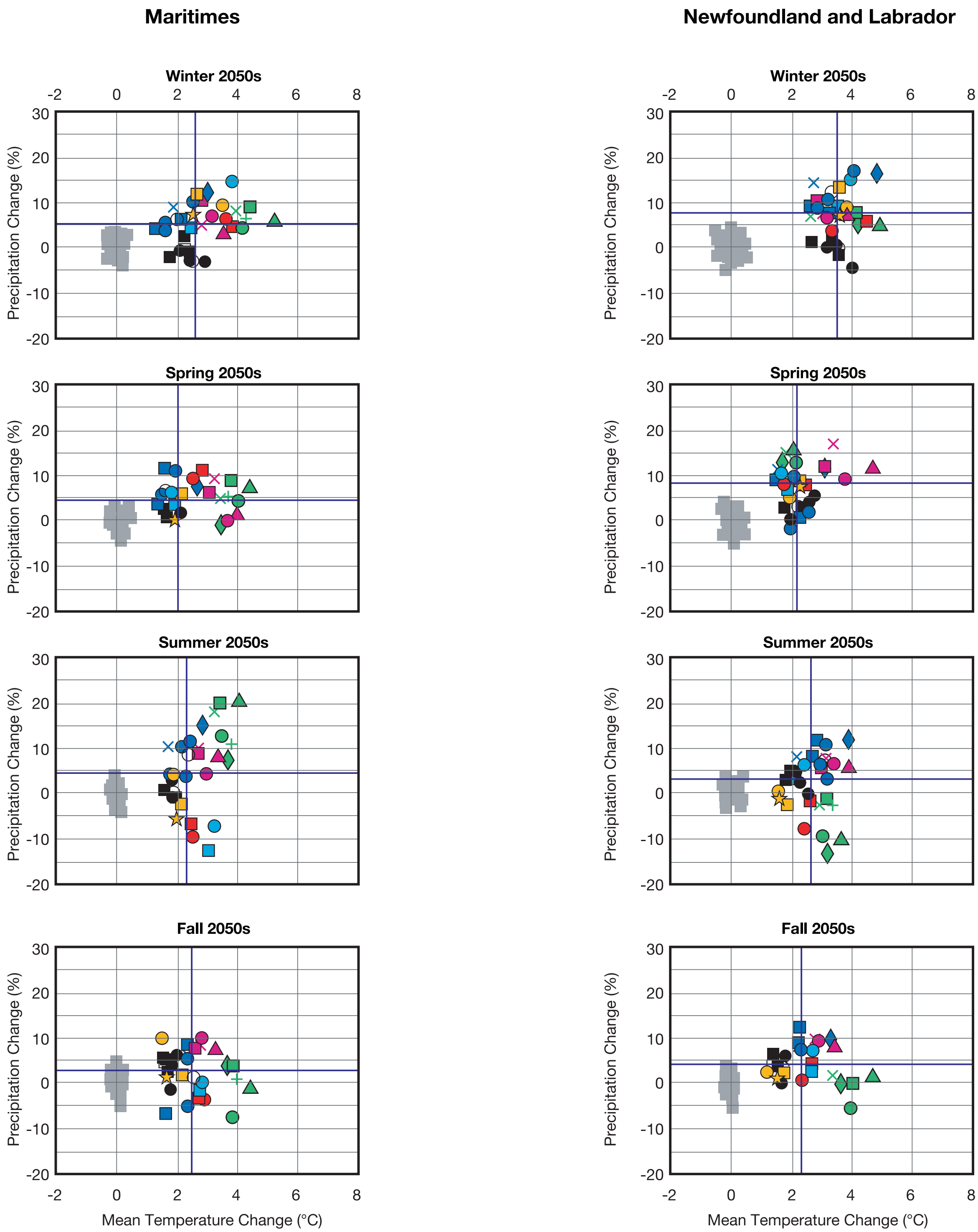


FIGURE 4b: Scatterplots of seasonal changes in mean temperature and precipitation for the Maritimes (left) and Newfoundland and Labrador (right), as projected by a suite of climate models for the 2050s. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot.

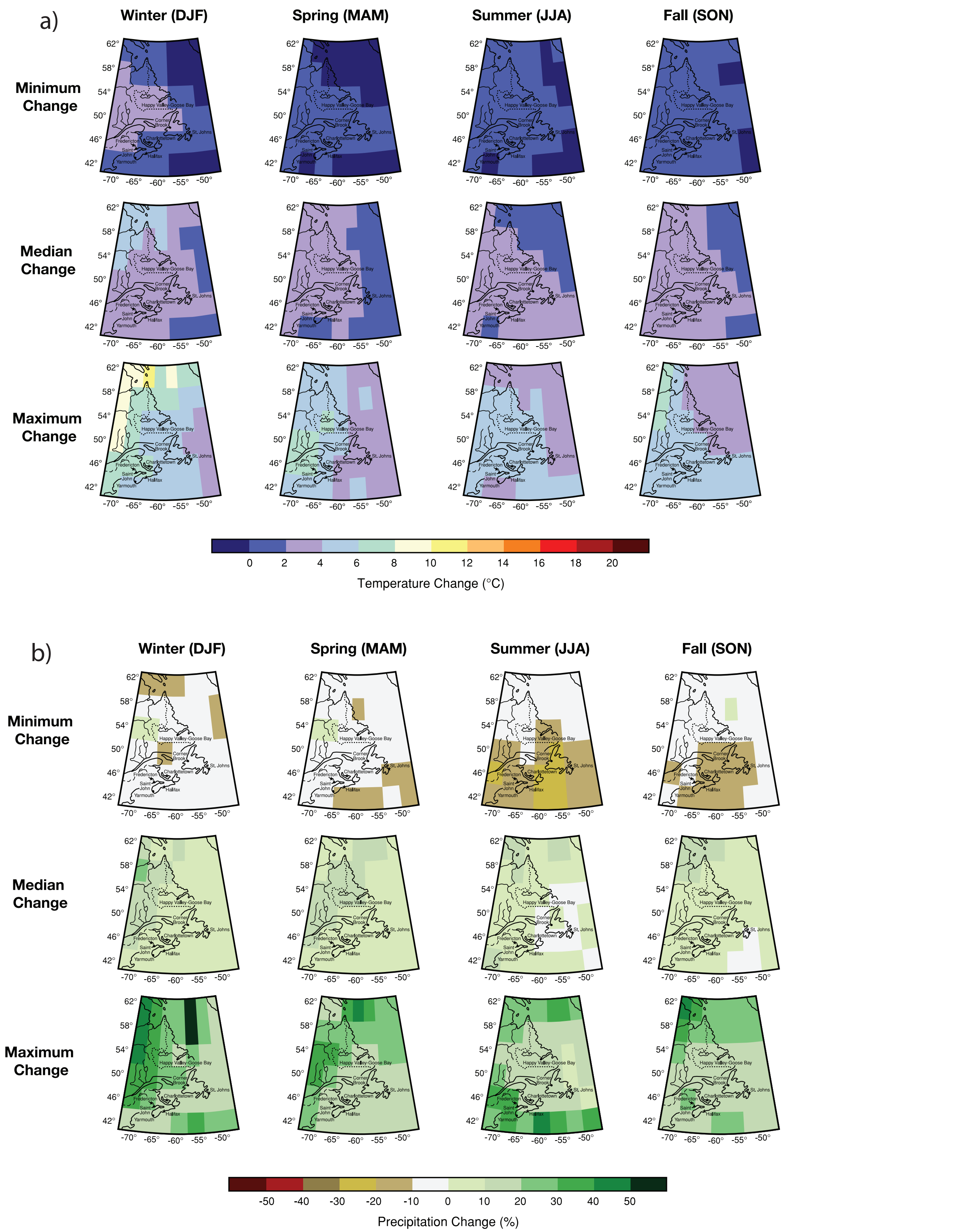


FIGURE 5: Climate scenario maps of a) annual minimum, median and maximum temperature changes (ºC) for the 2020s, 2050s, 2080s; and b) annual minimum, median and maximum precipitation changes (%) for the 2020s, 2050s, 2080s, as projected by a suite of climate models. Capital letters in parentheses after the seasons represent the relevant months.

Maritime Canada

Although there are important micro- and meso-scale variations between the climate projections, there are some general patterns that emerge. The Maritime Provinces are projected to experience increases in both mean annual temperature and precipitation (Figures 4, 5). By 2050, there would be a 2 to 4 C° increase in summer temperature, depending on model inputs and geographic location. Future warming of 1.5 to 6 C° during winter can be anticipated. Coastal areas would see lesser changes in temperature than would interior Nova Scotia and western New Brunswick. Precipitation in Maritime Canada is anticipated to increase in the future, continuing the trend established since 1948, but seasonal and yearly variations will become more evident. Drier summer conditions may characterize inland regions. For these areas, the change in rainfall may not offset the increase in evapotranspiration caused by higher summer temperatures.

Newfoundland and Labrador

Newfoundland and Labrador differs from Maritime Canada in terms of both present climate and projected changes. The influence of the Labrador Current and the variations associated with the NAO are critical influences (*see* Box 2 and Chapter 2). Coastal areas subject to the influence of the NAO differ substantially from interior areas, in terms of both their current conditions and their responses predicted for the future (Canadian Institute for Climate Studies, 1999–2005). The interior areas of Labrador are subject primarily to continental influences, driven by the dominant southwesterly winds. Climate change anticipated for this region, with warmer and drier summers and warmer winters (*see* Figure 5; Environment Canada, 2005a–c; Flannigan et al., 2001; Canadian Institute for Climate Studies, 1999–2005), represents a continuation of patterns observed recently.

BOX 2

Influence of the North Atlantic Oscillation on Newfoundland and Labrador

The North Atlantic Oscillation (NAO) is a cyclic variation in pressure regimes that influences northern North Atlantic environments and communities, including Newfoundland and Labrador (Hurrell, 1995; Topliss, 1997; Banfield and Jacobs, 1998; Delworth and Mann, 2000; Jacobs and Banfield, 2000; Kerr, 2000; Enfield et al., 2001; Marshall et al., 2001; Drinkwater et al., 2003; Hurrell et al., 2003; Catto and Catto, 2004, 2005; Catto 2006a, b, in press). A strongly positive NAO phase results in colder temperatures in Labrador, particularly along the coastline, and western Kalaallit Nunaat (Greenland). Positive NAO conditions also result in temperatures at or slightly below average along the eastern coastline of Newfoundland (Topliss, 1997; Catto et al., 2003). A positive NAO phase also produces strong northwesterly to northeasterly winds, varying with latitude from northern Labrador south to the Avalon Peninsula; large wind stresses on the ocean surface; low sea-surface temperatures (especially in winter); and extended areas and durations of pack ice and brash ice. The negative NAO phase produces the opposite effects, resulting in warmer drier winters, particularly with reduced snow cover, in Labrador and coastal Newfoundland. In recent years, there has been a trend towards a persistent strong positive NAO phase, which may be associated with greenhouse gas forcing (Kuzmina et al., 2005). Models also suggest that this influence may continue as carbon dioxide concentrations rise, although further research is needed to increase confidence in this hypothesis (Stephenson et al., 2006).

2.2 STORMS, STORM SURGES AND SEA-LEVEL RISE

The Atlantic region is subject to impacts from a wide range of seasonal and interannual events, including winter cyclonic storms, tropical cyclones and other severe weather events; summer heat and drought; early or late season frost; winter rain and thaw events; and river ice jams and flooding. There is evidence of recent trends toward greater extremes and higher frequencies of such events (e.g. Zhang et al., 2001; Beltaos, 2002; Bonsal and Prowse, 2003; Bourque et al., 2005; Bruce, 2005; Emanuel, 2005; Webster et al., 2005).

A storm surge is defined as the elevation of the water resulting from meteorological effects on sea level. The storm-surge elevation is the difference between the observed water level during the storm and the level that the tide would normally rise to in the absence of storm activity (Forbes et al., 2004). During the past 15 years, storm surges have resulted in property destruction in all four Atlantic provinces (Taylor et al., 1996a, b, 1997; Forbes et al., 2000; McLean et al., 2001; McCulloch et al., 2002; Catto et al., 2003; Catto and Hickman, 2004; Smith et al., 2004a, b; Wright, 2004; Catto, in press). Figure 6 shows the geographic distribution of positive storm surge heights with a 40-year return period throughout the Atlantic region (Bernier et al., 2006). This shows that storm surges are higher in coastal waters, with highest levels in the southern Gulf of St. Lawrence and the St. Lawrence Estuary.

Parts of eastern New Brunswick are especially susceptible to storm surges (Shaw et al., 2001; Thompson et al., 2005). In the Beaubassin area of southeastern New Brunswick, claims made to the provincial government for damage to houses, cottages, wharves and other structures following a storm surge in January

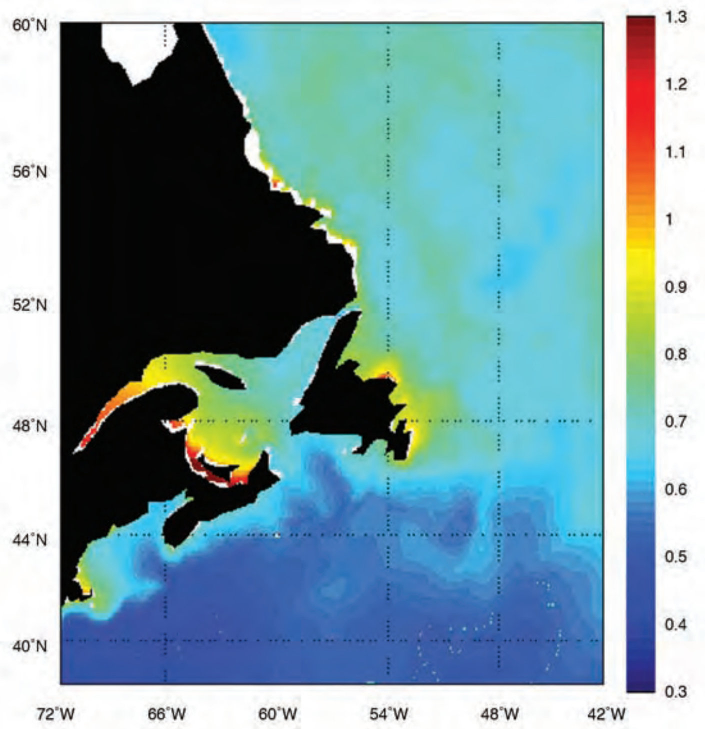


FIGURE 6: Spatial variability of storm surge with 40-year return period for the Atlantic coast of Canada, based on a 40-year hindcast (Bernier et al., 2006).

FIGURE 7: Damage from Hurricane Juan, Bishop's Landing, Halifax. Photo courtesy of Kyle McKenzie.

2000 exceeded $1.6 million (Robichaud, 2000). Historical events, such as the Great Hurricane of 1775 in eastern Newfoundland (Stevens and Staveley, 1991; Stevens, 1995a) and the Saxby Gale of 1869 in the Bay of Fundy (Hutchinson, 1911; Abraham et al., 1999; Parkes et al., 1999), provide ample evidence of the impact of extreme storms and storm surges in Atlantic Canada. More recently, Hurricane Juan (2003), the most economically destructive hurricane event in Atlantic Canadian history, killed eight people and was responsible for at least $200 million in damage to Nova Scotia and Prince Edward Island (Environment Canada, 2004b; Figure 7).

The effect of any particular storm at a location depends upon the angle of wave attack, the number of previous events during the season, whether it is low or high tide and other local factors (Hayes, 1967). Adjacent beaches can exhibit very different responses to a particular storm, as was evident for southwestern Newfoundland beaches impacted by Hurricanes Gustav (2002) and Frances (2004), for eastern Newfoundland beaches struck by Hurricanes Bob (1991), Luis (1995) and Irene (1999), and for Prince Edward Island beaches affected by Hurricane Juan (2003). Beaches separated only by a headland varied widely in the amount of geomorphic response to storms (e.g. Catto et al., 2003).

The northern Atlantic Ocean has been undergoing an increase in hurricane frequency and magnitude since 1995 (Goldenberg et al., 1997, 2001; Landsea et al., 1998; Debernard et al., 2002; Emanuel, 2005; Webster et al., 2005). However, the relationship between changes in frequency and magnitude of hurricanes and increases in air temperature or sea surface temperature (SST) is not clear at present, and consensus does not exist among hurricane specialists. Although causal links between SST changes and hurricane frequency and strength have been suggested (e.g. Sugi et al., 2002; Trenberth et al., 2003; Knutsen and Tuyela, 2004; Trenberth, 2005), other researchers have expressed reservations and recognized uncertainties (e.g. Swail, 1997; Shapiro and Goldenberg, 1998; Pielke et al., 2005; Webster et al., 2005).

At present, a storm surge in excess of 3.6 m above the mean sea level (chart datum, CD) occurs approximately once every 40 years in the southern Gulf of St. Lawrence. As sea level continues to rise, the frequency of higher storm surges will increase. At the present rate of sea-level rise, a storm surge of 3.6 m elevation above present CD would statistically occur annually in the southern Gulf of St. Lawrence by 2100 (Parkes et al., 2006). Storm surges in excess of 4.0 m elevation above present CD would occur approximately once every 10 years. At Charlottetown, the storm-surge height during the January 2000 event was 4.22 m above CD, causing unprecedented flooding and damage around the southern Gulf of St. Lawrence

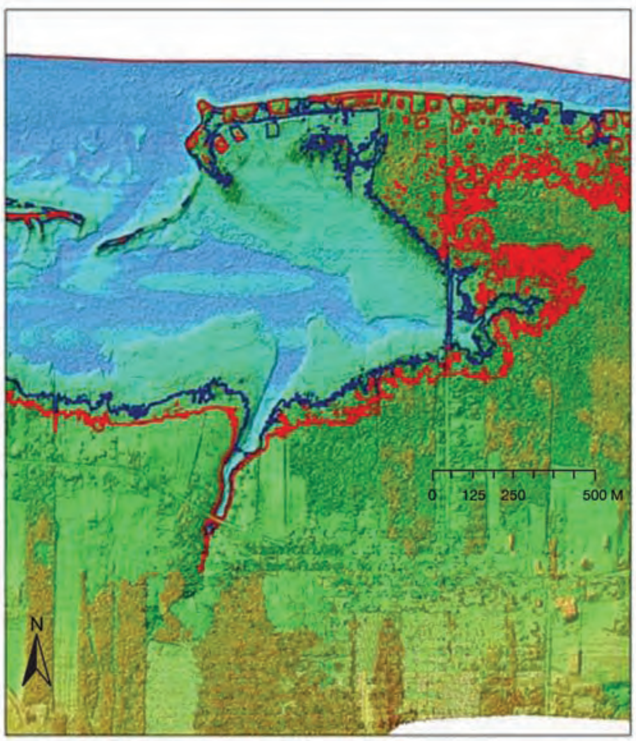


FIGURE 8: Flooding extents with present sea levels (blue line) and with a 60 cm sea-level-rise scenario (red line) for a 10-year return period, Pointe aux Bouleaux, NB (Bernier et al., 2006).

FIGURE 9: Coastal sensitivity to sea-level rise, Atlantic Canada (Shaw et al., 1998).

(Forbes et al., 2000; Bruce, 2002; McCulloch et al., 2002; Parkes et al., 2006). Rising sea level would produce comparable events approximately once every 10 to 15 years, even if the frequency and magnitude of the storms themselves did not change. Under the effect of rising sea level, a storm surge in January 2100 propelled by winds comparable to those of January 21, 2000 would rise 4.52 m above present CD in Charlottetown, flooding more terrain. Rising sea level will result in flooding of higher, previously immune areas (Figure 8), and more frequent flooding of low-lying areas.

Sections of the Atlantic coasts are among the areas in Canada most severely threatened by a rise in sea level (Figure 9; Shaw et al., 1998). Sea-level changes are driven by a combination of local, regional, hemispheric or global factors, including the changing volume of the oceans (due to thermal expansion and glacial melting) and glacio-isostatic activity. Each coastal area responds differently to a particular combination of factors, and the change in sea level is not identical, either throughout the world or along Canada's three marine coastlines. With the exception of northernmost Labrador and Lake Melville, Atlantic Canada is now subsiding. Archeological sites at Fort Beauséjour, NB (Scott and Greenberg, 1983; Shaw and Ceman, 1999), Louisbourg, NS (Figure 10; Taylor et al., 2000), St. Peters Bay, PE (Josenhans

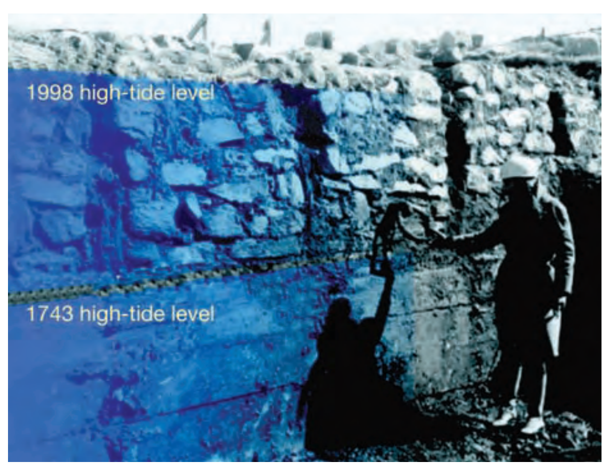


FIGURE 10: Rising sea level at Louisbourg, NS (from Natural Resources Canada, 2006c).

and Lehman, 1999; Shaw et al., 2002), and Ferryland, NL (Catto et al., 2000, 2003), among others, indicate that sea level has risen since ca. 1600. Evidence of transgression is indicated by enhanced erosion along many Atlantic Canadian beaches, and inundation of terrestrial peat deposits and trees. Over the past century, sea level in the Atlantic region has risen approximately 30 cm (Figure 11). Areas such as the coast of southeastern New Brunswick could experience sea-level rise on the order of 50 to 70 cm during the current century (2000–2100; Parkes et al., 2006). Continued sea-level rise will amplify storm surges and flooding in the Atlantic region.

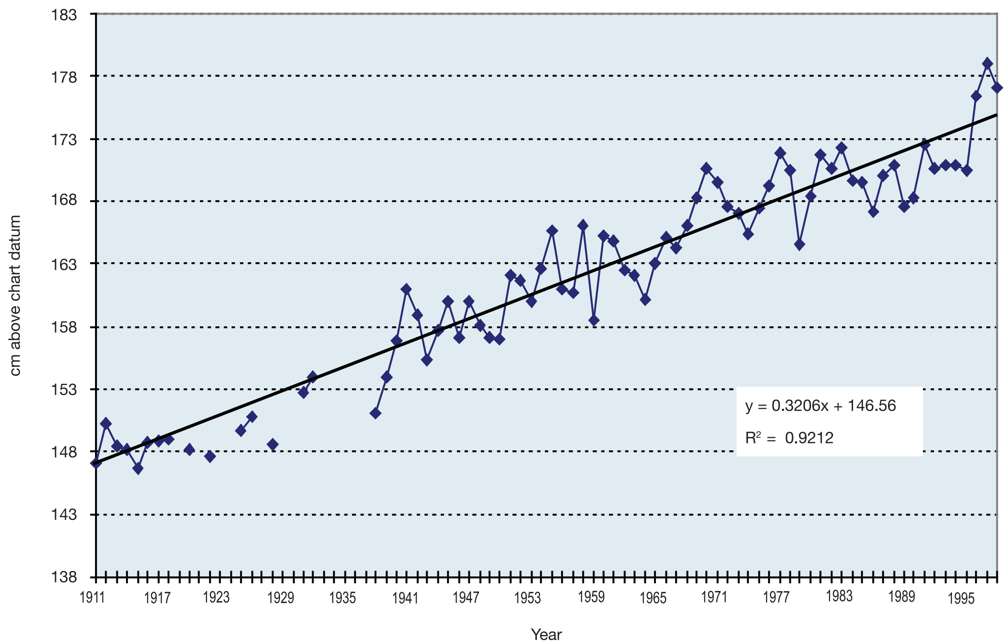


FIGURE 11: Annual mean water levels at Charlottetown, PE (1911–1998) in centimetres above chart datum (from Parkes et al., 2002). The linear regression through the data indicates a sea-level rise of approximately 32 cm/century. Similar rates of sea-level rise are reported for Halifax, NS (Shaw et al., 1998), New Brunswick's southeastern coast (Daigle et al., 2006), St. John's, NL (Catto, 2006b), and Channel-Port aux Basques, NL (Catto et al., 2006).

2.3 SEA ICE

Climate change will affect the duration and extent of sea ice, with the anticipated effects differing throughout Atlantic Canada. In the Gulf of St. Lawrence, warmer winters, coupled with stronger southwesterly winds, would result in reduced (or no) ice cover in the area south of the Îles de la Madeleine. This pattern, evident during periods of negative NAO conditions, results in enhanced coastal erosion in northern and eastern Prince Edward Island and southeastern New Brunswick, instability of nonvegetated coastal sand dunes (e.g. Catto et al., 2002) and northward displacement of seal breeding areas. Simultaneously, however, southwesterly winds can drive ice in the Gulf of St. Lawrence, resulting in thicker and more persistent ice around Anticosti Island, the north shore of the Gulf of St. Lawrence and the Northern Peninsula of the Island of Newfoundland north of St. Paul's. For species dependent upon ice-marginal conditions for breeding, the result is a displacement of the breeding areas to the northeast, rather than an absence of suitable conditions. Positive NAO conditions, dominated by northeasterly winds, would allow the ice front to move southwestward if the temperature of the Gulf of St. Lawrence waters remained unchanged.

Along the northeast coast of Newfoundland and Labrador, the strength of the Labrador Current carries ice southwards. Maximum ice extent off Newfoundland is generally reached in March or April (Markham, 1980; Côté, 1989). During negative NAO years (e.g. 1996–1997), maximum ice extent is restricted to the coastline north of Cape Bonavista, whereas coastal ice may extend south of Cape St. Francis during positive NAO years (1990–1992, 2004) and ice-foot development occurs on beaches in Placentia Bay. Positive NAO years are marked by increased northeasterly wind activity, which drives ice onshore in Labrador and northeastern Newfoundland, obstructing harbours, blocking drainage at the heads of estuaries and coves (causing local flooding) and resulting in ice shove, potentially damaging infrastructure (e.g. Catto et al., 2003; Catto, in press).

3 SENSITIVITIES AND ADAPTATION OF ECOSYSTEMS AND SECTORS

3.1 TERRESTRIAL ECOSYSTEMS

3.1.1 Sensitivities

Most natural systems have moderate to high exposure to the impacts of climate change, when considered over a time period of approximately 50 years. Because natural systems have evolved in response to climate since deglaciation, a sudden shift in climate conditions will challenge their ability to adapt. Boundary shifts at the ecoregion and ultimately the ecozone level may be expected. Climate change will lead to shifts in seasonally dependent biological rhythms and cycles, loss of habitat, extirpation or extinction of native plant and animal species, and the arrival of more invasive species. Other anthropogenic factors, principally those related to land use, will compound these impacts of climate change.

Changes in ecosystems and dominant species will occur due to changes in climate, either through conversion (replacement of the dominant species by a subdominant species) or migration (long-distance movement of species that can rapidly adapt to new soil or topographic factors; Nielson et al., 2005). In southern Atlantic Canada, the future fate of the already highly stressed ecosystems of the remnant Acadian Forest (Figure 12) remains uncertain (Mosseler et al., 2003a, b; Moola and Vasseur, 2004). The limit of the northern boreal forest may expand at the expense of tundra areas (Heal, 2001), although topographic and soil factors will limit the migration of treeline ecosystems (Holtmeier and Broll, 2005; Nielson et al., 2005). Available evidence suggests little or no recent observed change in the northern treeline position in Canada (Masek, 2001).

In concert with the regional warming in spring and summer, there has been a 5 to 6 day advance since approximately 1959 in the onset of phenological spring in eastern North America, as indicated by earlier leaf appearance or flower blooming and earlier bird nesting times (Schwartz and Reiter, 2000). In Atlantic Canada, earlier phenology of spring bloom was observed in interior regions, such as the Annapolis Valley (NS), but no significant differences were seen along the coast (Vasseur et al., 2001). Frequent episodes of winter thaw and late spring frost have led to widespread tree crown dieback in yellow birch throughout eastern Canada (Cox and Arp, 2001; Bourque et al., 2005; Campbell et al., 2005). Over the next few decades, shifting phenology of biological events may be either positive (e.g. enhanced productivity for trees) or negative (e.g. in the case of winter thaw, leading to trunk cracking for red spruce; *see* Mosseler et al., 2000).

FIGURE 12: Acadian Forest assemblage near Strathgartney, PE.

Birds are subject to problems associated with climate change, especially in relation to changes in the phenological spring. Early onset of warm days during the nesting season has been shown to negatively affect the breeding success of nesting seabirds due to heat stress and mosquito parasitism (Gaston et al., 2002). The timing of bird migration is also affected by increases in spring temperature, although long-distance migratory birds appear to alter the timing of migration in response to changes in weather and phenology (Marra et al., 2006). The broad spectrum of bird life in a region represents many different habits and habitats. Because they are widely observed and studied, they are useful indicators of environmental change (Boucher and Diamond, 2001).

Long-distance migration requires energy, and migrating birds must balance obtaining food with travelling in less-than-ideal weather. Use of a particular stopover varies with local weather and climate, and shows large interannual variation. The linkages to environmental factors suggest that migrating birds are sensitive to climate variability, which has implications for conservation efforts. A detailed study of the impacts of climate change on migratory songbird species in Atlantic Canada is in progress (Taylor, 2006).

Wildlife population dynamics are closely linked to climate. The seasonal migration of white-tailed deer in New Brunswick appears to be conditioned by winter climate variability as it affects snow cover (Sabine and Morrison, 2002). Milder winters may see this species occupying areas where they are currently absent in winter. Moose are at their southern limit of distribution in Nova Scotia and, under a warming climate, are expected to disperse northward (Snaith and Beazley, 2004). A review of NAO-related effects on northern ungulates found declines in caribou populations in northern Quebec and Greenland during periods of warmer winters (Post and Stenseth, 1999), suggesting that woodland caribou populations of Newfoundland and Labrador will be negatively affected by climate warming.

3.1.2 Adaptation

Natural systems have proven to be relatively resilient in the face of previous climate changes. However, these changes occurred over longer periods of time and were not compounded by additional stresses imposed by humans. Left to themselves, ecosystems would evolve in response to changing environmental conditions. The necessity of using natural resources for human purposes, however, means that short-term changes in ecosystems are cause for human concern.

Differences in lifespan and size of individual organisms influence the degree to which each species is exposed, as well as the immediacy of the reaction to changed conditions. Insect species respond more rapidly to climate variation and change, in terms of both survival and migration, than do trees and large mammals.

Approaches for adaptive responses to climate change impacts on natural ecosystems include comprehensive, integrated land-use management combined with protecting key habitats and species, promoting sustainable use of plant and animal species, and mechanisms for public education, awareness and action (Gitay et al., 2001; MacIver and Wheaton, 2005). Although comprehensive regional planning for biodiversity protection is yet to be realized for Atlantic Canada, all provinces have some kind of protected areas strategy, as well as wildlife and forestry management policies and legislation, and there are equivalent structures in areas of federal jurisdiction. For species at risk, such as the St. Lawrence aster and the piping plover (Figure 13) along the southern Gulf of St. Lawrence, and Long's and Fernald's braya in northern Newfoundland (*see* Box 3), it is important that climate change sensitivity and risk analysis are considered in recovery management plans. Maintaining and enhancing the interconnected network of parks and protected areas is one means of enhancing the ability of natural ecosystems to adapt to changing conditions (Mosseler et al., 2003a, b; Beazley et al., 2005). Although protected areas are themselves subject to the effects of climate change (Scott et al., 2002), they can provide a base for monitoring and assessing ecosystem change that is less disturbed by human activity than their surroundings.

FIGURE 13: Piping plover, an endangered species that utilizes coastal areas. Photo courtesy of Sidney Maddock.

BOX 3

Adaptive strategy for endemic limestone plants in Newfoundland

Plant and animal species are becoming extinct worldwide at an estimated rate of more than 20 per day, mainly due to habitat loss as a result of human activities. Recognizing the importance of maintaining biodiversity, governments have enacted legislation to recognize endangered species and facilitate their survival and restoration (Environment Canada, 2003). Climate change compounds the problem of critical habitat protection and species recovery.

Among species listed as 'endangered' is the arctic-alpine plant, Long's braya (*Braya longii*). It is found only in Newfoundland and occurs only on limited coastal limestone barrens near the tip of the Northern Peninsula. A second species, Fernald's braya (*B. fernaldii*), listed as 'threatened,' has a slightly wider and overlapping distribution in the same area. Together with the endangered barrens willow (*Salix jejuna*), these species are endemics that are found globally only on these limestone barrens. Hybrids between the two braya species have become established, primarily where road construction and gravel removal have allowed close contact. Both braya species are subject to infection by a fungal pathogen and suffer predation from larvae of the diamondback moth (a species that migrates to Newfoundland in spring and summer). The steep latitudinal gradient of temperature northward along the peninsula sets a limit for the severity of these effects. As several recent warm years have indicated, an increase in regional temperatures, as projected in climate change scenarios, will very likely intensify these natural threats (Hermanutz et al., 2004; Parsons and Hermanutz, 2006).

Photo: Long's braya (*Braya longii*) is an endangered species. Photo courtesy of Joe Brazil.

As with other species at risk in Canada, a recovery strategy has been implemented for the braya and barrens willow populations of the Northern Peninsula that combines habitat protection, monitoring and research. Given the importance of human disturbance, community stewardship is critical, and a strong sense of responsibility is evident in the communities. In the long run, climate change may mean Long's braya does not survive in its present setting. However, the adaptive strategy in place with the Limestone Barrens Species at Risk Recovery Team will provide for preservation of the species in the provincial Botanical Gardens (Hermanutz et al., 2002).

3.2 COASTAL ZONE

3.2.1 Sensitivities

Atlantic Canada is defined by its coastal environment. With increasing pressure from coastal development (mostly housing development and community wharves) and sea-level rise, erosion and flooding are increasing and will continue to increase in frequency (Daigle et al., 2006). Consideration of geological factors, rate of sea-level rise, amounts of coastal erosion, wave climate and tidal regime allow calculation of the sensitivity to sea-level rise of shoreline segments (e.g. Gornitz et al., 1993). This assessment has been completed for all of Atlantic Canada on a broad regional scale (Figure 9; Shaw et al., 1998), and more detailed assessments have been conducted for specific segments of the coastline (e.g. Chmura et al., 2001; Catto et al., 2003; Daigle et al., 2006; Shaw, 2006). Erosion occurs on the most sensitive coastlines, such as sand dunes, sand and pebble gravel beaches, or where unconsolidated sediments or weakly consolidated bedrock form coastal bluffs. Dune-backed coasts are present in all four Atlantic provinces.

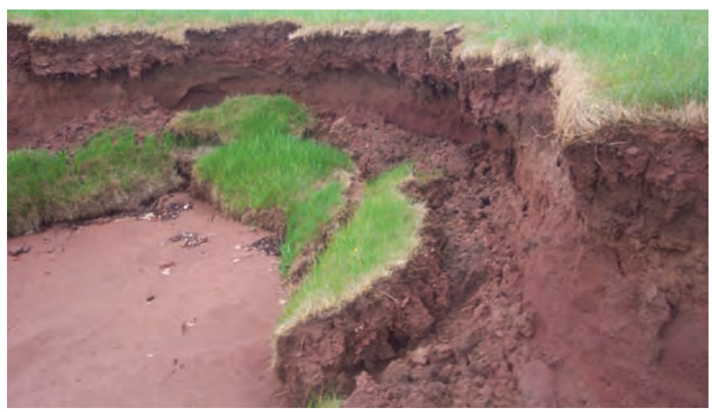
Throughout the southern Gulf of St. Lawrence, the combination of rising sea levels, increased human utilization of the coast for residential and tourism purposes, and limited offshore winter ice conditions have resulted in accelerated erosion and degradation of the dunes and coastline, such as in northeastern Prince Edward Island (Catto et al., 2002), southwestern and western Newfoundland (Pittman and Catto, 2001; Catto, 2002; Ingram 2005) and eastern Newfoundland (Catto, 1994). Winter storm erosion tends to result in coarser beaches with steeper profiles. Local factors, however, play a dominant role in the results observed at any particular beach (Catto et al., 2003; Catto, 2006a, b, in press).

Other coastlines are also sensitive to erosion (Figure 14 a, b). Coastal erosion rates in excess of 5 m/year have been measured in bluffs composed of glacial sediment at Chezzetcook, NS, coupled with landward migration of barrier beaches (Forbes et al., 1995; Orford et al., 1995; Taylor et al., 1997). Erosion rates of 0.7 m/month between December 2003 and April 2004 were observed at Sandbanks Provincial Park, NL (Ingram, 2004). Erosion at Cascumpec Bay, PE between 1974 and 2004 caused coastal retreat of 115 m, a rate of 3.8 m/year (Conroy, 2007).

Ongoing sea-level rise is increasing the risks associated with storm activity (Taylor et al., 1996a; Shaw et al., 1998, 2001; Bruce et al., 2000; Parkes et al., 2006). Coastal erosion, accelerated by rising sea levels, has occurred at several localities, notably along the south coast of Nova Scotia (Taylor et al., 1985, 1996a; Shaw et al., 1993, 1994), in eastern New Brunswick (Ollerhead and Davidson-Arnott, 1995; Shaw et al., 1998; Daigle et al., 2006; Ollerhead, 2006), along the north coast of Prince Edward Island (Forbes et al., 2002; McCulloch et al., 2002) and along Conception Bay, NL (Taylor, 1994; Liverman et al., 1994a, b; Batterson et al., 1999; Catto et al., 2003). As an example, observations at Mobile, NL between 1989 and 2005 (Catto, 2006 b) indicate that erosion has increased in the upper part of the beach system (Figure 15). Insufficient compensating deposition has occurred in the lower areas to maintain the overall volume of sediment. This beach is becoming coarser and narrower as sea level rises, and apparently less stable as storm activity, notably in winter and spring, combined with human foot traffic, results in enhanced profile modification.

An example of detailed mapping and evaluation of the sensitivity of a coastline to erosion is provided for Conception Bay South and Holyrood (Figure 16; Smith et al., 2004a; *see also* Smith et al., 2005). This coastal sensitivity map enabled the recognition of four main potential hazards: coastal flooding and storm surges, damage to coastal infrastructure by storms, coastal erosion and damage to the ecology of coastal areas (Shaw et al., 1998; Catto et al., 2003).

a)



b)

FIGURE 14: a) Coastal erosion, Union Corner Provincial Park, PE and b) Active bluff erosion, Middle Cove, NL.

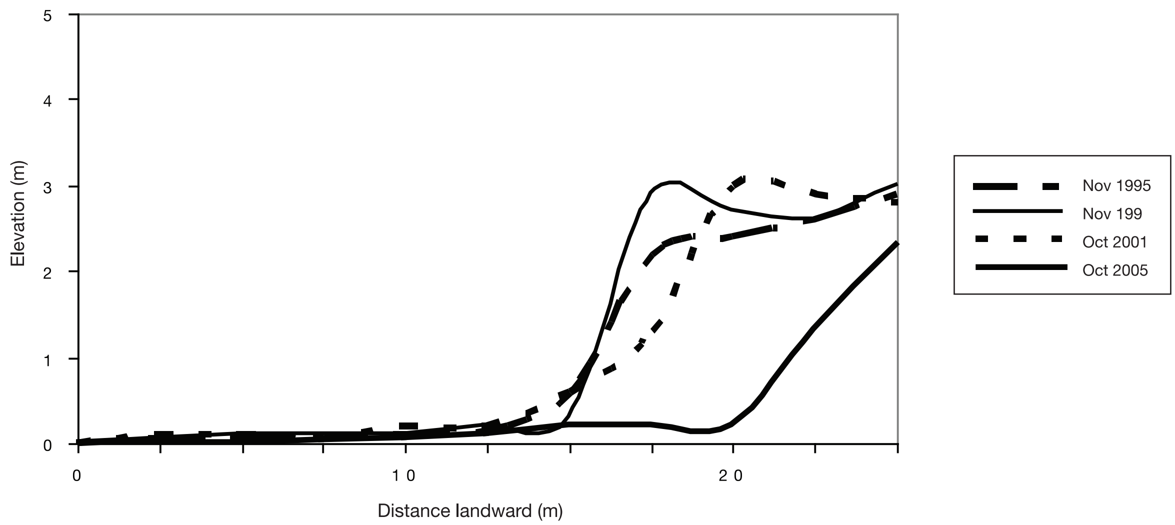


FIGURE 15: Successive measurements along a beach transect, Mobile, NL, showing erosion between November 1995 and October 2005 (Catto, in press).

FIGURE 16: Coastal sensitivity map for Conception Bay South and Holyrood, NL (Smith et al., 2005).

3.2.2 Adaptation

There are three generic categories of adaptation that can be used in areas affected by coastal erosion, sea-level rise and/or storm-surge activity (Nicholls and Mimura, 1998; Nicholls, 2003):

- Planned retreat involves recognition of the inevitability of coastal erosion, and responds by abandoning the areas closest to the shoreline or locating only temporary or expendable structures in these areas.
- Accommodation involves constructing structures in ways that minimize damage (e.g. by placing buildings on elevated pylons) or developing land-use and zoning plans that allow only those structures that must be built on the shoreline (e.g. port facilities or fish-processing plants) to be located there, while prohibiting others (such as private residences).
- Protection involves physical reinforcement of the shoreline, either by 'hard' measures (seawalls, rip-rap, groynes) or by 'soft' measures (e.g. vegetating dunes with marram grass).

Municipal planning that integrates a combination of the three categories can lead to long-term solutions for communities.

The simplest way to accommodate a major hazard is planned retreat. This involves designating a building set-back limit and establishing a zone along the coastline where no permanent construction is permitted. In the case of Shediac, NB, analyses of the historical damage and the current trends due to sea-level rise, storm surges and coastal erosion led to discussion of possible adaptation, including retreat (Figure 17; Murphy et al., 2006). Discussions were based on susceptibility of the residences in terms of economic compensation related to flooding, and included consideration of flooding area classes 5 and 6 (the most exposed zones). In New Brunswick, some planned retreat would be effective through the Coastal Areas Protection Policy (New Brunswick Department of Environment and Local Government, 2002) that is being implemented. This policy also encourages protection of the coastal areas through the avoidance of construction within 30 m of the high-tide shore, with permanent structures only permitted outside the set-back limit.

The New Brunswick Coastal Areas Protection Policy (New Brunswick Department of Environment and Local Government, 2002) provides an umbrella for coastal zone management and adaptation measures at a local level. However, stakeholders and planners indicated that delay in implementation of the policy created a rush of building near the shore, with owners wanting to build before regulations were enacted (Martin and Chouinard, 2005). Despite the risks involved, many are still willing to build near the shore. Although there are tools available and municipality representatives should have local plans that can be used to control development in coastal areas of their community, there is a perceived lack of resources and consistency of application (Martin and Chouinard, 2005), leading to complaints from individuals, municipality representatives and environmental groups.

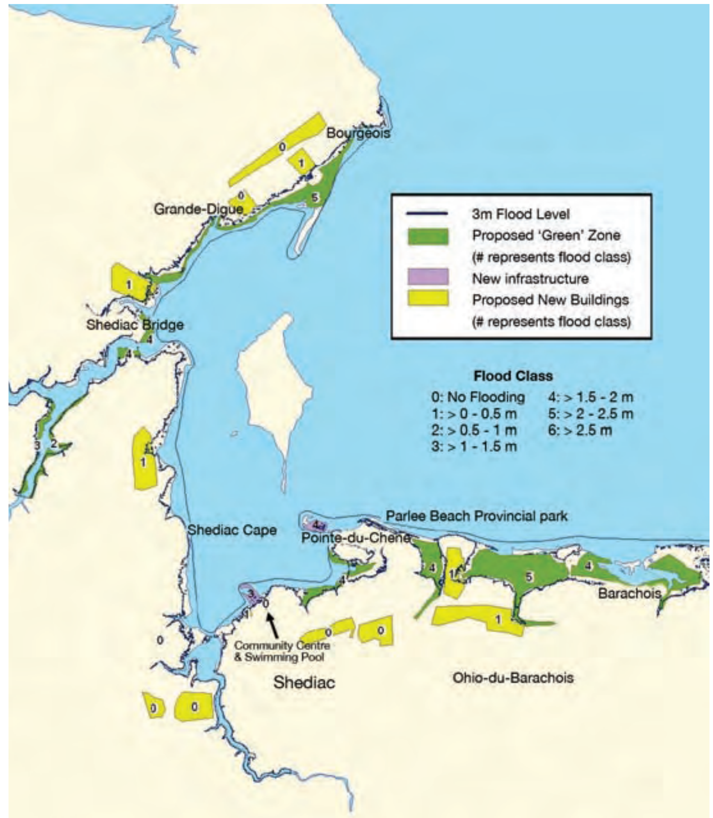


FIGURE 17: Coastal flood classification, optimistic economic conditions scenario, Shediac, NB (Daigle et al., 2006).

Studies in Prince Edward Island, New Brunswick and Newfoundland have underlined the need for better planning in rural and urban areas that includes sea-level rise and storm-surge considerations (e.g. Paone et al., 2003; Smith et al., 2005). However, there are currently no coastal protection policies in Prince Edward Island, Newfoundland or Nova Scotia (with the exception of the Beaches Act), and some areas are facing significant pressure from development. In coastal regions, attachment to the area is strong and few individuals have considered retreat as an option.

A long-term erosion rate is a useful guide for the establishment of set-back limits (Taylor, 1994) and indicates where specific structures are in danger. The absence of long-term monitoring of coastal erosion, however, means that present erosion rates may not serve to indicate the magnitude of previous (or future) events. In addition, as the majority of the erosion is caused by individual storms, hazard assessment requires consideration of the probability of the maximum impact of a particular storm, rather than only monitoring and dealing with the small, incremental removal of sediment on a daily basis.

Accommodation can allow impacts on natural systems to occur while adverse impacts on people are minimized by adjusting the human use of the coastal zone. At present, accommodation is not commonly employed as an adaptive strategy in Atlantic Canada. Nevertheless, there are local examples of houses constructed on elevated pylons (Figure 18), allowing storm-surge waters to pass beneath, in coastal New Brunswick and Nova Scotia, that have been constructed as a result of decisions taken by individual homeowners. Comprehensive zoning has been suggested as an option in many areas (e.g. New Brunswick Department of Environment and Local Government, 2002), but deviations and variances are commonly granted.

Protection, in which the effects of extreme events, ongoing erosion and climate-related changes to natural systems are controlled by soft or hard engineering, is frequently used as an adaptive strategy. Seawalls, breakwaters and groynes, and emplacement of rip-rap and gabions, are the most common adaptive measures and those most favoured by the majority of coastal residents and property owners. Such hard engineering structures are expensive, require constant maintenance and observation, and can fail if not adequately designed and constructed. Repetitive storm activity and rising sea level both pose problems for the design and maintenance of hard coastal protection. In addition, some communities and land owners have used maladaptive techniques to protect their coastal properties, such as using different construction materials in levees and transition sections of levees, leading to inconsistencies (as occurred in New Orleans; *see* Nicholson, 2005).

FIGURE 18: Construction of buildings on pylons as an example of adaptation that reduces vulnerability to storm surges, Grand-Barachois (near Shediac), Northumberland Strait, southeastern New Brunswick. Photo courtesy of Armand Robichaud.

In some areas, such as the Victoria Park area of Charlottetown, PE, aesthetic concerns influence the design of shoreline protection. In Summerside, PE and Trout River, NL, protective structures were designed to also provide a recreational walking trail. In some jurisdictions, protective measures are integrated in legislation, such as the Nova Scotia Beaches Act (Nova Scotia House of Assembly, 2000).

Soft engineering options include grading coastal bluffs to reduce erosion and planting or maintaining existing vegetation. Use of marram grass for this purpose is common in coastal dune areas in Atlantic Canada (e.g. Irving Eco-Centre in Bouctouche, NB; G. Arsenault, pers. comm., 2004). Conifers are also used, although they are more expensive and subject to damage from salt spray. Restoration of salt marshes is also potentially effective as an adaptive response to protect coastlines from rising sea level (Ollerhead, 2006).

An important aspect of any adaptation strategy is development of an understanding amongst the residents of the key issues facing their community. Community-based planning and activities are likely to be most effective. In order to involve the community, an education and public awareness program would need to be planned and implemented. Without community support, neither planned retreat nor accommodation through zoning can be effectively implemented.

Although most provincial legislation and municipal development plans (e.g. Beaubassin Development Commission; Daigle et al., 2006) have provisions to protect coastal zones, very few integrate climate change in their long-term planning and protection of these habitats, leading to difficulties in adapting to changes in sea level and coastal erosion. As a result, coastal infrastructure may have to be moved or face the risk of damage over time (Figure 19). In most cases, the lack of long-term planning, funding and available land to which to move the infrastructure are limiting factors for adaptation (DeLusca et al., 2006).

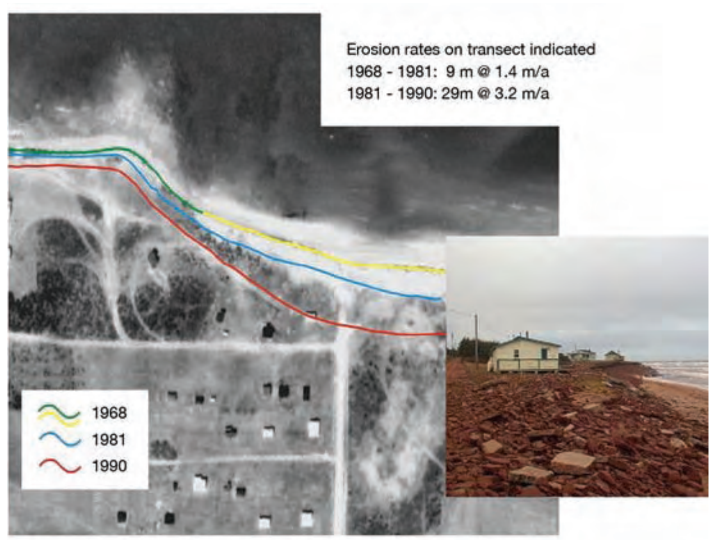


FIGURE 19: Aerial photograph of land in Pigots Point, PE. The coastlines of 1968, 1981 and 1990 are shown. Infrastructure is now being threatened due to sea-level rise and coastal erosion.

3.3 MARINE ECOSYSTEMS AND FISHERIES

3.3.1 Sensitivities

Marine resources form a vital socioeconomic component throughout Atlantic Canada. Direct impacts of climate change on biological species result from changes in surface and near-surface ocean temperatures, changes in sea-ice duration and extent, and changes in nearshore and beach areas used by species for feeding and spawning. Changes in pest species and pathogen distribution pose additional concerns. Aquaculture operations could be impacted by changes in storm activity along coastlines, coastal erosion of protective salt marshes and barrier dune systems (particularly along the Gulf of St. Lawrence coast), and changes in freshwater and terrestrial sediment influx into estuaries. Climate change would also affect numerous aspects of fishery operations, including transportation, marketing, occupational health and safety, and community well-being (*see also* section 3.10; Catto et al., 2006; Catto, in press; Sjare et al., 2006). Many of these impacts are related to changes in sea state and storm activity.

The role of climate change with respect to fisheries, fish harvesters and fishing communities has varied throughout the northwestern North Atlantic, both by place and over time, from that of 'supporting player' to mere 'background noise' (Catto and Catto, 2004). Only in cases of collapse of fish stocks due to purely ecological causes could climate change be considered as the 'driving force'.

The fisheries of Atlantic Canada are influenced by the Gulf Stream and the Labrador Current (Figure 20). The Gulf Stream is the most defined and strongest current in the North Atlantic, carrying 55 million m^3/second of water along the Atlantic Canadian seaboard (Narayanan, 1994; Beer, 1996; Kearns, 1996). Anticipated future conditions involve warming of the Gulf Stream and reduced influx and warmer water from the St. Lawrence River, particularly during the summer months. Increased southwesterly wind activity would produce an increase in current flow towards Atlantic Canada. In the Gulf of St. Lawrence, reduced and warmer flow from the St. Lawrence River during the summer would weaken the cold countercurrent that flanks the east coast of New Brunswick, all coasts of Prince Edward Island and the Atlantic coastline of Nova Scotia, generating further summer warming along these shores. The simultaneous weakening of the countercurrent and warming of the Gulf Stream would provide suitable conditions for the northward spread of marine organisms from the mid-Atlantic coastline of the United States, including both economically useful fish species and pests and pathogens.

Warmer water conditions in the Gulf Stream would result in lengthening of the 'soft-shell' phase of crab moulting. During this time, harvested crab cannot be effectively processed or marketed, leading to wasted effort and loss of income for harvesters. Fish harvesters have noted difficulties with earlier development of 'soft shell' in recent years. Early juvenile crab appear to be the most sensitive to changes in water temperature, since they have very narrow habitat requirements; this creates a weak link in the life cycle of the snow crab (Dionne et al., 2006).

In coastal waters of New Brunswick, Nova Scotia and Prince Edward Island (including those used for aquaculture), summer decreases in rainfall over land would result in diminished flow of river systems. In estuarine environments, low-flow events during the summer currently result in enhanced intrusions of saltwater wedges, thus raising salinity. Lowered velocity and reduced influx of rivers facilitates the spread of sea lettuce (*Ulva lattuca*), which acts to increase eutrophication, rendering estuaries both less suitable for shellfish or finfish aquaculture and less attractive to residents and tourists (Figure 21). The increased extent of sea lettuce in Cascumpec and Tracadie bays observed between 1990

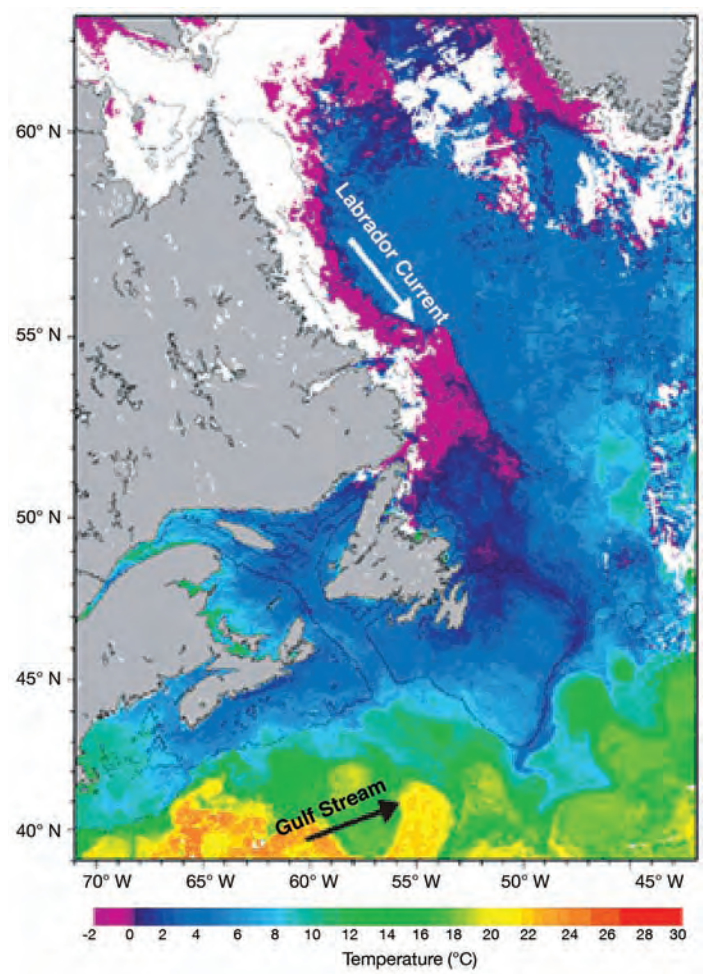


FIGURE 20: Thermal image of Atlantic Canada, showing the Labrador Current, Gulf Stream and cool countercurrent along the coastline of Nova Scotia (*from* Natural Resources Canada).

and 2006 is the result of diminished freshwater influx, reduced circulation of the estuaries and addition of fertilizers from agricultural areas (Conroy, 2007). Changes in agricultural practice that entail more use of irrigation and fertilizer will increase the likelihood of sea lettuce expansion. Reduced influx from the Saint John (*see* Bruce et al., 2003), Petitcodiac and Annapolis rivers would produce similar effects in Bay of Fundy coastal waters.

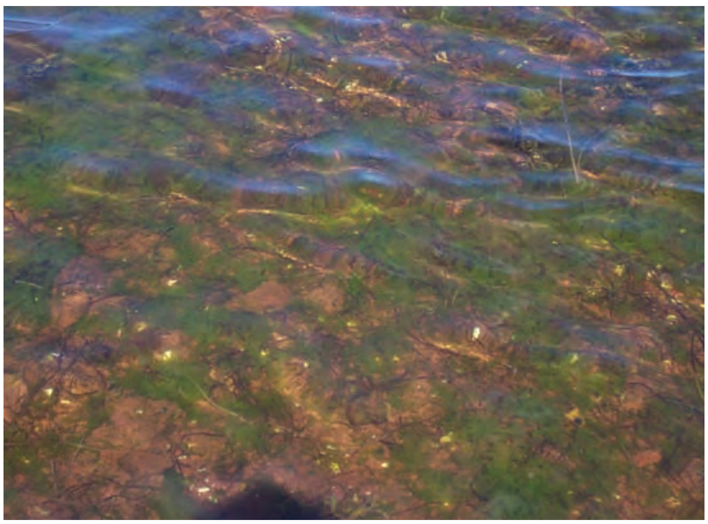


FIGURE 21: Extensive sea lettuce (*Ulva sp.*) growth, Cascumpec, PE, 2005.

The Labrador Current is fed by freshwater influx from Greenland, Arctic Canada and Labrador, in addition to water from the European Arctic. An increase in the rate of glacial melting in Greenland would cause the Labrador Current to freshen and strengthen, bringing colder water and icebergs south along the northeastern Newfoundland Shelf (Canadian Institute for Climate Studies, 1999–2005; Hadley Centre, 2006). Influx of colder Labrador Current waters locally produces fish kills, as in Smith Sound in February 2003 (Colbourne et al., 2003). Groundfish species such as *Gadus morhua* (cod) suffer terminal kidney failure when immersed in water temperatures below 2°C and react adversely to rapid decreases in temperature (Clark and Green, 1991; Chabot and Dutil, 1999; Petersen and Steffensen, 2003; Mosaker, 2005). Range contraction of cod in response to colder nearshore waters is well documented along the west coast of Greenland (e.g. Hansen, 1949). Strengthening of the Labrador Current would increase the probability of similar events in future. Changes in the strength of the NAO would also change water temperatures, thus impacting fish populations, notably cod (Drinkwater et al., 2003).

Changes in cod stocks are also related to the capelin (*Mallotus villosus*) population, a preferred prey species. Capelin is also a major food source for seabirds (Davoren and Montevecchi, 2003; Davoren et al., 2003) and is one of the most important species in the Atlantic region, ecologically and economically. Capelin stocks are concentrated in the region extending from the 2°C isotherm southwards to the northern fringes of the Gulf Stream (Narayanan et al., 1995). Spawning occurs both offshore and in nearshore and beach zones around Newfoundland, and capelin spawning time is inversely correlated to the temperature of the uppermost 20 m of the marine water column (Narayanan et al., 1995; Carscadden and Nakashima, 1997; Carscadden et al., 2000). Colder water conditions induce spawning later in the season. The health of capelin stocks is thus a critical indicator of the impact of changes in water temperature (Rose, 2005). Strengthening of the Labrador Current with cold, fresh water derived from melting glaciers in Greenland, combined with northeasterly winds pushing colder waters onshore, could thus negatively impact capelin, leading to later spawning times. If spawning is delayed until the start of hurricane activity, the net result could be a loss of productivity.

Changes in the extent and timing of sea-ice formation could impact seals and other marine mammals (Sjare et al., 2006). In several Newfoundland river and estuarine systems, seals have increased residence times by up to 3 months since the 1990s (Lenky et al., 2006). Historically, seals were not present in estuaries during the salmon smolt run. The increased time spent in estuaries by seals could lead to increased predation on both capelin and salmon. Further research is ongoing to assess the effects of seal predation on salmon stocks (Lenky et al., 2006).

The impacts of climate change are substantially different on nearshore fisheries and aquaculture in Labrador and northeastern Newfoundland compared to Maritime Canada. In the Maritimes and southwestern Newfoundland, summer impacts are primarily related to warming and increased salinity, whereas cooler waters (particularly during winter) will be notable in northeastern Newfoundland embayments. In Placentia and St. Mary's Bay, where the Gulf Stream and the Labrador Current seasonally interact, the transition between winter (Labrador Current–dominated) and summer (Gulf Stream–dominated) conditions would be expected to become sharper, having adverse impacts on fish species (e.g. Rose, 2005).

Most freshwater and marine aquatic species are adapted to a relatively narrow range of temperature conditions. With warmer water temperatures, salmonid species in Atlantic Canada will most likely suffer range contraction or extirpation as a result of changing habitat, introduced competitors and predators, and increased parasitism (Marcogliese, 2001; Schindler, 2001; El-Jabi, 2002). Significant changes have already been recorded in some rivers, such as the Miramichi in New Brunswick, and are correlated with loss of production due to unsuitable conditions for growth and survival of juvenile Atlantic salmon (Swansburg et al., 2002; El-Jabi and Swansburg, 2004).

Changes to river ice activity, either increases or decreases, would alter the overall ecological character of a river. Adverse effects of enhanced ice scour activity on the salmonid populations of the Miramichi were noted by Beltaos and Burrell (2003). However, a reduction in ice scour can be equally detrimental. Depressions created by ice scour and slab wallowing form low-energy pools, which are utilized as resting areas by salmonids during summers. Ice scour also removes vegetation and muddy organic sediments from the banks, opening the shoreline and increasing accessibility for fauna (*see* Johnston, 1993). Driftwood transported by ice and the spring freshet provides important habitats for invertebrates, vital as food sources for salmonids as well as for pollination of key species such as blueberries (Harmon et al., 1986; Lomond, 1997; Colbo et al., 1999).

3.3.2 Adaptation

Harvesters of wild marine resources are constrained in their potential responses to climate change and variation by existing regulatory regimes. Whereas farmers can plant different crops or adjust harvesting times in response to climate variations or meteorological events, fish harvesters cannot choose to harvest a different marine species (without previously obtaining a specific license), fish at different times (i.e. outside the established season) or harvest amounts in excess of established quotas. The 'soft-shell crab' problem represents one example where the constraints of an established season may conflict with ideal harvesting time under the influence of higher Gulf Stream temperature. Although species licenses, quota systems and harvesting seasons must be maintained for effective fisheries management, adjustments on regional bases may be required to effectively manage harvesting under changing water temperature and sea-ice regimes.

Aquaculture operations are theoretically able to respond to climate shifts with more flexibility than harvesters of wild marine resources. Adaptation would be most effective if aquaculture operations were sufficiently flexible to allow shifts in the species cultivated and the periods of cultivation.

Adaptation will also be required to help Atlantic fisheries deal with operational and occupational health-and-safety concerns related to increased storms, storm surges and sea-level rise. The need for vessels to travel farther seaward to find suitable resources places ships and crews at greater risk in the event of increased storm activity. This results in more demand being placed on search-and-rescue operations, notably the Coast Guard. This problem is compounded by current federal regulations that specify vessel length without corresponding restrictions on beam and height, resulting in the design of top-heavy vessels susceptible to rollover in more extreme storm conditions. Vessel development and design is currently under review in several provinces (e.g. Canadian Centre for Fisheries Innovation, 2004; Newfoundland and Labrador Fisheries and Aquaculture, 2006), and further research would be valuable.

3.4 WATER

Freshwater resources in the four Atlantic provinces represent less than 4% of the total available fresh water in Canada. The province of Newfoundland and Labrador accounts for almost 90% of the total resource in Atlantic Canada (Natural Resources Canada, 2006a, b), with most of the resource located in Labrador. The largest watersheds are those of the Churchill River (79 800 km^2) and the Saint John River (35 500 km^2 within Canada). Changes in temperature and precipitation influence evaporation and runoff, and the amount of water stored in glaciers, lakes, wetlands and groundwater (Freeze and Cherry, 1979; Jones, 1997; Hornberger et al., 1998: Rivard et al., 2003). This, in turn, results in changes in the quantity and quality of water available for human use, and impacts ecosystems and habitat.

Changes in water resources can have far reaching effects. Possible reductions in summer stream flow predicted for Atlantic Canada could impact tourism and recreation, freshwater fisheries, hydroelectric power generation, municipal water supplies and agriculture. Effects, however, will differ throughout the region. In some instances, the existing variability in annual and seasonal precipitation is greater than the anticipated impact of climate change (e.g. Barnard and Richter, 2004).

3.4.1 Sensitivities

Surface Water

Climate projections indicate that overall precipitation throughout most of Atlantic Canada, with the possible exception of western and central Labrador, will continue to increase (Figure 5b). However, increased precipitation does not necessarily lead to more water in rivers, lakes and wetlands. With increased summer temperatures, the increased rate of evaporation may exceed the influx of precipitation, causing declines in water levels. Global stream flow trends suggest that flows will increase in Labrador but decrease throughout the remainder of Atlantic Canada (Milly et al., 2005). Declining flows have been noted over the period 1970 to 2000 in the Saint John and St. Croix Rivers of New Brunswick (Bruce et al., 2003).

The increase in precipitation noted since 1948 (Lines et al., 2003) is not distributed evenly throughout the seasons in most areas of Atlantic Canada. Declines in summer precipitation at several Newfoundland sites (Catto and Hickman, 2004; Slaney, 2006) have contributed to seasonal desiccation of streams and wetlands, impacting salmonid populations (e.g. Marcogliese, 2001; Schindler, 2001) and causing shortages of domestic water supplies, as occurred in St. John's and other Newfoundland communities during the summers of 1997, 2003, 2004 and 2005.

Wetlands form a key element in the supply of water to stream systems, particularly during the drier summer months. Wetlands also moderate flooding by reducing influx to stream systems immediately following rainstorms (Freeze and Cherry, 1979; Jones, 1997; Hornberger et al., 1998). Overexploitation, inadequate wetland protection, and habitat destruction of wetland areas compound the problems generated by changes in seasonal rainfall (Schindler, 2001). In urban areas, development on former wetlands and floodplains can contribute both to lower water levels during summers and to flooding following rainstorms (e.g. Watt, 1989; Catto and St. Croix, 1998; Wohl, 2000; Liverman et al., 2006; Catto, 2006 b). Even in areas without substantial urban development, clearance of forests and drainage of wetlands have led to accentuated flood risk (e.g. Bosch and Hewlett, 1982).

Summer drought would likely diminish wetland areas. The effects would be felt primarily in areas that have been under stress from other causes. In communities where wetlands have not seen substantial development, decreases in summer rainfall within an overall pattern of increasing annual precipitation have not led to widespread desiccation (e.g. Slaney, 2006). Maintenance of wetlands is thus an effective mechanism for reducing the effects of seasonal variations in precipitation on stream flow.

Lowered water levels or decreased river flows could also lead to poor drinking water quality in some areas. Many municipalities throughout Atlantic Canada depend on surface water supplies, leaving them exposed to declines in water level in ponds and rivers, and contamination. A decrease in the supply of water to treatment plants could increase turbidity, resulting in the need for a greater level of treatment (Falkingham et al., 2001; Public Health Agency of Canada, 2002; Dolgonosov and Korchagin, 2005).

Increases in temperatures, prolonged summer dry seasons and heavier rainfall also increase the risk of contamination of drinking water by waterborne parasites, such as *Giardia, Cryptosporidium* and *E. coli* (Atherholt et al., 1998; Curriero et al., 2001; McMichael et al., 2003; Charron et al., 2004). *Giardia* cysts are frequently present even in treated water samples in Canada (Wallis et al., 1996), and are very common in raw sewage. In 2005, orders to boil water before human consumption were in place for more than 200 communities in Newfoundland and Labrador (Newfoundland and Labrador Environmental Industries Association, 2005). Similar 'boil water orders' have affected Charlottetown, Moncton and Saint John within the past 10 years.

Changes in snow cover will further impact water supply. The Maritime Provinces are expected to see a greater percentage of precipitation falling as rain rather than snow (Lines et al., 2003; Lines and Pancura, 2005). Winter runoff of rain means that less water would be available in the hinterland areas to replenish the lower reaches of stream systems during the summer (El-Jabi et al., 2004). Thus, an increase in winter precipitation would not result in an increase of available water for residents, unless winter runoff is stored in reservoirs.

In Newfoundland and coastal Labrador, winter precipitation will increase, particularly during positive phase NAO winters. Winter thaw and rain events could lead to increases in rain-on-snow flooding, as has been seen in Corner Brook since 1950 (Catto and Hickman, 2004). The anticipated changes in precipitation will not produce significant effects in the wettest areas of the province, including the southwest coast and the Avalon Peninsula (Barnard and Richter, 2004), but study of other areas is required. In interior Labrador, reduced snow cover could impact hydroelectricity production, but increased precipitation in spring and fall would help maintain the Smallwood Reservoir, reducing the impact on the system as a whole.

Groundwater

Groundwater reserves in Atlantic Canada contain water from recent precipitation and from precipitation that fell decades to centuries ago. If water is withdrawn at rates in excess of recharge by precipitation, the result is a drop in the water table. For shallow wells in Atlantic Canada, lowered water tables result after periods of summer drought. Water tables in deeper wells drilled into bedrock generally respond to yearly to decadal variations in precipitation and withdrawal.

The areas of Atlantic Canada most dependent on groundwater are southern Nova Scotia, eastern New Brunswick and Prince Edward Island (Rivard et al., 2003). Reductions in the water tables would result from decreased influx of seasonal precipitation, due to a combination of reduced summer rainfall and enhanced surface runoff of winter rain. Higher temperatures and earlier phenological springs, leading to plant growth earlier in the year, would increase evapotranspiration, thereby reducing groundwater recharge.

Prince Edward Island relies almost entirely on groundwater (Rivard et al., 2003; Savard, 2006). Recharge zones along the heights of land are adjacent to the discharge zones in low-lying areas. Water tables are located near the surface, and groundwater is depleted following periods of summer drought (*see* Government of Prince Edward Island, no date). Winter snowfall is critical for recharge under these circumstances. Water shortages may be compounded if demand for water increases from urban Charlottetown, for seasonal tourism operations or for agriculture. Businesses and communities dependent upon summer tourism, in particular, have concerns. During the relatively dry summer of 2002, at least 145 tourism-related businesses on Prince Edward Island were required to institute boiling of water (Prince Edward Island Eco-Net, 2003), necessitating careful monitoring of water supply and preventive maintenance. Drawdown of the water table due to withdrawal for irrigation is presently confined mainly to the direct vicinity of the wells (e.g. Somers and Mutch, 1999), but increased demand for water from all users will increase pressure on the resource.

In coastal communities, drawdown of the water table adjacent to the ocean, in conjunction with sea-level rise, allows seawater intrusion inland, eventually contaminating wells and rendering the water undrinkable. The areas most susceptible are coastal plains, such as southeastern New Brunswick and much of Prince Edward Island (Scott and Suffling, 2000). Low-lying areas adjacent to the Bay of Fundy, such as Wolfville, NS and Moncton, NB, are also susceptible, as both areas also have increasing demand for fresh water from agriculture and housing developments (Boesch et al., 2000).

Rapid withdrawal of groundwater in coastal areas can result in saltwater intrusion within a relatively short period. At L'Anse-aux-Meadows, with sea-level rise and the influx of approximately 35 000 tourists during the Viking Millennium celebration between mid-July and mid-August 2000, the drilled well at the Norstead re-enactment site experienced drawdown and salinization within one month (G. Noordhof, pers. comm., 2006). Ongoing salinization at L'Anse-aux-Meadows has required the owner-operators of the only restaurant in the community to dig a new well in each year since 2002 in order to supply their business with fresh water, and has effectively precluded establishment of other tourist-related businesses at L'Anse-aux-Meadows. In this case, the increase in tourist usage of groundwater has greatly accelerated the progress of salinization.

Flooding

Changes in the amount, timing and nature of precipitation can result in increased flooding frequency (Clair et al., 1998; Ashmore and Church, 2001). In the boreal climates of Atlantic Canada, winters with increased precipitation and marginal changes in temperature could result in an increase in rain-on-snow events that result in a large portion of the rain rapidly running off, rather than infiltrating the ground. Increased rain-on-snow flooding is already evident on the Saint John River (Beltaos, 1997; Catto, in press) and in the Corner Brook area (Catto and Hickman, 2004). In Nova Scotia, rain-on-snow events have led to more than 50 periods of severe floods since the beginning of records in 1759 (*see* Environment Canada, 2004a), including recent events in Colchester, Cumberland, Hants and Kings counties (e.g. Catto, in press). Mid-winter flooding during January 1956 resulted in the destruction of more than 100 bridges throughout Nova Scotia (Environment Canada, 2004a). A rain-on-snow flooding event that carved a 10 m deep channel through Bishops Falls, NL destroyed the Abitibi-Price powerhouse and dam, all major roadways and numerous structures, and required evacuation of the community (Ambler, 1985), costing more than $34 million (1983 values). In late winter 2006, rain-on-snow events impacted the Burin, Baie Verte (Middle Arm, Fleur-de-Lys, Baie Verte town) and northeastern Avalon peninsulas.

Along the Miramichi River, threats to cemeteries and other historical sites would increase because several historical and small community sites are located along the shore. Flooding of cemeteries has also been noted in Newfoundland, at Appleton and Indian Bay (Catto and Hickman, 2004; Catto, in press).

The Atlantic provinces experience alternating cold and mild spells throughout the winter and early spring, resulting in several freeze-up and break-up events in rivers each year (Watt, 1989; Shabbar and Bonsal, 2003). The combination of generally thicker winter ice cover (Clair et al., 1997), combined with irregular warm periods, will increase the potential for dynamic ice jams and consequent flooding. Dynamic ice jams result from the deposition of floating ice against obstructions in the river channel (Beltaos, 1983; Beltaos and Burrell, 2003). The formation of a dynamic ice jam occurs when a solid ice cover, formed during a cold period, resists break-up when impacted by a high-velocity flow event. Significant ice jam floods have occurred in recent years at Badger, NL (Figure 22; Fenco Newfoundland Limited, 1985; Picco et al., 2003; Peddle, 2004) and Perth-Andover, NB (Beltaos and Burrell, 2003; Environment Canada, 2004a), and along the Miramichi River, NB (Beltaos and Burrell, 2003). If historical trends continue, ice break-up and flooding will become more frequent and unpredictable. This would result in property damage and the destruction of highways and bridges, and could affect hydroelectric power generation.

Flooding is also associated with hurricane and storm events (Figure 23). Mid-latitude storm systems have caused serious flooding in communities in Atlantic Canada, such as Stephenville and St. John's, NL (e.g. Liverman et al., 2006). Extreme rainfall events over hydroelectric reservoirs can induce flooding, if the volume of rainwater exceeds the capacity of the reservoirs. All of the major population centres of New Brunswick have previously experienced river flooding.

FIGURE 22: Ice jam–induced flooding, Badger, NL. Photo courtesy of Brian Hawel.

FIGURE 23: Flooding in St. Lawrence, NL., due to storm surge from Placentia Bay, February 2004, triggered by southwesterly wind (*from* Southern Gazette, Marystown, NL).

Regardless of the cause of a flood, human health can be negatively affected and serious injury or death may result. Drowning, hypothermia and electrocution are all risks directly associated with floods (Environment Canada, 2004d; Health Canada, 2005; Jonkman and Kelman, 2005). Contamination of floodwaters by sewage, wastes and domestic, industrial and agricultural chemicals is common, resulting in lengthy and expensive cleaning procedures and delay in reoccupation of communities (e.g. Peddle, 2004). Sewage systems and water treatment facilities may be overwhelmed with a sudden influx of contaminated floodwater. Submergence of buildings in floodwaters produces more favourable conditions for the growth of moulds and fungi that, if not removed, can lead to health difficulties when the buildings are reoccupied (Dales et al., 1991; Health Canada, 2005). Waterborne diseases and parasites can also be spread as a result of flooding (Curriero et al., 2001; McMichael et al., 2003; Charron et al., 2004). The chance of an outbreak of a waterborne illness is more than doubled during the six weeks following an extreme rainfall event (Thomas et al., 2005). Current water treatment practices cannot easily address these risks.

Much research on climate change and water resources has focused on physical aspects, with relatively less work done on the socioeconomic impacts. Social impacts are difficult to quantify, and therefore may not be recorded in monetary estimates of 'total cost' of flood damage (H. John Heinz III Centre for Science, Economics and the Environment, 2000; Mitchell, 2003; Parson et al., 2003). Social impacts may persist much longer than the physical impacts of flooding.

3.4.2 Adaptation

Adaptation to changes in water resources and flooding represents application of well-established 'best practices'. All of the suggested adaptations would be advantageous to Atlantic Canada and its residents, regardless of climate change. Shortages in water resources for human consumption are best addressed through a combination of land-use and resource management, planning, and conservation and reduction of wasteful usage (Bruce et al., 2000). Preservation of wetlands has been documented as an effective adaptive response for runoff retention, both reducing spring flooding and increasing summer streamflow (see Watt, 1989; Booth, 2000; Coote and Gregorich, 2000; Wohl, 2000). Construction of retention ponds for storage of water and reduction of flooding, common in many areas of Ontario and western Canada (e.g. Ontario Ministry of the Environment, 1999; Marsalek et al., 2000; Environment Canada, 2004d; Kuehne and Cairns, no date), has not been common practice in Atlantic Canada. Adapting to changes in the frequency, intensity and duration of precipitation events will require adjusting reservoir management practices (c.f. Miller and Yates, 2006).

Urban municipalities in Atlantic Canada have been confronted with summer water shortages and water quality issues in recent years. Municipalities have responded by upgrading treatment facilities, accelerating development of new water supply areas, increasing security around surface water supplies and encouraging water conservation through combinations of educational programs and financial mechanisms. All of these adaptive mechanisms could be pursued further in the future.

Reliance on groundwater, particularly in coastal areas where saltwater intrusion due to rising sea level is coupled with decreased summer precipitation, necessitates conservation and careful monitoring of water quality. Detailed monitoring of consumption patterns, in combination with resource assessment, represents an effective adaptation approach, as in the Baltic, PE area (Somers and Mutch, 1999).

The most effective adaptation approaches to reduce flooding damage is to prevent new construction on flood plains, relocate existing structures and residents where economically feasible, and provide and maintain adequate drainage infrastructure for coping with rainfall events (Catto and Hickman, 2004). Relocation of structures and communities at risk has been successfully accomplished in several areas (e.g. Evans and Brooks, 1994; Shrubsole et al., 2003; Environment Canada, 2004d; Carter et al., no date), including Atlantic Canada (Peddle, 2004; Catto, 2006a). Mapping of flood-susceptible areas is a significant tool in reducing flood risk, when coupled with effective land-use planning and zoning. This requires effective communication between scientists, municipal planners, community leaders and residents (Berger, 2006; Leroy, 2006). Integrated mapping and assessment of all biophysical hazards affecting a community (e.g. Schmidt-Thomé et al., 2006a, b) is an effective starting point in the development of adaptive responses. Understanding the factors influencing the vulnerability of different communities to flood events is also important (*see* Box 4).

BOX 4

Factors affecting community vulnerability to flooding

Communities throughout Atlantic Canada exhibit variability in sensitivity and vulnerability to flooding, in part because of differences in local awareness of the hazard and investment in effective adaptation. Key physical influences on vulnerability include the frequency and severity of flooding. Social and community influences on community vulnerability include such factors as population dynamics and demographics; the location of the residential developments and critical infrastructure in relation to flood-prone areas; monetary property values; degree of alteration of natural drainage routes by human activity; resiliency of transportation and communication routes; presence of hazard-limiting infrastructure; recovery and adaptation abilities; and the existence of emergency and development plans.

Social impacts may increase as a result of misconceptions regarding the frequency of a particular flood hazard. There is a tendency to overestimate the frequency of lower probability flooding mechanisms (e.g. landslides blocking rivers or tsunamis), and underestimate the frequency of higher probability flooding events, such as storm surges, rain-on-snow events and dynamic ice jams (Viscusi, 1993). Although repeated flooding from similar causes has occurred in some Atlantic Canadian communities (e.g. Liverman et al., 2006), individuals and communities may fail to take the necessary precautions, leading to financial losses, personal and societal stress, and further physical, financial and psychological damages.

Community vulnerability is partly a function of the distribution and number of higher risk groups, who tend to have fewer resources at their disposal to cope following an event. Studies conducted following disasters in Canada, the United States and Japan indicate that neighbourhoods and communities that were poor or declining socioeconomically before a disaster do not succeed in achieving the socioeconomic status that they possessed prior to the event, even as reconstruction efforts progress (Morrow, 1999; Morrow-Jones and Morrow-Jones, 1991).

The tendency for residents of rural areas and smaller communities in Atlantic Canada to remain in their communities for long periods, developing local ties, reduces vulnerability. For many communities in Atlantic Canada, however, declining and aging populations with decreasing economic resources exhibit greater vulnerability, not only to flooding but to all hazards, risks and changes.

3.5 FORESTRY

3.5.1 Sensitivities

In Atlantic Canada, increased growing season temperature and rising levels of CO_2 will not necessarily result in increased ecosystem productivity (Flannigan et al., 2000). For example, for black spruce (*Picea mariana*), the dominant tree species in the boreal forest of Labrador, the net ecosystem productivity of the forest will likely increase with increased springtime temperatures. Nevertheless, elevated summer temperatures will likely decrease net productivity because of higher rates of evapotranspiration.

With decreased summer precipitation (Lines et al., 2003) and higher temperatures, the possibility of drought disturbance rises in Atlantic Canada (McCurdy and Stewart, 2003). Shallow-rooting trees, such as hemlock and spruce, are much more sensitive to drought than those with deep root systems (Dale et al., 2001).

With increased drought, the probability of forest fires increases significantly and the duration of the fire season is extended. Analysis of paleoecological data and modelling under General Circulation Model scenarios suggests a reduction of the potential for wildfires in eastern Ontario and Quebec, but an increase in Atlantic Canada, including Newfoundland and most of Labrador (Flannigan et al., 2001). Changes in forest fire characteristics have the potential for drastically altering interior forests by changing nutrient cycling. Forest fires also have implications for the health of nearby residents, with smoke and particulates aggravating respiratory illnesses (University of Washington, 2001; McMichael et al., 2003; University of British Columbia Okanagan, 2005; Moore et al., 2006).

Fire disturbance in ocean-influenced forest ecosystems has been extremely rare, with most disturbances originating from wind and storms (Figure 24; Wein and Moore, 1979; Runkle, 1985; Seymour, 1992; Foster et al., 1998). Increases in the strength and frequency of windstorms and thunderstorms are an important concern for forests. Wind speed is the determining factor in the extent of damage to trees (Figure 25). Larger trees are more susceptible to windthrow (McCurdy and Stewart, 2003), as are stands that have been recently burned (Flannigan et al., 2000). Damage to tree stands increases the probability of pathogen outbreak and tree mortality (Ayres and Lombardero, 2000).

Another aspect of climate change is the potential for an increased frequency of ice storms (Dale et al., 2001). Damage from ice storms, such as those that occurred in New Brunswick in 1998 (Natural Resources Canada, 2003b) and the Cobequid Hills of Nova Scotia in 2002 (Nova Scotia Department of Environment and Labour, 2003), can range from incidental damage of individual branches to annihilation of entire stands. Should a period of drought follow an ice storm, the probability of fire outbreak increases (Irland, 2000). Frequent episodes of winter thaw and late spring frost also pose problems, particularly for frost-sensitive species such as yellow birch (Cox and Arp, 2001; Bourque et al., 2005; Campbell et al., 2005).

Shifts in the abundance of insects, pathogens and herbivores have the greatest potential to adversely affect forests (Gray, 2005). Under a warmer climate, ranges of insects and pathogens are

FIGURE 24: Wind and coastal erosion resulting in death of conifers, Red Point, PE.

FIGURE 25: Cumulative windthrow and ice-load damage, Middle Cove, NL.

expected to shift north (Gray, 2005) and warmer winter temperatures will decrease mortality. With the relatively short lifespan of these species, the increased number of generations per season will allow for quicker adaptation to evolving climate conditions (Gray, 2005). As a result, greater numbers of insects and pathogens may disturb forest ecosystems, possibly resulting in changes to nutrient cycles and forest species composition that, in turn, can significantly alter soil associations for stands (Ayres and Lombardero, 2000). It is also possible that, in some regions, pathogen outbreaks may decrease if changed climate conditions favour the increased abundance of predators or competitors (McCurdy and Stewart, 2003).

Invasive species are also expected to benefit from a shifting climate, mainly due to their quick reproductive strategies that allow them to disperse quickly (Simberloff, 2000). Invasive species affect forests by shifting nutrient cycles, thus affecting forest succession and fire regime. Increases in the action of herbivores and predation can cause regional extinctions through hybridization with native species and cause increased mortality from the transportation of exotic diseases (Dale et al., 2001).

Climate change, and the broad nature of the associated disturbances that will accompany it, will have a tremendous impact on the genetic variation of forests. Genetic variation, the basis for forest health, will become increasingly important as climate shifts (Mosseler et al., 2003b).

3.5.2 Adaptation

Migration of tree species in response to changes in climate requires time, and there is a substantial time lag between the development of suitable climate conditions and the establishment of a forest. Considering the lifespan of tree species, adaptation options for the forest industry may be limited over the short term. Adaptation will be facilitated by management strategies that enhance the capacity of the forests to cope with shifting climate conditions and affected site conditions (Beaulieu and Rainville, 2005). Enhancement and preservation of genetic variability (e.g. during harvesting and reforestation) is critical, as it increases the ability of a forest stand to withstand an outbreak of pathogens or insects, which is important if the current forest cover is to be conserved (Ayres and Lombardero, 2000).

3.6 AGRICULTURE

Agriculture in the Atlantic region is a diverse, highly integrated sector representing 4% of the farms in Canada and utilizing 2% of Canada's agricultural land area (Statistics Canada, 2001a). In 1999, the value of the agri-food industry to the Atlantic economy ranged from just over 2% (NL) to over 12% (PE) of provincial GDP (Agriculture and Agri-Food Canada, 2005). Atlantic Canada produces 45% of Canada's potatoes, 39% of the country's berries and grapes, and 4.3% of the milk (Statistics Canada, 2001a). Throughout the region, processing of agri-food products remains a significant part of economic activity (Hauer et al., 2002), resulting in more than 50% of the total economic activity in the sector (Krakar and Longtin, 2005).

Agriculture is highly dependent on climate. The growth of crops relies on a sufficiently long period of favourable temperature and timely rainfall. For animal production, climate controls when and if animals can be pastured, as well as the expenses associated with maintaining suitable animal shelter. For Atlantic Canada, the projected changes in climate present both opportunity and risk (Wall et al., 2004). Opportunities include growing higher value crops as a result of longer growing seasons, whereas risks are associated mainly with the increased frequency of extreme events, potential changes in pests and diseases, and uncertainty in global markets.

BOX 5

Adaptive capacity in the Atlantic agriculture sector

There are several factors that affect the adaptive capacity of Atlantic Canada's agricultural sector, including the current economic state of agriculture, demography of producers, health of rural communities and ability to deliver new technologies (Wall et al., 2004).

Atlantic Canada's agricultural producers in 2003 were, on average, 53 years of age. A total of 43% had postsecondary education (the highest percentage in Canada) and 36% planned to retire by 2008 (Aubin et al., 2003). The majority of Atlantic agricultural operations are sole proprietorships (55%). Only 28% of operators plan to expand in the coming years (lowest in Canada; Aubin et al., 2003). The demographics of Atlantic agriculture represent both an opportunity and a threat in terms of response to climate change. The opportunity to recruit new, highly educated individuals into agriculture would enhance the capacity of the sector to adapt. The threat is that, because of the current economic climate, few young persons are electing to farm. This trend is not new: since 1981 there has been a 27% decrease in the number of farms in Atlantic Canada (Statistics Canada, 2001a), the highest rate of loss in Canada. This represents a significant vulnerability for agriculture in the Atlantic region.

There are also vulnerabilities associated with institutional support for agriculture, such as agricultural extension and breeding programs. Enrolments in faculties of agriculture have been in decline nationwide during the past 10 years. In response, many of the agriculture schools have become primarily environmental schools and fewer agricultural scientists are being trained. This diminished capacity will adversely affect the ability to identify and deliver the information needed to modify management practices to adapt to climate change, thus increasing sectoral vulnerability.

3.6.1 Sensitivities

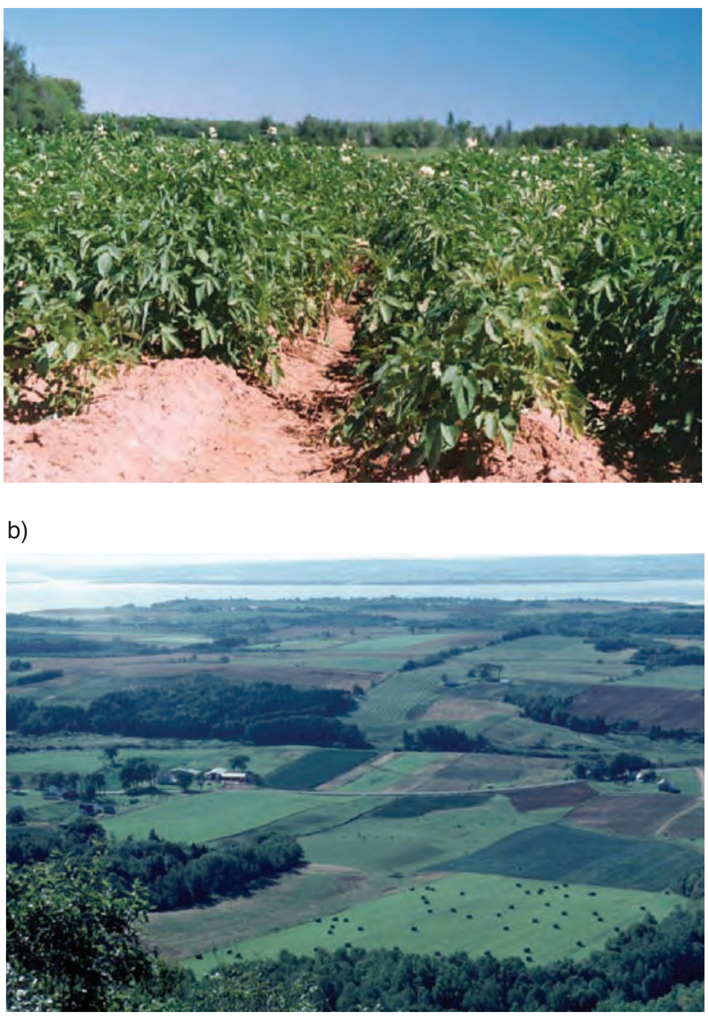
An increase in climate variability and the frequency of extreme events would adversely impact the agricultural industry. A single extreme event (later frost, extended drought, excess rainfall during harvest period) can eliminate any benefits from improved 'average' conditions. Climate scenarios suggest increased climate variability, including increases in the frequency of hot days during the growing season, heat waves, number of cold days, late spring and early fall frosts, and numbers of consecutive dry days and intense precipitation events (Lines et al., 2003; Lines and Pancura, 2005), all of which have the potential to dramatically impact agricultural production. A warmer, wetter growing season may increase the potential for forage production, but could be offset by greater winter kill resulting from warmer winters (Bélanger et al., 2001). Similarly, although warmer summer conditions may allow for a greater range of grapes and/or tree fruits, more extreme weather during the spring and fall could adversely affect the productivity of these crops. Fruit trees, which cannot be readily moved, are more susceptible to damage than are crops that can be replanted in subsequent seasons. The ability to respond to extreme events is related to the overall economic status of the sector (*see* Box 5) and the suitability of programs to deal with economic risk, such as income stabilization and crop insurance.

Extreme climate events can also increase agricultural impacts on the environment (Coote and Gregorich, 2000; De Kimpe, 2002). The primary environmental issues associated with agriculture in the Atlantic provinces are water quality, soil quality and, to a lesser extent, air quality. Atlantic producers acknowledge the importance of these impacts, identifying water pollution (52%) and soil erosion (47%) as the most significant environmental impacts of agriculture (Aubin et al., 2003). The past decade has seen efforts to implement management practices, such as improved crop rotations, soil conservation measures and more effective use of nutrients, that minimize environmental impacts. In many areas of Atlantic Canada, the management of manure is the primary environmental concern (e.g. Kings County, NS); in other areas, impacts are largely associated with intensified crop production (e.g. soil erosion and pesticide runoff from intensive potato production; Milburn et al., 1995). Water quality is of particular concern in Prince Edward Island, where groundwater is the only source of drinking water. Flooding increases the potential for agricultural impacts on surface water and groundwater.

An important limitation for agriculture in the region is the quantity and the agricultural capability of the soils. The soils are, for the most part, relatively fragile, and many have been degraded as a result of erosion, compaction and loss of organic matter related to a reliance on shorter, less diverse crop rotations and reductions in soil residue cover (Figure 26). The soils of Prince Edward Island and New Brunswick are most intensively managed, with 67% and 38% of the agricultural land, respectively, being cropped in 2001 (Statistics Canada, 2001a). Nova Scotia and Newfoundland have lower percentages of cropped land (29% and 21%, respectively) and have a greater predominance of permanent cover management systems, such as pasture and hay production. In Newfoundland, the amount of land available for arable production represents a significant constraint on the adaptation to climate change. Sustaining the productivity of agricultural soils and preventing increased impact on the surrounding environment will be important considerations in adapting to climate change (Coote and Gregorich, 2000).

The magnitude of relative changes in temperature and precipitation during the growing season (*see* section 2.1) will be important in determining adaptation in the agriculture sector. Bootsma et al. (2005a, b) examined the potential impact of changes projected by the first-generation coupled Canadian General Circulation Model (CGCM1; Boer et al., 2000) under

a)



b)

FIGURE 26: a) intensive potato farming, Mill River, PE and b) crop management, including hay cultivation, Arlington, NS.

emission scenario IS92a. Based on an increase in effective growing degree days and a decrease in growing-season water deficits (defined as the amount by which evapotranspiration exceeded precipitation) over much of the region for the 2040 to 2069 period, Bootsma et al. (2005 a, b) concluded that increased use of corn-soybean-cereal rotation, similar to that currently practised in southern Ontario, may give the best results. The result would be a doubling of income from these lands relative to their current use. In this analysis, the authors were not advocating the adoption of corn-soybean--cereal rotation but merely presenting an example of the potential implications of a change of climate on agricultural production. The study also emphasized that local climate will demand different adaptive responses across the region.

A warmer, wetter future would allow the growth of longer season, higher heat unit varieties and crop types. Given current market conditions, this would likely result in greater production of such cash crops as corn and soybeans, and the growth of more diverse tree fruits. Other market opportunities, such as the potential for producing feedstock for biofuel (e.g. ethanol and biodiesel) production or increased demand for organic foods, will influence the mix of crops being grown.

Climate change will also impact pest populations and their predators (Coakley et al., 1999). The warmer, wetter conditions predicted for Atlantic Canada will tend to favour a more diverse pest population (Rosenzweig et al., 2000). The complex interaction between crop pests, their predators and crop growth makes prediction of the potential impacts of climate change difficult. The rate of change in the size of pest populations and the spectrum of pests represents a key knowledge gap for agriculture. The time required to develop and adopt pest control approaches is significant, particularly if they require the registration of new chemical control agents (Coakley et al., 1999). The size of the Atlantic agricultural market is small, so the costs of developing and registering new products may not be considered economically viable. Furthermore, the development and dissemination of biological control agents or cultural practices used to control pests in organic production are difficult to achieve quickly.

As in crop production, the impacts of climate change on animal production are multifaceted, and include increased production costs resulting from increased energy demand to introduce artificial cooling of livestock buildings. In addition, animal diseases and their spread are significantly influenced by climatic conditions.

Bees have high economic value as pollinators in agriculture in Atlantic Canada. The apifauna is already under pressure from invasive species as well as parasitism and disease, and are likely to be negatively impacted by climate change (Richards and Kevan, 2002).

3.6.2 Adaptation

Adaptation to climate change for agriculture in Atlantic Canada will require a re-examination of cropping systems, including crop selection and soil management practices. There are many factors that influence the selection of crops, including agronomic, economic, environmental, social and cultural considerations. The limited analyses performed to date have generally focused on economic and, to a lesser degree, agronomic considerations. For example, Bootsma et al. (2005b) did not assess the range of cropping systems that might be suited to the projected future climate, whether the soils of the region could support the proposed change in cropping practices, the relationship to existing markets, or the suitability of current agronomic knowledge and infrastructure. All of these factors will influence future adaptation decisions.

It is also important to assess the potential impacts of proposed new cropping systems. Although a warmer and wetter future would allow for the adoption of more intensive cropping systems (Bootsma et al., 2005b), this transition would likely increase impacts on water as a result of increased soil erosion and leaching. The integration of animal and crop production is also an important consideration. One of the current issues in some areas is the concentration of animal production within a limited land-base. New cropping systems may provide an opportunity to address this issue.

The increasing demand for organically produced products and for the production of organic products within the region (Webb, 2002; Connell and Morton, 2003) could also shape future cropping practices. Although there are no climate impacts that are unique to organic production systems, the heavy reliance of these systems on legumes and the cultural control of pests may make management in a changing climate particularly challenging.

Perennial crops, including berry, grape and orchard industries, are economically important within the region. Warmer, wetter summers may expand the range of species and varieties that can be grown, but warmer winter temperatures may also result in increased winter damage to these crops (Bélanger et al., 2001).

Adaptation will also likely involve increased management of water on farms. These measures could include both improved drainage and erosion control, to facilitate the rapid removal of water from fields resulting from intense precipitation events, and on-farm or regional water management/storage to allow for irrigation during periods of drought. The restoration and maintenance of wetlands to process water from agricultural fields, by attenuating the flow of water to streams and retaining nutrients and sediments, is another important consideration.

3.7 TRANSPORTATION

Transportation in Atlantic Canada contributes significantly to Canadian, and especially provincial, GDP (Table 2) and to the Atlantic per capita economy (Table 3). Impacts on transportation will directly affect other sectors, such as manufacturing, tourism, urban growth, supplies and trade. In turn, changes in other sectors will influence demand for transportation (Yevdokimov, 2003). A warmer climate with varying precipitation changes will result in direct and indirect impacts on the transportation sector (Burkett, 2003). Transportation is linked to many socioeconomic activities (Zimmerman and Cusker, 2001; Transport Canada, 2003; Yevdokimov, 2003).

3.7.1 Sensitivities

Road

Road transportation is by far the largest component of the transportation sector in Atlantic Canada. Changes in climate that will affect road systems include periods of extreme heat and cold, increased freeze-thaw cycles and reduced ice cover. Greater numbers of hot days, as observed in interior New Brunswick and Nova Scotia, will likely lead to pavement softening (Mills and Andrey, 2003). Road damage resulting from both hot weather failure and enhanced frost heaving would leave regions susceptible to disruption of supplies and services.

For many coastal communities, sea-level rise will require coastal roads to be moved or rebuilt at higher elevations to avoid or

TABLE 2: Contribution of commercial transportation to provincial GDP in Atlantic Canada in 2001 (*from* Statistics Canada 2004, Table 379-0025).

Province	Expenditure (millions of dollars)	Percent of total Canadian GDP	Percent of total provincial GDP
Newfoundland and Labrador	448.7	1.1	3.5
Prince Edward Island	74.4	0.2	2.4
Nova Scotia	1 015.0	2.4	4.3
New Brunswick	1 011.6	2.4	5.4

TABLE 3: Personal expenditures on transportation by provinces in 2001 (*from* Statistics Canada, 2004, Table 379-0025).

Province	Expenditure (millions of dollars)	Expenditure per capita (dollars)	Percent of total provincial personal expenditures	Percent of total Canadian personal transportation expenditures	Percent of provincial final domestic demand
Newfoundland and Labrador	1 452	2 801	15.2	1.4	7.9
Prince Edward Island	372	2 711	14.2	0.4	8.1
Nova Scotia	2 720	2 711	14.2	2.6	8.2
New Brunswick	2 240	2 982	15.8	2.2	9.1
Canada	103 131	3 257	15.0	100	8.9

reduce flooding. In some areas that are experiencing coastal erosion, roads have already been moved and will have to be moved again. For example, Highway 117 from Bouctouche to Saint-Édouard has been moved twice during the past three decades (Arsenault, pers. comm., 2004). In southern New Brunswick and northwestern Nova Scotia, Acadian dikes have reduced the impact of sea-level rise on roads by protecting land from erosion and flooding. However, these dikes were built more than a century ago and the maintenance they require may make them an expensive means of adaptation (Shaw et al., 1998). Storm damage to roads is also a concern (Figure 27).

FIGURE 27: Storm-surge damage to road, April 2004, Ferryland, NL.

Marine

In the Atlantic region, marine transportation is composed mainly of short-sea shipping (i.e. over short distances without crossing open oceans and within coastal waters). In addition, marine transportation includes fishing harbours, small craft harbours and ferry services (Fisheries and Oceans Canada, 2006). Recreational harbours are currently growing in significance throughout the region. Ferry services, provided by Marine Atlantic Inc., Bay Ferries and Northumberland Ferries, are an important economic component. In 2004, 419 548 passengers and 223 044 vehicles moved between Newfoundland and Labrador and Nova Scotia (Transport Canada, 2004). As well, international cruise ship traffic has been increasing in eastern Canada. Halifax saw 212 000 passengers in 2004 (Halifax Port Authority, 2006) and Saint John had 138 622 passengers the same year (Saint John Port Authority, 2005). Cruise ship visits are seen as economically important, and projects to deepen harbours to accommodate larger vessels have been undertaken in Charlottetown, PE and St. John's, NL.

Little work has been done to evaluate sensitivities of the marine transportation system, especially for waterways. Catto et al. (2006) investigated the effects of storm winds and surge activity on marine and road transportation through Channel-Port aux Basques, NL, and concluded that increasing easterly wind strengths posed a potential hazard. Weather-related delays to the Marine Atlantic ferry service resulted in an economic cost of more than $5 million in 2004 (Catto et al., 2006). Wharf construction will have to consider sea-level rise and storm events, and wharves should be raised to avoid inundation (Mills and Andrey, 2003). Although breakwaters are not always recommended during the installation of a new wharf, due to their potential to interfere with current patterns, increased storminess could lead to increased reliance on these structures to reduce impacts and infrastructure damage (McLean et al., 2001).

Many marine vessels currently in operation were built within the last 30 years and will therefore remain in operation for many more years. Although some larger vessels could cope with changes in marine weather conditions, there will be a need for retrofitting (Green et al., 2004).

Warmer winter temperatures and greater ice-free time could facilitate transportation in winter, spring and fall (Easterling, 2002; Langevin, 2003), enhancing shipping in some parts of the region. This phenomenon is already being observed in northern parts of the Atlantic provinces, such as the coast of Labrador, where marine shipping is continuing for a longer season. Gradually, as winter ice cover diminishes, marine shipping is likely to become increasingly important for the transportation of goods and services to northern regions (Goos and Wall, 1994).

Demand for emergency services provided by the Canadian Coast Guard will likely increase as a result of more frequent storms and extreme events (Burkett, 2003). Reduction in the length of the winter period and less sea ice, especially in areas such as the Northumberland Strait, could lead to different types of emergencies, including ice-shove activity. The ability to accurately identify the location of ice blocks is necessary to avoid an increase in the number of incidents. Real-time information and integrated management are important for all aspects of marine transportation and safety.

Rail

Very little research has been carried out on climate change impacts and adaptation related to rail transportation in Atlantic Canada. Railroads play an important role in New Brunswick and Nova Scotia. The main impact of concern is the potential disruption of the critical link through the Chignecto Isthmus (Tantramar Marshes) due to storm-surge flooding or destruction or damage of the Acadian dikes (Forbes et al., 1998; Shaw et al., 1998). Management plans could be continuously revised to adapt to change in sea level rise. Rail transportation in Maritime Canada is also exposed to changes in market and trade arenas (Nederveen et al., 2003). Its relative lack of flexibility for locations and schedules, as well as the need for transfer onto a truck at distribution stations, make it difficult to modify.

Air

Problems with ice and fog are the main climate impacts likely to occur at Atlantic Canada's airports. Changes in cloud cover and winter temperatures could influence the use of de-icing for aircraft. Flooding and storm activity could impact airport operations at Stephenville, NL. Airports in Halifax, NS, Saint John, NB and St. John's, NL may experience an increase in the number of delays or closures due to storms. Enhanced frost activity would shorten the lifespan of paved runways at airports. The social and economic consequences may be significant for communities that currently rely on aircraft, especially during the winter months, for everything from food supplies to access to medical services.

3.7.2 Adaptation

Transportation decisions and investments are generally made at the provincial level (with some national regulations and private investment). Identification of key facilities or locations that may be impacted by climate change, such as wharves, terminals and gas stations, is an important starting point (Potter, 2003). Assessing the resiliency of infrastructure to storms and extreme events, and identifying the emergency measures and resources needed to respond to extreme events is also recommended (Transport Canada, 2003).

With a greater frequency of freeze-thaw events in winter months, changes to road maintenance and salt usage will be required in order to reduce pavement damage and improve safety. In extreme cold or heat waves, roads tend to be affected by changes in temperature, leading to greater road damage and more dangerous driving conditions. Currently, few adaptations to such conditions are available. Road safety will continue to be a priority consideration.

Major transportation projects will have to consider climate change (Almusallam, 2001; Burkett, 2003). As vehicles and related infrastructure are short lived (most less than 25 years), changes could be implemented to facilitate cost-effective replacement using improved designs (Mills and Andrey, 2003). Bridges with a longer expected lifespan will have to be examined in light of continued sea-level rise and/or greater flooding in streams. New structures should be located outside impact areas associated with sea-level rise (Zimmerman and Cusker, 2001).

3.8 ENERGY

3.8.1 Sensitivities

Priority energy issues related to climate change adaptation for Atlantic Canada include changes in supply and demand, as well as impacts on exploration, production, transportation/transmission and other infrastructure. Relative to other sectors, little research has been conducted on the impacts of climate change on the energy sector in Atlantic Canada (Bell and McKenzie, 2004). Currently, load forecasts for electricity do not include climate change and are not calculated as far in advance as 2020 (H. Booker, Market Advisory Committee, NB, pers. comm., November 28, 2005). There is tremendous variability between the Atlantic provinces in terms of current energy mix for electricity production (Table 4). For example, in Newfoundland and Labrador 97% of electricity production (2002) was from hydro, whereas electricity in New Brunswick was produced from coal, oil, nuclear and hydro. Prince Edward Island purchased most of its electricity from New Brunswick and generated small amounts from wind turbines and oil, whereas Nova Scotia relied most heavily on coal and oil for electricity production (Table 4).

Electricity demand currently peaks in the winter in Atlantic Canada. Increased temperatures in winter will decrease energy demands for heating, whereas increased summer temperatures will result in increased electricity demands for air conditioning and refrigeration. This shift in demand would also result in a shift from direct utilization of fossil fuels for heating to electricity for cooling. Increasing demand for electricity from the northeastern United States (Natural Resources Canada, 2003a; Energy Information Administration, 2005) may result in pressure to increase energy exports.

Energy infrastructure is sensitive to impacts from extreme weather events, as evidenced by storms in 2004 that caused $12.6 million and $4 million in damage to electricity lines in Nova Scotia and New Brunswick, respectively (Bell and McKenzie, 2004). Weather events can produce generation and transmission inefficiencies, resulting in loss of power due to storms, such as occurred in Nova Scotia in 2006, New Brunswick in 2002 and Newfoundland in 1984 (Catto, in press).

Hydroelectricity is an important electricity production method in Newfoundland and Labrador. Long-term changes in seasonal and annual precipitation would affect overall generation capability, although electric power systems with dams and reservoirs will likely be able to adjust their operating practices to accommodate these changes (cf. St. George, 2006). More rainfall does not necessarily lead to more water in rivers and lakes, due to increased evapotranspiration resulting from higher temperatures. Reduced stream flow (Bruce et al., 2003) will likely have an impact on generation during dry summers, but higher levels of precipitation during the spring and autumn would help maintain reservoir levels, thus reducing the overall impact.

Wind generation (Figure 28) has become the fastest growing renewable energy supply in Atlantic Canada. Wind atlases show wind energy resources in Prince Edward Island (Gasset et al., in press) and Nova Scotia (Nova Scotia Wind Energy Project, 2004). Newfoundland has no wind farms at present, although the Newfoundland government has issued a call for proposals for a 25 MW facility (*see* Canadian Wind Energy Association, 2006a) and more than 10 areas throughout the province have been proposed for wind turbine development by private companies. There may be as much as a 10% reduction in summer winds in the Atlantic provinces by mid-century, although no change is anticipated for winter winds (Price et al., 2001). Ice storms can pose threats to wind turbines, requiring them to temporarily shut down to avoid damage (American Wind Energy Association, 2003). However, the impact of ice buildup on turbine blades appears limited (Australian Wind Energy Association, 2006; Canadian Wind Energy Association, 2006b).

Offshore petroleum exploration and production is sensitive to changes in storms, sea ice and icebergs. Reduced sea ice in the Atlantic region (Drinkwater et al., 1999; Hill and Clarke, 1999; Hill et al., 2002) may allow greater offshore activity, although high variability in sea-ice extent may make it difficult to predict and prepare for events, such as that which occurred near Sable Island in spring 2004, when sea ice forced the temporary abandonment of the Canadian Superior platform, at significant expense (Bell and McKenzie, 2004). Coastal energy infrastructure, such as generating plants (Point Lepreau and Coleson Cove, NB; Lingan/Aconi NS; Holyrood, NL), oil refineries (Saint John, NB; Dartmouth, NS; Come By Chance, NL), proposed liquefied natural gas terminals (Saint John, NB; Bear Head and Goldboro, NS), and where offshore pipelines come ashore (Goldboro, NS), may be susceptible to impacts from sea-level rise, storm surges and coastal erosion.

3.8.2 Adaptation

Adaptation to climate change by the energy sector in the Atlantic provinces will require re-examination of design standards for transmission and distribution infrastructure, to enable it to better withstand extreme weather events. Anticipation of changes in demand (both seasonally and by fuel source), contingency planning for extreme events and taking advantage of new and improving opportunities will also be important. Energy conservation, increasing grid reliability through diversification, and resource modelling of wind, solar and biomass energy are potential no-regrets adaptations.

TABLE 4: Electricity production fuel type in the Atlantic provinces, resulting from production within each province (*modified from* Bell and McKenzie, 2004).

Province	Coal (%)	Oil (%)	Natural gas (%)	Nuclear (%)	Hydro (%)	Other (%)	Total Atlantic production (2002)
New Brunswick	32	29	0	20	15	4	24.00
Newfoundland and Labrador	0	3	0	0	97	0	59.62
Nova Scotia	66	23	0	0	9	2	16.35
Prince Edward Island	0	10	0	0	0	90	00.03
Total	**18**	**13**	**0**	**5**	**63**	**1**	**100.00**

FIGURE 28: Experimental wind farm, North Cape, PE.

3.9 TOURISM

3.9.1 Sensitivities

Tourism is currently the largest industry in Prince Edward Island (Government of Prince Edward Island, 2004) and is a major component in the economies of all four Atlantic provinces. Tourism is a vital component in the economic sustainability of most communities along the Atlantic coastline and is seen as a key component in the economic revitalization of formerly fishery-dependent communities. Recent increases in summer economic activity in some rural communities are notable.

Environmental conditions are an important factor in decisions made by prospective tourists, particularly where the natural environment is among the destination's primary attractions (Braun et al., 1999; Scott and Suffling, 2000). As climate change occurs in Atlantic Canada, tourism may be affected both positively and negatively (DeBaie et al., 2006). The impacts of climate change on tourism, and the impact of tourists on the environment, must both be considered.

Rising sea level, increased coastal erosion, beach narrowing and coarsening, and increased storm activity all have negative impacts on tourism in coastal regions (Mimura, 1999; Uyarra et al., 2005). Damage to infrastructure represents an additional concern. Coastal development and the construction of protective infrastructure would restrict the movement of the beaches and sand dune systems landward. Wave energy would be focused in progressively smaller areas, resulting in the preferential removal of sand and causing beaches to become narrower and coarser. Where coupled with restrictions on sand supply, the result would be to produce gravel beaches, which are less attractive for most tourists. This would have important economic impacts on the communities that rely on tourism for sustainability (Cambers, 1999; Fish et al., 2005; Uyarra et al., 2005).

Geomorphic stresses induced by climate change, in combination with increased visitation, lengthening of the tourist season and enhanced tourist use of coastal areas, have resulted in accelerated erosion of coastal tourist sites throughout the region and could have an impact on the long-term sustainability of coastal tourism (Daigle et al., 2006). Increased foot traffic and vehicular access to beaches and backing dunes (Figure 29) have also had an impact (e.g. Catto, 2002, 2006a, b; Catto et al., 2002). National and provincial parks are also vulnerable to sea-level rise and storm surges.

Iceberg viewing has become a popular form of tourism along the Newfoundland coastline. From the mid-1990s to 2003, iceberg numbers increased due to glacial calving in Greenland (Petersen, 2005), posing difficulties for petroleum-related operations but providing opportunities for tourism. During the period 2004 to 2006, iceberg numbers and sightings decreased along the northeastern Newfoundland coastline, causing concern for local tourism-related businesses (e.g. G. Noordhof, L'Anse-aux-Meadows, pers. comm., 2006). The number of icebergs is directly related to glacial activity in Greenland and water temperatures in the Labrador Sea (cf. Canadian Institute for Climate Studies, 1999–2005; Hadley Centre, 2006).

In the winter, changes in the duration and distribution of snow will impact winter recreational activities, such as snowmobiling and cross-country skiing (Abegg et al., 1998; Harrison et al., 2001; Scott et al., 2003). Climate change would reduce the number of days suitable for snowmobiling by 38 to 62% by the 2020s in eastern North America, compared to conditions in the 1970s (McBoyle et al., 2006). By 2050, the predicted snowmobiling season would be less than one week in Sydney and Gander, and between 0 and 20 days at Fredericton (McBoyle et al., 2006). Snowmobile sales declined by 38.4% in Canada and the United States between 1997 and 2005, while ATV sales increased by a comparable percentage. Manufacturers have adapted by increasing ATV production, and prospective riders are purchasing ATVs as all-terrain, all-weather vehicles.

3.9.2 Adaptation

In Atlantic Canada, tourism marketing is increasingly geared towards longer seasons, varied activities and diverse demographic audiences. Visitors are seeking cultural, historical a)

b)

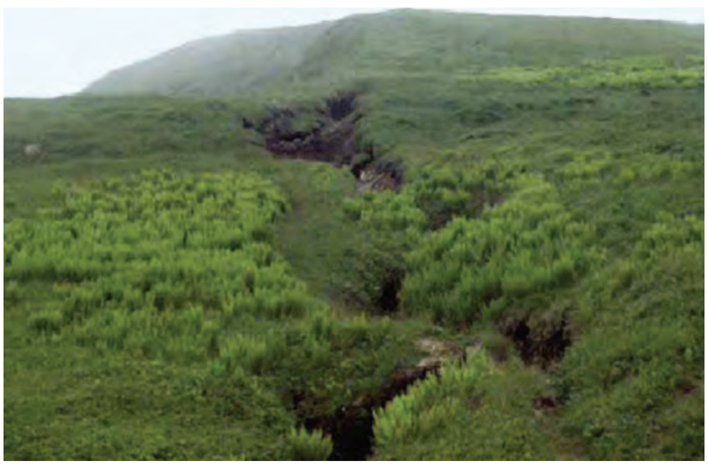


FIGURE 29: Excessive tourist foot traffic facilitates erosion a) of coastal dunes, Malpeque, PE and b) at Cape St. Mary's Ecological Reserve, NL.

and recreational opportunities. Tourist preferences are subject to fashion, transportation costs, exchange rates and perceived security issues, such that a single event may have disproportional, unforeseen and persistent effects.

Tourist operators and promoters, including multiple levels of government, can change advertising campaigns in response to changed conditions. Some aspects of tourism in Atlantic Canada, including longer summer seasons, are favoured by ongoing climate change. As warming increases more rapidly in central North America and western Europe, the relatively cool summers of Atlantic Canada are increasingly seen by tourists as an attractive environment for vacationing or a summer residence.

Comprehensive assessment of the stresses induced by tourist activity at coastal sites is needed to recognize the potential for erosion and changes in beach sediment before substantial degradation occurs. Important tourist sites, such as Panmure Island Provincial Park, PE and the dune at Bouctouche, NB, are currently at risk from coastal erosion, and protection work is needed to care for such sites. Tourism may be addressed in the design of coastal protection. For example, aesthetic concerns can influence the design of shoreline protection (as in Victoria Park, Charlottetown, PE), and structures may be designed to simultaneously provide recreational walking trails (as in Summerside, PE and Trout River, NL).

At Prince Edward Island National Park, many repairs have been needed as a result of storm surges. The winter storm of 2004, which occurred when no ice cover was present, was particularly damaging to park infrastructure. Retreat has been used as an adaptation approach for some campground shelters. Armour stone has been used in some road sections and to protect bridges. Numerous repairs to roads, boardwalk and other infrastructure have also been required. In Kouchibouguac National Park, some structures have been solidified, elevated, moved or removed seasonally in reaction to, or to prevent damage from, storms. These modifications have been ongoing since the park's creation.

3.10 COMMUNITIES

3.10.1 Sensitivities

Impacts from sea-level rise, modifications to wave regimes, storm surges, changes in the severity and frequency of storms, and alteration in the duration of ice cover will all affect communities in Atlantic Canada (McLean et al., 2001; Thompson et al., 2005; Catto et al., 2006). Recent flooding and hurricane events, which have resulted in property and infrastructure damage, injury and death, isolation from emergency services and power outages, demonstrate the vulnerability of Atlantic communities to climate impacts.

The geographic setting of communities (inland versus coastal) in the Atlantic region will result in different types of impacts with varying levels of both sensitivity and vulnerability. Coastal communities, such as Annapolis Royal and Halifax, must deal with impacts of storm surges (*see* Boxes 6 and 7). In contrast, inland communities are more susceptible to changes in temperature and precipitation, which impact water supplies, flooding, agriculture and forests. A distinction is also apparent between rural and urban communities, although differences in this case are more related to the ability to adapt. For all communities, climate influences are superimposed on other political, socioeconomic and technological factors that influence vulnerability (*see* Boxes 4, 5).

Rural communities in Atlantic Canada are, in many instances, facing economic difficulties resulting from their dependence on a single natural resource. Climate change, by placing additional pressure on natural resources such as marine species or agricultural crops, could worsen the situation for many communities. In this context, climate change should not be seen as an independent, solely dominant factor, but as one of several stressors acting on fishing, forestry and agricultural communities. The interaction of numerous stress factors substantially increases the vulnerability of rural, single-resource-dependent communities throughout Atlantic Canada.

Health and social effects will also be associated with the direct impacts of climate change on sectors such as tourism, agriculture and fisheries (Brklacich et al., 2007). Loss of income or employment can produce stress-related disorders and mental illnesses (Sowder, 1985; Health Canada, 2005). Severe weather events and associated natural hazards can result in people being dislocated and forced to temporarily reside in crowded shelters, which increases the risk of disease outbreak. Residents are also affected by the stress induced by such events, leading to a variety of mental health impacts, including depression from financial loss, injuries and relocation (Abrahams et al., 1976; Noji, 1997; Greenough et al., 2001; Soskolne and Broemling, 2002; Soskolne, 2004). Psychological effects commonly persist for several years following a disaster (Bennet, 1970; Powell and Penick, 1983; Sowder, 1985).

For interior communities, there are health risks associated with contamination of groundwater and surface water caused by heavy precipitation, as surface runoff may pollute water supplies with animal wastes and pesticides. Extreme precipitation events may

BOX 6

Annapolis Royal: coastal flood and storm-surge mapping

The Tidal Surge Study by the Clean Annapolis River Project (CARP), a citizen-based group, is an exemplary case of a project that increased the adaptive capacity of a community in the face of climate change (Belbin and Clyburn, 1998).

The town of Annapolis Royal, located at the west end of the Annapolis Valley on the northwest coast of Nova Scotia, was concerned about increased risk from flooding during perigean spring tides and extreme weather events. Annapolis Royal is in danger of flooding because much of the region is below sea level, reclaimed in the seventeenth century by the Acadian settlers using dykes. Additionally, the land has sunk lower over time. Roads, bridges and buildings have already been flooded, putting the town at risk.

All the data collected for this project were obtained from existing sources. Historical records regarding past extreme events were collected from museums, newspapers and historical societies within the region. The Saxby Gale of October 4–5, 1869 was used as model for sea-level predictions.

A few centimetres can be the difference between a disastrous flood and a non-event. Maps with 2 m contours and 0.1 m spot elevations were used to determine the locations at greatest risk from tidal-surge flows, and the regions most in danger of flooding. The maps revealed particular concerns, including the fact that the fire department is situated on a small rise (Figure 30). During flooding, it would be on an island, isolated from the community. Following the study, the emergency rescue equipment that was previously stored solely at the fire department was relocated around the town. The fire department also acquired a boat to be used for transporting personnel and equipment, and to provide access to the mainland during a flood.

The Emergency Measures Organization (EMO) has begun to closely monitor the patterns and heights of the tides in the region. Monitoring has now become a province-wide action, as it is recognized that the danger is not localized in the Annapolis region.

Another important action taken as a result of this project was the enactment of a mock disaster scenario. Annapolis Royal acted out step-by-step procedures of what would occur in an emergency. This allowed the town to become aware of what steps needed to be taken to prevent more damage or potential harm to people in a real disaster. Using a paper simulation, part of the town was evacuated and a county-wide scenario was built to deal with the implications of a storm surge. New mechanisms have been established within EMO to allow a seamless melding of services. The results of the Annapolis Royal case study are currently being used to develop a toolkit for land-use planners (Parks, 2006).

This case study shows that small communities can take steps to prepare for the impacts of climate change. By determining the damages that could occur during an extreme weather event, the town was able to take preventive measures that reduce the risk of large-scale economic loss from flooding.

FIGURE 30: Flood-risk mapping for Annapolis Royal, NS (*after* Belbin and Clyburn, 1998).

also overwhelm water treatment facilities or cause sewers to overflow, resulting in further contamination (Health Canada, 2005; New Brunswick Department of Health, 2005). Increases in heavy precipitation events will also affect storm-water systems. Sensitivity depends on the nature of the infrastructure and the intensity of precipitation events (Watt et al., 2003). Inquiries within some urban communities in New Brunswick revealed that present storm-water management does not take projected increases into account, although some communities do incorporate a certain level of uncertainty (e.g. 20% in Moncton, NB).

Atlantic Canada is recognized as one of four areas in Canada where air pollution is greatest, largely because of air masses from the eastern United States (Labelle, 1998). Ozone is the most common air pollutant; the national concentration of ground-level ozone increased by 16% between 1990 and 2003 (Statistics Canada, 2005c). An increase in heat waves, combined with air pollution, would increase the frequency of smog days in urban areas and associated health problems, such as asthma and other pulmonary illnesses, as well as heat stress and related illnesses (McMichael et al., 2003; Epstein and Rogers, 2004; Health Canada, 2005). Impacts of heat waves, smog events and airborne particulates from forest fires may be compounded as a result of climate change. Related illnesses and deaths, especially in urban areas, can be expected to rise as poor air quality aggravates cardiovascular and respiratory diseases (McMichael et al., 2003; Health Canada, 2005).

A total of 12% of Canadians under age 12, and 8% over age 12 have been diagnosed with asthma (Statistics Canada, 2005c), and the number of Canadian adults suffering from asthma increased from 2.3% in 1979 to 6.1% in 1994 (Health Canada, 1998). Atlantic Canada has some of the highest rates of asthma in the country (Public Health Agency of Canada, 1998; Canadian Council on Social Development, 2006). Heat waves and smog events can also increase the risk of strokes, with some studies showing a link between stroke and respiratory illnesses and environmental change (Epstein and Rogers, 2004). For example, increases in levels of suspended particulate matter (air pollutants) are positively correlated with increases in rates of myocardial infarction and pulmonary infection cases requiring hospitalization or resulting in death (Dominici et al., 2006; Murakami and Ono, 2006). As well, some authors underline the possible increase in allergens related to increases in CO_2, which will also affect respiratory health (Epstein and Rogers, 2004).

3.10.2 Adaptation

Although there has been much discussion on the capacity of different communities to respond to environmental changes (Pelling and High, 2005), there has been less research focused on building community adaptive capacity (Smit and Pilifosova, 2003; Brklacich et al., 2007). Nevertheless, individuals, groups and municipal governments in Atlantic Canada are already involved in adaptation efforts, mostly in the form of coastal protection.

Rural and urban communities in Atlantic Canada differ widely in their demographics, economic resiliency and robustness. Consequently, their ability to adapt, and therefore their vulnerability, differ substantially. Urban centres generally have greater financial, institutional and human resources to meet challenges, including climate change. Adaptations being undertaken by the Halifax Regional Municipality are currently beyond the means of rural communities.

Local governments are actively involved in adaptation efforts. Following severe damage due to storm events, droughts and non-native insect invasion, the Halifax Regional Municipality initiated sustainable planning, which includes planning for climate change adaptation. The Climate SMART program works with the private sector to include greenhouse gas reduction and climate change adaptation measures in the decision-making process. The building of a wastewater treatment facility with provision for 3 m rise in sea level, and a thermal energy co-generation plant for hospitals and universities, are two initiatives that have emerged from Climate SMART (*see* Box 7). Another example of adaptation at a municipal level is from the town of Rexton, NB. This community is affected by tides and storm surges on the Richibucto River, which have caused erosion and flooding. Rexton has been actively protecting historically and culturally significant parts of the shoreline along the river for several decades.

Many communities are requesting assistance from provincial governments for protection of their coasts, and all provinces are beginning to address the impacts associated with climate change. The Prince Edward Island Special Committee on Climate Change presented its final report in April 2005, recommending measures to protect coastal areas (Special Committee on Climate Change, 2005). The elimination of quarry permits for beaches and a revision of emergency response measures were also included in the report. The government of Nova Scotia released an Issues Paper in 2005 entitled Adapting to a Changing Climate in Nova Scotia: Vulnerability Assessment and Adaptation Options (Government of Nova Scotia, 2005). Nova Scotia has also worked on identifying the sensitivity of different coastal areas (Nova Scotia Department of Energy, 2001), although the report contains little in terms of adaptation measures. In Newfoundland and Labrador, an action plan containing measures to reduce greenhouse gas emissions, as well as some adaptation measures, was released in June 2005 (Government of Newfoundland and Labrador, 2005).

Many discussions with groups in New Brunswick have focused on the issue of governance, especially in rural areas. Rural areas of the province are grouped into Local Service Districts (LSDs), and a local committee of non-elected representatives makes recommendations to the provincial government regarding their needs. Many individuals think that this mechanism provides very little power to communities, and that demands regarding adaptation in their area are diluted among requests made by other LSDs (Martin and Chouinard, 2005). In the absence of other mechanisms, residents of the community of Pointe-du-Chêne took it upon themselves to take action following recent storm-surge events. A special committee organized an emergency shelter and is involved in discussions with different levels of government regarding investigation of long-term solutions to the flooding associated with storm surges.

The period of increased hurricane activity currently ongoing in the North Atlantic suggests a need for enhanced emergency preparedness and adaptation (Goldenberg et al., 2001). As a preventive measure, the Emergency Measures Organization has adopted a new awareness campaign to help citizens of Prince Edward Island better prepare themselves in case of hurricanes. The Canadian Hurricane Centre has also increased efforts to remind the population of the severity of hurricane warnings in order to improve preparedness (Environment Canada, 2004c).

One of the main obstacles to implementing adaptation remains the generally short-term view of developers and government officials relative to the long-term effects of climate change (Federation of Canadian Municipalities, 2002). The lack of resources is also a major obstacle that individuals and communities are facing in implementing adaptive measures (Federation of Canadian Municipalities, 2002). Protection structures are very costly, and conflicts between residents have occasionally resulted from the inability of some to contribute to structures deemed necessary by others (structures being more efficient if they are continuous along a given stretch of coastline).

There is a need for improved knowledge about climate change at all levels of decision-making. This will improve the adaptive capacity of communities, contributing to reduction of their vulnerability to climate change. Increasingly, this is being achieved by linking communities to research projects in ways that allow them to be consulted and to obtain an understanding of the potential impacts of climate change (e.g. Vasseur et al., 2006). One of the most effective means of accomplishing this is through the integration of climate change impacts and adaptive considerations into the Environmental Impact Assessment process.

BOX 7

Reducing vulnerability through the Climate SMART Initiative

Halifax Regional Municipality (HRM) covers more than 5000 km^2 and has a population of more than 350 000. It offers an international sea terminal and airport, as well as commercial, educational, research and technological centres for the region.

In recent years, Halifax has experienced a number of extreme climate events, with increased impacts, damages and costs. The category 2 Hurricane Juan (September 2003) made landfall outside of Halifax and tracked across central Nova Scotia, causing extensive damage to property, infrastructure and the environment. Only a few months later, in February 2004, the severe winter blizzard that became known as 'White Juan', dumped almost 90 cm of snow on HRM in one day. The storm resulted in $5 million of unbudgeted snow removal costs and repairs to utility infrastructure. Such events have cost HRM, and its businesses and citizens, millions of dollars, the loss of several lives, disruption of services and great inconvenience. These events have also drawn attention to, and triggered an increased level of concern regarding, the potential impacts of climate change.

Prior to Climate SMART, HRM did not have climate change planning strategies in place. Recognizing the increased risk to infrastructure, property and its citizens that could result from climate change, particularly projected increases in the frequency and/or intensity of extreme climate events, HRM looked for a mechanism to plan and implement climate change strategies.

Climate SMART (Sustainable Mitigation and Adaptation Risk Toolkit) has been developed to help mainstream climate change mitigation and adaptation into municipal planning and decision-making. It is a collaborative partnership between the public and private sectors. Partners in the HRM prototype project include the Federation of Canadian Municipalities, Natural Resources Canada, Environment Canada, Nova Scotia Department of Energy, Nova Scotia Department of Environment and Labour, Nova Scotia Environmental Industries Association, members of ClimAdapt, several community groups and local businesses, and HRM.

Climate Smart is the first initiative in Canada to advocate a fully integrated approach to addressing climate change at the municipal level. The HRM and its partners officially launched Climate SMART in March 2004. Principal tasks of the prototype HRM Climate SMART project include developing:

- vulnerability assessments and sustainability analyses;
- cost-benefit assessments;
- emissions management and mitigation tools;
- a plan for managing climate change risk;
- an emissions management and adaptation methodology, which includes methodologies for each sector of the community; and
- communications and outreach initiatives.

Several project components are already contributing to Halifax's overall environmental strategic planning efforts. Future plans include defining and conducting risk and vulnerability assessments, and developing the adaptation management tools that will enable HRM to incorporate climate change into municipal planning and decision-making.

4 ASSESSING VULNERABILITY AND MOVING FORWARD

4.1 ASSESSING VULNERABILITY

As shown throughout this chapter, it is clear that certain regions and sectors of Atlantic Canada are sensitive to climate change. Key sensitivities include those of coastal zones to sea-level rise and extreme events; marine ecosystems to shifting oceanic conditions; water resources to changes in temperature and precipitation; and managed systems, such as agriculture and forestry, to extreme weather and pests and pathogens. Considerable research has been conducted in each of these sectors, as illustrated in the respective sections. Although other sectors, such as transportation, energy and tourism, will also be impacted by climate change, there is less literature available on them, especially at the local level.

Understanding vulnerability also requires consideration of adaptive capacity. Although limited literature is available on adaptive capacity in the Atlantic region, certain conclusions can be drawn. Limited economic resources in many rural communities seriously constrain their adaptive capacity. The small size of farms, relative to elsewhere in Canada, and the quality of the soils reduce the ability of farmers to adapt. Previous over-harvesting restricts choices for some fish harvesters and communities, and regulations designed under previous climate conditions for vessel construction, setting harvesting seasons and other activities may be less suitable as climate continues to change. The expense of relocating existing critical infrastructure situated in vulnerable locations may be prohibitive. Local customs, traditions and personal attachment to the land make relocation or abandonment of houses along the coastlines or on floodplains unattractive or impossible for many people.

Atlantic Canada also has substantial assets that increase its adaptive capacity. The resilience of residents is strong. Residents have successfully adapted to the existing weather conditions. Climate change scenarios indicate that future conditions will involve 'more of the same' in terms of the types of extreme climate events that currently occur, although their frequency and magnitude are projected to increase. Historical events, such as the Saxby Gale of 1869 and the Great Hurricane of 1775, can be used as proxies for future events, both in terms of their physical effects and the individual human and community response. Although economic resources may be lacking in some communities, community resilience and social cohesion provide a counterweight that will help facilitate adaptation.

Successful adaptation depends upon recognition of the problem and application of thought and resources. To do so, education, information and especially change in people's attitude to climate change will be essential to accelerate the responses (especially adaptive actions) in communities. It will also depend on the degree to which humans can influence the sector under consideration. For marine and terrestrial ecosystems, where the possibility of direct human control is limited, the potential for adaptation is relatively low. In these areas, adaptation from the human perspective consists primarily of recognizing and monitoring the changes that are occurring from all causes, and employing management approaches that minimize non-climate stresses on the systems.

Adaptation in sectors such as agriculture, energy, transportation and communities also involves recognition of change and response. In many instances, adaptation is already underway: examples include changes in agricultural crops, efforts to conserve energy and water, design of more robust transportation and energy transmission infrastructure, and development of renewable energy technology. Communities such as Annapolis Royal, Channel-Port aux Basques, Beaubassin, Tignish and Halifax have all undertaken initiatives to adapt to ongoing climate change.

By assessing the available literature on impacts and adaptation in Atlantic Canada, and by considering these generalizations regarding adaptive capacity, the authors have developed a table summarizing the vulnerability of sectors discussed in the chapter (Table 5). These classifications, ranging from low to high, are subjective estimates based on discussion among the lead and contributing authors. As such, they represent expert opinion, based on current knowledge. The broad scale of the analysis means that generalizations and averaging were necessary, and these classifications may not apply to specific locations or industries.

From this table, it is apparent that key vulnerabilities in the Atlantic region relate to the coastal zone, agriculture and rural communities.

4.2 MOVING FORWARD

It is clear that successful adaptation would produce a variety of beneficial results. Social, economic and environmental impacts would be reduced through recognition of climate-related hazards and the implementation of appropriate responses. This would be facilitated by provision of better tools to integrate climate change and long-term impacts into development decision-making processes, adoption of new building codes to reduce potential damage, and strengthening of policies to protect sensitive ecosystems. Marine resources, for example, could be more effectively managed if climate change impacts were fully

TABLE 5: Exposure, sensitivity and vulnerability of the sectors in Atlantic Canada discussed in this report.

Sector	Exposure	Sensitivity	Adaptive capacity	Vulnerability	Confidence level
Terrestrial ecosystems	Low to moderate	Low to moderate	Moderate to high	Low to moderate	Moderate to High
Coastal zone	High	High	Moderate	High	High
Marine ecosystems	High to moderate	High to moderate	Low to moderate	High to moderate	Moderate to High
Water resources	Moderate	Moderate	High	Moderate	High
Forestry	Low	Low	Low to moderate	Low to Moderate	Moderate
Agriculture	High	High	Moderate	Moderate	Moderate to High
Transportation	Low	Low to Moderate	Moderate to high	Low to Moderate	Moderate
Energy	Low	Low to Moderate	Moderate to high	Low to Moderate	High
Tourism	Moderate	Modérée	Moderate	Moderate	Low to Moderate
Rural communities	Moderate to high	High	Low to moderate	High	Moderate
Urban communities	Moderate to high	Moderate	High to moderate	Moderate	High

integrated into assessments and policy development. Such policies need to recognize that climate will continue to change for many decades or centuries.

In many instances, desirable adaptations represent application of previously known principles, and would bring benefits regardless of climate change (no regrets). For example, all residents would benefit from improved management of water resources; diversification of energy sources; increased efficiency in the use of water, energy and other climate-sensitive resources; and improvements to the transportation systems. Designation of flood hazard zones is another example of a no-regrets adaptive measure. Residents of Atlantic Canada have the capacity to designate areas that are unsuitable for construction due to natural hazards, but also need to follow through by ensuring that, in future, structures are not built in areas at risk.

Many authors agree that the knowledge available is sufficient to begin adaptation, but there are important research and assessment needs that, if addressed, would help support adaptation decisions (Adger et al., 2005; Baethgen et al., 2005; Martin and Chouinard, 2005). Many studies also note a lack of awareness in communities of the seriousness of climate change impacts and the necessity for proactive adaptation. Further research, as well as awareness-building, is necessary.

Ongoing research continues to examine environment-human relationships and interactions. Projections of future impacts benefit from improved understanding of the impacts of previous events, monitoring of ongoing changes and recognition of the interactions between various sectors. One of the major benefits of research into climate change is a vastly improved understanding of current climate conditions, and the many ways that these influence humans.

Further research could profitably focus on areas where additional confidence would help facilitate decision-making. Better understanding of potential impacts and processes is needed. Specific examples of knowledge gaps relate to:

- changes in forest fire frequency and magnitude, and associated ecosystem impacts;
- impacts of invasive species, and development of adaptive measures to reduce impacts and protect biodiversity;
- impacts of changes in water temperature on freshwater and marine species;
- interspecies relationships in marine and estuarine communities;
- impact of climate change on tourism in Atlantic Canada;
- understanding community resilience and capacity to respond to climate change; and
- development and testing of ways to enhance adaptive capacity through existing mechanisms, such as environmental assessment, building codes and integrated decision-making tools.

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QUEBEC

CHAPTER 5
Quebec

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Recommended Citation:

Bourque, A. and Simonet, G. (2008): Quebec; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 171-226.

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TABLE OF CONTENTS

KEY FINDINGS

Climate change will have many environmental, public health and socioeconomic impacts. In Quebec, these impacts will differ depending on the particular sensitivities of each region. The extent and costs of climate change impacts will likely increase over time. Key findings include the following:

The extent and magnitude of climate change impacts depend largely on changes in demographic, socioeconomic and environmental conditions. Apart from climate change per se, an analysis of anticipated impacts must also include an analysis of the factors that will affect the vulnerability of each subregion. Accordingly, the following points should be considered:

- From 1960 to 2003, temperatures in southern Quebec increased by between 0.5°C and 1.2°C in the southwestern and south-central areas, and by less than 0.5°C in the southeastern part. In northern Quebec, a gradual cooling has been replaced by a sudden warming of about 2°C since 1993.
- Despite uncertainties, the use of increasingly high-performance climate models makes it possible to produce detailed climate scenarios for several parameters and several regions, all of which point to major changes in climate trends.
- In Quebec, there is a slowing of population growth and an increasingly aging population, except among First Nations and Inuit communities. There has been a population shift from urban centres mainly to the outer edges of developed areas and suburban belts in southern Quebec, resulting in urban sprawl onto high-potential agricultural land.
- Although the general state of public health is improving, the future trend is uncertain due to several factors, including the fact that high-risk populations are becoming increasingly vulnerable.
- Quebec's growing economy is now based primarily on the tertiary (service) sector and is largely integrated into the North American and world economies. In contrast, infrastructure is aging and is largely exposed to the vagaries of the weather. In addition, many communities outside large urban centres are dependent on natural resources and are therefore also highly vulnerable to the vagaries of the weather.

The largest climate changes in absolute terms are anticipated to occur in the northern subregion. They will exacerbate the problems already being experienced in this region with respect to communities' high level of exposure to natural disasters and their dependence on critical infrastructure, access to resources and traditional ways of life that are closely related to the existing natural environment. Terrestrial and aquatic ecosystems have begun to change, specifically in terms of their structure, due to permafrost degradation, the formation of thermokarst lakes and ponds, the expansion of shrub communities and wildlife population displacements.

Climate change will result in alterations to the natural environment with potentially significant implicationsin areas where natural resource development is central to the economy. The landscape, hydrology and geomorphology of streams, the distribution of plant and animal life, and regional biodiversity could all undergo significant changes, particularly in areas already subject to a high level of human pressure. In contrast, this could have a certain beneficial effect, due to an anticipated increase in productivity in certain sectors, such as hydroelectricity and forestry. Nevertheless, these scenarios remain tinged with uncertainty for several reasons: lack of data, conflicting historical trends, poorly understood processes, uncertainties related to the tools used, and North American market effects.

In the maritime subregion, where the coast is highly exposed to the hydrosphere, there will likely be increased shoreline erosion along the Gulf of St. Lawrence and the St. Lawrence River estuary, the area where most of the subregion's socioeconomic activity is currently concentrated. The combination of sea-level rise, the gradual disappearance of surface ice, the geology of certain coastlines and possibly changing storm patterns all appear to result in an increase in the natural process of erosion, causing adverse effects on the built environment, tourist attractions and the quality of life for many communities in this subregion, which depends heavily on waterways for access.

In the south subregion, an increase in the frequency, intensity or duration of extreme weather events is believed to pose increased risks for the aging built environment, vulnerable populations and communities living in areas exposed to natural hazards. Historical meteorological events have shown the high degree of dependency of urban and rural communities on water, energy supply and transportation infrastructure, all of which are exposed to the vagaries of the weather. Milder winters and hotter, more humid summers would lead to increased evaporation of natural waters; this could exacerbate water-use conflicts and lead to further degradation and loss of wetlands that rely on flooding. Climate change also poses significant risks to a number of threatened species already subject to various other stresses; these species have a low migration capacity and their habitat has become degraded. However, in this subregion, climate change could also result in energy savings (reduced demand) and development opportunities (increased plant productivity), resulting in annual gains of several hundred million dollars.

Adaptation to climate change offers many possible solutions to significantly reduce its adverse impacts. Human societies have always demonstrated an ability to adapt to climate variability and seem once again capable of overcoming the obstacles to climate change adaptation, which is based on the following elements: identifying and understanding the priority issues; collecting and disseminating information and data needed by the stakeholders involved in climate change adaptation; developing and applying the optimal techniques and technologies; amending or adapting policies, standards and organizational structures; and considering emerging uncertainties when making decisions. Quebec has a high degree of adaptive capacity, due specifically to its increasingly diversified knowledge economy. As for the natural environment, it adapts spontaneously and autonomously, and human systems may be able to assist with its adaptation. Although adaptation appears to be increasingly inevitable, little is generally known about its costs and limitations, particularly in the long term. Climate change adaptation measures should therefore be accompanied by reductions in greenhouse gas emissions in order to tackle the source of the problem and to minimize the 'nasty' surprises that the weather may hold in store for the future.

1 INTRODUCTION

The objective of this chapter is to update existing assessments (Bergeron et al., 1997; Ouranos, 2004; Lemmen and Warren, 2004) on sensitivity, impacts and adaptation to climate change; this summary of information concerning Quebec should thus contribute to a better understanding of the phenomenon and lead to the discovery of solution pathways.

Figure 1 presents the problem of impacts and shows how atmospheric conditions can directly or indirectly affect natural and human systems, either subtly or suddenly. All climate change impacts can be grouped into three elements that will react and adapt to the new situations (*see* United States Global Change Research Program, 2000). These three 'key elements' are population (human beings), the natural and built environment (their surroundings) and socioeconomic activity (the human dynamic), all of which can sustain direct impacts from changes in mean temperatures, variability and climate extremes, so long as they are exposed and sensitive to them. Moreover, any impact on one element can have repercussions on the other two as a result of indirect impacts; these are generally more difficult to quantify and are responsible for the complexity of overall impacts. For example, consider the effect of extreme precipitation events becoming more abundant: they directly influence the hydrosphere and frequency of sewer overflows and have an indirect influence on the frequency of residential flooding, as well as on public health, utility interruptions and the state of the economy, and thus lead to many other cascading effects. Given the scope of the problem, the Quebec chapter restricts itself to presenting a summary of the most important anticipated issues, based on available documentation.

Figure 1 raises one of the great challenges of this kind of synthesis, which is to choose an approach that makes the classifying and grouping of the many issues possible while dealing with cumulative and cross issues.

Following the 'Introduction', in which general information and concepts are presented, Section 2 briefly describes the current characteristics and evolution of the three 'key elements' under the influence of climate change. Section 3 constitutes the core of this update and outlines the current state of knowledge regarding the four subregions of Quebec and the three key elements. Finally, Section 4 presents a synthesis and recommendations to guide the development of the science of climate change, which includes research on climate, improvement of knowledge on expected impacts and the evolution of everything related to adaptation, an emerging theme of recent years. This science of climate change will become increasingly necessary for effective decision-making.

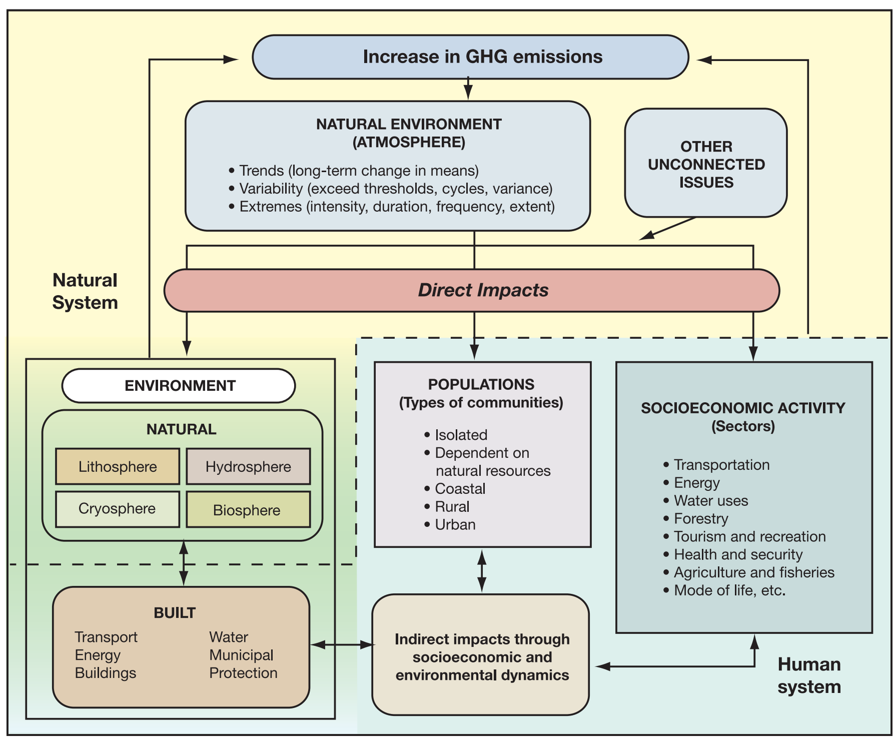

FIGURE 1: Direct and indirect impacts of climate, its variability and its extremes on the three key elements (the environment [natural or built], the population and socioeconomic activity), illustrating the significant influence and complexity of climate impacts. Other issues, such as technological development, societal choices, infrastructure aging and demographic changes, occur in parallel and interact with these climate changes. It should be noted that, in this document, the natural environment refers to the five climate subsystems defined by Peixoto and Oort (1992), in which the atmosphere is the initiator of the climate change that causes these impacts.

2 A CHANGING QUEBEC

With or without climate change, Quebec has never ceased changing over time. Its population, natural and built environment, and socioeconomic activity have transformed over recent centuries, and more particularly in recent decades. Since the nature and magnitude of climate change impacts will depend as much on features of these three key elements, as on climate change itself, it is important to summarize these characteristics, as well as those linked to climate. Before dealing with specific and regional issues related to the impacts of climate change, this section presents the broad features and likely picture of changes in Quebec for the coming decades.

2.1. POPULATION

With a population of 7.5 million (2005), Quebec is the second most populous province in Canada. A large part of its population (82%) is concentrated in the south and along the St. Lawrence River, while the remainder is scattered in other regions where the economy relies more heavily on natural resource development. Quebec is urbanized, with 75% of its population living in 73 cities of more than 10 000 inhabitants — including 54% in the nine cities with more than 100 000 inhabitants, namely Montréal, Québec, Lévis, Gatineau, Sherbrooke, Laval, Longueuil, Saguenay and Trois-Rivières — and its economy is diversified. The rural area (80% of inhabited territory) represents 1.6 million people (22% of the population) living in nearly 1000 villages. Finally, the total Aboriginal population of close to 83 000 consists of 73 000 First Nations people and 10 000 Inuit (Secrétariat aux affaires autochtones, 2006).

In the coming decades, Quebec's population will stabilize in numbers of inhabitants and will show changes in regional composition and age groups. According to the Institut de la statistique du Québec (ISQ), the population will increase to nearly 8 million in 2026 and 7.8 million in 2051 depending on the reference scenario (*see* Figure 2; Institut de la statistique du Québec, 2003). The uncertainty of this forecast is related mainly to assumptions regarding trends in net immigration and fertility that frame the weak and strong scenarios of the ISQ.

Moreover, 12 of Quebec's 17 administrative regions would experience a population decline by 2026. This decline would be even more pronounced in the long term, ranging from –16% to –32%. At the same time, the population of the Montréal region would increase by nearly 450 000 persons (+13%), who will settle primarily in the north and south belts, thus contributing to the trend towards urban sprawl. The Outaouais region would also experience strong growth, with an increase of 13% by 2041. Nunavik would see its population (10 000 in 2001) increase by 28% (13 000) by 2021, mostly due to special features inherent to this area (*see* Section 3.1). The current population is young (in 2004, 56% were under 25 years old) and lives in 14 villages located along the coasts of Hudson Bay, Hudson Strait and Ungava Bay (Institut de la statistique du Québec, 2004). Its growth is already creating strong demand for housing (*see* Section 3.1).

Given these projections, variations in population by age group will be even more pronounced than expected variations in total population in the regions (Figure 3). In fact, because of the ratio between the number of persons older than 65 and those who are younger, demography in Quebec will be completely transformed. In 2051, the number of persons aged 65 and over will exceed 2 million and, in 2026, their demographic weight may exceed 20% in all regions except northern Quebec. In 1996, the Mauricie region, with the greatest number of elderly, had fewer than 15% of persons aged 65 and more. By 2026, only one crescent-shaped area centred on the Montréal region (from the Outaouais to central Quebec) would be showing significant demographic change. As a result, a growing proportion of the population will swell those age brackets often associated with groups currently vulnerable to climate change. These changes will have impacts on the vulnerability of Quebec society, particularly on the financial resources available for health services, which are increasingly in demand (Godbout et al., 2007).

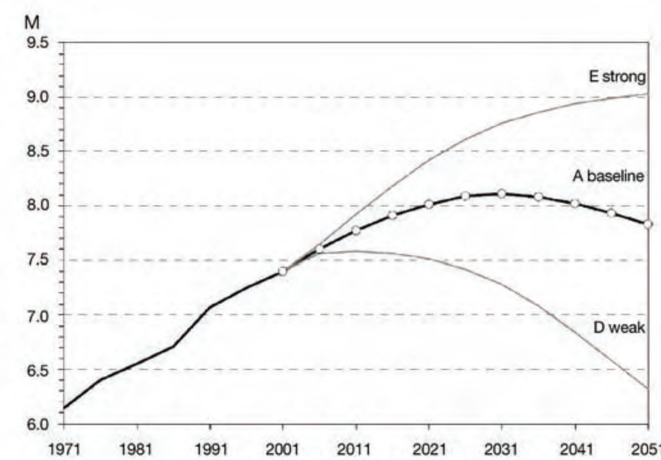

FIGURE 2: Scenarios for total population change in Quebec until 2051 (Institut de la statistique du Québec, 2003).

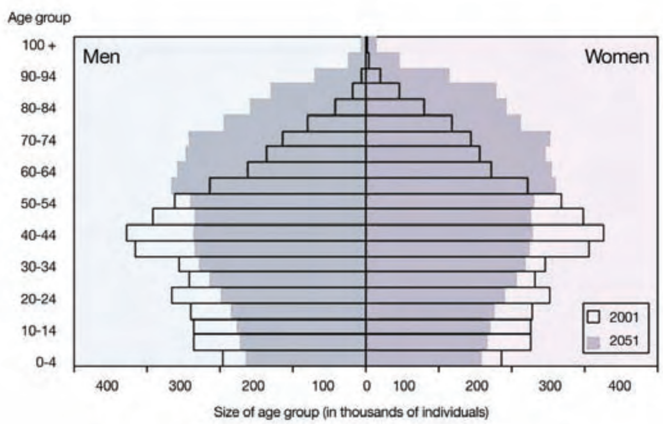

FIGURE 3: Age pyramid of the Quebec population, 2001 to 2051, reference scenario A (Institut de la statistique du Québec, 2003).

The state of health of the Quebec population is changing positively and is well documented for the different administrative regions of the province (Institut national de santé publique du Québec, 2006). Although most socioeconomic and health indicators show a gradual and steady improvement in health, an earlier report identified certain behaviour, perceptions and indicators conducive to a potential increase in vulnerable populations (sedentary behaviour, excess weight, elderly persons living alone; Institut national de santé publique du Québec, 2006). Since then, these trends have not generally been confirmed except in the case of already vulnerable populations, which have seen their vulnerability increase.

Given the slow rate of change in the demographic trends, projections show an aging population, slower growth of urban populations and depopulation of remote regions. Consequently, demographic changes and the state of health will contribute equally to increasing or decreasing the vulnerability of populations to climate change.

2.2. SOCIOECONOMIC ACTIVITY

2.2.1. Economy

Canada's largest province in terms of area, Quebec had a gross domestic product (GDP) of more than $274 billion in 2005 (Statistics Canada, 2007b). Its diversified economy, which is largely export oriented, provides Quebecers with a high standard of living and gives them considerable financial means to address the potential impacts of climate change (*see* Chapter 2, Section 2.3).

Long known for its natural resources, Quebec has seen a profound transformation of its economy in recent decades. It now has a service sector (tertiary sector) in which commercial and financial activities, health and education services, recreation and public administration account for nearly 70% of GDP compared to 30% for goods-producing primary and secondary sectors (Statistics Canada, 2007b). All indications are that this trend towards a service economy will continue, especially in light of continued growth in the information, leisure and tourism industries, and in the health services sector.

Although dominant at the beginning of the twentieth century, the primary sector, including activities such as agriculture, forestry and hunting and fishing, represented only 2.3% of GDP in 2005. In the manufacturing secondary sector, many industries are based on resource transformation, including agri-food and wood processing. The latter industry accounts for nearly 3% of GDP and a sizable share of Quebec exports. In addition, electricity production in Quebec, of which 96% is water-generated, accounts for 4% of GDP and should grow somewhat during the next decade. The same applies to wind power, an industry now flourishing in response to Quebec's new energy policy. Its installed capacity should grow from 100 to 4000 MW by 2015 (Ministère des Ressources naturelles et de la Faune du Québec, 2006a).

The Quebec economy is also characterized by profound differences between its regions. Although manufacturing and service activities play a significant role in providing work and employment in an economically highly diversified southern Quebec, a significant share of direct employment (12% to 20%) in certain other regions is provided by agriculture, forestry, hydroelectricity production and the mining and resource transformation industries. Several hundred communities depend directly on existing natural resources.

This portrait of the Quebec economy should change greatly in coming decades. Based on current demographic and labour productivity trends (+1.6% according to Lafrance and Desjarlais, 2006), Quebec will experience sustained economic growth and double its production in 50 years (Ministère des Finances du Québec, 2005). Households and individuals will see their incomes rise substantially, giving them greater means to satisfy their needs. A rise in education levels and urbanization is also expected (Institut de la statistique du Québec, 2003). In the different administrative regions, demographic change would create important differences in overall and per capita economic growth, compounded by the effects of the different growth rates of the resource industries relative to those of the other economic sectors.

Finally, the production of goods and services will be influenced by changes in trade (new trade agreements, economic development of emerging countries), in technology (demand, production methods or processes) or in the availability and cost of supplies. Although the evolution of certain sectors is easy to project for the first decades, it is less so for the next 50 or 100 years, particularly for industries such as pulp and paper, wood processing and agri-food, which are all subject to rapid socioeconomic changes.

Demographic and sociocultural changes will also have notable impacts on the demand for goods and services, such as an aging population's greater need for health services or that of retirees for recreation, accompanied by the development of technological means to satisfy them. In short, the socioeconomic context will also be quite different from that of the present day and increased links with international markets will result in complex changes (*see* Chapter 9) to the socioeconomic system's sensitivity to impacts occurring in Quebec and elsewhere.

2.2.2. Social change

The evolution of human systems is closely tied to numerous social aspects, ranging from individual perceptions to public policy and social capital (Adger, 2003), along with leadership (Bacal, 2006) and changing values. Beyond the more easily measurable physical and economic impacts, the magnitude of various impacts of climate change will be influenced by changes in perceptions and social values, both of which are difficult to evaluate. Decision-making designed to cope with the impacts of climate change will be particularly influenced by socioeconomic growth, rising education levels, increased sensitivity to environmental protection, communications and the complexities of environmental issues (Bryant et al., 2007). For example, the concerns of Quebecers for environmental quality prompted governments to strengthen the baselines for animal waste management (National Water Research Institute, 2004) and abandon other major projects such as the Suroît thermal power station, and even to enact new legislation for the conservation of water resources (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2002). Scientific research on certain extreme climate events, as well as their media coverage, probably had varied social consequences that were significant yet sometimes difficult to measure. Similar realities and perceptions had previously resulted in Quebec displaying an interest in climate change, starting back in November 1992 when it supported the principles and objective of the United Nations Framework Convention on Climate Change. Since then, Quebec has taken different steps, including the publication of its 2006 to 2012 climate change action plan (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2006) and the adoption of sustainable development regulations, that highlight how it supports a concept that was still relatively unknown scarcely 20 years ago.

On another level, a significant proportion of the population lives in precarious socioeconomic conditions related to employment, demographics and immigration, reduced buying power and the challenge of acquiring a higher education level (Institut national de la statistique du Québec, 2001). This part of the population is concentrated in the large cities and poses particular challenges. For other groups, such as the Inuit of Nunavik and the First Nations communities of other regions, their particular socioeconomic situation will increase or decrease their vulnerability to various aspects of climate change.

Nevertheless, there is every reason to believe that public interest in environmental issues, such as climate change, will increase despite the need to deal with many other rapid transformations, including greater international competition, demographics and technological advances, as well as in issues related to social, educational and individual and collective well-being.

2.3. ENVIRONMENT

2.3.1. Built environment

The built environment has grown rapidly in Quebec since the start of the twentieth century, as a result of urbanization, increased wealth, technological development, population growth and sprawl, and the growing interdependence and complexity of socioeconomic activity. The built environment, usually exposed to the climate, is vulnerable to climate events exceeding an established cost/risk threshold. Assuming a stationary climate, structural engineers incorporate climate data from past decades into infrastructure design intended to meet future needs. Naturally, any change to this stationary climate will affect performance, useful life and safety. Whether the impacts are direct or indirect, a climate event can cause destruction, failure, loss of performance or create an external hazard for all exposed infrastructure.

The grouping by type of infrastructure and buildings that constitute the built environment (Figure 1) is drawn from the *Loi sur les ingénieurs du Québec* (Quebec Engineers Act; Ordre des ingénieurs du Québec, 2006). Transportation infrastructure makes socioeconomic activity possible in many regions (isolated, coastal, urban, rural) using a variety of transportation modes (land [road, rail], maritime, air). Infrastructure related to water resources, such as dams (5144 in Quebec, including 333 large dams, according to the National Water Research Institute, 2004), canals and ports uses the hydrosphere. Infrastructure associated with energy and geology is related primarily to the use or conservation of landscapes. Municipal infrastructure deals with water distribution and treatment, surface water management and waste disposal. Buildings represent by far the largest infrastructure group and shelter people. Protection infrastructure, often described as critical, guarantees the safety of the public, of socioeconomic activity and of the natural and built environment. Well known examples include flood protection structures around the city of Winnipeg and New Orleans, as well as coastal riprap and breakwaters in eastern Quebec. Finally, the natural environment can be developed or modified to maintain or upgrade both it and the built environment (slope under a road or artificial shore).

Built environement, particularly municipal infrastructure, is aging overall and many structures have already exceeded their useful life span (Infrastructure Canada, 2004; Villeneuve et al., 1998; 2004). There is an important need now, and in years to come, for new infrastructure, but more so for refurbishing existing infrastructure, and the massive investments expected and planned for the next decades are already being sought (Statistics Canada, 2006). Due to their unique nature, the northern villages in Nunavik have received sizable investments over the past thirty years or so to acquire municipal, school and business infrastructure, as well as a transportation infrastructure. These villages are not connected to each other or to southern Quebec by a road network and therefore rely on supplies being delivered by boat or plane, the latter for the most part using airports with runways that are unpaved or built on permafrost.

Although the built environment will continue to grow, the trends with regard to aging infrastructure, public investments, demographics and urbanization, as well as the increasing density of southern Quebec, suggest that attention will have to be paid to the refurbishment and replacement of existing infrastructure to meet the needs of an aging population whose activities and socioeconomic interests are different from those associated with the twentieth century. These trends suggest that it will be essential to integrate, where relevant, new climate data or new approaches to future design and refurbishment when considering the future vulnerability of the built environment in Quebec.

2.3.2. Natural environment

Quebec covers an area of 1 667 441 km^2 and is made up of the Canadian Shield (hills, vast forests and many lakes), the clay plain of the St. Lawrence Lowlands and part of the Appalachians. The many cycles of glacial advance and retreat left the land with little relief, rarely exceeding 900 m in altitude. The northernmost part of the province is characterized by tundra vegetation, soil underlain by more or less continuous permafrost and a harsh climate with strong winds in which adapted plants and wildlife have become established. Farther south, the forest cover (757,900 km^2) is dominated by dense boreal forest (73.7%) that shelters considerable wildlife and a great variety of birds. The mixed wood forest, a combination of hardwoods and conifers, covers the St. Lawrence Lowlands and contains a great diversity of plant and animal species. Moreover, with its thousands of lakes and rivers, it is estimated that Quebec holds 3% of the planet's renewable water. Finally, 10% of groundwater underlies inhabited areas and one-third of Quebec is within the St. Lawrence watershed, which supplies 80% of the population (Ministère des Ressources naturelles du Québec, 2006; Le Québec géographique, 2006). Furthermore, Quebec's basic economic and societal needs for a growing quantity (in absolute value but not in percentage of GDP) of products and services is gradually being met by increasing development of natural resources.

With respect to the atmosphere, many climate characteristics, such as mean annual temperature and total annual precipitation (Figure 4), have contributed to shaping the cryosphere, hydrosphere, biosphere and lithosphere of Quebec over many centuries. The largely spontaneous nature of adaptation processes, in natural systems suggests a higher potential for significant direct and indirect impacts following any change in atmospheric conditions. This contrasts with populations and their socioeconomic activities, which are generally less exposed and have a variety of means for anticipating and adapting to climate change, thus creating a situation potentially conducive to more indirect, more complex impacts.

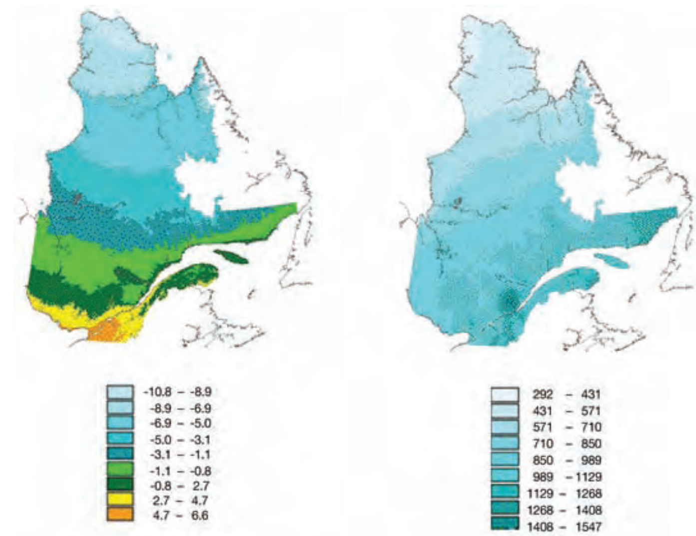

FIGURE 4: Mean annual temperatures (°C) and precipitation (mm) in Quebec between 1966 and 1996 (Ouranos, 2004).

Human activity has contributed to transforming landscapes, vegetation and wildlife, mainly through population growth and natural resource development. Despite an increasingly service-oriented economy and greater importance placed on the natural environment, human activity will induce further changes, including those related to changing climate. Some conclusions on climate trends and projections for Quebec are discussed in the following section, with detailed discussions of these points found in other documents (Ouranos, 2007).

2.3.3. Climate

In addition to the three key elements (population, natural and built environment, socioeconomic activity), regional and local climate changes will strongly influence the nature and magnitude of impacts and adaptation, responses.

Historic climate trends

Barrow et al. (2004) and Gachon et al. (2005) noted statistically significant rises over many decades in annual temperature, total annual precipitation and number of days of rainfall, but shrinking ice cover.

In recent studies, Yagouti et al. (2006, in press) observed significant warming in several parts of southern Quebec between 1960 and 2003. A marked increase in mean annual temperatures of between 0.5°C and 1.2°C was observed in southwestern and south-central Quebec. This warming trend shows a decreasing west-to-east gradient and, in southeastern Quebec, an insignificant increase of less than 0.5°C occurred over the same period. Most stations recorded that warming occurred more rapidly starting in the second half of the 1990s and was more pronounced at night than during the day, primarily in summer. The most significant warming occurred in winter and summer. For example, in summer, minimal temperature increases in south-central and southwestern Quebec ranged from 0.4 to 2.2°C, whereas the majority of stations in southeastern Quebec recorded no significant trend (Figure 5). Finally, the increase in winter and summer temperatures resulted in a distinct change in several climate indicators, such as growing degree-days, heating degree-days and length of the frost-free season. Readers interested in a more detailed analysis of the evolution of temperatures and the associated climate indicators are referred to the study by Yagouti et al. (2006).

Analysis of homogeneous data retrieved from several stations suggests that the climate in northern Quebec warmed faster than in any other part of the province during the twentieth century. For example, at Inukjuak, where the longest series of climate data has been collected, the trend in the mean annual temperature shows an increase of 2.9°C from 1922 to 2004. However, all northern stations (Figure 6), including Inukjuak, exhibit a flat or even slightly downward trend between 1950 and the early 1990s, followed by an increase of at least 1°C over the 1961 to 1990 normals. As an example of this increase's

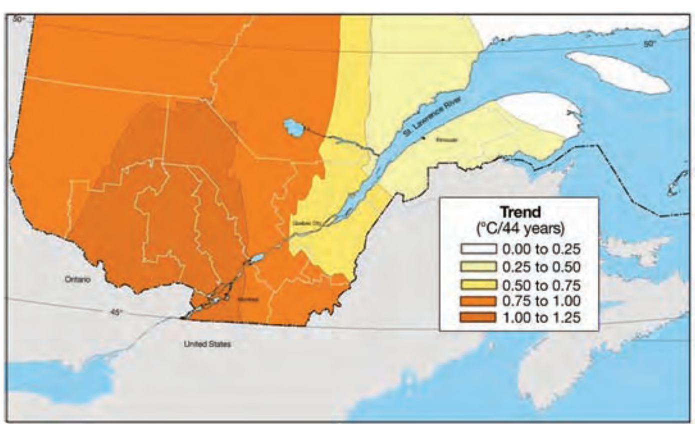

FIGURE 5: Interpolation of trends in mean annual temperature in Quebec between 1960 and 2003. The trends shown here are consistent with analyses done on a continental scale. The large water bodies to the east would explain the east-west difference (Yagouti et al., 2006).

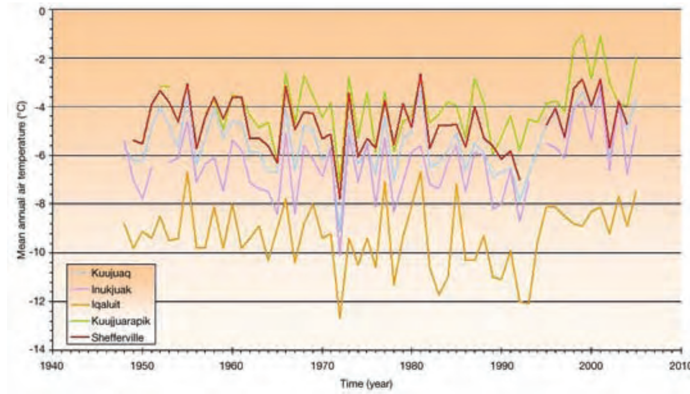

FIGURE 6: Trends in mean annual temperatures for five inhomogeneous stations in northern Quebec (M. Allard, pers. comm., 2006).

impact, the temperature of the surface permafrost warmed by nearly 1°C over 10 years at many locations in northern Quebec (Allard et al., 2004).

Other climate studies not specific to Quebec (Intergovernmental Panel on Climate Change, 2007) suggest potential climate trends within the province, including:

- increased cloud cover (Milewska, 2004);
- a decrease in mean sea level pressure gradients between northern and southeastern Canada (Gillett et al., 2003; Wijngaard et al., 2003);
- a recent increase in intense cyclones (McCabe et al., 2001; Lambert, 2004);
- a 181 km northward displacement of the average trajectory of winter depressions in the North Atlantic (Wang et al., 2006);
- an increase in fall precipitation (Stone et al., 2000), although interdecadal variability seems to dominate at the global scale (Zhang et al., 2001);
- less availability of water between 1950 and 2002, mainly in central Quebec (Dai et al., 2004; Ouranos, 2004; Déry and Wood, 2005); and
- a number of modifications to the cryosphere, specifically early spring disappearance of snow and ice between 1966 and 1995 (Groisman et al., 2003; Duguay et al., 2006).

Several studies link these observations to indices such as the North Atlantic Oscillation (NAO), particularly for the cold season (Voituriez, 2003), even in the case of temperatures (Wettstein and Mearns, 2002). Higuchi et al. (2000) suggested that the persistence of a positive NAO and El Niño conditions in the Pacific Ocean favour freezing-rain storms in southeastern Canada. An exhaustive description of these studies is, however, beyond the scope of this chapter.

Projected climate scenarios

Following the recommendations in Chapter 2, the seasonal temperature and precipitation changes projected by six global climate models (GCMs) using different scenarios for greenhouse gas emissions are presented for four subregions (Figure 7). Mean changes projected for three decades, centred on the decades 2020, 2050 and 2080, are presented and interpreted in relation to 1961 to 1990 climate normals (Environment Canada, 1993). The four scatterplots (Figures 8 to 11) and related summary tables (Tables 1 to 4) summarize the most recent seasonal projections (for interpretations, *see* Barrow, 2004; Ouranos, 2004; Chaumont, 2005; Chaumont and Chartier, 2005). The regional climate models (RCMs), which simulate dynamics and physics with greater refinement, produce results on spatial and temporal scales of interest for assessing regional impacts (Ouranos, 2004). Increasingly, the results of RCMs, including the Canadian model (CRCM), make it possible to develop more refined projections of climate change (Plummer et al., 2006), hence the inclusion of CRCM results in the scatterplots (*see* Figures 8 to 11).

Overall, mean temperatures would increase for the three climate decades, especially in the cold season. Total seasonal precipitation would also increase, especially in winter and spring. In the southern and maritime subregions, changes in total summer and autumn precipitation remain undetermined, with as many scenarios indicating decreases as increases, and some decreases being as much as 25%. The projected changes generally diverge from natural climate variability simulated by the CGCM3 starting in the 2020s for temperature and much later for precipitation, sometime in the 2050s or even later in the 2080s.

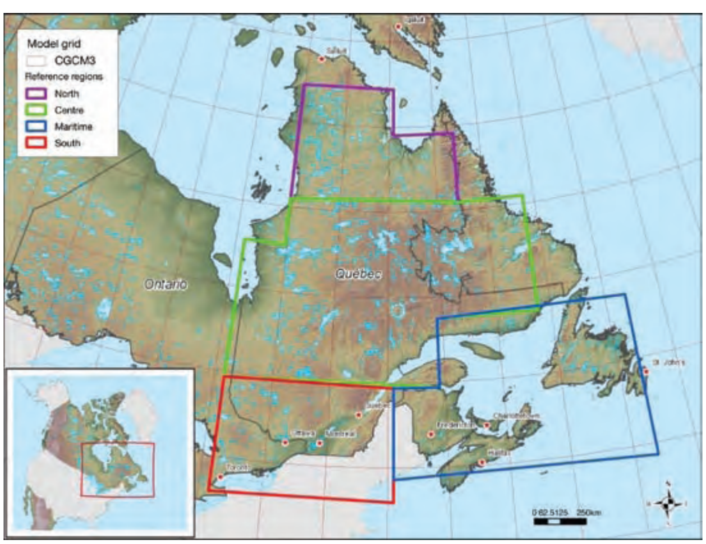

FIGURE 7: The four subregions chosen to establish equally probable scenarios expressed in the form of scatterplots (temperature/precipitation). The grid of the Canadian Global Coupled Model (CGCM3) was added to illustrate the typical spatial resolution of Global Circulation Models (GCMs).

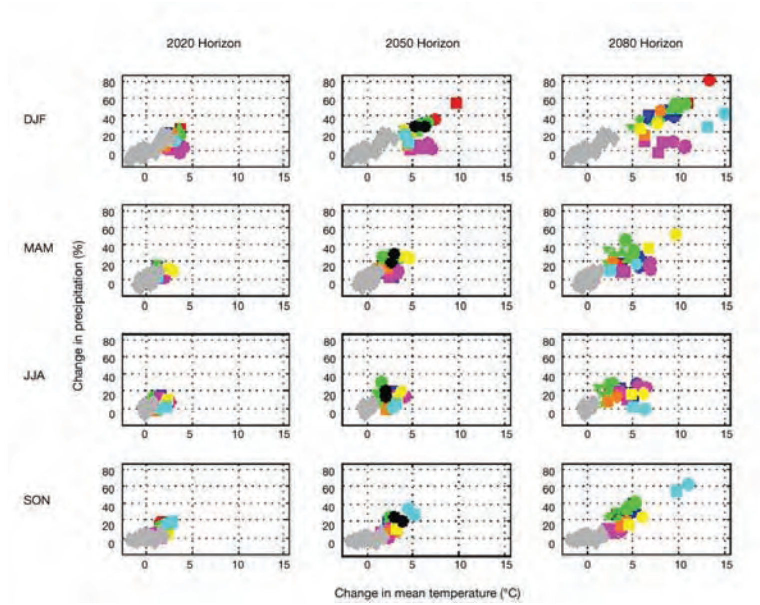

FIGURE 8: Scatterplots of changes in temperature/precipitation for the north subregion by season and by future climate period, compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s. For legend, *see* Figure 11.

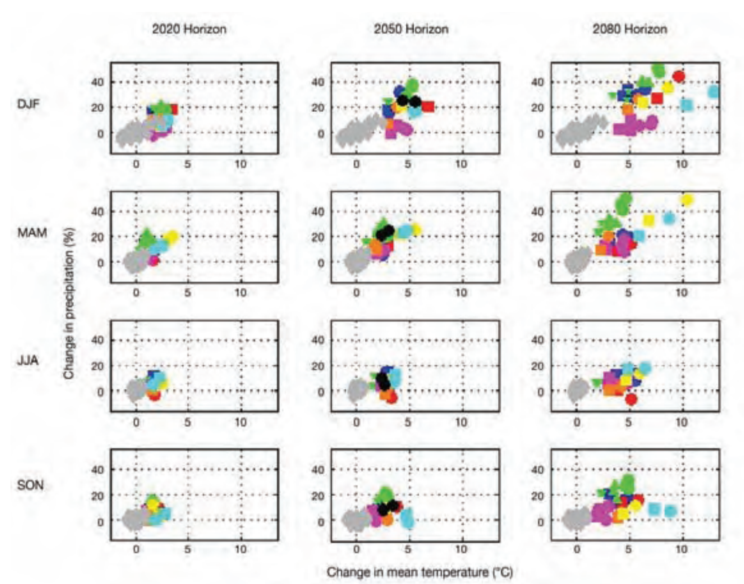

FIGURE 9: Scatterplots of changes in temperatures/precipitation for the central subregion by season and by future climate period compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s. For legend, *see* Figure 11.

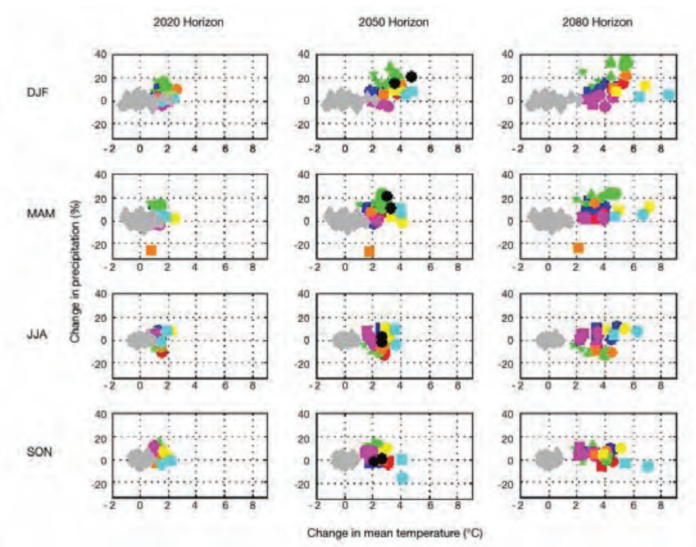

FIGURE 10: Scatterplots of changes in temperatures/precipitation for the maritime subregion by season and by future climate period compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s. For legend, *see* Figure 11.

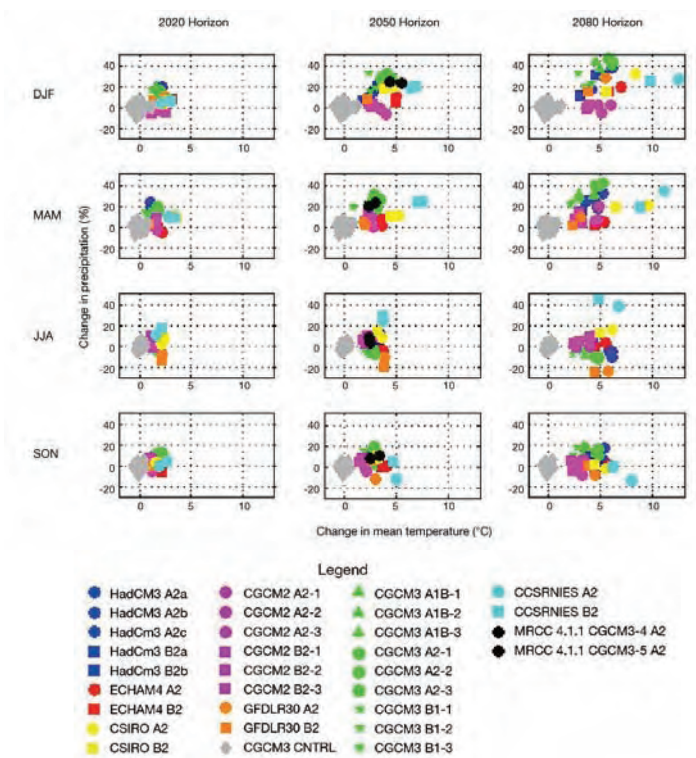

FIGURE 11: Scatterplots of changes in temperature/precipitation for the south subregion of Quebec by season and by future climate period compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s.

TABLE 1: Climate normals and synthesis of scatterplot for the north subregion

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-21 to 25°C	+2,5 to +3,5°C	+4 to +7°C	+6 to +12,5°C
	Precipitation	60 to 180 mm	+1 to +18%	+2 to +32%	+5 to +53%
Spring	Temperature	-7 to -17°C	+0,5 to +2°C	+1,5 to +3.5°C	+2,5 to +7°C
	Precipitation	75 to 125 mm	+1 to +12%	+4 to +26%	+8 to +35%
Summer	Temperature	6 to 10°C	+1 to +2,5°C	+1,5 to +4°C	+2 to +6°C
	Precipitation	150 to 230 mm	+1 to +12%	+3 to +19%	+5 to +28%
Fall	Temperature	1 to 4°C	+1,5 to +2,5°C	+2 to +3,5°C	+2,5 to +6°C
	Precipitation	150 to 240 mm	+2 to +16%	+5 to +24%	+9 to +42%

TABLE 2: Climate normals and synthesis of scatterplot for the central subregion

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-11 to -21°C	+1,5 to +3°C	+3 to +5,5°C	+4,5 to +9,5°C
	Precipitation	130 to 325 mm	+1 to +18%	+4 to +32%	+6 to +47%
Spring	Temperature	3 to -7°C	+0,5 to +2°C	+1,5 to +4,5°C	+2,5 to +8,5°C
	Precipitation	125 to 300 mm	+1 to +19%	+6 to +25%	+8 to +45%
Summer	Temperature	10 to 17°C	+1 to +2°C	+2 to +3,5°C	+2,5 to +5,5°C
	Precipitation	230 to 310 mm	0 to +8%	-2 to +13%	0 to +13%
Fall	Temperature	-1 to 6°C	+1 to +2°C	+1,5 to +4°C	+2,5 to +5.5°C
	Precipitation	215 to 300 mm	0 to +13%	0 to +20%	+2 to +26%

TABLE 3: Climate normals and synthesis of scatterplot for the maritime subregion

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-10 to -13°C	+1 to +2°C	+2 to +4°C	+3 to +6°C
	Precipitation	295 to 400 mm	-2 to +12%	–1 to +21%	+1 to +32%
Spring	Temperature	–1 to –3°C	+1 to +2°C	+1,5 to +3,5°C	+2,5 to +5°C
	Precipitation	250 to 325 mm	-3 to +13%	-2 to +16%	+1 to +23%
Summer	Temperature	13 to 17°C	+1 to +1,5°C	+1,5 to +3°C	+2,5 to +5°C
	Precipitation	250 to 350 mm	-6 to +7%	-10 to +9%	-11 to +9%
Fall	Temperature	3 to 6°C	+1 to +1,5°C	+1,5 to +3°C	+2 to +5°C
	Precipitation	275 to 350 mm	+2 to +11%	-3 to +11%	-3 to +11%

TABLE 4: Climate normals and synthesis of scatterplot for the south subregion

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-7,5 to -11°C	+1 to +2,5°C	+2 to +5°C	+3,5 to +8°C
	Precipitation	270 to 330 mm	-5 to +19%	0 to +32%	+1 to +43%
Spring	Temperature	3,5 to 6°C	+1 to +3°C	+2 to +5°C	+2,5 to +8°C
	Precipitation	240 to 280 mm	-1 to +19%	+2 to +25%	+4 to +39%
Summer	Temperature	18 to 20°C	+1 to +2°C	+2,5 to +4°C	+2,5 to +6°C
	Precipitation	280 to 350 mm	-5 to +10%	-7 to +13%	-11 to +15%
Fall	Temperature	6,5 to 9°C	+1 to +2,5°C	+2 to +4°C	+2,5 to +5,5°C
	Precipitation	270 to 330 mm	-1 to +10%	-8 to +16%	-7 to +18%

3 SENSITIVITIES, IMPACTS AND ADAPTATION

The key concepts presented in Chapter 2 provide the foundation for understanding the following description of the sensitivities, vulnerabilities, opportunities, anticipated impacts and possible adaptation strategies, both spontaneous and planned, for Quebec.

The approach used here is not only regional in focus (north, central, maritime and south subregions), but also sectoral and cross-sectoral (*see* Section 3.5), in order to integrate issues not addressed in the sections dealing with the subregions. As indicated in the Ouranos (2004) report, the boundaries of these four subregions must not be perceived as administrative boundaries, but rather as gradual transition between zones that share similar characteristics.

Figure 12, which should be referred to constantly throughout this section, synthesizes several key characteristics pertaining to Quebec, which can be summarized as follows:

- **the north subregion** (*see* Section 3.1) is characterized by the presence of a few isolated communities experiencing significant socioeconomic and demographic changes.
- **the central subregion** (*see* Section 3.2) is characterized by extensive natural resources that are important for the local and overall Quebec economy.
- **the maritime subregion** (*see* Section 3.3) is characterized by development along coastal areas.
- **the south subregion** (*see* Section 3.4) is the locus of steady urbanization and contains the majority of the population, economic activity and infrastructure, all of which create growing pressure on the environment.

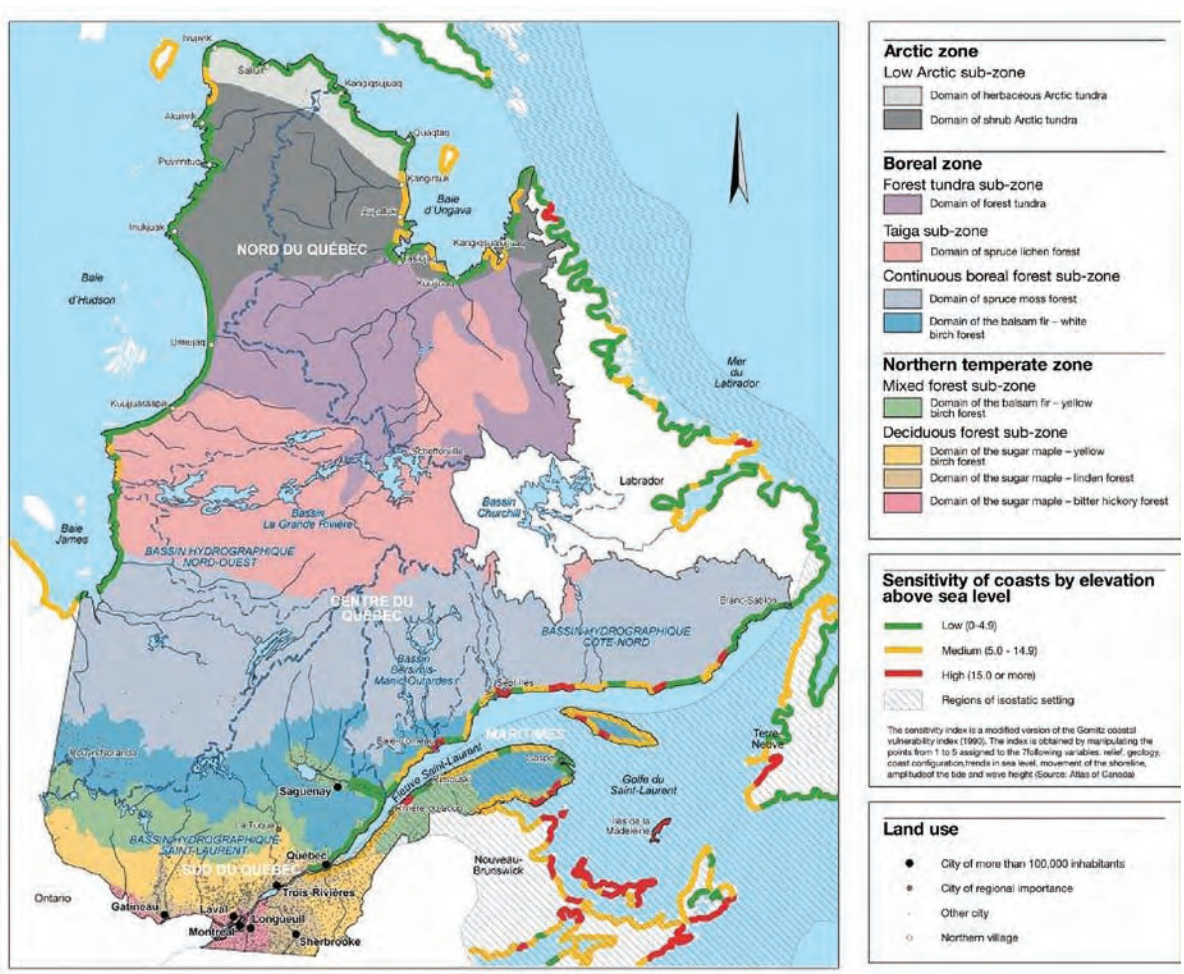

FIGURE 12: The four subregions and a variety of characteristics that help determine sensitivity to climate change.

3.1. NORTH SUBREGION

Nunavik differs from other Quebec regions due to its sparse plant and animal life, a long cold season and a landscape dominated by snow and ice. The way of life of its mainly Inuit population is closely tied to the environment. The Inuit live in 14 villages (Figure 12) where infrastructure is concentrated. Their society is coping with important generational changes and undergoing rapid demographic growth and a transformation of socioeconomic activity formerly based on traditional ways of life. Despite these profound changes, certain activities (food supply, fur sales on international markets) still account for an important share of the local economy. Figure 8 and Table 1 suggest that Nunavik will experience, along with many other diverse changes, the greatest climate change in Quebec in absolute value, mainly due to the climate feedback effect of snow and ice and the presence of Hudson Bay to the west. The results and conclusions of initiatives such as the Arctic Climate Impact Assessment (Arctic Climate Impact Assessment, 2004), ArcticNet (2006), the Canadian Climate Impacts and Adaptation Research Network (Canadian Climate Impacts and Adaptation Research Network, 2006) and the Ouranos projects, apply to this region north of the 55th parallel known as 'Arctic Quebec'.

Changes to the natural environment

Along with recent climate change, the temperature of the permafrost rose an average of 1 to 1.5°C to a depth reaching 20 m at some study sites in Nunavik between 1990 and 2002, accompanied by a noticeable deepening of the active layer, the surface layer that thaws in summer (Allard et al., 2002a). The Inuit report significant environmental changes and even experienced hunters say they have difficulty predicting weather, snow and sea conditions in their travels by snowmobile or canoe (Tremblay et al., 2006). Traditional Inuit knowledge seems less reliable and many accidents, sometimes involving experienced individuals, are reported (Nickels et al., 2005).

Heat transfer in the soil following climate warming will inevitably cause partial or total thawing of the permafrost, depending on the real extent of warming during the twenty-first century (Lawrence and Slater, 2005). Consequently, ecosystems will be greatly disturbed by permafrost degradation, which is already causing subsidence of the land and creating and expanding small thermokarst lakes (Seguin and Allard, 1984). Drainage networks on sensitive soils are likely to be modified by the drying and the extension of peat bogs and wetlands (depending on local topography and soil texture), as well as by gullying and rill erosion (Payette et al., 2004). Stimulated by milder summers and greater snow cover protection on the tundra in winter, the expansion of shrub populations would transform ecosystems significantly, increasing their primary productivity, which should have repercussions on the animal kingdom. The distribution of animal species is bound to move northward in keeping with these changes. It remains to be determined how this will affect the behaviour of such migratory populations as caribou herds, Arctic char, geese and ducks, seals and whales. Ecosystems that adapt spontaneously are discussed at the provincial scale in Section 3.5.

To the extent that precipitation, evapotranspiration and subsurface flow are affected, the hydrological regime of the rivers will change and water temperatures will rise. Sediment inflow may result from permafrost degradation, although its scope remains to be assessed. All these changes will have a significant effect on regional aquatic wildlife.

Sensitive infrastructure

The risk posed by permafrost degradation varies from community to community depending on geomorphology (rock outcrops, granular or clayey soils containing ice, instability factor when thawing). From the tree line to the shores of Hudson Strait, the climatic gradient is such that the discontinuous permafrost, having temperatures near the freezing point, becomes colder as one moves farther north. Consequently, a fairly uniform regional warming would act first on the southern fringes of the permafrost and then gradually on more northerly areas. Up to now, municipal planning has taken into account the nature of the terrain in each community as much as possible. Moreover, most institutional buildings, such as schools and hospitals, and most houses are built on piles or trestles, which allow air circulation and keep the soil at or near air temperature (Fortier and Allard, 2003a, b).

However, important buildings and infrastructure (airports, roads) are partially or totally built on sensitive terrain. In areas where the soil consists of unconsolidated deposits containing ice, permafrost thawing causes soil subsidence and buckling that can damage infrastructure. This is the case for airport infrastructure in 13 of the 14 villages. There is concern for the safety and integrity of these airports (Grondin and Guimond, 2005), which fall under the responsibility of the Quebec Ministère des Transports (MTQ). In fact, permafrost thawing has already caused subsidence, cracks and signs of deterioration on several airport runways and on roads connecting them to the villages (Beaulac and Doré, 2005). Existing maintenance measures have so far been enough to ensure safety. However, the frequency and rising cost of repairs, observed damage and increased maintenance activity have prompted the MTQ and Ouranos to draw up a research program to characterize the permafrost beneath and at the edge of infrastructure (thermal profile, subsidence, climate conditions) to assess the behaviour of this infrastructure since its construction, to predict its evolution and, finally, to develop adaptation measures (Beaulac and Doré, 2005; Ministère des Transports du Québec, 2006a).

Local transportation and access to resources

In Nunavik, the hunters and gatherers travel mainly by boat in summer and snowmobile in winter. The types of roads used (waterways and ice roads) are important for food supply (hunting, fishing, berry picking, egg gathering), moving goods and people between communities, and accessing sites for traditional pursuits, such as trapping, gathering or family and social activities. Travel and access to resources are critical both to acquire food and to preserve the social cohesion essential to maintaining a culture already weakened by other stresses (Lafortune et al., 2005). Climate impacts (difficult weather forecasting, late freeze-up and early melting of the ice) make travel more risky, and thus affect socioeconomic and cultural aspects as much as the transfer of traditional knowledge, and have repercussions on individual and collective identity in this changing society (Tremblay et al., 2006).

Growing economic activity

Resource development is growing in Nunavik. Mining activity is increasing rapidly as the area becomes more accessible and with the help of international metals markets. Climate change offers new development opportunities, such as the reduced cost of ore shipping made possible by waterways that remain ice-free for longer periods (Beaulieu and Allard, 2003). On the other hand, this new access will put additional pressure on species that depend on the ice cover, and on populations that depend on these species for their subsistence. Moreover, climate change makes it uncertain whether toxic mine tailings will freeze during mine operation and after the deposits have been depleted. The effect of this uncertainty on future production is higher-than-expected cost estimates during and after mine operation to prevent any contamination of the natural environment by the seepage or flow of toxic material.

If harnessing the rivers of Ungava Bay to generate electricity were ever to become acceptable from a business and social viewpoint, the promoter would have to manage uncertainties related to the hydrological regime due to a climate that is changed but probably more beneficial because of the expected increase in precipitation. In addition, the high wind potential of the subregion (Environment Canada, 2007a) would promote the development of wind energy as a complement to electricity production by diesel power stations in several communities, thereby achieving diversity of supply while reducing dependence on costly fossil fuels, which are transported by boat. Even by contributing in a small way to reducing GHG emissions, wind production would present a strong political argument, since the Inuit would help to reduce GHG emissions by greatly reducing their use of fossil fuels.

Adaptation strategies

Recent knowledge regarding permafrost located beneath infrastructure and the application of civil engineering practices and solutions will help manage the impacts of climate change on airports, roads and buildings (Allard et al., 2002b). To strengthen and maintain the integrity of infrastructure built on permafrost, various solutions are being tested or have already shown their effectiveness. For example, heat penetration into backfill can be countered by air convection and the use of insulation techniques and reflective surfaces; otherwise, the heat can be extracted from backfill using drains. Installing geotextiles, or even strengthening and raising infrastructure at risk, can also help diminish vulnerability (Beaulac and Doré, 2005).

Large-scale mapping of permafrost conditions in each village is a tool to improve municipal planning aimed at adaptation to climate change in the long term. In any event, building standards and decision-making must henceforth take climate change into account (Allard et al., 2004) to prevent an increase in vulnerability.

Access to the land for traditional pursuits receives special attention from local authorities such as the Kativik Regional Government in terms of ensuring safety along land routes (ice roads) or on navigable waterways (Bégin, 2006). In collaboration with local communities, a study is underway to determine how to better anticipate and better adapt to the new winter ice and snow conditions by relying on a network of northern weather stations (Lafortune et al., 2005). The small number of weather stations and the poor quality of chronological data series currently make it difficult to validate the models used, but this difficulty should be reduced with the establishment of new weather stations by Environment Canada.

At a workshop on the status of regional projects, held in Montréal on October 6, 2005, education and the development of awareness and information tools were identified as important ways to reduce the vulnerability of infrastructure to climate change. Officials from the Kativik Regional Government also emphasized the need to improve weather data and the ability to predict extreme events, such as blizzards, storms, gales, sudden thaws and fog. Concerns raised by the Inuit included their need for a better analysis of the impact of climate change on ecosystems and wildlife. Current studies focus on defining adaptation methods that resolve built environment or municipal planning problems. To a lesser extent, they also seek to better understand the most important changes affecting resources and the traditional pursuits of hunting, fishing and gathering.

In summary, strong regional population growth, the resulting urban development, and changes in access to resources and the traditional pursuits of hunting, fishing and gathering are responsible for bringing on difficult and multifaceted socioeconomic change. Accelerated thawing of the permafrost and pronounced climate change are raising the stakes and increasing the pace of change.

CASE STUDY 1

From impact to adaptation: case study of Salluit

To lessen the impact of accelerated permafrost degradation at Salluit and reduce the consequences on infrastructure, the Centre d'études nordiques (Nordic Studies Centre) and Ouranos are developing a geological and geothermal model that integrates all factors that could affect soil stability. The part of the study already completed provides maps (Figure 13) on which information layers identify sensitive soils and make it possible to optimize land-use planning that takes the impact of climate change into consideration (Allard et al., 2004). In communities as a whole, current planning practices, including urban drainage maintenance, snow removal methods, layout of new streets and design of foundations, should be revised to limit the impact of climate change on the land. Certain recent decisions should perhaps be reviewed, one example being the paving of streets, which can increase heat transfer into the permafrost and therefore constitutes a maladaptation. Various civil engineering–related adaptation methods, such as convection in backfill, heat drains and reflective surfaces, will be tested in Salluit as part of a project to assess their cost effectiveness given conditions prevailing in the study areas (Doré and Beaulac, 2005).

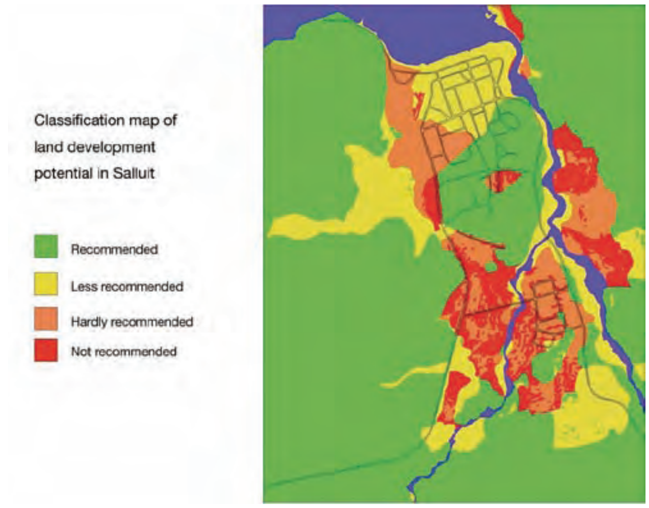

FIGURE 13: Sample map of Salluit in Nunavik, Quebec, showing vulnerability of the land with regard to infrastructure construction (Solomon-Côté, 2004).

3.2. CENTRAL SUBREGION

The environment in the central subregion is characterized by boreal forest and numerous lakes, rivers and reservoirs (Figure 12). Whereas the cold season is dominant in the north subregion and the warm season is dominant in the south subregion, the two seasons are closer in length in the central subregion. Snowfall is generally much more abundant in the east due to numerous winter storms arriving from the east coast of the United States. Population density is low and declining, and local economies often depend on a single industry, yet primary sector economic activity from natural resource (water and forest) exploitation stimulates the strength of Quebec's economy as a whole. Ouranos (2004) calls this subregion a 'resource region' and, for this reason, the sensitivity of forests and water resources to climate change is addressed here.

3.2.1. Forests

Since the last glaciation, Quebec forests have evolved under a harsh climate combined with dynamic natural disturbances, which have led to the formation, from south to north, of large forest ecozones of maple, balsam fir and spruce. Significant climate warming over the last century has already resulted in a change in equilibrium between the climate and forest composition (Forget and Drever, 2003). Anticipated warming will further accelerate the rupture of this equilibrium and result in changes in the composition and productivity of forest stands. The dynamics of natural disturbances (fire and insects) and the frequency of extreme weather events (droughts and freezing rain) are also bound to change.

Growth and productivity

A rise in temperature can act directly on physiology and metabolism and can also lengthen the growing season. Signs of a lengthening of the growing season are already visible. Bernier and Houle (2006) estimated that the budbreak date of the sugar maple has occurred earlier by several days in the past 100 years, and Colombo (1998) reported similar results for the white spruce. In Alberta, the blossoming date of the aspen poplar has advanced by 26 days in the past 100 years (Beaubien and Freeland, 2000). In Europe, the growing season of several plant species has lengthened by 11 days since just 1960 (Menzel and Fabian, 1999).

The preliminary results of growth prediction models based on a 2 x CO_2 scenario suggest an increase in net primary productivity for forests in eastern Canada, while forests in the west would be affected in the opposite manner (Price and Scott, 2006). However, most models are based on climate-growth relations of diverse species and do not consider factors that are potentially negative for productivity. The rather positive picture in Quebec must be considered as an optimistic scenario from which potential losses must be subtracted. For example, the emergence of exotic species or more frequent drought conditions could cancel out any gains (Kirschbaum, 2000; Johnston and Williamson, 2005).

A rise in atmospheric concentration of CO_2 would have a fertilizing effect on forests, leading to an increase in net primary productivity (Ainsworth and Long, 2005: Price and Scott, 2006). Greater productivity has already been observed in the upper and middle latitudes between 1980 and 1999 (Nemani et al., 2003), for black spruce at the northern limit of its distribution range since the 1970s (Gamache and Payette, 2004) and for poplar, whose average biomass increased by up to 33% (Gielen and Ceulemans, 2001). However, some studies suggest that the gains would be either cancelled by an acclimatization to the new CO_2 levels after a few years (Gitay et al., 2001) or limited by nutrients (Drake et al., 1997) and other factors (Kirschbaum, 2000; Johnston and Williamson, 2005).

Migration

Analyses of various biotic communities based on a 2 x CO_2 scenario suggest significant movements from geographic areas in both latitude and altitude, as was observed in the Rockies in response to the 1.5°C increase in mean temperature during the past 100 years (Luckman and Kavanagh, 2000). The migration should nevertheless take several centuries, since the dispersal capacity remains limited. For example, the anticipated rise in annual mean temperature of 3.2°C by 2050 for the central subregion (*see* Table 2) would cause climate zones to move 515 km northward at the rate of 10 km/year for forests — a speed clearly higher than the fastest observed migration speed of trees (500 m/year). The migration would probably not take place by groups of species, since dispersal speeds and physiological responses vary by species, as much for black spruce and jack pine (Brooks et al., 1998) as for mixed forest (Goldblum and Rigg, 2005). Finally, soil fertility would limit the movement of trees, since the nutrient requirements of the forest vary by stands (maple > balsam fir > spruce forest; Houle, pers. comm., 2006).

Disturbances

Natural disturbances play an important role in shaping the forest landscape. They affect ecosystem composition, structure and processes. These disturbances include insect epidemics, forest fires, disease and extreme weather conditions such as drought, ice storms and violent winds. A change in climate conditions will influence the severity, frequency and extent of these disturbances.

The short life cycle and ease of movement of insects would allow them to become established at higher latitudes with the help of milder winters, although the reduction in snow cover thickness could shrink the distribution range of certain species (Ayres and Lombardero, 2000). However, it is difficult to predict the reaction of a given insect due to differences between species with respect to seasonality, thermal reactions, mobility and host plants (Logan et al., 2003). Based on landscape-level models, Régnière et al. (2006) suggested that the range of the spruce budworm (*Choristoneura fumiferana* [Clem.]) would increase significantly, and Quebec would experience a southward extension of the gypsy moth (*Lymantria dispar* [L.]), a spread of the mountain pine beetle (*Dendroctonus ponderosae* [Hopk]) from west to east in the boreal forest, and the establishment of the Asian long-horned beetle (*Anoplophora glabripennis* [Motchulsky]) on maples, elms and poplars (Cavey et al., 1998; Peterson and Scachetti-Pereira, 2004). In addition, trade globalization and reduced merchandise transit times favour the introduction and establishment of new exotic species (Ayres and Lombardero, 2000).

There is some uncertainty regarding the future frequency of forest fires. Although most climate models predict an increase in fires for the northern hemisphere due to the lengthening of the growing season and the increased occurrence of lightning (Wotton and Flannigan, 1993), the situation could be more variable in Quebec because of more abundant rainfall (Flannigan et al., 2001). Thus, fire frequency could increase in the west and north, diminish in the east and remain constant in the centre (Bergeron et al., 2004). Under a 3 x CO_2 scenario, Flannigan et al. (2005) estimated that the burned area would increase by 74% to 118%. The differences between these studies arise from the lower reliability of regional predictions related to large ecozones and the fact that potential interactions with other disturbances (insect epidemics) are not considered. Considerable uncertainty also remains with respect to the frequency, scope and intensity of extreme events (violent winds, hurricanes, ice storms) affecting deciduous forests (Cohen and Miller, 2001; Hooper et al., 2001).

A reduction in the duration of winter has direct and immediate impacts on forestry activity and its planning, specifically a reduced period of site access (winter roads) and a marked change in the seasonality of employment. This type of direct impact is of interest to forestry companies because reduced thickness, discontinuity or early melting of the snow cover have become preoccupying issues where forests in the south subregion are concerned. The ground exposed to ambient air is subject to freezing, causing significant damage to tree roots and affecting growth (Boutin and Robitaille, 1995).

Adaptation strategies

There are various aspects to adaptation mechanisms. For example, adaptation to the anticipated effects of climate change can be considered from an operational standpoint or a strategic planning perspective. They could range from very concrete strategies regarding the condition of forest roads and modifications to machinery, particularly in areas dependent on winter operations, to more global considerations, such as taking the anticipated effects of climate change into account when undertaking forest management strategic planning. By integrating climate scenarios and knowledge on the fertility and characteristics of forest soils at the planning stage, forest management could promote adaptation to climate change.

A number of adaptation options appear to be feasible, such as the use of reforestation with seedlings that are more adapted to the new climate conditions, even though only 15% of harvested areas are currently reforested. However, this solution would require the availability of accurate regional climate predictions.

In the case of forest fires, there already exists a set of adaptation measures, including increased surveillance, an effective warning system and an improvement in salvage cutting (Wotton et al., 2003). If the number of forest fires were to increase significantly, it is possible that these adaptations would not be enough to reduce the impact of climate change on the fire regime.

Because of the large area covered by forests in Quebec, adaptation measures on a large scale are difficult to apply. In addition, uncertainty surrounding the potential impacts of climate change on the forest in general, and more specifically at the regional scale, limit the implementation of specific measures in the short term.

In summary, climate change will increase the growing period and the northward migration of vegetation zones. The frequency and intensity of natural disturbances, such as the spread of pathogens and insect pests, would increase along with extreme climate conditions. Given the importance of the forest industry in Quebec, adaptation strategies aimed at reducing these impacts are few in number and would be implemented on a case-by-case basis, based on the biophysical and socioeconomic characteristics of the subregions.

3.2.2. Hydroelectricity production

The energy sector holds a predominant place in the Quebec economy. Electricity comes mainly from hydroelectric generating stations (96%), a few thermal generating stations (oil, natural gas or biomass) and one nuclear plant, Gentilly-2. Some 80% of the installed capacity of 42 950 megawatts (Ministère des Richesses naturelles et de la Faune du Québec, 2006c) is located north of the 49th parallel and three large hydroelectric complexes (Bersimis–Manic-Outardes, La Grande and Churchill Falls) draw upon vast reservoirs (Institut national de recherche sur les eaux, 2004) to satisfy the bulk of Quebec demand. In the north, storage power stations represent 95% of installed capacity, whereas run-of-river power stations account for 95% of installed capacity in the south. For this reason, the anticipated impacts of climate change on these two types of power stations are considered separately. It is also important to clarify that changes in the hydrological regime depend both on changes in precipitation and variations in temperature. The latter are likely to affect evapotranspiration in watersheds and therefore have a significant impact on the hydrological cycle (Guillemette et al., 1999; Allen and Ingram, 2002).

In the northern part of the central subregion, all climate models forecast warmer temperatures and more abundant precipitation. The following considerations were drawn up according to regional climate scenarios, but they must be treated with caution given the level of uncertainty.

A modified thermal regime would result in reduced precipitation in solid form and snow cover. It would also cause an increase in evapotranspiration rates during the open water period, which would nevertheless be offset by an important increase in general precipitation, resulting in higher reservoir levels.

The anticipated hydrograph (Figure 14) was produced by feeding a hydrological model with observed climate data that were altered based on the differences in temperature and precipitation, as suggested by different climate scenarios generated by global climate models. It can be deduced from this figure that future natural inflow would be more sustained in winter (from November to April), that the spring flood would occur two to three weeks earlier, that the flood volume would probably be reduced and that summer inflow would probably be less important due to a significant increase in evapotranspiration. Adjustments in annual reservoir management practices must be expected, since reservoirs would be fed later in early winter by

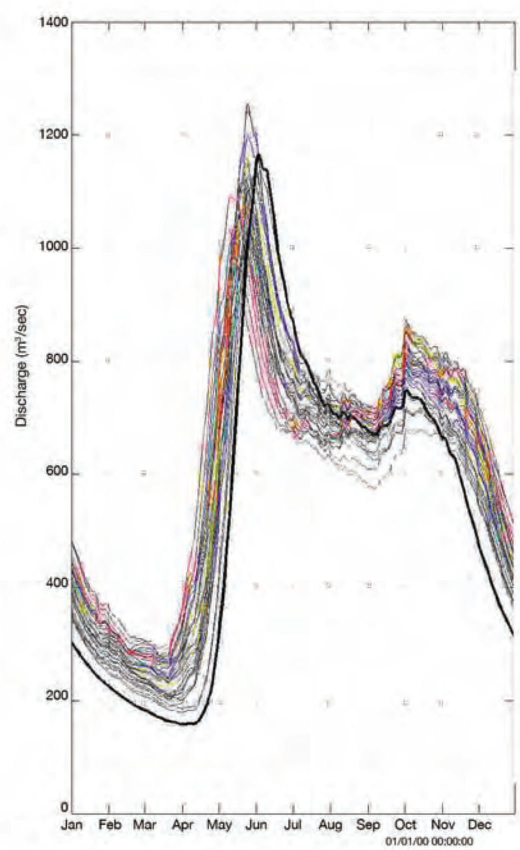

FIGURE 14: Average annual hydrographs simulated using climate observations (thick line: 1960-2002) and climate projections from 9 models running several different emission scenarios (thin lines: 2041-2070) for a northern Quebec watershed (Ouranos, 2007).

more precipitation in liquid form, while floods would occur earlier and be less significant. The new climate would have a greater natural regulating effect on an annual basis, a conclusion consistent with those reached by Slivitzky et al. (2004) using the first versions of the CRCM.

Since the historic annual inflow series (Figure 15) shows no statistical change in average, cycle or trend, it was agreed by Hydro-Québec for purposes of planning future production equipment that the mean value of inflow over the historical period would be observed over the coming years. However, available climate scenarios show a rising trend in mean annual inflow values over a 50-year period, together with larger year-to-year variations for the subregion, thereby casting doubt on the assumption of a stationary climate.

Furthermore, the periods during which temperatures fluctuate around 0°C would occur more frequently. These are periods of the year when reservoirs are filled to a high level. Indeed, high heating demand in winter requires reservoirs to be full at the start of winter to ensure sustained electricity production throughout the cold season. It is precisely at this time of the year that temperatures fluctuating around 0°C would either limit inflow (precipitation in the form of snow), or increase it if the precipitation was in liquid form and flowed on ground that was frozen or covered with a thin layer of snow. These particular conditions would require a change in current reservoir filling strategies to limit the risk of non-productive spillovers and their considerable financial consequences (Forget, 2007). However, if these rainfall events were to occur during mild spells later in the winter, when the snow cover is thicker, the rain would be absorbed by the snow and the impact on flow would be limited, all the more since reservoir levels would be somewhat lower due to intensive electricity production at that time of the year.

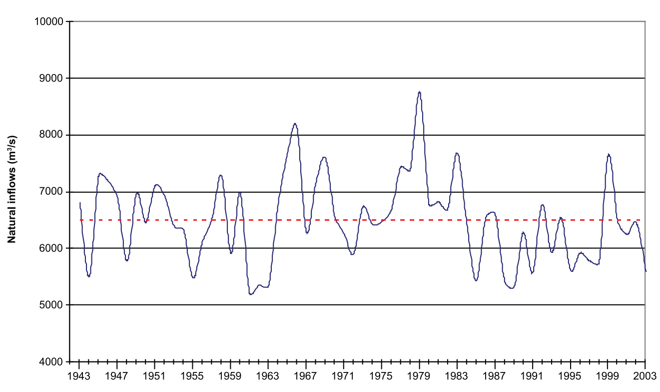

FIGURE 15: Distribution of mean annual inflow in watersheds developed for hydroelectricity production north of the 49th parallel, compared to the mean value (red dotted line) of inflows (Ouranos, 2004).

Despite the low certainty level, the frequency of extreme events associated with the water cycle is expected to increase. A higher frequency of intense storms, which produce heavy precipitation over a short period of time, would require that special attention be paid to affected facilities and more frequent non-productive spillovers. Aside from the economic consequences of such situations, at least the security of structures and populations would not be threatened. In contrast, greater vigilance must be shown in southern Quebec, where a dense population lives in proximity to dams and run-of-river generating stations. This requires better knowledge regarding the frequency and magnitude of possible extreme events to guide design work for new facilities, as existing facilities were designed to meet safety criteria related to past extreme events.

Adaptation strategies

In Quebec, lack of knowledge of future hydrological events is an issue of concern for water resource managers, and the related economic stakes are high (Hydro-Québec, 2006). However, different adaptation strategy elements can be considered that cover a wider range of scenarios with respect to an increase or a reduction of natural inflows. The high level of uncertainty associated with long-term forecasts of natural inflows in northern Quebec makes it impossible to decide which adaptation measures should be implemented right away. Considering that Hydro-Québec possesses significant financial and technical capacity to deal with any challenge, the choice of proper strategies depends on improved climate scenarios and a better understanding of their impact on the hydrological regime. In addition, given the extent of wetlands in northern Quebec (15% of the boreal area consists of peat bogs), a better understanding of their role in the hydrological balance seems to be required (Payette and Rochefort, 2001).

Quebec has considerable remaining potential for hydroelectric development, but the impact of climate change on future water availability should be considered when selecting regions suitable for hydroelectric development, just as it must be considered in developing design criteria for the facilities. For example, a more regular annual water regime would allow a smaller reservoir storage capacity, while a greater year-to-year variability would justify the need for larger reservoirs in order to counteract the impact of water deficits spread over several years. Solutions aimed at reducing risks related to uncertain hydrological conditions include diversification of electricity production sources and the gradual integration of wind energy production into the transmission network, even though little is known about wind in a climate change context. As for electrical transmission facilities, design criteria were revised after the 1998 ice storm to make the transmission network (conductors and towers) less vulnerable to severe weather (Hydro-Québec, 2006).

3.3. MARITIME SUBREGION

The maritime subregion includes the St. Lawrence River estuary and part of the Gulf of St. Lawrence, including the Côte-Nord, Bas-Saint-Laurent, Gaspésie, Îles-de-la-Madeleine and Île d'Anticosti. The population of this subregion declined from 430 000 in 1971 to 395 000 in 2004, and from 7.1% to 5.3% of Quebec's total population (Statistics Canada, 2005). More than a third of inhabitants are estimated to live less than 500 m from the banks of the St. Lawrence River, and more than 90% less than 5 km away. Communities in the maritime subregion are generally dependent on the coastal area for their social and economic well-being and security, whereas inland communities belong more to the central subregion. The main industries (tourism, fishing, pulp and paper, forestry, aluminum smelting and mining, as well as maritime transport) depend on critical infrastructure often situated in the coastal zone (provincial Highways 132, 138 and 199, as well as the ports) and on the resources found in this zone (beaches, lagoons, tidal marshes). A sizeable proportion of this infrastructure is affected by climatic and hydrodynamic processes that influence shoreline dynamics. As for population centres, most coastal villages were built on friable, weakly consolidated deposits bordering the shores. The value of the built heritage being threatened by erosion within thirty years is significant; on the Côte-Nord alone, east of Tadoussac, over 50% of the buildings in communities along the river, and their population of close to 100 000, are located less than 500 m from the shoreline (Dubois et al., 2006).

The geology of the maritime subregion is marked by the presence of a high proportion of friable, unconsolidated deposits easily subject to erosion under the action of low- to medium-energy hydrodynamic processes. For example, the Côte-Nord is covered mainly by postglacial clayey silt overlain by delta sand, all of which rests unconformably on Precambrian granite formations of the Canadian Shield (Comité d'experts de l'érosion des berges de la Côte-Nord, 2006). These unconsolidated deposits, up to about 100 m thick, extend into the gulf and form estuary deltas, terraces and beaches. In Gaspésie and Îles-de-la-Madeleine, rocky Appalachian formations are composed of sandstone and weakly consolidated clayey shale that erodes easily under the action of freezing, thawing, rain and hydrodynamic processes that attack the foot of slopes, causing regular slumping and landslides. Fluvial and marine erosion of these friable rocks loosens the sand and gravel that form the numerous beaches and sand spits dotted with lagoons or tidal bays. In the St. Lawrence River estuary, large tidal marshes shelter or serve as migratory halts for numerous wildlife species. In some cases, such as the snow goose, the bulk of the world population gathers in this area on its twice-yearly migrations.

Vulnerability of coastal zones

Coastal zones are generally vulnerable to climate change, and the shores of the Gulf of St. Lawrence are no exception. One of the main causes of growing vulnerability is the rise in sea level. This results in increased erosion rates, flood risks and saltwater intrusion into groundwater, or at least into municipal water intakes (Villeneuve et al., 2001), posing a threat to populations living near the high water mark (Neumann, 2000; Intergovernmental Panel on Climate Change, 2001; Zhang et al., 2004). Although some studies (Mörner, 2003) have questioned whether sea levels are actually rising, most models and studies anticipate a rise of 18 to 59 cm during the twenty-first century (Intergovernmental Panel on Climate Change, 2007). The rate of sea level rise varies depending not only on the rate of glacier and ice cap melting and the warming of ocean waters (warmer water expands), but also on the locally measured rate of vertical movement of the Earth's crust (isostatic rebound) and on factors that alter mean sea level (density of seawater, local gravimetric constant and mean atmospheric pressure).

In the Gulf of St. Lawrence, McCullogh et al. (2002) reviewed historical rates of change in mean sea level at Charlottetown (Prince Edward Island), showing that the mean level rose by about 2.0 to about 3.2 mm/year between 1911 and 2000. The northern part of the gulf is rebounding at a rate that tends to cancel the effect of rising sea levels. A recent study of historical rates of sea level variation in the gulf (Xu et al., 2006) emphasized the complexity of trends observed in this subregion. Nevertheless, it also highlighted a large increase in the frequency of storm surges in the Québec City region and the southern gulf region during the twentieth century. This trend is confirmed by an analysis of surges for the gulf as a whole, using a numerical model (Daigle et al., 2005). Based on a mean rise in sea level of 20 cm in 2050, Lefaivre (2005) estimated that net sea-level rise will be 14 cm in Québec City and Rimouski by 2050. Even if this change in mean sea level seems of little importance, the study by Xu et al. (2006) indicated that it could shorten the recurrence times for storm surges at Rimouski by a factor of more than three.

Several other climate factors can affect shore erosion, including a reduction of the freeze-up period and duration of sea ice cover (Bernatchez and Leblanc, 2000), as well as rises in the number of cyclones (Forbes et al., 2004) and the frequency of freeze-thaw cycles. Ice can help reduce bank erosion by attenuating waves and forming a protective screen that stabilizes beaches and slopes. The first attempts to model waves using a coupled climate-atmosphere model on a regional scale (Saucier et al., 2004) forecast a 60% reduction in the duration of sea ice by 2050 and its total disappearance before the end of the twenty-first century. The beaches would then be exposed to winter storms in addition to autumn storms. The data collected by the expert committee on shore erosion of the Côte-Nord (Dubois et al., 2006) show that erosion rates have increased greatly over the last ten years, a period during which the ice cover in the gulf, especially along the Côte-Nord, was much thinner than average (Environment Canada, 2007b).

Cyclones affect bank erosion in two ways. First, the intensity and frequency of storms can vary depending on climate conditions and change the number of storm surges caused by the reversebarometer effect and the wind on certain coasts. Next, the organization of cyclone systems (source and path of depressions) modifies the waves (height, frequency, direction) in the gulf, which affects the long-shore current and sediment balance of the beaches. In many cases, these modifications can take the form of a rise or a lowering of beaches, resulting in an increase or decrease of slope protection against erosion due to storm surges and waves. Daigle et al. (2005) found considerable variations in temperature and precipitation extremes between 1941 and 2000 in the gulf. Diaconesco et al. (2007) showed that the wind regime changed during this period. These studies suggest that the changes affecting extreme conditions also result in a reorganization of sediment transport, which would partly explain fluctuations in erosion rates of banks observed in several regions of the gulf.

The clayey slopes of the Côte-Nord and the friable sandstone cliffs of the Îles-de-la-Madeleine and Baie-des-Chaleurs are sensitive to frost weathering. An increase in the number of winter mild spells would lead to increased erosion of these cliffs (Bernatchez and Dubois, 2004). Other climate-related factors can also indirectly affect bank erosion. The increase in winter mild spells and the reduced quantity of snow spread out the period of spring floods and reduce their intensity. The reduction of floods favours the retention of sea front sand in coastal estuaries and deltas, and thus modifies the sediment balance of adjacent beaches. The absence of ice and snow also affects the wind balance and the formation of beach dunes. All these factors can contribute to shifting the equilibrium of sand inputs, resulting in modifications to the erosion rate (Dubois, 1999).

Climate change impacts and human activity

Although coastal erosion is a natural process, the vulnerability of coastal communities has increased in recent decades and should increase even more in the future due to imminent climate change (Morneau et al., 2001). However, certain factors that explain the increased vulnerability of communities are of human origin. Morneau et al. (2001) noted an increase in construction along shorelines since 1970, resulting from the growing tourism-related attraction to coastal areas and the availability of methods to protect banks.

Bank protection methods have enabled public authorities to safeguard infrastructure and residential or industrial zones in coastal areas. However, the technologies used to preserve banks, which consist mainly of linear protection by riprap and the erection of vertical walls (concrete, sheet pile, rocks and timber cribs), result in poor adaptation and, as such, are causing significant residual environmental impacts. One of the largest impacts is a deficit in granular materials, such as sand, in zones protected by a structure. On the Côte-Nord, nearly 40% of active slopes are being protected from erosion by riprap at the foot of the slope (Morneau et al., 2001). The cumulative effect of this protection is to reduce by half the inflow of sand resulting from erosion of the slope, which causes the sinking of beaches and increased erosion of unprotected slopes.

Human activity can also influence the natural processes that act on bank erosion. Examples of activities and structures that can alter sediment dynamics and affect bank erosion include modifications to the water regime due to river diversions and the presence of hydroelectric facilities, deforestation of banks, destruction of dune vegetation by all-terrain vehicle traffic, coastal infrastructure (jetties, wharves, artificial channels) and municipal storm sewers.

In coastal zones of the gulf, the economic, social and environmental stakes of climate change are high (Forbes, 1997). Climate change will greatly increase the vulnerability of populations in this subregion for several reasons. First, these populations are already displaying socioeconomic vulnerability, evidenced by data on population, employment, economic growth and other indicators of economic and social stability. The partial collapse of the fishing and forest industries has already hit this subregion hard. In this context, the future impacts of climate change will likely be negative and could vary depending on the capacity for preventive adaptation of the populations involved. The trends observed are consistent with conclusions reached in the chapter on Atlantic Canada (*see* Chapter 4) and closely tied to impacts on the marine ecosystem (discussed later). Moreover, coastal communities are already affected by coastal erosion (Canadian Climate Impacts and Adaptation Research Network, 2003: Dolan and Walker, 2003), a subject regularly covered by local media. The cost of erosion and damage to coastal infrastructure has been rising for several years, and is projected to continue rising quickly if nothing is done to correct the situation.

In addition, climate change affects several hydrodynamic variables that can combine to cause a significant rise in erosion rates, threatening the integrity of coastal infrastructure. Much of this infrastructure, especially roads, is of critical importance to the entire population of affected regions. Moreover, trends observed for several years indicate that residents and local decision-makers are reacting to the increasingly frequent and acute problems posed by bank erosion and extreme events by spontaneously applying improvised solutions (often in emergency situations) that are inappropriate and poorly adapted to long-term impacts. The challenge is to reverse this trend and have residents and decision-makers adopt a preventive approach by selecting adaptation strategies and methods that minimize undesirable impacts on the environment or avoid exacerbating the problem in the long-term (Klein et al., 2001; Bruce, 2003; Parlee, 2004).

CASE STUDY 2

Towards integrated management of coastal zones

The complexity of human interactions, combined with that of the causality chain that connects climate to bank erosion, requires a multidisciplinary and comprehensive approach to deal with this problem. Studies were begun in 1998 by the Quebec government and in 2002 by Ouranos, to assess the magnitude of the coastal erosion problem and evaluate the potential impacts resulting from climate change (*see* Figure 16). The studies in progress include three elements: 1) an historical tracking of the evolution of banks in the Gulf of St. Lawrence; 2) a detailed analysis using numerical modelling at the regional scale of climate and hydrodynamics of the gulf, which will make it possible to better evaluate the future climatic situation; and 3) an integrated manage-ment framework for coastal zones that involves local and regional communities and decision-makers supported by scientists.

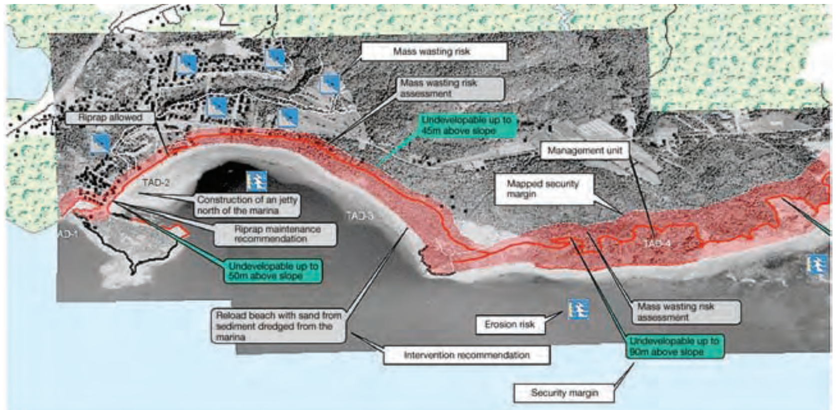

FIGURE 16: Zoning map of erosion risk for the Côte-Nord (*from* Dubois et al., 2006).

A comprehensive review of policies and associated regulations will also be required (municipal zoning, planning diagram, critical infrastructure management, public security policies, methods of protection and regulation). The adaptation choices will then be made by committees elected by an assembly of coastal community representatives.

The adaptation tools currently being developed include numerical models that integrate data on marine currents, ice, waves and water levels, and systems that monitor and analyze erosion scenarios. They could also include maps showing changes in the coastline over 30 years based on erosion scenarios that take into account available data, Internet communications and exchange tools, and updated documents on bank protection methods and their impacts and effectiveness. For example, Figure 16 was used in the adoption of regulation dealing with interim control of coastal management.

An important aspect of adaptation is the development of local and regional expertise among decision-makers and front-line stakeholders in management of the coastal zone (National Institute of Coastal and Marine Management of the Netherlands, 2004). Projects underway on the impact of, and adaptations to, climate change in the coastal area of the Gulf of St. Lawrence rely on committees made up of decision-makers and stakeholders to build a regional node of persons possessing the latest scientific and technical knowledge regarding the factors that control bank erosion and coastal dynamics in their region. Completed in 2008, this project shows the importance of a balanced approach between knowledge stemming from climate science and that stemming from the assessment of on-site vulnerabilities, processes and implications, and seeks to integrate stakeholders and actors involved in the problem into the understanding and search for optimal adaptation options.

3.4. SOUTH SUBREGION

The vast majority of Quebec's population lives in the southern part of the province (Figure 17), where most of the economic activity is concentrated. The impacts of climate change here could be numerous, varied and sometimes complex, given the interrelations between infrastructure and socioeconomic activities. The rural regions have a fragile primary manufacturing economy that can be directly affected by climate, whereas the urban regions rely on a tertiary economy on which climate can act indirectly (e.g. infrastructure failure during the 1998 ice storm crisis).

FIGURE 17: The south subregion presents a variety of issues. The rural landscape is characterized by a built or managed natural environment (agriculture, silviculture, residential) in which watersheds can play a unifying management role. The growing urban areas are dominated by a large quantity and variety of infrastructure related to the needs of a growing and aging population (Ouranos, 2004).

3.4.1. Energy

Quebec's economy is associated with high energy consumption because of its industrial base, climate, size and way of life. In 2002, the industrial sector accounted for 39% of energy demand, while transportation totalled nearly 25% and the commercial, institutional and residential sectors consumed 37% (Ministère des Ressources naturelles et de la Faune du Québec, 2004).

More than 38% of Quebec's energy needs are provided by electricity, of which 96% is water-generated. Demand reached 41.5 million oil-equivalent tonnes in 2002, an increase of 6% over 2001 (Ministère des Ressources naturelles et de la Faune du Québec, 2004).

The impact of global warming on energy demand would be lower heating needs in winter and higher air-conditioning needs in summer. The relationship between temperature, heating and air conditioning in the residential sector is well known and has been the subject of numerous analyses in recent decades (Lafrance and Desjarlais, 2006). However, knowledge of heating and air-conditioning needs in the commercial and institutional sector is more limited.

Residential heating needs in 2050 should decrease by 21% (Sottile, 2006) and air-conditioning needs should increase by 12% (Table 5), resulting in a net reduction (8.8%) in energy needs (Lafrance and Desjarlais, 2006) and considerable savings (Table 6).

In 2001, the share of commercial and industrial air conditioning was higher than the residential sector. In 2050, energy demand should fall in winter by 14.3% and air-conditioning needs in the commercial and industrial sectors should rise by 3%, for a net decline of 5 to 11% in total demand.

According to the reference scenario, energy demand (heating and air conditioning) in all sectors would decline by 2 to 3% in 2050. The increased annual savings would amount to several hundred million dollars. For southern Quebec, peak summer demand for air conditioning (between 7 and 17%) would rise, emphasizing the vulnerability of electricity production, transmission and distribution networks, as illustrated by the power failure that occurred throughout eastern North America (except Quebec) in 2003.

TABLE 5: Impacts (%) of climate change on heating and air conditioning in the residential sector (Lafrance et Desjarlais, 2006).

	Impact (%) on the total			Impact (%) on electricity demand		
	Heating	Air conditioning	Net	Heating	Air conditioning	Net
Scenario						
2030						
Optimistic	-7.5	3.4	-4.0	-5.8	4.3	-1.5
Median	-11.0	4.4	-6.7	-8.6	5.5	-3.1
Pessimistic	-15.7	6.4	-9.2	-12.1	8.1	-4.0
2050						
Optimistic	-10.5	5.5	-5.1	-8.5	6.6	-1.9
Median	-15.2	8.3	-6.9	-12.3	10.0	-2.3
Pessimistic	-21.1	12.3	-8.8	-17.1	14.8	-2.3

TABLE 6: Savings achieved in all sectors (residential, commercial, industrial) by demographic, economic and climate scenarios, in millions of 2003 dollars without tax. Note: For the definition of scenarios used in the table, *see* Lafrance and Desjarlais, 2006.

Baseline scenario		Optimistic	Median	Pessimistic
Residential	2030	-197	-329	-453
	2050	-229	-313	-397
Commercial	2030	-77	-139	-206
	2050	-104	-166	-259
Industrial	2030	-56	-83	-118
	2050	-82	-117	-163
Total	2030	-330	-552	-776
	2050	-415	-596	-820

Adaptation strategies

Planting trees and the use of shutters, more reflective surface coverings, green roofs and low-energy cooling systems (fans and evaporation air-conditioning systems) would lessen the rise in air-conditioning needs and increase the comfort level of residences without air conditioning. Since houses last more than 50 years, their design must be adapted to include the installation of efficient air-conditioning systems (Lafrance and Desjarlais, 2006). It would be useful to have a better understanding of the impact of more frequent extreme climate events on power grid behaviour and to study the impacts of diverse alternate climate scenarios (Lafrance and Desjarlais, 2006).

With Quebec's electricity transmission networks also supplying the United States, hydroelectricity production presents an opportunity for new market development, while reducing emissions from local thermal generating stations (Lafrance and Desjarlais, 2006).

3.4.2. Agriculture

Agricultural activity is concentrated primarily in the south subregion, an area favourable for agriculture due to its climate and fertile land. In response to various socioeconomic factors, the area under cultivation declined from 2.5 million ha in 1941 to 1.8 million ha in 2001 (Statistics Canada, 2002). Agricultural activity will continue to change due to a variety of factors, including climate change, that can result in both business opportunities and income loss, in both the quantity and quality of agricultural production and in the use of inputs (water, fertilizer, herbicides and pesticides).

Present agro-climate situation

The length of the growing season is a fundamental agro-climate factor that determines crop choice and yields. According to Yagouti et al. (in press), growing degree days increased by 4 to 20% between 1960 and 2003 in the western and central parts of southern Quebec, making the season more favourable for most crops.

Past year-to-year climate variability makes it possible to assess the current sensitivity of agriculture to climate conditions. Over the 1967 to 2001 period, the greatest reduction in corn yield took place in 2000 (Figure 18), a year marked by excessive moisture and insufficient sunshine to promote growth (Environment Canada, 2002). Consequently, crop insurance compensation for corn reached a record level of $97 million in 2000, compared to $191 000 in 1999 (La Financière agricole du Québec, 2006). During this period, regional differences were also evident in the impact of climate variability because of different biophysical environments — soil type, topography and temperature (Bryant et al., 2005).

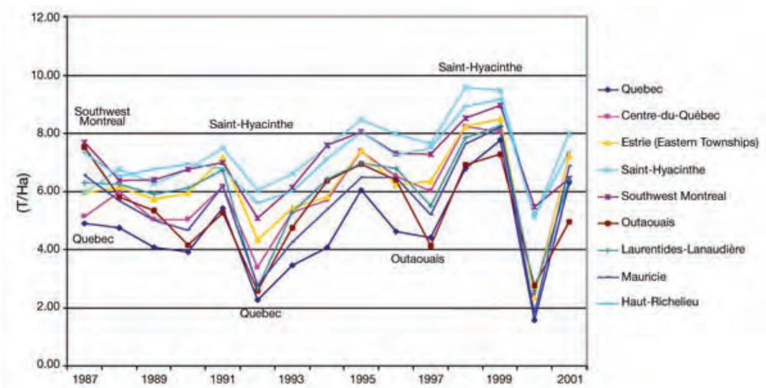

FIGURE 18: Changes in grain-corn yields as reported by farmers in their compensation claims, 1987 to 2001, in different agricultural regions of Quebec (Bryant et al., 2007).

Climate change impacts on Quebec agriculture

A considerable increase in thermal indices and growing season length for corn, soybeans, spring cereals and forage plants is predicted in the coming years (Bootsma et al., 2004, 2005a, b). On the other hand, barley would be less favoured by these changes. In addition, there is a greater probability of water stress during the growing season since, on average, possible increases in precipitation cannot offset the increased evaporation rates that accompany higher temperatures. Since the efficiency of water use by plants increases under an atmosphere enriched in CO_2 (Bunce, 2004), it remains difficult to assess the combined impacts of these different factors on crop productivity.

Excess water is also devastating to agriculture. Along with the question of water inputs, consideration must be given to changes in the intensity and the rain/snow ratio of precipitation (Nearing et al., 2004), since these factors influence runoff, soil erosion and water quality. The adaptation choices of farm producers can increase these anticipated risks when they expand surface areas by adopting crop management practices that leave soil exposed to erosion, or else mitigate the risks by improving soil conservation practices or water resources management practices (Madramootoo et al., 2001).

Horticultural production is particularly sensitive to water and thermal stress. These conditions also affect livestock production. The loss of at least 500 000 poultry in July 2002, despite the use of modern ventilation systems, shows the gravity of heat waves.

Climate conditions outside the growing season will also have impacts on agriculture. According to Rochette et al. (2004), there would be less risk of damage to fruit trees from the first autumn cold, but a higher probability of damage due to hardening losses. For forage plants, a reduction in snow cover and increase in winter rains would increase winter mortality risk despite autumn conditions more favourable to hardening (Bélanger et al., 2002). Less severe winter conditions would result in greater weight gain for beef cattle raised outdoors and reduce heating requirements for poultry and hog barns.

Changes in pathogen, weed and insect populations are inevitable. However, most studies lack an assessment of the magnitude of these impacts. Scherm (2004) explained this as being due to the sometimes large differences between climate scenarios, the existence of non-linear responses of biological systems to environmental parameters and the unpredictable capacity of organisms to adapt genetically to the new environmental conditions.

Not only are there many complex interactions between climate factors, but the role of decision-makers (producers, consultants and other stakeholders) is crucial. For these reasons, preparing an integrated picture of impacts and the potential adaptation of farming to climate change requires that the decision-making context of producers be taken into account (Wall et al., 2004). The European ACCELERATES project (Assessing Climate Change Effects on Land Use and Ecosystems; Rounsevell et al., 2006) attempts to integrate diverse biophysical and socioeconomic models in order to assess the future sensitivity of European agroecosystems. Rounsevell et al. (2006) noted that the most important impacts are related to economic rather than climate scenarios, and that the inherent variability of results prevents drawing clear conclusions as to the future of agriculture. The challenge for agriculture is to properly define the questions and pertinent applications of climate scenarios based on its own strengths and weaknesses, and to appropriately integrate its own relevant socioeconomic dimensions into these scenarios.

Adaptation strategies

At the farm enterprise level

Producers feel they possess the tools and methods to adapt the management of their farms to climate change, at least in the medium term (André and Bryant, 2001; Bryant et al., 2007). As for livestock production, recommendations exist to help producers care for livestock during hot spells in order to reduce their stress (Blanchard and Pouliot, 2003). They focus on the density of livestock indoors and their feeding, as well as on ventilation and misting of buildings. Outdoor livestock production would benefit from more shelters and drinking troughs.

With respect to crops, planting and harvest dates will be adapted to changes in the growing season. Producers will also be able to choose varieties currently used in more southerly regions. Although crop diversification is often considered as a risk management strategy related to climate change, Bradshaw et al. (2004) concluded that, despite the regional diversification of agriculture on the Canadian Prairies observed since 1994, the farms themselves have become more specialized.

Different agricultural practices, such as the establishment of riparian strips, management of field residues and fertilizer application timing and methods, have been developed to protect environmental quality. They could be re-assessed and strengthened if meteorological events such as precipitation and drought become more intense. Besides, a longer growing season would promote the establishment of cover crops that protect the soil against erosion and leaching of nutrients after harvest of the main crop.

At the institutional level

Many programs and regulations establish standards for farm practices. It should be noted that the rules concerning the capacity of manure storage facilities and the deadline dates for seeding, crop harvests and manure spreading are all connected to anticipated climate conditions. When these standards are revised, it would be timely to consider the changing climate and encouraging producers to adapt their practices accordingly.

With the support of government resources, certain losses related to problematic climate conditions can be prevented or reduced. The Plant Protection Warning Network (Réseau d'avertissements phytosanitaires) provides producers with information on the presence and evolution of crop pests and the most appropriate response strategies based on forecasts made by mathematical models using climate data. Bourgeois et al. (2004) emphasized that climate evolution will make it necessary to revise these models to take into account non-linear responses to higher temperatures.

The same applies to the water issue, which requires planning and co-ordination of adapted activities at the regional level. Several micro-irrigation projects are already proceeding in horticultural crop fields. This method allows for more effective use of water and represents a gain for the environment.

3.4.3. Water management

Surface water

Surface waters represent about 80% of the water volume used in Quebec (Mailhot et al., 2004; Rousseau et al., 2004). Although this resource is abundant in Quebec, the impact that climate change will have on it must be taken seriously (Rousseau et al., 2003; Nantel et al., 2005). There are two aspects to consider: 1) the impact on available quantity and raw water quality (Hatfield and Prueger, 2004; Booty et al., 2005); and 2) the impacts on land uses or users (Lauzon and Bourque, 2004; Lemmen and Warren, 2004). For example, the impacts on water availability will be linked to changes in the frequency and magnitude of low flows and droughts (Institut national de recherche sur les eaux, 2004), whereas the vulnerability of drinking water supply systems will depend on the magnitude of those changes (qualitative and quantitative), but especially on the capacity of infrastructure and organizations to cope with the changes, an area about which few evaluations have been done to date.

In addition to supply, the various uses of water are viewed as economic and regional development tools. In both rural and urban areas of the south subregion, there are major and numerous different water uses, including removals for various purposes (bottled water, industrial, municipal, aquaculture, agriculture and mining) and on-site use (hydroelectric production, river transportation, recreation, fisheries and wastewater evacuation; Vescovi, 2003; Ouranos, 2004). Given both the demographic and socioeconomic trends presented above and the fact that 65% of the population of Quebec already live in urban watersheds and 32% live in moderately urban watersheds (Statistics Canada, 2005), the pressure on watersheds in southern Quebec will result in increased vulnerability. Added to this is the possibility suggested by Table 4, and presented in recent studies (Turcotte et al., 2005; Rousseau et al., 2007), that climate change leads to summers characterized by higher temperatures but without sufficient additional precipitation to offset the increased evaporation rates, thus leading to hydroclimatic changes that are likely to exacerbate use conflicts. These conflicts have already generated interest among several groups, resulting in the adoption of a new water policy (Government of Quebec, 2002), which is a tool that can assist in reducing vulnerabilities.

As for hydroelectric production, even though the expected impact of climate change — especially a late start to freeze-up and an early spring — tends to favour production, the constraints associated with ice cover upstream from power stations would be emphasized. In fact, a recurring formation of ice cover in the same winter would affect the performance of power stations over a long period. Also, the more frequent alternation of freeze-thaw periods could cause problems of frazil ice and more frequent ice jams, and reduce the output of these power stations accordingly, while posing other risks. Beltaos and Prowse (2002) suggested that an increase in frequency of winter mild spells tends to increase the risk of ice jams in other regions of the country.

St. Lawrence River

A synthesis of the state of knowledge specific to this major river, which drains southern Quebec and central North America, is provided in a study by Ouranos (2004) entitled *S'adapter aux changements climatiques* (Adapting to Climate Change). In another study, Croley (2003) used the output of four global climate models to estimate that outflow from Lake Ontario to the St. Lawrence River would be reduced by 4 to 24% annually. Using a similar method, Fagherazzi et al. (2005) concluded that there would be a slight reduction in flow of between 1 and 8% from the Ottawa River, the main tributary of the St. Lawrence. Combining these two results, Lefaivre (2005) concluded that water levels on the St. Lawrence would be reduced in the Montréal area by a maximum of 0.2 to 1.2 m, depending on the scenario. This would considerably reduce the area of open water in the river, particularly in Lake Saint-Pierre, which is shallow. A cascade of effects could occur along the entire length of the river that are similar to those identified above but potentially of a different magnitude, given the size of the area affected.

In this context, the Comité de concertation navigation du Plan d'action Saint-Laurent (Navigation Committee of the St. Lawrence Action Plan) examined adaptation options that would make it possible to maintain maritime and harbour activities at their current level (D'Arcy et al., 2005). The study explored various adaptation options and found that, if water level reductions are small, improving long-term predictions would make it possible to optimize the safety margins established by overseas shipping companies, thereby reducing their vulnerability. If the reductions are more significant, adaptations of an organizational nature, such as the restructuring of maritime transport and its infrastructure, or of a technological nature, such as the adaptation of vessels to reduce the draught required, appear to be theoretically feasible. However, these could prove difficult to apply in a context of increased commercial activity and given the major investments required for such a reorganization ($260 million to $1 billion). Finally, adaptations of the physical environment (dredging, regulation structures) can reduce the vulnerability of shipping, but would cause significant environmental impacts. The effects and costs associated with compensation measures would be difficult to assess precisely.

A number of initiatives that illustrate the efforts being made by various authorities to minimize the risks and conflicts that could be caused by a significant decline in water levels merit discussion. Several years ago, the International Joint Commission (IJC) initiated an extensive study to evaluate various flow regulation plans. Several of the management plans tested included flow analysis under climate change conditions (International Joint Commission, 2006), and the options that were proposed could help with adaptation. This evaluation even addressed items such as the advantages of wetlands relative to the economic advantages and losses of regulation plans. Furthermore, in December 2005, the governments of Quebec, Ontario and the eight American Great Lakes states signed the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement, which regulates removals of water from the entire watershed in all sectors and prohibits out-of-basin removals. The agreement makes explicit reference to climate change and the precautionary principle (Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement, 2005).

Groundwater

This resource provides 20% of all drinking water in Quebec. Rivard et al. (2003) observed that the annual groundwater recharge seems to have remained stable or declined slightly in recent decades in Quebec and the Maritimes, while precipitation and temperatures have tended to increase. Significant declines in groundwater availability would have major impacts, especially in rural areas where a large proportion of the population (26% in Chaudière-Appalaches versus 10% for Quebec as a whole) is supplied by groundwater from individual wells (Régie régionale de la santé et des services sociaux de Chaudière-Appalaches, 2001). Their vulnerability is all the greater given that knowledge of groundwater in Canada remains incomplete. In Quebec, the mapping of the aquifer of the Châteauguay River basin (Côté et al., 2006) is a step in the right direction. Moreover, several research projects in this same basin, started in 2006 and supported by Ouranos and the National Science and Engineering Reseach Council (NSERC), are seeking to improve knowledge of systems that integrate both surface water and groundwater using coupled modelling. This knowledge will contribute to the study of the vulnerability of these aquifers on a local scale.

Management Plans for Southern Watersheds: the Case of the Upper Saint-François River Watershed

To assess the capacity of existing management plans for southern watersheds to adapt to anticipated hydroclimate impacts, a pilot project was conducted in the Upper Saint-François River basin, located in the south-central part of Quebec (Turcotte et al., 2005; Fortin et al., 2007). On the one hand, the approach was based on climate change scenarios (Chaumont and Chartier, 2005) and hydrological modelling on a day-by-day basis to assess the impact on basin hydrology. On the other, it was based on a model simulating the daily application of management plans for the Saint-François and Aylmer reservoirs.

The results are similar to those obtained for the Châteauguay River watershed (*see* Case study 3): the impacts on the intensity of spring (earlier and generally smaller), summer and fall peak flows, on winter flows, on the magnitude of low waters (sustained

CASE STUDY 3

Flooding in the Châteauguay River Watershed

The example of the Châteauguay River watershed is used to illustrate the problem of floods, particularly spring floods, in a climate change context. As demonstrated by several authors, flooding caused by high waters in spring remains one of the most damaging extreme hydroclimatic events (Ashmore and Church, 2001; Brissette et al., 2003; Ouranos, 2004) to which Quebec is continually attempting to adapt (Ministère de la Sécurité publique du Québec, 1996). To analyze the potential impact on water resources, Caron (2005) and Mareuil (2005) led a modelling exercise on this watershed based on the development of a stochastic climate generator, including monthly temperature and precipitation anomalies taken from three general circulation models: CGCM2, HadCM3 and ECHAM4.

The 2050s scenarios taken from the ECHAM4 model indicate a statistically significant reduction in spring floods for return periods of 2 to 500 years. The HadCM3 and CGCM2 models show similar results (but not statistically significant), namely a reduction in floods for short return periods and an increase for longer return periods. For the summer period, HadCM3 shows a slight (but not statistically significant) increase in flood intensity for all return periods. The ECHAM4 and CGCM2 models show a statistically significant reduction of 8 to 10% in flood intensity.

Another hydrological simulation was conducted on the Rivière des Anglais, a tributary of the Châteauguay River (Figure 19). The Hydrotel and HASMI models, using six future climate scenarios (the models ECHAM4, HadCM3 and CSIRO, to which were applied GHG emission scenarios A2 and, B2), show earlier peak floods, moving up from late April in the 1961 to 1990 period to early March in the 2050s. There would also seem to be a change in flood volume: HadCM3 projects a rise in spring flood volume, whereas ECHAM4 shows a major decline in flood volume. The CSIRO model presents results falling between those of the two other models. These discrepancies are explained by differences in the projected temperature and precipitation change shown by these climate models. Finally, the example seems to indicate a decline in low water flow caused by a rise in evapotranspiration volume, despite a projected rise in precipitation (Pugin et al., 2006).

Notwithstanding this observation, assessments on Norton Creek, a sub-basin of the Rivière des Anglais, of water content in upper soil layers using a balance model show an increase in irrigation water needs of agricultural land caused by the rise in evapotranspiration of plants resulting from higher temperatures. By taking into account certain environmental constraints related to removal of water from waterways, and despite the relative scattering of results from the different climate scenarios used, the study concludes that, to maintain the proportion of future needs for irrigation water that is currently being provided by surface water will require a more concerted approach to planning, based on integrated watershed-scale management of this resource (Pugin et al., 2006).

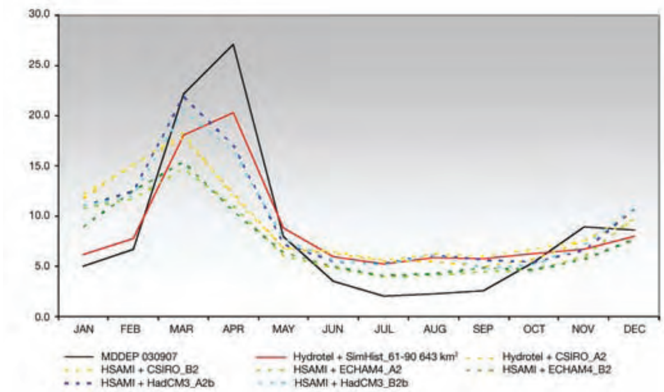

FIGURE 19: Mean annual hydrographs simulated by the Hydrotel and HSAMI hydrological models at the outlet of the Rivière des Anglais. The simulations correspond to the 1961 to 1990 reference period and the 2050 decade, covering 2040 to 2069 (Chaumont et Chartier, 2005).

Finally, Leclerc et al. (2005) indicated that floods caused by ice jams at Châteauguay itself result mainly from the behaviour of the hydrological basin and the presence of ice accumulating on the river. As for floods in open water, they would be the result of fluctuating St. Lawrence River water levels, causing the recurring floods experienced by this municipality. So, for southern Quebec in general and the Châteauguay River watershed in particular, the expected impact of climate change takes the form of earlier and more intense spring floods. Indirectly, variations in the water levels of the St. Lawrence and Ottawa rivers and summer floods in open water can be expected.

winter low waters and weaker summer low flows) and on the intensity of annual increases in volume vary depending on the general circulation model and GHG emissions scenario used (Figure 20). In the approach dealing with the analysis of management plans, the modelling exercise shows that climate change, as simulated by the ECHAM4 and CSIRO models, would result in a modification of current arrangements for the different uses of water from the reservoirs (Figure 21). No major adaptation would be required if the climate changes as simulated by HadCM3. In the first two cases, necessary adaptation measures would include filling the reservoir earlier and raising minimum levels.

Adaptation measures

Depending on the nature of the problem, many adaptation measures are considered, such as the rehabilitation or relocation of certain water intakes, more effective water treatment, reduced water volume loss in the system and increased reserve capacity. They target both infrastructure and management methods (a water-saving program).

Preliminary studies on flood management, such as those undertaken to solve problems related to meeting future needs for irrigation and drinking water, as well as those of ecosystems, must be addressed using an approach that favours planning based on integrated watershed-scale management of water. Large urban

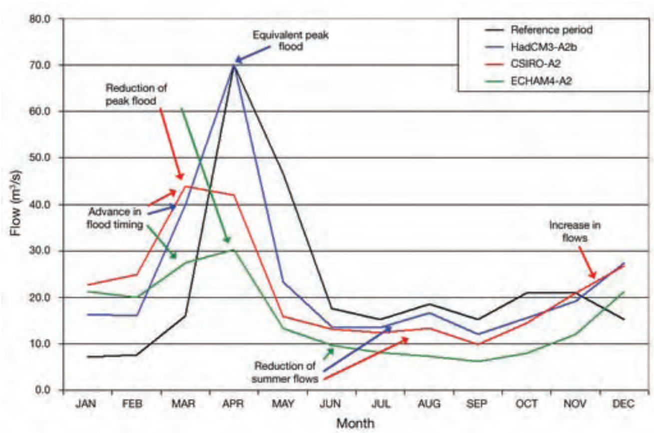

FIGURE 20: Monthly inflow into Lake Saint-François (Turcotte et al., 2005).

centres that depend on surface water seem vulnerable to change in levels of the St. Lawrence River. On the other hand, rural areas that can count on sufficiently abundant groundwater are less vulnerable in quantitative terms. Aside from quantity, the question of water contamination could be a problem, as indicated in Section 3.5.1. In general, the adaptation challenge for small municipalities with limited means is greater than for large population centres. Here again, adaptation solutions ideally involve global and integrated management adapted to the water cycle of southern watersheds as well as the Great Lakes and St. Lawrence system. They must be developed in a sustainable regional planning context that takes socioeconomic and environmental realities into account.

As for water management infrastructure, drainage systems were dimensioned using statistical recurrence criteria produced from available historical analyses of precipitation at a given site (Mailhot and Duchesne, 2005). The anticipated change in recurrence of heavy rainfall events should result in an increase in system overflows, backups and even flooding. Mailhot et al. (2007) stressed that, under the current conditions of aging infrastructure, the impact of a probable increase in intensity and probability of heavy rainfall events (Intergovernmental Panel on Climate Change, 2007) would be lessened if 1) design criteria for infrastructure and buildings were reveiwed; 2) new ways of using statistics on intense precipitation when dimensioning (Duchesne et al., 2005) were found; and, above all, 3) source control was improved through optimal city planning and maximized infiltration, especially in situations where existing infrastructure and buildings will still be in service for several decades.

Finally, adaptation strategies, which should include more robust management plans than those currently in place, will be defined with a view to improve risk management for each climate scenario, since it seems difficult at present to find a single strategy for all scenarios. The results show (Turcotte et al., 2005) that the current consensus on dam management plans must be discussed by community stakeholders even though an adaptation solution for all climate scenarios studied has yet to be defined. A preventive approach would minimize risks. More refined climate scenarios that better represent the future climate based on more advanced methods of scaling would reduce uncertainties. It would thus be possible to better prepare the community for possible changes in management rules and so ease its adaptation to the coming reality. To make consensus adoption of an adaptation strategy easier, it would be advisable to better integrate each step of the modelling (to properly understand the system studied) within the framework of integrated and participative watershed-based management. Besides, in the area of water management, just as watershed-based management has come to be recognized as one of the best climate change adaptation planning approaches, it is becoming increasingly apparent that climate change perspectives must also be integrated into watershed-based management planning. These two components naturally and mutually make a whole.

	Current management plan				Adapted management ECHAM4 A2			Adapted management CSIRO A2		
	Reference period	ECHAM4 A2	CSIRO A2	HadCM3 A2b	ECHAM4 A2	CSIRO A2	HadCM3 A2b	ECHAM4 A2	CSIRO A2	HadCM3 A2b
Rupture risk	0	0	0	0	0	0	0	0	0	0
Reservoir damage (upstream)	14	0	8	12	8	39	82	0	8	29
Tourism	481	2634	1137	480	461	192	61	2028	481	213
Water supply	0	310	15	0	0	0	0	272	0	0
Damage to Lake Louise (downstream)	16	4	17	13	4	16	29	2	12	12
Energy production	596	364	523	579	345	482	498	369	526	567

Current compromise

Adaptation unnecessary or negligible

Minimum level increased

Earlier fill period

Positive impact

Negative impact

Earlier fill period

FIGURE 21: Simulations to 2050 of the current management plan for the Saint-François and Aylmer reservoirs under climate change conditions, using ECHAM4 A2 and HadCM3-A2b models and scenarios. The figures in the table correspond to the number of days over a 30-year period (1961–1990) on which the limits set out in the management plan (for specific uses) were not met. These limits are reservoir water levels and/or river flows (Fortin et al., 2007).

3.4.4. Tourism and recreation

Tourism, through its contribution to gross domestic product and employment, is one of the important economic activities potentially affected by climate change. Climate is the primary element affecting sports and outdoor activities, either directly (sun, fine weather, snow and ice), or indirectly (scenery and plants). It determines the nature and duration of activities involving snow and cold (skiing, snowmobiling), water (swimming, nautical activities) or autumn colours (hiking), and influences living conditions for fish and game (fishing, hunting). It can even influence the number and duration of cultural outings.

Anticipated impacts

According to Wilton and Wirjanto (1998), a 1°C rise in summer temperature would increase Canadian tourism receipts by 4%, whereas a decrease of 1°C would have only a marginal impact in winter. The sensitivity of tourism and recreation activities to temperature varies depending on the season and includes different thresholds. Other phenomena also come into play, such as coastal erosion, water deficits in lakes and rivers, or water supply deficits (Wall, 1998).

According to Singh et al. (2006) and Scott et al. (2006), the Quebec ski industry must expect and adapt to more difficult climate conditions in the coming decades. The southern regions (Montréal, Eastern Townships) should see an increase in mild and rainy conditions during the ski season that will shorten its length. Certain profitable periods (Christmas, Easter, school break) would be affected. However, warming (less cold and wind) would increase the number of skiable days and use of trails, especially in January and February. The cost of artificial snow-making, despite the fact that the equipment is already installed, may rise, affecting profitability and making availability of the required water a critical issue. A higher extraction volume combined with a possible drop in water levels would trigger or amplify usage conflicts (Singh et al., 2006). The importance that customers give to natural snow and the skiing quality it provides should be an advantage for Quebec because of its latitude, particularly for those ski centres whose customers come from outside the area and whose advertising campaigns have been adapted. The urban perception (rain in the city means it is snowing in the countryside) can also have consequences on business traffic. Depending on the climate model used, a study of the Ontario ski industry (Scott et al., 2002) projected a reduction in snow cover of 21 to 34%, resulting in some activities losing their popularity (snowmobile, cross-country skiing) as the season becomes shorter by up to 50%. Ice fishing is highly vulnerable to temperature warming, as safety risks for fishermen increase. Finally, events such as winter festivals would also be affected.

The golf season should be extended by two to three weeks (Singh et al., 2006), mainly through an earlier start to the season, although 75% of play occurs between July and September. There should be an increase in the number of unfavourable days because of more frequent heat waves and, possibly, summer precipitation. Greater irrigation needs due to warmer temperatures would likely become a problem and a source of usage conflicts, given lower water levels and stricter withdrawal regulations, all of which represent the sector's main challenge. Current grass varieties would deteriorate more rapidly during summer and winter mild spells, as future climate conditions encourage bacteria and other pathogens. The quality of drainage on golf courses would also be affected by the intensity and recurrence of precipitation, and it would cost more to maintain the grounds if increased evapotranspiration dried out the course. These new climate constraints would be of major concern for operators already facing keen and recent competition and needing to meet mandatory environmental standards related to the regulated use of maintenance products (Singh et al., 2006).

With regard to other summer activities, despite the lack of studies on the subject, an increase in such summer tourist activities as hiking, park use, water recreation and boating, can be assumed (Jones and Scott, 2005). Several tourist regions with a more temperate climate would benefit from temperature warming, and Quebec would be privileged compared to more southerly regions, helping its overall tourist balance despite having to contend with socioeconomic factors that could limit revenue dedicated to tourism and recreation. The negative impacts would stem from increased precipitation, heat waves and deteriorating water quality, due specifically to the spread of cyanobacteria and other harmful species (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2005a). Fishing would be disturbed, since fish are sensitive to small variations in temperature.

Adaptation strategies

Faced with greater market competition, constant infrastructure renewal and cost increases (artificial snow-making, electricity, property taxes), many ski hill operators believe that better understanding of future climate phenomena, which leads to better planning of investments and satisfaction of increasingly demanding and selective customers, is the best adaptation strategy. While benefiting from steady technical progress, the ski industry shows a capacity to adapt to new consumption habits, growing competition and new social phenomena, such as excessive and rapid consumption, changes in the family situation and instant access to weather forecasts, which will play an increasingly dominant role. In the case of ski centres, diversification would be one way to adapt to climate impacts and variability, and could be seen as a useful adaptation pathway when dealing with more significant changes (Singh et al., 2006).

Adaptation strategies for the golf industry deal mainly with water management, both natural inputs and land drainage. Grass quality, a major customer requirement, must be monitored to avoid increased withering. Extending the season would generate additional income if the benefits reflect on other services such as food and lodging. However, climate change does not seem to be the priority of this sector, since golf course maintenance costs are mainly related to labour and plant health products (Singh et al., 2006).

As for other summer activities, impacts on sport fishing could be mitigated by planting a vegetation cover on banks, and water quality should be more closely monitored at sites reserved for swimming.

Developing appropriate adaptation strategies requires that stakeholders in these sectors be well informed to better grasp the significance of climate change scenarios, threshold levels for activities and the various possibilities for spontaneous or planned adaptation (Singh et al., 2006). As for consumers or users of tourism infrastructure, it would be advisable to clarify their reactions to different climate thresholds for each activity and the comparative attraction of these activities under the new climate conditions.

3.4.5. Transportation

The Quebec road network is influenced by a harsh climate, the size of the province, the population distribution and heavy traffic in large population centres (Ministère des Transports du Québec, 2006b). This particular situation increases the sensitivity of infrastructure (*see* Section 3.5.3) and transportation activity to climate change.

Winter maintenance

Winter driving on Quebec roads is a challenge, mainly due to difficult and changing conditions. Winter storms are predicted to be less frequent but more intense (Cohen and Miller, 2001). This should increase the complexity of managing winter road maintenance, which covers all measures taken by various parties to combat or adapt to the deterioration of driving conditions in winter. On the other hand, a winter maintenance decision support system (named DVH-6024), using information obtained from stations equipped with weather and road sensors, was set up by the MTQ in 1999 (Tanguay and Roussel, 2000). The development and application of road weather technologies continues, particularly in the case of fixed and mobile instrumentation deployed across the province.

Road surface

In the south subregion, temperatures can change by up to 25°C in a few hours. For more than four months, the ground freezes to depths of 1.2 to 3 m, and precipitation can reach 1000 mm a year (Ministère des Transports du Québec, 2006c). In spring, after resisting deformation due to deep frost, the road must once again be able to support heavy loads while pavement strength is reduced by 40% (Frigon, 2003). Scenarios derived from climate models suggest an increased incidence of mild spells (Government of Quebec, 2006c). Since freeze-thaw cycles and the presence of increased water on the road exacerbate surface deterioration, the new climate conditions will have an impact on pavement conditions and, consequently, on maintenance costs. The rapid evolution of methods and knowledge concerning road surface design and the emergence of new technologies and products have led the MTQ to adapt diverse technologies to the Quebec situation and to design and fine-tune new pavement assessment equipment. These activities, conducted in collaboration with the university community, have been the subject of meetings and technical exchanges, as well as joint research projects with several countries, including France (Doré and Savard, 2006) and the United States.

3.4.6. Context specific to the south subregion

A high level of socioeconomic activity is concentrated in southern Quebec, which places significant stress on the environment and inevitably complicates the analysis of vulnerabilities and the prediction of climate change impacts on both the natural and human systems. In fact, the complicating factors are similar to those of other highly developed, densely populated regions:

- a high and growing population density
- growth of the built environment serving a heavily service-oriented economy
- ubiquity of institutions with important investment and regulatory capacities
- change in public perceptions with respect to activities less and less directly related to climate conditions and ability to choose from among a wide range of historical choices when making land-use decisions
- pressures brought on by urbanization of watersheds that were previously largely agricultural or forested.

This dynamic is also influenced by global socioeconomic issues and associated climate impacts that are likely to have repercussions in the south subregion (*see* Chapter 9). In this context, and as illustrated in Sections 3.4.1 to 3.4.5, the available studies are essentially sectoral, except when dealing with water management, in which case the studies start quantifying and integrating the impacts of different users on the management rules.

The weather event that best illustrates the vulnerabilities associated with a high degree of infrastructure interdependence is the ice storm of January 1998. In that event, the impacts hit several sectors simultaneously, generating a complex series of effects that, when combined, led to the failure of socioeconomic activities and to outcomes whose cost has been estimated at several billion dollars (Ministère de la Sécurité publique du Québec, 1999). Since all infrastructure or societal choices are actually socioeconomic compromises between what is considered acceptable costs and desired benefits, climate change could affect this ratio. These compromises, once considered acceptable, could be revisited on the basis of past or anticipated extreme weather events. However, while quantitative climate studies on the links between climate change and extreme weather events are emerging (Tebaldi et al., 2006), they rarely allow an assessment of impacts at the infrastructure, building or community scale. An increase in heavy precipitation simulated by one version of the CRCM for the south subregion would affect the urban area, overloading municipal infrastructure and triggering flash floods in rural watersheds (Mailhot et al., 2007). Various tools (Secretan et al., 2006), policies (Government of Quebec, 2006c) and land uses (Mailhot et al., 2007) would help reduce the vulnerability.

Little is known about links between the regional climate and the geology of the south subregion, but most of inhabited Quebec lies on clay soil subject to landslides (*see* Case Study 4). This area is characterized by significant urban sprawl, and any increase in the number of landslides would have significant consequences for the security of people and property. As mentioned in Chapter 2, lack of knowledge about a potential problem can significantly affect the adaptive capacity of a system.

3.5 OTHER INTEGRATED ISSUES AT THE PROVINCIAL SCALE

This section will present the key issues for the four subregions, followed by a discussion of other sensitivities and impacts at the provincial level. Although this discussion cannot be exhaustive, given the potential scope of the problem and the limited number

CASE STUDY 4

Landslides in Quebec

Hundreds of landslides occur every year in Quebec, most of them in clay soils (Figure 22) in areas experiencing significant population growth, as discussed in Section 2. Water infiltration into the ground following the spring snow melt or during rainfall events is one of the two major causes of landslides, others being the gradual erosion of stream banks or destabilizing human activity. Extreme weather events often take the form of heavy rainfall that frequently causes major floods. This is shown by the many landslides that occur in spring or during exceptional events — such as the torrential rains of July 1996 in Saguenay–Lac-Saint-Jean, when more than 1000 landslides occurred in less than 36 hours (Ministère des Transports du Québec, 2000).

FIGURE 22: Inventory of requests to respond to landslides in Quebec between 1972 and 2005. The grey zone shows the limits of the postglacial marine transgression that left clay deposits (map provided by the Ministère des Transports du Québec, pers. comm., 2006).

Although the link between these events and climate change does not seem obvious, it appears that the increase in this phenomenon in a region experiencing significant urban sprawl can generally be linked to an increase in extreme precipitation events. Nevertheless, the Saguenay flood improved understanding of the phenomenon through mapping of certain regions at risk, thus adding to the historic efforts initiated by the 1971 landslide at Saint-Jean-Vianney (Figure 23) to assess vulnerabilities and promote a safer use of the territory.

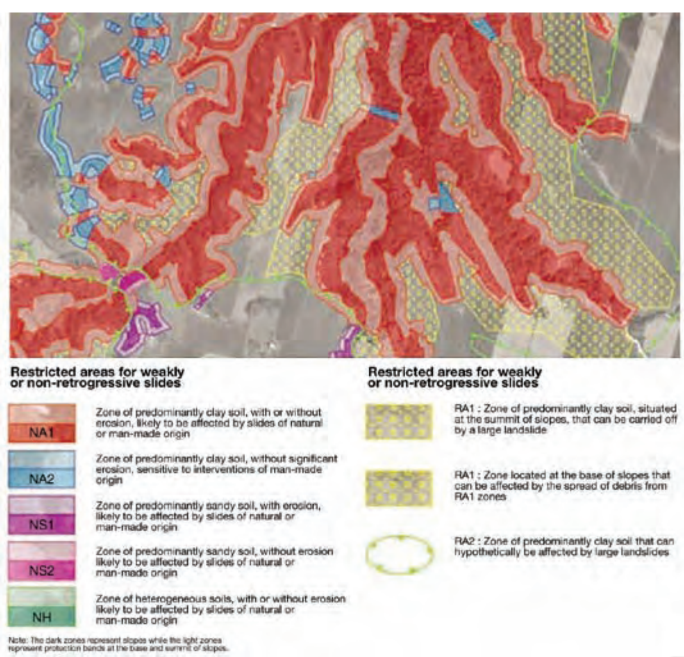

FIGURE 23: Sample map showing areas at risk from landslides for a locality of Saguenay–Lac-Saint-Jean (Government of Quebec, 2005).

of pertinent studies on the subject, the objective is to obtain a clearer overall picture of the situation and to examine certain specific issues that have not previously been discussed. The discussion is based on the three key elements identified in Figure 1.

Although it is valid for all of Quebec, the present section is particularly pertinent for the socioeconomically dominant south subregion that will see climate change combined with interrelated environmental and socioeconomic changes that have already been underway for several decades. The vulnerability of this subregion, and Quebec as a whole, will be influenced by climate changes, weather events, information distribution, international negotiations, public perceptions, the market economy and the public policies of different levels of governments.

3.5.1. Sensitivity and adaptation of populations

Climate change presents a challenge for human health. Its impact is either direct (e.g. death due to heat stroke), or indirect (e.g. outbreak of pathogenic insects). On the other hand, populations show different degrees of vulnerability to climate change, which complicates the introduction of adaptation measures to limit anticipated impacts.

Impacts and sensitivities

Impact of mean warming on mortality

In Quebec, the anticipated rise in mean temperatures may lead to an increase in annual mortality rates (Figure 24). The study by Doyon et al. (2006) predicted a rise in summer mortality (all non-injury causes) on the order of 2% for 2020 and 10% for 2080, according to the A2 scenario (Intergovernmental Panel on Climate Change, 2001a); this increase is not entirely offset by lower winter mortality. Hence, the rise in the annual mortality rate would be about 0.5% for the 2020 period and 3% for 2080, a conclusion similar to that reached for many cities in the United States by Kalkstein and Green (1997), who estimated the number of deaths on hot days to be three times higher than on cold days. Keatinge et al. (2000) predicted a net annual drop in mortality in the United Kingdom due to decreased mortality during winter, which does not seem to be the case in Quebec. However, these simulations do not consider population aging — which can substantially increase mortality rates — nor do they consider physiological and environmental adaptation measures or those related to housing — which can reduce mortality by the same amount. In Québec, there will be more and more people aged 65 and over. Their proportion rose from 9.7 to 12% between 1986 and 2001, and should reach around 24% in 2025 (Institut de la statistique du Québec, 2000). What's more, the study by Doyon et al. (2006) confirmed that the group aged 65 and over is historically much more vulnerable to climate warming than the group aged 15 to 65.

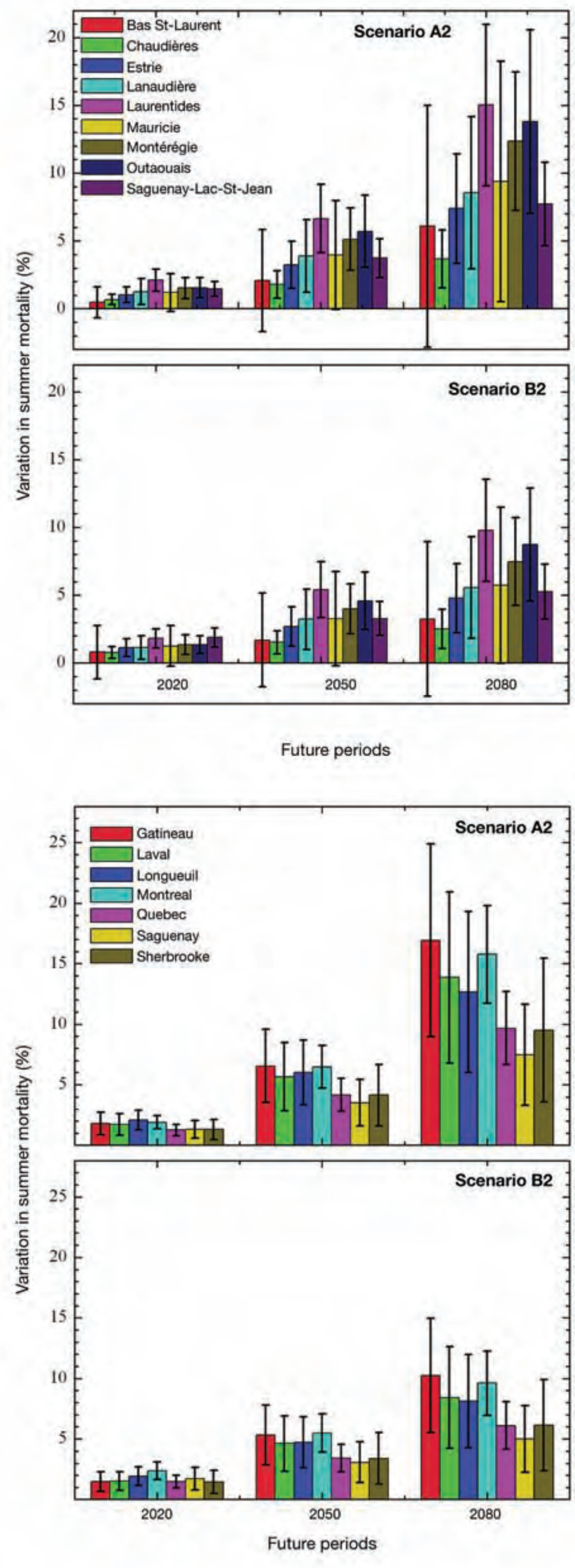

FIGURE 24: Variation in summer mortality in Quebec (cities and regions) according to various scenarios (Doyon et al., 2006).

The direct health effects of violent rain and floods include injury, heart problems and death by drowning. The indirect effects take the form of infectious diseases, such as conjunctivitis and dermatitis, caused by contaminants present in the flood waters and gastroenteritis due to microbiological contamination of drinking water sources. Respiratory problems linked to mildew are also listed. Victims and aid workers would suffer post–traumatic stress that could lead to depression, anxiety, psychosocial troubles and even suicide (World Health Organization, 2005).

The direct health effects of winter storms include injury, chilblain, hypothermia and sometimes death, with 100 Canadians dying every year (Institute for Catastrophic Loss Reduction, 2005).

In 2004, lightning was responsible for about 12% of forest fires (Organisation de patrouilles de la Société de protection des forêts contre le feu, 2006). In addition to their considerable economic impact on the forest industry, forest fires emit chemical compounds into the atmosphere (e.g. particles, nitrogen oxides, carbon monoxide, organic compounds). In humans, these emissions can cause irritation of respiratory pathways, worsening of chronic diseases and poisoning due to smoke inhalation. Acute syndromes may also occur in firefighters and forestry workers exposed to smoke for long periods (Dost, 1991). The indirect effects on health are post–traumatic stress, possibly leading to suicide (World health Organization, 2005), particularly in the case of a significant economic loss (e.g. residential fire or plant fire with job losses). However, the current scenarios associated with the boreal forest do not predict significant changes in precipitation or forest fires in Quebec, but uncertainty remains (Ouranos, 2004).

In January 1998, freezing rain fell on Quebec for five consecutive days, leaving more than 3 million people without electricity, some for as long as 40 days. This event was responsible for 21 deaths and 200 cases of carbon monoxide poisoning (Roy, 1998), mainly in the Montérégie and on the Island of Montréal (Tremblay et al., 1998). Laplante et al. (2004) conducted a study on 224 women who were pregnant at the time or became pregnant in the three months following the storm. 'Objective' stress factors (number of days without electricity) and 'subjective' reactions (post–traumatic stress syndrome) were assessed. The results show a connection between major prenatal stress in the mother and elevated perinatal mortality, differences in psychomotor development in children aged 2 to 5.5 years and behavioural problems in children from 4 to 5.5 years old.

In the north, recent climate trends may be related to the avalanche at Kangiqsualujjuaq in 1999, where 9 people died and 25 were injured (Public Security Canada, 2006). Other, less tragic incidents occurred in other villages during the same time. In Salluit (Hudson Strait), a landslide occurred in 1998 following failure of the active soil layer. In Tasiujaq (Ungava Bay), permafrost thawing was in part responsible for subsidence of a building and deformation of the airport runway (Allard et al., 2002). In addition to putting lives in danger, these events cause considerable insecurity among residents who depend on air transport for food supplies and medical evacuations to hospitals.

Impact of heat waves and of the urban heat island effect on health

Higher temperatures, a daily Humidex that has been rising during the past four decades in Montréal and Québec City, and more frequent and intense heat waves represent important risks for human health (Environment Canada, 2004a, b). Adding to these events is the urban heat island effect, produced by asphalt surfaces and infrastructure materials that absorb heat and raise the ambient air temperature by 0.5°C to 5.6°C in urban settings (Oke, 1982).

The heat can cause discomfort ranging from weakness to consciousness disorders, as well as fainting and heat stroke that can cause death (Besancenot, 2004). Indirectly, heat can also exacerbate such chronic diseases as diabetes, respiratory insufficiency and kidney failure. Sunshine also contributes to the formation of ground-level ozone in urban areas, a gas harmful to human health. Ground-level ozone can irritate the eyes and respiratory pathways, reduce respiratory function, exacerbate respiratory or heart disease, and even cause premature death (Health Canada, 2004).

Southern populations are more sensitive to an increased frequency of oppressive heat episodes, whereas people in the north suffer more from the rise in temperature, since they are not acclimatized (Health Canada, 2005). Several scientific studies (Commission de la santé et de la sécurité du travail, 2004; Direction de la santé publique de Montréal, 2004) referred to people with higher vulnerability based on environmental characteristics (e.g. housing, work, access to cool places) or personal characteristics (e.g. diseases, disabilities, age). The study by Bélanger et al. (2006) shed new light on the vulnerability of certain groups to heat. It highlighted certain known factors and documented new relationships that can exacerbate the impact of heat waves, including 1) elderly persons living alone; 2) economic precariousness; 3) limited mobility; 4) chronic neurological problems (epilepsy, multiple sclerosis); 5) social support; 6) type of housing (including certain types of residential buildings); and 7) access to recreational activity during heat waves (such as bathing areas).

The relationship between multiple-storey residential buildings and higher mortality during heat waves has been established by several researchers (Klinenberg, 2002; Dixsaut, 2005), and public perceptions throughout Quebec have also recognized this vulnerability (Bélanger et al., 2006).

A tracking study conducted in the Eastern Townships on the use of prescription drugs during intense heat episodes showed the importance of the warnings issued by pharmacists (Albert et al., 2006). A significant percentage (30.2%) of people aged 65 and older take a type of prescription medication whose absorption can be affected by dehydration, or that can impede caloric loss and kidney function. Nearly 5% of elderly persons had three or more prescriptions for drugs of this type to be taken simultaneously.

Effects of air pollution on health

The World Health Organization recently presented the hypothesis that a warmer and more humid climate would increase the atmospheric concentration of certain pollens and thereby provoke an outbreak of allergic disorders such as allergic rhinitis and asthma (McMichael et al., 2003). Allergic rhinitis is a serious public health problem in industrialized countries, altering the quality of life of affected populations and causing absenteeism and loss of productivity at work. The costs related to hospitalization, drugs and medical consultations are also significant (Breton et al., 2006; Garneau et al., 2006). In the Québec City and Montréal regions, a rise in both pollen concentrations and frequency of medical consultations for rhinitis was noted between 1994 and 2002. Allergic rhinitis due to pollen and other allergens, or resulting from a non-specific cause, ranks 5th (9.4%) among declared health problems (Institut de la statistique du Québec, 2000). This prevalence seems to have increased by 6% since 1987 (Garneau et al., 2006), but many external factors could also contribute to it apart from climate.

According to Garneau et al. (2006), allergic rhinitis affects mainly the 15 to 24 age group (14.6% of the Quebec population) and the 25 to 44 age group (13.6%). Medical consultations for the 1994 to 2002 period were more frequent among women than men. However, for the 0 to 14 age group, they were higher for males. These results are consistent with those of studies by Banken and Comtois (1990) and Goulet et al. (1996) that reported a maximum incidence of allergic rhinitis among those 0 to 24 years of age.

The use of fossil energy produces not only a significant amount of CO_2 emissions but also of precursors to ground-level ozone and fine particulate matter. Climate change would increase temperature extremes, resulting in a rise in the frequency and duration of heat waves and smog (House and Brovkin, 2005; World Health Organization, 2005). In Quebec, low-altitude ozone levels have been rising constantly during the past 15 years on a seasonal mean basis (Environment Canada, 2005), although the number of acute episodes varies greatly from one year to another. With greenhouse gas increasing by 6% from 2001 to 2003 (Institut national de santé publique du Québec, 2006), this risk remains significant and growing, to varying degrees, for most of the south subregion.

Effects of climate change on the quantity and quality of water resources

In the south subregion, if the projected effects of climate change result in lower stream levels and flows, a change in precipitation (*see* Section 3.4.3) and a rise in salinity levels of the St. Lawrence River (Bourgault, 2001), this would be a serious concern since more than 70% of the public takes its drinking water from surface water (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2004a). The risks of microbial, chemical and natural biotoxin contamination are also higher. Moreover, water shortages, linked to reduced capacity of aqueducts, present a higher risk in case of fire, with injury, death and considerable psychological impact for families whose personal property is destroyed (Enright, 2001).

Water-borne diseases can appear if pathogenic micro-organisms migrate to groundwater or surface water sources used for water supply (Canadian Council of Ministers of the Environment, 2005a, b). Phosphorus, sunshine and temperature are the key factors responsible for blue-green algae blooms (Agence de développement de réseaux locaux de services de santé et de services sociaux, 2003). In Quebec, this phenomenon has already affected about 84 lakes and streams between 1999 and 2003 (Institut national de santé publique du Québec, 2006) and has led to prohibitions on water consumption and bathing, but without any human illness being reported so far. Cyanotoxins, produced by cyanobacteria, can cause skin irritation and serious liver or nerve damage, through both skin contact and water ingestion (American Water Works Association, 1999; Agriculture and Agri-Food Canada, 2003). Young children, the elderly and persons with chronic diseases are more at risk of developing severe symptoms resulting from water contamination. Persons practicing water activities are particularly vulnerable to contamination by natural biotoxins (Agence de développement de réseaux locaux de services de santé et de services sociaux, 2003; Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2005b). The general public would be affected by water shortages at the physical and psychological levels; families already in precarious situations would experience more insecurity with respect to food supply by having to buy their water (Direction de la santé publique de la Montérégie, 2004).

Water-borne diseases (transmitted through protozoa, bacteria or viruses) are common in Nunavik and, from 1990 to 2002, certain of these diseases (e.g. giardiasis, salmonellosis) were found in proportionately higher numbers there than elsewhere in Quebec, while the number of other types of infectious diseases was lower

(Furgal et al., 2002). Climate change can affect water supply (individual or community systems), degrade the permafrost and contribute to saltwater intrusion in aquifers, thereby exacerbating a situation that is already cause for concern. For many villages, burying garbage in the permafrost would pollute groundwater, streams and adjacent lands (Furgal and Seguin, 2005). In Nunavik, one person in five is under five years of age — a group at risk for gastroenteric diseases because of the weakness of children's immune system (Martin et al., 2005b). The feared changes highlight the urgent need to improve environmental monitoring and health surveillance systems for quick detection and treatment of health problems related to water quality (Owens et al., 2006). A pilot project related to this is currently underway in Ungava Bay within the framework of the ArcticNet Network of Centres of Excellence (Gosselin, 2006).

In 2004, QANUIPPITAA, the health survey among the Inuit of Nunavik (Régie régionale de la santé et des services sociaux Nunavik, 2004), conducted in all villages of the subregion, prompted the development of new strategies. During the visit of the Amundsen, an icebreaker for scientific research, 232 homes and 19 raw water supply sites were visited as part of an ArcticNet project (Martin et al., 2005c) associated with the health survey. This survey provided both an understanding of drinking water consumption habits of residents and an overall picture of bacteria levels in the water consumed. It will be used to develop important environmental and health databases for the north subregion, which can then be used for climate-based tracking.

A similar survey was conducted among the Cree population of Mistissini (Nituuchischaayihtitaau Aschii, 2005). It will contribute to the creation of a valuable database on changes in water quality during the next seven years in First Nations communities of the north subregion.

Impacts of climate change on the emergence and intensification of zoonotic and vector-borne diseases

Climate change would modify the distribution range of parasites and diseases transmitted by animals, insects and ticks, resulting in a rise in existing infectious diseases and the appearance of new infectious diseases in Quebec.

Zoonotic diseases include the hantavirus pulmonary syndrome (HPS), for which certain rodents are the vectors. A warmer climate would result in the propagation of rodents into new areas. Many indigenous rodents carry this disease: a first case was reported in Quebec in 2005 (Direction de la santé publique, 2005). Rabies is another disease that can be transmitted to humans through bites or scratches received from infected animals. Climate change would give rise to changes in habitat and length of hibernation and breeding conditions of vector animals, leading to the northward spread of diseases (Ontario Forest Research Institute, 2003).

Quebec presently has few mosquito species that are vectors of viral diseases transmissible to humans. However, a few species present in the south subregion are vectors for the West Nile virus, St. Louis encephalitis, La Crosse encephalitis and eastern equine encephalitis (Institut de santé publique du Québec, 2003a, b). Encouraged by milder winters and longer summers, the mosquitoes live longer and the season during which the St. Louis encephalitis virus can be transmitted is extended. La Crosse encephalitis is endemic to the United States, and the Snowshoe Hare variety of this virus is present in Quebec, as is the eastern equine encephalitis virus, with no cases reported so far (Institut de santé publique du Québec, 2005a, b). However, it can be reintroduced every year by migrating birds (Ontario Forest Research Institute, 2003).

Lyme disease, an emerging zoonotic disease in Canada, can be transmitted by bacteria to humans through bites from infected ticks. According to Université de Montréal researchers, the ticks responsible for the spread of Lyme disease will spread to several parts of eastern Canada, including Quebec, within 10 to 20 years, as the climate warms (Ogden, Faculté de médecine vétérinaire, Université de Montréal, pers. comm. 2005).

Several zoonotic diseases already exist in Arctic animal species, such as tularemia in hares, muskrats and beavers; rabies in foxes (Dietrich, 1981); brucellosis in ungulates, foxes and bears; and echinococosis in canine species (Chin, 2000). The Inuit present high levels of many parasitic zoonotic diseases, particularly toxoplasmosis (Tanner et al., 1987), and climate change is likely to increase the incidence of transmission, either through eating flesh or by water-borne contamination. From 21 to 56% of Inuit households already report a certain level of insecurity with respect to food (Statistics Canada, 2001). The QANUIPPITAA survey will update this data at the beginning of 2008.

Other effects on the north subregion

For millennia, the Inuit have practiced subsistence hunting and fishing. Although they have access to food imported from the south, they continue to feed themselves in traditional ways and derive much more beneficial health effects from 'country foods' than from imported products (Ministère de la Santé et des Services sociaux du Québec and Institut national de santé publique du Québec, 2004). However, should the animals be sick, harbour parasites, suffer from an increase in biting insects, experience famine, change or loss of habitat, the Inuit would then be exposed to a double change because their resources would be transformed or moved, which might, in turn, affect their quality. Their intake of highly nutritious animal protein would be reduced, a matter of some concern, since demographic growth and the maintenance of their hunting and fishing skills are in decline (Furgal et al., 2002). This change is also a concern for public health officials because the replacement of traditional foods with imported foods that are higher in sugar and carbohydrates would lead to cardiovascular problems, diabetes, vitamin deficiencies, anemia, dental problems and obesity, as well as lower resistance to infections. The Inuit already present much higher mortality or morbidity rates than elsewhere in Quebec, mainly in relation to food (Institut national de santé publique du Québec, 2006) and reduced life expectancy due in large part to death by injury, cancer and, to a lesser extent, cardiovascular disease.

The direct and indirect impacts of climate conditions on the natural and built environment would probably increase risks to health, security and well-being of these isolated populations. For example, the considerable increase in quantity and intensity of precipitation would cause more landslides or avalanches. Following the Kangiqsualujjuaq avalanche in 1999 (9 dead and 25 injured), a thorough risk assessment was conducted in all villages and critical infrastructure was moved, particularly the diesel power stations and fuel tanks (Schweizer and Jamieson, 2003).

Adaptation strategies

Mortality and morbidity

The modelling of the relationship between mortality and mean temperature conducted for most regions of Quebec (Doyon et al., 2006) would be complete if the morbidity-climate connections were quantified and variations in hospitalization or emergency consultation rates were examined. Specific response thresholds for regions and cities could be established and modified from time to time, depending on changes in the temperature as well as death and disease. This work is planned in the framework of an Ouranos program, while some cities have already begun to adapt (Kosatsky et al., 2005a, b).

Extreme climate events

Quebec has good mechanisms for reacting to emergencies, and most existing adaptation initiatives consist of surveillance and monitoring activities, training and education, and changes to regulations and policies. In surveillance and monitoring, however, several observers (Giguère and Gosselin, 2006a) believe it is necessary to extend and strengthen the role of geographic information systems (GIS) and new technologies in the management of flood risks. Different Quebec government departments (Public Security, Health and Social Services), Public Safety Canada and organizations such as the Red Cross make guides available to the public on measures to take during different types of extreme events. The creation of Ouranos and its health section (in collaboration with Health Canada, the Ministère de la Santé et des Services sociaux du Québec and the Institut national de santé publique du Québec) fits with Quebec's strategy on adaptation to climate change (Ministère de la Sécurité publique du Québec, 2003a, b; Institut national de santé publique du Québec, 2005a, b). Management by watershed, now being developed, will provide for an ecosystem approach to water management that includes public health officials (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2004a).

On the other hand, it would be desirable to develop and encourage a number of other initiatives for adapting to extreme climate events (Giguère and Gosselin, 2006a), in particular:

- enhanced preventive planning associated with extreme climate events;
- the modelling and communication of risks tied to different types of extreme climate events, in the short, medium and long terms, in order to develop adequate initiatives; and
- research on the impact of extreme climate events on health in the short and long terms, as well as improvement of emergency health measures.

The Ministère de la Santé et des Services sociaux (Gouvernement du Québec, 2006a) announced its intention to establish, by 2011, a system for surveillance and epidemiological tracking of the consequences of extreme climate events.

Air pollution

According to Garneau et al. (2006), critical pollen thresholds must be determined and warning notices issued when the thresholds are exceeded. Control methods should also continue against *Ambrosia* spp., the pollen associated with the largest percentage of allergy symptoms, and the main parties should be made to strengthen their responses. The Quebec Ragweed Board (Table québécoise sur l'herbe à poux) was set up in 1999 for this purpose and continues to support the actions in the field of municipal, private and non-government partners to control this risk (Agence de la Santé et des Services sociaux de la Montérégie, 2007). Different public health notices aimed at reducing urban sprawl and automobile traffic have been issued in recent years (Direction de santé publique de Quebec, 2004; King et al., 2005), but with no measurable impact to date. The Info-smog program is now available for all of southern Quebec, all year long (Ministère de la Santé et des Services sociaux, 2006b), but its impact on behaviour seems minor up to now (Bélanger et al., 2006; Tardif et al., 2006).

Adaptation strategies related to preserving air quality generally focus on promoting the purchase of smaller, more fuel efficient vehicles, travel by bicycle or on foot, or the promotion of public transit, for which the Government of Quebec (Gouvernement du Québec 2006b) is encouraging an annual increase in ridership of 8% by 2012.

Quantity and quality of water resources

In the context of climate change, several major adaptation initiatives related to the quantity and quality of Quebec water resources are already established, or will be by 2007 (Giguère and

Gosselin, 2006c). Programs to monitor surface water quality will contribute to safe aquatic activities, but only at some sites. The Règlement sur la qualité de l'eau potable (Regulation Respecting the Quality of Drinking Water) requires that employees who supervise and control drinking water quality or are responsible for maintaining wastewater treatment plants be adequately trained. Research and development programs on methods for treating drinking water have been underway for several years in many Quebec universities. The new Quebec regulation (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2005b) on water quality prescribes strict surveillance using standards that are among the highest in North America. However, it provides no standard for cyanotoxins, toxic to humans, which may spread at a faster pace under warmer climate conditions. Research is also underway on the links between climate, health and water quality. According to Charron et al. (2005), water- or food-borne diseases represent the most important health problem of the planet. The Centre for Infectious Disease Prevention and Control of the Public Health Agency of Canada, in collaboration with the Institut de santé publique du Québec, is currently conducting a study on health-related aspects (ecosystems, population, society, individual) in order to define the vulnerability of Canadians to water- and food-borne diseases arising from climate change, including those in rural Quebec. The Quebec government's 2006 to 2012 Action Plan (Gouvernement du Québec, 2006a) calls for an improvement in methods for detecting epidemics and infectious disease based on climate variables.

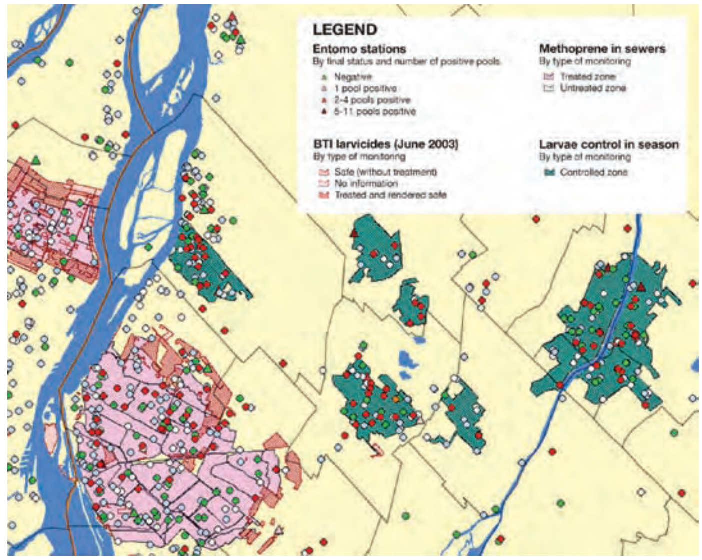

FIGURE 25: Example of thematic map from the real-time monitoring system of the Institut national de santé publique du Québec (Système intégré des données de vigie sanitaire – Virus du Nil occidental or SIDVS-VNO). It shows different preventive insecticide treatments (darkened zones) against larvae of the vector mosquito for the West Nile virus on the south shore of Montréal, in 2003 (*see* Gosselin et al., 2005).

Zoonotic and vector-borne diseases

In Quebec, most initiatives related to climate change adaptation seem to focus on zoonotic and vector-borne diseases, although risks seem low here compared to other socioeconomic sectors. The Institut de santé publique du Québec co-ordinates activities on early detection, real-time monitoring (Figure 25) and research on the West Nile virus (Bouden et al., 2005; Gosselin et al., 2005a; Institut de santé publique du Québec, 2005a, b). The Quebec government makes information documents available to the public on zoonotic and vector-borne diseases, as well as on ways to protect oneself. The Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2006) has invested large amounts of funding into research to better monitor and combat these diseases.

In addition, some experts (Giguère and Gosselin, 2006b) have suggested developing and implementing initiatives such as integrating climate change impact indicators into the monitoring of zoonotic and vector-borne diseases; and intensifying research on methods to control these diseases.

Heat waves and urban heat island effect

In 2006, seven out of eight regions had an emergency response plan for a heat wave, as required by the Ministère de la Santé et des Services sociaux (Ministère de la Santé et des Services sociaux, 2006a). These emergency plans, involving early warning systems and mobilization, are based on a threshold established by an analysis of health and weather data collected over the past 20 years. Some include monitoring of deaths in a crisis situation. The Direction de la santé publique de Montréal has developed expertise in this field since 2004, but the emergency plans have not yet been tested in an actual situation of a prolonged heat wave, although a simulation exercise was carried out for the Island of Montréal (Health Canada, 2005), leading to some improvements in the emergency plans. Other simulation exercises also revealed several shortcomings (Health Canada, 2004). Other initiatives dealing with the risk of oppressive heat were implemented to inform the public and the most vulnerable groups (Ministère de la Santé et des Services sociaux, 2006c), specifically the elderly and their attendants as well as certain groups of workers. A similar approach was undertaken with health establishments, agencies (e.g. Commission de la santé et de la sécurité au travail, Réseau public québécois de la santé au travail) and organizations (e.g. medical clinics, pharmacies, Association des locataires des habitations à loyer modique). Initiatives aimed at workers were developed, particularly in the Chaudière-Appalaches region and mainly related to the dissemination of information. In addition, research projects on heat waves and urban heat island effects (UHIE) are presently planned or have been undertaken by Ouranos (2006).

According to Bélanger et al. (2006), adaptation strategies related to heat waves should be geared to monitoring, research, information dissemination and assistance programs. Research would determine what services vulnerable people need to ensure their security during these heat episodes. The key findings should be conveyed to community organizations and front-line workers assigned to civil security.

The study by Vescovi et al. (2005) made it possible to map zones presenting risks for climate warming. An Internet atlas project dealing with certain public health vulnerabilities is being developed on a Quebec-wide scale (Gosselin, 2005) and in more detail for the Island of Montréal (Kosatsky et al., 2005b).

To combat the UHIE, the use of green roofs or roofs built with high-albedo materials is attracting growing interest, as is the use and availability of public transit in certain regions (Ducas, 2004; Ville de Montréal, 2005). Certain regional public health administrations are starting to promote these approaches in urban settings.

However, certain supplementary initiatives could be implemented (Giguère and Gosselin, 2006d), such as:

- training health professionals;
- establishing pilot projects for mass education on the subject of personal protection in case of heat waves and to help combat the UHIE; and
- adding economic incentives that encourage initiatives to mitigate the phenomenon of intense heat.

The Quebec government's 2006 to 2012 action plan calls for promoting islands of coolness and training personnel in practices adapted to climate change over the next few years, under the supervision of the Ministère de la Santé et des Services sociaux.

Ultraviolet rays (UV)

In Quebec, climate change would lengthen the warm season, prompting people to spend more time outdoors and thus be increasingly exposed to ultraviolet (UV) rays (Hill et al., 1992; Diffey, 2004), an impact quantitatively more significant than that arising from the thinning of the ozone layer. The health consequences of overexposure to UV (skin cancer, cataracts, immunosuppressive effect reducing vaccine effectiveness, epidemic development) would increase (World Health Organization, 2003). However, at the Quebec scale as opposed to the Canadian scale, protection against UV rays is not yet properly taken into account (Institut de recherche en santé du Canada, 2002), despite the 80 000 new cases of skin cancer diagnosed each year in Canada. It is the most common form of cancer in the country (National Cancer Institute of Canada, 2005). Environment Canada issues a UV index that is widely available to the public, and there is a National Sun Safety Committee (Canadian Strategy for Cancer Control, 2001). Adaptation, whether through education or behaviour modification, nevertheless seems a cost-effective measure. In Australia, protecton against the effects of UV rays costs an average of US$0.08 per capita, whereas cancer treatment costs reach US$5.70 per capita (Organisation mondiale de la santé, 2003). The effect of climate change on this factor is not yet known (Institut de recherche en santé du Canada, 2002), but preventive measures aimed at creating shade for protection from the sun could prove useful (Government of Quebec, 2006a).

3.5.2. Sensitivity and adaptation of socioeconomic activity

The sensitivity of the Quebec economy to climate change shows significant differences in the quantification of impacts, associated degree of certainty and difficulty in specifying a monetary value. Impacts on the economy can be grouped into several categories:

- The first category includes impacts on infrastructure and buildings. This can mean loss of infrastructure or buildings, maintenance work, greater protection, relocation, reconstruction or redevelopment. In this regard, the Arctic region and the maritime coastline are particularly vulnerable (permafrost thawing, coastal erosion, change in precipitation).
- The second category covers impacts on economic activity that would change productivity or demand and prices. Long-term economic vulnerability depends on the importance of the sectors affected (positively or negatively) by temperature and precipitation changes. Given the importance of natural resources in its economy (Figure 26), Quebec is more sensitive than some other developed regions of the world where economy is less linked to climate. Indeed, the forest industry, agriculture and hunting and fishing represent 2% of the province's economy ($3.8 billion), and precipitation-dependent hydroelectricity production represented $7.8

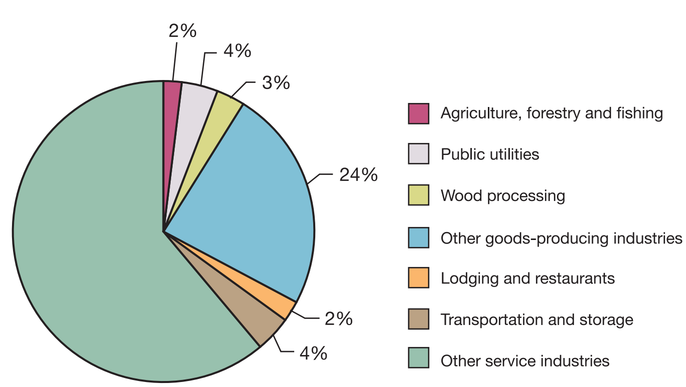

FIGURE 26: Breakdown of Quebec GDP by types of economic sector affected by climate (Ministère des Transports du Québec, 2006c).

billion in 2001. Transformation industries (agri-food, lumber, pulp and paper, metal fabrication) would be affected in terms of availability and cost of raw materials. In addition to resource-based industries, the services sector — such as tourism (restaurants and accommodation, or $4 billion and many jobs) — would likely be affected, either positively or negatively, depending on its adaptation to the changing conditions. Health and medical services would have greater needs faced with the new risks. Other sectors (highway and marine transportation, financial services and insurance) will have to adjust to greater uncertainty and higher claims. In short, a significant share of the Quebec economy would be directly or indirectly affected.

- The third category includes impacts on the security, health and well-being of populations, as well as ecosystems, following a change in both mean and extreme values of climate. However, and despite the major role they play in the economy, it is difficult to quantify the real value of these variables other than with indirect measurements.
- Finally, extreme climate events, such as flooding, ice storms, tornadoes and heat waves, represent a set of impacts on the economy that warrant being grouped, as they vary in their duration and magnitude. They affect public security, the integrity of natural ecosystems, the conduct of economic activity and numerous buildings and infrastructure, resulting in high costs (in the billions of dollars) but limited in time.

The south subregion has a diversified economy in which manufacturing and services occupy a large proportion of work production and employment. The resource and rural regions are much more dependent on just one or two activities, including logging, tourism, hunting and fishing, or agriculture. The distribution of climate change impacts would not be uniform across Quebec, and the very survival of certain communities would depend on their capacity to adapt efficiently to the new climate. Climate change is only one aspect of a world in constant evolution. Indeed, Quebec will experience sustained economic growth, doubling its production over 50 years, according to one extrapolation of current trends. Business and technological changes will affect this evolution, making it difficult to forecast the impact of climate change (Ministère des Finances du Québec, 2005).

With respect to the little-studied social dimension, it is likely that the adaptation of Quebec society will require an increased awareness of the phenomenon, such that 1) it would mean relying on an education system systematically embedded in communications aimed at young people (and their parents) on the issue of climate change; 2) this would positively influence the economic and political system, as adaptation measures require action from the public sector; and 3) the media would have an expanded role related to awareness. Media coverage would probably increase with the rising number of victims of climate change. This situation already exists and is expected to grow in importance.

3.5.3. Sensitivity and adaptation of the natural and built environments

Natural environment and ecosystems

Each ecosystem has its own biodiversity that maintains itself dynamically over time, in line with the evolution of environmental parameters (Di Castri and Younes, 1990). Biodiversity takes three forms — genetic diversity, species diversity and diversity of ecosystems (Di Castri and Younes, 1996). A population is a group of individuals of the same species that tries to maintain its numbers from generation to generation. It is the unit on which adaptation pressures are exerted. With each new generation, the individuals must adapt to a set of ecological factors and beget fertile descendants to maintain the species. Ecosystems offer a multitude of goods and services essential to human survival, as shown by certain aboriginal or rural communities that are particularly dependent on these resources (Intergovernmental Panel on Climate Change, 2002).

Climate is the principal factor acting on vegetation structure and productivity and on the global distribution of animal and plant species (Intergovernmental Panel on Climate Change, 2002). Climate change expected for Quebec will probably have locally observable effects on sensitive populations and ecosystems. For certain species, climate change will result in reduced numbers or the disappearance of populations. For others, it will be an opportunity to multiply numbers and extend their distribution range. Climate change will modify the ecological conditions specific to known ecosystems, and even landscapes in the medium and long term (McCarty, 2001; Root and Schneider, 2002; Scott et al., 2002; Walther et al., 2002). These transformations are not deterministic. Living creatures are subject to multiple pressures and climate change is but one part of the equation.

Different issues

The majority of threatened or vulnerable species and ecosystems live in the south subregion (Institut québécois d'aménagement de la forêt feuillue, 2003) and will be affected by the rise in mean temperature and change in the frequency of floods and winter mild spells (Kling et al., 2003). The impact of climate change on the Great Lakes will indirectly alter flooding and mean flows and water levels of the St. Lawrence River; the resulting geomorphological adjustment will affect numerous plant and animal species, some related to wetlands, which already feel the impact of human activity (Mortsch et al., 2000; Morin et al., 2005). The change of St. Lawrence River flows and base levels implies a morphological readjustment of tributary mouths, resulting in the incision and destabilization of beds and banks. Structures on two deltas of Lake Saint-Pierre show the result of the rapid adjustment processes accompanied by a progradation of these features into the river (Boyer et al., 2004).

Plant and animal species in the central subregion have a high resiliency and the communities are ecologically young, arising from the postglacial retreat that ended less than 10 000 years ago. These species, well-adapted to significant annual climate variations and recurring catastrophes and forming large populations distributed over an immense area, will be affected mainly in transition zones (mountainous and riparian areas).

In the maritime subregion, coastal and estuary ecosystems are most at risk from greater erosion, resulting in reduced reproduction and feeding areas for many resident or migratory species (Harvell et al., 2002; Jackson and Mandrak, 2002; Kennedy et al., 2002).

The north subregion will possibly be most affected by the scope of climate change (Flanagan et al., 2003). Ecological changes will occur to the detriment of species adapted to extreme Arctic conditions (Rizzo and Wilken, 1992; Payette et al., 2001). The northward expansion of species typical to the boreal forest will be initiated by existing trees, which produce viable seeds more easily. A certain adaptation of black spruce (*Picea mariana*) has already been noted (Gamache and Payette, 2004, 2005). However, the migration speed of isotherms will be much faster than that of plants.

River systems and lakes everywhere are particularly sensitive, given their compartmentalization with respect to the migration of fish species (Hauer et al., 1997). Phenological changes in species are also conceivable, as well as an extension of species range limited by mean or minimum temperatures (Edwards and Richardson, 2004).

Sensitivity of species

Living organisms react directly to ecological factors and survive based on their tolerance. Hence, the number of individuals in an ecosystem population is an indicator of their adaptation (Dajoz, 2000) — the higher their tolerance, the better their adaptation, as was shown for fish by Albanese et al. (2004).

An invasive species quickly expands its range in a new ecosystem, either because it is no longer limited by a previously active ecological factor or because it benefits from new conditions created by a disturbance influencing the dominant species of the environment (Bagon et al., 1996).

Phenology is the study of climate-based variations in the periodic phenomena of the plant and animal life cycle, such as dates of migration, triggering of reproductive behaviour, moult, flowering or foliage drop (Budyko, 1974). Several phenological changes have been observed in the twentieth century and this trend will accelerate (Intergovernmental Panel on Climate Change, 2002), triggered by temperature, precipitation, photoperiod or a combination of events. Visser and Both (2005) showed that most species are unable to co-ordinate changes in their phenology optimally with changes in their diet. For example, the migration date triggered by a specific photoperiod will not change with a rise in temperature, but instead based on the behaviour of prey. This absence of co-ordination risks reducing the number of migrating predators (Jones et al., 2003; Strode, 2003).

In the south subregion, species dependent on the flood regime of the St. Lawrence River, including the northern pike (*Esox lucius*) and perch (*Perca flavescens*), will be affected (Casselman, 2002; Chu et al., 2005; Brodeur et al., 2006). The approach combining multivariate habitat models with 2-D physical modelling (Morin et al., 2003; Mingelbier et al., 2004, 2005) makes it possible to measure the impact of climate change on habitat areas available to several fish species during critical periods of their life cycle. Water temperature, current speed and water level are key variables for understanding how climate change will affect fish. Already, data indicate a warming of water in certain areas (Hudon, 2004), and the atypical temperatures of summer 2001 produced a massive mortality of carp in the fluvial St. Lawrence River and its tributaries (Mingelbier et al., 2001, Monette et al., 2006). Changes in spring floods will result in a decline in breeding in both marshland birds and waterfowl of the St. Lawrence plain, which include several species at risk (Giguère et al., 2005; Lehoux et al., 2005; Desgranges et al., 2006). In the river flood plain, the muskrat is particularly sensitive to winter fluctuations in water level, and changes will profoundly affect it (Ouellet et al., 2005).

In the Arctic region, the polar bear (*Ursus maritimus*) is dependent on sea ice, while the Arctic fox (*Alopex lagopus*) has to contend with an extension in the range of the red fox (*Vulpes vulpes*), which lives off the same food resources (Hersteinsson and MacDonald, 1992; Stirling, 1999; Walther, 2002; Derocher et al., 2004).

Sensitivity of ecosystems

Aquatic ecosystems seem most sensitive to climate change since their biotic communities have difficulty moving from one watershed to another (Hauer et al., 1997). Species such as the Atlantic salmon (*Salmo salar*) will be disturbed by rising water temperatures that will reach the upper limits of their survival range (Swansberg and El-Jabi, 2001). The new temperature conditions will favour species more tolerant of high temperatures (Figure 27).

Populations of cold-water fish in the south subregion will be affected by rapid eutrophication and the arrival of sudden, potentially more frequent floods that will result in erosion of the watershed and sediment transport into lakes, a trend already reinforced by human activity such as agriculture, urbanization and logging (Shuter et al., 1998).

Increasing southern lake temperatures will lengthen thermal stratification periods, resulting in anoxic conditions in the hypolimnion during part of the year. Lake trout (*Salvelinus namaycus*) are sensitive to these two latter stresses (Hesslein et al., 2001). Changes in the flow of the St. Lawrence River will also modify the spatio-temporal distribution of water masses and the typical physical and chemical properties (Frenette et al., 2003, 2006). These changes may affect the nutritive quality of algae (Huggins et al., 2004) and their community structure. The shallower depths should result in more light near the bottom, leading to an increase in the quantity of submerged plants and changes in the properties of dissolved organic matter and particles in the water (Martin et al., 2005a).

Wetlands in all subregions are sensitive to climate change due to the greater variation in annual or inter-annual flood and low water levels associated with violent precipitation or droughts. Turgeon et al. (2005) showed that there exist fundamental links between hydrology and the spatial distribution of major classes of wetlands. Many wildlife species using wetlands will be disturbed, an important issue for the St. Lawrence ecosystem and the marshes of Lake Saint-Pierre (Hudon et al., 2005). Other pressures will also be exerted here, including agriculture and industrial and urban development (Bernier et al., 1998; Robichaud and Drolet, 1998; Jean et al., 2002; Ouranos, 2004), resulting in a fragmentation of habitats (Root and Schneider, 2002).

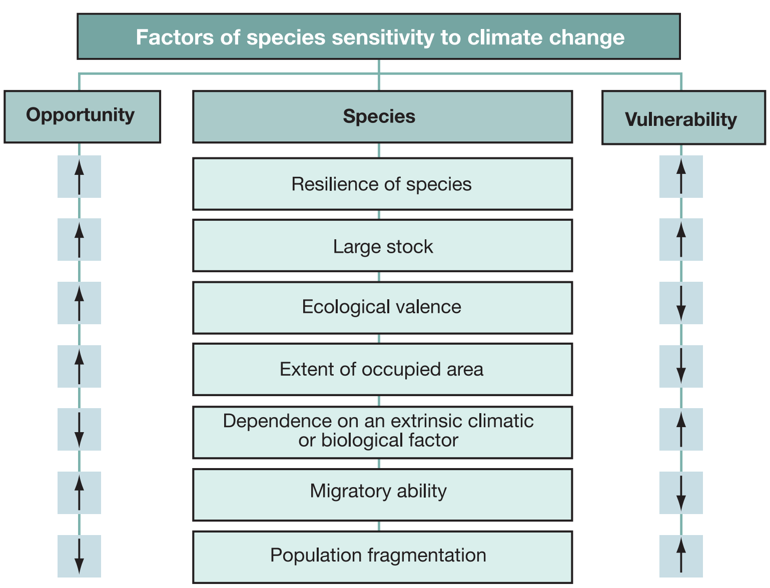

FIGURE 27: Factors of species sensitivity to climate change. Climate change should not result in the disappearance of many species in Quebec, but rather in changes to distribution ranges. However, certain populations will probably disappear in the most sensitive ecosystems because of the appearance of new limiting factors (Root and Schneider, 2002) or a combination of man-made factors degrading their environment.

The forest ecosystems of the central subregion should not experience major changes in their species composition. On the other hand, forest fire frequency and human activity can encourage certain plant associations locally by hastening the process of making forested land available (Gagnon, 1998; Payette, 1999; Coté and Gagnon, 2002; Jasinski and Payette, 2005).

Adaptation strategies

Several actions could be taken to adapt to climate change and reduce the impact on biodiversity:

- **Ecosystem resilience:** Increasing connectivity and reducing fragmentation between ecosystems seem to be effective pathways for maintaining genetic heterogeneity.
- **Monitoring sensitive species:** Quebec's biodiversity strategy encouraged each department to establish an action plan and present regular progress reports to the Ministère du Développement durable, de l'Environnement et des Parcs du Québec (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2004b). However, as noted by Gérardin et al. (2002), information on plants and wildlife is incomplete, particularly on the subject of unforested areas (e.g. unproductive forest land, wetlands, subarctic and alpine plants), which can undermine the government authorities' capacity to monitor species sensitive to climate change.
- **Strategy for protected areas:** Protected areas, in which some or all human activities are prohibited, serve to ensure the preservation of natural areas or ecosystems that are representative or rare (Figure 28). In contrast to the past, the current approach (Protected Areas Strategy) to selecting new protected areas underlies "a holistic approach of the territory, where the ecosystem is considered as a spatial entity and where the concept of coarse filter appears" (Gérardin et al., 2002, [translation]). However, this method, which places a predominant value on the physical elements of the ecosystem — climate, geology, topography, hydrology, soils — risks weakening the future network of protected areas and its role in protecting species and ecosystems, since the climate and hydrology are destined to change in the medium term. At the national level, Parks Canada developed a strategy that considers climate change in its approach to biodiversity management in existing parks (Wrona et al., 2005). At the municipal and private levels, such mechanisms do not seem to exist. Protected areas could usefully be considered as control areas for natural regions and their evolution, and their management could take future climate change into account. Therefore, in promoting adaptation, it would be advisable to:
    - complete the network of protected areas as soon as possible in order to conserve areas representative of each natural region; and
    - promote the scientific management of protected areas using inventory, research and monitoring programs to

track changes in species and ecosystems under climate change conditions, while maintaining comparison points with adjacent areas.

- **Change of harvest rules for live resources:** Changes observed in the numbers of certain animals sought by sport and commercial hunters and fishermen will require closer monitoring to avoid additional pressures on fragile species or to slow the expansion of certain species into areas where they were historically absent, thus putting previously resident species in danger.
- **Integration of climate change in land management:** Génot and Barbault (2005) presented a strategy that describes in detail the issue of preserving biodiversity in a context of climate change. It calls for extending responsibility for monitoring and managing biodiversity to land managers, who could then better understand the issue and better adapt their practices to promote the adaptation of species to the new conditions.

Conclusion: Quebec's changing natural environment

The importance of climate to living organisms needs no further demonstration. Climate change will not result in direct and continuous changes in the composition of ecosystems and the range of species. Instead, its effects will combine with other factors to cause environmental degradation at the local and regional scales. Adapting to climate change will require efforts to reduce the stress imposed on ecosystems. Above all, it will be necessary to develop knowledge about, and monitor, species and ecosystems that are most likely to be vulnerable, in order to adjust management methods to this new reality.

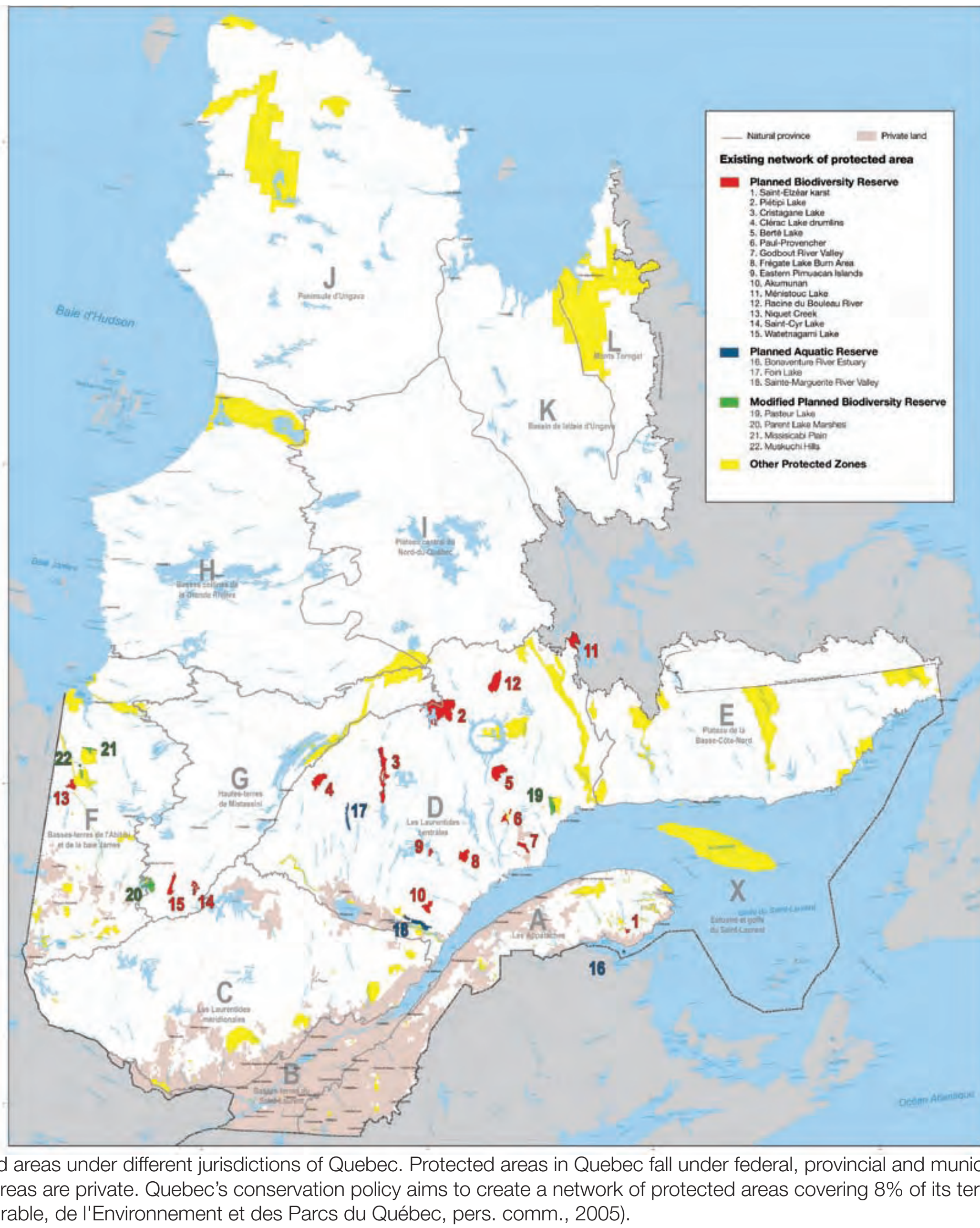

FIGURE 28: Protected areas under different jurisdictions of Quebec. Protected areas in Quebec fall under federal, provincial and municipal jurisdiction, and some protected areas are private. Quebec's conservation policy aims to create a network of protected areas covering 8% of its territory (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, pers. comm., 2005).

Built environment

The preceding sections dealt with several aspects of the vulnerability of climate-sensitive infrastructure and buildings. The evidence is clear that the vast majority of infrastructure sensitive to climate and built in the last century was designed using statistics on past climate and risks, considered at the time to be representative of future climate conditions. This criterion is questioned throughout this document, raising questions about the security and performance of this infrastructure, particularly in the long term. Fortunately, users and engineers are increasingly aware of this problem (Engineering Institute of Canada, 2006) and adaptive capacity seems to be growing (Infrastructure Canada, 2006). Nevertheless, there will continue to be considerable need for new infrastructure related to socioeconomic development as well as for the refurbishment of a variety of aging infrastructure (Statistics Canada, 2006).

In the long term, the direct and gradual impacts of climate change (*see* Figure 1) will result in faster wear or loss of performance of different types of infrastructure and buildings. An increase in freeze-thaw cycles tends to accelerate degradation of infrastructure that receives large quantities of abrasives. Road surfaces would buckle more under higher summer temperatures, while poorly adapted buildings would make indoor temperatures risky for vulnerable people. In Quebec, building damage has sometimes been observed when clay soils dry out (Canada Mortgage and Housing Corporation, 1996) following hot and dry summers. In addition, any change in the frequency, duration, intensity and even range of extreme weather events would have significant impact on the vulnerability of the built environment, particularly as such events, depending on the type, have a tendency to involve the hydrosphere (e.g. floods), cryosphere (e.g. ice jam) or lithosphere (e.g. landslide). In fact, there is no shortage of examples in Quebec where low-probability climate events presenting a risk actually happened, affecting the built environment as well as socioeconomic activity, populations and even the natural environment. For example, failing infrastructure contributed significantly to the socioeconomic and environmental impacts of the Saguenay flood in 1996 (Ministère de la Sécurité publique du Québec, 1996). Damage to the built environment can be caused by a multitude of other failures related to destructive waves, storm surges or tides following the passage of storms (*see* Section 3.3); landslides caused by heavy saturation or destabilization of the soil (Lebuis et al., 1983); avalanches (Public Security Canada, 2006); excessive precipitation in solid form (Ministère de la Sécurité publique du Québec, 1999); or even forest fires.

Adaptation of infrastructure and buildings

Such events, as well as those expected in the future, tend to prompt officials to review their operating methods in order to reduce vulnerability (*see* Table 7). These officials have thus started to:

- revise design criteria and technologies used;
- establish improved emergency measures;
- set up communications networks, while ensuring information circulation and knowledge transfer;
- re-examine land-use planning policies and regulations; and
- develop preventive warning systems.

Despite this experience and learning, planned adaptation to minimize the impact of climate change remains rare. Although studies on this subject are few, it would be beneficial to consider various available climate scenarios when designing infrastructure, since infrastructure, once built, has little adaptability and often has a long life cycle. This was done for Confederation Bridge (Canadian Environmental Assessment Agency, 2000). As for highways, which have a shorter life, it is easier to introduce lower cost adaptation solutions as and when they are repaired. For critical infrastructure related to essential services (energy, water, food, health services), it is essential to minimize its vulnerability and introduce mitigating measures in case of failure. This latter consideration may be difficult to achieve at reasonable cost for remote regions.

In fact, adaptation measures can be implemented or introduced at different stages in the life cycle of infrastructure (Figure 29). An analysis of climate risks would support the decision to build or restore critical infrastructure far from a coastal site. It would promote the use of better adapted construction materials, suggest a revision of building criteria and refocus maintenance programs on anticipated problems. These are the types of decisions currently made by engineers to resolve or minimize a problem.

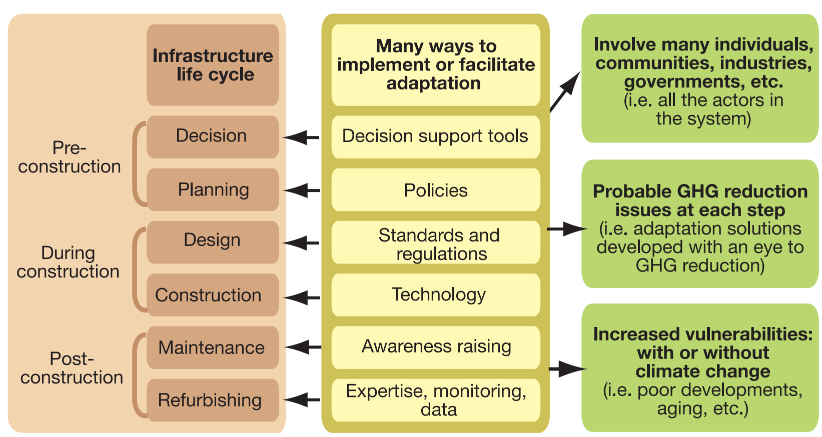

FIGURE 29: Various types of adaptation solutions related to infrastructure life cycle. A detailed analysis of acceptable risk compared to cost-benefits would make it possible to develop a strategy designed to minimize risk and maximize performance; it could also make it possible to implement other strategies meant to reduce GHG emissions responsible for climate change (Gosselin et al., 2005).

TABLE 7: Examples of applied or experimental decisions (grouped by type) promoting adaptation to climate change for various communities and sectors (developed for this study). The numbers match references given on pages 217-218.

	Develop and understand Acquire information and develop expertise	Communicate and raise awareness Increase awareness and modify behaviour	Respond and legislate Amend laws, regulations and standards	Apply new or existing technologies Use techniques, products and materials	Apply/recommend guidelines or ways of doing things Adjust practices and policies
COMMUNITIES					
Isolated	Map sensitive zones for the development of infrastructure (1)	Disseminate information on transportation system conditions (2)	Establish land-use planning standards based on sensitive zones (2-3)	Apply techniques to reduce permafrost thawing (4)	Produce a best practices guide for building on permafrost (46)
Dependent on natural resources	Identify the best sources of seeds/genotypes (6)	Inform communities on fire risks using the forest fire-weather index (7)	Regulate fishing (opening and closing dates, places, etc.) (8)	Manage fishing by habitat to ensure the viability of resources (8)	Establish a program for economic diversification of communities at risk (9)
Coastal	Creation of an integrated scientific project acting in coordination with other participating agencies to meet needs of coastal regions (10)	Hold a simulation exercise to help prepare citizens, municipalities, governments and other actors (11)	Regulate construction in flood-prone areas, zoning and temporary control regulations (12)	Monitor protection structures (13)	Establish integrated management of coastal areas (14)
Rural	Learn about varieties used farther to the south (analogs) and adapted to the region (5)	Increase public awareness about saving water during droughts (16)	Establish a program of income stabilization, private insurance and incentives to take climate change into consideration (17)	Extend drip irrigation and the combined technologies of surface drainage and flow (18)	Install effective ventilation systems or sprinklers to cool livestock (19)
Urban	Identify lands favourable to allergens and map sources of allergenic emissions (20)	Give information on municipal emergency measures (21-22)	Regulate resistance standards in construction (23) and the Building Code concerning energy (24)	Extend the use of reflective surfaces and coverings (roofs, facade paints, etc.) (25)	Set up local heat-health-heat wave systems (26)
SECTORS					
Health	Analyze the link between morbidity-mortality and climate (27-28)	Increase public awareness about smog and heat waves and give advice (29)	Take preventive measures to limit polluting emissions (at the start of the anticyclone) (30)	Launch campaigns to pull up ragweed and plant competing species (20)	Use green roofs or high-albedo materials (12-25). Establish care guides adapted for home care clienteles during extreme events
Infrastructure	Analyze aerial photos of the coastline over time and calculate the erosion rate (12)	Set up forecast and early warning systems systems and public education systems (23)	Provincial Civil Protection Act adopted in 2001 following the ice storm crisis of 1998 (31)	Design more resistant buildings (12) or better adapted to the new means (32)	Add 1 m to the Confederation Bridge due to the anticipated rise in sea level (38)
Primary sector of the economy	Develop biological methods to control propagation (6)	Increase awareness about harvest and field management adapted to present and anticipated climate conditions (15)	Amend the Forest Act to remove the outdated concept of sustained volume yield (34)	Use species and varieties adapted to different climate conditions (10)	Anticipate by building up one's own financial reserve (35)
Tertiary sector of the economy	Economic assessment tools (39-36)	Diversify recreational tourism choices to minimize climate risk (37)	Insure against losses due to bad weather and climate by-products (22)	Establish emergency, response and evacuation plans (15)	Raise the design criteria for bridges and culverts by 10% (civil engineering, MTQ) (38)
Water	Update the IDF curves (40,41)	Communicate practices to manage rainwater recovery (24)	Implement international agreement on the Great Lakes basin water resources (48)	Rehabilitate degraded resources (22)	Test and review management rules based on various possible climate scenarios (42)
Ecosystems	Map ecological niches and assess the changes (43)	Symposium at popular science events (44)	Maintain representative regional plants and wildlife (protected areas) (45)	Restore and preserve wetlands (46)	Protection of species and habitats (47)

The impact of changing climate-related risks to the built environment requires that 1) better climate scenarios and better impact scenarios be developed (for both the natural and built environment); 2) climate uncertainty be considered in risk analysis at the infrastructure design stage; and 3) new risk tolerance thresholds be integrated, subject to change depending on the needs.

Adaptation under a stationary climate is a known field of expertise sprinkled with success stories, but adaptation under a new, highly variable and uncertain climate is a recent field of expertise for which success stories are yet to come, though likely achievable. Moreover, pertinent adaptation solutions for municipal engineers (e.g. surface retention pond for urban drainage) can become major problems for other factors affected by climate change (e.g. increased breeding of mosquitoes, which can spread the West Nile virus).

4 SUMMARY AND CONCLUSION

The influence of weather conditions and climate is vast. Impacts that are generally poorly documented appear gradually and subtly at the pace of changing mean values or variability statistics. Until now, these changes have generally followed global trends anticipated by the Intergovernmental Panel on Climate Change and presented in their assessment reports. The impacts of extreme events are remarkable because of their scale, suddenness and spectacular nature, but it is difficult to tie them directly and exclusively to climate change because they are, by definition, rare events. Globally, the scope of climate change, including some extreme events for which an increase in frequency, intensity and duration is predicted, is expected to have an increasingly significant and perceptible impact on the public, the natural and built environment, and socioeconomic activity. Given the anticipated scope of climate change, natural and human system reaction (adaptation) will be able to adjust and even transform impacts that are sometimes negative, other times positive. Despite the many remaining uncertainties and the complexity of direct and indirect impacts occurring in parallel with other changes that affect vulnerability, the following qualitative observations emerge from this summary:

- For the public, the impact of climate change — particularly indirect impacts through reactions of the natural and built environment — would result in heightened risk to health, security and well-being. The application of adaptation measures, mainly preventive and prioritized for populations now or soon to be at risk, would minimize the scope of negative impacts, including oppressive heat, increased pollution, poorer water quality, exposure to ultraviolet rays, zoonotic diseases and events causing injury and death. These measures include actions to alter risk-creating behaviour, assist vulnerable groups and strive to reduce climatic risk in land-use planning.
- In the natural environment, the lithosphere, hydrosphere, cryosphere and biosphere would experience gradual transformations corresponding to long-term trends, with occasionally more perceptible displays related to changes in the frequency, intensity and duration of extreme or threshold events. Landscapes would, of course, be reshaped under the influence of climate change, as would the hydrology and geomorphology of streams and the distribution and relative abundance of plants and wildlife. Various regional impacts would trigger spontaneous and complex adaptation reactions. Of more serious concern than the northward movement of ecosystems, many threatened species and rare ecosystems would be at risk of disappearing, particularly in areas of intense human activity, but the effects of these changes would be positive or negative depending on the subregion, uses or interests, and according to perceptions. With respect to forest resources, it is difficult to predict the changes that will occur, given that both positive (e.g. CO_2 level and higher temperatures, longer growing season) and negative impacts (e.g.insects and pathogens, extreme weather events) are anticipated.
- The built environment does not adapt spontaneously. For example, engineering practices that have been based on the assumption that climate has been historically stable should be revised in light of new and changing climate data. Although changes in means can result in accelerated wear or loss of performance of infrastructure, several types of infrastructure are known to be particularly sensitive to increases in the frequency of extreme events. Adaptation strategies applied on a priority basis to critical infrastructure or infrastructure with favourable cost-benefit analyses (costs of adaptation solutions versus life cycle of infrastructure) would make it possible to limit the magnitude of anticipated impacts. In a context of widespread aging of infrastructure contributing to a potential

rise of vulnerability in Quebec, it will be crucial to invest in the refurbishment or replacement of infrastructure and in new projects in order to reduce climate risks in a preventive way, rather than react after events with significant direct and indirect impacts.

- Of all the anticipated impacts, those that affect socioeconomic activity remain the most difficult to identify. In fact, they depend on still poorly quantified biophysical impacts and complex reactions, such as market mechanisms, perceptions and technological development. Certain activities would benefit from gradual changes of low amplitude, whereas others would be disadvantaged by more dramatic, unpredicted changes or, also, by an increase in the number of extreme weather events. The economic impacts are starting to be estimated, but social impacts in the medium and long terms are more speculative, if not unknown. Although many economic gains and economic development opportunities worth an estimated several hundred million dollars per year could stem from climate change in Quebec, feared economic losses and risks are much more difficult to estimate and go far beyond uniquely economic consequences. Nevertheless, the socioeconomic capacity of Quebec to adapt to climate change, especially gradual change, is high relative to less robust and less diversified economies. The challenge lies in structuring efforts to identify the challenges and implement sustainable solutions in a complex sociopolitical system. The capacity to manage the change — like the opportunities to be seized — will tend to lessen the magnitude of impacts.
- The north subregion should undergo the most significant climate change in absolute terms. It will contribute to the complexity of the issues the subregion is currently facing, which are associated, among other things, with the high exposure of communities to natural risks, to their dependence on critical infrastructure, their access to resources and their traditional way of life, which is closely related to maintaining the current natural environment. It will therefore be necessary to manage the impacts of permafrost thawing, changes in the snow and ice regime, and the transformation of the biosphere, particularly the increased risks to species that are dependent on sea ice, at the same time as high population growth, the many issues related to development, and major socioeconomic changes. Development opportunities associated with navigation, energy production and the mining sector in warmer winter conditions, and diversification of plant and animal life, are possible. Although efforts are being made to minimize the costs of impacts and adaptation, the issues are associated primarily with security, health and well-being of the vulnerable populations due to their isolation. Climate change should be considered in environmental impact studies pertaining to new development projects.
- The vast, resource-filled central subregion could see its environment transformed and its economic sectors increase their productivity (e.g. hydroelectricity production due to higher annual inflows and forest productivity due to faster growth resulting from warmer climatic conditions). However, this scenario remains uncertain for several reasons, including limited historical observations and inconsistent recent trends, lack of understanding of the phenology of species and regional hydrology, assessment tools under development, higher risk related to poorly understood extreme weather events, uncertainty of climate scenarios and, finally, the impacts on the price of resources on continental markets. In addition, given the limited literature available on this sparsely populated subregion, it is likely that many environmental and social impacts that may be considered undesirable are completely unknown at this time.
- The maritime subregion is strongly exposed to climate vagaries and the hydrosphere. Its communities are coastal and partially isolated, and present a marked socioeconomic vulnerability emphasized over the last decade by the collapse of the fishing and forest industries. Moreover, already-occurring coastal erosion will accelerate, increasing the vulnerability of infrastructure, the built environment, or even tourist attractions. Integrated management, including good planning and sustained and early development, appears to be the best adaptation strategy for limiting impacts. One of the great challenges in the coming decades is, beyond question, impact management and prevention in regions of growing risk.
- The south subregion could profit from greater crop productivity if problems of water availability and climate variability are limited. In addition, one effect of an increase in temperature will be a reduction in annual energy consumption. In contrast, whether in rural or urban areas, the built environment will not be optimized as a function of the anticipated climate. Therefore, this subregion, which is characterized by a growing population and increasing population density, the complex interdependence of infrastructure, a shift of its economy towards the service sector associated with changes in international markets, a changing social fabric and a population that is increasingly desensitized to climate conditions, brings together numerous factors that can generate many complex and sometimes costly impacts, related especially to an increase in the frequency, intensity or duration of extreme weather events. The anticipated changes in the water cycle and impacts on water's many uses would help keep sustainability of the resource and public security from floods on the agenda. Finally, an array of indirect impacts often poorly documented and combining with events not connected to climate change, will affect regional biodiversity and public health, security and well-being, the price of seasonal goods and services, immigration, tourism and recreation. Risks should be reduced by applying solutions as diverse as integrating the idea of adaptation to climate change into legislation, building standards and organizational policies, and making efforts to enhance public awareness of climate change. Although planning that integrates the anticipation of impacts can contribute to

adaptation, a variety of information, tools and policies will also make society more resilient to climate change.

Clearly, adaptation solutions add to the efforts made to reduce greenhouse gas emissions in the context of the challenges posed by climate change. For hundreds of years, human systems have tended to react to the impacts of the natural variability of the climate system in such a way as to reduce their exposure to climate and increase their adaptive capacity and resilience. With respect to initiatives designed to address future climate unknowns, Table 7 briefly presents a variety of adaptation strategies that already exist or are under study, applied and applicable both to communities and to socioeconomic activities. The table illustrates that human systems will adapt in different ways to minimize or address adverse impacts, or to optimize development opportunities. The table shows that adaptation involves many actors (individuals, communities, industries, provincial, federal and international authorities), that response time varies in length (short-term decision and long-term planning) and that the strategies target different obstacles to adaptation. These strategies can be grouped into five categories:

- **develop and understand** refers to information acquisition;
- **communicate and increase awareness** is related to aspects affecting awareness and behaviour modification
- **respond and legislate** refers to amendments to laws, regulations and standards;
- **apply new or existing technology** refers to the use of techniques, products and materials;
- **apply and recommend guidelines or ways of doing things** gives examples of adjustments to internal practices and policies.

The table therefore gives a brief portrait of what could become more general in future.

The challenges that Quebec must meet, along with all inhabitants of the planet, are immense and coloured with uncertainty. As set out in Chapter 10, there are many requirements for meeting the challenge of climate change. They include 1) more relevant and higher-quality data for understanding; 2) better monitoring and warning systems for preparing; 3) greater interaction between scientists and political and operational players in the field of adaptation to maximize technology transfer; 4) leadership and open-mindedness of all society to identify and prioritize the right problems and know how to question oneself at the right time and in the right way; and 5) growing multidisciplinarity and interdisciplinarity while pursuing research in various specialized climate-science related fields, other biophysical sciences, economics, social sciences and health sciences.

Finally, the perceptions and behaviours, the processes and factors leading to decision-making, and the goals and convictions of individuals and communities appear fundamental to the adaptation of human systems because it is humans who will, in the end, make the right or wrong decisions influencing the future.

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5 ACKNOWLEDGEMENTS

This Report is the product of the work of many scientists who acted as collaborators or revisers. We would like to express our sincere thanks to them for their contribution, and to their institutions for supporting their participation.

We also thank Steve Arsenault, Louis Belzile, Guy Bergeron, Denis Demers, Michel Michaud. Roxanne Fraser, Gilles Grondin, Anick Guimond and Kathy Rouleau from the Ministère des Transports du Québec, Michel Campagna and Marc Mingelbier from the Ministère des Ressources naturelles et de la Faune du Québec, Jean-François Cyr from the Centre d'études hydriques du Québec, Monique Plamondon from the Ministère du Développement durable, de l'Environnement et des Parcs du Québec. We thank Louis Théberge from the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, and Jean-Philippe Détolle from the Ministère du Développement économique, de l'Innovation et de l'Exportation du Québec, Anne Debrabandere et Caroline Larrivée from Ouranos, Denis Isabel from SNC Lavalin Inc. and Hervé Logé from the Ville de Montréal. Finally, we wish to acknowledge the contribution of Jean Morin from Environment Canada, Jean Paquette from Natural Resources Canada, Jean-Pierre Trudeau from the Ordre des ingénieurs du Québec and Liette Vasseur from Laurentian University.

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ONTARIO

CHAPTER 6
Ontario

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Recommended Citation:

Chiotti, Q. and Lavender, B. (2008): Ontario; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 227-274.

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CONTENTS

KEY FINDINGS

The social, economic and cultural health of Ontario is influenced by climate. Vulnerability to climate variability and change is demonstrated by the impacts of recent severe weather events, such as drought, intense rainfall, ice and windstorms, and heat waves. Those impacts include water shortages, lower Great Lakes water levels, flooding, forest fires, reduced agricultural production, damages to infrastructure and property, power outages and outbreaks of water-borne diseases.

Since 1948, average annual temperatures in Ontario have increased by as much as 1.4°C. This trend is projected to continue, with the most pronounced temperature increases occurring in winter. Projections also indicate that intense rainfall events, heat waves and smog episodes are likely to become more frequent.

Physical infrastructure, water quality and supply, human health and well-being, remote and resource-based communities, and ecosystems are highly sensitive to climate. The degree to which the associated systems are vulnerable depends on their ability to successfully adapt to changes in both climatic and non-climatic stresses.

Disruptions to critical infrastructure, including water treatment and distribution systems, energy generation and transmission, and transportation have occurred in all parts of the province, and are likely to become increasingly frequent in the future. In recent years, flooding associated with severe weather has disrupted transportation and communication lines, with damage costs exceeding $500 million. Lengthy and extensive power outages have resulted from the failure of transmission grids and distribution lines. Projected decreases in Great Lakes water levels may compromise shipping and reduce hydroelectricity output by more than 1100 megawatts.

Water shortages have been documented in southern regions of the province, and are projected to become more frequent as summer temperatures and evaporation rates increase. Sections of Durham County, Waterloo and Wellington Counties, and the shoreline of southern Georgian Bay, where growth strategies indicate that the population will continue to increase significantly, will become more vulnerable to shortages within the next 20 years.

The health of Ontario residents has been at risk of illness, injury and premature death from such climate-related events as extreme weather, heat waves, smog episodes and ecological changes that support the spread of vector-borne diseases. Heat-related mortality could more than double in southern and central Ontario by the 2050s, while air pollution mortality could increase about 15 to 25% during the same interval. Extreme heavy precipitation events, such as the one in May 2000 that contributed to the *E. coli* outbreak in Walkerton, Ontario, which killed 7 people and made 2300 ill, are projected to increase. Adaptation, in the form of smog alert advisory systems, is now commonplace, and some cities have recently introduced heat-health alert systems.

Remote and resource-based communities have been severely affected by drought, ice-jam flooding, forest fires and warmer winter temperatures, which have caused repeated evacuations, disrupted vital transportation links and stressed forestry-based economies. Projected increases in winter temperatures will further reduce the viable operating season of winter roads, limiting access for the delivery of construction materials, food and fuel to many communities and mine sites in the far north. Increased frequency of forest fires and outbreaks of forest pests will adversely impact the health and economic base of communities dependent on the forest industry, particularly in the far northern parts of Ontario's boreal forest.

Ontario's ecosystems are currently stressed by the combined influence of changing climate, human activities and such natural disturbances as fire and outbreaks of insects and disease. Wetlands are particularly sensitive and have undergone dramatic declines in recent years, especially in southern Ontario. Observed changes in the relative abundance of fish species in southern Ontario show a shift from cold- and cool-water species to more warm-water species. Changes in the composition of aquatic and terrestrial ecosystems in the Hudson Bay region, and reduced numbers and health of polar bears and seals, are other examples of current impacts. Lower water levels in the Great Lakes, as projected for the future, will further compromise the wetlands that presently maintain shoreline integrity, reduce erosion, filter contaminants, absorb excess storm water, and provide important habitat for fish and wildlife. Invasive species in the Great Lakes are likely to increase, requiring modification to infrastructure and/or management activities.

Ontario has a strong capacity to adapt to climate change, based on a variety of indicators, such as economic wealth, technology, information and skills, infrastructure, institutions, social capital and equity. However, this capacity is not uniform across subregions and sectors. Adaptation is starting to occur in Ontario. For example, climate change has been incorporated into some long-term planning and decision-making, most notably by some conservation authorities (e.g. for storm-water management) and public health departments (e.g. with heat-health alert systems). Opportunities exist for mainstreaming adaptation to climate change into decision-making through, for example, the Clean Water Act, and other legislation, regulations or planned activities that relate to, among other things, infrastructure renewal programs, low-water response programs and growth strategies.

1 INTRODUCTION

The social, economic, environmental and cultural health of Ontario has been shaped largely by the region's geography, its natural resources and its climate. Although most activities in the province are relatively well adapted to current climate conditions, extreme climate events can bring about considerable damage. Climate warming is, and will continue to be, manifested in changes to both average and extreme climate conditions in Ontario. Such recent climate events as drought, flooding, heat waves and warmer winters have resulted in a wide range of impacts in Ontario, including water shortages, forest fires, lower Great Lakes water levels, declines in agricultural production, power outages and outbreaks of water-borne diseases. These impacts have had substantial economic and social costs, raising questions about Ontario's vulnerability to future climate change. The impacts of greatest current concern, both at present and in the future, differ within the various subregions of the province.

The degree to which Ontario will be affected by climate change is strongly influenced by its adaptive capacity. The most commonly used indicators of adaptive capacity are: economic resources; availability of, and access to, technology, information and skills; and the degree of preparedness of its infrastructure and institutions (Smit et al., 2001; *see* Chapter 2). Based on these factors alone, it can be inferred that the potential for Ontario to adapt effectively to climate change is high. Whether that potential is realized will depend on individuals, industry, communities, institutions and government incorporating climate change, along with all other important factors, into their decision-making. However, there are significant differences in adaptive capacity between all subregions and sectors. It also is possible that some changes in climate may occur too rapidly for ecosystems, social systems and industry to adapt effectively. Unless adaptation planning decisions are well informed by an improved understanding of both current vulnerabilities and the magnitude and timing of future change, the potential exists for insufficient action or for maladaptation (actions that inadvertently increase vulnerability to climate change).

This chapter presents an assessment of the most significant issues expected in Ontario as a result of climate change. The chapter is presented in four sections. Following this 'Introduction', Section 2 provides an overview of key current and future environmental, demographic and economic conditions that influence vulnerability to climate change. Section 3 presents what is known about climate sensitivities, impacts and adaptive capacity for three subregions of the province (Figure 1; described below), highlighting the risks and, where information is available, the opportunities presented by changing climate. Section 4 presents a synthesis of results across subregions, identifying potential areas of greatest concern. The discussion addresses the social, economic and environmental risks that residents of Ontario are facing from climate change impacts at the regional, sectoral and community scales. It also presents analysis of factors that could exacerbate vulnerability to future climate change, the role of institutions in enhancing adaptive capacity, and discusses the need to mainstream adaptation to climate change into long-term planning processes. Case studies are used to illustrate different aspects of managing climate risks.

Much of the literature published since the last national assessment, the *Canada Country Study* (*see* Chapter 1; Smith et al., 1998) has continued to focus on biophysical impacts, with relatively less attention given to social or economic impacts and adaptive capacity. In some cases, significant knowledge gaps

FIGURE 1: The three subregions of Ontario used in the chapter (*modified from* Natural Resources Canada, 2002).

identified in the Canada Country Study remain, most notably for some sectors (e.g. mining), subregions (e.g. the north subregion), communities (e.g. First Nations communities) and extreme events (e.g. insured and uninsured costs). The overwhelming majority of research is focused on potential negative impacts of climate change. As a result, positive impacts (benefits) may not be well understood. Clearly, just as adaptation will be needed to minimize negative impacts, so too will adaptation be required to capitalize effectively on any opportunities climate change may bring to Ontario.

For the purposes of this assessment, Ontario has been divided into three subregions, based on physiographic, social and economic characteristics (Figure 1, Box 1). This structure is used to highlight the fact that both key impacts of concern and the capacity to adapt to those impacts differ among the three subregions of the province, and likely require adaptation measures tailored to each subregion's circumstances.

The south subregion extends from the southernmost tip of Canada eastward to the border with Quebec. It is bounded to the south and west by lakes Huron, Erie and Ontario, and the St. Lawrence River, and to the north by the Precambrian Shield of the central subregion. The south subregion is the most densely populated area in Canada, and contains eight of Canada's sixteen most populous metropolitan areas, including its largest city, Toronto. The topography ranges from extremely flat in the southwest and southeast to the rugged Niagara Escarpment, with much of the natural landscape having been modified for urban development, transportation networks and agriculture. Although the Great Lakes border both the south and central subregions, they are treated in this chapter as a single system and part of the south subregion.

The central subregion encompasses more than half of the province and is dominated by forested terrain underlain by the mineral-rich Precambrian Shield. It includes a number of medium-sized cities, such as Sudbury and Thunder Bay, but is characterized by huge areas with low population densities. Resource-based communities, dependent on forestry, mining and tourism, are located primarily along major transportation corridors. The vast majority of forestry- and mining-reliant communities in Ontario are located in this subregion. The central subregion contains two-thirds of Ontario's provincial highway system that, along with rail lines, provides critical transportation linkages between eastern and western Canada.

BOX 1

Ontario subregions used in this analysis

SOUTH

Major ecosystems: Mixed plains and the Great Lakes; contains 40% of Canada's species at risk

Includes: Windsor, London, Kitchener-Waterloo, Hamilton, Niagara Falls, Toronto, Peterborough, Kingston, Ottawa, Orillia, Barrie, Owen Sound

Economy: service sector, manufacturing, tourism, agriculture

CENTRAL

Major ecosystem: Boreal Shield

Includes: Pembroke, North Bay, Sudbury, Sault Ste. Marie, Timmins, Cochrane, Thunder Bay, Kenora, Armstrong, Sioux Lookout, Huntsville, Red Lake, Pickle Lake

Economy: forestry, mining, service sector, tourism, transportation

NORTH

Major ecosystems: Boreal Shield, Hudson Plains, Hudson Bay–James Bay (marine); coastal marshes support 50% of the eastern Brant goose population during migration, and provide staging grounds for more than 2.5 million snow geese

Includes: Moosonee, Kashechewan, Attawapiskat, Fort Severn, Sandy Lake

Economy: mining, fisheries, forestry, tourism, subsistence ways of life

The north subregion extends from the northern boundary of the central subregion to the coasts of Hudson and James bays. It is sparsely populated, primarily by small Aboriginal communities affiliated with the Nishnawbe-Aski First Nation. Continuous and discontinuous permafrost is found throughout the more northerly areas of this subregion. Much of the landscape is low lying and poorly drained, providing critical habitat for migratory bird species. The subregion is highly dependent on more than 3000 km of winter roads to provide supplies to numerous remote communities for which air transport is the only means of year-round access.

2 REGIONAL CONTEXT: CURRENT AND FUTURE CONDITIONS

This section provides an overview of several factors that influence vulnerability to climate change in Ontario. These include the many non-climatic factors that influence adaptive capacity, including demographics, human health determinants, economic activities and institutional capacity. Emphasis is placed on populations considered vulnerable to climate change, as well as factors deemed to be critical to ensuring continued economic development. Historical trends and future projections of climate provide context for assessing how changes in exposure are likely to influence vulnerability.

2.1 POPULATION AND HEALTH STATUS

Over the past 20 years, Ontario's population has increased by almost 3.3 million to more than 12.5 million, with growth concentrated in urban centres, particularly the Greater Toronto Area (GTA), the Kitchener-Waterloo-Cambridge region, the Hamilton and Niagara region, and Ottawa (Statistics Canada, 2002). Almost 85% of Ontario's population lives in urban areas, reflecting a continuing rural to urban migration trend. Of the approximately 250 000 annual immigrants to Canada, about half choose the GTA as their primary destination (McIsaac, 2003). The central and north subregions of the province are generally characterized by rural depopulation. Although the populations of some remote and resource-based communities have remained stable, others have experienced significant declines (Table 1). These trends are expected to continue.

TABLE 1: Ontario municipalities with populations of 5000 or more whose populations are declining the fastest, 1996–2001 (*from* Statistics Canada, 2003a).

Community	Population		% change
	1996	2001	
Greenstone	6530	5662	-13.3
Kirkland Lake	9905	8616	-13.0
Elliot Lake	13 588	11 956	-12.0
Iroquois Falls	5714	5217	-8.7
Timmins	47 499	43 686	-8.0
Kapuskasing	10 036	9238	-8.0

Aboriginal communities are found throughout the province. In 2001, 1.7% of the provincial population was Aboriginal, of which more than 70% were First Nations peoples, with Inuit and Métis peoples representing less than 1% and about 26% of the total Aboriginal population, respectively. In Ontario, 78% of Aboriginal people live off-reserve, many them in the census metropolitan areas of Toronto (Statistics Canada, 2006a).

In general, the health of Ontario's population is high, compared to the Canadian average and that of other countries. Life expectancy is a widely used indicator of population health, and the Ontario average has been consistently higher than the national average (Federal, Provincial and Territorial Advisory Committee on Population Health, 1999). There are, however, some significant differences in health status among subpopulations. Urban populations, especially in and around the GTA, tend to be healthier than their rural counterparts (Altmayer et al., 2003). Women, and especially Aboriginal women, are at particular risk in rural areas due to social and environmental conditions, health behaviours and access to health care (Grace, 2002; Ontario's Women's Health Council, 2002). Studies also indicate that the health of women, children and youth tends to be lower in the central and north subregions, compared to the south (Northern Ontario Perinatal and Child Health Survey Consortium, 2002; Haque et al., 2006).

Population projections for 2031(Ontario Ministry of Finance, 2006) include the following:

- The population of Ontario will grow by 31%, to 16.4 million, with relatively steady growth rates of 140 000 to 160 000 people per year.
- In the south subregion, more than 60% of growth will occur in the GTA, which will increase from 5.8 million in 2005 to more than 8 million by 2031. Population in the remainder of the south subregion is also projected to increase, from about 6 million in 2005 to more than 7.5 million by 2031.
- The central and north subregions are projected to experience a 7.4% decline in population, falling from about 810 000 in 2005 to below 750 000 by 2031.

Ontario's population will also be aging over the next two decades, which will result in a considerably different age distribution (Figure 2) and higher dependency ratios (the ratio of children under 15 years of age and persons over 65 years of age to the core working age population). There are exceptions to this trend, however, most notably in northern First Nations communities,

FIGURE 2: Ontario population pyramids, 2006 and 2031 (Ontario Ministry of Finance, 2006).

where a shift towards a more youthful population is projected, and in the case of immigrants, whose average age tends to be considerably younger than that of established Ontario residents (Ontario Ministry of Finance, 2006).

2.2 GOVERNMENT AND INSTITUTIONS

In Ontario, all three levels of government play a fundamental role in shaping the social, economic and institutional landscape of the province, and therefore also strongly influence the region's capacity to adapt to changing climate. The governance system is highly integrated and complex, combining formal and informal agencies, in some cases resulting in blurred areas of responsibility. Many sectors that will be impacted by climate change, such as managing natural resources, generating and delivering electricity, and providing health care services, fall largely under provincial authority. Municipalities implement and enforce national and provincial policies, supply essential services such as drinking water and play a fundamental role in land-use planning. Establishing national standards and guidelines, managing cross-border issues and providing essential services in Aboriginal communities fall under federal jurisdiction.

2.3 ECONOMIC GROWTH AND DEVELOPMENT

Economic growth in Ontario has been relatively strong during the past two decades, with gross domestic product (GDP) annual growth rates of around 3.0% (Ontario Ministry of Finance, 2005). Economic growth is expected to slow to 2.3% but remain strong until 2025. The Ontario economy has been shifting from manufacturing towards the service sector, and this trend is expected to continue. However, manufacturing productivity has risen and it is expected that the sector will continue to be an important part of the economy, particularly in southern Ontario (Ontario Ministry of Finance, 2005). Transportation continues to dominate the manufacturing sector, followed by food, petroleum products and chemicals, primary metals and forestry/paper products. Economic activity and growth are regionally diversified, and the agriculture and resource sectors will remain important in rural regions. Many Ontario communities obtain 30% or more of their employment income from the natural resource sectors, primarily agriculture and forestry (Figure 3).

In 2004, Ontario had Canada's largest tourism industry, which made a greater contribution to provincial GDP than agriculture, forestry/paper, commercial fishing/hunting and mining industries combined, and accounted for 3.3% of the province's total employment (Ontario Ministry of Tourism, 2006). Tourism has become increasingly important in many rural non-farm areas, and some communities are now highly dependent upon this sector. Through the ongoing industrialization of agriculture, farm numbers continue to decline, farm productivity continues to increase and conventional farm activity continues to become more spatially concentrated. In 2001, there were 186 000 people living on 60 000 farms across Ontario, a decline of 11 and 15%, respectively, from 1996 (Statistics Canada, 2003b). Some agricultural areas have undergone considerable change due to non-climatic factors, such as the rapid decline of the tobacco industry in the southwestern part of the south subregion and the replacement of tender fruit orchards (peaches, cherries) with vineyards (and the associated wine industry) in the Niagara region. Farmers have been adopting more ecologically sound management practices that should promote longer term sustainability. However, a rapidly aging farm population (Statistics Canada, 2003b) is placing substantial pressures on the agricultural sector.

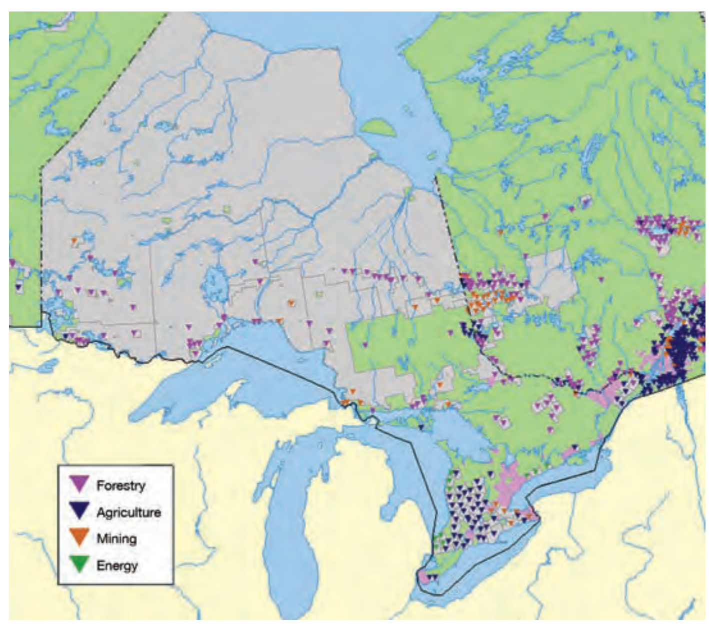

FIGURE 3: Communities in Ontario more than 30% reliant on resource-based industry (Natural Resources Canada, 2001).

Many communities in the central and north subregions continue to be resource based, dependent on forestry, pulp-and-paper activities and mining, while many Aboriginal communities rely on hunting, trapping and agriculture to offset the high cost of non-traditional foods. Aboriginal communities throughout the province lead ways of life that are closely tied to the natural environment. The Walpole Island First Nation in the south subregion contains some of the most biologically diverse areas in Canada, which support traditional harvesting and practices such as hunting, fishing and trapping, in addition to a large market economy based on recreation and tourism (Resource Futures International, 2004).

2.4 ENERGY GENERATION, TRANSMISSION AND DEMAND

Ontario's socioeconomic outlook is very closely linked to availability of a stable source of power for industrial, commercial and residential use. Currently, Ontario's installed generation capacity of approximately 30 000 megawatts (MW) includes a diverse range of energy sources (nuclear, coal, natural gas and renewable sources) that are responsible for varying amounts of electricity production (Figure 4). There is an extensive electricity transmission grid throughout the populated areas of the province, whereas some northern communities remain off the grid and generate their own electricity. In the past decade, the electricity system has experienced two catastrophic events: a severe ice storm in 1998 that affected most of southeastern Ontario, Quebec and New Brunswick, and a blackout in August 2003 that affected most of Ontario and the northeastern United States. Most urban centres are well supplied with natural gas, whereas alternative fuels (in addition to electricity), such as propane, wood and diesel, predominate in rural, central and northern markets. Much of Ontario's electricity transmission grid is more than 50 years old. Most municipal electrical distribution lines tend to be above ground in older well-established neighbourhoods and underground in newer suburban developments and redeveloped commercial centres.

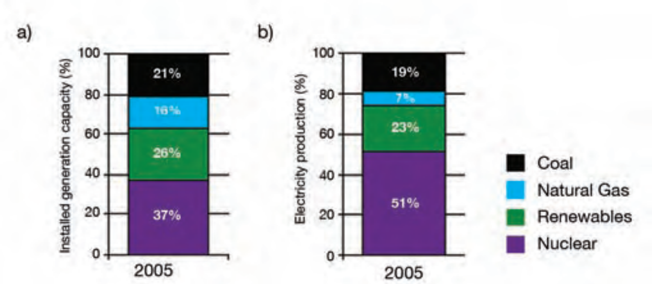

FIGURE 4: Ontario's electricity system, 2005 (Ontario Power Authority, 2005): a) installed generation capacity, and b) electricity production.

The Independent Electricity System Operator (IESO) forecasts that, without energy conservation strategies, energy consumption will grow from about 157 terawatt•hours (TW•h) in 2006 to about 170 TW•h in 2015, an average annual growth rate of 0.9% (Independent Electricity System Operator, 2005). However, effective energy conservation and efficiency measures could keep energy supply and demand in balance, even with increases in population (Gibbons and Fracassi, 2005; ICF Consulting, 2005, 2006). A stable electricity network must be able to handle peak demand. Ontario's electricity demand now peaks in the summer months due to the increased use of air conditioners and other cooling devices during heat waves, whereas warmer winter temperatures, increased energy efficiency and wider use of natural gas for home heating have decreased winter peak demand. The IESO forecasts that normal-weather peak demands will increase by 11% from about 24 200 MW in 2006 to 26 900 MW in the summer of 2015, and possibly 30 000 MW under extreme weather conditions (Figure 5), depending upon the success of efficiency and conservation measures. The upper limit of these projections is based on cold winters and/or hot summers, whereas the lower limit considers mild winters and cool summers. Climate change is not factored into these forecasts. New demand records were set during the summers of 2005 (26 160 MW on July 13) and 2006 (27 005 MW on August 1), caused in part by prolonged heat waves and extremely warm night-time temperatures (Independent Electricity System Operator, 2006).

For much of the past decade, the Ontario government has been examining ways of phasing out coal-fired electricity generation. A commitment to phasing out 6500 MW of coal-fired generation in Ontario has been targeted for 2014; if implemented, this will result in a supply and demand gap that will have to be addressed through a combination of new sources and energy efficiency (Legislative Assembly of Ontario, 2002). To help meet this gap, the Ontario government announced in 2004 a Renewable Portfolio Standard of 5 percent (1350 megawatts) of new

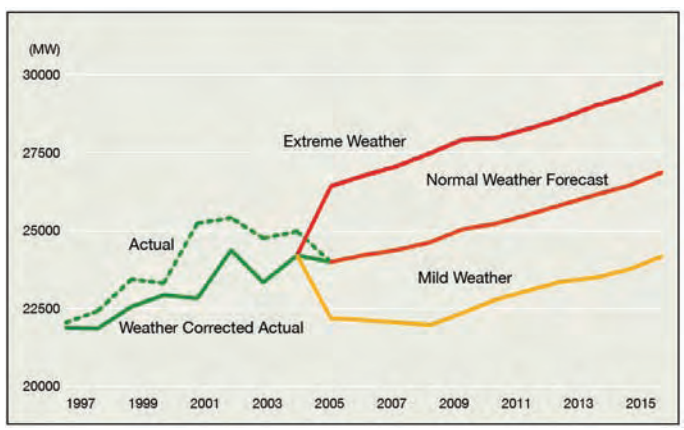

FIGURE 5: Hourly peak demand forecasts under three weather scenarios (Independent Electricity System Operator, 2005).

renewable energy by 2007 and 10 percent (2700 megawatts) by 2010 (Robson and Gruetzner, 2004). In addition to new sources within the province, such as wind and water power (Figures 6 and 7), long-distance transmission from large-scale hydroelectric projects in Manitoba, Quebec and Newfoundland are also options being considered. During the past 30 years, Ontario has demonstrated a substantial capacity for energy efficiency and greater energy intensity use, and there remains much potential for savings in both residential and industrial sectors (ICF Consulting, 2005, 2006).

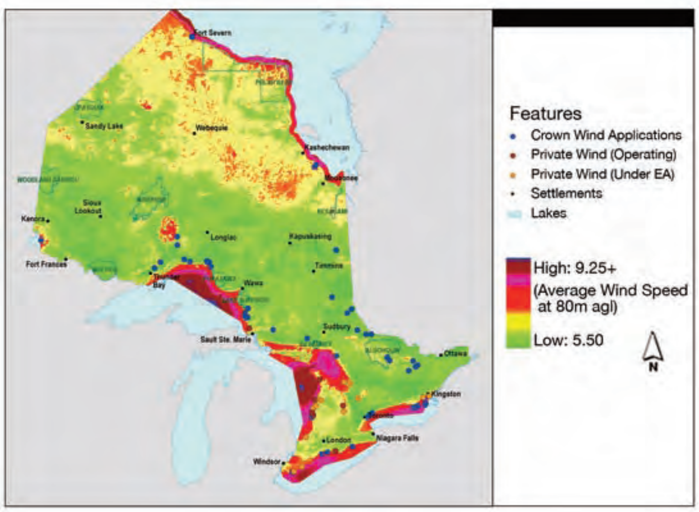

FIGURE 6: Wind power resources in Ontario (Ontario Ministry of Natural Resources, 2006a).

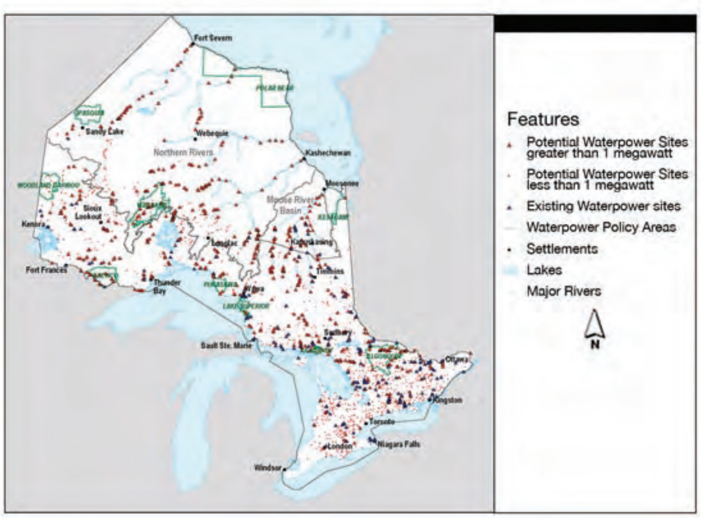

FIGURE 7: Water power resources in Ontario (Ontario Ministry of Natural Resources, 2006b).

2.5 ATMOSPHERIC TRENDS AND PROJECTIONS

Ontario's climate and air quality vary widely from season to season and from one part of the province to another. In the south subregion and part of the central subregion, climate is highly modified by the influence of the Great Lakes, resulting in higher autumn and winter precipitation, protection from the worst of winter's cold and summer's heat, and very heavy snowfall in the regions to the lee of lakes Superior and Huron, and Georgian Bay. Spring and summer also include the tornado season in the south subregion, which has the highest frequency of tornadoes in Canada. Stagnant tropical air masses in the summer can bring poor air quality, heat waves and drought, although elevated levels of particulate matter can also occur during winter months. In autumn, remnants of hurricanes occasionally produce high winds and excessive rainfalls. The north subregion has cold winters and mild summers. Most precipitation falls in the form of summer showers and thunderstorms, although winter snowfall amounts can be significant. Low winter temperatures permit construction and operation of winter ice roads for community access and commercial mining and forestry operations.

Ontario experiences a variety of extreme weather events and associated natural disasters. In spring, rapid snowmelt or ice jamming can lead to flooding, especially in northern communities. Major storms hit most parts of Ontario at least once or twice per year, with high winds, rain, freezing rain or snow. In recent years, Ontario has experienced some exceptionally severe weather events, including the 1998 ice storm, which remains the costliest natural disaster in Canadian history. In that storm, eastern Ontario, southwestern Quebec, southern New Brunswick and Nova Scotia, and portions of the northeastern United States received 80 mm or more of freezing rain, double the amount received in any previous ice storm (Lecomte et al., 1998). In Canada, this event caused 28 deaths, cost more that $5.4 billion and left 250 000 people in Ontario without power, some for up to 24 days (Lecomte et al., 1998; Kerry et al., 1999).

Climate Trends

During the last half of the twentieth century (1948–2006), the period for which data are available for northern as well as southern Canada, national annual temperatures have increased by 1.3°C (Environment Canada, 2006a; *see* Chapter 2). During the same time period, annual average temperatures across Ontario have increased between 0 and 1.4°C, with larger increases observed in the spring.

Examination of trends in warm days and warm nights between 1950 and 2003 shows that the largest increase in the number of warm days is found in the north subregion (Figure 8). During this same period, there has also been a significant decrease in the number of cold days in the central and western parts of the north subregion (Vincent and Mekis, 2005). The largest decrease in diurnal temperature range occurred in the central subregion (Vincent and Mekis, 2005).

Annual precipitation in southern Canada has increased by about 5 to 35% since 1900 (Zhang et al., 2000), and the number of days with precipitation (rain and snow) has increased significantly in the south and central subregions. Furthermore, the number of days with rain only has increased in the south subregion and parts of the central and north subregions (Figure 9; Bruce et al., 2000; Vincent and Mekis, 2005). Precipitation in some parts of the province (e.g. Maitland River valley east of Lake Huron) has become more variable, with high-intensity storms becoming more common since the late 1950s (Mekis and Hogg, 1999). Snowfalls show a significant upward trend in the north subregion in the fall, but have declined in the central subregion in spring and winter. Snowfall trends in the south subregion are not statistically significant, although there is evidence of an increase in snow in the western part of the subregion and a decrease in the eastern part (Zhang et al., 2001).

A significant increase in lake-effect snow has been recorded since 1915 for areas of the United States in the lee of the Great Lakes (Burnett et al., 2003). Heavy lake-effect snow presents a hazard for communities and transportation networks, and its accumulation and subsequent melt play an important role in regional hydrology.

Between 1953 and 2001, days with freezing rain events occurred, on average, between 2 and almost 10 times per year, with Ottawa, North Bay and Sudbury having the highest annual averages and Thunder Bay, Kenora and Sioux Lookout the lowest. Risk of freezing rain has remained relatively stable during this period, with a statistically significant decreasing trend in Wiarton and London, and a slight (not statistically significant) increasing trend in much of the central subregion and Ottawa (Klaassen et al., 2003).

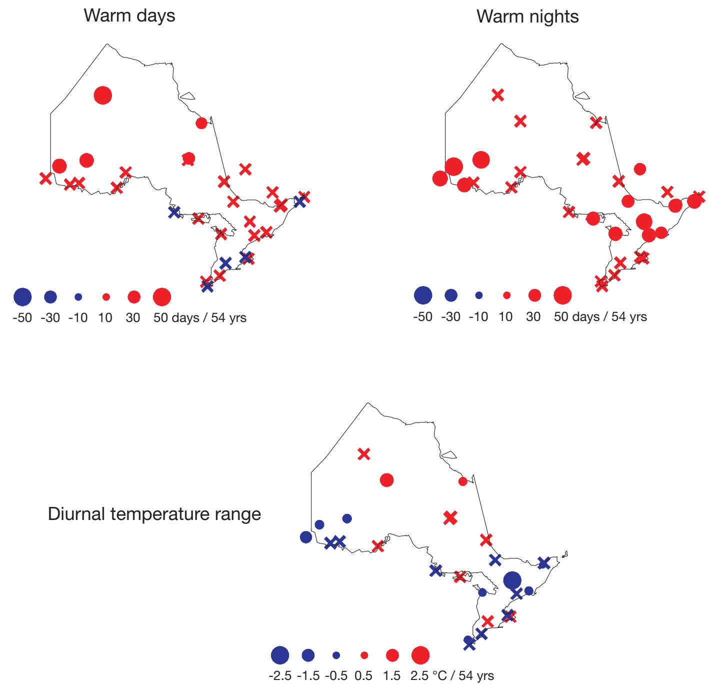

FIGURE 8: Trends for warm days, warm nights and diurnal temperature change, 1950–2003 (Vincent and Mekis, 2005). Blue and red dots indicate trends significant at the 5% level, and the size of the dots is proportional to the magnitude of the trend. Crosses denote non-significant trends.

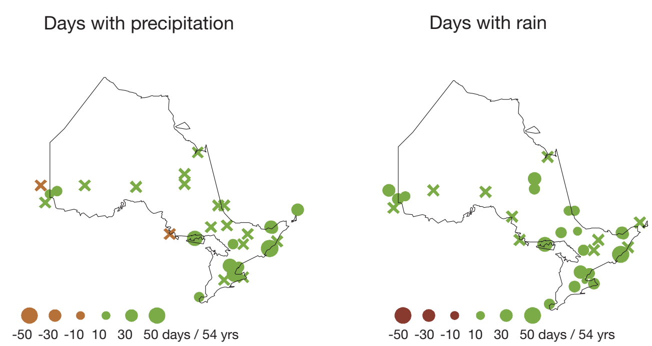

FIGURE 9: Trends in precipitation indices, 1950–2003 (Vincent and Mekis, 2005). Brown and green dots indicate trends significant at the 5% level, and the size of the dots is proportional to the magnitude of the trend. Crosses denote non-significant trends.

Climate Projections

The limited scale of Global Circulation Model (GCM) output precluded meaningful analysis at the scale of the subregions used in this chapter, so the province was divided into east and west sections for the purpose of this analysis. Projections of changes in temperature and precipitation from runs on seven GCMs, using seven different emission scenarios, are presented in Figure 10. These 49 scenarios provide a robust range of plausible climate futures, expressed in terms of change over the average values from 1961 to 1990 (*see* Chapter 2). All results (ranging from conservative to aggressive assumptions regarding future emission rates) indicate an increase in annual temperature, and the majority also project increases in annual amounts of precipitation within the next 20 to 50 years. The

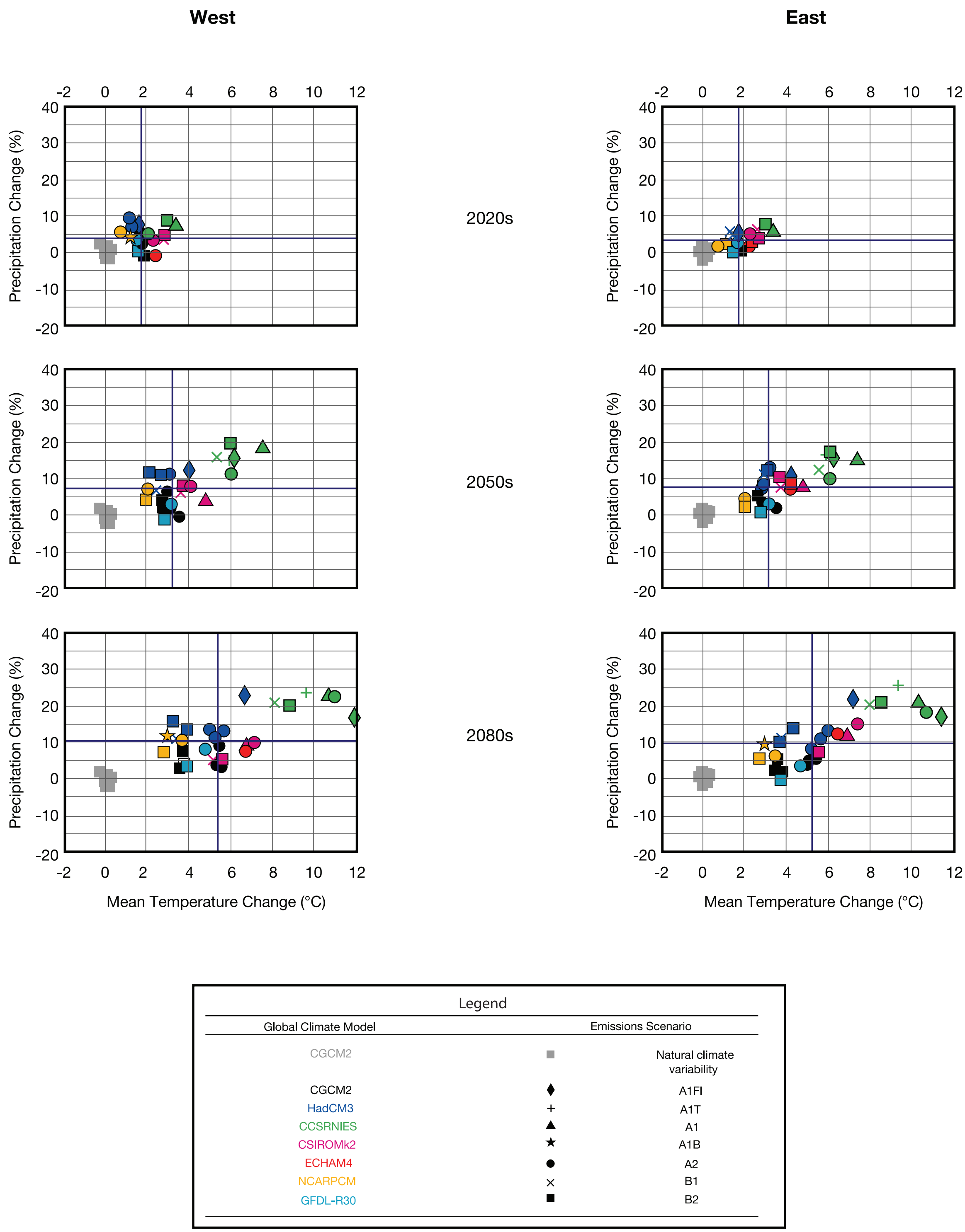

FIGURE 10: Scatterplots of projected change in annual mean temperature and precipitation. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot. (*see* Appendix 1 of Chapter 2 for details).

range of results increases over time, reflecting fundamental differences among emissions scenarios and among models.

Seasonal projections of temperature scenarios (Figure 11) indicate that maximum warming will occur in winter, in the north subregion. It is also expected that changes in extreme warm temperatures will be greater than changes in the annual mean (Kharin and Zwiers, 2005). The number of days exceeding 30°C in the south subregion is projected to more than double by 2050 (Hengeveld and Whitewood, 2005). A separate study suggests that such severe heat days could triple in some cities by 2080 (Cheng et al., 2005).

There is greater variation in projections of precipitation than those of temperature, with the greatest precipitation increases projected for the north subregion (Figure 12). However, it must be noted that some of the projections indicate a slight decrease (<2.5%) in annual precipitation for most of the province in the next 50 years.

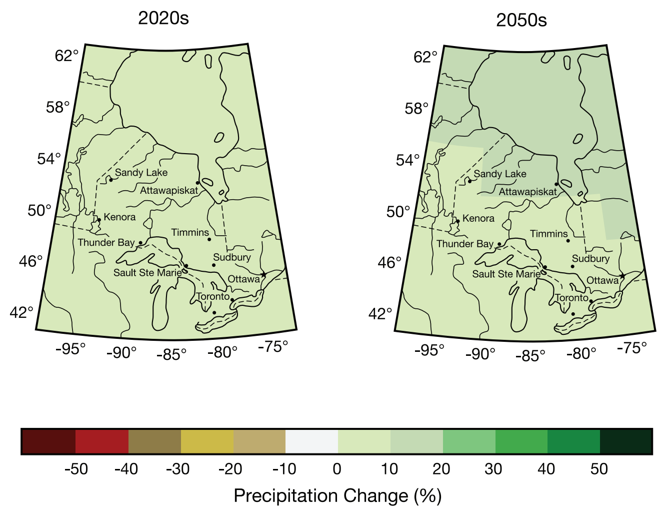

FIGURE 12: Projected annual change in precipitation (%) for the 2020s (left) and 2050s (right), relative to 1961–1990, based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

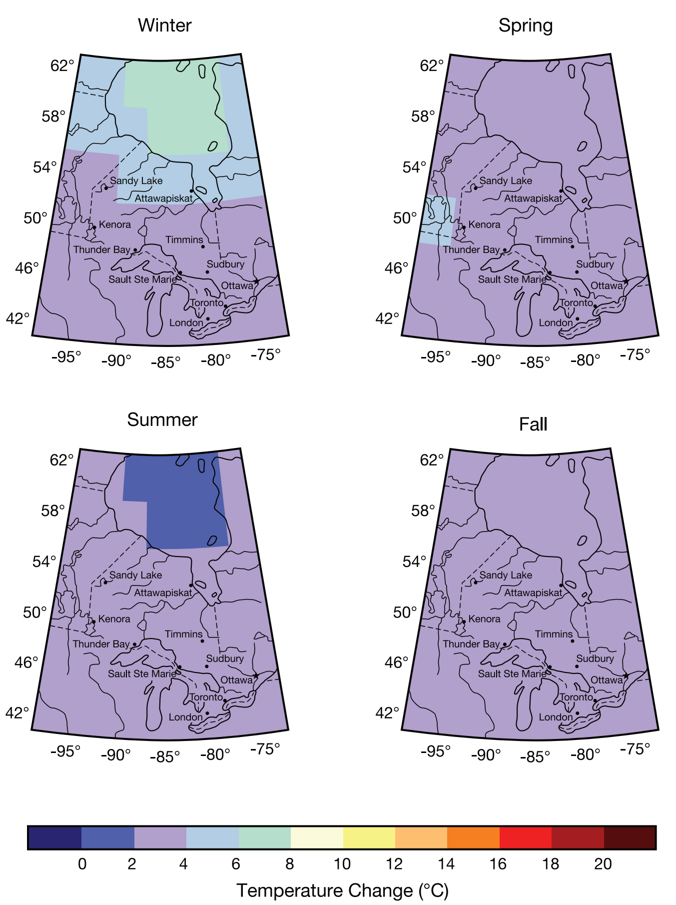

FIGURE 11: Projected seasonal change in temperature by the 2050s (relative to 1961–1990, based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

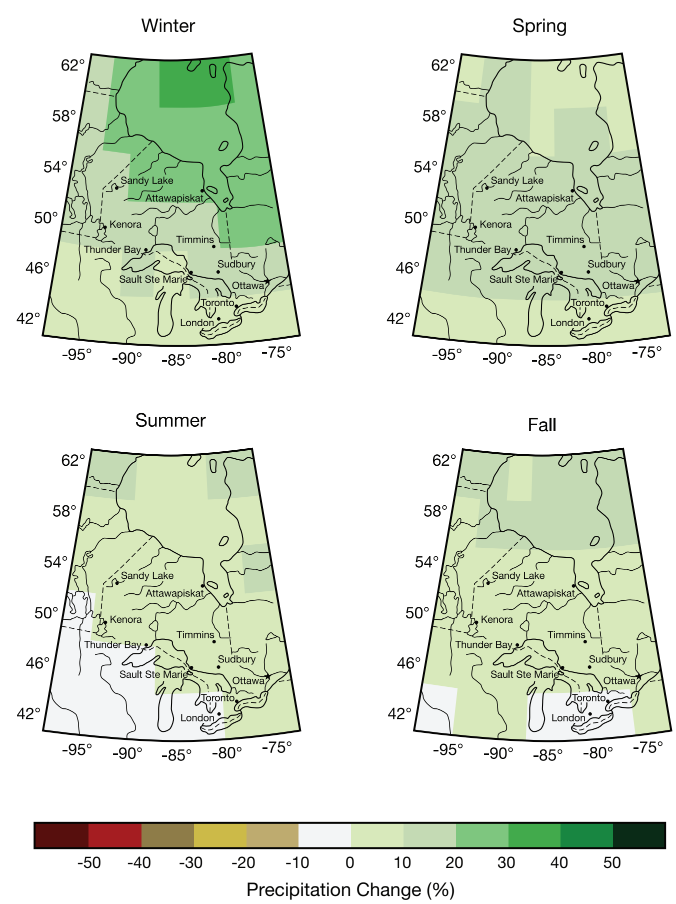

FIGURE 13: Seasonal change in precipitation (%) by the 2050s, relative to 1961–1990, based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

Although annual precipitation totals are likely to increase, summer and fall decreases of up to 10% are projected for the south subregion by 2050. Net moisture availability will also be impacted by warmer temperatures and longer growing seasons, with resultant increases in evaporation and evapotranspiration rates. Winter projections show increases in precipitation, increasing from south to north and ranging from 10% to more than 40% (Figure 13).

Changes in the extreme daily precipitation amounts are expected to be greater than the changes projected in the annual mean amounts (Kharin and Zwiers, 2005), meaning that these types of events will become both more intense and more frequent (Hengeveld and Whitewood, 2005). It is likely that lake-effect snow will increase in the short to medium term as lake temperatures rise and winter air temperatures are still cool enough to produce snow. By the end of the twenty-first century, however, snowfall may decrease and possibly be replaced by heavy lake-effect rainfall events (Kunkel et al., 2002; Burnett et al., 2003).

Air Pollution

Air pollution has a significant impact on human and ecosystem health, causing illnesses and even death among vulnerable populations. It also reduces the yields of many agricultural crops. Climate change impacts ambient air pollution levels through changes in meteorological conditions and changes in atmospheric chemistry. There are also potential synergistic health impacts between warmer temperatures and air pollution, with emissions from fossil fuel–based electricity generators possibly increasing to meet the increased peak demands. In Ontario, air-quality problems related to ozone and fine particulate matter are extensive, particularly throughout the south subregion. On an episodic basis, particulate matter and ozone are issues in other parts of the province as well.

Concentrations of particulate matter and precursors to ozone have declined during the past 30 years, although this decline has generally levelled off or stagnated since the mid-1980s (Brown and Palacios, 2005; International Joint Commission, 2006). However, some cities, such as Toronto, have experienced increased levels of nitrogen dioxide and fine particulate matter, in part due to increases in emissions from coal-fired electricity generating plants and from the transportation sector (Campbell et al., 2004). Despite decreases in ozone precursor pollutants, Ontario has exhibited statistically significant increases in the seasonal means for summer and winter ozone from 1980 to 2005 (Ontario Ministry of the Environment, 2006a). In Canada, ozone concentrations are highest and are rising most rapidly in the south subregion of Ontario (Environment Canada et al., 2005; Ontario Ministry of the Environment, 2006a). In recent years, both large and small urban and rural monitoring sites in Ontario have exceeded the Canada-wide standard for ozone, with the exception of Thunder Bay. A significant part of the problem is transborder pollution, which can be equal to, if not greater than, that from local sources during smog episodes (Yap et al., 2005). Ontario is also a significant source of air pollution for downwind regions in Quebec, Atlantic Canada and parts of the American northeast.

3 CLIMATE SENSITIVITIES, IMPACTS AND VULNERABILITY: SUBREGIONAL PERSPECTIVES

3.1 SOUTH SUBREGION

The south subregion (Figure 1, Box 1) includes southwestern Ontario, extends east to the Quebec border and includes the Great Lakes (Box 2). The majority of research examining climate change impacts and adaptation in Ontario is focused on this subregion. Changes in Great Lakes water levels (Case Study 1) are projected to be one of most significant impacts of changing climate in this subregion, with implications for water management, hydroelectricity generation, transportation, tourism and recreation and ecosystem sustainability. Other key issues include the impacts of climate change and extreme weather events on water quality and quantity (Case Study 2), critical infrastructure (Case Study 3), human health (Case Study 4) and agriculture.

3.1.1 Ecosystems

Regional warming is strongly reflected in the physical attributes of aquatic ecosystems. For example, there is a strong regional trend toward later freeze-up and earlier break-up of ice on lakes. On Lake Simcoe, average freeze-up occurs 13 days later and average break-up occurs 4 days earlier than 140 years ago (Canadian Council of Ministers of the Environment, 2003). On the Great Lakes, the season of ice cover has been shortened by about 1 to 2 months during the last 100 to 150 years (Kling et al., 2003). The ice-cover period for Lake Ontario's Bay of Quinte has also decreased substantially, particularly since the late 1970s, with the fall and winter of 2005–2006 showing the least ice cover in the last 50 years or more (J.M. Casselman, pers. comm., 2006). Projected warming, particularly in winter months, will lead to further changes in the duration and extent of ice cover on the lakes. For example, Lofgren et al. (2002) determined that the ice-in period over selected parts of the Lake Superior and Lake Erie basins could be further reduced by 16 to 52 days by 2050, from a current average of 11 to 16 weeks. Less ice cover results in greater loss of water through evaporation and enhanced shoreline erosion during winter storms, and may affect lake-effect snowfall (Mortsch et al., 2006).

Increases in nearshore temperature have been recorded at several locations around the Great Lakes since the 1920s. They are most pronounced in the spring and fall, and are positively correlated with trends in global mean air temperature (King et al., 1997, 1999; McCormack and Fahnenstiel, 1999; Shuter et al., 2002; Kling et al., 2003). This warming has likely contributed to major ecosystem impacts on the Great Lakes associated with extensive algae (green and blue-green) blooms and invasions of non-native invertebrates (e.g. spiny water flea, zebra mussels and quagga mussels) and vertebrates (e.g. round goby and various carp species; Schindler, 2001; Kling et al., 2003; MacIssac et al., 2004). These impacts have required that many coastal communities make modifications to infrastructure, such as water treatment plants, and implement other remedial measures, such as removing mussels from encrusted water intake pipes (Sarrouh and Ramadan, 1994; Aldridge et al.,

BOX 2

The Great Lakes

The Great Lakes cover an area of 244 160 km^2, and have a total shoreline length of 17 000 km and a volume of 22 684 km^3 (Figure 14; Environment Canada, 1991). They are connected to the Atlantic Ocean by the St. Lawrence River and contain almost 20% of the Earth's unfrozen surface fresh water. The area surrounding the Great Lakes region is home to more than 90 million people, and supports the generation of more than 30% of the continent's gross national product and the production of more than 60% of Canada's industrial output (Sousounis and Bisanz, 2000).

FIGURE 14: The Great Lakes basin.

CASE STUDY 1

Climate and Great Lakes Water Levels

Although water levels within the Great Lakes are regulated to a certain degree at the outflows of Lake Superior and Lake Ontario, and several diversions exist throughout the basin, climate is the dominant factor affecting lake levels (Changnon, 2004). Lake levels reconstructed from tree ring studies show that low water levels occurred more frequently prior to the twentieth century, indicating that natural variability is greater than that of recent experience (Quinn and Sellinger, 2006). In the past 150 years, annual average water levels in the Great Lakes have varied, with the range between minimum and maximum levels being around 180 cm (Mortsch et al., 2006). Water levels were 50 to 80 cm higher than average in 1973 to 1975, 1985 to 1986 and 1997, and 50 to 80 cm lower than average in 1934 to 1935, 1964 to 1965 and 1999 to 2002 (Changnon, 2004; Mortsch et al., 2006). In 2001, Lake Superior was at its lowest level since 1925 and lakes Michigan-Huron were at their lowest levels since 1965. Low water levels reflect substantial loss of water volume in the Great Lakes system. For example, between April 1998 and May 1999, reductions in Great Lakes water levels resulted in a loss of about 120 km^3 from the system — the equivalent of almost 2 years of flow over Niagara Falls (Moulton and Cuthbert, 2000).

While it is clear that temperature and precipitation greatly influence lake levels, the exact relationship is not well understood, in part because neither precipitation nor evaporation are measured over the lakes. Analysis of long-term regional climate data suggests that precipitation accounts for 55% of the variability in lake levels, with temperature accounting for 30% (Changnon, 2004). However, there is also evidence that increased temperatures can be the primary cause of low water levels, at least over the short term, as found in a study of the 1997 to 2000 period (Assel et al., 2004).

Although most scenarios of future climate project increases in regional precipitation (Figure 12), the increase in evaporation caused by higher temperatures is expected to lead to an overall decrease in Great Lakes water levels (Mortsch et al., 2000, 2006; Cohen and Miller, 2001; Lofgren et al., 2002; Kling et al., 2003). Increased evaporation is expected in all seasons, and particularly in winter as a result of decreased ice cover on the lakes. Results from studies that have modelled future changes in the water levels of lakes Ontario, Erie, St. Clair and Michigan-Huron are presented in Figure 15. In the majority of experiments, lake levels are projected to decrease (Mortsch et al., 2000, 2006; Cohen and Miller, 2001; Lofgren et al., 2002; Kling et al., 2003). For all but Lake Ontario, projected water levels under warm and wet, and warm and dry scenarios fall below the lower bounds of variability observed during the last 50 years. Under scenarios of lower temperature increases and wetter conditions, increases of 0.02 m annually and 0.07 m in the winter are projected for Lake Ontario. Reductions are projected to be most pronounced in the lakes Michigan-Huron basin, at 0.73 to 1.18 m by the 2050s (Mortsch et al., 2006). It is also expected that low levels will occur more frequently, especially in Lake Erie, and that seasonal variation will increase (Mortsch et al., 2000; Lofgren et al., 2002; Croley, 2003). The impacts of lower water levels will be most pronounced in parts of the system that are already shallow, specifically western Lake Erie, Lake St. Clair, and the St. Clair and Detroit rivers (de Loë and Kreutzwiser, 2000).

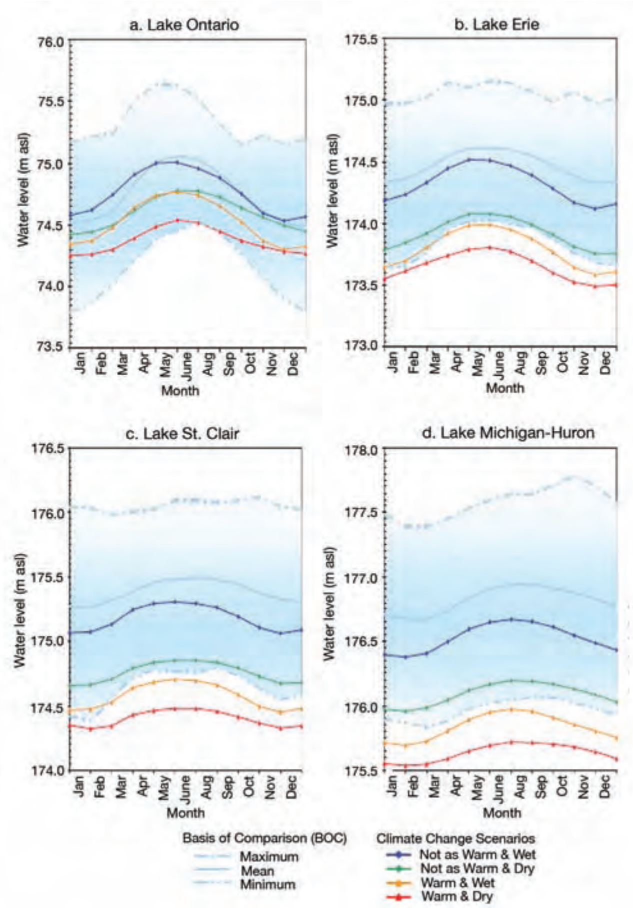

FIGURE 15: Projected changes in Great Lakes water levels (Morstch et al., 2006), based on a 101-year average for Lake Ontario (a) and a 50-year average for lakes Erie (b), St. Clair (c) and Michigan-Huron (d).

The projections of water level changes described above consider only changes in climate. Moulton and Cuthbert (2000) evaluated the cumulative impact of change in climate, consumptive uses, and diversions and bulk water transfers within the watershed on lake levels. Additional water removals of up to 200 m^3/s were assumed, a value consistent with current consumptive use (Moulton and Cuthbert, 2000). The study concluded that the cumulative impacts on Great Lakes water levels from these multiple stresses may necessitate that changes be made to the transborder Niagara Treaty and to the Lake Superior and St. Lawrence River orders of approval, administered by the International Joint Commission. The study further noted that the control structures on the St. Mary's and St. Lawrence rivers may require significant modification to accommodate water level changes, and that the increased dredging required to maintain navigation routes under low water conditions would involve excavation and subsequent management of contaminated materials. Finally, the study concluded that the existing Lake Superior and Lake Ontario water level regulation plans are inadequate to deal with future low water levels, as maintaining minimum outflows would draw down the level of the lakes by several metres.

2006). Projected warming will further exacerbate these problems, as these and other species that were inadvertently introduced from warmer habitats will find it easier to establish themselves in a warmer climate (Schindler, 2001; MacIsaac et al., 2004). Average annual surface-water temperatures for all of the Great Lakes are projected to increase in the future; for Lake Superior, the deepest and coldest lake, they have been projected to increase by between 3.5 and 5°C by 2050 (Lehman, 2002).

Increasing water temperatures also impact the composition of fish communities, affecting both commercial and recreational fisheries. Fish communities in the Great Lakes basin are highly diverse, and include species with preferences for cold water (<15°C), cool water (15–25°C), and warm water (>25°C). Acceleration of this warming trend will enhance production of warm-water fish and negatively affect production of cool-water and cold-water species, as has been documented in Lake Ontario's Bay of Quinte (J.M. Casselman, pers. comm., 2006). It is expected that the disappearance of cool- and cold-water species, particularly lake trout, will be most pronounced in Lakes Ontario and Erie (Casselman, 2002; Casselman et al., 2002; Kling et al., 2003; Shuter and Lester, 2003; Casselman and Scott, 2003). Many warm-water species, such as bigmouth buffalo and flathead catfish, are already being seen more frequently in the Great Lakes basin.

Coastal wetlands function as important staging, breeding and wintering habitat for waterfowl, and breeding and nursery areas for many fish. Reduced water levels as a result of changing climate (*see* Case Study 1) will modify or eliminate wetlands that help maintain shoreline integrity, reduce erosion, filter contaminants, absorb excess storm water and provide fish and wildlife habitat (Mortsch, 1998; Branfireum et al., 1999; Devito et al., 1999; Mortsch et al., 2000; Lemmen and Warren, 2004). Many coastal wetlands in the Great Lakes basin are already under significant stress from non-climatic factors, such as land-use change and nutrient loading, and may be unable to maintain their function and integrity in response to the additional pressures of a changing climate (Easterling et al., 2004). Protecting areas for new wetlands to develop has been identified as an ecosystem management issue for the coming decades (Whillans, 1990; Inkley et al., 2004).

Climate change also represents an important additional stressor on terrestrial ecosystems in the south subregion. The loss of natural habitat associated with agricultural development and urbanization has been a major factor resulting in biodiversity loss. The remaining remnants of Carolinian forests contain rare and endangered species, such as the tulip tree, black gum, sycamore, Kentucky coffee tree and papaw. The southwestern part of this subregion features the most extensive remaining remnants of tall-grass prairie vegetation in the province. There are few studies on the impacts of observed climate change on plants and animals of these ecosystems (e.g. Hussell, 2003).

3.1.2 Water Resources Management

Supply

Water resources management in the south subregion is complex and balances the demands of many different users, rapidly increasing urbanization and economic growth, and in-stream flow needs. Most communities in this subregion rely on surface water, although 90% of rural inhabitants rely solely on groundwater for their potable water supply (Ontario Ministry of the Environment, 2001, 2006b). Although total annual runoff is projected to decrease as a result of future climate change, this will consist of increased flows during the winter months and significantly decreased flows during the summer months when demand is the highest (Mortsch et al., 2000; Cunderlink and Simonovic, 2005).

Despite the general abundance of freshwater supplies, seasonal water shortages have been documented (de Loë et al., 2001; Ivey, 2001) in the Region of Waterloo (Cambridge, Kitchener and Waterloo), Wellington County (Guelph), Dufferin County (Orangeville) and Peel County (Caledon). Many shallow wells in the subregion are sensitive to low water or drought conditions, and some areas may be susceptible to wells going dry (Ontario Ministry of Natural Resources, 2006c). Many of the areas identified as most vulnerable to water shortages have been included within the Greenbelt Area of the Growth Plan for the Greater Golden Horseshoe Region, which places limits on, among other things, urbanization (Ontario Ministry of Public Infrastructure Renewal, 2006).

Several studies have investigated the impacts of climate change on water resources in areas surrounding the Great Lakes basin (e.g. Mortsch et al., 2000, 2003; Bruce et al., 2003; Kling et al., 2003). Projected changes in regional hydrology that have implications for water quality and quantity are identified in Table 2. Of particular concern are areas already under stress from non-climatic factors (Box 3). Communities accessing water from the Great Lakes via shallow water intakes or pipelines designed for relatively high historical water levels may experience problems in future, resulting from more frequent low water levels. In conjunction with increased algal growth, low water levels will likely cause problems for water supply, odour and taste (Mortsch et al., 2000; Bruce et al., 2003; Kling et al., 2003).

In general, communities dependent on surface water systems other than the Great Lakes will also become increasingly susceptible to more frequent water shortages (Kreutzwiser et al., 2003). The impacts of climate change projected for 2020 are likely to be more significant than changes arising from projected urban development, in terms of both magnitude of peak flows and total loads of nitrogen and phosphorous (Booty et al., 2005). The same study concluded that subwatersheds have unique sensitivities and responses to similar stressors. As a result, communities within these subwatersheds may require different adaptation responses (Booty et al., 2005).

In addition to projected decreases in seasonal water supply, forecast population increases will increase the demand for potable water. Eighty per cent of Ontario's population growth by 2031 is expected to occur within the Greater Golden Horseshoe region (which includes the GTA). Some of the largest percentage increases in population growth are forecast to occur in the Region of Waterloo and the counties of Wellington, Dufferin and Simcoe, where periodic water shortages already occur (Ontario Ministry of Public Infrastructure Renewal, 2006).

Reducing vulnerability to more frequent water shortages can be accomplished by understanding source waters and demands within a watershed and addressing possible threats. For example, in response to past water shortages, the Grand River Conservation Authority conducted a comprehensive assessment of water use within the watershed (Bellamy and Boyd, 2005). This analysis found that irrigation, the eighth largest water user over the course of a year, is the second largest water user in July, the time of lowest surface water availability (Bellamy and Boyd, 2005). Combining this information with climate and population projections will help determine problem areas during the next 20 to 50 years.

The vulnerability of water supply to drought in the south subregion is reduced by the ability to access water of the Great Lakes through deepwater intakes, and by the interconnected water treatment and distribution systems, which allows sharing between plants during shortages (Kreutzwiser et al., 2003). In areas reliant on groundwater, deeper sources are more protected from climate variability, and are often exploited as shallow sources become compromised (Environment Canada, 2004). Protection of source water is a critical adaptation measure to reduce the risks to safe and reliable groundwater supplies resulting from a changing climate (Case Study 2).

Flooding

Since the south subregion is the most intensely urbanized area of the province, the magnitude and economic cost of infrastructure impacts and disruption of services caused by extreme weather events is significantly higher than elsewhere in the province. The majority of the flood emergencies reported between 1992 and 2003 in this subregion occurred between the months of January and May, and were the result of rain-on-snow conditions. Increasing winter temperatures will mean that the spring freshet

TABLE 2: Expected changes to water resources in the Great Lakes basin (*from* de Loë and Berg, 2006).

Hydrological parameter	Expected changes in the 21st century, Great Lakes basin
Runoff	• Decreased annual runoff, but increased winter runoff • Earlier and lower spring freshet (the flow resulting from melting snow and ice) • Lower summer and fall low flows • Longer duration low flow periods • Increased frequency of high flows due to extreme precipitation events
Lake levels	• Lower net basin supplies and declining levels due to increased evaporation and timing of precipitation • Increased frequency of low water levels
Groundwater recharge	• Decreased groundwater recharge, with shallow aquifers being especially sensitive
Groundwater discharge	• Changes in amount and timing of baseflow to streams, lakes and wetlands
Ice cover	• Ice cover season reduced, or eliminated completely
Snow cover	• Reduced snow cover (depth, areas, and duration)
Water temperature	• Increased water temperatures in surface water bodies
Soil moisture	• Soil moisture may increase by as much as 80 percent during winter in the basin, but decrease by as much as 30 percent in the summer and fall

BOX 3

Climate change and water quality in systems under stress

The Great Lakes Remedial Action Plan Program was created in 1987 by the International Joint Commission (IJC) as part of the Great Lakes Water Quality Agreement (International Joint Commission, 1989) between Canada and the United States. Under this process, areas that have experienced environmental degradation in the Great Lakes basin are identified as Areas of Concern (AOCs), and Remedial Action Plans (RAPs) are developed and implemented. Currently there are 10 AOCs in Canada, 26 in the United States and 5 shared by both countries. The IJC monitors progress in all of the AOCs. Of the 43 AOCs initially identified, two have been de-listed: Collingwood Harbour and Severn Sound in Ontario (Environment Canada, 2006b).

The success of RAP efforts will be affected by the hydrological impacts of climate change. For example, Walker (1996) stated that periodic reduction in seasonal flow, along with increased winter rainfall and erosion, already make it difficult for water managers to meet the Quinte RAP phosphorus loading targets in some catchments. Projected changes in climate will put additional stresses on investments in effluent treatment, agricultural conservation practices and urban storm-water management. The RAPs and Lake-Wide Management Plans (LaMPs) will need to account for the impacts of climate change when establishing and reviewing water quality objectives, and it is likely that further investments will be required to meet their objectives (Bruce et al., 2000).

will likely occur earlier and, because of more frequent winter thaws, it will likely be lower (Kling et al., 2003). This, in turn, will likely decrease the risk of spring flooding (Hengeveld and Whitewood, 2005).

Flooding damage also occurs from heavy rainfall events. Between 1979 and 2004, the southwestern part of this subregion received the greatest number of heavy rainfall events in the province (Figure 16). An exceptionally heavy event occurred on August 19, 2005 and led to considerable damage in Toronto (*see* Case Study 3). There have been seven other heavy rainfall events resulting in severe flooding in Toronto in the past 20 years, all of which were considered to have return periods of greater than 25 years (D'Andrea, 2005).

The Region of York and City of Niagara have reported an increase in basement and localized flooding (Brûlé and McCormick, 2005), and several municipalities are looking into the need to retrofit their storm-water infrastructure in order to accommodate heavier rainfall events (Ormond, 2004; Brûlé and McCormick, 2005; D'Andrea, 2005). In 2001 and 2002, the City of Stratford experienced heavy rain events that caused widespread flooding. As a result, the city has adopted a 250-year design storm standard (*see* Case Study 3) and is investing $70 million in retrofitting their storm-water infrastructure (Rickett et al., 2006).

Projected increases in the frequency, and possibly the intensity, of extreme rainfall events will result in increased summer flood risk (Hengeveld and Whitewood, 2005), with implications for large urban drainage systems (Table 3). The Toronto and Region Conservation Authority (TRCA) has recognized climate change

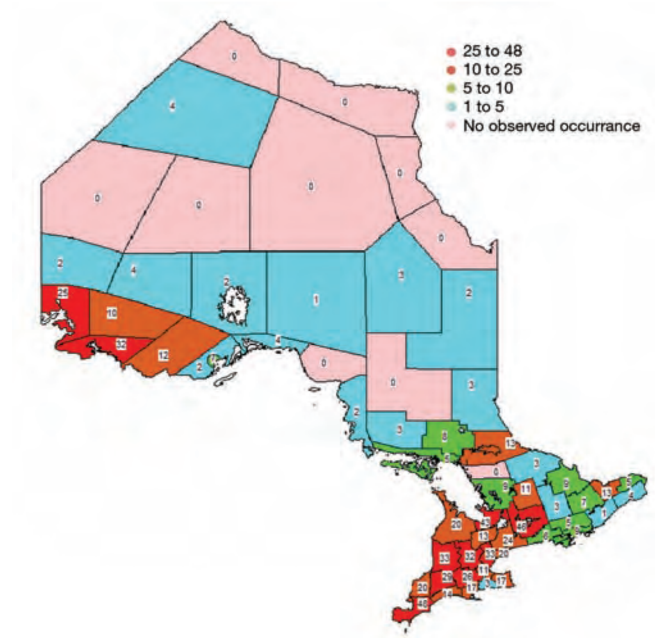

FIGURE 16: Occurences of heavy rainfall 1979-2004. Heavy rainfall is defined as rainfall that is greater or equal to 50 mm/hour or greater or equal to 75 mm in three hours (Environment Canada, 2005b).

as one of the key challenges facing its water management and conservation mandate (Toronto and Region Conservation Authority, 2006a). In 2005, the TRCA initiated work to enhance flood protection on the lower Don River. Following sensitivity testing to determine the potential impact of an increase in extreme rainfall on storm flows and flood levels, the TRCA designed the flood protection berm to be able to withstand a 15 to 20% increase in the regulatory flood to address future uncertainties, including climate change. Further, they designed the berm so that it could be raised 1 to 2 m in the future if required (Toronto and Region Conservation Authority, 2006b).

3.1.3 Human Health

There is a substantial body of literature dealing with the impacts of climate on human health in the south subregion of Ontario

CASE STUDY 2

Source-Water Protection

(*adapted from* de Loë and Berg, 2006)

Between May 8 and 12, 2000, extraordinary rainfall facilitated the transport of microbiological pathogens (*E. coli* 0157:H7 and *Campylobacter*) into the municipal water system in Walkerton, Ontario, through a shallow well. The source of the pathogen was manure that had been spread on a field using accepted best practices. Seven people died and 2300 became ill because of improper water disinfection treatment (O'Connor, 2002; Richards, 2005). In response to this tragic event and the subsequent public inquiry, provincial water policy has shifted towards a multi-barrier approach to ensuring drinking water safety. Although the inquiry report does not address climate change in any great detail, it does recognize that increasing frequency of extreme rainfall events as a result of climate change may have long-term impacts on the quality and quantity of drinking water sources in Ontario (O'Connor, 2002).

The Ontario Clean Water Act (CWA), passed in October 2006, requires that source-water protection plans be developed and reported based on assessments of water quantity and quality in each watershed of the province. These plans, among other things, must include a water budget for each watershed and identify existing and future threats to drinking water in vulnerable areas. The process also provides an opportunity for assessing vulnerability to climate change. Although the focus in the guidance document related to watershed characterization is on past and current trends, teams preparing these characterizations are also expected to consult appropriate climate change models. Therefore, the requirement to consider future climate change explicitly, in concert with other projected changes for the watershed (such as population growth and land-use or -intensification change) will allow comprehensive identification of vulnerable areas.

CASE STUDY 3

Extreme Rainfall and Storm-Water Infrastructure

Flood management planning relies on historical rainfall data to develop infrastructure design standards. These standards are generally based on the larger of the following two calculations: 1) the maximum peak flow in a basin that results from a storm with a return frequency of once every 100 years; or 2) the maximum peak flow that results from applying a 'design storm' (a historical storm that exceeds the once every 100 years storm) to the basin. Changes in basin characteristics, such as the proportion of impermeable surfaces, are also considered. The impacts associated with the following three examples highlight the vulnerability of critical infrastructure. Adaptation strategies that address infrastructure maintenance, upgrading and design will need to consider uncertainties in the changing frequency and magnitude of extreme climate events, existing infrastructure and land-use vulnerability, and the costs of proactive action relative to those of reactive recovery and repair.

South Subregion: North Toronto Flood, August 19, 2005

An intense storm system moving across southwestern Ontario on August 19, 2005 caused extensive flooding and infrastructure damage, and more than $500 million in insured losses (Klaassen and MacIver, 2006). Rain gauges at the northern end of the city recorded 103 mm of rainfall in one hour, and City of Toronto rain gauges recorded total rainfall of up to 153 mm during the roughly 4 hours of the rainfall event. Both measurements are two to more than three times the rainfall intensities of the 1954 Hurricane Hazel design storm (Environment Canada, 2005a). The 2005 storm highlighted the interconnectivity of different kinds of infrastructure in large urban areas, and the resulting vulnerabilities. For example, the storm resulted in the collapse of a section of Finch Avenue, a major arterial street, which resulted in damage to two high-pressure gas mains, a potable water main, and telephone, hydro and cable service lines that were buried beneath the road (Figure 17).

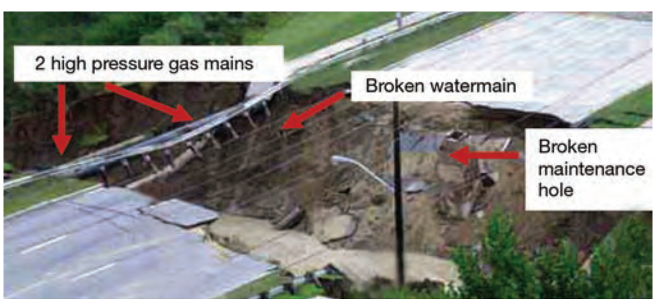

FIGURE 17: Damage at Finch Avenue and Black Creek, north Toronto flood, August 2005 (courtesy of City of Toronto).

South Subregion: Peterborough Flood, July 15, 2004

In July 2004, an intense one-hour storm hit the City of Peterborough (Figure 18) with almost as much rain as would be expected to fall in 24 hours from a 100-year design storm. A number of factors compounded the effect of the intense rainfall. First, rainfall was concentrated in downtown Peterborough, which consists of largely impervious paved surfaces, including streets that were not well designed to convey floodwater, thereby producing large overland flows. Second, it has been estimated that 82% of the pipes in the city's storm-water system did not meet current design standards, resulting in bottlenecks in the conveyance of floodwaters. Finally, excess water in the sanitary system from groundwater seepage into cracked or misaligned sanitary sewer pipes led to system back-ups and basement flooding. It has been estimated that the cost of actions to rectify the infrastructure deficiencies could reach $200M (Klaassen and Seifert, 2006).

The Peterborough flood resulted in $95 million in insured loses (Insurance Bureau of Canada, 2005) and illustrates the importance of non-climatic factors in determining vulnerability to flood risk.

FIGURE 18: July 2004 flood, Peterborough, Ontario (courtesy of City of Peterborough Emergency Management Division).

Central Subregion: Northwestern Ontario Storm, June 8 to 11, 2002

Between June 8 and 11, 2002 a series of very intense thunderstorms dropped between 220 and 401 mm of rain in the central subregion of Ontario, far exceeding previous records (Klaassen, 2005). Rail and road networks were disrupted, and estimated damages directly related to flooding totalled $31 million in Ontario, more than $7 million in Manitoba and an estimated US$70 million in Minnesota and North Dakota (Figure 19; Cummine et al., 2004; Klaassen, 2005; Groeneveld, 2006).

The Longbow Dam basin (49 km^2), which received 187 mm of rain and a peak flow of 30.1 m^3/s in the 1961 Timmins design storm, received 361 mm of rain and a peak flow of 57 m^3/s during the 2002 event (Groeneveld, 2006). Based on the historical record, this one event has been calculated to have a return period of 1486 years. Water managers and engineers need to consider whether the 2002 event should now serve as the design storm for planning purposes.

FIGURE 19: June 2002 storm, northwestern Ontario (Groeneveld, 2006).

TABLE 3: Sensitivities of large urban drainage systems to climate change (*adapted from* Kije Sipe Ltd., 2001).

Anticipated climate change	Expected system sensitivity		
	Combined systems	**Partially separated systems**	**Fully separated systems**
Increased rainfall intensities, similar event type and similar annual volume	Increased risk of basement flooding. Lower level of service.	Minor impact on peak flows and available capacity.	Minimal impact on peak flows and available capacity.
Increased frequency of large volume–high intensity events, similar annual volume	Increased risk of basement flooding. Lower level of service. Potential increase in combined sewer overflow (CSO) volume but reduced frequency.	Increased risk of surcharge and basement flooding. Lower level of service.	Potential impact on available capacity for growth. Increased risk of sewer surcharge and risk of flooding.
Increased rainfall event frequency and annual volume, minimal increase in peak intensities or frequency of large volume events	Minimal impact on system capacity. Increase in CSO volume and frequency.	Potential increase in risk of system flooding. Potential impact on wastewater treatment costs as a result of volume and degraded quality.	Potential impact on wastewater treatment as a result of volume and degraded quality.

(e.g. Smoyer et al., 2000; Last and Chiotti, 2001; Chiotti et al., 2002; Cheng et al., 2005). The most significant impacts are likely to relate to temperature stress; air pollution; extreme weather events; vector-, rodent- and water-borne diseases; and exposure to ultraviolet (UV) radiation.

Temperature Stress

The south subregion experiences warmer temperatures and higher humidity, relative to other regions of the province, due to many factors, including urban heat-island effects that can produce temperatures as much as 3°C warmer than in surrounding rural areas (Gough and Rozanov, 2002). Environment Canada issues a Humidex Advisory when the temperature is forecast to reach 30°C or when the humidex reading (considering both temperature and relative humidity) reaches 40°C (Smoyer et al., 1999, 2000). The estimated average number of excess deaths during periods of hot weather in 1999 amounted to 120, 41 and 37 for Toronto, Ottawa and Windsor, respectively (Cheng et al., 2005). Ambulance calls and hospital admissions in cities in the south subregion generally increase during hot weather (Thompson et al., 2001; Dolney and Sheridan, 2006).

Climate change projections of milder winters and warmer summers will have both positive and negative consequences for temperature-related morbidity and mortality. The annual average number of 'hot days' (1961–2000) with temperatures of 30°C or above was 8 in Toronto, 8 in Ottawa and 15 in Windsor (Cheng et al., 2005). According to Cheng and Campbell (2005), these numbers could more than double in these cities by 2050, and more than triple in Windsor and nearly quadruple in Toronto and Ottawa by the 2080s. In the absence of effective adaptation measures, this could lead to a proportionate increase in the number of heat-related deaths. In contrast, cold-related mortality could decrease by about 45% for Ottawa and 60% for Windsor and Toronto by 2050, and by 60 to 70% in all three cities by 2080 (Cheng et al., 2005; Pengelly et al., 2005). However, this positive health impact may be counterbalanced by the increased risk of winter mortality associated with air pollution, if climate change is associated with increased incursions of maritime tropical air masses into the subregion during winter (Rainham et al., 2005).

Concern over the potential for more frequent heat waves has prompted seven municipalities in the south subregion to develop heat-alert plans, most of them based on humidex advisories. The City of Toronto's Hot Weather Response Plan (Case Study 4), which was part of a World Health Organization–World Meteorological Organization showcase project, uses a spatial synoptic classification system based on local climate conditions, and incorporates information on the impacts of, and responses to, past heat waves (Rainham et al., 2005). Other communities across the GTA are considering adopting their own synoptic classification systems based on the Toronto model.

Air Pollution and Related Diseases

Thousands of Canadians die prematurely each year from short- and long-term exposure to air pollution (Judek et al., 2004). The Ontario Medical Association (2005) has estimated that the annual illness costs of air pollution in Ontario include 5 800 premature deaths, more than 16 000 hospital admissions, almost 60 000 emergency room visits and 29 million minor illness days. Estimates are also provided for 2015 and 2026, assuming no improvements in regional air pollution levels and taking into account an aging population. Under such conditions, the number of premature deaths is expected to rise to about 7 500 by 2015, and may exceed 10 000 by 2026. The total number of minor illness days is projected to increase to more than 38 million annually by 2026, with most of this increase associated with persons 65 years and older (Ontario Medical Association, 2005).

CASE STUDY 4

Toronto's Hot Weather Response Plan

The City of Toronto's Hot Weather Response Plan is an example of municipal adaptation to changing climate, and highlights how frequent review, assessment and refinement of adaptation measures can reduce vulnerability. The response plan is designed to alert those most at risk to heat-related illness and death due to hot weather conditions that either exist or are expected, and of the need to take precautionary action. High-risk groups include socially isolated seniors, persons with chronic and pre-existing illnesses (including mental illness), children and persons who have low incomes or are homeless.

The process of developing Toronto's plan began in 1998, when the Seniors Task Force and Advisory Committee on Homelessness and Socially Isolated Persons asked Toronto Public Health to develop a comprehensive hot weather emergency response plan. This was the result of the increasingly hot summers in Toronto, and the devastating effects of heat waves in the United States, including that in Chicago in 1995. Toronto Public Health was tasked with identifying weather conditions that would establish the threshold for calling a heat alert, and the development of a co-ordinated response plan involving all key partners. An initial heat alert system introduced in 1999 was based on forecast humidex readings over 40°C. However, rapid changes in humidex levels made this threshold of limited value. Furthermore, studies found that heat-related deaths were occurring in the south subregion when the humidex was less than 40ºC, again suggesting the need for a more appropriate threshold measure.

The summer of 2001 saw the launch of an improved alert system developed specifically for Toronto. The system utilizes calculations of the probability of excess morbidity or mortality, based on local climate conditions (e.g. temperature and dew point, wind speed and direction, and cloud cover), and incorporates information on the impacts of, and responses to, past heat waves (Rainham et al., 2005). The system utilizes historical meteorological and mortality data, classifies weather according to air masses and then determines the most 'oppressive' weather types and conditions that affect the city's population. An alert is issued when an oppressive air mass is forecast for the area. A heat alert is issued when the likelihood of excess mortality is between 65 and 90%; when this likelihood exceeds 90%, a heat emergency is issued. A heat emergency will always be preceded by at least a one-day heat alert, in order to ensure that everything is in place to provide the appropriate emergency response.

When a heat alert is issued, Toronto Public Health officials notify the media and community stakeholders likely to be affected by extreme temperatures, such as child care centres, long-term care facilities and hospitals, local shelters and community agencies. Other measures include distributing bottled water where the vulnerable are likely to gather, asking shelters to ease their curfew rules and providing a Heat Information Hotline to answer heat-related questions. If a heat emergency is called, additional actions taken include the opening and staffing by Community and Neighbourhood Services of four cooling centres located in city-owned buildings throughout the city. If needed, one of the centres would be open 24 hours, and bottled water, cots and an air-conditioned space would be available to anyone needing them.

Three times a year, a Hot Weather Response Committee meets to monitor, evaluate and update the Hot Weather Response Plan. Early changes included having the Red Cross operate the Heat Information Hotline on all days when an alert is called, including weekends, and co-ordinate the distribution of bottled water. In 2001, additional partners were recruited and outreach efforts were enhanced. Steps were taken to ensure that 1) drinking water fountains in city parks were functioning properly; 2) the hours of operation for city pools would be extended during heat alerts; and 3) street patrol teams would provide free transit tokens to those found to be in need of a cooling centre.

A record number of heat alert–heat emergency days was issued in Toronto in 2005. Despite full implementation of the Hot Weather Response Plan, a number of heat-related deaths prompted a coroners inquiry and calls for improvements to cooling centres, including their opening in the event of a heat alert, not just a heat emergency. Of particular concern was that many vulnerable groups do not have access to a TV, radio or telephone, and may therefore be unaware that a heat alert or emergency had been announced. In response, Toronto Public Health embarked on a targeted, city-wide education campaign of landlords and tenants regarding the health risks of heat stress, especially for persons taking psychiatric drugs and other medications.

A Hot Weather Response Plan based on the Toronto system is being developed for Peel Region, while the Region of Waterloo, the Regional Municipality of Halton, the City of Kingston and the City of Ottawa have introduced advisory systems based on Environment Canada's humidex advisories, with the latter two municipalities also incorporating air-quality conditions into their heat advisories.

Higher temperatures associated with climate change will increase the potential for photochemical oxidant (smog) formation (Pellegrini et al., 2007), and also increase ambient air concentrations of pollen (Breton et al., 2006). Increased energy use, and especially increased demand for air conditioning in summer, could also have a significant impact on air quality, depending upon how electricity is generated. Cheng et al. (2005) provided projections for air quality in the Windsor, Toronto and Ottawa regions, and concluded that premature death associated with air pollution could increase 15 to 25% by 2050 and 20 to 40% by 2080.

The Ontario Ministry of the Environment currently calculates and publishes an air-quality index for 37 urban and rural sites across the province, and provides air-quality forecasts year round. These initiatives are important means of minimizing exposure of vulnerable people during poor air-quality days. Many municipalities in the south subregion have developed their own smog response plans, based on provincial guidelines (Ontario Ministry of the Environment, 2005). These plans tend to focus on emission reduction measures that address the immediate local contribution to pollution levels, but also recommend measures that individuals can adopt, such as reducing outdoor physical activity, to lower their risk of exposure to air pollutants.

Extreme Weather Events

Extreme weather and associated natural hazards can have significant direct and indirect impacts on human health. In the last 55 years, the south subregion has experienced a number of notable extreme weather events, including Hurricane Hazel in 1954, the Barrie tornado in 1985, the ice storm of 1998 and the Toronto snowstorm in 1999, among others (Mills et al., 2001; Chiotti et al., 2002). The 1998 ice storm, which in Canada impacted eastern Ontario, southern Quebec and parts of the Atlantic provinces, resulted in 28 deaths, an estimated 60 000 physical injuries and tens of thousands of individuals potentially affected by post–traumatic stress disorder (Edwards et al., 1999; Kerry et al., 1999; Chiotti et al., 2002).

Climate models project that certain kinds of extreme weather are expected to become more frequent in a warmer world (e.g. Intergovernmental Panel on Climate Change, 2007; *see* Chapter 2). Based on historical experience, the associated health impacts could be considerable (Chiotti et al., 2002). In addition to death and injuries directly attributable to natural hazards, examples of indirect impacts include injuries associated with serious traffic accidents that are often caused by extreme weather (Andrey and Mills, 2003), and illness associated with the spread of toxic moulds and compromised indoor air quality that may follow flooding of residential and institutional buildings.

Vector- and Rodent-Borne Diseases

Future changes in climate could lead to more favourable conditions for the establishment and re-emergence of vector- and rodent-borne diseases, as evidenced by the recent spread of Lyme disease (Ogden et al., 2004, 2005, 2006a–c). The range of the tick vector, *Ixodes scapularis*, is thought to be constrained by temperature, spring migratory bird densities and woodland habitats (Ogden et al., 2004). Although this tick has historically been isolated along the north shores of Lake Erie and Lake Ontario, it has recently been discovered that birds migrating northward in spring are carrying *I. scapularis* long distances north and west, beyond the boundaries of Ontario and into neighbouring provinces (Ogden et al., 2006a). Projected temperature increases could lead to the northward expansion of the potential range for Lyme disease by up to 1000 km, while greatly increasing the survival rate of ticks in the south subregion (Ogden et al., 2005a, 2006b). The current health risks related to infected ticks are well recognized by public health officials in the south subregion (Charron and Sockett, 2005).

The first death in Ontario from hantavirus pulmonary syndrome (HPS), a rare but very serious lung disease transmitted to humans through the urine, saliva and droppings of rodents, was recorded in Owen Sound in 1997 (Egan, 1997; *see* Section 3.2.6). Since outbreaks of HPS in the United States have been greatly influenced by weather (Glass et al., 2000; Hjelle and Glass, 2000; Charron et al., 2003), changing climate may alter the health risk in Ontario, especially in the urban-rural fringe where people and mice are likely to come into contact (Chiotti et al., 2002). However, there are a number of measures that can be taken to reduce human exposure to the virus, such as preventing access of rodents to buildings and precautionary measures for handling of dead rodents.

Examples of mosquito-borne diseases that may become more prevalent as a result of climate change include West Nile virus and malaria (cf. Duncan et al., 1997; Chiotti et al., 2002). West Nile virus arrived in Ontario in 2001, and its rapid spread throughout the province has been related to weather conditions favourable to the host vector (Chiotti et al., 2002). Domestically contracted malaria is not currently a health concern, although the climate is capable of supporting the mosquito vector species. Of more immediate concern for the health care system is the importation of the disease as the result of increased travel and immigration, and the disease's increased resistance to drugs (Chiotti et al., 2002; Riedel, 2004).

Water-Borne Diseases

The young, the elderly and people with impaired immune systems are particularly sensitive to water-borne gastrointestinal diseases. The incidence of enteric infections, such as *Salmonella* and *Escherichia coli* (*E. coli*), is sensitive to weather conditions, particularly heavy rainfall and high temperatures, and climate change could lead to an increased risk of such infections (Schuster et al., 2005; Waltner-Toews, 2005). Non-climatic factors, such as close proximity to animal populations, treatment system malfunctions, poor maintenance of infrastructure and treatment practices have all been associated with past disease outbreaks from drinking water supplies (Schuster et al., 2005). Historical experience, including the Walkerton outbreak described previously, indicates that Ontario's water supply is vulnerable to weather-induced water-borne disease outbreaks (Richards, 2005). Source-water protection represents an important first step in reducing the risks of water-borne diseases (*see* Case Study 2). Auld et al. (2004) proposed using weather monitoring and forecast information as the basis for a 'wellhead alert system', in order to alert managers of water supply systems to weather conditions that could increase the risk of system contamination.

Ultraviolet Radiation

If projected warming leads to an increase in outdoor activities, there is an associated risk of greater exposure to ultraviolet (UV) radiation (Craig, 1999; Chiotti et al., 2002; Riedel, 2004). Related health impacts would include temporary skin damage (sunburn), eye damage (e.g. cataracts) and increased rates of skin cancer (Martens, 1998; Walter et al., 1999). Toronto is already experiencing an increase in the number of days with high or extreme UV readings (Perrotta, 1999). A UV index is issued daily across Canada, as part of a broader adaptive response by public health departments to educate the public about health risks associated with UV exposure.

3.1.4 Agriculture

Studies examining the impacts of climate and climate change on agriculture in the south subregion include discussion of technological, institutional and behavioural adaptations that reduce the vulnerability of crop production, farming systems and agriculture-dependent communities to climate-related risks (Bryant et al., 2000; Wall et al., 2007). Agriculture has a long history of adaptation based on management of risk. For example, agricultural support programs have proven to be an important mechanism for dealing with the short-term impacts of recent drought, with crop insurance payments from 2000 to 2004 exceeding $600 million (Figure 20).

The relationship between climate and agriculture is complex, with a wide range of climate parameters influencing crop and livestock production. These include maximum and minimum temperatures, growing degree days, length of growing season, amount and timing of rainfall, extreme weather events, drought, snow cover and frost periods. Climate change also indirectly impacts agricultural productivity by affecting the viability of pests, invasive species, weeds and disease, and through interactions with other air issues, such as acid rain and smog. Projected changes in agri-climate conditions could be beneficial for production of many crops, including corn, sorghum, soybeans, maize and some forage crops, and could lead to a northward extension of crop production (e.g. Singh et al., 1998; Andresen et al., 2000). Fruit production could also benefit from a longer growing season and seasonal heat accumulation (Winkler et al., 2002).

However, most impact studies do not include potential effects of pest infestations or other disturbances, the impacts from extreme weather events, or the cumulative impacts of climate change and other air issues, such as acid deposition and air pollution (Drohan et al., 2002). Projections based on average temperatures and precipitation also do not always consider important spatial and inter-annual variability in agri-climate (Kling et al., 2003). When factors such as the frequency and timing of threshold events (e.g. fall and spring freeze dates) are considered, it appears that farming in the south region of Ontario will remain vulnerable to springtime cold injury (Winkler et al., 2002). In the case of the grape and wine industry, warmer winter temperatures and less snow cover could also have adverse impacts on icewine production, depending on the timing and frequency of the cold spells that are required for harvesting (Chiotti and Bain, 2000).

Climate change is expected to produce conditions that favour agricultural pests and diseases, which could negatively impact crop production. Increased migration, reproduction, feeding activity and population dynamics of insects, pests and mites are expected to lead to greater crop losses (Lipa, 1999). Similarly, changing climate is projected to alter the geographic distribution of plant diseases and challenge existing plant disease management practices (Chakraborty et al., 2000). Climate change may also impact the survival of pathogens, the rate of disease progress during a growing season and the duration of the annual epidemic in relation to the host plant (Boland et al., 2003). Invasive weed species are expected to show a strong growth response to increased atmospheric CO_2 levels, which may possibly be combined with a weakened efficacy of herbicides (e.g. Archambault et al., 2001; Ziska, 2004). While it is widely recognized that too much or too little precipitation has more pronounced effects on plant disease than temperature, there is comparatively little research on plant disease management (cf. Boland et al., 2003; Coakley, 2004; Guiterrez, 2004).

Changing climate may also have direct impacts on livestock production. For example, increases in heat stress are expected to result in lower weight gains in beef cattle, lower milk production in dairy cattle, and lower conception rates and substantial losses in poultry production (e.g. Owensby et al., 1996; Kling et al., 2003). Climate change also affects animal diseases, and therefore livestock production, by altering the chances for survival and enhancement of insect vectors (ticks, mosquitoes) and associated diseases that are presently considered exotic or rare (Charron et al., 2003). Milder winters may reduce some current problems, such as pneumonia in adult cattle, but will also increase parasite survival in and on animals. Water supplies for livestock can be

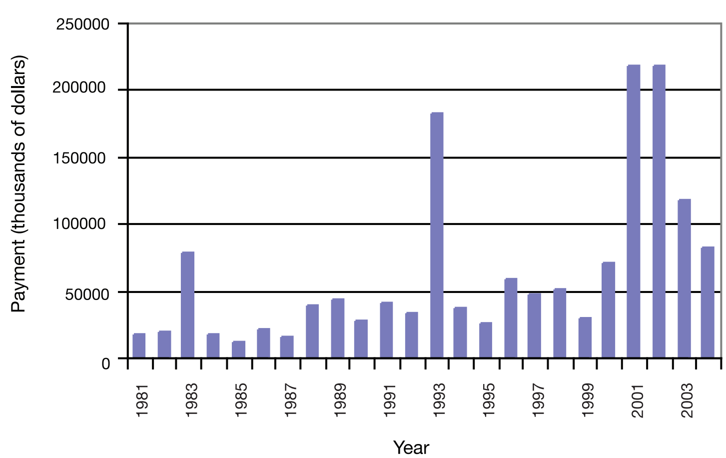

FIGURE 20: Ontario crop insurance payments, 1981–2004 (Statistics Canada, 2005).

contaminated by run-off in watersheds where heavy rainfalls flush bacteria and parasites into water systems. In extreme drought conditions, the potential for water to become toxic from sulphur and Cyanobacteria (blue-green algae) creates serious problems for cattle production (Prairie Farm Rehabilitation Administration, 2003).

Producers' perceptions of climate risk appear to vary by commodity (Harwood et al., 1999). In the south subregion, cash crop producers voiced more concern about impacts from climate change than livestock operators during focus group discussions (Reid, 2003). Generally speaking, Canadian producers think the agricultural industry will continue to furnish adequate technological solutions to meet a variety of risks, including stresses from changing climate and weather conditions (Holloway and Ilbery, 1996; Brklacich et al., 1997; Bryant et al., 2000; Smit et al., 2000).

Producers inevitably face risks associated with year-to-year climate variability (Kling et al., 2003), with the greatest fluctuations in farm profits resulting from variability in precipitation and extended frost-free seasons (Brklacich and Smit, 1992). The capacity of individual producers to manage risk and undertake adaptation depends on many factors, including the size and diversity of their operations. Livestock operators, whose farms tend to be relatively large, are likely to adopt a wider range of actions than farmers who presently have diversified operations (Brklacich et al., 1997). Small- to medium-size operations will be relatively more disadvantaged in higher risk circumstances (Kling et al., 2003).

The impacts of the 1998 ice storm, where dairy farmers in Ontario were impacted more severely than their Quebec counterparts, demonstrate how experience can significantly affect vulnerability. Ontario operators had not generally been exposed to frequent losses of electricity prior to this major storm; as a result, only about 20% of them had backup generators in place (Kerry et al., 1999). Since the ice storm, there has been a substantial increase in the installation of backup generators in rural areas, reflecting responsive adaptation.

Ontario producers perceive that climate conditions have changed noticeably in the past five years, and their responsive actions have included growing different crops and/or crop varieties, altering tile drainage, employing conservation tillage, changing the timing of planting and installing irrigation systems (Canadian Climate Impacts and Adaptation Research Network–Agriculture, 2002; Wall et al., 2007). Soybean producers have adapted to recent climate stresses by planting new or improved crop varieties, adopting crop rotation and altering the timing of planting (Smithers and Blay-Palmer, 2001). Tomato producers in the southwestern part of the south subregion have adopted measures to reduce the impact of extended droughts, including the use of improved irrigation systems adapted from Australia. In 2002, one of the driest years in history, Ontario tomato growers who were using the new system had their second highest yield ever (Agriculture and Agri-Food Canada, 2003). Given recent drought, decreases in streamflows and increased irrigation demands, producers at the community level in the south subregion have worked with local water managers to develop a framework for participatory irrigation advisory committees to ensure both the fair sharing principle and the maintenance of flows for ecosystem services (Shortt et al., 2004).

3.1.5 Energy

Changes in Great Lakes water levels and temperatures directly impact hydroelectricity generation in the south subregion. Historical water level changes (*see* Case Study 1) have reduced hydroelectricity output by up to 26% at some stations and required that additional supplies of electricity be secured from other domestic or American sources during periods of peak demand (Mercier, 1997; Smith et al., 1998). In 1998, low water levels, in combination with hot summer temperatures that resulted in increased demand for air conditioning, placed considerable stress on the electricity generation and transmission system (Ligeti et al., 2006). In recent years, rising water temperatures in the Great Lakes have impacted electricity generation from nuclear and coal-fired plants by reducing the efficiency of their cooling systems, and could potentially force cutbacks in production in order to meet limits on the temperature of discharged water (Spears, 2003).

The transmission and distribution grid is also sensitive to extreme weather events. The impacts of the 1998 ice storm on the south subregion were most severe in the Ottawa to Kingston area, affecting 600 000 electricity consumers, damaging more than 100 high-voltage transmission towers and requiring at least 10 500 new poles (Kerry et al., 1999; Chiotti, 2004; *see also* Chapter 5). A number of storms, generally associated with strong winds, disrupted service to hundreds of thousands of customers in a 12-month period beginning September 2005 (McMillan and Munroe, 2006; Table 4). Extreme summer warmth results in

TABLE 4: Storm damage to electricity transmission and distribution grid in the south subregion of Ontario, September 2005 to September 2006 (*from* McMillan and Monroe, 2006).

Severe storm dates	Customers affected (loss of service)
September 29, 2005	93 000
November 6, 2005	120 000
November 16, 2005	50 000
February 4, 2006	100 000
July 17, 2006	170 000
August 2, 2006	150 000
September 24 and 27, 2006	93 000

greater losses along the transmission and distribution lines. In 2002, these losses amounted to 11.5 kW•h, or 7.5%, of the province's total generation supply (Ontario Energy Board, 2004; Gibbons and Fracassi, 2005).

The 2003 summer blackout in southeastern Canada and the northeastern United States, although not directly caused by hot weather, demonstrated the vulnerability of the electricity transmission system and illustrated the types of impact that Ontario could experience as a result of future large-scale power interruptions. Although the shutdown and restart of hydro, coal-fired and nuclear electricity generating facilities were done in an orderly fashion, full power was not restored until 11 days after the blackout began (Ontario Ministry of Energy, 2004; United States–Canada Power System Outage Task Force, 2004). Although the exact costs of the blackout are unknown, gross domestic product in Canada was down 0.7% in August, there was a net loss of 18.9 million work hours and manufacturing shipments in Ontario were down $2.3 billion (United States–Canada Power System Outage Task Force, 2004). The blackout also put at risk vulnerable persons, such as the elderly, mothers and children in shelters, and persons in palliative care units (Ligeti et al., 2006).

Changing climate, with a trend towards warmer winters and hotter summers, has contributed to the peak energy demand in Ontario now occurring in summer (Independent Electricity System Operator, 2006). Electricity demand decreases as mean daily temperatures rise until roughly 18°C, the threshold at which electricity demand begins to climb (Cheng et al., 2001; Figure 21). Annual heating degree days have decreased in Toronto during the past century (Figure 22), with the lowest number of heating degree days occurring in the warmest year on record (1998), due

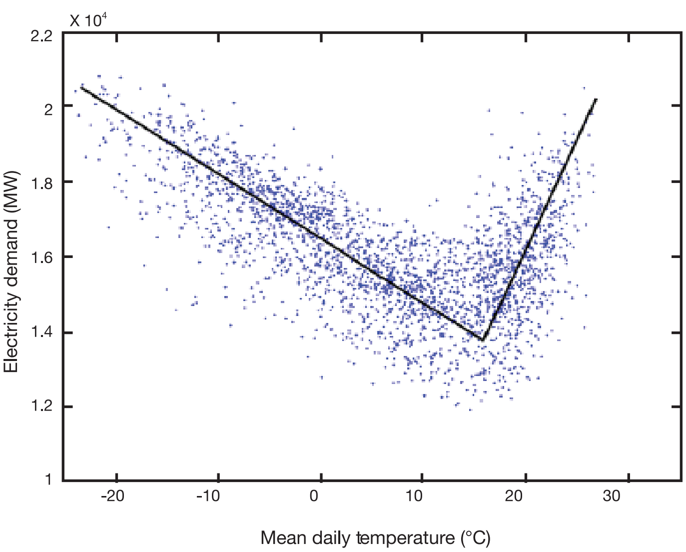

FIGURE 21: Impact of mean daily temperature on electricity demand in Ontario (Cheng et al., 2001).

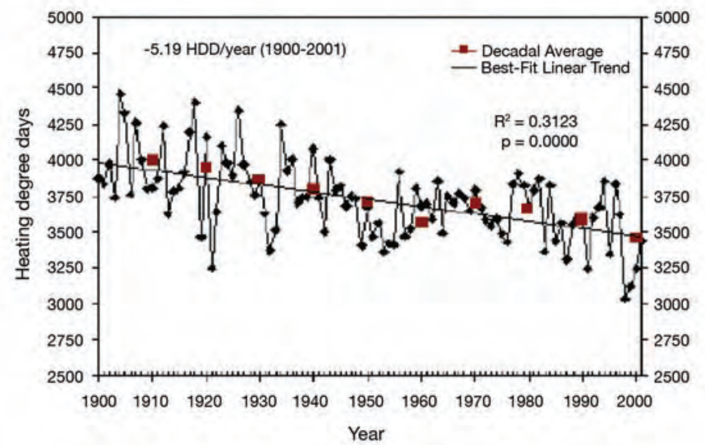

FIGURE 22: Annual heating degree days (HDD) in Toronto, 1900–2000 (Klaassen, 2003).

largely to unusually mild winter temperatures (Klaassen, 2003; Chiotti, 2004). Recently, this ongoing decrease has lowered demand for heating fuels, including natural gas (Klaassen, 2003).

Projected impacts of Great Lakes water level changes (Case Study 1) on hydroelectricity facilities on the Niagara and St. Lawrence rivers for 2050 range from small increases in production to a 50% decline in hydroelectricity output, the latter representing a loss of more than 1100 MW annually (Buttle et al., 2004; note that this analysis does not consider the potential contributions of any new hydroelectric developments). The decline could be even more significant during extremely low water years (Buttle et al., 2004). Lower water levels in the Great Lakes will also impact the cost of shipping coal to supply coal-fired electricity generating plants (Quinn, 2002; Millerd, 2005). If these plants are still operating in 2050, the average annual cost of shipping coal from American Lake Erie ports and Lake Superior ports could be 13 to 34% higher than in 2001 (Millerd, 2005). Continued warming of Great Lakes water will further reduce cooling efficiency in nuclear and coal-fired generating plants. Output has been reduced from 1 to 3% during past hot summers (Chiotti, 2004).

Future changes in the frequency and magnitude of extreme weather events, particularly ice storms, heavy snow storms and wind storms, are likely to increase the risk of interrupted electricity supply and distribution. For example, the frequency and duration of freezing rain events are projected to increase throughout the subregion, with greater increases in the eastern portion (e.g. Ottawa) and smaller increases in the south-central portion (e.g. Toronto; Klaasen et al., 2003; Cheng et al., 2007). In the event of future catastrophic failures of the electricity transmission system, large urban areas are at higher risk of extended blackouts because local electricity generation, as a percentage of local electricity consumption, is very low in Toronto (1.2 per cent), London (4.4 per cent) and Hamilton (0.8 per cent; Gibbons and Fracassi, 2005).

Demand for electricity in the south subregion will continue to reflect changing climate, with summer demand projected to increase significantly (Figure 23), although average monthly demand may still be highest in winter, particularly in unusually cold years (Klaassen, 2003). Changes in electricity demand are significantly higher for changes in cooling degree days than for changes in heating degree days, depending on the cooling source (Canadian Council of Ministers of the Environment, 2003), with a 1°C increase in summer temperature having four to five times the impact on energy demand of a 1°C drop in temperature in winter (Cheng et al., 2001).

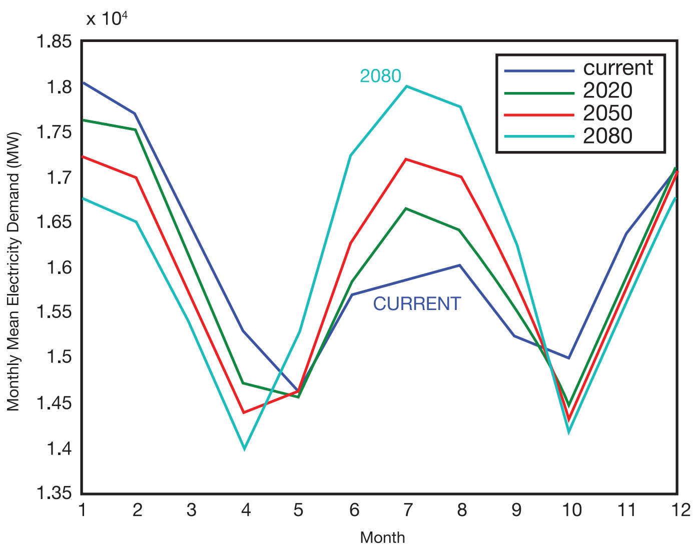

FIGURE 23: Projections of monthly mean electricity demand in Ontario as a result of climate change (Cheng et al., 2001).

Further changes in Ontario's energy mix will be necessitated by decreased hydroelectric capacity of existing Great Lakes facilities and increased energy demand for summer cooling. Some options, such as the greater use of coal, will not likely be considered viable in the future (Mirza, 2004), thus placing more emphasis on nuclear, combined-cycle natural gas, untapped hydroelectric sources and other renewable sources. For example, there is considerable wind power potential in the south subregion, much of it located along the shores of the Great Lakes (Figure 6). The potential for wind, solar, biomass and new river-run hydro has been estimated to be considerably greater than the province's proposed green power target of 10% of its total energy capacity by 2010 (Pollution Probe and the Summerhill Group, 2004). However, none of these renewable sources can address short-term increases in peak demand as effectively as large-scale hydroelectric developments (Pollution Probe and the Summerhill Group, 2004).

Increased energy efficiency, as well as behavioural changes on the part of consumers, should play a significant role in reducing total demand. Extreme estimates for more energy efficiency are in the 50% range (ICF Consulting, 2005), and adaptation measures such as developing green roofs and expanding urban forests could lead to even more energy savings by reducing the urban heat-island effect (Banting et al., 2005). Peters et al. (2006) have argued that aggressive energy efficiency measures could be implemented in Ontario relatively quickly and cost effectively.

3.1.6 Transportation

Shipping

The Great Lakes–St. Lawrence River system provides a convenient, low-cost and relatively environmentally friendly means of commercial transportation (Millerd, 2005). Handling approximately 200 million tonnes of cargo each year, the seaway provides access to the industrial heart of North America. Almost 50% of seaway traffic travels to and from ports in Europe, the Middle East and Africa (Statistics Canada, 2005; Great Lakes–St. Lawrence Seaway System, 2006; Transport Canada, 2006).

Most vessels used are designed specifically for the seaway, and are operated to take advantage of maximum water depths in connecting channels and ports. As such, their usable capacity diminishes with decreases in water levels (Millerd, 2005; *see* Case Study 1). Depending on the size of the ship, each 2.5 cm loss in draft translates into between 100 and 270 tonnes of lost carrying capacity (Lindberg and Albercook, 2000). During 2000, lake cargo carriers were forced to reduce their loads by 5 to 8% and, in 2001 a proportion of the slow-down in navigation (causing a $11.25 million decrease in business volume) could be attributed to low water levels (AMEC Earth and Environmental, 2006; International Lake Ontario–St. Lawrence River Study Board, 2006). In October 2001, sustained high winds on Lake Erie resulted in already low water levels falling another 1.5 m at the lake's western end, making the link between lakes Erie and Huron impassable for large vessels for two days (Canadian Council of Ministers of the Environment, 2003).

Adaptive measures to address future decreases in Great Lakes water levels include reducing the weight carried per ship and dredging connecting channels and ports, both of which have significant environmental and economic costs. Projected increases in shipping costs by 2050 range from 8 to 29%, depending on commodity, with higher increases for coal, aggregates and salt, and lower increases for petroleum products and grain (Millerd, 2005). Some of these costs could be offset by a longer shipping season because of warmer winter temperatures and reduced winter stockpiling and ice-breaking costs, but this has not been assessed (Millerd, 2005). Increased costs will reduce the competitive advantage of shipping by water, and shifts in modes of transport may occur. In some cases, operations established specifically to access the low-cost water transportation, such as some gravel, sand and stone quarries, may no longer be economically viable (Millerd, 2005).

Extensive dredging could be employed to deepen channels and harbours and keep connecting rivers navigable for commercial shipping. Estimated costs have been as high as US$31 million per harbour on the American Great Lakes, not including the costs associated with physical infrastructure (Changnon et al., 1989; AMEC Earth and Environmental, 2006). For the 101 km Illinois shoreline of Lake Michigan including the Port of Chicago, it was estimated that $138 to $312 million would be needed over a 50-year period for dredging harbours to compensate for a 1.25 to 2.5 m decline in lake level. Another study estimated dredging costs as high as $6.84 million for Goderich harbour on Lake Huron if water levels were to drop 1 m below February 2001 levels (Schwartz et al., 2004). These cost estimates do not include treatment costs or other environmental risks related to contaminated materials brought up during the dredging (Moulton and Cuthbert, 2000; *see* Case Study 1).

Road and Rail

The most significant impacts of changing climate on land transportation in the south subregion are expected to be temperature-related damage to paved roads and rail systems, snow and ice control, and infrastructure damage related to heavy rainfalls and other extreme weather events.

Climate variability exacerbates rutting, thermal cracking and frost heaving of paved surfaces. Increases in the number and severity of hot days in southern Ontario will result in an increase in rutting and flushing or bleeding of asphalt from older pavement, which in turn affects functional performance of the pavement (ride quality) and has implications for safety and maintenance costs (Mills and Andrey, 2002). Currently, however, cold winter temperatures are a much greater concern for paved surfaces in Canada than summer heat. Freeze-thaw cycles accelerate road deterioration, particularly in wet areas with a subgrade composed of fine-grained sediments (Haas et al., 1999). Freeze-thaw cycles have increased in recent years in the south subregion, except in the City of Toronto, where they have decreased (Canadian Council of Ministers of the Environment, 2003). As a result of an increase in freeze-thaw cycles, the County of Haldimand is accelerating its conversion of granular roads to tar and chip roads (Brûlé and McCormick, 2005). Although some studies suggest that freeze-thaw cycles will decrease significantly in the south subregion by 2050 (e.g. Andrey and Mills, 2003), detailed analysis for Toronto suggests that projected warming is unlikely to significantly change the number of freeze-thaw cycles experienced this century (Ho and Gough, 2006).

Railway track can experience buckling in extreme summer heat. While buckling is likely to become more frequent in future, cold temperatures and winter conditions are currently responsible for a much greater proportion of the damage to tracks, switches and railcars. Based on limited analysis, a warmer climate is expected to have a net benefit for rail infrastructure in Ontario (Andrey and Mills, 2003).

The Province of Ontario allocates approximately $120 million per year to de-ice and plough provincially designated roads (Andrey et al., 1999). Snow and ice removal is also a significant component of municipal budgets. For example, the City of Ottawa spent $53.9 million in winter maintenance of roads, rights-of-ways and sidewalks in 2004 (City of Ottawa, 2005). Assessment of total costs for 1998 winter road maintenance incurred by the provincial government and municipalities representing 51.4% of the population calculated these costs at $273.5 million (Jones, 2003). Projected increases in freezing rain (Klaassen et al., 2003; Cheng et al., 2007) could increase de-icing costs in most areas of the province during the next 50 years, but overall snow removal costs are expected to decrease (Jones, 2003).

3.1.7 Tourism and Recreation

Cold Weather

The south subregion contains most of the downhill ski areas in Ontario, located primarily along the southern shore of Georgian Bay. Projections of decreases in the length of the ski season range from to 0 to 16% for the 2020s and 7 to 32% for the 2050s, with continually increasing dependence on machine-made snow (Scott et al., 2003, 2006). Future challenges to the ski industry may have been foreshadowed in January 2007, when the delayed start of winter, warm night-time temperatures and a lack of snow resulted in the first closure in the history of Intrawest Blue Mountain, Ontario's largest ski resort (Teotonio et al., 2007; Rush, 2006).

Vulnerability of ski-facility operators to these projected impacts is variable. Large corporate ski entities are generally less vulnerable to climate change impacts than are smaller ski operations. This is because large operations tend to have more diversified business operations involving real estate and four-season activities, and generally have greater capacity to make substantial investments in state-of-the-art snowmaking systems. Most importantly, however, corporate operations tend to be regionally diversified, reducing their overall business risk to poor snow conditions in one location (Scott et al., 2006).

The longstanding tradition of ice fishing in the subregion is diminishing as a result of reduced lake-ice cover and less safe ice conditions. During 1997–1998, the Lake Simcoe ice fishing season was 52% shorter than the near-normal winter of 2000–2001 (Scott et al., 2002). In 2002, the lack of ice on Lake Simcoe resulted in the cancellation of the Canadian Ice Fishing Championship. Winter festivals may also need to adapt to changing climate. For example, the renowned Rideau Canal Skateway in Ottawa is a key recreation resource and primary attraction for the city's Winterlude Festival. The average skating season between 2001 and 2006 was 50 days (Blackman, 2006). The 2002 skating season was one of the shortest on record (at 34 days), and the 2006 season was plagued by a delayed opening and sporadic closures. Organizers have adjusted by moving more activities on land and by making snow for slides and storing ice blocks (for sculptures) in large freezers (Blackman, 2006). The average skating season is projected to start later and last 43 to 52 days in the 2020s and 20 to 49 days in the 2050s (Scott et al., 2005; Jones et al., 2006).

Warm Weather

Although the recreational boating season is expected to increase as a result of longer ice-free seasons, the Great Lakes recreational boating and fishing industry is negatively impacted by extremely low water levels (Thorp and Stone, 2000; American Sportfishing Association, 2001). A 2001 survey of marinas on Lake Ontario and the upper St. Lawrence River found that fluctuating water levels had a 'major' or 'devastating' impact on the majority of respondents during the previous five years (McCullough Associates and Diane Mackie Associates, 2002). In response to low water levels on Lake Huron, the federal government created a $15 million Great Lakes Water-Level Emergency Response Program to aid marina owners and operators with emergency dredging costs (Scott and Jones, 2006a). Given that the frequency of low water levels is projected to increase in future, there is a high likelihood that marinas and recreational boaters will experience similar conditions to those experienced during 1999 to 2002 on a regular basis (Jones et al., 2005). Projected declines in water levels will also reduce navigability in some channels as a result of newly exposed sandbars and accelerated plant growth, necessitating changes in the location of launch points for boats and possibly requiring restrictions on the size and weight of boats allowed to operate in certain water bodies (Jones et al., 2005).

The recreational fishery in Ontario is the largest in Canada, valued at more than $1.5 billion annually (Ontario Ministry of Natural Resources, 2005a). Ecosystem changes described previously may force fishers seeking cold-water species to travel outside the south subregion (Minns and Moore, 1992). However, smallmouth bass, a popular warm-water sport fish species, is projected to increase substantially in eastern Lake Ontario and adjacent areas (Casselman et al., 2002). The sustainability of recreational fisheries may depend largely upon fishers being made aware of such changes, and their willingness to adjust their preferences to reflect new opportunities. The overall impact of climate change on recreational fisheries in Ontario remains uncertain, and any analysis would have to consider a range of potential adaptation responses, including changes in lake stocking strategies (Ontario Ministry of Natural Resources, 2005a).

Other important warm-weather recreation industries in Ontario are generally expected to benefit from the longer seasons that will result from changing climate, but adaptations will be needed to realize these benefits. The golf season in the Greater Toronto Area is projected to increase by up to 7 weeks in the 2020s and up to 12 weeks in the 2050s, with golf courses experiencing a 23 to 37% increase in annual rounds played in the 2020s, and a 27 to 61% increase in the 2050s (Scott and Jones, 2006b). Aspects of golf operations, including turf grass selection, irrigation and pest management, would need to be adapted for these increases to be realized. Higher temperatures will also extend the shoulder seasons for beach recreation, and increase demand during summer months. Analysis of beach use and lake swimming at several sites in the subregion projected a 2 to 4 week increase in season length by the 2020s, and an increase of as much as 8 weeks in the 2050s (Scott et al., 2005).

3.2 CENTRAL SUBREGION

The central subregion (Figure 1, Box 1) is characterized by huge areas with low population densities, vast expanses of forested land and a rich endowment of mineral resources. Most of the research on the impacts of climate variability and change in this subregion has focused on ecosystem impacts, particularly aquatic ecosystems and forest disturbance (Case Study 5). Climate change adaptation issues of greatest concern include the sustainability of resource-dependent communities, particularly those related to forestry and tourism, and the vulnerability of critical transportation infrastructure to extreme weather events.

3.2.1 Ecosystems

The entire central subregion lies within the Boreal Shield ecosystem. Changing climate will result in ecosystem shifts, including changes in the distribution of individual species. Paleoecological evidence demonstrates that, during past warm intervals (7000–3000 BP), thermal habitats were suitable for deciduous forest as far north as Timmins (Liu, 1990). Nonetheless, wholesale ecosystem changes will be limited by species-specific migration rates, as well as a host of environmental factors including soil types, migratory pathways and presence of pollinator species (e.g. Cherry, 1998; Thompson et al., 1998; Loehle, 2000). Hence, more southerly tree species (e.g. those in the oak-hickory forests of southwestern Ontario, south-central Minnesota and Michigan) would require hundreds of years to migrate naturally into the central subregion, even if suitable climate habitats are established in coming decades (Davis, 1989; Roberts, 1989). The lag between changes in regional climate and species response could result in reduced local biodiversity (Malcolm et al., 2002).

The net impact of climate change on forest productivity will be influenced by increases in the frost-free period, growing season temperatures and atmospheric CO_2 concentrations, as well as changes in moisture supply and disturbance regimes. Longer and warmer growing seasons, as well as enhanced CO_2 fertilization, will have a positive effect on tree growth (e.g. Colombo, 1998; Chen et al., 2006). At sites where moisture and soil nutrient supply are presently the limiting factors for tree growth, the positive effects of temperature and CO_2 increases may be minimal (e.g. Jarvis and Linder, 2000). In addition, elevated CO_2 will increase the growth of grasses and other understorey species, potentially delaying forest regeneration after disturbance (e.g. Gloser, 1996; Wagner, 2005).

The primary sources of natural disturbance in the boreal forest are insect outbreaks, disease, fire and wind, all of which will be impacted by climate change. Fire is an integral part of the Boreal Shield ecosystem. In more southerly portions of the boreal forest, where fire suppression is practiced, the area burned is limited to about 0.11% of the total forest per year (Ward et al., 2001). The length of the fire season has increased by up to 8 days in many Ontario boreal forest ecosystems since 1963 (R.S. McAlpine, unpublished data, 2005). Drought and high temperatures sometimes create conditions that make present fire suppression techniques ineffective. There is a strong interrelationship between forest fire risk and the impacts of forest pests and diseases, since dead trees increase the fuel load (Fleming et al., 2002; *see* Case Study 5). Weber and Flannigan (1997) concluded that changes in fire regimes may be more important in determining changes in boreal forest ecosystems in the twenty-first century than changes in productivity and species composition. Future increases in forest fires will remove standing forests at a greater rate (Flannigan et al., 2005), leading to an increase in the number of early successional ecosystems dominated by fire-adapted species, such as jack pine, black spruce, white birch and trembling aspen. Similarly, extreme climate events such as drought will affect forest composition, with recurrent moisture deficits favouring drought-tolerant species (Grime, 1993; Bazzaz, 1996; Hogg and Bernier, 2005), including jack pine, white spruce and trembling aspen at the expense of species such as black spruce and balsam fir.

Spruce budworm is currently the most damaging forest insect in Ontario (Candau and Fleming, 2005; *see* Case Study 5). Since the late 1980s, Ontario has experienced repeated infestations of the spruce budworm, resulting in the die-off of large tracts of forested area (Ontario Ministry of Natural Resources, 2004). Susceptibility to disease is enhanced by host tree stress, particularly related to moisture (e.g. McDonald et al., 1987; Greifenhagen, 1998). The limited water retention capacity of the shallow soils that are common in this subregion makes them particularly susceptible to drought (Greifenhagen, 1998).

Among the projected impacts of climate change on boreal forests in the subregion is the potential arrival of the mountain pine beetle, which is presently limited to British Columbia and northeastern Alberta (*see* Chapters 7 and 8). Projected warming may allow this pest to reach Ontario by mid-century (Logan and Powell 2001; Logan et al., 2003), where it could cause great damage to extensive forests of jack pine, white pine and red pine (Parker et al., 2000). Other projected impacts include increases in the severity of forest fires throughout the subregion (McAlpine, 1998) and an increase in average area burned (Flannigan et al., 2005). The combined impact of higher temperatures and increased drought may create a 'tipping point' beyond which fire suppression is no longer feasible (Flannigan et al., 2005).

Comparatively little attention has been given to the impacts of climate change on Boreal Shield fauna. Nonetheless, environmental monitoring has provided insights into the climate sensitivity of some boreal species (e.g. Bowman et al., 2005). Thompson et al. (1998) concluded that larger wildlife will be most affected by changes in landscape structure, and they projected significant decreases in the moose population and increasing numbers of white-tailed deer. The impacts on moose reflect the northward expansion of white-tailed deer, increased mortality from the brain worm carried by white-tailed deer, and elevated predation by grey wolves (Thompson et al., 1998), illustrating the complex interactions that will influence the distributions of a single species.

The abundant rivers and lakes of this subregion support a wide range of fish species, including: 1) those with cold-water requirements (<15°C); 2) those with cool-water requirements (15–25°); and 3) those with warm-water requirements (>25°C). As in the south subregion, projected climate change is expected to favour expansion of fish species with warm-water requirements, such as largemouth bass, smallmouth bass, pumpkinseed, rock bass and bluegill, and place stress on cool- and cold-water species. Historical data demonstrate that warm-water species recruitment is much enhanced in an increasing temperature regime (Casselman, 2002). Temperature increases of 1, 2 and 3°C at spawning time resulted in 2.0-fold, 3.9-fold and 7.7-fold increases, respectively, in rock bass (a warm-water species) recruitment (Casselman, 2005). Cool- and cold-water species were negatively affected, with the same temperature increases at spawning time resulting in 1.5-fold, 2.4-fold and 20.1-fold decreases, respectively, in lake trout emergence the following spring. Warm-water species can negatively affect growth and production of cold-water species by out-competing them for available prey fish (Vander Zanden et al., 2004; Casselman, 2005).

3.2.2 Forestry

In 2005, the value of exports from Ontario's forestry and forestry-related industries was $8.4 billion, with 84 500 persons employed in this sector (Natural Resources Canada, 2006). The vast majority of the forestry-reliant communities in Ontario are located in the central subregion, and the forestry sector accounts for more than 50% of employment income in more than half of these communities (Natural Resources Canada, 2006). In addition to international market forces affecting the industry across the country (*see* Chapter 9), the forestry sector in Ontario currently faces a range of other non-climatic stresses. The forest supply near established major mills is dwindling, forcing the industry to move farther north into areas that are more costly to harvest. Energy costs in Ontario, which have risen by as much as 30%, have also affected logging, road building and transportation; in some cases, they have been cited as the main reason for recent mill closures (Natural Resources Canada, 2006).

CASE STUDY 5

Spruce Bud Worm and Forest Fires

A forest insect native to North America, the spruce budworm has caused more damage than any other insect in North America's boreal forest (Figure 24a, b). Spruce budworm larvae feed on the flowers, cones and youngest available foliage of its preferred hosts, balsam fir and white spruce (Candau and Fleming, 2005). Damage caused by defoliation interferes with forest stand development and causes tree mortalities in dense, mature stands of forest over a wide area, with outbreaks occurring in cycles of approximately 35 years (Candau et al., 1998). The most recent outbreak ran from 1967 to 1999, with a peak year in 1980 that caused 18.85 million hectares of severe defoliation (Ontario Ministry of Natural Resources, 2002). Outbreaks occur more frequently in the warmer margins of the host tree's range and seem to be associated with drought, which is projected to become increasingly frequent in the future. Late spring frosts also play a key role in terminating outbreaks in the north, and these are projected to become less frequent in the future (Volney and Fleming, 2000).

FIGURE 24a: Spruce budworm larva (*Source:* Ontario Ministry of Natural Resources).

FIGURE 24b: Forest damaged by spruce budworm (*Source:* Natural Resources Canada).

Areas devastated by spruce budworm increase the fire fuel load and can burn more readily than non-affected forests (Flannigan et al., 2005). Although the forest industry has successfully salvaged and renewed significant portions of areas infested in the most recent outbreak (Ontario Ministry of Natural Resources, 2004b), there are still large tracts of dead or dying forest, killed by budworm, that pose a substantial fire hazard. Forest managers confronted with damaged forest areas recognize the value of fire in renewing these stands. Forest health depends on fire as the vehicle for converting insect- and disease-infested or wind-damaged stands to fire succession species (Canada Interagency Forest Fire Centre, 2005).

Four broad components have been defined for adaptation strategies to deal with disturbances in forests that can reduce vulnerability and enhance recovery (Dale et al., 2001). These include:

- managing the system before the disturbance (e.g. planting or maintaining tree species that are less vulnerable to fire and insects will reduce vulnerability to those disturbances);
- managing the disturbance through preventive measures or manipulations, such as fire control;
- managing the recovery either immediately after the disturbance (e.g., through salvage logging), or during the process of recovery (e.g., through reseeding); and
- monitoring for adaptive management, to determine how disturbances affect forests and to continually upgrade understanding of how climate change can influence the disturbance regimes.

Current forestry operations at some sites in the central subregion rely on the presence of frozen ground and winter roads for harvesting and hauling activities. These operations are shut down during periods of winter thaw to avoid road damage through rutting and compaction by harvesting equipment and skidders. Periods of winter thaw and extended spring conditions also require that hauling be shut down on some all-season forest roads that would be damaged by heavy loads. It is anticipated that the incidence of such shutdowns on forestry activities will increase as winters become shorter and milder. An adaptation to these conditions would be to construct more all-weather roads, although this would involve significant cost.

As noted in the preceding discussion of ecosystems in the central subregion, fire, insect and pathogen outbreaks and wind are important climate-sensitive stresses affecting forests in this subregion (*see* Case Study 5). A recent assessment (Munoz-Marquez Trujillo, 2005) of the impacts of climate change by 2060 in the Dog River–Matawin River forest west of Thunder Bay concluded that the combined impact of climate change and harvesting could reduce timber availability by 35% over a 1961 to 1990 baseline. The primary factor in this reduction was projected increases in forest fire activity, resulting in a younger forest. Although changes in tree species composition would not be noticed in the short term, there would be a shift in dominance from hardwood to softwood by 2060 (Munoz-Marquez Trujillo, 2005).

If the growth rates of economically important species decrease due to increased moisture stress, pest outbreaks or other factors resulting from changing climate, logging prior to stand deterioration can be used to speed the replacement of forest types. Stands in which trees are too small for commercial harvest may be thinned to promote stand productivity and health; to remove suppressed, damaged or poor-quality individuals; and to increase the vigour of the remaining trees (Wargo and Harrington, 1991). During periods of severe insect infestation, insecticides may used to protect young stands and reduce losses of timber volume.

Where it is preferable to regenerate with species or genetic sources not in the existing stand, planting would be required. For example, sites being affected by increasing moisture stress could be regenerated with drought-tolerant tree species. Planting also provides an opportunity to move species from current to future ranges (Davis, 1989; Mackey and Sims, 1993). According to Mackey and Sims (1993), tree migration can be facilitated in the near term by limited experimental planting of selected species to appropriate sites as much as 100 km north of their current range limit. Given the uncertainty regarding the timing and magnitude of future climate change, the use of planting stock representing widely adapted populations and diverse seed source mixtures is a low-risk adaptation strategy to increase the likelihood of regeneration success of forests adapted to future climate.

Some non-commercial tree species, shrubs and herbaceous species respond more positively to elevated CO_2 concentrations than do commercial tree species. This may require increased use of mechanical or chemical site preparation and site tending, to assist the regeneration of commercial tree species (Dale et al., 2001).

3.2.3 Water Resources Management

The central subregion is characterized by large numbers of lakes and rivers. Historical trends indicate that the smaller lakes in the Boreal Shield ecosystem are more sensitive to climate variability and change than are larger water bodies (Environment Canada, 2004). Between the 1970s and 1990s, stream flow in the northwestern part of the subregion (Experimental Lakes Area) declined significantly in response to decreased precipitation and increased evaporation. Associated changes to lakes included longer water renewal times, increasing water temperatures, longer ice-free seasons and changes in lake-water chemistry (Schindler et al., 1996). Much less is known about the climatic sensitivity of water resources in the rest of this subregion. Although quantity of source water is not a present concern in this part of the province and population growth is not projected to add additional stress, decreased water quality associated with changing climate could increase treatment costs and may compromise already stressed water treatment systems in some First Nations communities (*see* Section 3.3.3).

Half of the 46 flood emergencies declared by Ontario municipalities between 1992 and 2003 occurred in the central subregion (Wianecki and Gazendam, 2004). There appears to have been a recent shift in the causes and timing of flood events. Although the overwhelming majority of flooding has historically been associated with spring snowmelt runoff, only 34% of floods between 1990 and 2003 occurred in the spring (March and April), with the remainder occurring throughout the year as a result of heavy rainfall, rain-on-snow conditions and ice jamming. The most damaging of these resulted from a series of very intense thunderstorms between June 8 and 11, 2002 that dropped up to 400 mm of rain (*see* Case Study 3).

3.2.4 Transportation

More than $32 billion in minerals, wood, paper and other products are produced and shipped on highways of the central subregion each year (Ontario Ministry Transportation, 2005), which include major segments of two trans-Canada highways (highways 11 and 17). Highway transportation is especially important in this subregion because the sparse population and long distances reduce the viability of other modes of passenger transportation. Many small communities rely on highways to access essential services provided in urban centres. The road system provides physical links between eastern and western Canada, and serves as a gateway to the United States (Ontario Ministry of Northern Development and Mines, 2006b). When these transportation routes are damaged or cut off, shipping delays are costly and alternative access to many communities is difficult.

Climate-related disruptions to the road network in this subregion are most likely to result from extreme precipitation (rainfall or snow). As a result of a June 2002 storm that brought unprecedented rainfall (*see* Case Study 3), major and secondary highways were closed for a week or more, and bridges, culverts, railways, private residences, commercial properties and agricultural operations were damaged by associated flooding (Cummine et al., 2004). A temporary bridge had to be installed to restore traffic on the Trans-Canada Highway between Kenora and Thunder Bay. The CN Rail line between Winnipeg and Thunder Bay was washed out in more than thirty places, with one of the washouts measuring almost a kilometre in length. Projected increases in extreme precipitation events, a trend supported by the limited data available for this area (Wianecki and Gazendam, 2004), therefore pose a significant risk to transportation infrastructure in this subregion.

3.2.5 Tourism and Recreation

Ontario's most northerly downhill ski area is located near Thunder Bay. Analysis of the impact of climate change on the downhill ski industry in this area suggests that the length of ski seasons would decrease by up to 17% in the 2020s and up to 36%

in the 2050s (Scott and Jones, 2006a). To maintain viable operations, snowmaking will need to increase. This would add significant costs for ski resort operators and would be dependent upon the availability of adequate water supplies.

Unlike the downhill skiing industry, snowmobiling relies on natural snowfall and is highly vulnerable to climatic change. In seven snowmobiling areas across the central subregion, the average projected reduction in season length may be between 30 and 50% by the 2020s and between 50 and 90% by the 2050s (Scott et al., 2002). Recent market trends showing decreases in sales of new snowmobiles and increases in sales of all-terrain vehicles (ATVs) may already reflect adaptation by recreationists to these climate trends (Suthey Holler Associates, 2003). It is noteworthy that climate change was not considered in the development of Canada's recent (2001) National Snowmobiling Tourism Plan (Scott et al., 2002).

3.2.6 Human Health

Currently, less than 300 premature deaths a year are attributed to air pollution in the central and north subregions of Ontario (Ontario Medical Association, 2005), indicating it is much less of an issue there than in the more populous south subregion. Neither has heat stress associated with extreme hot days historically been a significant problem. Increases in either factor as a result of changing climate could lead to disproportionate health impacts, as studies have shown that mortality caused by air pollution and high temperatures is often greater in communities that are not accustomed to such conditions, relative to those that experience more frequent smog episodes and heat waves (cf. Cheng et al., 2005).

The central subregion contains woodland habitats that could support populations of *Ixodes scapularis* ticks, with Lyme disease projected to spread across most of the subregion by 2050 (Ogden et al., 2006c). The virus responsible for hantavirus pulmonary syndrome (*see* Section 3.1.3), has been found in deer mice collected in Algonquin Provincial Park near the southeastern limit of the central subregion (Drebot and Artsob, 2000).

3.2.7 Energy

Coal-fired electricity generating stations in Atikoken and Thunder Bay provide much of the electricity to communities in this subregion through the provincial energy grid. Electricity is also produced from co-generation facilities that burn natural gas or forest-based biomass, especially from pulp-and-paper operations. Both coal-fired electricity generating stations have been targeted for shutdown by 2014. Electricity demand is presently falling in the subregion. While projected increases in temperature could increase summer electricity demand in the future, there are significant opportunities for enhanced energy efficiency, especially in the pulp-and-paper and mining sectors (ICF Consulting, 2005).

Future electricity needs could also be provided by alternative sources. The subregion has extensive river-run hydro facilities in operation (Figure 7), but many dams are aging and changing precipitation patterns could cause reservoirs to exceed their capacity, suggesting a potential need for upgrading of this infrastructure. There is also considerable potential for wind power, particularly along the north shores of Lake Superior (Figure 7). Biomass could be an additional option for many industrial sites, especially in the pulp-and-paper industry, where facilities have a ready-made source of electricity and heat as a by-product of their manufacturing activities.

Increases in the frequency and duration of ice storms are projected for both the central and north subregions (Cheng et al., 2007), thus presenting an increasing climate risk to the power transmission and distribution grid.

3.2.8 Mining

Most of the mining-reliant communities in Ontario are located within the central subregion (Natural Resources Canada, 2001). There are more than 25 mines operating in the area, including gold, base metal, and platinum group metal mines, as well as major industrial mineral operations (Ontario Prospectors Association, 2007).

Both drought and extreme precipitation impact mining infrastructure. Tailings ponds currently capped with water to prevent oxidation and acid mine drainage are at risk of overflowing and releasing contaminants when heavy rainfall events occur (Mining Watch Canada, 2001; NorthWatch, 2001). Slope stability and integrity of engineered berms are also vulnerable to extreme precipitation. Increased temperatures will lead to increased evaporation from tailings ponds, potentially exposing raw tailings to subaerial weathering. Wind erosion of any exposed fine-grained tailings could contribute to the acidification of the watershed (Nriagu et al., 1998). Nonetheless, all of these potential impacts are manageable with application of appropriate adaptation measures already practiced elsewhere in the mining sector.

Of greater long-term consequence may be projected reductions in water levels of lakes and rivers. Warm dry conditions in 2005 reduced water levels throughout the watershed near the Williams, David Bell and Golden Giant mines. In response, efforts were made to reduce water intake, and recycling of process water was increased. Infrastructure was also established to move water from tailings ponds, pits and quarries for underground use (Brown et al., 2006).

3.2.9 Agriculture

Agriculture is presently of only limited significance in the economy of the central subregion. Although a longer growing season and increased growing degree days could present opportunities for northward expansion of some crops, constraints presented by soil quality and other factors are likely to preclude development of extensive new areas of agriculture (Bootsma et al., 2001, 2004). Impacts of changing climate on livestock are expected to parallel those for the south subregion (*see* Section 3.1.4).

3.3 NORTH SUBREGION

The north subregion (Figure 1, Box 1) remains the least studied part of Ontario with respect to climate change impacts (cf. Smith et al., 1998), and very little of the available research considers adaptation. There is also limited knowledge of current vulnerabilities that may be climate related. Because of its northern latitude, the key issues in the subregion are, in some cases, similar to those of the northern parts of the adjacent provinces (*see* Chapters 5 and 7) and the Northwest Territories (*see* Chapter 3). In a recent risk assessment workshop on the impacts of climate change on Aboriginal and northern communities (Indian and Northern Affairs Canada, 2007), potential issues of particular concern included impacts on traditional food supplies, increased risk of forest fires and impacts on infrastructure, including reduced winter road access and declining water quality. Traditional knowledge represents a valuable source of information on climate variability and ecosystem impacts in this subregion (e.g. McDonald et al., 1997).

3.3.1 Ecosystems

Changes observed in both marine and terrestrial ecosystems of the north subregion primarily reflect recent changes in climate. For example, decreases in the proportion of Arctic cod in the diet of thick-billed murre chicks near Coats Island, NT and associated increases in warmer water species, such as capelin and sandlace, suggest that the marine fish community in northern Hudson Bay changed from Arctic to subarctic around 1997 (Gaston et al., 2003, 2005). These changes were associated with a 50% reduction of the mid-July ice cover in Evans Strait from 1981 to 1999, likely reflecting a general warming of Hudson Bay waters.

Ringed seals and bearded seals depend on sea ice in Hudson and James bays to provide a safe and predictable birthing platform, while polar bears depend on the ice to mate and to hunt seals. The ice platform that forms each year in eastern Hudson Bay and James Bay is melting about 2 to 3 weeks earlier than 20 to 30 years ago (Gagnon and Gough, 2005), with similar trends reported for southwestern Hudson Bay (Stirling et al., 1999; Gough et al., 2004). An earlier melt reduces the amount of time available for the polar bears to forage on seals and accumulate the body fat needed to get them through the ice-free season when they are on land and have limited access to high-protein foods. The trend toward decreasing sea-ice cover has led to long-term declines in the body condition of polar bears in the western and southern Hudson Bay populations (e.g. Stirling et al., 1999). Although the southern Hudson Bay population has remained steady at about 1000 individuals, the western Hudson Bay population has declined from about 1200 in 1987 to less than 950 animals in 2004 (Obbard, 2006).

While the observed declines in sea-ice cover have not yet had a demonstrable impact on ringed or bearded seal reproduction, projections of reduced snowfall and increased spring rain events are expected to negatively impact ringed seal reproductive success by weakening or destroying birthing lairs (Stirling and Smith, 2004). In the short term, such events may have a positive effect on the polar bear population by increasing the vulnerability of ringed seals and their pups to predation, but a decline in this important prey species will negatively impact polar bear populations in the long term (Stirling and Smith, 2004). Polar bears in Ontario often construct maternity dens in permafrost features such as palsen (Obbard and Walton, 2004). Projected changes in permafrost extent resulting from increasing air and ground temperatures (Gough and Leung, 2002) are likely to lead to palsa collapse, negatively affecting the reproductive success of polar bears.

Arctic char and brook trout are two anadromous fish species that use salt and fresh water in the Hudson Bay basin. Both of these are cold-water species that will be affected by changes in water temperature, with the Arctic char being near the southern limit of its range and the brook trout near its northern limit. With anticipated increases in water temperature, the range of the Arctic char would be expected to be restricted, while the range of the brook trout is expected to expand (Chu et al., 2005).

The impacts of changing climate on forest disturbances are a concern to many communities in the Boreal Shield ecosystem (*see* Section 3.2.1). Climate change could result in annual burn areas increasing 1.5- to 5-fold by the end of this century (*see also* Ward et al., 2001; Flannigan et al., 2005). Changes in forest insect disturbance are more difficult to predict, since their occurrence is affected by complex climatic interactions with biochemistry and phenology of the host plant, and by the life cycles of the insects themselves and their parasites (Scarr, 1998; Logan et al., 2003). Warmer temperatures will tend to expand ranges northward and enhance insect growth rates (Logan et al., 2003). Spruce budworm is historically the most damaging forest insect in Ontario (*see* Section 3.2.1, Case Study 5) and is predicted to become even more damaging in the northern parts of the boreal forest (Fleming and Candau, 1998).

3.3.2 Transportation

None of the communities in the north subregion have access to all-weather roads and, except for the winter months, are accessible only by air or water. During the summer months, the port of Moosonee provides barge services to neighbouring communities, supplying bulk materials and essential supplies that are transported to Moosonee by train. However, the key to supplying most communities in this subregion is a winter road system that operates between late January and late March (Figure 25). Annual construction of the 3000 km road network provides cheaper transport of heavy equipment and materials, allowing the communities to lower their cost of living and reduce the cost of capital construction projects (Ontario Ministry of Northern Development and Mines, 2005). The new Victor diamond mine, 90 km west of Attawapiskat, will also rely on ice and winter roads for transportation of equipment and supplies. In addition to direct economic benefits, these roads also facilitate social interaction between isolated communities (Ontario Ministry of Northern Development and Mines, 2006a; *see also* Chapter 7).

Delays of up to 10 days in opening several sections of the winter road network, particularly routes that cross lakes and rivers, occurred in 2005 and 2006 (Wawatay News, 2005a, b). Projected increases in winter temperatures of 4 to 6°C by 2050 will undoubtedly affect the viability of this seasonal transportation network. A study of the Berens River area of Manitoba, on the northeast shore of Lake Winnipeg, concluded that the winter road season would be 5 days shorter by the 2020s and 10 days shorter by the 2050s (Blair and Babb, 2002). As discussed in Chapter 3, modifications in ice road construction may be able to compensate for decreased winter cold in the short to medium term; however, longer term adaptation measures may involve construction of all-season water crossings, and ultimately construction of all-season roads.

Air transportation plays a crucial role in delivering essential goods and services to many remote northern communities year-round. Where landing strips have been built on permafrost, increased seasonal thaw or disappearance of permafrost as a result of climate change will necessitate increased maintenance and likely the reconstruction of some facilities.

3.3.3 Water Resources Management

Although no assessment of the impacts of climate change on water quality has been undertaken in the north subregion, decreases in river flows have been documented for the Severn, Winisk, Ekwan, Attawapiskat, Albany and Moose rivers between 1964 and 2000 (Déry et al., 2005). Reduced flows and increased temperatures further stress water treatment systems that are already approaching, or have surpassed, their capacity to provide safe drinking water.

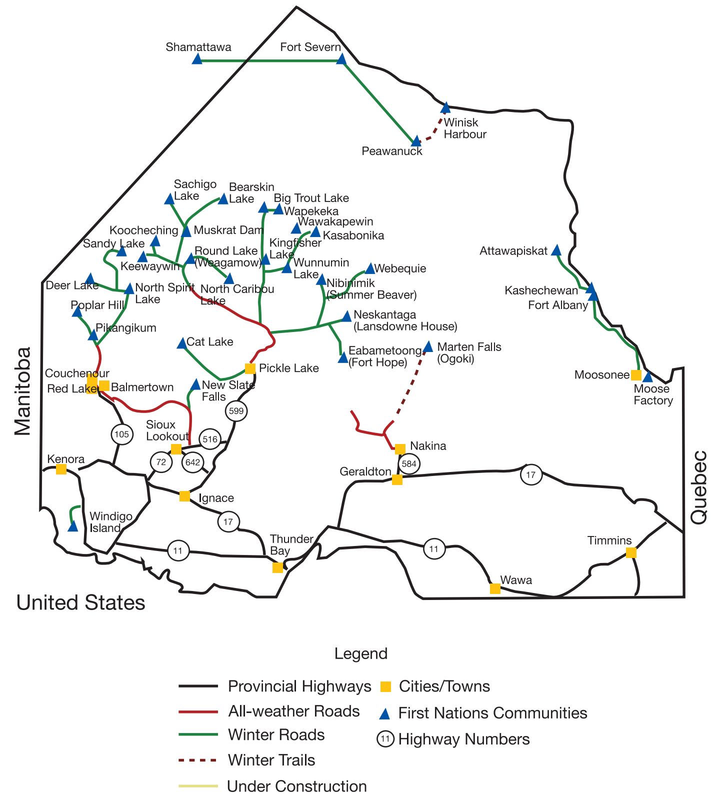

FIGURE 25: Communities and road networks in the north subregion and the western part of the central subregion (*see* Figure 1). Winter roads and trails are critical for accessing communities of the north subregion (Ontario Ministry of Northern Development and Mines, 2006a).

Communities located on floodplains in this subregion are susceptible to infrastructure damage from spring flooding and ice jams. Because northern communities are small and remote, they depend greatly on emergency access and the ability to evacuate the residents if needed. Spring flooding in 1986, when precipitation was nearly three times the historic normal, resulted in two deaths and the evacuation of 129 people from the community of Winisk (Public Safety Canada, 2006). The community of Attawapiskat was evacuated in 1989, 1992, 2002 and 2004, each time because of spring floods (Environment Canada, 2005b; Public Safety Canada, 2006). In 2005 and 2006, spring floods forced the evacuation of 200 people from Kashechewan. The impact of projected changes in climate on flood hazards has not been assessed specifically in this subregion; however, projections of increased winter precipitation and earlier springs will affect the timing and intensity of spring flooding. Adaptation will likely involve evaluation of existing emergency management activities, including relocation of buildings or even entire communities as the result of detailed assessment of flood risk potential at the local scale.

3.3.4 Human Health

The remote location of communities in the north subregion presents a number of challenges to human health in addition to limited access to health care services. For example, the impact of climate change on traditional ways of life, particularly regarding access to country foods, is a significant health concern (*see* Chapters 3 and 5). Although there is access to expensive southern foods, traditional foods constitute a significant proportion of the local diet with important nutritional value. In a survey conducted in Fort Severn in 2002, 40% of the households that reported food insecurity over the previous year indicated that they rely on hunting and fishing to supplement their food supply (Lawn and Harvey, 2004). Changing climate impacts ecosystems directly, and also affects access to traditional territories (*see* Chapters 3 and 7), with implications for both food security and availability of traditional medicines.

The potential for outbreaks of waterborne disease represents a primary health risk in the north subregion that is likely to be exacerbated by changing climate, especially extreme climate events. Several First Nation communities have been identified as having vulnerable water treatment systems (O'Connor, 2002; Commissioner for the Environment and Sustainable Development, 2005). Two communities (Kingfisher and Muskrat Dam Lake) were included in the March 2006 priority list of 21 First Nation communities across the country identified as having high-risk water systems (Indian and Northern Affairs Canada, 2006).

Woodland habitats in the southern part of the north subregion have potential to support populations of *Ixodes scapularis* ticks (vectors of Lyme disease), as their range expands northwards in response to warmer temperatures. Modelling by Ogden et al. (2006c) indicated that Lyme disease could encroach upon communities in this region by 2080.

3.3.5 Energy

Space heating accounts for the largest portion of energy use in the north subregion, roughly 70% of community energy needs. As of 2000, 31 First Nation communities in this subregion were off-grid, of which 13 used diesel generators. The electricity provided by these systems serviced approximately 18 000 residents living in over 4000 homes (Zulak et al., 2000). Supply of diesel fuel is dependent on a viable winter road network, which will be difficult to maintain in the face of projected climate change, for the reasons given in Section 3.3.2.

In recent years, there have been efforts by federal departments and Aboriginal organizations to promote energy efficiency, energy conservation and energy from renewable sources to First Nations communities as part of a broader national effort to reduce greenhouse gas emissions (Neegan Burnside Ltd., 2004; Fox, 2006). Renewable options being promoted include electricity generation from river-run hydro and wind power, and there is considerable potential for the development of new generation from these sources (Figures 6 and 7). Developing community-based renewable energy sources is also viewed as an economic development tool, creating jobs in the local community (Venema and Cisse, 2004; Chiotti et al., 2005). These initiatives also enhance adaptive capacity by reducing community vulnerability to interruptions in the supply of diesel fuel via the winter road network.

3.3.6 Mining

There is currently extensive exploration for mineral resources in the north subregion, particularly for diamonds. The Victor diamond mine is currently under construction in the Hudson Plains west of Attawapiskat, while the Boreal Shield hosts active gold mining and past production of a wide range of minerals. Extrapolation from other regions of Canada suggests the potential for climate-related issues, including access via winter roads and the impact of permafrost degradation on containment structures and other physical infrastructure (e.g. Arctic Climate Impact Assessment, 2005; Mining Environment Working Group, 2004; *see* Chapter 3). Impacts of climate change on mining in the Boreal Shield are discussed in Section 3.2.8.

4 SYNTHESIS

Climate change presents challenges for Ontario's ecological, social and economic systems. In many parts of the province, changing climate is having noticeable impacts on natural and human systems. Such impacts include decreases in the duration of lake-ice cover, increases in some climate extremes, and shifts in aquatic and terrestrial ecosystems. Recent social and economic impacts resulting from shortened winter road seasons, increased forest fire risk, lower Great Lakes water levels, disruptions to winter tourism activities, and more frequent smog episodes and extreme heat events illustrate that these systems are both sensitive and vulnerable to the type of climate conditions that are projected to occur more frequently in the next 20 to 50 years.

Although the magnitude and timing of projected climate change vary across the province, Ontario will experience impacts in virtually every economic sector. Adaptation responses to address these impacts will require consideration of both the potential economic, social and environmental consequences of climate change and the probability that these impacts will be experienced within the planning horizon. Table 5 summarizes the major negative impacts by subregion, and the general time frame when these impacts are expected to become problematic for social and/or economic systems. Opportunities presented by changing climate, as described previously for agriculture, warm-season tourism and other sectors, are not included in the table but will require some degree of adaptation in order to realize maximum benefits. Although there remain significant knowledge gaps regarding the vulnerability of some systems, there is generally sufficient knowledge to identify short-, mid- and long-term priorities and to implement no-regrets adaptation actions (*see* Chapter 10).

Since anticipatory adaptation requires the use of predictive information, risk management offers a practicable and credible approach for defining measures to achieve acceptable levels of societal risk (Bruce *et al*., 2006). An example of how this approach, based on the Canadian standard *Risk Management: Guidelines for Decision-Makers* (Canadian Standards Association, 1997), can be applied through a series of clearly defined steps is found in *Adapting to Climate Change: A Risk-Based Guide for Ontario Municipalities* (Bruce *et al*., 2006; Box 4).

TABLE 5: Major negative impacts of climate change and onset of 'problems' by subregion in Ontario.

Cumulative stresses/region	Subregion		
	North	Central	South
Ecosystems			
Fish	Present to 20 years	Present to 20 years	Present to 20 years
Fauna	Present to 20 years	No information on timing	Present to 20 years
Flora	Present to 20 years	No information on timing	No information on timing
Water			
Quality	50 to 80 years	20 to 50 years	Present to 20 years
Quantity (shortages)	No significant impact expected	No significant impact expected	Present to 20 years
Flooding	Present to 20 years	Present to 20 years	Present to 20 years
Health			
Heat	No significant impact expected	20 to 50 years	Present to 20 years
Insect/vector disease	50 to 80 years	20 to 50 years	Present to 20 years
Water quality	50 to 80 years	20 to 50 years	Present to 20 years
Air quality	No significant impact expected	20 to 50 years	Present to 20 years
Agriculture			
Drought	No significant impact expected	No significant impact expected	Present to 20 years
Energy			
Increased demand	No significant impact expected	No significant impact expected	Present to 20 years
Lower production	No significant impact expected	No significant impact expected	20 to 50 years
Forestry			
Fire	Present to 20 years	Present to 20 years	No significant impact expected
Pests and disease	20 to 50 years	20 to 50 years	No significant impact expected
Transportation			
Winter roads	Present to 20 years	No significant impact expected	No significant impact expected
Paved surfaces	No significant impact expected	No significant impact expected	20 to 50 years
Navigation	No significant impact expected	20 to 50 years	20 to 50 years
Tourism and Recreation			
Cold season	No significant impact expected	Present to 20 years	Present to 20 years

- Present to 20 years
- 20 to 50 years
- 50 to 80 years
- No information on timing
- No significant impact expected

BOX 4

Steps in the risk management process

(*from* Bruce et al., 2006)

"Risk management is a systematic approach to selecting the best course of action in uncertain situations by identifying, understanding, acting on and communicating risk issues. In the context of adapting to climate change, risk management provides a framework for developing adaptation strategies in response to potential climate changes that create or increase risk. …whether the issue is as large as a municipal strategic plan for climate adaptation or a smaller study around specific issues such as extreme rainfall events, heat, health issues or others, the risk management process will guide staff towards the optimal solutions." (Bruce et al., 2006, p. 6)

Step 1: Getting started

1) Identify the specific problem or hazard and the associated risks.
2) Identify the stakeholders and the project team, especially those with the relevant expertise.
3) List the responsibilities of each member of the project team and the resources needed to complete the risk management framework.
4) Draft the work plan and estimate the schedule.

Step 2: Preliminary analysis

1) Define the climate-related hazard and the potential risks that may cause harm, in terms of injury, damage to property and/or the environment, or monetary losses to the community.
2) Identify possible outcomes from the risk situation.
3) Conduct a quick overview of the process to help determine the complexity of the project, the probable time-frame for completing the work and a sense for whether the project team and resources assigned are sufficient.

Step 3: Risk estimation

1) Identify the frequencies and consequences associated with each of the risk scenarios.

Step 4: Risk evaluation

1) Develop a process for comparing or ranking each risk scenario.
2) Evaluate the risks by examining them in terms of costs, benefits and acceptability, considering the needs, issues and concerns of stakeholders.
3) Identify unacceptable risks and prioritize them for risk reduction or control strategies.

Step 5: Risk controls and adaptation decisions

1) Identify feasible strategies for reducing unacceptable risks to acceptable levels.
2) Evaluate the effectiveness of the adaptation or risk control strategies, including the costs, benefits and risks associated with the proposed adaptation measures.
3) Select the optimal adaptation or risk control strategies and consider the acceptability of residual risks.

Step 6: Implementation and monitoring

1) Develop and implement the adaptation plan.
2) Monitor and evaluate the effectiveness and costs of the adaptation responses.
3) Decide to continue or terminate the risk management process.

Of particular importance are planning decisions involving physical infrastructure, which involve large capital investments and, by virtue of their anticipated lifespan, will have to be resilient to changes in climate parameters across many decades. The construction industry, building codes and standards, and land-use planning are all slow to change, and decisions pertaining to land use and building materials are often dominated by short-term commercial interests (Auld and MacIver, 2005). Adaptation with regard to infrastructure will have to consider the variable life cycles of structures and replacement cycles (Table 6), in conjunction with projected changes in climate (Auld and MacIver, 2005). Updating of existing codes and

TABLE 6: Infrastructure life cycle timeframes (*adapted from* Auld et al., 2006).

Structure	Phase	Typical expected life cycle time-frame (years)
Commercial buildings	Retrofit	20
	Demolition	50–100
Roads	Maintenance	Annually
	Resurface	5–10
	Reconstruction or major upgrade	20–30
Bridges	Maintenance	Annually
	Resurface	20–25
	Reconstruction or major upgrade	60–100
Rail	Major refurbishment	10–20
	Reconstruction or major upgrade	50–100
Airports	Major refurbishment	10–20
	Reconstruction or major upgrade	50
Dams and water supplies	Major refurbishment	20–30
	Reconstruction or major upgrade	50
Sewers	Reconstruction or major upgrade	50
Waste management	Upgrade	5–10
	Major refurbishment	20–30

standards using trends evident in historical climate records represents a potential starting point in reducing infrastructure vulnerability (Auld and MacIver, 2005, 2006).

4.1 KEY AREAS OF CONCERN

The information gathered for this assessment points to five key areas of climate sensitivity in Ontario: critical infrastructure, water quality and supply, human health and well-being, remote and resource-based communities, and unmanaged and managed ecosystems. The degree to which these systems are vulnerable to future climate change will depend on the success of adaptation actions, which will, in turn, require enhancement and application of existing adaptive capacity.

Critical infrastructure, as used in this analysis, includes water treatment and distribution systems, energy generation and transmission systems, and transportation. Disruptions to all of these have occurred in all subregions of the province in recent years, and are expected to occur more frequently during the present century. In recent years, flooding associated with severe weather has disrupted transportation and communication lines, with damage costs exceeding $500 million. Lengthy and extensive power outages have resulted from the failure of transmission grids and distribution lines. Warmer winters have resulted in a shorter winter road season, limiting access to remote communities and natural resources. Lower water levels in the Great lakes have increased shipping costs in some seasons, and reduced hydroelectricity output. Climate change is expected to result in even lower water levels that would further compromise Great Lakes shipping and potentially reduce hydroelectricity output by more than 1100 MW by 2050.

Since infrastructure must be resilient under both current and future climate conditions, climate change needs to be factored into design. Nonetheless, understanding of the impacts of climate change on infrastructure remains limited, and would benefit from further research to refine projections of regional impacts and climate parameters that are critical for infrastructure design, such as maximum wind speeds, snow loads and precipitation intensities (Auld and MacIver, 2005). In the south subregion, infrastructure is aging, thus increasing the proportion of infrastructure that is vulnerable to climate extremes (Auld and MacIver, 2005). Investment in water and wastewater infrastructure alone over the next 15 years in Ontario is expected to range from $30 to $40 billion, with $25 billion to be spent on capital renewal and the remainder on deferred maintenance and growth (Ontario Ministry of Public Infrastructure Renewal, 2005). As demonstrated by the 1998 ice storm, the 2003 blackout and Toronto's 2005 flood, all components of critical infrastructure are interconnected, as much of Ontario's economy, industry and urban communities depend on 'just-in-time delivery' and uninterrupted service (Auld *et al*., 2005).

Water shortages, already documented in the south subregion of the province, are projected to become more frequent as summer temperatures and evaporation rates increase. Sections of Durham County, Waterloo and Wellington Counties, and the shoreline of southern Georgian Bay, where growth strategies indicate that population will continue to increase significantly, will become more vulnerable to shortages within the next 20 years. Current legislation provides the framework to deal with both gradual changes in average conditions and changes in the frequency and magnitude of drought. The Clean Water Act requires that source protection planning be an ongoing, long-term undertaking, as the many climatic and non-climatic factors influencing water resources will be changing. As a result, climate change can be mainstreamed in subsequent plans as data gaps are closed, skills are developed and experience is gained (Box 5; de Loë and Berg, 2006). The Ontario Low Water Response similarly provides a strategy to ensure provincial preparedness to respond to extreme drought conditions, and provides an existing structure to deal with more frequent droughts as they occur.

BOX 5

Mainstreaming adaptation

"Source protection planning under the Clean Water Act has created an outstanding opportunity to mainstream climate change. The focus in source protection planning is necessarily on threats to drinking water safety. However, under the Clean Water Act these threats are characterized broadly to include both those that pertain to water quality and water quantity. The Act also requires unprecedented attention to concerns such as the relationship between land and water, and between water uses and water supplies. Climate change must be a central consideration when these relationships are explored through watershed characterizations and water budgets." (de Loë and Berg, 2006)

The **health risks** to Ontario residents as a result of changing climate include illness, injury and premature death related to extreme weather, heat waves and smog episodes, as well as gradual changes in ecological conditions that facilitate the spread of vector- and rodent-borne diseases. Approximately 6000 Ontario residents die prematurely each year due to air pollution, and heat waves may be a contributing factor in about 20% of these deaths in cities in the south subregion. Smog alert advisory systems are commonplace in the south subregion of Ontario (and some cities in the central subregion), and some southern cities have recently introduced heat-health alert systems. Heat-related mortality could more than double in these cities by the 2050s, while air pollution mortality could increase about 15 to 25% over the same interval. The types of extreme weather that contributed to the *E. coli* outbreak in Walkerton, Ontario, which killed 7 and caused 2300 illnesses, are projected to increase. Changes in climate are also expected to enhance the northerly expansion of Lyme disease, and hantavirus pulmonary syndrome could emerge as a health risk.

Remote and resource-based communities are particularly sensitive to climate variability and change. Recent drought, ice-jam flooding, increases in forest fires, warmer winters and the absence of late spring frost have presented challenges for forestry operations and restricted access to communities and resources. Projected increases in winter temperatures will further reduce the viable operating season of winter roads, limiting access for the delivery of bulk construction materials, food and fuel to many far northern communities. Increased frequency of forest fires and pest outbreaks will adversely impact the health and economic base of communities dependent on the forest industry, particularly in Ontario's boreal forest. Communities looking to diversify their economies by developing winter tourism activities should do so with caution, with snowmobiling, cross-country skiing and ice fishing all being vulnerable to projected climate change in the middle to long term.

During the next 30 years, the vulnerability of many resource-dependent Ontario communities may increase as the average age of residents increases, population declines and youth leave the communities to seek employment elsewhere (Ontario Ministry of Finance, 2006). The cumulative impacts of changes in climate and other factors will have ramifications for the health status of residents in these communities and implications for the level of social services required.

Ontario's ecosystems are currently stressed by the combined influence of climate, human activities, movement of indigenous and non-indigenous species, and such natural disturbances as fire and outbreaks of insects and disease. Wetlands are particularly sensitive to changes in climate and other factors, and have experienced dramatic declines in recent years, especially in the south subregion of Ontario. Warmer winters, longer summers and associated changes in the mean average temperature have led to lower Great Lakes water levels, warmer water temperatures and reduced available soil moisture in forests and on agricultural land. Examples of impacts already occurring include observed changes in fish dominance from cold- and cool-water species to warm-water species in the south subregion; changes in the compositions of aquatic and terrestrial ecosystems in the north subregion; and reduced numbers and health of polar bears and seals . Further reductions in Great Lakes water levels as a result of climate change will further compromise wetlands that presently maintain shoreline integrity, reduce erosion, filter contaminants, absorb excess storm water, and provide important habitat for fish and wildlife. The number and populations of invasive species in the Great Lakes are likely to increase.

As climate change impacts all species and all ecosystems, agencies and organizations responsible for natural asset management will be required to address a plethora of emerging issues in the twenty-first century. For example, climate-induced changes to habitats and the distribution and abundance of plants and animals will alter the character of many parks and protected areas established and managed in support of biodiversity conservation efforts, necessitating fundamental changes to existing management strategies (Lemieux *et al.*, 2007).

4.2 VULNERABILITY AND ADAPTIVE CAPACITY

Adapting to climate change will involve making decisions aimed at reducing vulnerability to experienced and anticipated impacts, as well as taking advantage of new opportunities. These decisions will be made in the context of the myriad of non-climatic factors influencing environmental, economic and social systems. Vulnerability to climate (current and future) is influenced by a range of social, economic, political and cultural factors that, like climate, are not static but change over time. Reducing vulnerability to current risks and enhancing the capacity of systems to adapt to changing conditions are effective adaptation goals in light of the uncertainties inherent in climate change projections. Communities can improve their ability to respond to changing conditions by educating their members, protecting the most vulnerable, developing and implementing adequate adaptation measures, and building social resilience (Crabbé and Robin, 2006).

Adaptive capacity is defined as the "potential, capability or ability of a system to adapt to climate change stimuli or their effects or impacts" (Smit *et al.*, 2001, p. 894; *see* Chapter 2). An initial characterization of some basic determinants of adaptive capacity in each of the subregions of Ontario is presented in Table 7. This listing is based on basic statistics, available literature (not limited to climate change) and the judgment of the chapter authors. It is not the product of extensive analysis, but rather is intended to stimulate future analyses of adaptive capacity. The table suggests that all subregions have strengths and weaknesses with respect to adaptive capacity, and further understanding of these may assist in deciding what constitute the most appropriate adaptation measures in each region.

The limited research available on adaptive capacity in Ontario with specific reference to climate change deals largely with institutions. Institutional capacity depends on appropriately perceived risk and the ability to intervene in a timely and anticipatory fashion. Perceptions of the risks associated with experienced or anticipated impacts of climate change are strongly influenced by local experience of extreme events and severe impacts, such as ice storms, floods and well contamination. Institutions can both facilitate, and create barriers to, adaptation.

The strengths that have been identified with regard to institutions in Ontario include the high level of expertise for storm water management within conservation authorities; access to available technological options; municipal access to reciprocal insurance; and the persistence, sustainability and resilience of institutions and social arrangements. Increased flexibility and autonomy of municipalities to facilitate appropriate reaction to local economic, environmental and social issues, as outlined as one of the objectives of the Municipal Act 2001, also increase the adaptive capacity of local decision-makers (Crabbé and Robin, 2006). Identified weaknesses include overlapping jurisdictions and blurred areas of responsibility; requirement for agreements between municipalities to manage resources that cross jurisdictional boundaries; reliance on voluntary implementation of some key activities; institution restructuring; constrained financial and expert resources, particularly in rural areas; uneven distribution of resources; and the lack of expertise regarding the impact of climate change on built infrastructure and available adaptation technology (Ivey *et al*., 2004; Crabbé and Robin, 2006).

Effective adaptation is also dependent on decision-makers being well informed and having a solid understanding of climate change risks. A recent survey conducted within the Forests Division and the Science and Information Resources Division of the Ontario Ministry of Natural Resources, for example, indicated that, while a large majority of respondents believed that climate change would affect forests in the next 50 years and about half of respondents believed the impacts would be significant for forest communities, nearly all strongly believed that neither forest policymakers nor the public understood how climate change would affect forest communities (Colombo, 2006). Despite these concerns, the importance of taking actions that enhance efforts to understand and adapt to climate change is highlighted in the Ministry's *Strategic Directions* report for 2005 (Ontario Ministry of Natural Resources, 2005b).

TABLE 7: Broad characteristics of adaptive capacity within sub regions of Ontario[1].

-- Determinant	Subregion		
	North	Central	South
Economic Resources	• Highly dependent on climate-sensitive natural resources • Significant non-market economy	• Highly dependent on climate-sensitive natural resources • Increasing diversification	• Highly diversified • Limited climate sensitivity
Technology	• Access somewhat constrained by economic resources	• High access to technology • Key aspect of economy in some areas • Limited knowledge of relevance of technology to address climate sensitivity	• High access to technology • Key aspect of economy • Limited knowledge of relevance of technology to address climate sensitivity
Information and Skills	• Strong traditional and local knowledge of climate sensitivities and adapting to change • Smaller percentage of workforce with technical training	• Significant proportion of workforce with technical training • Good understanding of climate sensitivities in resource-based industries	• Significant proportion of workforce with technical training • Limited knowledge of climate sensitivities
Infrastructure	• Limited infrastructure • Maintenance and expertise issues • Ground access to many communities limited to seasonal roads • Permafrost sensitivity problematic	• Well-developed in urban areas • Concerns about renewal • Lack of expertise regarding climate change impacts on built environment	• Highly developed • Much of infrastructure is aging • Lack of expertise regarding climate change impacts on built environment • High dependence on potentially vulnerable electricity grid
Institutions	• Limited access • Strong social cohesion	• Well developed • Overlapping jurisdictions can hinder decision-making ability	• Highly developed • Overlapping jurisdictions can hinder decision-making ability
Equity[2]	• Broad disadvantages for aboriginal populations, rural communities, and the urban poor. • Municipalities have access to reciprocal insurance and disaster relief		

1 Based on judgement of chapter lead authors, and intended to stimulate future analyses of vulnerability.

2 Most appropriate to examine at regional / provincial scale.

4.3 CONCLUSIONS AND RECOMMENDATIONS

Given its strong and diversified economic base and abundant natural resources, Ontario as a whole is well placed to manage adaptation to changing climate conditions. Opportunities exist for rapidly mainstreaming adaptation to climate change into decision-making through, for example, the Clean Water Act, and other policies or programs that deal with, among other things, infrastructure and renewal, low water programs and growth strategies.

A number of knowledge gaps have emerged from this assessment, including limited understanding of cumulative impacts and the implications of climate change for specific regions, sectors and segments of the population. Particularly notable are the knowledge gaps for the central and north subregions, adaptation options, and understanding adaptive capacity in all subregions. Many potential adaptive actions and measures to address climate change impacts exist for all sectors, systems and subregions, but there is wide variation in the documentation of what these actions/measures are, whether they are currently in place or being developed, and whether they are likely to be effective at the local or community level. The 'tool kit' of adaptation measures can be extensive but, with a few exceptions (e.g. Edwards *et al*., 1999; Bruce *et al*., 2006), there is limited knowledge regarding how these could be applied in most settings.

As a result, understanding of the vulnerability of natural and human systems to climate change is also limited, particularly in the context of multiple stressors such as human activities, economic growth and invasive species. Vulnerability usually only becomes truly evident when conditions comparable to those projected for the future as a result of climate change, interact with a sensitive population. This chapter, therefore, has drawn heavily on lessons learned as a result of recent extreme climate events. In the case of heat stress, for example, experience in the City of Toronto clearly indicates that vulnerability among a sensitive population is shaped by the effectiveness of existing warning systems and the social determinants of health that either exacerbate or reduce risk exposure.

The resilience of communities, regions and sectors to address the risks and opportunities presented by climate change may be enhanced by development and implementation of adaptation plans or strategies, such as has been recommended for First Nation communities and health infrastructure (Chiotti *et al*., 2002; Resource Futures International, 2004). Elements likely to be common to such plans or strategies include the following:

- **Stakeholder engagement:** This is critical in identifying research priorities, assessing the effectiveness of current adaptation actions to future conditions, and determining the most appropriate response actions.
- **Monitoring and surveillance:** Data related to climate, ecosystem function, social conditions and economic impacts, including those derived from community-based monitoring, are needed to inform effective adaptation decision-making.
- **Education:** Increased awareness of the social, economic and environmental impacts of climate change at local to regional scales will help facilitate development of adaptation measures.
- **Partnership building:** Effective adaptation measures will require co-operation and co-ordination between all orders of government, industry, communities, universities and colleges, voluntary organizations, public interest groups and individuals.

5 ACKNOWLEDGEMENTS

In addition to those noted as contributing authors, the lead authors would like to extend particular thanks to Dieter Riedel, Tom Brydges and Joan Klaassen (Environment Canada) for their active participation in the development of this chapter and their valuable insights. We would also like to thank Graeme Spiers (Laurentian University), Rob de Loë (University of Guelph), Jean Andrey (University of Waterloo), Craig Wakefield (Insurance Bureau of Canada), Gordon Miller (Environmental Commissioner of Ontario), Jennifer Penny (Clean Air Partnership), Louise Aubin (Peel Region Public Health) and Brenda Sakauye (City of Mississauga) for their input and/or informal review comments. We also gratefully acknowledge the financial contribution from the Ontario Ministry of the Environment and the Ontario Ministry of Energy that was used to support the writing efforts of some contributors.

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PRAIRIES

CHAPTER 7
Prairies

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Recommended Citation:

Sauchyn, D. and Kulshreshtha, S. (2008): Prairies; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 275-328.

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CONTENTS

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.

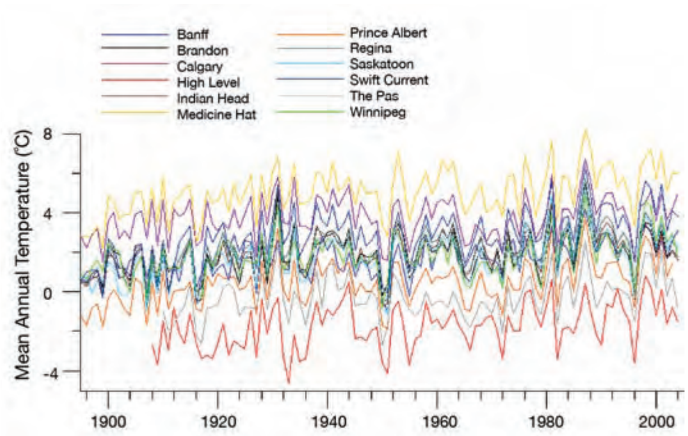

FIGURE 1: Trends in mean annual temperature since 1895 for 12 climate stations spread across the Prairies. The average increase in mean annual temperature for the 12 stations is 1.6°C. *Source:* Environment Canada, 2005.

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

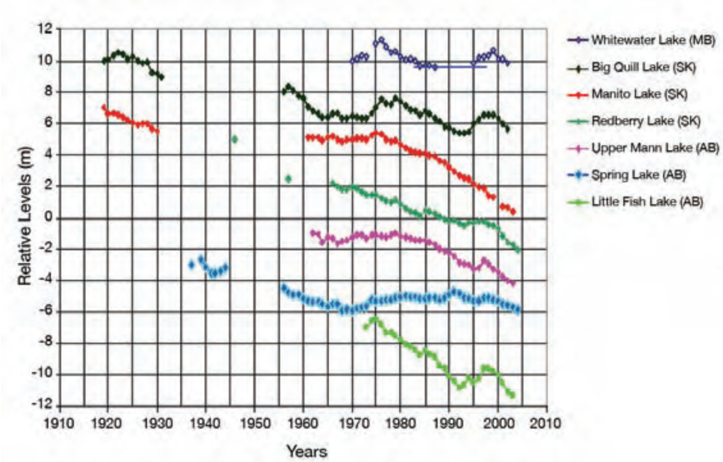

FIGURE 2: Historical water levels for closed basin prairie lakes
Source: van der Kamp et al., 2006; van der Kamp and Keir, 2005.

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.

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 km² 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

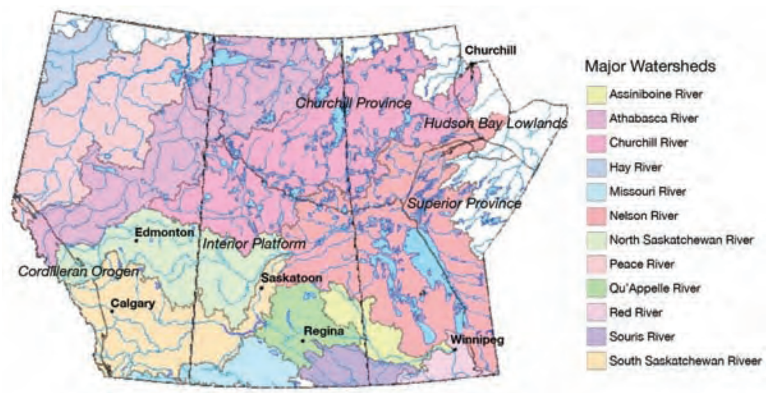

FIGURE 3: Major watersheds and the geological provinces of the Prairies.

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

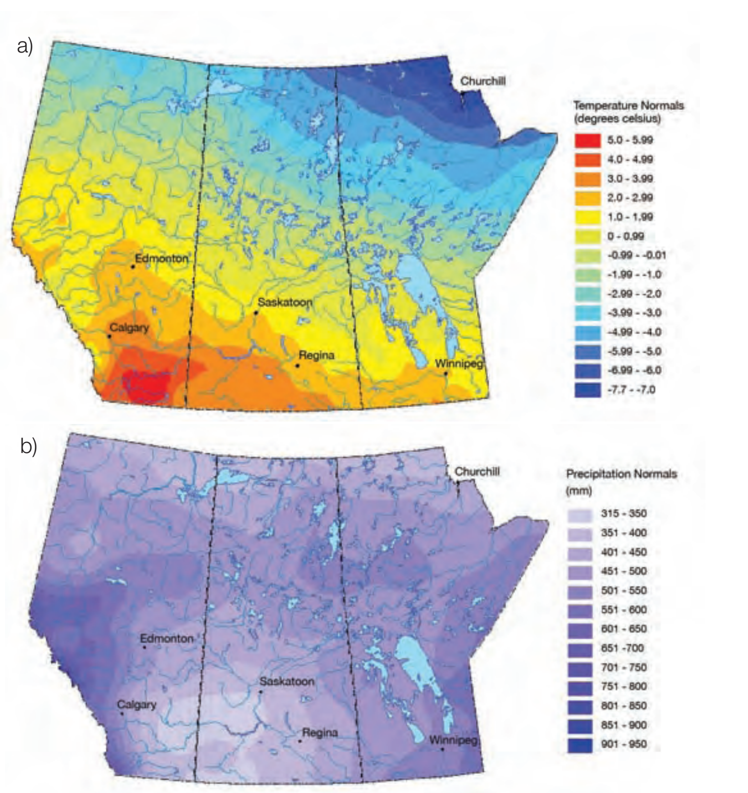

FIGURE 4: Climate normals (1961-1990) for the Prairies: a) temperature, and b) precipitation.

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.

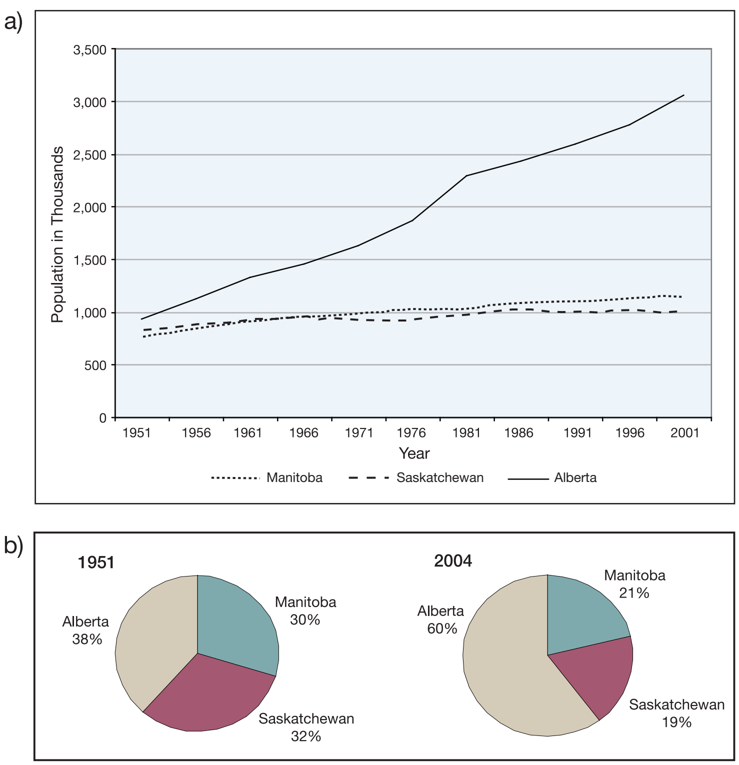

FIGURE 6: Population of the Prairies: a) trend, by province, 1951–2001; and b) relative distribution, by province, 1951 and 2004 (*from* Statistics Canada, 2005d).

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.

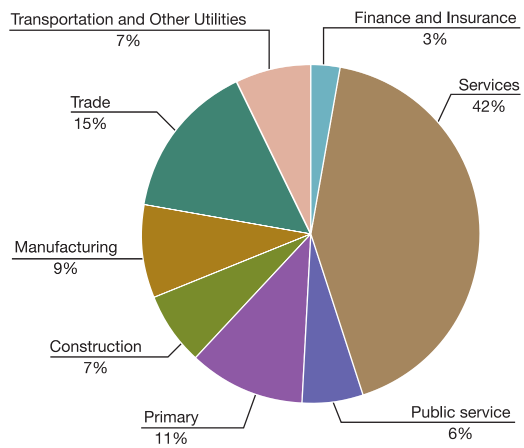

FIGURE 7: Distribution of employment in the Prairies by major industry groups, 2001 (*from* Statistics Canada, 2005d). Note that primary industries include agriculture, fisheries, mining and forestry.

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.

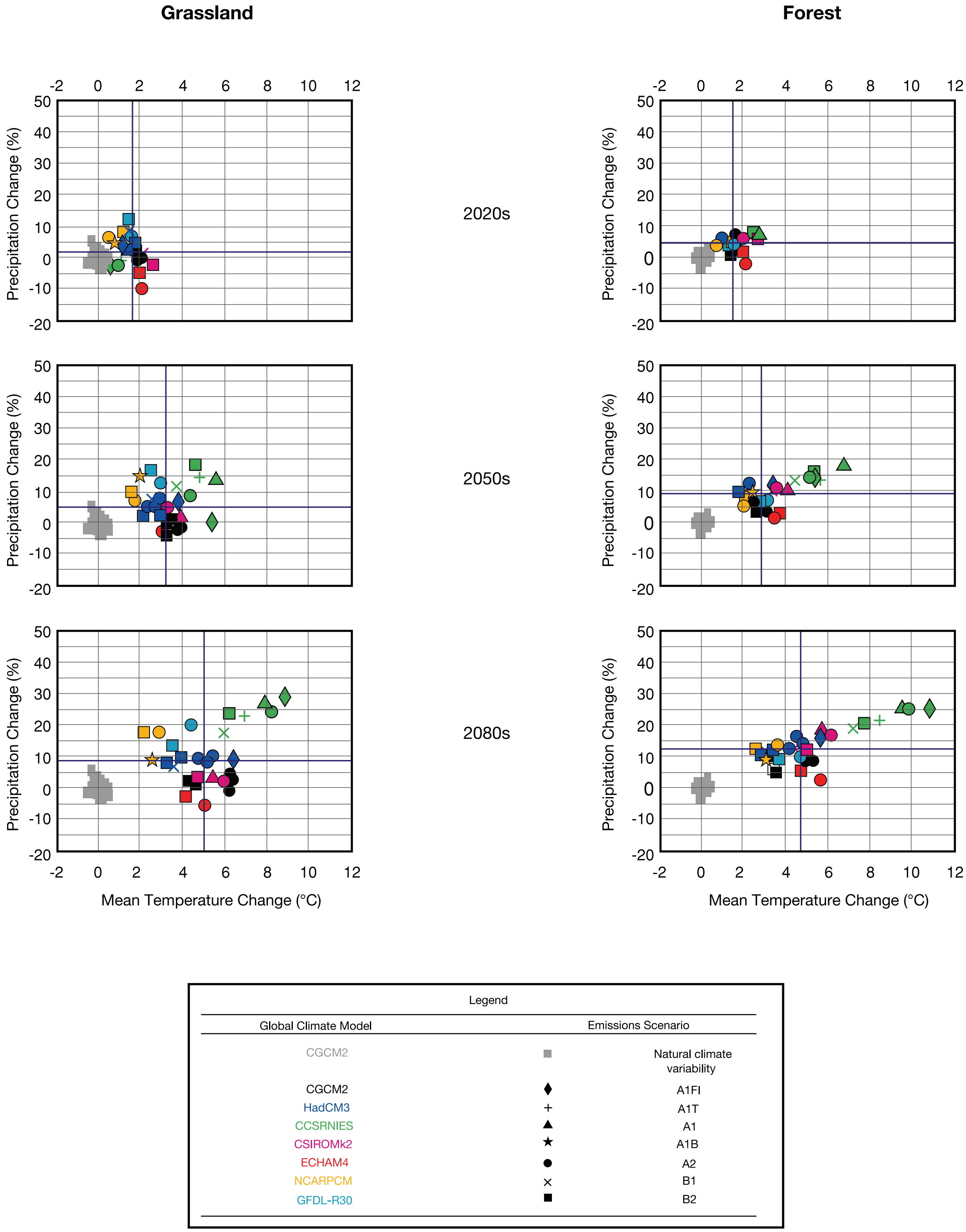

FIGURE 8a: Scatterplots of projected changes for the forest and grassland regions of the Prairies for the 2020s, 2050s and 2080s in mean annual temperature and precipitation. The grey squares indicate the 'natural' climate variability simulated by a long control run of the Canadian Coupled Global Climate 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.

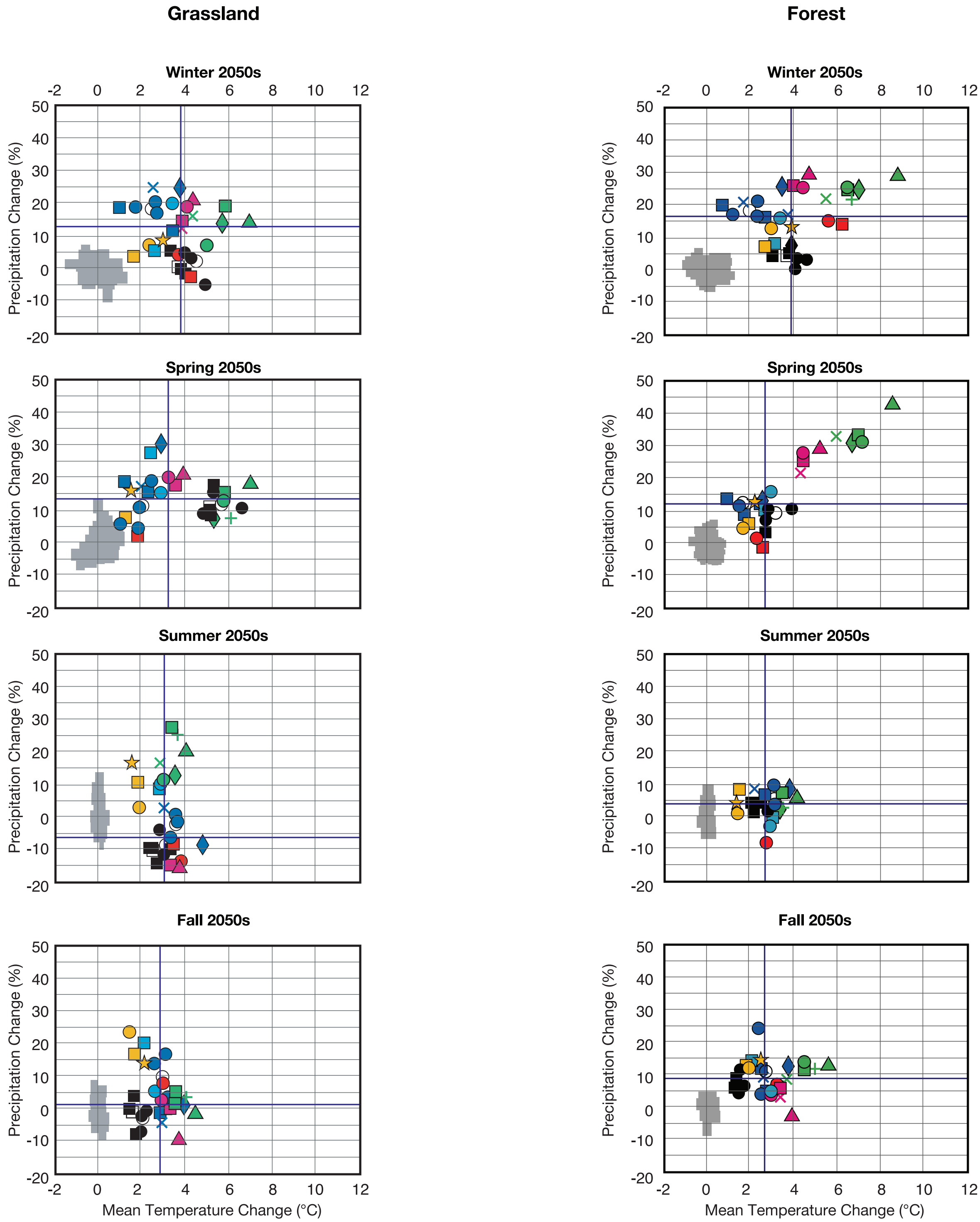

FIGURE 8b: Scatterplots of projected changes for the forest and grassland regions of the Prairies for the 2050s in mean seasonal temperature and precipitation. The grey squares indicate the 'natural' climate variability simulated by a long control run of the Canadian Coupled Global Climate Model 2 (CGCM2), 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.

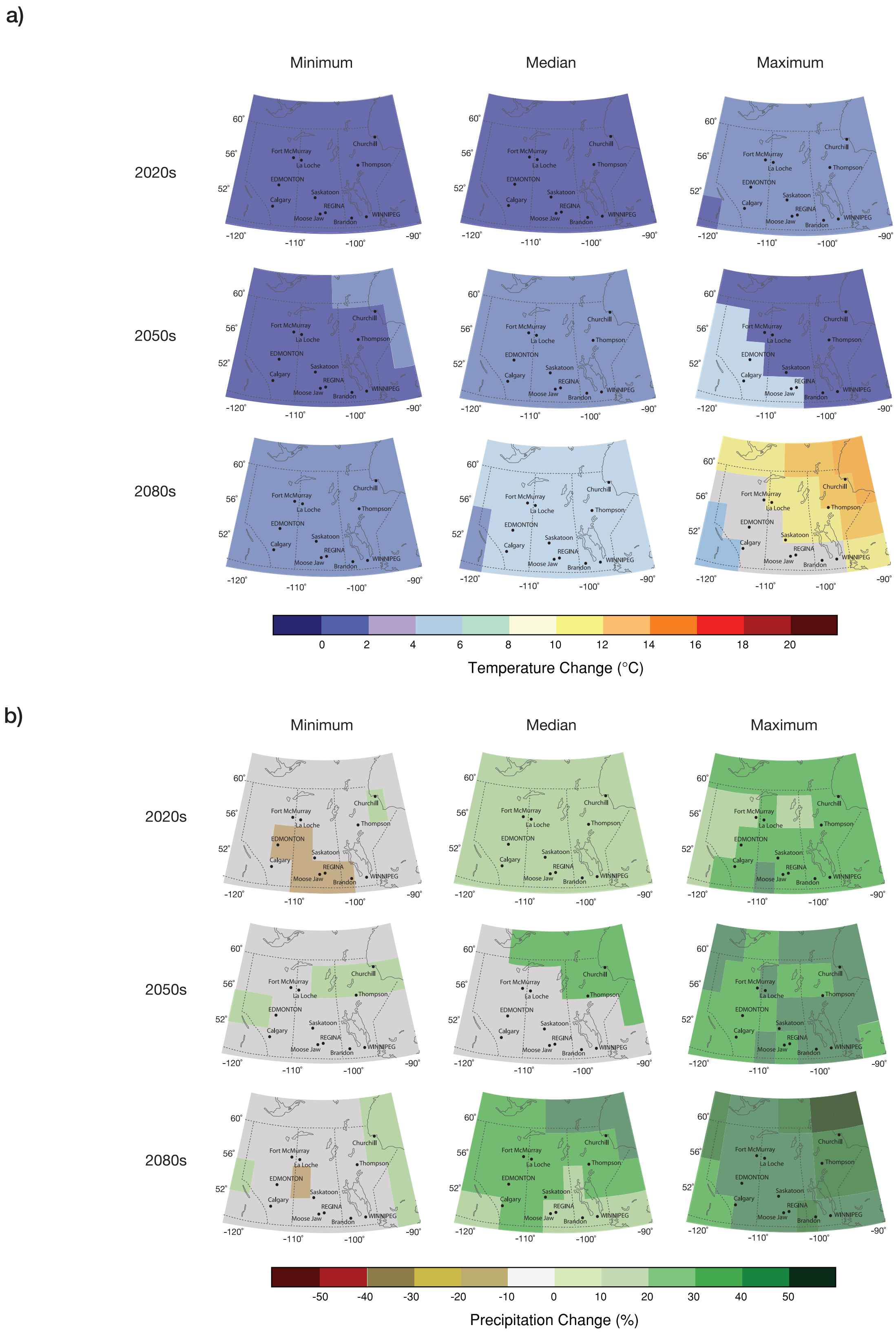

FIGURE 9: Climate change scenario maps for the Prairies in the 2020s, 2050s and 2080s, showing minimum, median and maximum projections of changes in a) mean annual temperature, and b) mean annual precipitation. Note that maximum and minimum changes for precipitation refer to wettest and driest scenarios,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

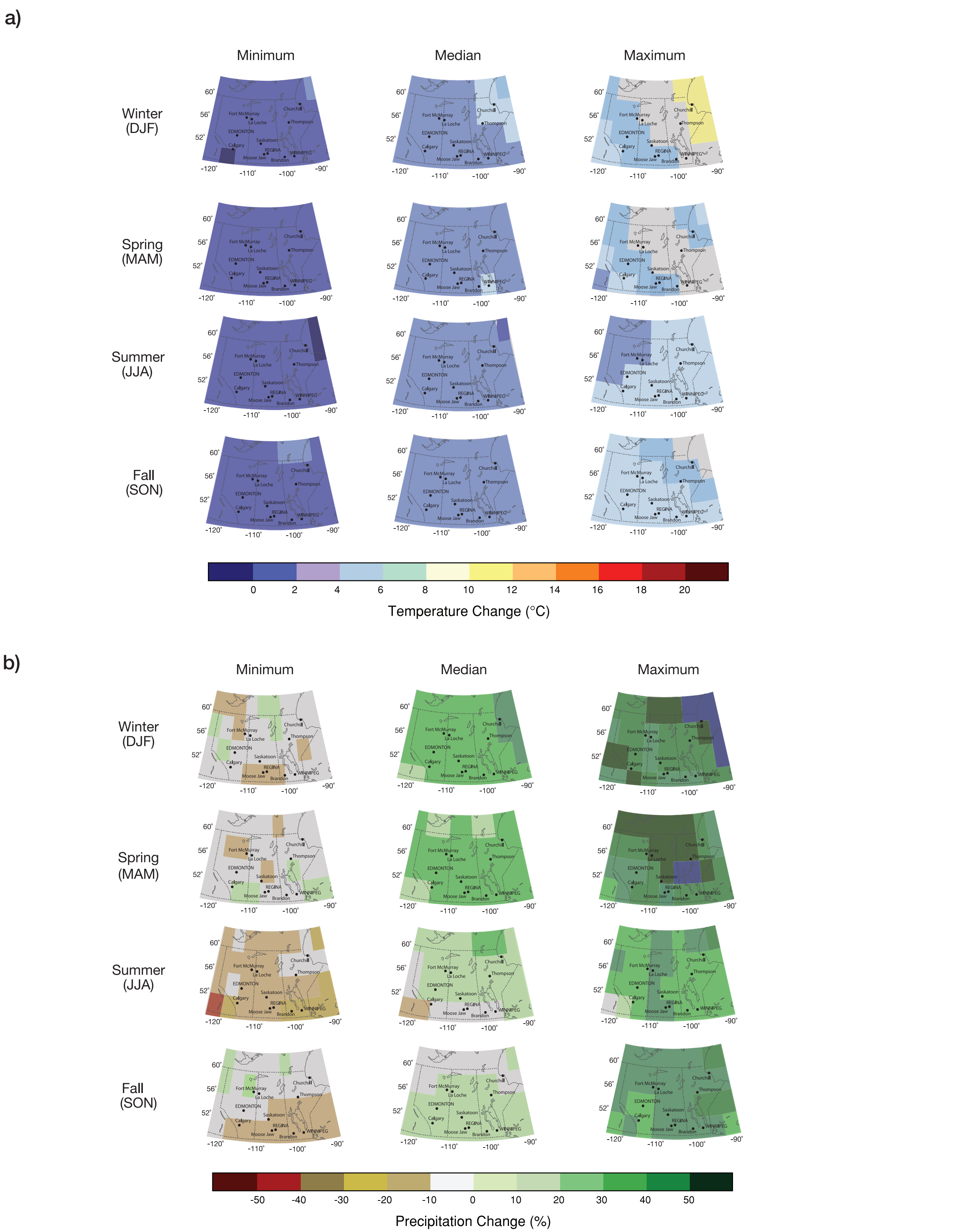

FIGURE 10: Climate change scenario maps for the Prairies in the 2050s, showing minimum, median and maximum projections of changes in a) mean seasonal temperatures and b) mean seasonal precipitation. Upper-case letters in parentheses after each season represent the months in that season. Note that maximum 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.

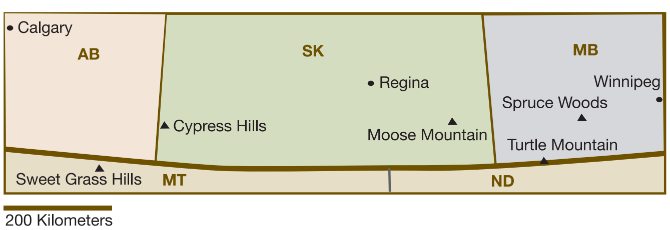

FIGURE 11: Location of the island forest study sites.

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.

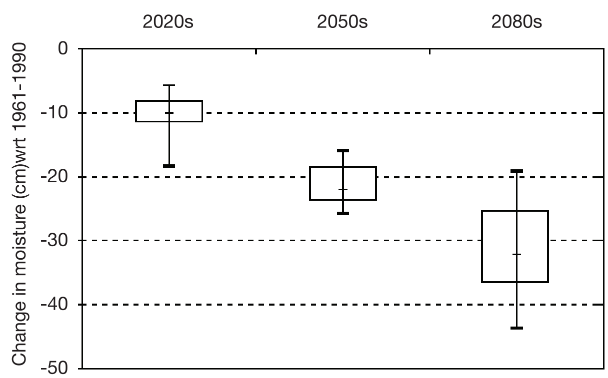

FIGURE 12: Summary of the projected changes in soil moisture levels (averaged over the five island forest study sites) for the 2020s, 2050s and 2080s. The thin vertical lines in the plot indicate the range of possible future moisture levels compared with the climate of 1961-1990. The boxes indicate the 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% 42 to 45%	CSIROMk2b B2, greater changes with the other models CGCM1 GA1	2050s; greater changes in the north 2050s for Lethbridge and Yorkton	Thorpe et al. (2004) CCIS[2] (2002)	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
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 CGCM1 GA1	2050s 2050s	Gameda et al. (2005) Nyirfa and Harron (2001)	As for droughts As above	As for droughts 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).

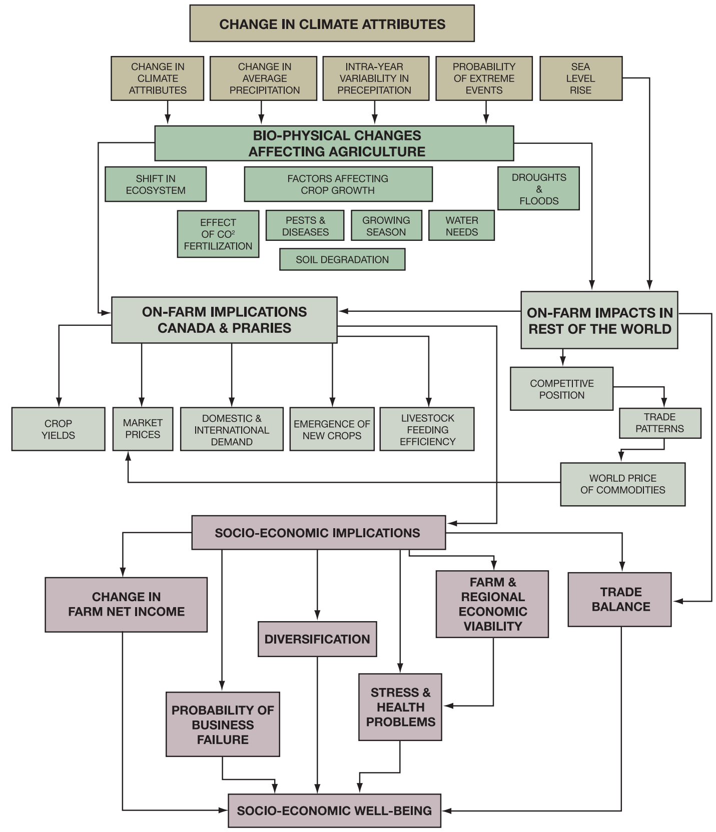

FIGURE 13: Interrelationships between climate change and socio-economic impacts related to agriculture.

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).

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

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

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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CHAPTER 8
British Columbia

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Recommended Citation:

Walker, I.J. and Sydneysmith, R. (2008): British Columbia; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 329-386.

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CONTENTS

KEY FINDINGS

Climate change is increasingly affecting British Columbia's landscapes, communities and economic activities. Future projections show that climate change will continue and suggest that direct and indirect impacts will become more pervasive. The following are some of the key risks and adaptation opportunities associated with climate change in BC:

Many regions and sectors of British Columbia will experience increasing water shortages. Smaller glaciers, declining snowpack, shifts in timing and amount of precipitation, and prolonged drought will increasingly limit water supply during periods of peak demand. Competition amongst water uses will increase and have implications for transborder agreements. Ongoing adaptive measures include the incorporation of climate change impacts into some official water management plans, upgrades to reservoir capacity and various demand management initiatives.

Hydroelectric power generation, especially during (increasing) peak energy demands in summer, is particularly vulnerable to climate change. Hydroelectricity currently accounts for nearly 90% of BC's power supply. Adaptation will involve managing electricity demands, which are expected to increase by 30 to 60% by 2025, and updating power-generating infrastructure, both of which are already part of current planning and management measures. Small hydro and 'run of river' alternatives can increase capacity but are more vulnerable to variable river flows than are facilities with large storage reservoirs. Alternative 'clean' sources of energy, such as wind power, will help meet increasing energy demands in the future, but are currently only a small contributor to BC's power supply. Coal-fired generating plants are also being considered, although their status is uncertain as they must now meet strict new zero net emissions targets established by the recently released BC Energy Plan.

Increasing frequency and intensity of extreme weather and related natural hazards will impact British Columbia's critical infrastructure. Windstorms, forest fires, storm surges, coastal erosion, landslides, snowstorms, hail, droughts and floods currently have major economic impacts on BC's communities, industries and environments. In low-lying coastal areas, certain risks will be magnified by sea-level rise and increasing storminess. The costs associated with managing and reducing impacts of extreme events are rising. British Columbia's transportation network, port facilities, electricity and communications distribution infrastructure are major investments where replacements or upgrades present adaptation opportunities for incorporation of revised hazards assessments that consider changing climate conditions and sea-level rise. Integrated stormwater management, an approach adopted by the Greater Vancouver Regional District, aims to manage stormwater run-off to protect urban stream health and includes consideration of climate change impacts. Integrating climate change and sea-level rise into infrastructure planning improves risk and life-cycle cost management, and will reduce the vulnerability of BC's critical infrastructure.

British Columbia's forests, forest industry and forestry-dependent communities are vulnerable to increasing climate-related risks, including pest infestations and forest fires. As of 2007, the mountain pine beetle outbreak affected approximately 9.2 million ha of BC's forests. The severity and longevity of this outbreak are linked to past management practices (e.g. fire suppression) and climate change. Major hydrological and ecological changes are expected in pine-dominated watersheds as a result of tree mortality and massive increases in logging activity to salvage beetle-killed timber. Initial economic gains will be substantial, but may give way to longer term social and economic instability without careful planning. Increasing international competition in the forestry sector will result in additional future challenges. The Future Forests Ecosystem Initiative of the BC Ministry of Forests and Range represents an early step toward long-term forest management planning that considers climate change in conjunction with other pressures.

Climate change will exacerbate existing stresses on British Columbia's fisheries. Future impacts include invasion of coastal waters by exotic species, rising ocean and freshwater temperatures, and changes in the amount, timing and temperature of river flows. Freshwater fisheries may experience increased water management conflicts with other uses (e.g. hydroelectric power generation, irrigation, drinking water), particularly in the southern interior. The vulnerability of Pacific salmon fisheries in both freshwater and saltwater environments is heightened by the unique social, economic and ecological significance of these species. Aquaculture, an increasingly important element of economic development on the coast, has potential to enhance food security while lessening the stresses on wild fisheries. However, the cultural and ecological impacts of aquaculture, and salmon farming in particular, are controversial.

British Columbia's agricultural sector faces both positive and negative impacts from climate change. Changes in precipitation and water supply, more frequent and sustained droughts, and increased demand for water will strain the adaptive capacity of most forms of agriculture. Growing conditions may improve in some regions or for some crops, although the ability to expand agricultural regions will be constrained by soil suitability and water availability. Increasing demand for irrigation will have to compete with other water uses, especially in areas of high growth.

Integrating climate change adaptation into decision-making is an opportunity to enhance resilience and reduce the long-term costs and impacts of climate change. Currently, this happens indirectly in larger urban centres, where sustainable building practices and demand management of water and energy arise from efforts to enhance sustainability and reduce greenhouse gas emissions. Drought-prone regions, such as the Okanagan region and the Victoria Capital Regional District, have aggressive restrictions on watering and rebates for high-efficiency consumer product replacements that have both adaptation and mitigation benefits for climate change. In remote coastal and rural communities, resilience arises from experience and exposure to the impacts of extreme weather on critical infrastructure (e.g. coastal highways, ferries, air service, power generation and communication) and on natural resources (e.g. fisheries and forests). Social networks, volunteerism, income diversification and food stockpiling also contribute to adaptive capacity and enhance resilience.

1 INTRODUCTION

1.1 ORGANIZATION OF THIS CHAPTER

This chapter provides an overview of climate change impacts and adaptation issues in British Columbia, with an emphasis on recent and ongoing work leading to adaptation action. The impacts of, and adaptation to, climate change in British Columbia will vary across the province's diverse landscapes, communities and socioeconomic activities. Available information covers the breadth of issues unevenly, with research being abundant on some topics (e.g. water resources and fisheries) and very limited for others (e.g. energy and transportation). Available information also focuses strongly on the impacts of climate change, although adaptation is becoming a more significant element of recent studies.

This introduction provides a broad overview of BC's physical and human landscapes, and briefly summarizes some key adaptation challenges in different regions of the province. Section 2 discusses drivers of climate variability in BC, and examines historical trends and future projections of major biophysical indicators of climate change. In Section 3, the implications of these biophysical changes are discussed in the context of adaptation to multiple stressors within key economic sectors. Greater detail on selected regional issues is presented in Section 4 as integrated case studies, highlighting the general trend from impacts research towards adaptation action. The concluding section of the chapter presents a synthesis of common themes, key insights and lessons learned from materials presented in the preceding sections.

1.2 CLIMATE AND PHYSICAL GEOGRAPHY

British Columbia is the most physically and biologically diverse region in Canada. The proximity of the Pacific Ocean and presence of several major mountain chains significantly influence BC's climate and ecosystems (Valentine et al., 1978). On the coast, mild, moist Pacific air encounters the steep Coast Mountains to produce a humid, maritime climate with annual air temperatures above 5°C and total annual precipitation exceeding 1000 mm (Figures 1 and 2). Some of the warmest climates in Canada occur in BC's southern coast and interior regions. The south-central BC coast has a warmer and drier climate in the rain shadow of Vancouver Island. The driest and warmest climates of BC (semiarid steppe) occur in the rain shadows of the Coast and Cascade ranges, and in the valleys of the southern interior west of the Columbia Mountains.

A humid continental climate predominates in central and southeastern BC. The Rocky Mountains restrict westward flow of cold Arctic air from the Prairies, moderating winter climate in the region. The Interior Plateau underlies most of this area and is the main catchment area for the Fraser and Columbia rivers. The climate of northern BC is controlled by the influx of cold Arctic air, the intensity of the continental high-pressure system, and inflow of warm dry air in the summer. This produces subarctic and boreal climates with very cold winters and short mild summers. This region is a complex landscape of mountains and plateaus that grade northeastward into the Great Plains. Average annual precipitation is low (less than 500 mm) in the interior plains and valleys, increasing to greater than 1000 mm along the coast and in the mountains. Three major river systems, the Peace, Liard and Skeena rivers, occupy this landscape.

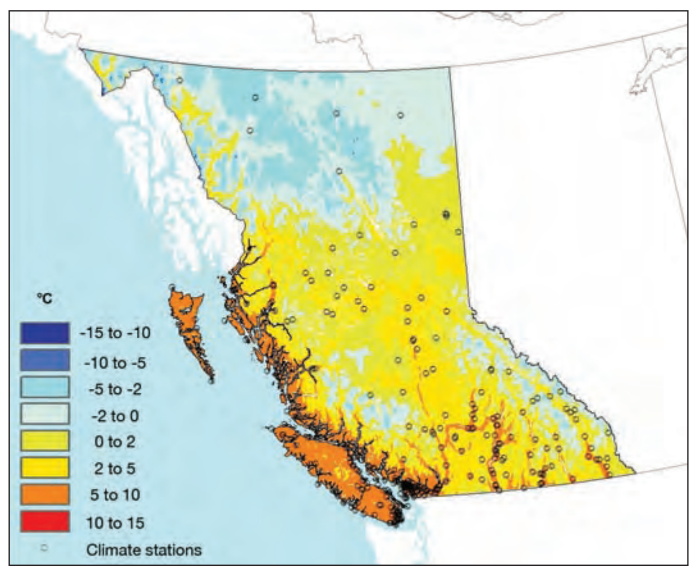

FIGURE 1: Annual mean temperature in British Columbia 1961-1990 PRISM[3] average. The PRISM numerical method interpolates station observations to a 4 km grid considering physical factors such as slope aspect and elevation . The PRISM model is considered more robust in areas with higher density of data collection stations and at elevations near the stations (Daly et al., 2002).

[3] Parameter-elevation Regressions on Independent Slopes Model, for more information *see* http://www.ocs.oregonstate.edu/prism/index.phtml [accessed May 18, 2007].

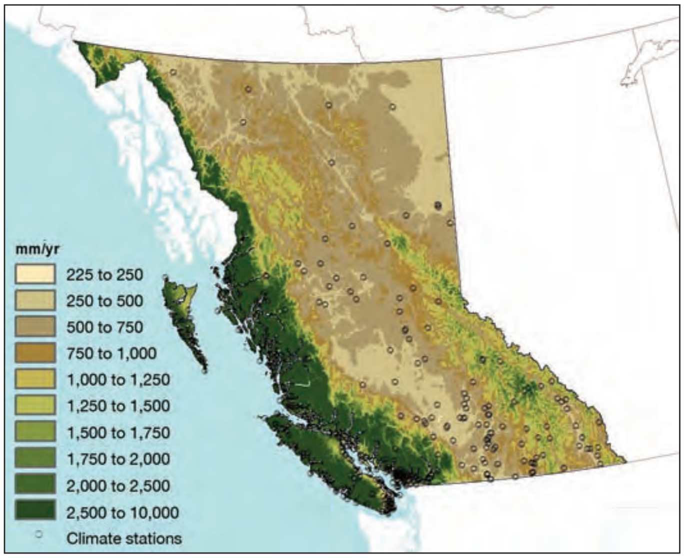

FIGURE 2: Annual total precipitation in British Columbia from 1961-1990 PRISM (*see* Figure 1) average. The wettest climates in Canada occur on BC's coast, especially on mountain slopes of Vancouver Island, the Queen Charlotte Islands and the mainland Coast Mountains.

Coastal British Columbia has a cool, moist, maritime climate influenced by the northeastern Pacific Ocean. In winter, midlatitude cyclonic storms move ashore and bring abundant precipitation to much of the coast. Variations in winter climate result from changing frequency and intensity of coastal storms. In part, this is due to the position of the prevailing storm track and the intensity of major low-pressure systems, such as the Aleutian Low. In summer, a subtropical high-pressure system moves northward in the northeastern Pacific, and storms are less frequent and approach the coast farther north. Variability in BC's climate is responsive to changes in the intensity of these oceanic pressure systems, which in turn are associated with changing ocean temperatures and currents. As such, variability in most of BC's climate is connected to large-scale ocean-atmospheric phenomena, namely the El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO; *see* Section 2.1 and Chapter 2).

1.3 BIOGEOGRAPHY AND ECOLOGICAL DIVERSITY

British Columbia can be divided into 14 biogeoclimatic zones (Krajina, 1965; Pojar and Meidinger, 1991; Hebda, 1998), distinguished by climate, latitude, elevation and distance from the coast (Figure 3). This biogeoclimatic classification system is used widely for both planning and research purposes (e.g. Mitchell et al., 1989; Hamann and Wang, 2006). Biodiversity varies within and between zones, although there are generally more species in the south and/or at lower elevations. In some regions, such as mountainous areas of southern BC, as many as six biogeoclimatic zones supporting thousands of species can be encountered across distances of only a few kilometres.

Local disturbances, such as fire, insects, disease, windthrow and human activity, significantly influence species distributions. Some disturbances, such as mountain pine beetle outbreaks, are exacerbated by climate change (*see* Section 4.2). Ecosystem responses to future climate change will be localized and depend on both natural and anthropogenic factors, including species sensitivity, the severity of the climate change and features that inhibit or enable species migrations, such as urban sprawl and the presence of migration corridors.

1.4 HUMAN ENVIRONMENT

The ability of British Columbia's communities and economic sectors to respond and adapt to climate change will depend as much on social and economic characteristics as it will on location and climate. Eighty-five per cent of British Columbians live in urban areas, mainly within the regions of greater Vancouver and Victoria, but also in several 'regional hubs' that include Kelowna-Vernon, Kamloops, Prince George and Prince Rupert. Rural BC consists of many smaller towns and First Nations communities dispersed along the coast and in the interior. The social and cultural landscape of BC is changing in many ways in response to local and global economic shifts, urbanization trends, immigration and technology. Climate change will influence and affect these communities differently.

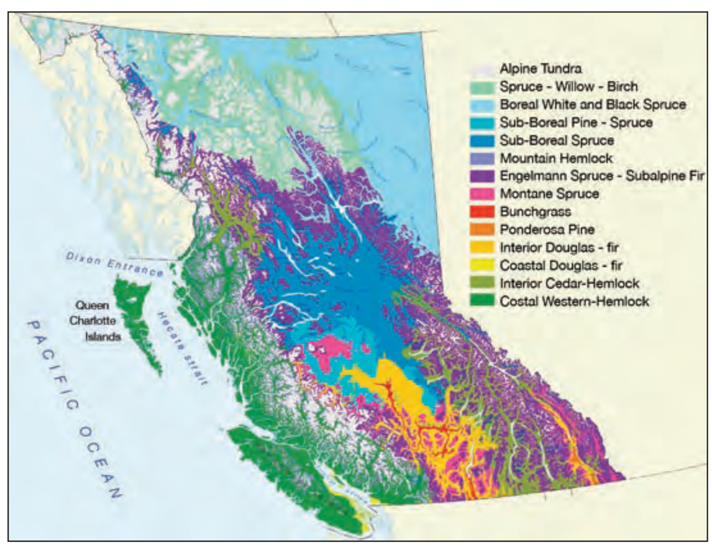

FIGURE 3: British Columbia's 14 biogeoclimatic zones (*after* Pojar and Meidinger, 1991).

The historical mainstay of BC's economy is the extraction, processing and export of natural resources, mainly wood, fish and minerals. Over the past 15 to 20 years, the contribution of natural resources to BC's economy, relative to total production and employment income, has declined in response to various environmental, social and economic changes (*see* Section 3). Traditional patterns of development and the relationship between major urban centres and rural regions are beginning to change in response to globalization and other factors (Matthews and Young, 2005). Despite this ongoing transformation, natural resources continue to dominate provincial exports and remain especially vital to the social and economic health of rural BC (Baxter and Ramlo, 2002; BC Ministry of Labour and Citizens' Services, 2004b).

Recent demographic trends in BC have been driven by urbanization and immigration. The province has the second highest immigrant population in Canada after Ontario (Statistics Canada, 2001). Population in 2005 was 4.25 million, and is projected to reach 5.6 million by 2031 (BC Ministry of Labour and Citizens' Services, 2005a; Statistics Canada, 2005). Growth is concentrated in the Greater Vancouver Regional District (+8.5%), the Okanagan region (+8.2%) and the Squamish-Lillooet Regional District (+12.3%)[4]. In contrast, some northern and coastal districts, such as northern Vancouver Island (–10.2%) and the Skeena–Queen Charlottes (–12.5%), have experienced recent population declines (Statistics Canada, 2001). In part, this reflects out-migration spurred by job losses in resource-dependent communities and the general economic downturn in remote and rural communities during the past 10 to 15 years (Marchak et al., 1999; Hayter, 2000; Baxter and Ramlo, 2002; Matthews, 2003; Hanlon and Halseth, 2005; Young, 2006a, b).

The historical tendency in BC for broad swings across the political spectrum between successive elections has had both positive and negative effects on adaptive capacity at the community scale. Restructuring of rural and resource development policy and the delivery of services to remote communities has led many communities to become 'entrepreneurial risk takers' (Young 2006a, b), and to assume a greater role in local resource management, community development and service delivery (Young, 2006a, b; Matthews and Young, 2007; Ommer, 2007). For small communities with limited adaptive capacity, dealing with such short-term issues limits their ability to simultaneously prepare for, and adapt to, a changing climate (Brenner and Theodore, 2002; Herbert-Cheshire and Higgins, 2004).

Another key factor that will affect future adaptation in British Columbia is the pending changes in jurisdiction and responsibility for future land- and resource-use management and planning that will occur as treaties are eventually signed between First Nations and the governments of Canada and BC[5]. These changes will have important, although as yet undetermined, implications for adaptation, especially in coastal and rural regions of the province.

1.5 REGIONAL CHALLENGES

The impacts of climate change and the approaches to adaptation will vary across British Columbia's disparate regions and economic sectors (*see* Section 3).

About 75% of BC's population lives in the Vancouver–Lower Mainland region, where both the population and the economy have greatly diversified in recent decades. The communications technology, entertainment (especially film production), light industry, greenhouse agriculture, biotechnology, construction, retail and service sectors have all become major elements of the regional economy, joining more established sectors such as tourism, transport and port functions (Vancouver Economic Development, 2006). Currently, the region is investing heavily in infrastructure for the 2010 Winter Olympics and to support continued growth and development over the next few decades. Managing growth within the objectives of the official 'Liveable Region Strategic Plan' (Greater Vancouver Regional District, 1999) will require consideration of, and planning for, climate change. The Victoria Capital Regional District (CRD), the political and administrative hub of the province, is also expected to see continuing population and economic growth. Current climate risks in both the Greater Vancouver Regional District (GVRD) and the CRD include water shortages associated with frequent droughts and the impacts of extreme weather events. These risks are expected to increase in the future, with significant implications for municipal infrastructure (*see* Section 4.4).

In northern and central BC, the current mountain pine beetle (MPB) outbreak exemplifies the linkages between climate change, natural pest cycles and resource management practices (*see* Sections 3.3 and 4.2). The initial response to the crisis was to increase harvest levels two to three times in an effort to secure the timber value of infected trees before they rot. The social and environmental consequences of both the outbreak and the response, although uncertain, are a concern for many interior communities. In areas most heavily infected, managing the current and anticipated impacts of the outbreak overshadows most other issues.

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[4] Population growth projections and more detailed statistics and analysis are also available at <http://www.bcstats.gov.bc.ca/DATA/pop/popstart.asp> [accessed May 18, 2007].

[5] The BC Treaty Commission and Treaty Negotiation Process were established in 1992 to facilitate negotiation of "fair and durable treaties" (<http://www.bctreaty.net/files/publications.php> [accessed April 30, 2007]) between BC First Nations and the governments of British Columbia and Canada. Unlike the rest of Canada, most indigenous groups in BC never formally relinquished rights or title to their traditional territories (Tennant, 1990; Muckle, 1998). Aboriginal title was officially recognized by the courts in the 1990s (Delgamuukw v. British Columbia, [1997] 3 S.C.R. 1010).

Northeastern BC is currently experiencing an oil and gas resource boom, which started in the 1990s and peaked in 2003 (Canadian Association of Petroleum Producers, 2005, 2006). The strong regional economy attracts workers from areas of high unemployment around BC and across Canada. There has been little study of the impacts of climate change in this corner of the province, although adaptation challenges are likely to be similar to those in adjacent parts of Alberta (*see* Chapter 7).

Communities along the north-central coast of BC have experienced significant social and economic change in the past 10 to 20 years, with many communities experiencing significant unemployment, social stress and depopulation (Matthews, 2003; Ommer, 2006; Young, 2006a, b). Communities along the southern coasts have faced similar challenges, although they are ameliorated partly by proximity to the major economic centres of Vancouver and Victoria. The future of coastal communities in light of climate change and other stressors will depend on economic diversification and renewal; as such, adaptation will be closely linked to regional development. Potential areas for diversification include tourism, community forests and aquaculture (BC Ministry of Environment, 1997a; Matthews and Young, 2005). Although all have their limitations, salmon aquaculture faces additional challenges due to the politically and ecologically contentious nature of current practices (BC Ministry of Environment, 1997b; Gardner and Peterson, 2003; Naylor et al., 2003; Morton et al., 2005; Gerwing and McDaniels, 2006; *see* Section 3.2).

Southeastern BC encompasses two subregions, unified by the central role of water supply in land-use and resource management decisions. The Okanagan valley has strong orchard industries and more than 90% of BC's wineries and vineyards (Northcote, 1996; BC Ministry of Labour and Citizens' Services, 1997, 2005c; Bremmer and Bremmer, 2004). The region has experienced rapid growth and development in the past twenty years, and now supports an established tourism sector and burgeoning retirement population (McRae, 1997). The region's water resources are already stressed, and future shortages will be exacerbated by climate change (Cohen et al., 2003, 2006; *see* Section 4.3). To the east, the Columbia-Kootenay region hosts much of the province's hydroelectric generating capacity. Climate change impacts on snow pack and glaciers will limit the quantity and alter the timing of water availability for power generation in the region. These changes will excacerbate the existing challenges for water managers of reconciling competing demands of domestic, agricultural, fisheries, industry and commercial users, as well as meeting obligations to partners in interprovincial and international agreements (Volkman, 1997; Smith et al., 1998).

2 INDICATORS OF CLIMATE VARIABILITY AND CHANGE

2.1 UNDERSTANDING CLIMATE VARIABILITY

Two major ocean-atmosphere phenomena strongly influence climate variability in British Columbia: 1) the El Niño–Southern Oscillation (ENSO), and 2) the Pacific Decadal Oscillation (PDO). Both are naturally occurring patterns, but their frequency and intensity appear to be changing in response to global climate change (Trenberth and Hurrell, 1994; Timmermann, 1999).

The ENSO is a tropical Pacific phenomenon that influences global weather patterns. It has a cycle of 3 to 7 years (Wolter and Timlin, 1993, 1998; *see* Chapter 2). During warm 'El Niño' events, warm waters from the equatorial Pacific migrate up the west coast of North America and influence sea-surface temperatures, sea levels, and local climate across BC. Impacts of ENSO are strongest in winter and spring. El Niños bring warmer temperatures (by 0.4–0.7°C) and less precipitation to BC, whereas cool 'La Niña' events bring cooler and wetter conditions (Climate Impacts Group, 2006).

The PDO is a longer (approx. 20–30 year) climate variability pattern similar in effect to ENSO, but it occurs in the midlatitude northeastern Pacific (Mantua et al., 1997). The positive (warm) PDO phase is characterized by warmer coastal waters in the northeastern Pacific. It is associated with slightly warmer conditions across BC during winter and spring, and variable effects on precipitation. The opposite occurs during the negative PDO phase, with cooler and wetter conditions. Shifts between PDO phases result in major changes in climatic and oceanographic regimes, affecting winds and storms, ocean temperatures and currents (Bond and Harrison, 2000; McPhaden and Zhang, 2002). The PDO shifted from a negative (cold) to a positive (warm) phase in 1976 (Hare and Mantua, 2000) and has been positive ever since, except for the late 1980s and early 2000s.

These two climate variability patterns are linked, since the PDO either amplifies or dampens the effects of ENSO events (Gershunov and Barnett 1998; Biondi et al., 2001), affecting not only temperature and precipitation but also snowpack, streamflow, growing degree days, frost-free periods, winds, seasonal ocean levels and storm surges. The effects of PDO and

ENSO in western North America are widespread and well documented (e.g. Fleming et al., 2006; Stahl et al., 2006; Wang et al., 2006).

Understanding these factors that control climate variability in BC is important for a wide range of planning purposes. Perhaps most important is that the use of short-term (30-year) climate averages cannot capture the variability introduced by the PDO. Second, the strong influence of ENSO means that seasonal climate predictions can be used for operational planning on a year-to-year basis (American Meteorological Society, 2001). Seasonal climate forecasts are presently available for some areas and seasons based on statistical relationships with climate variability patterns[6]. These forecasts can assist with risk assessments for forest fires, droughts, water and energy supply/demand, snow removal, river forecasting and flooding. Such predictions represent a major improvement over the use of historical information only. It has been estimated that incorporation of seasonal climate predictions into planning of hydroelectric reservoir operations on the Columbia River could increase annual revenues by an average of CDN$153 million (Hamlet et al., 2002).

Prehistoric Records of Variability and Change

Natural archives, such as lake and ocean sediments, tree rings, glacial ice and landforms, provide insights into the climate variability and environmental history of British Columbia prior to the instrumental record. Extensive paleoclimatic research has been conducted in BC. Recent reviews document that, following a colder drier climate toward the end of the last glaciation (approx. 12 500 years ago), BC's climate warmed rapidly by 5°C over only a century or two (Hebda and Whitlock, 1997; Walker and Pellatt, 2003). Following this were three broad climate intervals: 1) a warm and dry interval from approximately 10 000 to 7400 years ago; 2) a warm and moist interval from 7400 to 4400 years ago; and 3) a cooler interval, analogous to the modern climate, from about 4400 years ago (Figure 4).

Superimposed on this longer term climate history is a complex pattern of climate variability that includes 1) abrupt changes in climate (Gedalof and Smith, 2001; Chang et al., 2003; Chang and Patterson, 2005; Zhang and Hebda, 2005); 2) periods of intense, persistent drought (Gedalof et al., 2004; Watson and Luckman, 2004, 2005); 3) inconsistent relationships between ENSO, PDO and the climate of BC (Gedalof et al., 2002, 2004; Watson and Luckman, 2004, 2005) and 4) multiple periods of alpine glacier advance and retreat (Ryder and Thomson, 1986; Luckman, 2000; Larocque and Smith, 2003, 2004; Koch et al., 2004; Lewis and Smith, 2004). In particular, the glacial record shows that current warming rates are unprecedented in the last 8000 years (Menounos et al., 2004). Together, these records demonstrate the dynamic nature of BC's climate and the great likelihood that climate 'surprises' will occur in the future.

[6] Seasonal climate predictions are available from various agencies and are published on the Internet. For a listing, *see* <http://www.pacificclimate.org/impacts/index.php?id=6> [accessed May 18, 2007].

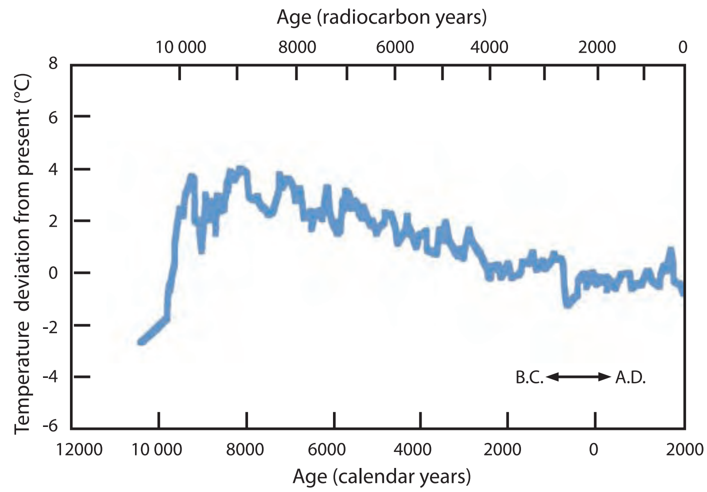

FIGURE 4: Inferred temperature records from southern British Columbia (*from* Rosenberg et al., 2004).

Three key lessons emerge from the prehistoric climate record that are of relevance to the assessment of future climate change:

- Abrupt changes in climate, similar to the shift in 1976, are common in the prehistoric record, as are abrupt changes in ocean circulation.
- Influences of large-scale patterns of climate variability (e.g. ENSO and PDO) on BC's climate have not been consistent in recent centuries. Consequently, the instrumental record probably does not reflect the full range of variability of the climate system, which may respond unpredictably to changes in forcing.
- Severe, sustained droughts occurred more frequently in previous centuries than over the past few decades, and would therefore be expected to occur in the future irrespective of climate change.

2.2 TEMPERATURE AND PRECIPITATION

Historical Trends

Although there are several long-term instrumental climate records for British Columbia, most stations began recording around 1950, which presents challenges for the identification of long-term trends. The present-day climate station network (shown in Figure 1) is also not sufficiently dense to characterize adequately BC's highly variable climate (Miles and Associates, 2003). Regardless of length of record, however, all trends show that BC's climate has warmed significantly in recent decades (Zhang et al., 2000; BC Ministry of Water, Land and Air Protection, 2002; Whitfield et al., 2002a; BC Ministry of Environment, 2006). Longer records suggest that the rate of change in temperature and precipitation in southern BC and much of the Pacific Northwest during the twentieth century exceeded global averages (Zhang et al., 2000; Mote, 2003a, c). Most of the province experienced warming in both mean annual temperature (Figure 5) and during all seasons (Table 1), although there are large regional and seasonal disparities in trends (Whitfield et al., 2002a). Annual and seasonal precipitation trends also vary by region (Figure 6, Table 2).

Future Projections

Global climate models (GCMs) are used to project future climate with plausible scenarios of future greenhouse gas emissions and physical models of climate that include atmospheric, ocean, ice and land-surface components (*see also* Chapter 2). Multiple projections and/or models are used to address uncertainty and produce a range of possible futures.

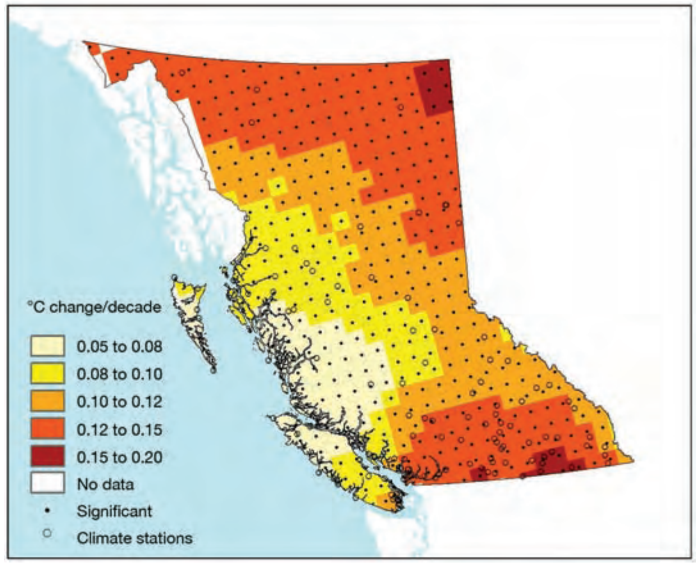

FIGURE 5: Trend in annual mean temperature (in °C per decade) for British Columbia, 1900–2004. Use of annual averages may mask seasonal trends that are larger than the annual average and/or of opposite sign. Long-term trends should be considered in the context of climate variability (*see* Section 2.1).

TABLE 1: Historical trends in temperature in British Columbia's northern, southern and coastal regions.

Region	Extremes	Seasonal	Annual
BC	Increased warm temperature extremes[1]; fewer extreme cold days and nights, fewer frost days and more extreme warm nights and days[2]; longer frost-free period[3]	Daily minimum and maximum temperatures higher in all seasons; greatest warming in spring and winter[3]	0°C isotherm shifting northward[4]
Southern BC	Interior warmed more than the coast[3]	Warming in spring, fall and winter, but not summer[5, 6]	
Northern BC		Warmer winters, cooler falls[7]	Warmer average annual temperature[5]
Coastal BC	Coast warmed less than interior[3]	Warmer in spring and fall[8]; Georgia Basin–Puget Sound region warming in all seasons, especially last 30 years[9]	

[1] Bonsal et al. (2001)
[2] Vincent and Mekis (2006)
[3] For the period 1950-2003 (B. Taylor, Environment Canada, pers. comm., 2007)
[4] Bonsal and Prowse (2003)
[5] Zhang et al. (2000)
[6] Whitfield et al. (2002a)
[7] Whitfield et al. (2003)
[8] Whitfield and Taylor (1998)
[9] Mote (2003a)

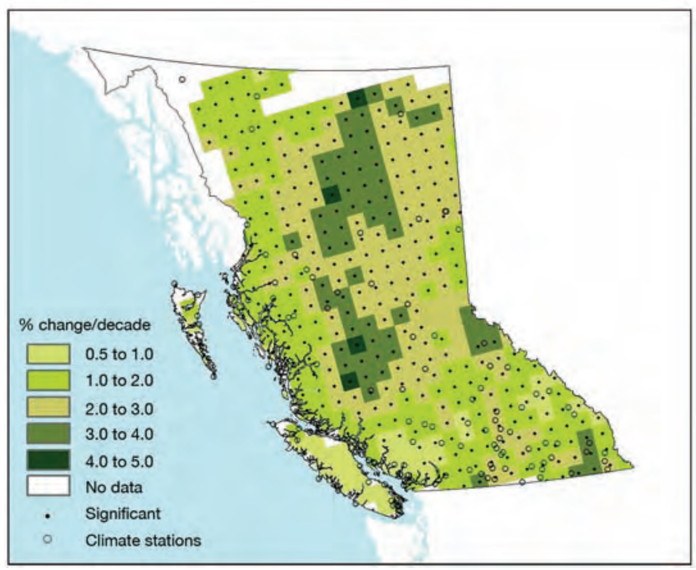

FIGURE 6: Trend in annual total precipitation for British Columbia, 1900-2004, in % change per decade from 1961-1990 (trends shown are relative to what is normal at a given location). See Figure 2 for the 1961-1990 average. Use of annual averages may mask seasonal trends that are larger than the annual average and/or of opposite sign. Long term trends should be considered in the context of climate variability (*see* Section 2.1).

TABLE 2: Historical trends in precipitation in British Columbia's northern, southern and coastal regions.

Region	Extremes	Snow/rain	Total annual precipitation	Total seasonal precipitation
BC	More precipitation days, decreased consecutive dry days, decreased mean daily precipitation; no consistent changes in extremes[1]	Decreased snow to total precipitation ratio (more rain, less snow during cold season)[2]	Slightly wetter[2, 3]	
Southern BC	Wetter winter wet periods	Less annual snowfall in last 50 years[1]; ratio of rain to snow increased (more rain, less snow) in Okanagan[4]; decreased snowpack in spring and at lower elevations[5, 6, 7]	Wetter in 20th century, with majority of increase before 1945[8]	Wetter in spring, summer, fall[3]; drier in winter, wetter in summer in Okanagan[4]; drier in winter in interior[2]
Northern BC		More snowfall since 1950s[1]		Wetter in all four seasons[3]
Coastal BC		Less snow throughout, more than 40% less at some sites[5]; greatest loss of snow in Pacific Northwest on south coast; more locations with no snow on April 1		Wetter in winter (more rain)[9], except Georgia Basin (no trend November to March)

1 Vincent and Mekis (2006)
2 For the period 1950-2003 (B. Taylor, Environment Canada, pers. comm., 2007)
3 Zhang et al. (2000)
4 Whitfield and Cannon (in press)
5 Mote (2003a)
6 Mote (2003b)
7 Mote et al. (2005)
8 Mote (2003c)
9 Whitfield and Taylor (1998)

For BC, three large scenario regions (northern, southern and coast) were chosen for this assessment, based on large (approx. 100 km^2) GCM grids. Scenarios are displayed as changes from an observed 1961–1990 mean climate to the 2020s, 2050s and 2080s for temperature (Figure 7a) and precipitation (Figure 7b). Scenarios of precipitation by season[7] for BC suggest that conditions will be wetter over much of the province in winter and spring, but drier during summer in the south and on the coast.

Scenarios of finer spatial resolution are available using regional climate models (RCMs); however, the computational costs generally limit RCMs to fewer emissions scenarios than presented above. Downscaling methods, such as the ClimateBC program (University of British Columbia, no date) that uses high-resolution elevation and historical data to generate statistical predictions, also provide enhanced spatial resolution (Hamann and Wang, 2005; *see* Section 3.6 for application to parks adaptations).

[7] Available from <http://www.PacificClimate.org> [accessed May 18, 2007].

2.3 EXTREME WEATHER AND WEATHER-RELATED EVENTS

Extreme weather and weather-related events directly affect British Columbians more than any other climate risk. Windstorms, forest fires, storm surges, landslides, snowstorms, hail and floods all have major impacts on communities, infrastructure and industry (Hamlet, 2003; Sandford, 2006). The impacts and steps toward adaptation for various climate-related extreme events are discussed in Section 4 (*see also* Sections 3.7 and 3.8). Increased occurrence of extreme weather events is documented worldwide, and climate models project a continuing rise in their frequency (Easterling et al., 2000; Milly et al., 2002; Palmer and Rälsänen, 2002; Schumacher and Johnson, 2005). In western North America, forest fires have become more frequent and severe with recent warming (Gedalof et al., 2005; Westerling et al., 2006), and this is projected to continue in western Canada (Gillett et al., 2004; Flannigan et al., 2005).

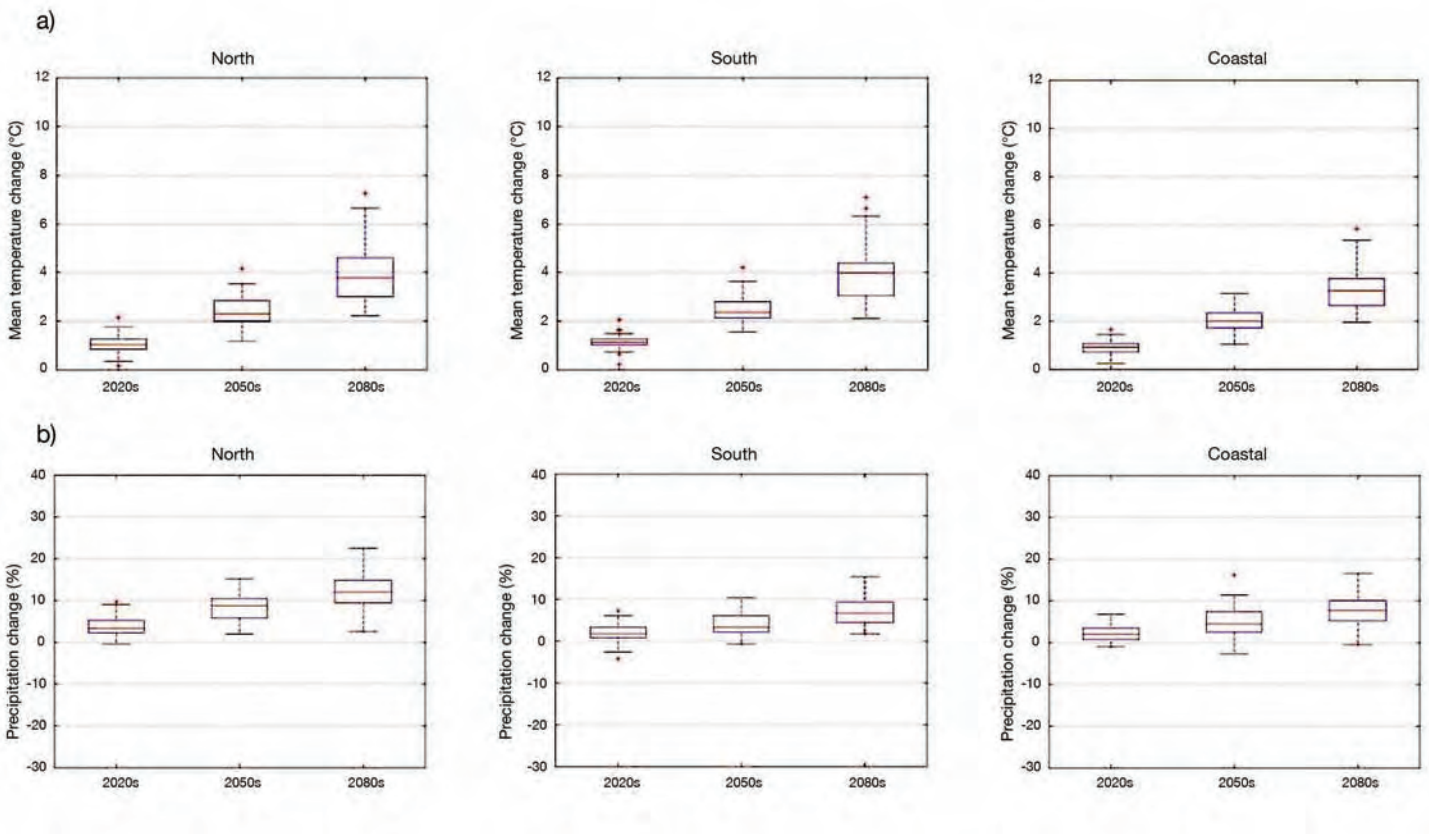

FIGURE 7: Changes from the 1961–1990 historical climate to the 2020s, 2050s and 2080s in a) temperature (°C), and b) precipitation (%). See Appendix 1 in Chapter 2 for description of box-and-whisker plots.

British Columbia's Provincial Emergency Program (BC-PEP) records extreme weather events that cause personal and economic losses due to infrastructure damage. From 2003 to 2005, the frequency, severity and costs of extreme events recorded by BC-PEP rose dramatically as a result of wildfires, storm surges, heavy rains causing flooding and landslides, and drought. Warmer winter weather, resulting in ice jams, freezing rain and rain-on-snow events, also resulted in economic losses. These events cost BC taxpayers an average of $86 million per year in payouts of disaster financial assistance, compared to an average of $10 million per year from 1999 to 2002 (Whyte, 2006). This increase is consistent with increasing weather-related hazards, as documented in the Canadian Disaster Database (McBean and Henstra, 2003; Public Safety and Emergency Preparedness Canada, 2006b).

2.4 HYDROLOGY

Regional hydrological changes are linked to temperature and precipitation trends (Tables 2 and 3; *see* Sections 3.1 and 4.3). Large temperature increases have resulted in a reduced snowpack, even in snowmelt-dominated basins where net

TABLE 3: Regional trends in river runoff in British Columbia.

Location	Trend in runoff
Provincial trends	• Shifts in stream flows and seasonal transitions[1] • Earlier spring runoff[2, 3] • Increasing river temperatures[4]
Coastal	• Increased winter flows[5, 6] • Decreased late summer flows[5]
Northern	• Streamflow increases throughout the year, particularly in winter[7]
Southern	• Extended lower flows in late summer and early fall[1] • Longer periods of low flow[1] • Higher early winter flows (southern interior)[1]

1 Leith and Whitfield (1998)
2 Whitfield et al. (2003)
3 Zhang et al. (2000)
4 BC Ministry of Water, Land and Air Protection (2002)
5 Whitfield and Taylor (1998)
6 Whitfield et al. (2002b)
7 Whitfield and Cannon (2000)

BOX 1

BC's glaciers: a dwindling natural resource

Glaciers are a major source of fresh water for western Canada, with glacial runoff currently maintaining river discharge and regulating temperatures in many western Canadian rivers (Fleming, 2005; Fleming and Clark, 2005; Moore, 2006), supplementing surface runoff during the summer when aquatic ecosystems are most vulnerable and demand for water highest. For instance, in the Columbia River basin, 10 to 20% of annual flow and 50% of summer flows are glacier fed (Brugman et al., 1996).

In 2005, glaciers covered 3% of BC (30 000 km^2) and were retreating at rates unprecedented in the last 8000 years (Lowell, 2000). Most of BC's glaciers are losing mass and many will disappear in the next 100 years. Information on the rates and magnitude of glacier retreat is important for water resource management and planning, which has to address demands for human consumption, irrigation, industrial use and hydroelectric power generation, as well as in-stream ecological needs. Climate change and increasing water resource demands are expected to exacerbate existing supply-demand mismatches (Environment Canada, 2004). Decreasing summer flows resulting from reduced glacier melt, combined with increasing summer water demands to meet rising irrigation requirements and energy needs for cooling, presents one of the most significant water resource challenges for BC, a province seemingly blessed with water.

precipitation has increased (Mote, 2003a, b; Stewart et al., 2004). Reductions in snowpack have changed streamflow volumes and timing, while many lakes and rivers also show shorter periods of ice cover (BC Ministry of Water, Land and Air Protection, 2002) and earlier spring ice melt (Bonsal et al., 2001). Spring melt now occurs earlier in many BC rivers (Zhang et al., 2001a), a trend that climate model projections indicate will continue (Barnett et al., 2005). Also significantly impacting regional hydrology is the rapid melting of alpine glaciers, many of which may disappear in the next 100 years (Box 1).

Analysis for the entire Pacific Northwest suggests that historical streamflow trends will continue, with many rivers running 30 to 40 days earlier by 2100 (Stewart et al., 2004). Increasing temperatures and precipitation changes will reduce snowpack and increase winter runoff for most of BC (Hamlet and Lettenmaier, 1999; Mote and Hamlet, 2001). Reduced snowpack and earlier snow melt, combined with higher evapotranspiration, will result in earlier spring peak flows and reduced April to September streamflows. For example, by 2045 in the Columbia River basin, April to September runoff could be reduced by 10 to 25% relative to a simulated hydrological base case (Hamlet and Lettenmaier, 1999). Combined, these hydrological impacts will affect several of BC's key economic sectors, including hydroelectric power generation (*see* Section 3.7), fisheries (*see* Section 3.2) and agriculture (*see* Section 3.4).

Climate change also impacts groundwater systems, with the greatest changes evident in shallow aquifer systems (Rivera et al., 2004). Even small changes in temperature and precipitation alter groundwater recharge rates and water table depths (e.g. Changnon et al., 1988; Zektser and Loaiciga, 1993). Reductions in stream flow will have negative effects on both groundwater recharge and discharge (Scibek and Allen, 2006). As groundwater discharge serves to moderate stream temperatures, reduced summer discharge would result in even greater increases in surface water temperatures than would occur from air temperatures alone. In coastal regions, climate change will also impact groundwater quality due to saltwater intrusion in response to sea-level rise (e.g. Lambrakis and Kallergis, 2001; Yin, 2001).

2.5 SEA LEVEL

Globally, mean eustatic sea level increased 10 to 20 cm during the twentieth century, and is anticipated to rise another 18 to 59 cm by 2100, due largely to melting glaciers and ice sheets, and thermal expansion of warming seawater (Intergovernmental Panel on Climate Change, 2007). In British Columbia, relative sea-level change differs from the global trend due to vertical land movements. During the twentieth century, sea level rose 4 cm in Vancouver, 8 cm in Victoria and 12 cm in Prince Rupert, and dropped by 13 cm in Tofino (BC Ministry of Water, Land and Air Protection, 2002). Sea-level rise is an important issue in BC, as it impacts coastal infrastructure, such as highways, sewer systems, shipping terminals and Vancouver International Airport. For perspective, an arbitrary 1 m rise in sea level would inundate more than 4600 ha of farmland and more than 15 000 ha of industrial and residential urban areas in British Columbia (Yin, 2001). Approximately 220 000 people live near or below sea level in Richmond and Delta in Greater Vancouver, and are protected by 127 km of dykes that were not built to accommodate sea-level rise (B. Kangesneimi, BC Ministry of Environment, pers. comm., 2007). Many remote coastal communities and First Nations' heritage sites are vulnerable to enhanced erosion and storm-surge flooding associated with sea-level rise. Finally, sea-level rise can result in saltwater intrusion into freshwater aquifers, affecting the quality and quantity of drinking and irrigation water supplies (Liteanu, 2003; Allen, 2004).

On British Columbia's coast, the height of damaging extreme high-water events is increasing at a rate faster than sea-level rise (e.g. 22–34 cm/century at Prince Rupert, 16 cm/century at

Vancouver; BC Ministry of Water, Land and Air Protection, 2002; Abeysirigunawardena and Walker, in press). At Tofino, where relative sea level has fallen, the extreme high-water events show little change. Extreme sea levels, storm surges and enhanced coastal erosion are strongly influenced by ENSO and PDO (Storlazzi et al., 2000; Dingler and Reiss, 2001; Allan and Komar, 2002; Abeysirigunawardena and Walker, in press). Extreme water levels have increased significantly since the positive PDO shift of 1976 (Abeysirigunawardena and Walker, in press). During the El Niños of 1982–1983 and 1997–1998, sea levels from California to Alaska rose as much as 100 cm above average (Subbotina et al., 2001), and more energetic wave conditions produced extensive coastal erosion and infrastructure damage (Storlazzi et al., 2000; Allan and Komar, 2002). On BC's north coast, sea levels rose 10 to 40 cm above seasonal heights in 1997–1998 causing extensive localized erosion (Crawford et al., 1999; Barrie and Conway, 2002).

2.6 ECOSYSTEMS

Climate change impacts ecosystem distribution and biodiversity (*see* Sections 3.2, 3.3, and 3.6). Several consistent themes emerge from a wide range of studies:

- Pacific salmon, sardine, anchovy, mountain pine beetle and western red cedar have shown abrupt changes in abundance and/or distribution in response to past, relatively minor changes in climate (Robinson and Ware, 1994; Hebda, 1999; Ware and Thomson, 2000; Brown and Hebda, 2002, 2003; Wright et al., 2005). Such changes can have significant social and economic implications (*see* Sections 3.2 and 3.3).
- Large shifts in species ranges are expected to occur (Royal BC Museum, 2005a), often with little overlap between current and projected distributions (Shafer et al., 2001). Species will respond individually, and resulting vegetation communities may not resemble current communities (Brubaker, 1988; Gavin et al., 2001).
- Many of BC's specialized habitats (e.g. alpine ecosystems, deserts, cold steppe) will become reduced in extent and more fragmented (Shafer et al., 2001).
- The capacity of BC's system of protected areas to maintain biodiversity will be challenged, as many species will be forced to migrate over natural barriers (water, mountains) and human-induced landscape fragmentation (Overpeck et al., 1991; Dyer, 1995; Lemieux and Scott, 2005; *see* Section 3.6).
- Wildfire frequency and severity will increase in coming decades (Flannigan et al., 2001; Gillett et al., 2004; Gedalof et al., 2005; Westerling et al., 2006). While this will likely present challenges for some ecosystems, others (e.g. Garry oak and ponderosa pine forests), which are fire maintained, may expand in range (Agee, 1993; McKenzie et al. 2004).
- Large-scale outbreaks of pests, such as mountain pine beetle and spruce bark beetle, are expected to persist and expand with continued warming. These pose an increasing threat to species such as high-elevation whitebark pine and eastern jack pine forests across western Canada (Logan and Powell, 2001; *see* Section 4.2).

2.7 SUMMARY

Key findings regarding ongoing and future climate changes in British Columbia include the following:

- Major shifts in climate variability and extremes are inherent to the system and can be expected in the future. Climate changes in BC during the twentieth century exceeded most global trends, with considerable regional variability.
- British Columbia's climate is substantially influenced by large-scale variability patterns, including ENSO and the PDO. Associated extreme weather events are increasing, and resulting damage costs are on the rise.
- Increasing temperatures have resulted in decreased snow accumulation in many locations, particularly at low elevations.
- British Columbia's glaciers are retreating at rates unprecedented in the last 8000 years, with implications for existing and future water and energy demands, agriculture and aquatic ecosystems.
- Vegetation reconstructions show that plant species respond individually to climate change. Future ecological changes will be complex and potentially rapid.
- British Columbia could warm by 2 to 7°C by 2080. Biophysical impacts will include sea-level rise, changing frequency and magnitude of precipitation and extreme events, major hydrological changes and reorganization of ecosystems.
- Seasonal climate forecasts incorporating ENSO and PDO effects are useful for year-to-year operational planning, but are currently underutilized.
- Instrumental records used to compute climate normals, trends and probabilities of extreme event occurrence (floods, droughts, storms) are often too short, and assume static (unchanging) conditions, and are therefore inadequate for many planning purposes.

3 SECTORAL IMPACTS AND ADAPTIVE CAPACITY

How biophysical changes affect British Columbia's society depends on social and economic factors at both local and regional scales. The vulnerability of people and communities to climate change risks is a function of their physical exposure to natural hazards, their interdependencies with the natural environment (e.g. natural resources) and their adaptive capacity (Dolan and Walker, 2007; *see also* Chapter 2). Although the trend towards a more diversified economy improves the adaptive capacity of the BC economy as a whole to climate change and other stressors, it is unlikely that such diversification will be evenly distributed across all regions and sectors.

Climate change will impact economic development in BC, in ways that range from changes in domestic natural resources (e.g. forests, water and wilderness) to changes in the geography of optimal land-use activities (e.g. high-value agriculture crops, forage crops and commercial forestry) to increases in the social and economic costs associated with expected increases in extreme weather events.

The following sections examine how different economic sectors of BC are being impacted by changing climate, including, where possible, discussion of current and possible future adaptation initiatives.

3.1 WATER RESOURCE MANAGEMENT

Water resources, and their management and use, are highly sensitive to climate variability and change. Water managers will be challenged to meet multiple, often competing objectives (energy, irrigation, navigation, flood control, in-stream requirements) under conditions of changing supply and demand.

Surface Water

British Columbia has immense water resources, with approximately one-third of Canada's surface water. The implications of climate change for management of surface water resources have received considerable attention in the Columbia River basin (cf. Hamlet and Lettenmaier, 1999; Mote et al., 1999; Miles et al., 2000), including consideration of transborder issues (Cohen et al., 2000; Hamlet, 2003; Payne et al., 2004). As discussed above (Section 2.4), climate-induced changes in hydrology, including reduced snow pack and earlier snowmelt peaks, have significant implications for regional water supplies and fisheries. Increased flows during winter months and an earlier flood season will result in less water flowing during the summer months, when irrigation demand is highest. Reduced summer flows will also affect hydroelectricity generation and salmon habitat. It will be difficult to achieve current management objectives for both hydroelectric generation and in-stream flows to support fisheries under virtually all future climate scenarios (Payne et al., 2004). Within the Fraser River basin, a longer low-flow period could elevate summer stream temperatures by almost 2°C, with serious implications for fisheries (Morrison et al., 2002; Loukas et al., 2004). Hydrological scenarios for the Okanagan valley and implications for fisheries are discussed in detail in Section 4.3.

Although some research is available on hydrological impacts in the Liard River and Peace River basins of northeastern BC (*see* Cohen, 1997), climate change has not been considered in current management plans. For example, although the Peace River Water Use Plan includes reduction of greenhouse gas emissions as a management goal, it does not discuss management options for the hydrological changes that will be associated with climate change (BC Hydro, 2004).

Groundwater

Approximately 600 000 people (22% of British Columbia's population) rely on groundwater as a source of drinking water (BC Ministry of Environment, Land and Parks, 1993). Agriculture and industry, including irrigation, pulp and paper, fish hatcheries, food processing, mining, chemical and petrochemical industries, parks and airports, are all major users of groundwater in the province (Liebscher, 1987). To date, more than 600 aquifers have been mapped and classified according to the BC Aquifer Classification System[8].

In addition to the direct impact of climate change on groundwater tables and quality (*see* Section 2.4), increased demand for groundwater is anticipated in areas of the province where surface-water systems are unable to meet consumptive and in-stream demands. In some areas, such demands may necessitate deepening water supply wells to access deeper aquifers that are less sensitive to changing climate (Rivera et al., 2004).

[8] The website <http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/index.html> [accessed April 30, 2007] provides information on aquifiers in British Columbia and a link to the Aquifier Classification Database.

3.2 FISHERIES

The fisheries and aquaculture sector, including commercial and sport fishing, aquaculture and seafood processing, employs about 20 000 people throughout British Columbia (BC Ministry of Agriculture and Lands, 2005a; Table 4). In 2004, BC seafood had annual raw-harvest and processed wholesale values of $620 million and $1.1 billion, respectively (BC Ministry of Agriculture and Lands, 2005a). Sport fishing, with important links to tourism (*see* Section 3.5), forms the largest single component, accounting for around 8900 jobs and contributing about $233 million per year to provincial GDP (BC Ministry of Agriculture and Lands, 2004). British Columbia aquaculture includes 700 site licenses for 30 species of fish, shellfish and marine plants. Aquaculture sales increased rapidly from $3 million in 1983 to more than $212 million in 2005 (BC Ministry of Agriculture and Lands, 2005a). Nevertheless, the fisheries sector accounted for less than 1% of provincial GDP in 2001 (BC Ministry of Labour and Citizens' Services, 2006).

Fisheries, and species such as Pacific salmon, are also keystone contributors (*sensu* Garibaldi and Turner, 2004) to the social, cultural, legal and ecological fabric of British Columbia (Pearse, 1982; Glavin, 1996). Sustainable fisheries, and the status and trends of wild salmon in particular, are viewed as vital indicators for maintenance of ecosystem integrity. Moreover, constitutional guarantees of access to fish to meet the food, cultural and societal needs of Aboriginal peoples make the maintenance and restoration of traditional fisheries key elements in treaty negotiations throughout BC (Raunet, 1984; Harris, 2001). Economic impacts on the fisheries sector therefore have important consequences for activities in other sectors (e.g. agriculture, forestry, mining, energy development and urban development).

During the past century, fisheries in British Columbia have changed in response to many factors (Box 2), including climate variability. The relationships between climate variability and the many physical variables affecting BC fish populations have been summarized for freshwater (Northcote, 1992) and marine environments (King, 2005; Fisheries and Oceans Canada, 2006a). These relationships make it clear that climate change will induce a wide range of responses from fish and fisheries in BC.

Sensitivity to climate variability and change varies greatly between short-lived species, such as shrimp, salmon, herring and sardines, and long-lived species, including geoduck clams, ocean perch and halibut (Fisheries and Oceans Canada, 2001). Short-lived species respond quickly to changes in climate, and populations can collapse or recover without warning, as evidenced by sardines (Hargreaves et al., 1994), herring (Schweigert, 1993) and salmon (McKinnell et al., 2001; Hyatt et al., 2003; Riddell, 2004; Fisheries and Oceans Canada, 2006b, c). Climate- or fishery-induced production trajectories of longer lived species change slowly, sometimes over a decade or longer, allowing greater predictability of fisheries yield, as in the case of halibut (Clarke and Hare, 2002). These differences between species will affect adaptation decisions.

TABLE 4: British Columbia's fisheries and aquaculture sector (BC Ministry of Agriculture and Lands, 2005a).

Sector	Sector revenue (millions of dollars)	Contribution to BC's gross domestic product (millions of dollars)	Contribution to BC's employment (thousands of jobs)
Commercial fisheries	358	170	5.4
Aquaculture	287	116	1.9
Seafood processing	602	82	3.9
Sport fishing	675	233	8.9
Sector total	**1922**	**601**	**20.1**

BOX 2

Fisheries sector trends in British Columbia

Halibut, herring, sardines, hake and salmon have supported major fisheries in BC since the late 1800s (Fisheries and Oceans Canada, 2001). Salmon fisheries have been dominant from a socioeconomic perspective for much of the past century. Salmon catch reached historical highs in the 1980s, followed by extreme lows in the 1990s (Beamish and Noakes, 2004) due to changes in marine productivity (Hare and Mantua, 2000; Beamish et al., 2003), management agency objectives (e.g. protect biodiversity; Hyatt and Riddell, 2000; Irvine et al., 2005) and low prices for wild salmon due to increased competition from aquaculture (Noakes et al., 2002). Currently, wild-capture fisheries are stable (major groundfish species and most invertebrates) or decreasing (e.g. salmon), whereas aquaculture production is increasing (Fisheries and Oceans Canada, 2001). Despite changing conditions, the fisheries sector has maintained an average landed value of $550 million (range $380–720 million) since 1985 (BC Ministry of Agriculture and Lands, 2002).

Fisheries responses to climate change will vary greatly among regions (Ware and McFarlane, 1989; Ware and Thomson, 2005). In freshwater ecosystems, climate change is already affecting the quantity (lake levels, river flow) and quality (temperature, nutrient levels) of seasonal to annual water supplies around Georgia basin (Whitfield et al., 2002b; Quilty et al., 2004), the Fraser River basin (Morrison et al., 2002) and the BC southern interior (*see* Sections 2.4 and 3.1), disrupting life histories and production of resident and migratory salmonids (Levy, 1992; MacDonald et al., 2000; Hyatt et al., 2003).

The Georgia Strait and the coastal upwelling zone west of Vancouver Island support some of the richest marine fisheries in BC (Ware and McFarlane, 1989). Studies of prehistoric (Wright et al., 2005) and historical intervals (Fisheries and Oceans Canada, 2006a) suggest that species dominance in these areas is highly variable, with salmon, herring and resident hake being most prevalent during cool conditions and migratory hake, along with such 'exotic' species as mackerel, tuna and even Humboldt squid, infiltrating from the south during warm conditions (Fisheries and Oceans Canada, 2006a). Experience suggests that economic gains from harvest of larger quantities of migratory hake (Ware and McFarlane, 1995), sardine (McFarlane and Beamish, 1998) and tuna under a warmer regime will not immediately offset losses from collapses of higher value (Table 5) salmon fisheries (Hyatt et al., 2003; Fisheries and Oceans Canada, 2006a). In addition, established coldwater fisheries have mature infrastructure (catching and processing capacity, established markets and fisheries management systems) that is lacking in new fisheries for exotic species. Economic dislocation and social stress in fisheries-dependent communities are likely to increase as climate continues to change, with losses from traditional fisheries exceeding returns from efforts to develop new ones or to replace them with aquaculture operations. Outcomes like these stress small coastal communities in particular, given their high reliance on traditional fisheries (Ommer, 2006, 2007).

Climate impacts on fisheries in the area of the Queen Charlotte basin are less certain. The historical effects of warmer waters, altered production regimes (e.g. King, 2005; Ware and Thomson, 2005) and exotic species have not produced obvious declines of herring and salmon in this region. In fact, some evidence suggests increased production of these species during warmer intervals (Boldt et al., 2005).

Many BC salmon rear for 1 to 4 years in the offshore waters of the Gulf of Alaska, so climate change in that region will impact salmon distribution (e.g. displacement to the Bering Sea; Welch et al., 1998). Changes in thermal stratification, nutrient delivery, primary production (Behrenfeld et al., 2006) or even ocean acidification (Raven et al., 2005) could profoundly influence salmon and fisheries production throughout BC. The ultimate consequences of such complex changes are unknown, but likely place southern rather than northern fisheries at greater risk of future losses.

TABLE 5: Total catch and maximum age of finfish supporting major fisheries (landed value greater than $1 million) on Canada's west coast as of 2002 (*adapted from* BC Ministry of Labour and Citizens' Services, 2002; King and McFarlane, 2003).

Species group	Maximum age of fish (years)	Total weight (metric tons)	Average landed value[1] (millions of dollars, 1985-2002)	Approximate value[1] in 2002 (millions of dollars)
Rockfish	58–205	15 236	10	
Sablefish	113	3 947	25	21
Ocean perch	100	6 179	5	6
Pacific halibut	55	6 096	30	43
Pollock	33	1,044	1	
Lingcod	25	1 984		
Pacific cod	25	708	4	1
Pacific hake	23	22 347	12	12
Pacific herring	15	27 725	60	50
Sardine	13	800		
Tuna albacore	10	233		
Chinook and coho salmon	4–8	540	500	600
Sockeye salmon	7	8 670	100	40
Chum salmon	7	2 780	20	3
Pink salmon	3	7 160	20	5
Total			**$787 million**	**$781 million**

[1] Values identified here refer to landed value for all species except chinook and coho salmon, for which recreational fisheries in marine and tidal waters generate much higher revenues.

Adaptation

Three public enquiries in the past 15 years (Pearse and Larkin, 1992; Fraser River Sockeye Public Review Board, 1995; Williams, 2005) considered causes, consequences and solutions for precipitous declines in production and harvest levels for southern coho, steelhead and Fraser River sockeye salmon (Fisheries and Oceans Canada, 2006b). Economic losses to the commercial sockeye fishery alone were estimated at $72 million in 2002, and likely exceeded this in 2004 (Cooke et al., 2004). Each enquiry identified a complex set of factors driving the declining fishery, including climate-induced production losses and associated management uncertainties. Declines of salmon in the Fraser River and elsewhere have stimulated initiatives calling for agencies and society to safeguard the productive capacity of habitats for wild fish and fisheries, given rapid human population increases combined with climate change threats in BC (Pacific Fisheries Resource Conservation Council, 2006). Without adaptation, continued reductions or elimination of salmon could occur in extensive areas of the BC interior and Georgia basin, where cumulative human impacts (Slaney et al., 1996), plus climate-induced changes to flow and temperature conditions (Rosenau and Angelo, 2003), have created significant problems for maintenance of fish populations and habitat. Conflicts over meeting the requirements for fisheries habitat as well as the water needs of other sectors (e.g. mining, agriculture, energy, urban development) are certain to intensify in the future.

Awareness of climate-induced impacts on the fisheries sector, relative to non-climatic factors, varies greatly among recreational, commercial, First Nations and management agency groups. Multi-party discussions at recent colloquia suggest a growing awareness that fisheries are unlikely to return to a state of business-as-usual (Interis, 2005), and that a range of adaptive responses will be required to meet challenges posed by climate change. Specific adaptation measures that have been discussed include 1) reducing harvest rates to provide conservation buffers, given increasingly variable stock productivity (Mantua and Francis, 2004); 2) reinforcing habitat protection and restoration measures by all sectors to promote increased sustainability of capture fisheries; 3) increasing hatchery production of salmon to counter declining productive capacity of freshwater or marine habitat; 4) licensing and regulating river systems; or 5) promoting accelerated development of aquaculture to meet market demands for products that capture-fisheries cannot satisfy. Shifting harvest opportunities provided by short-lived versus long-lived species, or from established (e.g. salmon, herring) to relatively unexploited species (e.g. mackerel, squid) may require a different suite of adaptation measures. These might involve licensing processes that promote participation in multiple fisheries for a diversity of short- and long-lived species, and increased investment to speed the development of processing, marketing and management infrastructure for newly emergent fisheries.

3.3 FORESTRY

British Columbia's 62 million ha of forest provide a wide range of social, cultural, economic and biological values and services (Gagné et al., 2004; Forest Products Association of Canada, 2006). Approximately 0.3% of BC's forests are harvested annually, and fire protection is the only management activity currently practiced over a large area of the land base.

The current age distribution of forests in BC is skewed toward old trees, resulting in increased sensitivity to disturbance by fire and pests (Cammell and Knight, 1992; Dale et al., 2001; Volney and Hirsh 2005). Climate changes are considered a contributing factor to recent increases in fire activity (Gillett et al., 2004) and outbreaks of the mountain pine beetle (Carroll et al., 2004) and needle blight (Woods et al., 2005). As illustrated by the Kelowna and Barriere fires in 2003, forest fires have a direct impact on property and safety (Volney and Hirsch, 2005), with health impacts extending considerable distances from the fire. The economic and social impacts of mountain pine beetle are discussed in detail in Section 4.2. Continued climate change is expected to further increase disturbance risks, and involve other pest species, such as the leader weevil (Sieben et al., 1997). Coastal forests will likely see an increase in the number and intensity of storms, thereby increasing windthrow damage. Drier areas of the southern interior may experience regeneration problems due to an increase in summer droughts.

Climate change directly affects tree species, as optimum growth conditions for local populations can be relatively narrow (Rehfeldt et al., 1999, 2001; Parker et al., 2000; Wang et al., 2006). Consequently, although species may survive in their current location under a changed climate, growth rates will be affected and there will be increased competition from other species more suited to the climate. The potential ranges of species will move northward and upward in elevation (Cumming and Burton, 1996; Hebda, 1997; Hansen et al., 2001; Hamann and Wang, 2006), although species migration will be constrained by barriers to movement, slow migration rates, unsuitable soils or lack of habitat (Stewart et al., 1998; Gray, 2005). Overall, losses in productivity of natural and planted stands are expected to occur in the drier and warmer regions of BC, while modest increases are anticipated in the north (Rehfeldt et al., 1999, 2001; Spittlehouse, 2003; Johnson and Williamson, 2005).

Forestry operations will be impacted directly by climate change. Changes in productivity will affect rotation ages, wood quality, wood volume and size of logs. Access to timber may be limited during both winter, because of warmer and wetter conditions, and summer, due to increased fire risk. Increases in the frequency and magnitude of extreme precipitation will affect design and maintenance of logging roads (Bruce, 2003; Spittlehouse and Stewart, 2003), and increase the probability of landslides and debris flows (Wieczorek and Glade, 2005). Impacts on the forest sector will also be influenced by technological changes, trade issues and changes in consumer preferences that will take place concurrent with climate change. Countries that are expected to see significant production benefits from a changing climate, particularly those in South America and Oceania, are already replacing BC products in the global market (Perez-Garcia et al., 2002; Sohngen and Sedjo, 2005). Such changes affect forestry product supply-demand dynamics.

Adaptation

The long growth period before trees are harvested means that the wood supply for the next 50 or more years is already 'in the ground'. As a result, short-term adaptations will focus primarily on operational changes. Already, the increase in disturbance by fire and insects has resulted in greater amounts of the harvest being salvaged wood, a trend that will continue in the future (Spittlehouse and Stewart, 2003; Volney and Hirsch, 2005). Forest management adaptation will also have to consider climate change impacts beyond those directly affecting timber resources, in order to maintain biodiversity and ensure landscape connectivity (cf. Harding and McCullum 1997; Stenseth et al., 2002; Mote et al., 2003; Moore et al., 2005). In addition, increased competition from species more suited to changed climate conditions may create a need for increased management activities in established stands (Parker et al., 2000; Spittlehouse and Stewart, 2003; Spittlehouse, 2005).

Longer term adaptation measures include changes in reforestation practices, especially species selection, as the tree types best suited to particular sites change (Rehfeldt et al., 1999; Parker et al., 2000; Spittlehouse and Stewart, 2003). Wang et al. (2006) showed that a mid-range climate change scenario for BC shifts seed planting zones for lodgepole pine many hundreds of kilometres north. However, matching planting stock to new climate regimes is further complicated by the climate continuing to change over the life of the stand. In this case, planting genotypes that grow well under a wide temperature range could help maintain productivity at some sites in BC (Wang et al., 2006).

Although consideration of weather and climate is part of forest management, current policies on forest utilization and preservation are based on understanding how forests developed under past climatic conditions. This may limit the ability of the sector to respond optimally to both the negative and potentially positive impacts of climate change on different forest regions. There are presently no requirements or guidelines to include climate change adaptation measures in forest management plans, and there are limited experienced personnel to aid such activities (Spittlehouse and Stewart, 2003; Spittlehouse, 2005). As most of BC's forests are on crown land, the provincial government is responsible for setting policies, developing management objectives and approving forest company stewardship plans. The government also sets standards for species selection, seed transfer and stocking; allocates land to parks and wilderness areas; and is responsible for maintaining forest health and growth-monitoring plots. In this context, Spittlehouse (2005) noted the need for more comprehensive assessment of vulnerability to climate change and developing and applying adaptation measures for forest management. The actions of the BC Ministry of Forests and Range outlined in Section 4.2.2 are a first step in this process.

3.4 AGRICULTURE

British Columbia's mountainous landscape and climatic diversity result in only 4.5% of land being suitable for farming. The protection of this limited resource was a major factor in the creation of a 4.7 million ha Agricultural Land Reserve (ALR) in 1974. The ALR is a useful institutional tool to help manage and maintain the province's agricultural resources under climate change and other compounding demands.

More than 200 major commodities are produced by BC's agri-food industry, which directly and indirectly employs about 290 000 people, or about 14% of the province's employed labour force (BC Ministry of Agriculture and Lands, 2005a). The primary industry is relatively small, but spin-offs in the food processing, wholesaling, retailing and food service sectors are worth more than $22 billion per year in consumer sales (BC Ministry of Agriculture and Lands, 2005b). Nearly 60% of the food needs of British Columbians are produced in the province (Smith, 1998), and BC exports food products valued at more than $3.4 billion (BC Ministry of Agriculture and Lands, 2005a, b). Agricultural production is concentrated in rural communities, where it provides stability to local resource-based rural economies.

The vulnerability of the agricultural sector in BC is a product of the interaction of specific climate changes with global and regional issues, including new markets and competitors, and production and transportation costs (Heinberg, 2003). Recent trends in the agriculture sector include a declining role in BC's economy; increased reliance on imports from other parts of Canada, the United States and Mexico; increased production of nursery and greenhouse products; declines in food processing capacity; increasing concerns surrounding food safety; and declines in consumer demand for meat products (BC Ministry of Agriculture and Lands, 2005a). Non-climatic risks to the agriculture sector include loss of arable land through development and urban sprawl, an increasingly competitive global market, and unmanageable and unpredictable markets.

Potential effects of climate change have been previously assessed for agriculture in British Columbia (Table 6) based on expert judgment (Zebarth et al., 1997). In all areas of the province, longer growing seasons and milder winters were expected to increase the range of crop types suitable for economic production. Increasing requirements for irrigation were predicted for the south coast and southern interior regions, with possible water shortages caused by reduced precipitation, limited water storage capacity and competition from burgeoning urban populations. The greatest potential for development was considered to be in the northern interior and Peace River regions, with large areas of currently uncultivated land becoming increasingly suitable for agriculture. Lack of infrastructure for water supply, transportation and distance from markets, however, were considered barriers to agricultural development in these areas.

It is likely that crop production areas will adjust to accommodate a changing climate and that some producers will be able to take advantage of new opportunities to grow different, and perhaps more valuable, crops (Zebarth et al., 1997). In BC, crop production areas are defined by soil productivity, water availability and climate. Growing regions for annual crops are limited by length of the growing season and heat units (growing

TABLE 6: Current and future climate limitations to crop production (Zebarth et al., 1997).

South coastal region	
Current climate:	**Future temperature:**
Mild, wet climate.	Projected to increase 2–3°C
Mean annual temperature: 10°C.	**Future precipitation:**
Mean annual precipitation: 800–1700 mm, 70% of which falls between October and March	Projected to increase from November to May (5–10%)
Frost free period: 175–240 days	Projected to decrease from June to October (10–20%)

Type of agriculture	Current agriculture	Climate limitations	Effects of future temperature change	Effects of future precipitation change
Horticulture	Small fruit: raspberry, strawberry, blueberry Field vegetables: corn, potato, cabbage family crops, salad crops	Perennials: summer moisture deficits, require some irrigation Raspberries: winter damage from Arctic outflow Field vegetables: low temperatures, wet soil conditions in spring	Warmer summer: increased productivity Warmer winter: longer growing season; increased viability of bell pepper, melon, overwintering cabbage family crops and double cropping Increased winter precipitation could limit annual crop production in water-logged soils Decreased summer precipitation could mean that more irrigation is required Reduction in diseases due to drier conditions could favour berry production	Increased winter precipitation could limit annual crop production in water-logged soils Decreased summer precipitation could mean that more irrigation is required Reduction in diseases due to drier conditions could favour berry production
Forage crops	Grass: pasture, hay, silage Corn: silage	Grasses: winter damage from Arctic outflow Forage crops: summer moisture deficit, require irrigation on Vancouver Island	Warmer spring: earlier harvest of forages New, heat tolerant forage species required	Increased spring precipitation could limit harvest and quality of forages Dry, hotter summer could mean that irrigation will be required in Fraser River valley
Greenhouse	Vegetables: cucumber, tomato, bell pepper Ornamentals		Warmer winter: lower heating costs, increase in tropical species Hotter summer: higher cooling costs	
Other effects			Increased pest pressure: winter survival of pests and diseases, more life cycles	Flooding, soil drainage, soil compaction, increased leaching of agricultural chemicals

TABLE 6: *(Continued)*

Southern interior region				
Current climate: Mean annual temperature: 2–5°C Mean annual precipitation: 250–540 mm Frost free period: 110–180 days			**Future temperature:** Projected to increase 2–3°C **Future precipitation:** Projected to increase from November to May (0–15%) Projected to decrease from June to October (0–10%)	
Type of agriculture	**Current agriculture**	**Climate limitations**	**Effects of future temperature change**	**Effects of future precipitation change**
Horticulture	Perennials: apple, pear, peach, plum, cherry, wine grape Field vegetables: tomato, pepper, eggplant, cucumber	Perennials: summer moisture deficits could require irrigation; winter damage from Arctic outflow Field crops: summer moisture deficits could require irrigation	Warmer winter: longer growing season; new, longer season varieties; reduced risk of cold damage Earlier spring: increased frost risk Warmer summer: increased risk of poor fruit quality Warmer summer: higher grape quality	Increased winter precipitation could keep soils wet and reduce risk of cold damage to roots; could improve spring moisture availability Decreased summer precipitation could mean that more irrigation is required Reduction in diseases due to drier conditions; reduction in cherry splitting
Forage crops	Grass: pasture, hay, silage Others: alfalfa, corn, cereals Extensive dry rangeland	Summer moisture deficit may require some irrigation Low winter temperatures may limit production	Warmer spring, longer growing season: more harvests of forages, more range grazing New, heat-requiring species viable (silage corn)	
Greenhouse	Vegetables: cucumber, tomato, bell pepper Ornamentals		Warmer winter: lower heating costs. Hotter summer: higher cooling costs	
Other effects			Increased risk of limited water supply for irrigation Increased pest pressure: winter survival of pests and diseases, more life cycles.	Increased risk of limited water supply for irrigation

Northern interior region				
Current climate: Mean annual temperature: 2–5°C Mean annual precipitation: 450–600 mm Frost free period: 110–180 days		**Future temperature:** Projected to increase 2–3°C **Future precipitation:** Projected to increase from October to May (0–10%) Projected to decrease from June to September[1] (5–20%)		
Type of agriculture	**Current agriculture**	**Climate limitations**	**Effects of future temperature change**	**Effects of future precipitation change**
Forage crops	Grass: pasture, hay, silage Cereals Extensive natural rangeland	Summer moisture deficit may require some irrigation Low winter temperatures may limit production Short growing season will limit choice of crops	Warmer spring: longer growing season, higher productivity, more range grazing New, heat-requiring species viable (silage corn)	
Other effects			Increased risk of limited water supply for irrigation Increased pest pressure: winter survival of pests and diseases, more life cycles	Increased risk of limited water supply for irrigation

[1] except August (increase of 5%)

degree days, or GDD). Perennial crops are limited primarily by winter minimum temperatures, but also by length of growing season and GDD. Current agricultural land-use patterns are based on long-term experience, and defined by climate and the frequency of extreme weather events (Caprio and Quamme, 1999, 2002, 2006). Under a moderate climate change scenario, projected changes in GDD (Royal BC Museum, 2005a) indicate that, by 2020, there would be potential to grow cereals, cabbage and potatoes (1000–1500 GDD) on much of the Interior Plateau, and corn and tomatoes (1500–2000 GDD) along the Fraser River as far north as Prince George. By the 2050s, GDD would be sufficient to potentially support growth of corn and tomatoes in the Peace River area and in northern coastal valleys. Full understanding of changes in agricultural suitability, particularly for perennial crops, requires assessment of future growing season length, boundaries for extreme minimum winter temperatures and the potential for irrigation in water-limited regions, as well as development of detailed soil maps for non-agricultural areas. Estimations of potential future land-use patterns also need to consider topographically defined microclimates, which ultimately determine crop location (e.g. Bowen et al., 2006).

In all areas of BC, the possibility of increased summer drought, coupled with decreasing water resources, will provide challenges for water supply to support irrigation (Zebarth et al., 1997; Neilsen et al., 2004a, b). In areas that are highly or entirely dependent on irrigation, such as the Okanagan basin, economic production requires timely availability of water, both to assure quality and to protect investment in perennial plants. The risks associated with drought are determined by the severity and frequency of drought conditions (Neilsen et al., 2006). For the Okanagan (*see* Section 4.3.2) and other regions, a key adaptation by the agriculture sector will likely involve conservation irrigation practices (Neilsen et al., 2001, 2003), including deficit irrigation, where water is underapplied to enhance crop quality and reduce consumption (Dry et al., 2001).

Although few data are available for BC, increased summer and winter temperatures may also result in new agricultural pests and diseases.

Risk Perception and Adaptation

Agricultural producers are accustomed to dealing with uncertainty in weather, markets, pests and diseases, and potential income. Grower surveys in the Okanagan region showed that producers face weather-related risks, risks from market factors and risks from the impacts of pests and diseases on crop quality and quantity (Belliveau et al., 2006a, b; *see* Section 4.3.2). Responses to address weather-related risks can be either short or long term, ranging from specific practices to processing and/or product choices (Belliveau et al., 2006a, b). A risk-management strategy to handle one problem may inadvertently increase risk in another. For example, the grape pullout program in 1988 and the apple replant program from 1992 onwards have increased vulnerability to climate risks (*see* Section 4.3.2). Support programs, such as the Canadian Agriculture Income Stabilization Program, may be a disincentive for producers to take other adaptation measures to reduce risks (Belliveau et al., 2006a, b). In general, safety net programs are a good hedge against crop losses caused by weather but are less effective in sheltering farmers against losses caused by more subtle impacts on quality and by the longer term persistence of climate change.

3.5 TOURISM AND RECREATION

Tourism is BC's second largest economic sector next to forestry, generating approximately $5.8 billion in 2003 and $9.5 billion in 2004 (BC Ministry of Labour and Citizens' Services, 2005b; Tourism BC, 2005a). Tourism provides more than 117 500 jobs, approximately 7% of total provincial employment (Hallin, 2001; Tourism BC, 2005a). Although Vancouver and Victoria are major urban destinations, visitors are also drawn to BC's mountains and coastal regions. Many resource-based communities now view tourism as a means of economic restructuring after declines in the forestry and fishery sectors (Reed and Gill, 1997).

British Columbia's scenery, wilderness, wildlife viewing, and hunting and fishing opportunities provide for a burgeoning adventure and nature-based tourism industry. In 2001, nature-based tourism contributed $1.55 billion in revenues (including spin-off activities) and $783 million in provincial GDP (Tourism BC, 2005a, b). Most of this occurs at destination resorts and within BC's many parks and protected areas (*see* Section 3.6).

The effects of climate change on tourism destinations are already evident. In BC's drier southern interior, drought and forest fires during the summer of 2003 closed many major transportation routes and destroyed orchard and winery crops in the Okanagan and North Thompson valleys. Agri-tourism to wineries and orchards was impacted and regional hotel room revenues declined by 3% (BC Council of Tourism Associations, 2004). These areas and activities can expect increasing frequency of drought hazards in the future.

Projected rises in snowlines due to warming temperatures (Scott, 2003a, b, 2006a) will impact ski operations across the province. For example, the retreat of alpine glaciers that support off-season skiing will affect mountain resorts such as Whistler-Blackcomb. Inadequate snowfall reduces the number of suitable skiing days available to local resorts, such as Vancouver's Grouse, Seymour and Cypress mountains (Scott et al., 2005).

Tourism in coastal communities will be affected by sea-level rise and increased coastal erosion and flooding hazards (Craig-Smith et al., 2006), and associated impacts on transportation infrastructure, marina maintenance and dredging activities, boating safety, floatplane travel, vacation housing and resort infrastructure. Key impacts on coastal fisheries relevant for sport fishing are discussed in Section 3.2.

Adaptation

Successful tourism operations are inherently dynamic and resilient to environmental and other changes. This adaptive capacity suggests that the sector is relatively well positioned to respond to climate change impacts (Scott et al., 2003). Adaptation measures typically involve short-term responses, such as marketing strategies aimed at changing tourist behaviour, or longer term planning to adjust to local climate change impacts. However, climate change is only one of many factors to which tourism operations must adapt. Other key factors include changing market competition, fluctuating currency values, and changing tourist demands, interests and demographics (Uysal, 1998). Adaptive measures, such as re-marketing, re-imaging and diversification of activities, are already happening. For instance, Tofino, a traditionally popular summer tourist destination on Vancouver Island's west coast, is now also attracting tourists for winter storm watching (Dewar, 2005).

A key adaptation strategy for weather-dependent tourism is to spread the risk by diversifying operations and reducing reliance on single-season activities. Ski resorts are adapting to recent climate change through snowmaking and introduction of activities that are not dependent upon snow (Scott et al., 2003; Scott, 2006b). Snowmaking is capital intensive and requires significant water resources that, in many regions, are already under stress. Larger, multi-resort corporations have a higher adaptive capacity than smaller operators, as they generally have greater access to capital to undertake adaptation and are less impacted by poor conditions at a single site. The longer, more predictable ski season that snowmaking can produce reduces business risks during the winter and further stimulates diversification. In turn, this encourages property and infrastructure investments throughout the year (Scott, 2006b). For example, the Whistler-Blackcomb resort has diversified itself into a multi-season resort that includes golfing, mountain biking and alpine hiking. Some of these activities use the same infrastructure used in the winter for skiing.

Other important adaptive measures include hazard risk reduction and comprehensive emergency management to deal with increased floods, landslides and avalanches associated with wetter and warmer fall-winter conditions.

3.6 PARKS AND PROTECTED AREAS

British Columbia has the highest biodiversity of any province and hosts some of Canada's most vulnerable and fragmented ecosystems. There are 859 protected areas in BC, accounting for more than 13% of the landscape (approx. 12.6 million hectares). Climate change impacts in Canada's national parks are only beginning to be considered, for example, through identification of key 'geoindicators' for monitoring changes (Welch, 2002, 2005). Impacts on ecosystem integrity from species migrations and major biome shifts, expected as a result of climate change, have yet to be considered (Scott and Lemieux, 2005). Compared to terrestrial areas, marine protected areas are under-represented, with less than 1% of BC's waters fully protected. Climate change impacts on sea-surface temperatures, species migrations and diversity, and ocean productivity have received little consideration in the planning and management of marine protected areas.

The ClimateBC program was used to simulate changes in temperature and precipitation, at a downscaled resolution of 1 km^2, within selected protected areas (Table 7; Hamann and Wang, 2005, Wang et al., 2006) to assess possible ecosystem responses. Such modelled results need to be considered in the context of past ecosystem dynamics, changes in disturbance regimes (fire, invasive species, pests), land management objectives and human demands on resources, to contribute to the development of adaptive management plans addressing multiple objectives.

Tourism, traditional Aboriginal resource use, park operations and research are the main human activities in BC's parks. Key climate change risks to be managed in the park system include 1) alpine and subalpine ecosystem decline and fragmentation due to increased temperatures (Scott and Suffling, 2000; Suffling and Scott, 2002); 2) increasing impacts from natural hazards (avalanches, wind storms, storm surges, droughts and landslides) as a result of increased frequency and/or magnitude of extreme weather, affecting visitor safety and maintenance of park infrastructure and services; and 3) species migration, extirpation and increasing exotic species competition, impacting harvest rights, biodiversity and population sustainability for both terrestrial and marine species. The most vulnerable protected areas are those subject to intense human activity and development pressures, such as those in the Greater Vancouver–lower mainland region, on southern Vancouver Island and in the Okanagan valley.

Adaptation

Climate change represents a challenge to the fundamental goal of most protected areas, and requires that a dynamic perspective be applied to the concept of maintaining ecological integrity. Parks Canada has developed a list of possible responses to current and future climate change impacts, including enhancing connectivity to enable species migration, expanding some protected areas, limiting other stressors on ecosystems, and species relocation programs (Hannah et al., 2002; Welch, 2005). Similarly, conservation networks between protected areas in developed regions would help facilitate species movements and biodiversity conservation under a changing climate.

TABLE 7: Climate normals (1961–1990 averages) and forecasted values (2050) for selected British Columbia parks (average estimates generated on a 1 km grid using ClimateBC v2.0 software and the CGCM2 climate model with Intergovernmental Panel on Climate Change SRES A2 emissions scenario).

	Elevation (m)	Mean annual temperature (°C)		Mean warmest month (°C)		Mean coldest month (°C)		Mean annual precipitation (mm)	
		Normal	2050	Normal	2050	Normal	2050	Normal	2050
Tweedsmuir Provincial Park (PP)	1254	1.2	3.4	11.3	13.4	-9.7	-7.0	914	938
Wells Gray PP	1487	0.8	3.0	11.7	13.9	-10.1	-6.7	1203	1241
Spatsizi PP	1522	-2.4	0.3	10.0	12.7	-13.9	-9.4	906	969
Garibaldi PP	1580	2.1	4.2	11.7	13.7	-6.2	-3.9	2745	2852
Granby PP	1759	1.6	3.9	12.8	15.0	-8.6	-5.9	966	973
Kootenay National Park (NP)	1830	-0.1	2.4	11.6	13.9	-12.1	-8.3	1082	1099
Glacier NP	1829	-0.5	1.8	10.7	12.9	-11.3	-7.8	1988	2057
Gulf Islands NP Reserve	84	9.7	11.8	16.2	18.3	3.8	5.9	798	842

	Mean summer precipitation (mm)		Mean annual snowfall (mm)		Frost-free days		Growing degree days (GDD; >5 °C)		Day of year when GDD total 100 (budburst)	
	Normal	2050	Normal	2050	Normal	2050	Normal	2050	Normal	2050
Tweedsmuir PP	253	246	493	416	124	158	682	1029	N/A	145
Wells Gray PP	456	457	616	540	126	159	703	1049	166	145
Spatsizi PP	406	424	477	467	103	138	423	737	179	155
Garibaldi PP	569	538	1402	1077	136	169	725	1047	169	152
Granby PP	407	383	445	361	135	169	815	1163	165	147
Kootenay NP	500	486	518	459	116	150	678	1040	166	144
Glacier NP	565	555	1230	1126	121	152	542	852	N/A	157
Gulf Islands NP Reserve	157	146	42	30	322	349	1957	2688	89	27

Monitoring and research on species and ecosystem responses remain important, as this helps to document impacts and inform adaptive planning and management approaches. Protected areas serve as 'benchmarks' for adaptive ecosystem management within larger landscapes subject to the additional pressures of resource extraction, agricultural use and urban development.

3.7 ENERGY

Discussions of climate change and energy typically focus on the links between energy production and greenhouse gas emissions.

In British Columbia, where 89% of the province's electricity is hydro generated (BC Hydro, 2006), the energy sector is highly sensitive to the impacts of climate change on water resources (*see* Sections 2.4, 3.1 and 4.3.1). Research on climate change impacts and potential adaptive measures of the energy sector in BC is extremely limited. However, the following considerations are beginning to attract the attention of energy researchers and managers:

- Water shortages are already a risk for BC's hydroelectric resources. Storage reservoirs face reduced snow packs, declining glacier contributions and frequent drought, all of which tax the system's capacity to meet demands (BC Hydro, 2004).

- Electricity demand in BC by 2025 is expected to be 33 to 60% higher than in 2005 (BC Hydro, 2006). All new electricity generation measures, including coal-fired plants, are planned for zero net greenhouse gas emissions (BC Ministry of Energy, Mines and Petroleum Resources, 2007).
- Seasonal and longer term energy demands for buildings (e.g. increased summer cooling needs, lower heating requirements) will change across the province in response to changing climate. By 2010, new energy-efficient bulding standards are proposed for implementation (BC Ministry of Energy, Mines and Petroleum Resources, 2007).

British Columbia's main hydroelectric generation reservoirs on the Columbia and Peace rivers depend on water flows mainly from snow pack and/or glacial melt. Some smaller 'run-of-river' facilities have limited storage and require continuous flow. Studies of the impacts on water supply and hydroelectric generating vulnerabilities are ongoing in the Williston-Peace, Bridge River and Columbia River basins, and current climate variability is an important consideration in planning reservoir operations strategies (BC Ministry of Environment, 2004).

Substantial shifts in energy demand are also anticipated as a result of increasing temperatures, with heating energy demands decreasing and cooling energy demands increasing. Illustrative models developed by the Royal BC Museum (2005b), based on projected changes in cooling and heating degree days, suggest that domestic heating energy demand may decrease 28 to 55% and summer cooling demand may rise 150 to 350% by 2080 in the Vancouver region (Figures 8 and 9).

Adaptation

BC Hydro aims to meet approximately 50% of increased electricity demands by 2020 through conservation and efficiency measures, including programs for consumers and the construction industry (BC Ministry of Energy, Mines and Petroleum Resources, 2007). Numerous programs exist that

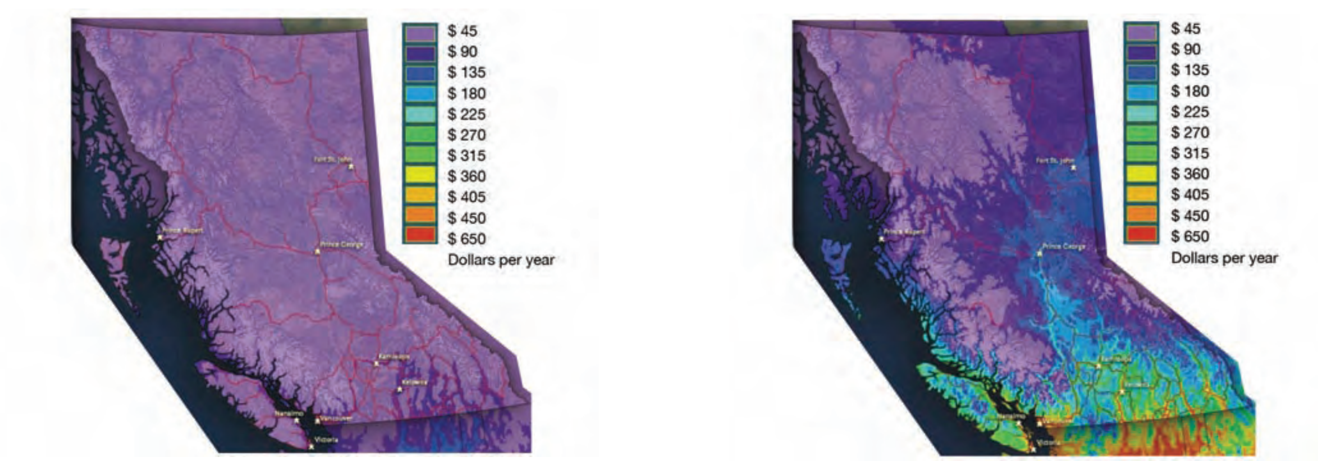

FIGURE 8: Summer cooling costs for a typical British Columbia house. The left panel shows baseline costs, and the right panel shows projected costs for 2080 based on a high change climate scenario (Royal BC Museum, 2005b)

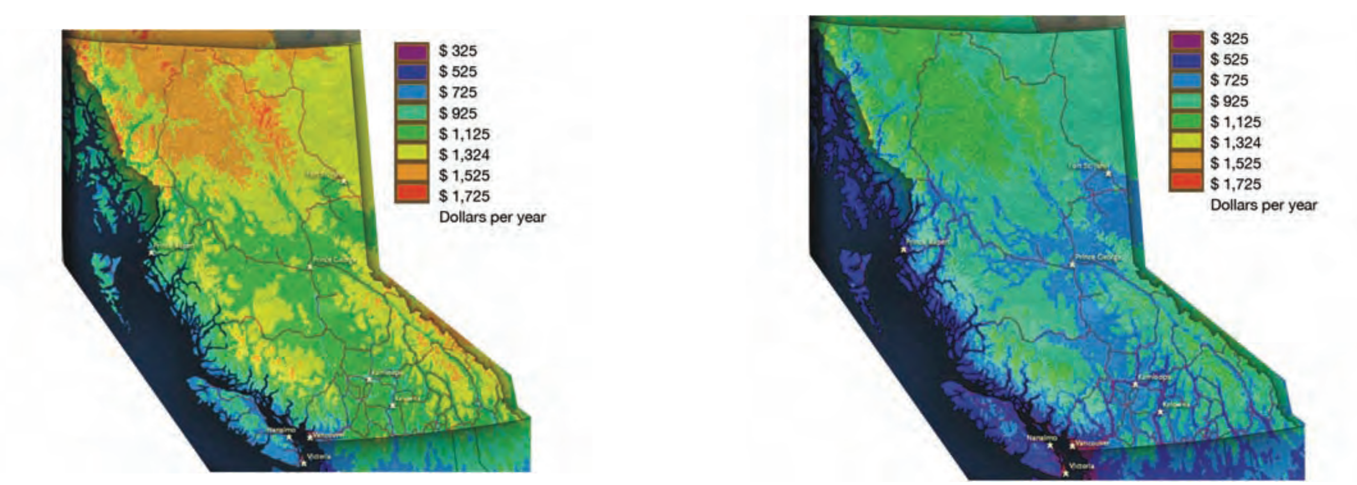

FIGURE 9: Winter heating costs for a typical British Columbia house. The left panel shows baseline costs, and the right panel shows projected costs for 2080 based on a high change climate scenario (Royal BC Museum, 2005b).

promote energy efficiency (e.g. BC Sustainable Energy Association, 2006; BC Ministry of Energy, Mines and Petroleum Resources, 2006; FortisBC, 2006; Natural Resources Canada, 2006). These and similar initiatives have both mitigative and adaptive benefits, in that they reduce greenhouse gas emissions and reduce demands on climate-sensitive sources of electricity.

Independent power producers, potentially including coal-fired generating plants, and efficiency improvements to existing hydroelectric plants will supply British Columbia's remaining future demands (BC Hydro, 2006). BC Hydro's (2006) Integrated Electricity Plan states that at least 50% of new power supply needs will come from renewable sources, including hydroelectricity, biomass and wind power. All new power generation facilities and coal-fired plants are planned for zero net greenhouse gas emissions (BC Ministry of Energy, Mines and Petroleum Resources, 2007).

Future energy demand forecasts and resource supply options must consider climate change impacts, as improved energy efficiency measures and building designs will only alleviate some of the expected increases in power demand. Improvements in stream-flow prediction modelling that consider changing climate represent a starting point in assessing supply vulnerabilities for hydroelectric power generation. Potential adaptation measures include expansion of reservoir systems to include supplemental 'pumped-storage' facilities, which store water above the reservoir to supply a generating station.

3.8 CRITICAL INFRASTRUCTURE

Critical infrastructure includes various technology networks, facilities, systems and services that are key to the well-being and operations of society (Public Safety and Emergency Preparedness Canada, 2006b). It involves a multitude of systems for energy and public utilities, health care, transportation, food supply, industry, communications and information technology, finance, safety and rescue, and defence. Impacts of recent extreme weather events demonstrate that vulnerabilities exist in these interconnected and interdependent systems. British Columbia's Emergency Response Management System (BC-ERMS; Public Safety and Emergency Preparedness Canada, 2006a) reports on, and aims to reduce the impacts of, environmental hazards, such as floods and wildfires. Critical infrastructure protection and planning, however, resides with a host of public agencies from all levels of government.

In 2003–2005, British Columbia experienced a significant increase in the number of extreme weather events requiring widespread emergency responses, compared to the previous decade (Table 8). Such emergencies are managed through BC-ERMS when the impacts to a community or significant infrastructure are likely to overwhelm the response capacity of local authorities. The BC-ERMS organization recognizes the potential for increasing frequency and severity of such natural hazard risks as wildfires, flooding, drought, mass-wasting events and pest proliferation as a result of climate change. The system is both reactive, through financial claims support to communities, businesses and homeowners, and proactive, through support to local authorities and communities for hazard risk-reduction initiatives and education and awareness programs. The maximum support for individual damage claims has recently been tripled from $100 000 to $300 000 (Whyte, 2006). By increasing risk awareness and emergency preparedness, BC-ERMS also enhances adaptive capacity to address climate change adaptation.

TABLE 8: Trends in emergency events in British Columbia (Whyte, 2006). The damage claims referred to in the table are 'eligible damages' that qualify under the Disaster Financial Assistance program (not inclusive of all damages that might have occurred), and represent both the federal and provincial share of costs.

Parameter	1990–2002	2003–2005
Average number of threshold events[1] per year	1	2
Number of major Disaster Financial Assistance (DFA) events per year	2–3	3–5
Average DFA and response costs	$10 million	$43 million
Frequency of evacuations	Every 2–3 years	2 times/year
Frequency of States of Emergency (SOE)	Rare	1 provincial SOE and 10 local SOEs in 3 years

[1] A threshold event is one where eligible costs reach $4 million.

Transportation

Transportation and associated activities (e.g. warehousing, pipelines, sightseeing, couriers) are an important component of BC's economy, accounting for 6% of the provincial GDP and employing 6% of the workforce (more than 115 000 people) in 2004 (BC Ministry of Labour and Citizens' Services, 2005a). Road, rail, air and marine transport are all important components of the transportation system, providing critical links for other key economic sectors (e.g. forestry) to associated processing facilities and markets. More than 65 000 km of roads in BC carry more than 2 million passenger and service vehicles per year (Transport Canada, 2005). Almost 65% of the network is provincially owned, 32% is municipal and 3% is federal. In the area of marine transport, British Columbia has more than 135 public and private ports that facilitate 95% of international trade moving through the province (BC Ministry of Small Business and Economic Development and Ministry of Transportation, 2005). Goods shipped to and from the three main trading ports of Vancouver, Fraser Port and Prince Rupert are moved by rail (66%) and truck (33%), with shipping container traffic projected to triple from 2 to 6 million containers per year by 2020 (Greater Vancouver Transportation Authority, 2005).

Climate change impacts BC's transportation infrastructure in many ways. Increases in the frequency of some extreme weather events will increase maintenance and insurance costs, and expose the limitations of some current design standards. Wear on highways, although primarily a function of vehicle weight and traffic volume, is also impacted by climate conditions. For example, rising maintenance costs in Prince George are partly attributed to more frequent freeze-thaw events associated with recent warmer winters (Dyer, 2006). Climate change will also have positive impacts on transportation. For example, during the El Niño winter of 1997–1998, milder weather helped to significantly reduce motor vehicle accidents on BC roads (Environment Canada, 2003).

Utilities and Services

Water supply and stormwater management systems in BC will continue to be impacted by changing climate and increasing development pressures. Key impacts to be considered include 1) decreased water supplies during summer and fall (*see* Sections 2.4 and 3.1); 2) supply-demand mismatches in reservoir systems that supply BC's major urban centres (*see* Section 4.4.1); 3) increased demands on drinking water and sewage treatment facilities in rapidly growing communities; and 4) increased loading of stormwater management systems as a result of more frequent and/or more intense extreme precipitation events (*see* Section 4.4.2).

Major pipeline infrastructure expansions are planned for the near future to move producible oil and natural gas from the northern territories and northeastern BC to international markets. The impacts of a changing climate in mountainous and permafrost regions of BC (e.g. permafrost melt, landslides, rockfalls) need to be considered in the planning, design and construction of pipeline infrastructure to avoid increased maintenance costs and, potentially, major repair and environmental rehabilitation efforts.

3.9 HEALTH

Vulnerability of human health is a function of interacting biological, environmental and socioeconomic factors (e.g. immunity, urban setting, income, access to health care services; Woodward et al., 2000). Climate change poses both direct and indirect health threats at the individual and population levels. Direct threats include increases in the number of injuries, illnesses and deaths related to poor air quality, natural hazards, extreme weather and heat. Indirect threats include exposure to air-, water- and vector-borne diseases and declines in ecosystem health (McMichael et al., 2003; Haines and Patz, 2004).

Heat Stress and Air Quality

Heat stress is associated with thousands of deaths each year in Canada (Smoyer-Tomic et al., 2003). More frequent, intense and longer lasting heat waves associated with climate change are expected to produce significant heat-related impacts, including heat stroke, dehydration and cardiovascular-respiratory illness and mortality (McGeehin and Mirabelli, 2001). The impacts of recent heat waves elsewhere in the world demonstrate that vulnerable populations include seniors, children, the poor and those who are socially isolated (Klinenberg, 2002; Crabbe, 2003). Although heat stress may appear less threatening in BC compared to central Canada (*see* Chapters 5 and 6), much of the BC population is less acclimatized to temperatures above 30°C (Smoyer-Tomic et al., 2003). Large urban populations in the Greater Vancouver Region and the Okanagan valley are particularly vulnerable. Non-respiratory emergency room visits in Vancouver currently increase with high summer temperatures (Burnett et al., 2003) and are expected to increase further with an aging population.

Air pollution increases in urban areas already exposed to air-quality hazards, particularly Greater Vancouver, Prince George and the Okanagan valley, will also have significant health consequences. Airborne pollutants cause wheezing, asthma attacks and impaired lung function, and are associated with increased respiratory illness, stroke, heart attack and premature death, especially for the elderly and children (Brook, 1998; Burnett et al., 1998; Caulfield, 2000; Kondro, 2000; Van Eeden et al., 2001; Brauer et al., 2002, 2003). Expected increases in forest fire frequency associated with changing climate will increase exposures to fine particulate matter from wood smoke (cf. Dods and Copes, 2005). Fine particulate matter is linked to premature deaths, exacerbation of asthma, acute respiratory symptoms and chronic bronchitis, and decreased lung function, especially in children (Vedal, 1993).

Together, increasing heat stress and exposure to air pollution will increase illness, absenteeism, hospitalization and premature mortality. Already, the annual health burden of outdoor air pollution for BC is estimated at approximately $85 million (BC Ministry of Health, 2004).

Disease Exposure

Diseases spread by water, vectors (e.g. animals, insects) and air are expected to increase as a result of climate change. Water-borne diseases are likely to increase in some areas of BC as a result of increased precipitation and flooding. Twenty-nine waterborne outbreaks have occurred in the province since the 1980s, due to parasites, bacteria and viruses in drinking water systems (Mullens, 1996; Wallis et al., 1996). Boil-water advisories are common. Three hundred and four were issued in August 2001 (BC Ministry of Health Planning and Ministry of Health Services, 2001). Extreme precipitation also contributes to elevated turbidity levels that reduce the effectiveness of drinking water disinfection systems. During November 2006, a boil-water advisory was issued by Greater Vancouver Regional District (GVRD) Medical Health officers that affected almost 1 million people for 12 days following an extreme rainfall that led to turbidity levels "unprecedented in recent years" (Greater Vancouver Regional District, 2006). First Nations communities are particularly vulnerable to water-quality advisories and currently experience more than the rest of Canada, due to poor infrastructure.

Climate change will enable many disease vectors, such as mosquitoes, ticks and rodents, to extend their range and thereby increase human exposure. For instance, the mosquito-borne West Nile virus, although not yet found in BC, is spreading due, in part, to changing climate, and may become one of North Americas' leading arboviral diseases (Morshed, 2003). Encephalitis and Lyme disease from ticks may expand in range with expected warmer winters, as observed in Europe in the 1990s (Lindgren et al., 2000).

In 1994, the first Canadian case of hantavirus pulmonary syndrome (HPS) was identified in BC (Stephen et al., 1994), and 50 more cases have emerged since then (BC Ministry of Health, 2005). In the United States, HPS epidemics are linked to rising rodent populations associated with climate and ecological changes (Wenzel, 1994; Engelthaler et al., 1999; Glass et al, 2000). Rodent breeding capacity is increased by mild winters (Mills et al., 1999; Drebot et al., 2000), conditions that are likely to be exacerbated by climate change.

Cryptococcus gattii, a tiny tropical yeast-like fungus, was identified on Vancouver Island in 1999 and more recently by the Vancouver Coastal and Fraser health regions (BC Centre for Disease Control, 2005). After inhalation, the fungus can cause serious illness and occasional death as it affects the lungs (pneumonia) and nervous system (meningitis). The changing distribution of this pathogen is linked to warming conditions (Kidd et al., 2004).

Food Security, and Public Safety and Well-being

Climate change will affect access to food resources, particularly for rural and First Nation communities that rely on hunting, trapping, gathering and fishing for subsistence (O'Neil et al., 1997; Wheatley, 1998), thus exacerbating existing food insecurities (Willows, 2005).

Harmful algal blooms (HAB), or 'red tides', can flourish in summer months during extended warm periods. Increases in ocean surface temperature and storminess associated with climate change are stimulating HABs in British Columbia (Mudie et al., 2002). The most toxic red tides result from dinoflagellates, which cause illness or fatalities if large amounts of diseased shellfish are consumed (Mudie et al., 2002). Severe incidents of paralytic shellfish poisoning (PSP) have occurred on the BC coast (Taylor, 1993). In June 2006, most shellfish harvesting areas on Vancouver Island and the Gulf Islands were closed for several weeks. Rising ocean surface temperatures, in conjunction with the expansion of aquaculture in BC, can be expected to increase the incidence of economic and health impacts from harmful algal blooms.

Drinking water security is a major concern for water-stressed regions. Historically reliable water sources are not an assurance of continued supplies, as evidenced by the experience of Tofino, a resort town on the west coast of Vancouver Island. Tofino, accustomed to a very wet climate, experienced a major water shortage in the summer of 2006 due to increasing water demands and prolonged summer drought. The vulnerability of such communities to water shortages and related health impacts will likely increase due to climate change and increasing development pressures. The Drinking Water Protection Act (BC Statutes and Regulations, 2001) is intended to strengthen water protection in BC, but mentions little about adapting to climate change.

The increasing frequency of extreme weather events, such as flooding, storm surges, landslides and wildfires, constitutes a significant risk to public safety. Associated health impacts include injuries, increased disease exposure and mental health effects from financial and emotional stress (Ahern et al., 2005). Remote communities are particularly vulnerable, as they often depend on limited essential services and vulnerable critical infrastructure for the distribution of food, medical supplies and other essential goods and services (*see* Sections 3.8 and 4.1).

Finally, there are also strong relationships between ecosystem impacts, whether caused by climate or other factors, on economic livelihoods (i.e. jobs, incomes) and community and population health (Hertzman et al., 1994; Raphael, 2001). Research in BC's coastal communities clearly links deteriorating ecosystem, economic and social conditions with health consequences (Ommer, 2007).

Adaptation

Awareness of climate change impacts on public health is growing, particularly in relation to increasing air pollution (BC Ministry of Health Services, 2004). Research networks on health are also growing (e.g. BC Environment and Occupational Health Research Network). There remains a need, however, for additional research on linkages between climate change and health impacts. In addition, co-ordination of disease surveillance with climate monitoring and environmental surveillance could provide important new insights.

Public health adaptation requires cross-sector approaches involving environmental managers, infrastructure developers, rural and urban planners, health care workers and administrators, public health educators, politicians and researchers. It also requires more information on prevention, protection and treatment of climate-related diseases (Parkinson and Butler, 2005) being made accessible to British Columbians.

4 TOWARDS ADAPTATION: CASE STUDIES IN BRITISH COLUMBIA

Vulnerability and adaptive capacity to climate change in British Columbia's communities are a product of social processes and environmental conditions and especially their interaction at the local or regional scale (Dolan and Walker, 2007). Key factors influencing adaptive capacity in BC include the following:

- The heavy reliance on natural resources, particularly forestry, exposes BC communities to environmental and market changes, and to combined climatic and non-climatic stresses (O'Brien and Leichenko, 2000).
- Governance structures, which regulate how ecosystems can be used and accessed by people, mediate both the social and economic use of natural resources. Few existing structures explicitly consider climate change impacts; fewer still have implemented adaptation-specific policy changes.
- Diverse sociocultural values and competing socioeconomic interests underlie debates over how best to plan and protect resources and the environment. Climate change makes the process of reaching effective compromise more complex and the outcomes more difficult to predict.

The case studies presented in this section highlight how these factors and other aspects of a community, region or economic activity influence its capacity to adapt to climate change. In general, adaptive communities require resilient social networks, services, governance, infrastructure and economic activities that can withstand a variety of socioeconomic and environmental changes (e.g. Dolan and Walker, 2007; Young, 2006b; Ommer, 2007; Page et al., 2007; Enns et al., in press). Adaptive capacity can be enhanced, or constrained, by the nature and structure of decision-making relationships and planning policy. Increased stakeholder involvement in BC's sociopolitical landscape, at both local and regional scales (Hoberg, 1996; Seely et al., 2004), has enhanced incorporation of local values and interests into land-use planning. For instance, conflict over logging practices in old-growth forests in the 1990s (Stanbury, 2000; Cashore, 2001) led to the development of the multi-stakeholder Land and Resource Management Planning (LRMP) process (BC Ministry of Agriculture and Lands, 1993), which is typically enacted at the local to regional scale. The LRMP process has had some success in reconciling conflicting positions and contentious land and resource disputes (Frame et al., 2004), although it has not yet integrated potential climate change impacts and adaptation into its mandate (Hagerman and Dowlatabadi, 2006).

The effectiveness of governance, from local to higher levels, is another factor influencing adaptive capacity. At the local level, community planning is a key mechanism for stakeholders in BC to consider and incorporate the effects of climate change. Planning is guided by the BC Municipal Act and other policy instruments, including Official Community Plans (OCPs), local zoning and building codes, and the provincial Agricultural Land Reserve (ALR). Currently, few regional decision-making processes, policies and institutions explicitly consider the potential impacts of climate change. Regional planning districts, water districts and other 'improvement districts' are mid-level jurisdictions in BC that will play a critical role in preparing for and managing some of the expected impacts of climate change (Jakob et al., 2003), such as for water supply and stormwater management (*see* Section 4.4; Burton et al., 2005).

At the provincial level, the BC Government released the report *Weather, Climate and the Future: BC's Plan* (BC Ministry of Environment, 2004), which discusses greenhouse gas mitigation and adaptation actions. The BC Ministry of Forests and Range (MFR) has also taken a proactive approach to integrating climate change considerations into medium- and long-term regional and resource planning procedures (BC Ministry of Forests and Range, 2006; *see* Section 4.2.2). The Ministry of

Community Services, which provides funding for community infrastructure, is now increasingly considering climate change in reviewing proposals from local authorities (B. Kangasniemi, BC Ministry of Environment, pers. comm., 2007).

Finally, there are striking differences between urban and rural communities in BC in terms of local policies, growth patterns, planning issues and social attitudes. Climate change impacts and adaptation issues need to be seen as relevant to local concerns within communities' planning and risk management responsibilities. Issues such as water management in the Okanagan basin, sea-level rise in coastal communities and the impacts of the mountain pine beetle in BC's interior forest-based communities are examples that illustrate how impacts and steps toward adaptation are being experienced in BC. Although explicit integration of climate change considerations is relatively rare, these case studies provide perspectives on steps being taken towards adaptation to a variety of social, economic and environmental stressors.

4.1 COASTAL COMMUNITIES: VULNERABILITIES AND ADAPTATION TO SEA-LEVEL RISE

Climate change affects British Columbia's coastal communities through the gradual effects of accelerated sea-level rise and the more immediate impacts of extreme events, including increased storm-surge flooding, accelerated coastal erosion, contamination of coastal aquifers and various ecological changes. Such biophysical changes create risks of land loss, coastal infrastructure damage, coastal resource changes and shifts in related economic, social and cultural values (Klein and Nicholls, 1999). Climate change impacts are, and will continue to be, unevenly distributed among coastal communities due to differing local exposures and vulnerabilities (Clark et al., 1998; Dolan and Walker, 2007). These impacts are superimposed on non-climatic issues, including First Nations land claims, decline or collapse of key natural resource industries, economic restructuring, and the loss or reduction of social support and government services (Ommer, 2007; Sydneysmith et al, 2007).

A Canada-wide assessment of the impacts of sea-level rise (Shaw et al., 1998) defines 'coastal sensitivity' as the degree to which sea-level rise will initiate or accelerate physical changes to the coast. Most of BC's coast is steep and rocky, and therefore has a moderate to low sensitivity. Exceptions include the northeastern coast of Graham Island, Haida Gwaii (Queen Charlotte Islands) and the Roberts Bank–Fraser Delta region in Greater Vancouver. These areas are ranked amongst Canada's most sensitive coastlines to climate change. However, this sensitivity analysis does not fully assess vulnerability to climate change, as it does not consider adaptive capacity (cf. Luitzen et al., 1992; Smit et al., 2001). Adaptive capacity is determined by socioeconomic setting (access to economic resources, political and social capital, and coastal planning policy) and local experiences with environmental hazards and socioeconomic changes (Dolan and Walker, 2007). The two cases presented here highlight communities experiencing similar physical impacts in very different socioeconomic settings. Key vulnerabilities, adaptive capacities and steps toward adaptation are discussed.

4.1.1 Northeastern Graham Island, Haida Gwaii (Queen Charlotte Islands)

Graham Island is the largest, northernmost island in the Queen Charlotte archipelago (Haida Gwaii). Relative sea level is currently rising at 1.6 mm/a and extreme annual sea levels at 3.4 mm/a (Abeysirigunawardena and Walker, in press). The shores of northeastern Graham Island consist mostly of highly erodible dune and bluff sediments. This, combined with high tides, energetic wave climate, frequent storm surges and high winds, creates a highly dynamic coastline with actively shifting beaches (Walker and Barrie, 2006). Water level and coastal erosion trends are strongly influenced by ENSO and PDO (Storlazzi et al., 2000; Dingler and Reiss, 2001; Allan and Komar, 2002; *see* Section 2.1). During El Niño 1997–1998, sea level rose 0.4 m and caused 12 m of local erosion along this shoreline (Barrie and Conway, 2002), and extreme water levels have increased significantly since the positive PDO shift of 1976 (Abeysirigunawardena and Walker, in press).

Climate change is one of many stressors affecting communities in Haida Gwaii. The local forest industry has experienced turbulent international timber markets, increasing costs of access, and changes in forest management, technology and protection, leading to declines in on-island processing and jobs. The local fishing industry has experienced changing populations of salmon, herring and clams, as well as restricted fishing privileges. In addition, closure of Canadian Forces Base Masset led to the out-migration of hundreds of people, resulting in further job losses and socioeconomic restructuring.

Adaptive Capacity

Dolan and Walker (2007) presented an integrated, human-environmental research framework to assess climate change–related risks and vulnerabilities of communities on northeastern Graham Island. Resulting research by Walker et al. (2007) involved assessment of climate change trends, impacts and sensitivities (Walker and Barrie, 2007; Walker et al., 2007; Abeysirigunawardena and Walker, in press), and a sociocultural assessment by Conner (2005) used a 'participatory approach', incorporating local knowledge, perceptions and experiences to define attributes of adaptive capacity and identify key vulnerabilities. This study identified many attributes capable of strengthening adaptive capacity (Table 9) that may not be readily captured by the typical attributes of vulnerability, such as wealth. In Haida Gwaii, a historically high dependence on natural resources for jobs, below-average household incomes, high unemployment rates and income instability suggest a high vulnerability and low adaptive capacity. At the household level, however, socioeconomic resilience is enhanced by income diversification (multiple jobs, arts and crafts, tourism) and food gathering and stockpiling. This suggests a higher adaptive capacity to the risks of climate change than would be interpreted from income and employment statistics alone.

Access to technology, information and skills, critical infrastructure and essential services are other community-level factors of adaptive capacity (Goklany, 1995; Barnett, 2001). Most critical infrastructure and transportation services in Haida Gwaii are highly vulnerable to coastal storm damage. Frequent power outages, interrupted ferry and flight service, short-term grocery and supply shortages, occasional highway closures and wind damage are commonplace. Most communication services are available in Haida Gwaii, including high-speed Internet and cellular phone coverage. Community messages are broadcast on local TV, in flyers and in the local newspaper. A tsunami evacuation plan exists, but is not well recognized, despite established protocols and tests. Recognition of the need to adapt, knowledge about available options, capacity to assess them and ability to implement the most appropriate options are all dependent on the availability of credible information and appropriate skills (Fankhauser and Tol, 1997).

Risk perception, awareness and preparedness are also attributes of adaptive capacity (Burton et al., 1978; Barnett, 2001; Smit et al, 2001; Dolan and Walker, 2007). Risk perception depends on knowledge and past experience with hazards, such that greater awareness comes with greater knowledge and experience (Hutton and Haque, 2004; Degg and Homan, 2005). Despite generally low levels of formal education in Haida Gwaii, high informal education, local and traditional environmental knowledge, and a diverse informal skill set (e.g. hunting, gathering and backcountry skills) result in a high general risk awareness and preparedness for natural hazards. However, many residents do not perceive risks from longer term climate change *per se*, compared to those associated with extreme events such as storms, coastal erosion or tsunami.

Social capital, which includes relationships, networks and infrastructure that support the flow of information and skills toward shared values, goals and collective action (Coleman, 1988; Tobin, 1999), is another important determinant of adaptive capacity. Communities with greater social capital may

TABLE 9: Local attributes of vulnerability and adaptive capacity to climate change impacts in Haida Gwaii (*modified from* Walker et al., 2007).

Factors that increase vulnerability[1]	Factors that enhance adaptive capacity[2]
• Geographic isolation • High exposure to climate variability hazards and sea-level rise	• Strong attachment to Haida Gwaii • Connectedness with nature • Frontier mentality • Experience with environmental changes and hazards
• Low formal education levels (cf. Holman and Nicol, 2001)	• High informal education, local knowledge, traditional ecological knowledge • Haida culture and rediscovery • Diverse skills (hunting, gathering, etc.)
• Limited provision of essential services (health care, social services, education) • Generational health impacts (alcoholism, abuse, apathy)	• Strong community cohesion and support networks (e.g. family ties, volunteer groups) • Increasing volunteerism and local involvement in essential services (e.g. women's shelters, community health programs)
• Poor dissemination and awareness of emergency plans	• Established evacuation protocols and tests • Increased communication between communities
• Frequent power outages • Short-term food shortages	• High coping capacity with power shortages • Local food gathering and hunting • Food stockpiling and preserving
• High unemployment • Dependence on unstable natural resource sector • Low, long-term economic stability	• Household income diversification/subsidization (multiple jobs, arts, food gathering, tourism) • Seasonal jobs (fisheries/crabbing, mushrooms, tourism/charters) • Increased resilience to economic hardships
• Lacking official land-resource and/or land-use management plans[3]	• Ongoing development of integrated LRMP incorporating Haida Land Use Vision and resident values
• Local, regional and federal political tensions	• Increasing local involvement and Haida governance in decision-making process

[1] as defined in existing scholarship (*see* Chapter 2).
[2] as found in Conner (2005).
[3] in January 2006, a recommendation plan was forwarded to the BC Integrated Land Management Bureau (<http://ilmbwww.gov.bc.ca/lup/lrmp/coast/qci/> [accessed August 20, 2007]); as of November 2006, no formal land use plan existed.

deal more effectively with hazards and the impacts of climate change (Buckland and Rahman, 1999). In Haida Gwaii, high social capital is suggested by strong community cohesion, numerous support networks, community activism and increasing local involvement in community services.

Institutions and governance also influence adaptive capacity. Historical conflict between community groups and orders of government on forestry and fishing, provision of services and local control in decision-making makes for a complex sociopolitical environment in Haida Gwaii. Longstanding negotiations between community groups, the Haida Nation and the BC government have yet to establish a Land Resource Management Plan (LRMP) for Haida Gwaii (Haida Gwaii–Queen Charlotte Islands Land Use Planning Process Team, 2006). An LRMP will be critical in determining future planning in Haida Gwaii; however, climate change considerations, such as coastal setbacks and limiting development on eroding coasts, are not part of the current report's recommendations.

Impacts and Adaptation

Projected future impacts associated with changing climate include increasing coastal erosion, rising storm-surge damage and flooding, more frequent disruptions to critical transportation services, likely loss of coastal sections of Highway 16, rising costs of infrastructure maintenance, changes to coastal habitat and species abundance (crabs, clams) that will affect both commercial and sport fishing, and changes in the form and ecology of Rose Spit, an ecological reserve and Haida spiritual site.

Walker et al. (2007) have provided several adaptation considerations that build on existing community strengths and locally defined vulnerabilities. Adaptive planning is needed to reduce the vulnerability of exposed critical infrastructure, including coastal roads, low-lying buildings and airports, power-communication transmission lines and essential services. Possible initial actions include continued protection of vulnerable coastal stretches of Highway 16 and upgrades to existing logging roads for an alternate inland route. Consideration of coastal setbacks and land-use rezoning along eroding and flood-prone coastal areas are still needed. Economic development and renewal initiatives in tourism, arts, culture and resource stewardship will continue to diversify the local economy, enhancing community resilience. Enhancement of existing cultural, socioeconomic and political strengths will also improve overall adaptive capacity of Haida Gwaii communities to longer term climate change.

4.1.2 Roberts Bank, Greater Vancouver Regional District

The Roberts Bank tidal flats are located on the seaward edge of the Fraser River delta, bordering the Corporation of Delta and the Tsawwassen First Nation (TFN). The Corporation of Delta is a mixed urban and rural community that forms part of the Greater Vancouver Regional District. Delta and TFN are protected from river and storm-surge flooding by dykes along the river and shoreline. The tidal flats provide an important habitat for both birds and fish. Thousands of waterfowl, shorebirds and gulls use the tidal flats (Vermeer et al., 1994). Extensive beds of native eelgrass (*Zostera marina*) provide important spawning habitat for Pacific herring and feeding grounds for juvenile chinook and coho salmon (Levings and Goda, 1991).

The issue of assessing rising sea level and changing storm impacts on the Roberts Bank tidal flats involves complex stakeholder values and interactions (Hill et al., 2004). Two major causeways cross the southern end of Roberts Bank: a Vancouver Port Authority (VPA) structure providing access to the Delta Port shipping terminal and a BC Ferries Corporation structure serving a major ferry terminal. Both causeways were constructed in the 1950s, with little consultation with the communities, causing longstanding grievances and tensions. Stakeholder interviews identified key issues and positions around land and resource management on Roberts Bank. This information was used to design a workshop deliberation of potential climate change concerns, unhindered by historical grievances. Key concerns identified at the workshop included the integrity of infrastructure (dykes, causeways and port facilities), increased flood risk, loss of fresh water for irrigation during the summer, and loss of fish and bird habitat.

Impacts and Adaptation

The main biophysical impacts of sea-level rise on the tidal flat environment are summarized in Table 10 (Hill, in press). The projected range of net relative sea-level rise for Roberts Bank is 0.23 to 1.02 m by 2100, based on Intergovernmental Panel on Climate Change (2001) projections of global sea-level rise, the historical rate of relative sea-level rise from tide-gauge data, and new ground subsidence data. Land subsidence in the Delta region accounts for 0.2 to 0.3 m of this relative rise (Mazzotti et al., 2006).

The tidal flats are characterized by different ecological zones supporting distinct habitats. These zones tend to migrate inland in response to rising sea levels. However, the presence of dykes impedes natural shoreline migration with sea-level rise, effectively 'squeezing' these zones against the dykes (Clague and Bornhold, 1980; Hughes, 2004). As sea level rises, wave motions presently attenuated by friction over the shallow delta surface will increase in amplitude, resulting in increased sediment transport and potential erosion of the marsh. This will be exacerbated greatly if the frequency of intense storms increases. Although uncertainties exist regarding marsh accretion and future sediment transport rates, it is expected that the mud-flat area will decrease significantly over the next century. These changes are likely to have a negative impact on certain bird populations (Hill, in press), as the marshes and mud flats are critical feeding habitat for migratory birds, such as the western sandpiper (Elner et al., 2005). Sea-level rise, as well as development pressures, will likely favour continued expansion of eelgrass beds, thus favouring fish habitat and bird species that feed on them, such as heron.

An immediate outcome of the Roberts Bank study (Hill, in press) is, as stated by the mayor of the Corporation of Delta, to make climate change and its effects on Delta a priority in the coming three years. A survey of municipal officials, including scientists, engineers and planners, demonstrates a high level of concern about the effects of climate change. Key concerns include the implications of sea-level rise and storm surges for protection of critical infrastructure and the natural environment. The effects of rising sea level are now being considered in a re-evaluation of dyke design by Delta, and in the development of an adaptive management plan for the Delta Port expansion project. A preliminary set of climate change impact indicators (Gregory et al., 2006), including biophysical (e.g. shoreline erosion, sedimentation), ecological (e.g. critical habitat area), socioeconomic (e.g. agricultural revenue), infrastructure (e.g. dyke integrity) and cultural (e.g. area of traditional land use), will provide a basis for future adaptive planning.

4.1.3 Summary and Lessons Learned

The Haida Gwaii study highlights aspects of remote coastal communities facing climate change and sea-level rise. Findings include the following:

- Remote communities and residents possess many resilient socioeconomic and sociocultural attributes that enhance their adaptive capacity to climate change risks in an otherwise exposed environment.

TABLE 10: Summary of biophysical impacts caused by rising relative sea level on Roberts Bank (*from* Hill, in press).

Element	Effect	Impact	Confidence level
Global sea-level rise	0.08–0.88 m by 2100 (Intergovernmental Panel on Climate Change, 2001)		High
Land subsidence	2–3 mm/year in the Fraser River delta		High
Net relative sea level rise	Median values using 2 mm/yr subsidence: 2030: 0.17 m 2050: 0.27 m 2100: 0.62 m		High
River flood frequency	Flood return periods will decrease due to rising base (sea) level, leading to higher risk	Negative	High
Marsh	Erosion of marsh due to coastal squeeze and increased wave attack; mitigated by natural marsh accretion up to a threshold rate	Negative	• Moderate confidence that the marsh will be stressed • Low to moderate confidence that drastic changes will not occur before 2050 • Low to moderate confidence that the marsh will decline more rapidly after 2050
Mud flat	Projected 45–63% reduction in area due to coastal squeeze; mitigated by some sedimentation over present marsh area; may be exacerbated by increased storminess and wave action	Negative	Low
Eelgrass	High modern expansion rates suggest eelgrass will migrate landward with changes in water depth	None	Moderate to high
Biofilm	Area likely to decrease with reduction in mud flat; higher wave energy may coarsen sediment and reduce productivity	Negative	Low
Predation of shorebirds	Likely to increase due to landward migration of optimum feeding grounds into range of predatory raptors (Butler, 1999).	Negative	Low

- Community responses to past social, cultural and/or economic changes provide key information on elements of adaptive capacity to climate change (e.g. social capital, community cohesion).
- Despite inherent resiliencies, adaptive capacity to long-term impacts is challenged by 1) direct exposure to coastal storms and sea-level rise; 2) dependence on vulnerable critical infrastructure and limited essential services; 3) limited economic resources to cope with continued and increasing impacts; and 4) limited land-use development plans that typically do not consider climate change.

In the urbanized, complex multi-stakeholder situation represented in the Roberts Bank study, key findings include the following:

- Careful design of the stakeholder process is required to alleviate pre-existing conflicts and enable focused discussion on climate change issues.
- An analytical-deliberative process is required, whereby technical analysis informs deliberations that, in turn, refine understanding of overall risks (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, 1996), thus providing a mechanism for moving towards adaptation. This process needs to be iterative to allow technical experts and stakeholders to converge on a common understanding of key vulnerabilities and adaptation options.
- In coastal environments with considerable human interventions, climate change is superimposed on a variety of other biophysical changes. As such, climate change impacts must be assessed as part of a broader suite of cumulative environmental impacts occurring at a site.

Common findings from these studies relevant to other Canadian coastal communities include the following:

- Climate change is only one of many risks, changes and challenges facing coastal communities. This stresses the need to understand past community responses (e.g. social and economic restructuring, coastal development and infrastructure measures), in order to plan for future changes. Interventions in the coastal zone benefit from cumulative impacts assessments and integrated coastal zone management (ICZM) planning. Jurisdictional issues and historical conflicts can present key barriers to ICZM implementation.
- Community involvement is key to obtaining locally relevant results for adaptive planning. Reasonable time frames of 5 to 10 years are required to properly engage community stakeholders and develop feasible adaptation measures.
- The timelines required for community planning that incorporates consideration of climate change are long compared to most community planning processes in British Columbia. Rates of sea-level rise are initially slow but are likely to accelerate with time. Climate change risks (e.g. erosion, groundwater contamination, storm flooding, increasing transportation and infrastructure costs) are insidious and may occur sporadically. Thus, communities are faced with more complex risk analysis and high levels of uncertainty in the planning of infrastructure and land use. Furthermore, the process of adaptation evolves through time from early actions and monitoring of key indicators toward longer term planning strategies.

4.2 CENTRAL AND NORTHERN BRITISH COLUMBIA: MOUNTAIN PINE BEETLE AND FOREST-BASED COMMUNITIES

The communities and landscape of central and northern British Columbia epitomize the historical role of forestry in the province's development. Today, forestry management practices of the past have collided with contemporary climate conditions to produce a dramatic example of the impact of changing climate in Canada. This case study looks at the causes and consequences of the current outbreak of mountain pine beetle, how one forest-dependent community is attempting to understand its own vulnerability, and at a recent initiative of the provincial Ministry of Forests and Range that is taking a proactive approach to incorporating climate change impacts and adaptation into long-range forest resource planning and management.

4.2.1 Mountain Pine Beetle

The mountain pine beetle (MPB) is a native insect that occurs from northern Mexico to central British Columbia. It feeds on the succulent tissues beneath the bark of most pine species in its range (Furniss and Schenk, 1969). Although MPB is normally innocuous, populations periodically erupt into outbreaks that kill millions of trees over large areas (Taylor et al., 2006).

Mountain pine beetle outbreaks have occurred in BC several times during the twentieth century, but the area affected by the present outbreak is nearly 10 times greater than any previously recorded. In 2007, MPB infestations were recorded over 9.2 million ha of pine forests (BC Ministry of Forests and Range, 2007). For a MPB outbreak to occur, two main conditions must be satisfied. First, there must be an abundance of large, mature pine trees. As a result of fire suppression and historical factors, there was over three times the amount of mature pine in BC at the start of the current outbreak compared with 100 years ago (Taylor and Carroll, 2004). Second, there must be several years of favourable weather for beetle survival: specifically, warm summers for beetle reproduction and mild winters that allow their offspring to survive (Safranyik and Carroll, 2006). The climate in central BC during recent decades has been highly suitable for beetle survival, most notably in the lack of sustained cold conditions in winter (Carroll et al., 2004). The result has been the largest outbreak of mountain pine beetle in history.

In addition to the unprecedented size of this outbreak, the range of MPB is expanding into formerly unsuitable habitats, especially toward the north and east (Carroll et al., 2004). The present range is not restricted by the availability of suitable host trees, as pine forests extend north into the Yukon and the Northwest Territories, and east across the continent as part of the boreal forest. Instead, the potential for beetles to expand north and east has been limited by climate (Safranyik et al., 1975). Modelling indicates that climate conditions favourable to MPB have recently improved over large portions of western Canada (Figure 10), increasing the amount of climatically optimal habitat by more than 75% (Carroll et al., 2004). Climate change scenarios discussed by Flato et al. (2000) suggest continued expansion of favourable conditions for MPB eastward into Alberta and north into the boreal forest.

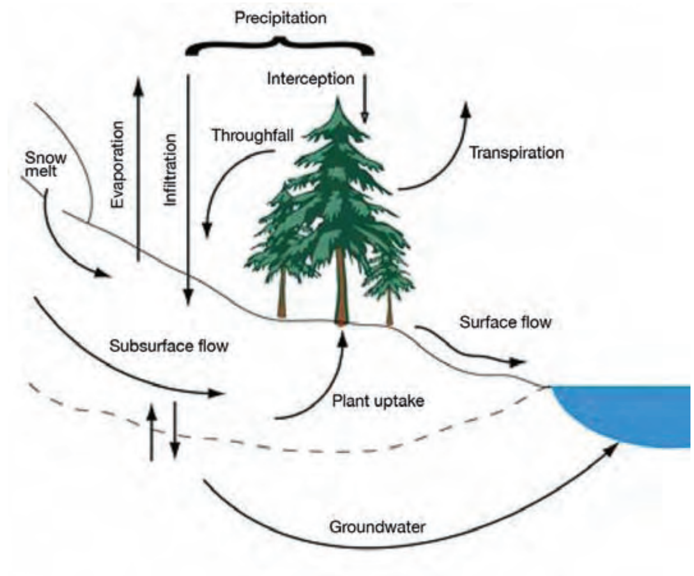

FIGURE 11: Forest hydrological cycle (*adapted from* Hélie et al., 2005).

The unprecedented tree mortality associated with the current MPB epidemic significantly impacts forest hydrology (Figure 11; Hélie et al., 2005). The current and projected MPB infestation in BC will kill enough trees to cause greater exposure of soils to precipitation, potentially deeper snow accumulation and earlier melt, thereby increasing the risk of flooding. Such modifications to the hydrological cycle may account for observed changes in annual water yields and peak flows, and increased base flows/low flows in watersheds affected by MPB (Forest Practices Board of BC, 2007; cf. Cheng, 1989). More recently, other regions in BC have reported the occurrence of higher water tables (e.g. Vanderhoof Forest District) in MPB-affected areas (BC Ministry of Forests, 2005). The City of Prince George is also concerned about the potential for a heightened risk of flooding in low-lying parts of the city due to anticipated rises in the levels of the Nechako and Fraser rivers, especially during spring runoff (Dyer, 2006).

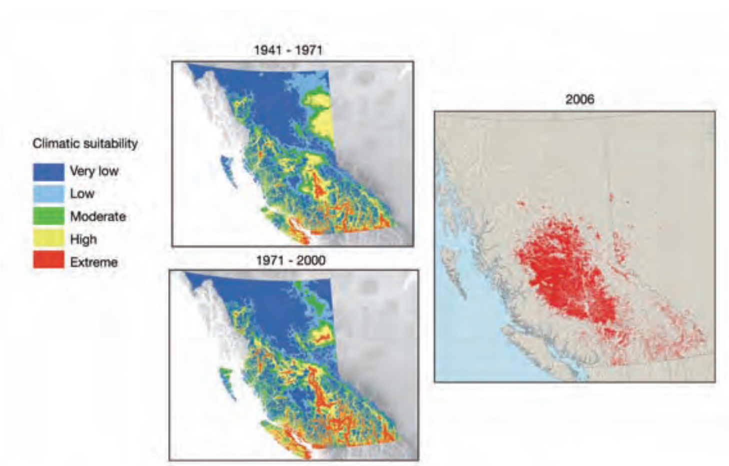

FIGURE 10: Left: Historical distributions of climatically suitable habitats for the mountain pine beetle (MPB) in British Columbia (*adapted from* Carroll et al., 2004). Areas with 'very low' suitability are unsuitable for MPB, where as 'extreme' areas are those considered climatically optimal. Right: Total area affected by mountain pine beetle in British Columbia in 2006 (Natural Resources Canada, 2007).

The magnitude of hydrological impacts resulting from an MPB infestation depends on the extent and location within the watershed, as well as the geography of the watershed. Although these impacts will decrease as affected areas recover, higher flows could persist, at a decreasing rate, for as long as 60 to 70 years (Troendle and Nankervis, 2000). Some evidence suggests that harvesting MPB infested trees could advance the timing of hydrological recovery, as compared to a worst case scenario for natural regeneration (Dobson Engineering Ltd., 2004). Better understanding of the impacts of MPB and related harvesting on the hydrology of forested watersheds in BC is needed to determine appropriate levels of intervention and guide broader adaptation measures..

4.2.2 Vulnerability of Forest-Based Communities

The implications of changes in forest resources for residents of Vanderhoof and its surrounding region in north-central British Columbia exemplifies the challenges facing close to 110 forest-dependent communities in British Columbia. Although these communities face the same general impacts associated with climate change as other communities in BC, there are additional factors affecting their vulnerability. First, their economic dependence on extraction and processing of forest resources means that the local economy is highly sensitive to climate-induced changes in resource availability (Davidson et al., 2003). This economic exposure is magnified by the fact that climate change may lead to relative increases in the supply of timber and forest products from other nations, resulting in increased competitive pressures on the BC forest industry (Perez-Garcia et al., 2002; Sohngen and Sedjo, 2005). Second, many forest-based communities are relatively small and remote, with undiversified economies and specialized labour forces, limiting their capacity to adapt to climate change. Third, as the incidence and severity of wildfires are projected to increase as a result of climate change (Flannigan et al., 2005), forest-based communities will face increased risk of property loss, evacuation and deterioration in air quality due to increased fire activity (Davidson et al., 2003). Fourth, forest management and large-scale forest-processing facilities represent long-term investments that are difficult to reverse. Forestry decision-makers face long investment periods, dynamic risk and uncertainty that increase relative to the length of the forecast periods (Davidson et al., 2003). These factors underscore the importance of risk management in forestry and forest-based communities as an adaptation to climate change (Ohlson et al., 2005).

Vanderhoof has a population of 4400 with strong economic and social ties to the surrounding forest land base. The forest sector accounts for about 63% of the economic base of the community. The most immediate effect of changing climate on Vanderhoof is the current mountain pine beetle epidemic. The outbreak is having, and will continue to have, significant impacts on resource supply and local production of forest products. Prior to the MPB outbreak, the historical allowable harvest rate in the Vanderhoof Forest District was around 2 million m^3 per year, whereas the current annual harvest target is 6.5 million m^3 (Pederson, 2004). This increase has been implemented to utilize beetle-killed timber. Once the MPB has subsided (i.e. within about 10 years), the annual harvest level is projected to drop to between 1.25 and 1.75 million m^3 (Pederson, 2004). Thus, the Vanderhoof economy will experience significant volatility over a short time period. The challenge for Vanderhoof will be to manage this transition by ensuring that reductions in natural capital caused by the mountain pine beetle are offset by increases in other forms of useable capital (human-made capital, new forest or alternative land uses), to ensure that the long-term economic viability of the region can be maintained (cf. Pezzy 1989; Solow 1991).

Residents of Vanderhoof also have a strong cultural and psychological connection to their surrounding forest landscape, and are very concerned about the long-term implications of environmental changes for the community and future generations (Frenkel, 2005). The Canadian Forest Service is developing methods to simulate the long-term effects of climate change on forests at scales most relevant to communities. These methods have been applied to a 40 000 km^2 study area around Vanderhoof, to simulate future distributions of forest cover type in the year 2100 under two different climate futures (Table 11, Figure 12). Both simulations indicate significant changes in forest composition and provide general indications of potential changes over the next 100 years. The long-term impacts of climate change in terms of the nature and magnitude of forest ecosystem effects are not necessarily catastrophic — although the composition of the forest will change, forest cover will continue to exist under all future climate scenarios considered.

The Vanderhoof case study highlights that information on the magnitude and timing of impacts at locally relevant scales is required to facilitate consideration of adaptation. The experience of Vanderhoof also shows that the goal of managing a single resource in a sustainable manner may be difficult to achieve at a community level. Instead, reduction in one form of capital, in this case forests, may need to be offset by increases in other forms of capital, such as more land in agriculture or investment in new industries.

TABLE 11: Approximate areas in each of the simulated vegetation types, as a percentage of total area, in the Vanderhoof study area, British Columbia (*Source:* D. Price, Natural Resources Canada).

Vegetation/forest type	Present-day (ca. 2000)	HadCM3-B2 (ca. 2100)	CSIRO2-A2 (ca. 2100)
Temperate softwood	46	24	6
Temperate hardwood	<1	0	10
Boreal softwood	54	75	26
Boreal hardwood	0	0	14
Temperate mixed	<1	1	33
Boreal mixed	0	0	11
Conifer-grassland mixed	0	<1	0

4.2.3 British Columbia's Climate Change Task Team and Future Forest Ecosystems Initiative

Climate change will play a major role in shaping the composition and use of forests in British Columbia. In recognition of this fact, the British Columbia Ministry of Forests

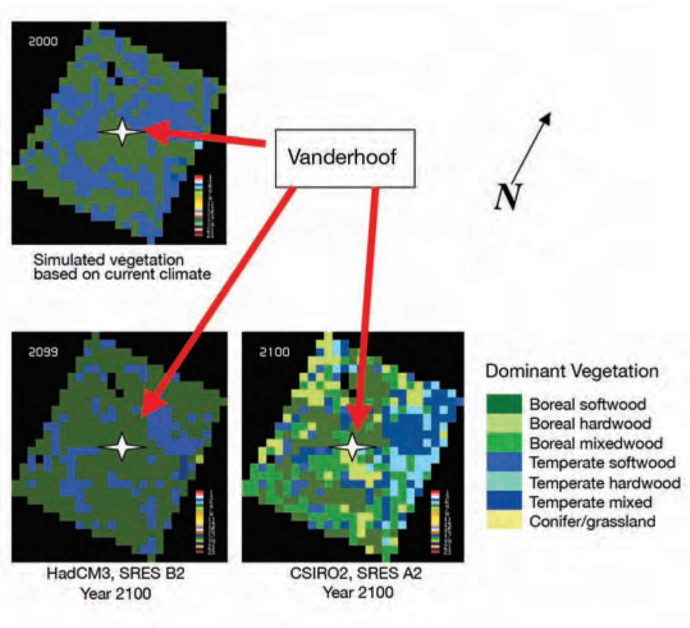

FIGURE 12: Simulated vegetation cover in the Vanderhoof study area, British Columbia (using IBIS, a dynamic global vegetation model), based on current climate and, at the turn of the next century, under two alternative climate scenarios (*Source*: D. Price, Natural Resources Canada). Study area is approximately 200 km by 200 km, with Vanderhoof at its centre. Each grid simulated by the IBIS model measures 10 km by 10 km.

and Range (MFR) established two interconnected initiatives to examine the potential future condition of forest ecosystems and to identify management responses. These initiatives recognize climate change as one important influence — along with global competition and new working relationships between governments and First Nations — on the future of forests, the forest sector and forest-based communities in BC. They reflect an effort to move from studying impacts to implementing adaptation.

In the fall of 2005, the MFR established a Climate Change Task Team to review potential impacts of climate change on provincial forest and range resources, identify knowledge gaps and develop recommendations on how the MFR could respond. Recommendations from the team were released in a report entitled *Preparing for Climate Change: Adapting to Impacts on British Columbia's Forest and Range Resources* (BC Ministry of Forests and Range, 2006). The Future Forest Ecosystems Initiative (FFEI), launched in December 2005, brought together representatives from academia, provincial and federal government agencies, First Nations, the forest industry, consultants and environmental organizations for a two-day symposium and workshop.

The MFR consulted widely on the reports of the Task Team and the FFEI. The recommendations from the reports and the consultations were amalgamated under the goal of adapting BC's forest management framework to changing climatic conditions. This will be achieved by increasing the understanding of ecological processes and the risks to forest ecosystems, and by communicating how to adapt the forest management framework to the changing environment. Strategies are being developed to meet these objectives. Although it will be a few years before operational adaptation actions are implemented, consultation, capacity building and vulnerability assessments are the first steps in the adaptation process.

4.3 SOUTHERN INTERIOR: OKANAGAN AND COLUMBIA BASIN REGIONS

The southern interior of British Columba includes the Okanagan region and the upper Columbia River basin. Both watersheds feed into the lower Columbia River system. The major climate adaptation challenge in both areas is the need to manage water resources for multiple, often competing uses. The Okanagan is experiencing rapid growth in population and irrigated agriculture, while the Columbia region is unique because of its importance to BC's hydroelectric power grid and the Columbia River Treaty with the United States. Both areas are also faced with issues concerning the management and conservation of fisheries resources. The discussion below reflects the fact that there is substantially more research available on the Okanagan.

4.3.1 Water Issues

The Okanagan is already experiencing stresses on its water systems associated with rapid population growth and land-use changes (Cohen et al., 2004, 2006). Recent droughts in 2001 and 2003 are examples of short-term extreme events that have affected water supply, water demand and perceptions of risk in the region. The drought of 2003 saw the emergence of local water conflicts (Moorhouse, 2003) and the implementation of both emergency and longer term conservation measures (Johnson, 2004). These droughts have raised awareness about climate sensitivities, and possibly about vulnerability to climate change. When coupled with anticipated population growth, concerns about fisheries and aquatic ecosystems, and long-term directions in regional development, the implications of future climatic change become an important addition to the concerns that need to be addressed by water planners and managers in this region.

The diversity of views in the region regarding the implications of climate change provided the foundation for a dialogue on how the region might adapt to climate change (Cohen et al., 2000). Research described potential impacts on hydrology and water management of the Columbia River system, including potential trade-offs between managing for hydroelectric production versus in-stream flows for fisheries (Payne et al., 2004). Within the Okanagan, case studies addressing hydrology and crop-water demand (Cohen and Kulkarni, 2001; Neilsen et al., 2001) were followed by collaborative work that included estimates of the region's water balance, considering both agricultural and residential water demand (Neilsen et al., 2004a,b). This also included adaptation experiences, a preliminary look at costs of adaptation options and a dialogue on potential implementation of adaptation options.

Climate change scenarios based on two emissions scenarios (A2 and B2) and three climate models were used to generate hydrological scenarios for various catchments in the Okanagan watershed for three time periods (2020s, 2050s and 2080s; Merritt et al., 2006). All results suggest an earlier snowmelt peak in spring, with reduced summer flows and increased winter flows, although the shape of this peak varies considerably (Figures 13 and 14). The hydrographs built from these scenarios proved to be an important tool for translating the implications of climate change into terms that are meaningful and tangible to local decision-makers.

Hydrological scenarios for the Okanagan watershed are similar to those for the Columbia River system as a whole. Maximum snowpack would occur up to 4 weeks earlier by the 2080s. Spring peak flow would be 15 to 40 days earlier by the 2050s, and 20 to 70 days earlier by the 2080s. Earlier and smaller snowpacks have a critical impact on the Columbia River system due to the snowpack's importance to the continuity of hydroelectric power generation (Columbia Mountain Institute for Applied Ecology, 2003). Annual supply from surface-water sources would vary from modest decreases to extreme reductions of around 65% by the 2080s (Merritt et al., 2006). At the same time, agricultural and residential water demand are projected to increase, thereby increasing the likelihood of water shortages. Crop-water demand in the 2080s would increase by up to 60% due to the longer and warmer growing season, although factors such as land-use change and carbon dioxide fertilization will affect this estimate (Neilsen et al., 2004a, 2006). A comparison between inflows to Lake Okanagan and projected crop-water demand shows that the overall ratio of demand to supply would increase from approximately 25 to 50% (Figure 15).

Anticipated population growth and a longer growing season could result in substantial increases in residential demand. A case study of Oliver, BC shows that demand could triple by the 2080s. Implementation of a portfolio of demand-side measures could slow down the projected increase in demand (Figure 16), buying time for the community to consider any requirements for increased water supply (Neale et al, 2006). Without specific measures to manage agricultural, residential and aquatic ecosystem maintenance demands, as part of a broader adaptation portfolio, total annual demand will exceed available annual inflows in the Okanagan watershed later this century (Langsdale et al., 2006).

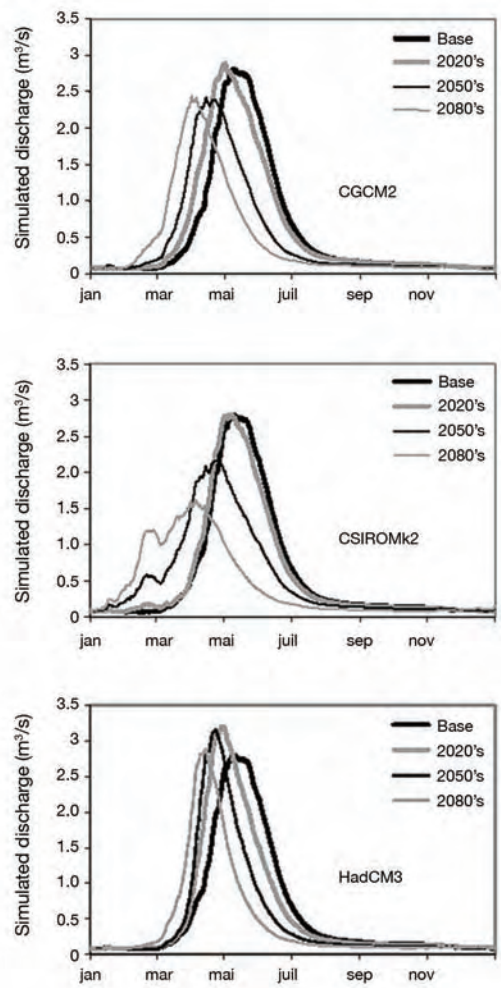

FIGURE 13: Hydrological scenarios for Whiteman Creek, British Columbia, using 3 models (CGCM2, CSIROMk2 and HadCM3) and the A2 emissions scenario (Merritt et al., 2006).

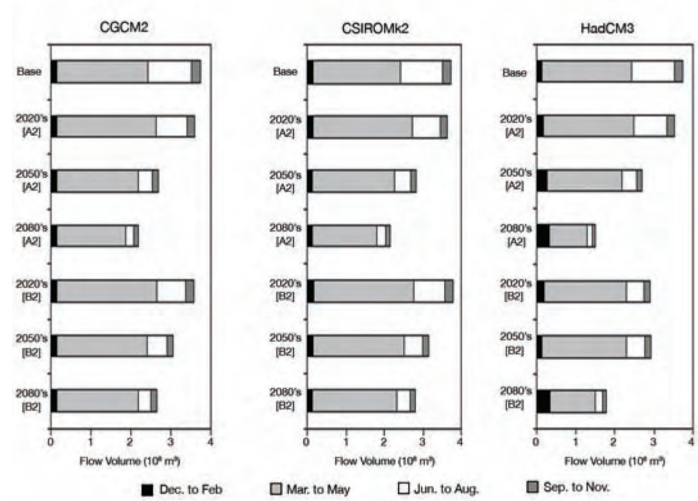

FIGURE 14: Projected hydrological responses in flow volume using three climate models and two emissions scenarios (A2 and B2) for Vaseux Creek, Okanagan watershed, British Columbia (Merritt et al., 2006).

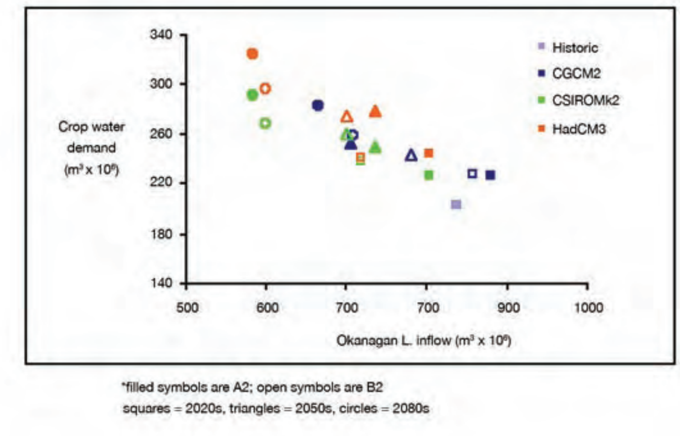

FIGURE 15: Projected changes in Okanagan Lake inflows and crop-water demand (Neilsen et al., 2004a).

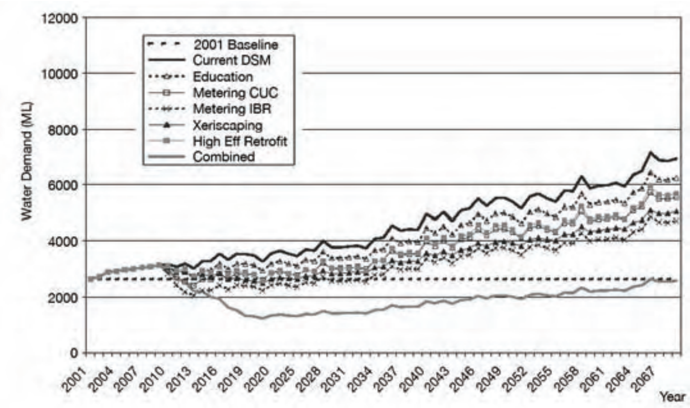

FIGURE 16: Projected changes in residential water demand, Oliver, British Columbia, due to population growth and climate change, and assumed application of demand-side adaptation measures (Neale et al, 2006).

Adaptation

The Okanagan basin has had considerable experience adapting water systems to new challenges and opportunities. Examples include the regionalization of water delivery systems in Vernon, and the installation of meters in the Southeast Kelowna Irrigation District (SEKID) and the City of Kelowna. In SEKID's case, the trigger for action was dry conditions in 1987. Decisions were made through various means, sometimes aided by provincial incentives or influenced by environmental pressures or changing costs. So far, the SEKID and Kelowna cases appear to show that the measures were effective in reducing water demand, although it is too early to assess the outcome of regionalizing Vernon's water delivery (Shepherd et al., 2006).

In terms of adapting to future climate change, there is a wide range of measures available at varying costs (Hrasko and McNeill, 2006), recognizing that other factors in addition to cost will influence decision-making (Tansey and Langsdale, 2004). For example, dialogue participants in Oliver expressed interest in expanding usage of groundwater, and agreed with the need to be more efficient water users. However, they were concerned that improvements in efficiency of water use by agriculture might lead to a loss of water rights in favour of residential uses, and lead to rapid population growth. In Westbank, part of a planning unit known as the Trepanier Landscape Unit (TLU), an area experiencing rapid population growth, dialogue participants expressed interest in increasing water supply through pumping from Okanagan Lake and in improving efficiency through leak detection and other means.

A basin-wide workshop, held in Kelowna, was a more strategic discussion. Support was expressed for basin-wide integration of land and water planning, and a governance structure to reflect this. Concern was expressed regarding a perceived lack of public awareness of regional water resource problems, and the need for expanded public education. An important outcome of this participatory approach to climate impacts and adaptation research has been the explicit inclusion of climate change in the Trepanier Landscape Unit Water Management Plan (Summit Environmental, 2004).

4.3.2 Agriculture

Crop production in the Okanagan basin is entirely dependent on irrigation, and agriculture accounts for 75% of consumptive water use. Currently, the region supports mostly perennial crops (high-value tree fruits and wine grapes, with the balance in pasture and forage) and a small acreage of annual crops (silage corn, vegetables) planted in suitable microclimates. Economic production of high-value crops requires timely availability of water, both to assure quality and to protect investment in perennial plant material. Planned water deficits are used to enhance quality attributes in some crops, including wine grapes (Dry et al., 2001), while conserving water. Consequently, potential limitations and adaptation to the availability of irrigation water under current and future climates are important considerations for agriculture in BC.

Although changes in average climate will determine, in the long run, which crop production systems are viable in a region, extreme climate events present a greater challenge to adaptation (Intergovernmental Panel on Climate Change, 2001). The major risk facing Okanagan agriculture is the occurrence and frequency of drought, and the resultant lack of water that puts irrigation-dependent agriculture at risk.

Water demand models using climate scenarios from three GCMs and two emissions scenarios all project increased demand for water in the Okanagan basin, ranging from 12 to 20% in the 2020s, 24 to 38% in the 2050s to 40 to 61% in the 2080s (Neilsen et al., 2006), reflecting increases in peak demand and in growing season length (30 to 35% longer by 2100 for all crops). Increased evapotranspiration is the most important factor in the increase in crop-water demand. In a case study of one sub-basin (Trout Creek) with predominantly agricultural water demand, the frequency with which modelled crop-water demand exceeded a dam storage threshold increased over the century in response to all climate change scenarios (Neilsen et al., 2006). Coupled with increased drought frequency associated with climate change, it is apparent that the existing water infrastructure, typical of many upland storage reservoirs in the region, will be unable to meet demand in years of extreme climate.

Producer Vulnerability

Two separate studies of the vulnerability of apple and grape producers to climate and other risks have been carried out in the Okanagan valley (Belliveau et al., 2006a, b), using methodology from Ford and Smit (2004). Producers were asked a structured series of questions to characterize good and bad years and the management strategies they used in response. All factors affecting production and returns were considered, with climate change and variability introduced only at the end of the survey.

The risks identified by apple and grape producers differed, despite co-location of the two industries. For grape growers, weather-related risks were critical (Figure 17) and confirmed by examination of long-term weather and crop production records (Table 12; Caprio and Quamme, 2002). Although apple growers also cited weather as a major concern in defining good and bad production years, market price was considered the most important determinant (Figure 17). A combination of low market prices and bad weather resulting in lower quality fruit was identified as the worst-case scenario. As with the grape growers, winter kill and cold damage, as well as high summer temperatures and damage from hail storms, are the main climate-related concerns.

Both grape and apple growers have adapted in order to minimize risk (Table 13). For both products, fruit quality is the major determinant of price; thus, considerable effort is aimed at achieving the highest quality crop. A number of practices can be used to offset weather effects, including frost protection using irrigation or wind machines, heat stress protection using irrigation for evaporative cooling, and increased disease and pest management in cool wet years. There are also non-horticultural responses to weather, such as changing the type of wine

TABLE 12: Major climatic factors defining suitability for woody perennial crops in British Columbia (after Caprio and Quamme, 2002).

Phenological stage	Plant factor	Climate effect	Apple	Cherry	Apricot/peach	Grape
Current year						
Dormancy	Winter hardiness	Detrimental	< –7°C to < –29°C from Nov. to Feb.	< –13°C to < –24°C from Nov. to Feb.	< –13°C to < –24°C from Nov. to Feb.	< –6°C to < –23°C from Nov. to Feb.
	De-acclimation	Detrimental	> 5°C in Jan.			> 9°C from Nov. to Dec.
	Root protection	Beneficial		Snowfall	Snowfall	Snowfall in Jan.
Bloom	Spring frost injury	Detrimental	< 5°C	< –2°C	< –2°C	
Pollination/pollen tube growth	Outside optimum temperature range	Detrimental	> 28°C day; < 10°C night			
		Beneficial	> 21°C day; > 11°C night	> 16°C	> 16°C	
Fruit-cell division and expansion	Outside optimum temperature range	Detrimental	> 33°C Aug.	> 33°C to > 37°C at harvest	> 31°C at harvest	> 32°C Jul. to early Aug. (veraison[1])
	Cherry cracking/ disease/reduced photosynthesis	Detrimental		Rainfall just before and during harvest		Rainfall at any time (disease)
		Beneficial	> 17°C at harvest			> 26°C entire season
Previous season						
Flower-bud initiation	Outside optimum temperature range	Detrimental	> 30°C Jun.			> 32°C
		Beneficial				> 26°C (other than mid-Jul.)
Flower-bud development	Outside optimum temperature range	Detrimental	> 26°C Aug.		> 27°C Aug.	
	Reduced photosynthesis/disease	Detrimental		Precipitation	Precipitation	
		Beneficial		>19°C from Sep. to Oct.	>26°C from Sep.to Oct.	> 26°C (other than mid-Jul.)

[1] physiological stage when grapes start to colour

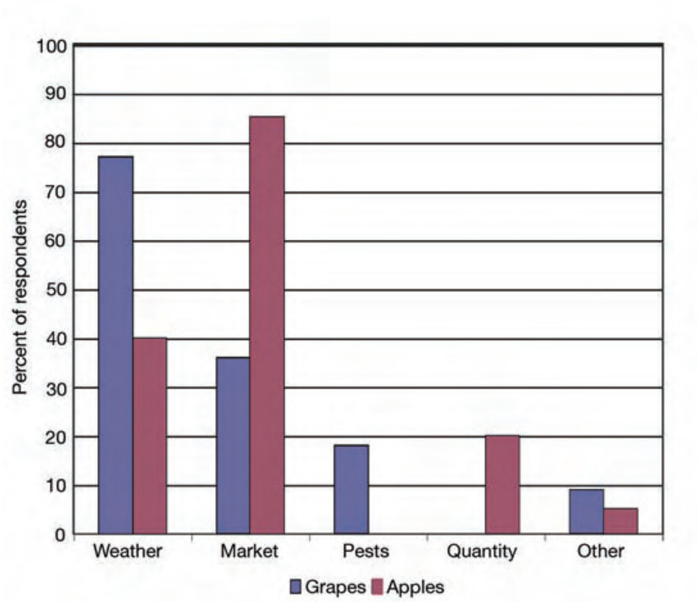

FIGURE 17: Risks that characterize bad economic years, as identified by grape and apple producers, Okanagan valley, British Columbia (Belliveau et al., 2006a, b).

produced or shipping fruit for processing, rather than fresh to market. Crop insurance is a major risk management strategy employed by 85% of apple growers and 72% of grape growers to offset losses due to weather.

Risk management strategies to handle one problem may inadvertently increase risk in another. For example, two government sponsored strategies — the grape pullout program in 1988 and the apple replant program from 1992 onwards — have inadvertently increased vulnerability to climate risk. In the case of grapes, cold-hardy hybrid varieties have been replaced by more tender varieties and, in the case of apples, dwarfing rootstocks have increased susceptibility to winter root damage and apple sunburn. Support programs, such as the Canadian Agriculture Income Stabilization program, may also undermine measures taken by producers to reduce climate risks. For example, diversification of varieties by apple growers may mean that failure in one crop is masked by success in another, thus disqualifying the farm for income assistance. Similarly, diversification of location by grape growers may prevent loss of crop in one location from being compensated for if other locations are unaffected, unless each location is covered by a separate agreement.

Average temperature increases of 1.5 to 4.0°C, projected by the 2050s for this region, may create opportunities for grape growers to grow later maturing varieties or those requiring more heat units to achieve higher quality. Apple producers may also be able to grow longer season varieties. However, risks from spring and fall frost will likely remain the same or possibly increase if advances in bloom date are not accompanied by equivalent decreases in frost risk. Excessively high temperatures in the summer, however, might decrease suitability for apple growing. Irrigated perennial crops, such as tree fruits and grapes, require large investment ($15 000–20 000/ha) in plant material and infrastructure. Varying lengths of time, depending on crop type (5–10 years), are needed to show a return on investment, and plantings may be expected to last 15 to 20 years. Although horticultural techniques exist (e.g. grafting) to change specific varieties mid-stream, such production systems are inherently less flexible than annual crop farming and therefore more vulnerable to climate change.

TABLE 13: Farm-level adaptations by Okanagan valley grape and apple producers in bad years (Belliveau et al., 2006a, b).

Stimulus	Adaptations	
	Grape producers	Apple producers
Weather		
Cold, wet season	- Remove crop and shoots, additional spraying for mildew - Make sparkling wines - Lower price of wine	
Frost	- Irrigate - Wind machines - Crop insurance - Choose an early-maturing variety	- Irrigate - Wind machines - Crop insurance
Extreme heat	Irrigate	- Irrigate - Diversify household income (spouse works off farm)
Hail		- Crop insurance - Send salvaged fruit to packing house
Fire/smoke damage	Crop insurance	
Market		
Low prices		- Tighten budget/reduce spending - Change crop varieties - Produce high-quality fruit - Income stabilization - Diversify household income
Low tourism	- Be more aggressive in other market channels Increase local sales	

4.3.3 Aquatic Ecosystems and Fisheries

During the past century, the original mosaic of terrestrial and aquatic ecosystems within the Okanagan River basin has become increasingly dominated by human activities. One-third of all plant and animal species listed as being at imminent risk of extinction in British Columbia are found in Okanagan basin ecosystems (Bezener et al., 2004). Eighty-five per cent of valley bottom wetland and riparian habitats have been lost to human activity and disruption (BC Ministry of Environment, 1998). Over the past 30 years, recreational and First Nation salmon fisheries, afforded constitutional protection, have been virtually eliminated throughout the basin (Hyatt and Rankin, 1999; Andrusak et al., 2002). Migratory species, such as sockeye (*Oncorhynchus nerka*) and steelhead (*Oncorhynchus mykiss*) salmon, are subject to both domestic and international conservation and management objectives and agreements. Long-term maintenance and restoration of aquatic ecosystems and native fish populations in the Okanagan valley represent a significant challenge with complex regional, national and international dimensions (e.g. Shepard and Argue, 2005).

Attempts to restore salmon populations in the Okanagan-Columbia basin (e.g. Wright, 2004) are part of an extensive effort to manage regional aquatic ecosystems for multiple objectives that include hydroelectric power generation, irrigation, navigation, flood control, recreation, municipal and industrial water supply, and fish and wildlife habitat (Lee, 1993). Climate change poses a significant challenge to these efforts in general, and to the conservation and restoration of depressed salmon populations in particular, because climate change affects the quantity and quality of seasonal water supplies that control habitat features (temperature, oxygen levels, flow and nutrient loading) critical to salmon. Higher water temperatures, plus changes in volume and timing of stream flow, will create conditions that are increasingly inhospitable to salmon in the Okanagan and Columbia basins (Hyatt et al., 2003; Casola et al., 2005). Such climate change impacts will exacerbate existing conflicts (Whitfield and Canon, 2000; Moorhouse, 2003) and create new ones over allocation of limited water supplies to maintain lake levels and in-stream flows for fish, versus water for other consumptive uses at regional and international scales (Pulwarty and Redmond, 1997; Payne et al., 2004).

There is a long history of dialogue and actions to satisfy competing water management objectives in the Okanagan basin (Hourston et al., 1954; Anonymous, 1974; Cohen and Kulkarni, 2001). Thus, many details of the current water management framework are specified as prescriptive elements of national (Canada–British Columbia Okanagan Basin Agreement, or OBA) or international (Canada–United States) agreements. The OBA specifically recognizes that water management decisions influence aquatic ecosystems and fish production, so provisions of the agreement focus on control of lake- and river-discharge levels that are adjusted seasonally to protect the productive capacity of salmon populations throughout the system (Anonymous, 1974). Poor compliance with lake elevation and discharge provisions of the OBA (Bull, 1999) has been attributed to the complexity of balancing fisheries, flood control and water allocation objectives (Alexander et al., 2005).

Adaptation

Climate change further complicates the difficult task of balancing competing objectives of managing water supplies for both maintenance of natural ecosystems and the engineered systems that increasingly dominate the Okanagan and Columbia basins. Although decades of experience in American portions of the Columbia River basin suggest that future increases in conflict over water management objectives may be inevitable (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, 1996), they also underscore the value of searching for viable adaptive responses to eliminate or minimize conflict whenever possible. Potential avenues include 1) developing and maintaining an informed dialogue among government agencies, industry and local communities (e.g. Tansey and Langsdale, 2004) to address competing water management objectives; 2) establishing increased levels of co-operation and integration among all groups involved in specifying and maintaining water management frameworks; and 3) developing leading-edge science and technology to provide resource managers with new tools to satisfy key information needs for complex water management decisions (Hyatt and Alexander, 2005).

4.4 METROPOLITAN REGIONS: VANCOUVER AND VICTORIA

The Greater Vancouver Regional District (GVRD) and the Victoria Capital Regional District (CRD) form the economic and political hub of British Columbia. Although adapting to climate change is typically not at the forefront of city managers' and leaders' minds, it is an emerging issue on the management and planning agendas of some departments and decision-makers. This section provides a brief summary of two key challenges that face BC's most populous districts: water supply and stormwater management.

4.4.1 Water Supply Management

Both the CRD and GVRD face the familiar challenge of managing water supplies in the face of rising population, aging infrastructure and changing climate. The Sooke Reservoir on southern Vancouver Island is the main water supply to the CRD. The region's climate is characterized by mild wet winters and warm dry summers. The area's water balance has a winter surplus of 1226 mm during times of reservoir filling and a summer deficit of 138 mm when reservoir drawdown occurs. Thus, there is a natural mismatch between water supply and water use in the region (Figure 18), as is common for many watersheds in coastal BC. Also, there is considerable inter-annual and inter-decadal variability in seasonal precipitation, with periods of water surplus and extreme water shortages being common since the early 1980s (Figure 19). The PDO significantly influences this variability and the reservoir's water budget (Figure 19).

In response to severe droughts and expected continued population growth, the CRD raised the level of the Sooke Reservoir by 6 m in 2002, increasing storage capacity by 78%

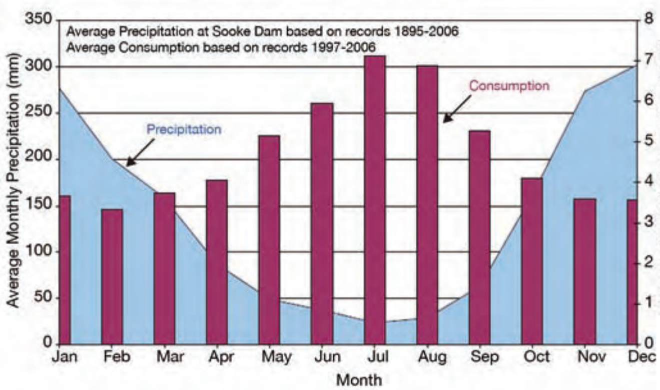

FIGURE 18: Average precipitation inputs and consumption withdrawals from the Sooke Reservoir, southern Vancouver Island, British Columbia (*from* Capital Regional District Water Services, 2007).

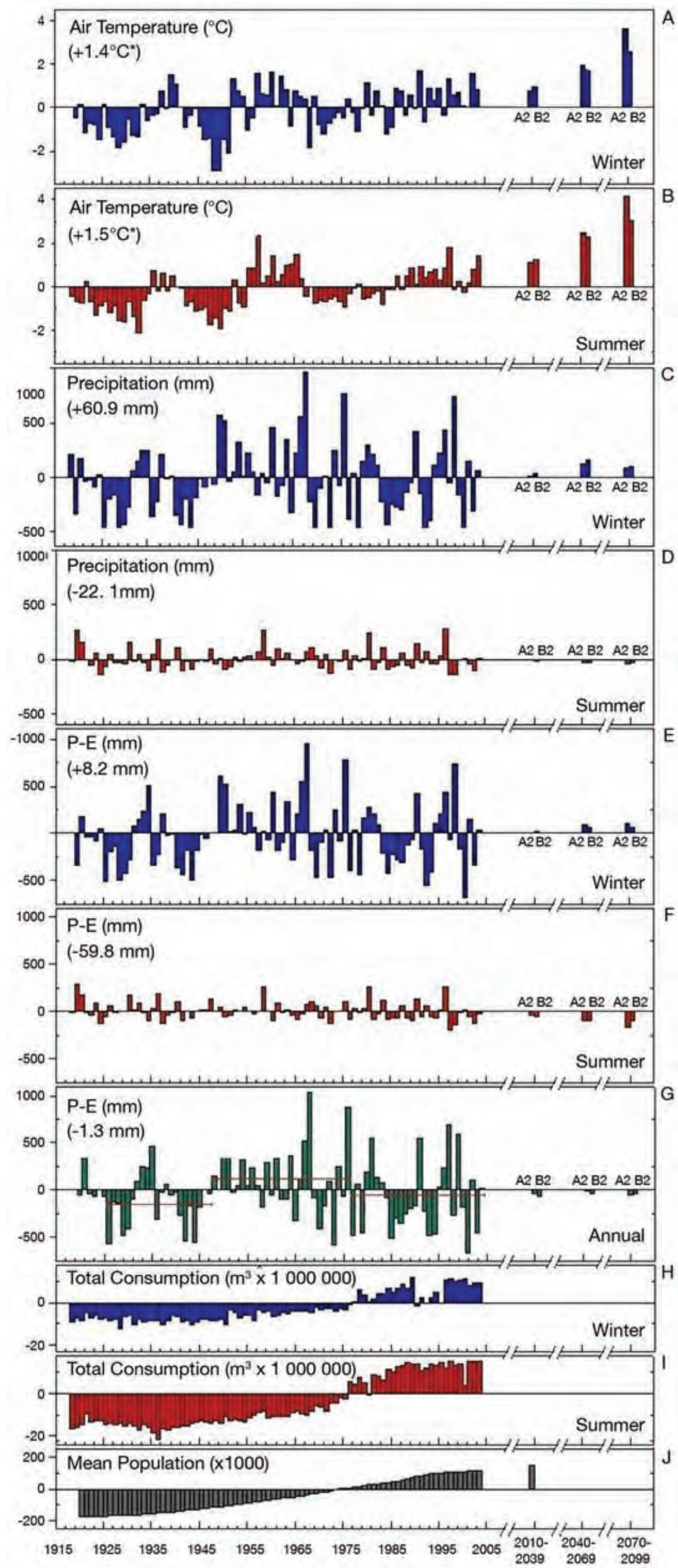

FIGURE 19: Winter (October–March) and summer (April–September) departures of Sooke Reservoir water supply variables relative to 1961–1990 mean values (linear trends over the 87-year period provided in brackets; * signifies trends significant at the 0.05 level). Temperature, precipitation and consumption data provided by the Capital Regional District. Note that 1966–1994 temperature and 1971–1977 consumption values are estimates. Evaporation was estimated using day length and air temperature (per Hamon, 1963). Future temperature, precipitation and precipitation-evaporation values for 30-year periods centred on the 2020s, 2050s, and 2080s are also shown. Projections are based on ensemble averages for the A2 and B2 emissions scenarios using the seven global climate models recommended by the Intergovernmental Panel on Climate Change (2001).

(Capital Regional District Water Services, 2004). Based on historical climate conditions and a maximum growth rate of approximately 1%, the expanded reservoir capacity will only meet projected demands until 2023 (Capital Regional District Water Services, 2004). The CRD has implemented several conservation and demand-management initiatives, including residential water metering, multi-stage lawn watering restrictions and rebates for high-efficiency equipment (toilets, washing machines), to offset the demand increase.

The GVRD's water supply comes from the Capilano, Seymour and Coquitlam watersheds, located in the Coast Mountains along the northern fringe of the city. These watersheds have a much wetter and colder climate than Sooke, with significant runoff occurring in spring and fall, and snow accumulation during winter. There is large storage capacity during the summer in six mountain reservoirs. Current constraints on GVRD water supply are associated with the ability of system infrastructure, specifically pipelines, water intakes and water treatment facilities, to meet rising demand from an increasing population.

In future, climate change will result in a decreased snow pack as a greater proportion of annual precipitation falls as rain. In conjunction with longer drier summers, infrastructure will be further stressed, especially during periods of peak seasonal demand. Climate change will likely advance the time when upgrades and capital investments are required for additional storage capacity. Demand management and water conservation programs are important first steps and should help delay the timing of capacity upgrades. The GVRD's Drinking Water Management Plan (DWMP) does include provisions for ongoing assessment and monitoring, including biennial progress reports that consider the potential impacts of climate change on supply and the implications for capacity upgrade planning (Greater Vancouver Regional District, 2005a, b).

Both of BC's principal metropolitan areas have already taken steps to anticipate some impact of climate change on water supplies. These impacts will increase the pressure of rising populations and demand, and effectively bring forward the date when current supplies will be insufficient. Ongoing conservation and demand management represent key adaptation strategies, even if they are not explicitly implemented as such. Longer term adaptation actions are likely to involve further infrastructure upgrades and increased storage capacity.

4.4.2 Stormwater Management

Since 2000, the Greater Vancouver Regional District (GVRD) has been examining the potential risks from climate change on sewer and drainage infrastructure. Trend analysis of more than 40 years of rainfall data indicated an increase in the frequency of extreme rainfall events, such that the recurrence interval of 25 years for an extreme event (4% probability in any given year) had decreased to about 10 years (10% probability; Jakob et al., 2003). Research concluded that observed increases in the frequency of intense rainfall could be correlated with the 1976 phase shift of the PDO. As the present methodology used to generate the rainfall intensity-duration curves for sewer design and stormwater management does not explicitly take into account climate oscillations, it remains possible that rainfall intensity-duration curves could be over- or underestimated, depending on when the majority of rainfall data were collected.

Jakob et al. (2003) also noted that statistically measurable increases in the non-extreme rainfall intensity and volume were evident, and they interpreted these to relate to larger scale climate change. Such increases, although not impacting sewer design, are anticipated to negatively impact the health of urban streams and their populations of salmon and trout. These impacts are similar to those from urbanization and the associated construction of hard surfaces (roofs, roadways, etc). The Water Balance Model for Canada, and the GVRD's design guidelines for stormwater source controls (Lanarc Consultants, 2005) were developed as tools for GVRD municipalities to address the effects of urbanization and climate change on urban streams (Hicks and von Euw, 2004). These represent a first step in the explicit recognition and inclusion of observed and future climate change impacts on urban infrastructure in BC. A pracitioner's perspective on this issue and the role of risk management approaches are presented in Box 3.

BOX 3

Climate change and risk management: a practitioner's perspective

(Robert Hicks, P.Eng., Member, British Columbia Water and Waste Association, Water Sustainability Committee)

Fundamental to local governments is the provision of basic services to their communities. Core services include potable water supplies, streets and roads, and land-use planning, while more comprehensive services include libraries, public housing, and parks and recreation. Municipalities and regional districts form the basis for local governments in British Columbia. 'Improvement districts' effectively form another level of local governance that provides limited function-specific services, such as rural water distribution, flood protection and dyking.

Significant obstacles to climate change adaptation arise from the competition for funding between short-term priorities and long-term risk management. For any community experiencing pressures on a limited tax base or facing significant core infrastructure costs, it is questionable whether there would be the financial means or will to address climate change impacts as a priority. The weighing of priorities is further complicated by difficulties in quantifying the long-term benefits of climate change adaptation programs and/or by the lack of understanding of climate change issues.

Risk Management

Although local governments face challenges in addressing climate change adaptation as a stand-alone issue, they are experienced risk managers, particularly with respect to the provision of their utility services and maintaining their capital assets (roads, bridges, buildings, pipelines). The life cycles of roads, sewer and water systems, and community buildings range from 20 years to a century or more. Such assets are managed with respect to risk of service interruption, level of performance, control of operating costs, and planning and budgeting for replacement and renewal. It is through this context that local governments are well situated to address impacts from climate change as an additional risk related to their provision of municipal services.

Addressing climate change risks related to land use and zoning is more challenging for local governments. It is possible that some proactive adaptation responses might exceed municipal mandates and be difficult to implement. Without compelling justification, local governments are unlikely to implement programs and zoning changes that would adversely affect the value or utility of private lands.

Climate change impact awareness and skills are needed for climate change adaptation to be effectively integrated into day-to-day local government planning and risk management processes. The use of return periods — commonly used to describe technical design thresholds and performance targets for stormwater, drainage, sewers and water supply systems — create a false sense of understanding, as they are based upon past events. Return periods are common in regulations and in 'standard engineering practice'. However, using return periods without considering their response to climate variability and climate change is like 'driving a car through the rear-view mirror, it only works if the path is linear'. Consequently, the use of return periods could result in poor long-term decision-making and prevent proactive adaptation if not put into the context of climate change.

5 CONCLUSIONS

5.1 KEY MESSAGES AND THEMES

Climate change impacts and the costs of extreme events are increasingly evident but responses and adaptation measures remain reactive.

Although well-known ocean-atmospheric cycles, such as ENSO and PDO, are the drivers of short- and long-term climate cycles and weather extremes in British Columbia, there is strong evidence linking global climate change to increasing climate variability and extreme events (Sections 2.1 and 2.3). During the past century, the province warmed significantly across all seasons, and projections of future climate change suggest continued warming for all seasons, wetter conditions for much of BC in winter and spring, but drier conditions during summer in the south and on the coast (Section 2.2).

Changes in the amount and type of precipitation, mainly more rain and less snow, are already evident in BC. Persistent droughts are common during summer months. Prehistoric climate records show that severe droughts occurred more frequently in previous centuries than during the past few decades (Section 2.1), suggesting that BC can expect more severe droughts in the future, irrespective of climate change.

Most of BC's alpine glaciers are retreating rapidly and many may disappear in the next 100 years (*see* Box 1). Coupled with reduced snowpack and warmer spring temperatures, this will result in earlier spring freshets, warmer river temperatures, declining summer river flows and increasing peak flows for many of BC's watersheds (Section 2.4). Impacts on current and future water supplies, hydroelectric power generation, fisheries and river ecosystem integrity are significant concerns for BC. These changes will pose numerous challenges for water managers and other users, and increase the likelihood of inter-sectoral and transborder water conflicts (Section 3.1).

Geological effects will offset or exacerbate global trends in sea-level rise on the BC coast. Superimposed on sea-level rise is increasing extreme water levels driven by climatic variability events. Accelerated coastal erosion and flooding are expected to pose ongoing and increasing hazards for BC's coastal communities and infrastructure (Sections 2.5 and 4.1).

The frequency of, and costs associated with, most types of extreme weather events and related natural hazards (e.g. coastal storms and surges, forest fires, droughts, landslides) are increasing (Section 2.3). Most climate-related adaptations in BC are reactive responses to such 'surprises' as the unprecedented mountain pine beetle outbreak or the extreme forest fires of 2003. Examples of adaptation planned specifically for climate change are scarce. In some respects, this relates to a limited perception of climate change as a risk to the livelihoods, activities and economies that support British Columbia; in other cases, it is a matter of other priorities competing for limited capacity. As climate change is only one of many stressors that affect the province's industries, communities and ecosystems, a 'cumulative impact' perspective may be most appropriate for adaptation planning. There are several examples of recent studies and risk assessments involving researchers, community groups and decision-makers in BC (*see* Section 4) that represent an important first step towards a more comprehensive approach to planned adaptation. Awareness of the current and potential impacts of climate change and understanding of the need to address adaptation as well as mitigation is growing in communities around the province.

Management of increasingly frequent and severe water shortages will entail complex trade-offs and require improved consideration of climate change.

Retreating glaciers, declining snowpack, increasing drought, and shifts in timing and amount of precipitation will increasingly limit water supply during peak demand periods for hydroelectric power generation, agriculture and drinking water, although this may be partially offset in some regions by increased precipitation. Approximately 78% of British Columbia's population depends on surface-water supplies for drinking, while 89% of the province's electricity comes from water (Sections 3.1 and 3.7). Declining water supplies raise numerous management challenges, particularly in such areas of rapid growth as the Greater Vancouver Regional District (GVRD), the Capital Region District (CRD; i.e. Victoria and surrounding municipalities), the Okanagan region and even certain small communities such as Tofino. Increasing conflict between supply and demand will necessitate trade-offs between alternative uses and values (e.g. maintaining stream levels for fisheries habitat versus irrigation needs for agriculture).

Since the 1980s, BC's major urban centres have experienced several extreme summer droughts and water resource limitations. Drinking water supplies may become stressed in the CRD and the GVRD. Increasing future supplies will require significant infrastructure upgrades and demand management strategies (Section 4.4.1). This is also a concern for smaller rapidly developing areas (e.g. Tofino-Ucluelet). The CRD recently completed a substantial upgrade to increase storage capacity of its main water source, the Sooke Reservoir. To avoid the need for major new infrastructure investment, the CRD aims to implement aggressive demand management measures to meet demand over the next 50 years. The GVRD is also aware of potential challenges presented by increasing demand and climate change impacts, and is planning for increased storage capacity and enhanced demand management.

British Columbia's hydroelectric power generation capacity is currently vulnerable to declining water supply and changing river flow patterns, most notably in the Columbia River basin, where more than half of the province's hydroelectricity originates. By 2025, electricity demand in BC is expected to be 30 to 60% higher than in 2005. Targets set by the recently released BC Energy Plan include aims to meet 50% of incremental growth through conservation and efficiency measures, and to generate at least half of all new power from renewable sources, such as wind, geothermal, biomass and hydro. The connection between climate change and water will be an increasingly important consideration in planning to meet many of the key energy production and mitigation strategies outlined in the plan.

Current institutional and planning structures, for the most part, do not consider existing climate variability or future projections of climate change in the management of water resources. Climate change considerations could be effectively integrated with land-use, community planning or resource management processes.

British Columbia's critical infrastructure faces immediate challenges and long-term threats from climate variability and change.

Extreme weather and associated natural hazards currently present challenges to British Columbia's critical infrastructure, and these impacts are projected to increase as a result of continued climate change. In many places, critical infrastructure, including pipelines, power and telecommunication transmission lines, and transportation networks, are geographically confined to narrow valleys and coastal stretches, and therefore vulnerable to disruption from natural hazards, such as landslides, coastal storms and surges, flooding and forest fires. Research on the impacts of climate change on BC's critical infrastructure systems remains limited, while insurance and costs for emergency response and recovery are rising (Section 3.8).

Central and northern communities, such as Prince George, report increases in road maintenance and flood management costs directly or indirectly related to changing climate conditions. Climate change impacts are now being considered in the GVRD's Integrated Stormwater Management Plans (Section 4.4.2).

Life-cycle cost analysis, return period statistics for extreme events and engineering standards all influence management decisions on how or when to maintain or replace infrastructure. Updating these analyses, statistics and design standards so that they consider climate change impacts and trends will enable managers to better plan for future changes. Institutional constraints remain, however, as many standards and policies that guide infrastructure decisions rely only on past climate statistics.

British Columbia's forests, forest industry and forestry-dependent communities are vulnerable to increasing climate-related risks.

Forestry remains a cornerstone of the BC economy. British Columbia's forest resources are vulnerable to a host of impacts related to changing climate conditions, including fires, pests, disease and ecosystem shifts. Conditions conducive to forest fires are expected to increase (Sections 2.3 and 3.3) and will lead to an increase in associated health risks (Section 3.9) and post-wildfire flood and landslide hazards (Section 3.3).

The current mountain pine beetle (MPB) outbreak affects almost 10% of BC's land base. At 9.2 million ha in 2006, this outbreak is unprecedented in its extent and longevity (Section 4.2). Past forest fire suppression and management, drought conditions in the 1990s and warmer winter temperatures have provided favourable conditions for the current outbreak. The infestation is advancing into northeastern BC, and projections of future climatic suitability for MPB suggest that continued eastward expansion into the boreal forest is highly likely.

Communities are responding quickly to the MPB infestation. Vanderhoof, in north-central BC, is exploring adaptation options to manage future opportunities as they transition from a pre- to a post-beetle economy (Section 4.2.1). Prince George is surrounded by MPB-devastated forests and, like other communities in the interior, is experiencing increased economic activity from expanded salvage logging operations. This short-term economic gain from beetle-killed trees will have long-term ecological, hydrological and economic implications. City planners in Prince George are concerned about the increased flooding potential of the Nechako and Fraser rivers as trees are removed from surrounding watersheds. Many forest-based communities will face substantial economic challenges once the current round of logging has cleared beetle-killed trees, as it will take almost a generation for resource stocks to replenish.

The long growth period before trees are ready for harvest means that much of the resource that will support the forest industry and communities for the next few decades is already in the ground. Forest management options are limited if site productivity is affected and existing species turn out to be poorly suited to changing conditions. Similarly, the industry has invested in large equipment and processing facilities that are difficult and expensive to adapt. These long investment periods increase the risk and uncertainty for both the industry and dependent communities to the impacts of climate change and to challenges such as international market competition.

The BC Ministry of Forests and Range has developed a 'Future Forests Ecosystem Initiative' that incorporates climate change adaptation into forest management (Section 4.2.2). This initiative is an early step toward long-term forest planning that includes climate change in conjunction with other pressures, including international competition, forest health, increases in forest fire regimes, and changing social and economic conditions.

Existing stresses on British Columbia's fisheries will be exacerbated by climate change.

The social, cultural and ecological importance of fisheries in British Columbia far exceeds their relatively small economic contribution to the provincial GDP. Fisheries are especially important to coastal communities and First Nations, they attract thousands for sport-fishing tourism, and they are key indicators of water quality and ecosystem health. Most capture fisheries are either stable or declining, whereas aquaculture continues to grow steadily (Section 3.2).

Salmon far outweigh other species in terms of social, economic and cultural importance in BC. Coastal salmon fisheries are already under stress from a combination of factors, including habitat loss in spawning watersheds and overfishing. Climate change will cause further stress as water temperatures rise and through indirect effects on other sectors, such as the influence of MPB-related tree mortality on hydrology. Northward migrations of exotic fish species from warmer southern waters already threaten young salmon during warm El Niño events. Continued ocean warming as a result of climate change will pose a longer term and more severe threat to salmon and other coastal fisheries.

Inland fish populations, including migratory salmon, are sensitive to increasing water temperatures and to changes in river and lake levels. Climate change impacts on water resources are a major concern for inland fisheries (Section 4.3.3). Constitutional guarantees of access to fisheries for First Nations' use give fisheries some priority. Management conflicts between in-stream water needs for fish, hydroelectric power generation, irrigation, and domestic consumption are likely to increase with continuing climate change and future treaty negotiations.

Adaptation to climate change in the fisheries sector involves primarily management responses that protect or enhance stocks. Potential adaptation measures include reducing harvest rates, reinforcing habitat protection and restoration, increasing hatchery production of salmon, licensing and regulating river systems, promoting accelerated development of aquaculture and/or diversifying fisheries to take advantage of short- and long-lived species and exotics as traditional single-species fisheries decline.

British Columbia's agricultural sector will see increasing threats and some opportunities from climate change.

Similar to fisheries, agriculture makes only a modest contribution to British Columbia's economy, but indirect benefits and employment are substantial. Agriculture, particularly the wine industry and orchards, is a lucrative component of tourism in areas such as the Okanagan valley. Farming and ranching are also important in many rural regions. Suitable lands for farming in BC are limited to approximately 4.5% of the land base (approx. 4.7 million ha), and much of this is protected by BC's agricultural land reserve (ALR; Section 3.4). The greatest threat to agriculture from climate change in BC is the impact on water resources. This results not only from increasing water scarcity and extended drought, but also from heightened competition with other uses. Increases in extreme weather, associated natural hazards, and outbreaks of pests and disease are also of concern.

Climate change also presents potential opportunities for agriculture in BC as a result of longer growing seasons and milder winters, which could increase the range and/or number of economically viable crops that can be grown (Section 3.4). Constraints on this potential opportunity include limited soil suitability, water supply, irrigation infrastructure and transportation distance to markets. Isolated valleys of quality agricultural land (e.g. Bella Coola valley) may be the greatest beneficiaries. Introduction of new and potentially more lucrative crops into existing agricultural regions has also been considered, although these perceived opportunities will face development and water availability challenges similar to those that currently face existing crops, with added risks as a result of climate change.

Farmers' experience in dealing with climate variability and extreme weather events, disease and crop failures, and market fluctuations results in considerable capacity to adapt to climate change. Strategies include both long- and short-term approaches, such as diversification of crops where possible and alternate processing techniques. Support programs designed to help farmers manage market-related risks and occasional crop failures are a good hedge against crop losses caused by climate variability and extreme events, but may also serve as disincentives for adaptation to longer term climate change.

Integrating climate change adaptation into decision-making is an opportunity to reduce long-term costs and impacts on British Columbia's communities and economy.

Enhancing adaptive capacity and implementing adaptation measures to climate change does not require managing or planning resources and infrastructure in a whole new way. Rather, opportunities to improve the effectiveness and reduce the costs of adapting to climate change impacts exist through integration of climate change information into existing planning, management and decision-making processes. Existing datasets, simulation models and scenarios, and seasonal climate forecasts that incorporate climate change and related impacts can inform ongoing management and planning decisions (Sections 2.1 and 2.2).

Currently, climate change is being considered indirectly in a variety of settings to inform or guide decision-making. Experience in the Okanagan illustrates the importance of translating climate change scenarios and impacts into terms and language relevant for local planning and management (Section 4.3.1). In Vanderhoof, a community pilot project is underway to develop and test methods for assessing the vulnerabilities and adaptive capacity to forest changes using simulation models, surveys and interviews within the community (Section 4.2.1). Similarly, researchers are working with councillors, planners and engineers in the Corporation of Delta to understand impacts and vulnerabilities to storm surges and sea-level rise (Section 4.1.2). This type of community-based research is seen as an important first step to integrating climate change into local and regional planning.

British Columbia's most populated regional districts are pursuing sustainable development and climate change mitigation initiatives, some of which include adaptive benefits. Among these are water and energy conservation measures that include design features, materials, equipment and/or processes that use or recycle energy and water within the building plant. Such practices reduce greenhouse gas emissions from building operations (mitigation) and place less demand on city infrastructure and resources (adaptation).

Vulnerabilities and adaptive capacity vary widely across regions, scales and economic sectors in British Columbia.

There are significant differences between rural and urban British Columbia with respect to climate change vulnerabilities and adaptive capacity. These are largely a function of economic dependence. Reliance on natural resources is most pronounced in remote rural and coastal communities, whereas urban areas have more diversified economies.

Vancouver and, to a lesser extent, Victoria have increasingly diversified economies based on information, technology, tourism and related service sector activity, in conjunction with transportation, finance, port and government functions. Their dependence on BC's resource economy is indirect and, while still significant, is largely surpassed by post-industrial economic drivers. In contrast, rural BC remains intimately dependent on natural resources, particularly forestry and fisheries. The sustainability of rural communities will depend, to a large degree, on how they are able to cope with changes to their resource base(s). This involves planning to manage both risks and opportunities. There is some evidence of communities adapting to the new global economy in ways that bypass dependence on metropolitan centres, suggesting increasing capacity to deal with change in general, and increased ability to manage resource dependence in particular (Section 1.4).

In remote coastal communities, resilience and adaptive capacity emerge from a variety of sources, including 1) the strength of local and regional institutions; 2) patterns of local social and economic development; 3) the nature and condition of critical infrastructure; and 4) level of experience with extreme weather and exposure to other forms of environmental and/or socioeconomic change. In addition, income diversification, self-reliance, volunteerism and strong social networks and cohesion are all important factors that contribute to a remote community's capacity to adapt to broader issues such as climate change (Section 4.1.1).

Social, cultural and economic factors may limit capacity to undertake climate change adaptation at the community level. Many coastal and rural BC communities are currently experiencing significant social and economic hardship due to multiple stressors. Resilience based on social capital and strong social cohesion enable some communities to cope with these stresses, even where other attributes of adaptive capacity are limited (e.g. access to physical and financial capital, technology, expertise and other resources). The key challenge for enhancing adaptive capacity in such locations is to build on initiatives that currently address economic and environmental changes, by including consideration of the impacts of climate change.

5.2 BUILDING ADAPTIVE CAPACITY

Steps to enhance adaptive capacity must be locally relevant, oftentimes building on existing strengths, programs and community attributes. Building adaptive capacity requires effective communication between communities, other orders of government and researchers. This involves both the two-way transfer of knowledge and the development of tools and other resources to assist regional and local decision-making. The concept and goals of building adaptive capacity need to be conveyed, as does the appropriate information to support improved resource, community and ecosystem planning. In some cases, more information is needed; in others, it is the access to, and communication of, the information that needs to be improved. For example, more research on impacts and adaptation in economic sectors, especially with respect to extreme events, would be useful, as would improved monitoring of key climate elements and environmental variables (e.g. glaciers, groundwater, stream gauging, coastal water levels and erosion/sedimentation, oceanography, floodplain hazard mapping, wildfires and pest spread).

The development of methods and tools by which this information can be disseminated and used is as important as expanding the existing knowledge base. The crucial link is to make the information accessible, by delivering it in a context and language that resonate with the issues and concerns of planners and engineers, resource managers and industry, and leaders of local governments and First Nations. In other words, those most directly responsible for implementing the adaptation.

Finally, it is important to further explore and understand the social and cultural underpinnings of local governance, in particular the makeup and function of local institutions, such as municipal governments, regional districts and First Nations councils, planning and health authorities, engineering departments and resource management bodies. Local and regional interests, and the institutions and organizations that support them, provide the context into which adaptation policies and plans will be introduced and implemented. Understanding how local institutions are set up and how they 'work' within the local and regional environment is a crucial element that will influence the uptake of new information and knowledge, and ultimately determine the success or failure of proactive adaptation.

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CHAPTER 9
Canada in an International Context

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Recommended Citation:

Bruce, J.P. and Haites, E. (2008): Canada in an International Context; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 387-424.

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INTERNATIONAL CONTEXT

CONTENTS

KEY FINDINGS

Climate change is already affecting the residents, economies and environments of all regions of the world through higher temperatures, sea-level rise, more frequent heavy precipitation events, more intense storms, more severe droughts, melting glaciers, changes to river flows, more evaporation, permafrost degradation, less sea and lake ice, and more heat waves. These impacts, mostly adverse, are expected to continue and intensify in the future.

The impacts of climate change and the adaptation measures that other countries take to respond to them can affect Canada in a number of ways. The effects on Canada arise from impacts that occur elsewhere in North America, the surrounding oceans or globally.

NORTH AMERICAN ISSUES

- An increase in health problems and mortality is associated with ozone precursors and small-particle emissions, with extensive transborder effects. Although longer and more intense heat waves are likely to result in the intensification of smog episodes, further reductions of these emissions in both the United States and Canada would help reduce health risks.
- Declining flows in many southern Canadian rivers are resulting in increased problems over sharing and quality of water along the Canada–United States border, including the Great Lakes.
- Growing air conditioning loads, and probable reduced hydroelectric supply in the United States and some regions of Canada, are changing transborder transfers of electrical energy.
- With increasing drought projected for the southwestern United States and Mexico, growing demands for export of Canadian water can be anticipated.

OCEAN AND COASTAL ZONE ISSUES

- Warming of the Arctic will result in reduced sea ice and increased marine traffic and development activity in Canadian Arctic waters, likely increasing the resources needed for continued protection of Canada's safety, security, and environmental and Inuit interests in the Arctic.
- Rising sea levels, increased storminess and reduced ice cover regimes increase shoreline erosion and require adjustments to road locations, port facilities, navigation systems, vessels and search-and-rescue capability on the Atlantic, Pacific and Arctic coasts.
- Impacts on fish distributions and foreign fishing patterns are poorly understood but potentially of major significance to Canadian fishing communities, thereby representing a key knowledge gap.

GLOBAL ISSUES

Health

- Diseases currently prevalent in warmer climates will become increasingly greater threats in Canada as a result of greater incidence of disease and vectors in countries that are involved in trade and travel with Canada.
- Increased transmission of persistent toxics and pollutants to northern Canada will occur as more chemicals are volatilized from warming lakes in Eurasia and North America, thereby affecting the health of northern residents and ecosystems.
- Increased international assistance to developing countries will be needed for safe water supplies and food handling, in order to reduce deaths and illness due to diarrhea and other diseases.

Population Movement

- Many people will be forced to relocate internally within countries and internationally due to sea-level rise and growing water and food shortages in many countries, with implications for Canadian policies and activities related to aid, peace-keeping and immigration.

Increased Disasters

- Weather-related disasters, including drought, are projected to continue to increase in frequency and severity worldwide, resulting in increasing need for disaster relief and assistance from Canada, and losses for those Canadians with business and property abroad.

Canadian Tourism

- In the longer term, prospects are for greater warm-season tourism in Canada. Significant adaptation by winter tourism facilities will be needed for them to remain viable.
- Less travel by Canadians to warm destinations is projected because of longer warm seasons at home.

Canadian Trade

- Increased global forest productivity could contribute to lower prices for Canadian wood products if fire and insect infestation effects abroad are minimized.
- Canadian exports of grains and corn could find greater markets, and imports of fruits and vegetables could be reduced.

Canada is in a position to — and has an obligation to — assist developing countries to adapt to climate change. Canada, together with other developed countries, has committed to reduce greenhouse gas emissions, assist developing countries with adaptation to the adverse impacts of climate change, and assist transfer of environmentally sound technology and know-how. Canada's participation in international programs in natural and social sciences related to climate change contributes to international understanding and to Canadian science assessments. The knowledge gained by Canadian experts through this participation also benefits the development of domestic policies and programs.

Understanding these international issues contributes to development of Canada's foreign policy, stimulates and protects international trade, and protects Canadian resources, environment and health. The potentially significant effects and requirements need to be taken into account by all orders of government and by many businesses. Little research has been undertaken on these issues from a Canadian perspective, although studies elsewhere, including those cited here, have important implications for Canada.

1 INTRODUCTION

1.1 PURPOSE OF CHAPTER

Climate is changing the world's economy and environment. In a world of increasing interactions between citizens and companies of different countries through travel and trade, and with migration of species and transborder threats to ecosystems, the impacts of climate change are not confined by national borders. Key issues for Canada include changes in trade, immigration and tourism patterns; transborder effects on water, health and air pollution; increasing stresses over resources; and the need for international responses to more frequent and larger disasters. In a number of cases, stresses brought about by 'economic globalization' will be exacerbated by climate change.

Northern circumpolar countries are already experiencing major climate change effects, and adaptation by one nation can have consequences for others. In all three oceans bordering Canada, changes in currents and distribution of fish, more severe winter storms, and rising water temperatures and levels will trigger actions by other countries that could have significant effects in Canada.

In short, climate change impacts and adaptation in other countries may have profound effects on Canada. This chapter is an initial attempt to identify some key issues for Canada from an international perspective and discuss possible responses.

1.2 INTERNATIONAL CLIMATE CHANGE TRENDS AND PROJECTIONS

What climate changes have other countries experienced in recent decades, and what are the likely changes over the next four or five decades? Much of the information here is drawn from the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) and from scientific publications since 2000.

Temperature

Global mean temperature has increased about 0.74°C during the past century, with the rate of temperature rise being much greater after 1979 (Intergovernmental Panel on Climate Change, 2007a). Large departures from this average have been experienced in various regions, as illustrated in Figure 1. By 2050, the range of expected warming (1.3–1.7°C relative to 1980–1999) shows limited sensitivity to the choice of emission scenarios

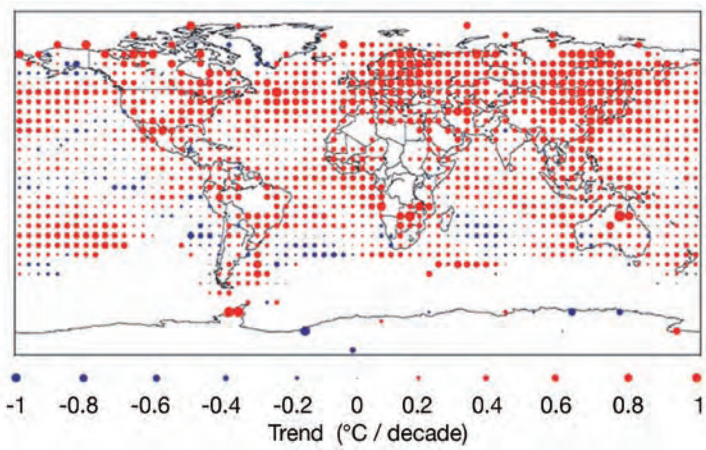

FIGURE 1: Annual temperature trends (°C/decade), 1976–2000. Red indicates warming trend, blue indicates cooling trend, and the size of circles is proportional to the magnitude of change (Folland et al., 2001).

(Intergovernmental Panel on Climate Change, 2007a). Again, large regional departures from these mean temperature values are expected. Evaporation rates will generally increase as air and especially water temperatures rise.

Precipitation

Globally averaged precipitation since the 1960s has remained largely unchanged (Gruber and Levizzani, 2006), although other estimates suggest an average increase of about 2% over land areas (Folland et al., 2001). Increases and decreases in annual precipitation for the past 3 to 4 decades are regionally variable (Groisman et al., 2005). Regions of declining rainfall include much of the Mediterranean basin and northern Sahara, southern Africa and Argentina, parts of the Middle East, northern Mexico and the southwestern United States. Global climate model projections of precipitation changes during the next few decades are somewhat inconsistent, although they suggest a continuation of the patterns observed since 1970. In many locations, it may be most useful to simply extrapolate the trends of the past few decades. In most regions, observed changes in heavy and very heavy precipitation are more significant than changes in mean precipitation (Groisman et al., 2005). The global distribution of trends in heavy precipitation is shown in Figure 2. Climate models project a continued increase in the intensity of rainfall events that have been observed in many parts of the world (e.g. Alexander et al., 2006).

FIGURE 2: Regions of disproportionate changes in heavy and very heavy precipitation. Thresholds used to define heavy and very heavy precipitation vary by season and region (*modified from* Groisman et al., 2005).

Sea-Level Rise and Oceans

Global mean sea level has increased about 18 cm during the past century, and at an accelerating rate of 3 mm/a since 1992. The further rise projected by the Intergovernmental Panel on Climate Change (2007a) for the years 2090–2099 relative to 1980–1999 ranges from 18 to 59 cm. However, these results do not include the full effect of potential changes in ice-sheet flow or breakup in Greenland and Antarctica (Intergovernmental Panel on Climate Change, 2007a). From 2001 to 2004, glacier melt contributed about 1 mm/a to sea-level rise and accounted for 20 to 30% of the total rise from 1991 to 2004 (Kaser et al., 2006). Many low-lying coastal plains and small island states are vulnerable to the rising seas, especially in storm conditions.

Globally averaged sea-surface temperatures have risen 0.4°C since 1970 and 0.6°C during the past century (Rayner et al., 2003; Pierce et al., 2006). The anthropogenic (greenhouse gas) warming signal is clearly evident in all ocean basins: Indian, Pacific, Atlantic and Arctic (Pierce et al., 2006). This has also contributed to sea-level rise through thermal expansion. Increased acidity of ocean surface layers, due to more CO_2 absorption, has also been detected and is projected to cause further reductions in pH of between 0.14 and 0.35 units by 2100 (Intergovernmental Panel on Climate Change, 2007a).

Extreme Events

Severe winter storms in the Northern Hemisphere have increased in intensity in some regions (McCabe et al., 2001), a trend that is projected to continue (Lambert, 1996; Lambert and Fyfe, 2006). This increase, combined with higher sea level, will lead to greater storm surges, shore erosion and flooding effects in many coastal areas.

The average annual number of tropical cyclones (hurricanes) has not changed, but intensities are increasing, with a greater proportion of category 4 and 5 storms observed since 1970 (Emmanuel, 2005; Webster et al., 2005). Models suggest that intensification is related to sea-surface temperatures and will continue in the future (Knutson and Tuleya, 2004).

Changes in other extreme events have been assessed by the Intergovernmental Panel on Climate Change (2001a, 2007a), and include increased frequency of high-intensity rainfall in many areas, more frequent and intense droughts in midcontinental and low-latitude regions, and an increase in areas subject to drought (Intergovernmental Panel on Climate Change, 2007a)

Other Trends and Impacts

- **Permafrost** is thawing in North America, Europe and Asia, a trend that will continue or accelerate, with resulting impacts on hydrology, wildlife and the built-environment (Intergovernmental Panel on Climate Change, 2001b; Arctic Climate Impact Assessment, 2004).
- **Snow cover** in the Northern Hemisphere at the time of spring melt (March–April) continues to decline, with more melting generally occurring during the winter months (Mote et al., 2005). Less flow in the summer and autumn dry seasons is affecting, and will continue to affect, water availability for irrigation and other uses.
- **Very dry areas** have increased globally in extent, from 12 to 30% of total landmass since 1970 (Dai et al., 2004). The Palmer Drought Severity Index (Figure 3) has shown widespread drying trends over large regions, including much of Africa. Increasing drought also characterizes many important food-producing regions, including the Great Plains of North America.
- **Wave heights** have increased by up to 1 cm/decade (1950–2002) in much of the North Pacific and North Atlantic, in the Mediterranean and along the east coast of South America (Gulev and Grigorieva, 2004), with consequent effects on shipping and drilling platforms. Recent studies indicate that these increases are expected to continue (Caires et al., 2006).
- **Greater variability in the summer monsoon rainfall** is likely causing more severe drought and flood events in India and southeast Asia (Lal et al., 2001). Monsoonal rainfall in Mexico and the northern Caribbean, the sub-Saharan grasslands and southeastern Africa has declined since 1975 (Chen et al., 2004).
- **Reduced lake-ice cover**, earlier spring algal blooms, higher spring surface-water temperatures and earlier stratification of lakes (by two to four weeks) have been observed in Europe and other temperate regions (Mortsch et al., 2003).

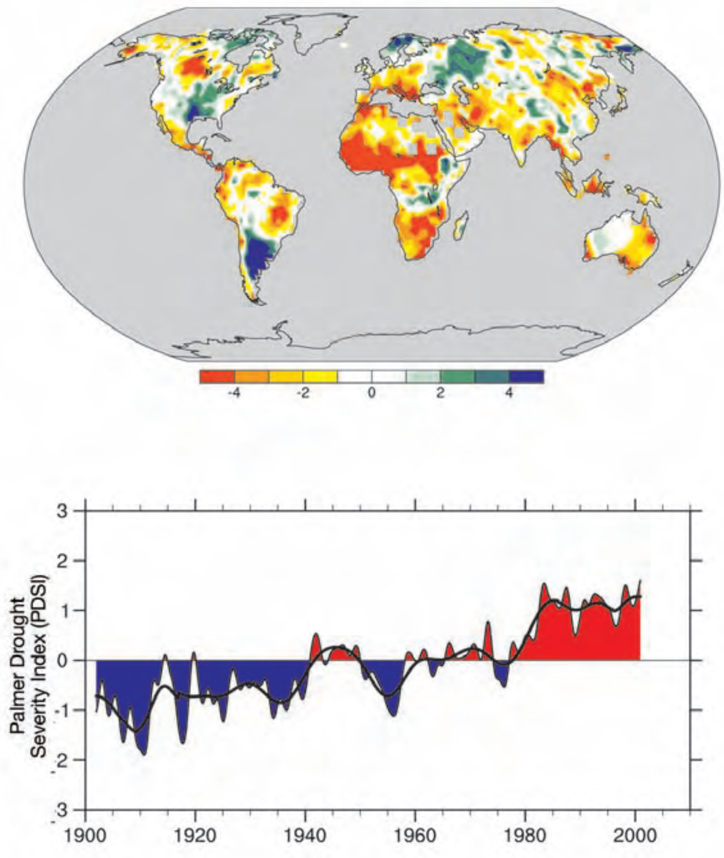

FIGURE 3: "The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. The PDSI is a prominent index of drought and measures the cumulative deficit (relative to local mean conditions) in surface land moisture by incorporating previous precipitation and estimates of moisture drawn into the atmosphere (based on atmospheric temperatures) into a hydrological accounting system. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (negative). The smooth black curve shows decadal variations. The time series approximately corresponds to a trend, and this pattern and its variations account for 67% of the linear trend of PDSI from 1900 to 2002 over the global land area. It therefore features widespread increasing African drought, especially in the Sahel, for instance. Note also the wetter areas, especially in eastern North and South America and northern Eurasia." (Trenberth et al., 2007 p. 263, which was adapted from Dai et al. 2004).

- **Phenological events** for land species are also now earlier in the year by 5 to 14 days, providing a longer growing season in the Northern Hemisphere since the 1950s for various plants and trees. Global terrestrial net primary production has increased 6% between 1982 and 1999, according to satellite measurements, especially over northern temperate latitudes (Nemani et al., 2003).

- **More heat waves** have been observed over most land areas. In addition to having major health implications and causing premature deaths (e.g. in Europe during the summer of 2003), heat waves can also result in agricultural losses, changes in ecosystems and wildlife, and increased energy demand for cooling. On the other hand, continuation of the current trend of fewer very cold days (Alexander et al., 2006) will reduce heating needs and the number of cold-related injuries and deaths.

- **Arctic sea-ice annual area** has decreased significantly (7.4%; Johannessen et al., 2004) in the 25 years prior to 2002. The year 2005 had the least Arctic sea-ice extent in September since satellite observations began in 1979. These changes, projected to continue, could accelerate the use of shipping channels and exploration for oil, gas and minerals, but have adverse effects on wildlife and hunting activities of Arctic people (*see* Section 3.3 of this chapter, as well as Chapter 3).

- **Widespread retreat of glaciers** is underway in the western Americas, the Alps and most of the Himalayas, threatening key water supplies in South American countries (Mark and Seltzer, 2003) and elsewhere. Total ice loss from the Greenland Ice Sheet in 2005 was double the 1996 value (Rignot and Kanagaratnam, 2006), contributing to freshening of northern North Atlantic waters, although the central ice cap has either remained unchanged or perhaps thickened due to greater snowfall. The freshening of the northern extension of the Gulf Stream may be weakening thermohaline (meridional overturning) circulation, including the Gulf Stream. If this persists as predicted, it would result in less warming than would otherwise occur in Europe and northeastern North America (Intergovernmental Panel on Climate Change, 2007a).

Based on these trends and impacts, as well as consideration of adaptive capacity, the regions assessed as being most vulnerable to the risks associated with climate change and sea-level rise are the Arctic, sub-Saharan Africa, small islands and Asian megadeltas (Adger et al., 2007). Nevertheless, all regions have vulnerable areas, communities and sectors (Adger et al., 2007).

2 GLOBAL ISSUES

2.1 OVERVIEW OF GLOBAL IMPACTS AND ADAPTATION — EQUITY ISSUES

Geographic Equity

Climate change involves a classic case of inequity between the rich and the poor of the world. The people and countries that have grown wealthy through economies driven by fossil fuels are visiting upon the poorest countries damaging changes in the form of disasters and threatened water and food supplies, due to a changing climate. These poorest and most vulnerable countries contribute least to the global greenhouse gas burden (Intergovernmental Panel on Climate Change, 1994; Stern, 2006). The disparity between rich and poor due to social and economic factors is likely to be exacerbated by climate change (Intergovernmental Panel on Climate Change, 2001c).

Coastal communities may also suffer disproportionately from climate change because some of the most pervasive impacts are those arising from warming of the global oceans. This contributes to sea-level rise, more intense and long-lived tropical cyclones, and redistribution of fish populations. Impacts on coastal areas and nearshore communities include erosion of beaches and shorelines, loss of coral reefs, and more frequent and severe flooding of low-lying areas during storms. Without significant adaptation measures, an additional 80 million people are at risk of flooding in coastal areas by the 2080s, and the problem is only going to increase with time (Parry et al., 2001).

Impacts on human health through changes in water availability and quality, spread of tropical diseases, impacts on food systems, and natural disasters also affect most seriously the poorest communities, those least able to adapt (Intergovernmental Panel on Climate Change, 2001b, 2007b). Subsequent sections outline some of the ways in which Canada can support adaptation in less developed countries. Sustainable development pathways can help significantly to reduce the impacts associated with climate change (Intergovernmental Panel on Climate Change, 2007b).

Intergenerational Equity

In addition to concerns over geographic inequity, the climate change issue is also characterized by inequity over time. Emissions now, will have impacts, mostly adverse, on many future generations. For example, if greenhouse gas concentrations were stabilized at 2006 levels (379 ppm CO_2), sea level would continue to rise for more than 500 years due to thermal expansion and for thousands of years due to melting of ice on land (Intergovernmental Panel on Climate Change, 2007a). Adaptation measures in coastal regions require long-term strategies.

2.2 NATURAL DISASTERS, INSURANCE AND REINSURANCE, AND HUMANITARIAN ASSISTANCE

Extreme weather events can become natural disasters when they strike vulnerable communities that are unable to manage the risk and unprepared to cope with the hazard. People in Canada can be affected by natural disasters in other countries through indirect impacts on the availability and cost of goods and services, changes in financial markets, and requests for donations of money, clothing and food. An example was the spike in oil and gas prices in Canada following Hurricane Katrina in 2005, and the storm's impact on Gulf oil production (Kovacs, 2005).

The potential impacts of climate-related trends, and their continuation under the changing climate, have important implications for the insurance industry, as well as human suffering. These trends also indicate an increasing need for humanitarian emergency assistance abroad, and the importance of assisting developing regions with disaster-loss-mitigation projects as an adaptation to climate change.

Changing Conditions

As the global population continues to grow, and exposure of infrastructure to weather-related disasters increases, economic losses are also expected to increase. However, there is evidence that losses from climate/weather events have been rising at a greater rate than would be expected from changes in exposure alone. It is also evident that the frequency of severe weather events resulting in major losses, such as storms, floods and droughts, has also been rising. The global number of severe damage-causing storms has increased from an average of 150 per year in the early 1980s to between 250 and 300 per year in the period 2000 to 2004 (Mills, 2005). Total property losses (excluding health impacts) have been rising twice as fast as would be expected due to growth in world economies and population (Mills, 2005). Thus, a portion of the growth in disaster losses is attributable to a changing climate, as demonstrated by the increase in climate extremes of various kinds (*see* Section 1.2), and is consistent with climate model projections (Intergovernmental Panel on Climate Change, 2001a, 2007a). This has occurred despite attempts in many countries to reduce losses through, for example, tougher building codes, better warning systems and flood-loss-reduction projects. Nevertheless, the improved warning systems have resulted in fewer fatalities in the 1990s than in the 1970s, even as affected populations have risen dramatically (Figure 4; World Meteorological Organization, 2006).

In 1975, worldwide economic losses due to severe weather disasters, adjusted for the effects of inflation, were US$4 billion; 30 years later, losses in 2005 were more than US$200 billion, representing a fifty-fold increase (Munich Reinsurance, 2006). Property damage payments by insurance companies also increased fifty-fold during this period, from US$1.6 billion to US$83 billion, again adjusted for the effects of inflation. Although the insurance industry has been in business for more than three hundred years, seven of the ten most costly disasters affecting the industry have occurred since 2001 (Mills, 2005). Data from the Centre for Research on Epidemiology of Disasters indicates that 80% of all natural disasters in the decade from 1996 to 2005 were meteorological or hydrological, and that more than 1.5 billion people worldwide were affected by weather- and water-related disasters between 2000 and 2004 (United Nations Educational, Scientific and Cultural Organization, 2006).

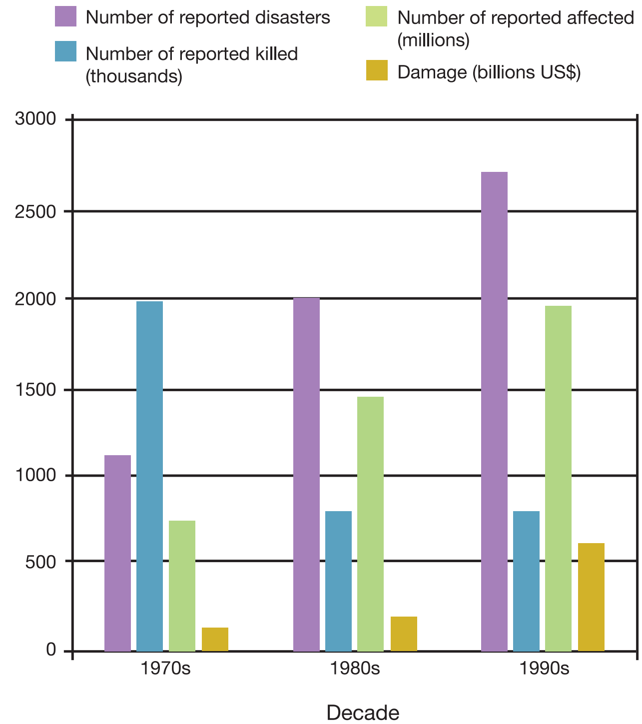

FIGURE 4: Global frequency of natural disaster impacts and associated human and economic losses from the 1970s to 1990s (World Meteorological Organization, 2006).

The International Federation of Red Cross and Red Crescent Societies (2004) studied 3000 natural disaster events that occurred around the globe between 1994 and 2003. More than 80% of these were high-impact weather-related events. During this period, 580 000 fatalities and economic losses of US$680 billion were recorded, and an average of 250 million people per year displaced from their homes. More than 95% of the damage to property was recorded in affluent or moderate-income countries, with the largest losses in the United States. In contrast, more than 90% of the disaster fatalities and 98% of the people displaced by disasters lived in moderate- or low-income nations, primarily in Asia and Africa (International Federation of Red Cross and Red Crescent Societies, 2004). High-impact weather is largely an economic shock in affluent countries like Canada, but severe weather in poorer countries is also a significant threat to life, health and safety.

In highly developed countries, the average number of deaths per disaster is 23, whereas the number increases dramatically to more than 1000 deaths per disaster in less developed countries (World Meteorological Organization, 2006). Although the absolute dollar costs of disasters in highly developed countries are large, they are usually much less than the gross domestic product (GDP) of the country (Handmer, 2003). Although Hurricane Katrina caused large losses, it was a small fraction of the United States GDP. In contrast, losses from the hurricane in 1998 in Honduras amounted to more than 75% of its GDP. In Central America and the Caribbean, damages from hurricanes can set back national economic development for years by diverting investments from growth to recovery (International Strategy for Disaster Reduction, 2005a).

International Assistance

Canadians have long supported international disaster-relief efforts, and this support has increased in recent years. The tsunami in south Asia, drought in Africa, and hurricane damage in the Caribbean, Central America and the United States are some recent events that have led to significant support from people across Canada.

International and Canadian assistance to disaster victims has been growing for several decades with the increase in extreme events. An important challenge is to look beyond disaster relief and begin to build resilient communities that are better able to cope with the threat of high-impact weather. The period of rebuilding following a natural disaster can be an ideal time to invest in disaster-resilient infrastructure and buildings, as well as relocation, rather than put people and infrastructure back in harm's way. In addition, this is a period appropriate for investment in non-structural disaster-risk-reduction activities, such as improved warning and preparedness systems and appropriate land-use changes. These concepts are important for disaster-loss-reduction assistance.

International Insurance

The global insurance industry provides the primary mechanism used to value and pool the threat of property damage due to high-impact weather.

The cost of insurance for homes and businesses has increased in recent years in regions where new research shows that the expected future damage is higher than historical damage. This has been evident in Florida and along the Gulf coast of the United States. In most markets, however, the cost of property insurance has been stable or declining when measured relative to the value of the property. Some severe weather events did not affect the cost of insurance. For example, the 1998 ice storm, the most costly event faced by Canadian insurers, did not result in higher rates because it was generally viewed by the industry as a risk that has not changed in likelihood. Moreover, more than 90% of the factors affecting the cost of insurance (e.g. frequency of theft or urban fires, or vehicle repair costs) are not related to weather, so increases in severe weather damage may have only a modest impact on the overall cost of comprehensive insurance policies.

Some companies insure insurance companies; this is called reinsurance. Much of the cost of repairing property damaged by severe weather events is borne by the reinsurance industry, through the payments it makes to insurance companies. The reinsurance business is volatile. Insurance companies are paying more for reinsurance in regions where there is a growing risk of severe weather events, such as the Caribbean and the Atlantic coastal region of the United States. This has placed the cost of insurance beyond the reach of many less well-off citizens of these affected regions. To date, however, the cost of reinsurance has been stable for insurance companies in Canada.

Supply of International Goods and Services

Extreme climate events affect the availability and cost of goods and services purchased by Canadians. The impact of Hurricane Katrina on gasoline supplies and prices was noted above (Kovacs, 2005). Severe weather has, at times, affected the harvest of such crops as coffee and oranges. Increased hurricane activity has disrupted Canadian vacation plans to Mexico, the Caribbean and the United States. Many Canadian individuals and companies own property at risk, especially in Florida, the Gulf States and the Caribbean, and have faced major increases in insurance premiums.

Large disasters can influence international financial markets, in which many Canadians invest. Such disasters have impacted certain sectors, particularly energy and food, as in the case of Hurricane Katrina. These shocks frequently have an immediate impact on the Canadian financial markets, even if the disaster struck in a distant location.

2.3 TRADE ISSUES

Canada, perhaps more than any country in the Organisation for Economic Co-operation and Development (OECD), has good reason to ask how climate change might affect its patterns of international trade, since trade occupies an exceptionally strong position in the national economy. Canadian exports and imports as a percentage of gross domestic product stood at 70% in 2006, and trade directly contributed 12.8% to GDP (Foreign Affairs and International Trade Canada, 2006).

The most likely impacts of climate change on international trade stem from its potential to fundamentally alter the basis for comparative advantage — one of the key drivers for trade. These impacts may manifest themselves by:

- altering the competitiveness of Canadian producers (for better and for worse);
- similarly altering the competitiveness of foreign firms that compete with Canadian producers, both in the Canadian market and in third-country markets; and
- leading to policies that will, in turn, impact competitiveness in foreign markets.

The third factor (impacts of policies) lies outside the scope of this analysis. The first two factors are illustrated below by exploring climate change implications for some of Canada's key export sectors: forestry, agriculture and fisheries. Energy is dealt with in Section 4.2.

It is not possible to say with certainty what the impacts of climate change will be for Canada's trade patterns in any of these sectors. In many cases, there is still some uncertainty regarding the regional and local changes in climate, and about the dynamics of the linkages between those changes and biophysical impacts (e.g. on net primary productivity). Moreover, some types of impacts (such as extreme weather events) can at best only be expressed in terms of probability. And, although the literature focuses most heavily on supply-side issues, highly speculative assumptions about mid- to long-term demand for Canada's exports are required to translate this research into price impacts. Finally, there is a range of climate change models, sectoral models and assumptions about mitigation and adaptation from which to choose, resulting in a range of plausible scenarios.

Forestry

Forestry is one of Canada's leading export sectors. Forest products amounted to more than 10% of Canada's total merchandise exports, averaging $45 billion per year in the five years ending

2005 (Table 1). The forest sector as a whole creates direct employment for more than 370 000 people (Natural Resources Canada, 2001) and an estimated 555 000 indirect and induced jobs (Natural Resources Canada, 2005).

The biggest export market by far is the United States, which takes some 85% of Canada's forest product exports and is where Canadian softwood producers compete directly with American producers. China, Japan and the European Union are the other important export markets. Pulp and paper products dominate the export picture, accounting for roughly half the value of merchandise trade (Table 2). Primary wood products and wood fabricated materials roughly split the remaining half. Most production is centred either in the east (Quebec and Ontario) or the west (British Columbia and Alberta), the former accounting for more of the processed exports and the latter accounting for more primary exports. Exports of wood paneling have steadily increased during the last decade, now displacing the once prominent newsprint exports that, along with wood pulp exports, have steadily declined during the same period (Natural Resources Canada, 2005).

TABLE 1: Canada's major global export sectors (millions of 2005 dollars; Industry Canada, 2006).

Sector	Value (millions of 2005 dollars)					Percentage (2005)
	2001	2002	2003	2004	2005	
Mineral products	61 560	53 826	64 996	72 373	92 651	21.3
Vehicles, aircraft, vessels and other transportation equipment	97 394	98 988	90 107	91 199	89 676	20.6
Machinery: mechanical, electrical, and electronic appliances or equipment	56 785	52 601	47 764	51 589	54 286	12.5
Base metals and articles of base metals	24 946	26 591	24 934	30 690	32 613	7.5
Wood pulp, paper	27 769	26 471	24 102	24 677	23 707	5.4
Products of the chemical or allied industries	16 275	16 890	16 877	20 106	22 881	5.3
Wood and wood articles	19 127	19 023	17 694	22 003	20 316	4.7
Plastics, rubber and articles made from these materials	15 628	16 180	15 791	17 088	18 210	4.2
Live animals and animal products	11 274	11 830	9 701	9 912	10 522	2.4
Vegetable products	10 284	9 013	9 118	10 258	9 480	2.2
Food products, beverages, spirits, tobacco products	8 436	8 912	9 207	9 523	9 176	2.1
Total exports	**404 085**	**396 381**	**381 000**	**411 840**	**435 641**	**88.0**

TABLE 2: Canada's forest products exports by region (Statistics Canada, 2004).

	Value in 2004(millions of current dollars) Percentage					
	Quebec	Ontario	Alberta	British Columbia	Other	Canada
Primary wood products (mostly softwood logs)	4 580	3 204	1 902	9 174	2 189	18 860
	24.3 (%)	17.0 (%)	10.1 (%)	48.6 (%)	10.4 (%)	
Wood-fabricated materials (lumber, plywood)	7 246	5 653	1 467	4 954	3 343	19 321
	37.5 (%)	29.3 (%)	7.6 (%)	25.6 (%)	14.8 (%)	
Pulp and paper products (pulp, paper, newsprint)	11 896	8 978	3 399	14 693	5 601	38 966
	30.5 (%)	23.0 (%)	8.7 (%)	37.7 (%)	12.6 (%)	

Climate change will affect the productivity, distribution and species composition of North American forests (Shugart et al., 2003; Lemmen and Warren, 2004). Studies tend to consider either the impacts on forest productivity (the results of temperature change and increased CO_2 fertilization) or the impacts of disturbances, such as fires, pests, drought and storms. There are, unfortunately, only a handful of studies that integrate these two research streams.

Studies of the first type tend to predict that more timber will be available during the next century as a result of increased productivity — the result of a longer growing season, increased precipitation (in places) and increased CO_2 fertilization (Medlyn et al., 2000; Irland et al., 2001; Sigurdsson et al., 2002), although there is still some uncertainty on whether the latter would have more than a short-term impact. Specific effects will vary by region as a function of differing climate changes, pre-existing conditions and forest type. For example, although increased temperature generally leads to greater productivity, it may mean more drought conditions for the western aspen parklands, resulting in significant dieback (Hogg et al., 2002).

Studies of forest disturbances frame predictions in terms of lost forest area. Modelling by Sohngen et al. (2001) estimated that some 1.6 million ha of the forest decline that occurs annually in North America is attributable to climate change. A number of insect pests expand their range as winter temperatures increase (Hogg et al., 2002; Williams and Liebhold, 2002; Carroll et al., 2004). The boreal forest, where insect damage may constitute up to twice the damage done by fires, is particularly vulnerable (Volney and Fleming, 2000). Fire hazard is also a significant problem, with a number of studies predicting longer, more severe Canadian fire seasons under climate change scenarios (Li et al., 2000; Flannigan et al., 2001, 2005; Brown et al., 2004; Gillett and Weaver, 2004). Most predict higher risks in western Canada and lower risks, due to projected increased precipitation, in the eastern boreal forests. Flannigan et al. (2005) saw the possibility of a doubling of annual area burned in Canada by 2100. Lightning strikes and forest area burned are projected to increase in the United States as well.

The combined effects of increased moisture stress, increased fire hazard and increased pest activity seem most likely to adversely affect British Columbia and Alberta. British Columbia's mountain pine beetle infestation is already affecting trade, causing accelerated salvage harvest and presaging a supply crunch in the medium term (Natural Resources Canada, 2005; *see also* Chapter 8). It has now begun to spread east, with about 2.8 million trees affected in Alberta as of spring 2007 (Alberta Sustainable Resource Development, 2007). Quebec and Ontario are the other two major producers of forest products, with a strength in pulp and paper, and they may experience the benefits of both increased precipitation and increased productivity in some subregions of the provinces. Potential gains in regions of Ontario, however, would be tempered by losses in other parts of the province resulting from reduced soil moisture and drought stress (*see* Chapter 6).

One of the few global analyses to include both the effect of increased productivity and that of disturbances is Sohngen et al. (2001). Although this study predicts a net expansion of Canadian (and North American) forests by 3 to 4%, it notes that dieback in North America will be more pronounced than that experienced by our global competitors (28–29% versus 6–14%, respectively). The economic result of increased North American supply is predicted to be lower prices for forest products, not compensated for by increased sales (Sohngen and Sedjo, 2005). Moreover, increases in productivity in North America will be less pronounced than for other producers (e.g. 17% versus 32–42% respectively; Sohngen et al., 2001). This single study suggests that there will be lower world prices (depending on assumed demand) and a smaller share of the global market for Canadian (and North American) producers.

In the final analysis, prices for Canada's exported forest products seem likely to fall as supply increases. In western Canada, this may be a short-term phenomenon, driven by accelerated salvage harvesting (*see* Chapter 8). The increased productivity of global competitors will add to this effect, particularly as it concerns non-American export destinations. The increased volumes exported may not be sufficient to compensate for lowered prices.

Agriculture

Agriculture is another important export sector for Canada, averaging 5% of total merchandise exports over the five-year period ending in 2005 and more than $20.2 billion in annual sales (Table 1). Canadian producers are keenly aware that they will be impacted not only by changing climate within Canada but also by climate events in other parts of the world, as reflected by the following headlines in *The Western Producer* (2006): 'U.S. wheat struggles in drought' and 'Australian drought alters auction business' (Duckworth, 2007).

Grains and oilseeds, and products thereof, dominate this sector in Canada, accounting for some 40% of the value of merchandise exports (Agriculture and Agri-Food Canada, 2005). Live animal and red meat exports, mostly to the United States, have traditionally also been strong in this mix at around 25%, but have dropped to 20% since the 2003 trade bans in key export markets resulting from bovine spongiform encephalopathy (BSE). The United States was the destination for more than 60% of Canada's agricultural exports in 2004, with Japan and the European Union the next most important markets at 9.4% and 6%, respectively.

Wheat is Canada's largest crop in terms of both area planted and export value; it is the single largest agricultural earner of export revenue, at $3.8 billion in 2004 (Agriculture and Agri-Food Canada, 2004).

As noted in the various regional chapters in this volume, the agricultural sector in Canada can expect both positive and negative impacts from climate change. Positive impacts include longer growing seasons, increased productivity from warmer temperatures and CO_2 fertilization and, in some areas, decreased moisture stress. Negative impacts include increased moisture stress in many areas, increased losses from pests, more difficult crop planning due to increased climatic variability (with wrong choices resulting in crop losses) and increased crop damage from extreme weather events (e.g. heat waves, hail, floods, drought). Impacts on water availability — a key issue in arid areas such as the Great Plains (the location of most wheat production) and the interior valleys of British Columbia — will be a function of small changes in rainfall and heat-induced increases in evapotranspiration.

The net impacts on Canadian agriculture are uncertain (Lemmen and Warren, 2004). At a general level, the effects of increased temperature and increased CO_2 concentrations are understood: they will bring increased net primary productivity and increased moisture loss. Less clear are other key variables: water availability and incidence of weeds, pests and disease. These uncertainties are largely a function of limitations in modelling of local/regional climate changes (e.g. changes in precipitation patterns, variability/predictability of climate behaviour, incidence of extreme weather events).

In the case of the United States, Thomson et al. (2005a, b, c) derived greater certainty from their assessments. Areas such as the American midwest and southwest, where water resources are a limiting factor, may experience problems as water becomes more scarce and interannual variability of water supply increases significantly. For example, wheat yield potential was adversely affected by the 2005 drought, when Oklahoma and parts of Texas had deficits of more than 50 cm from normal rainfall averages (The Western Producer, 2006). Irrigated winter wheat is expected to increase in acreage, while irrigated soybeans and corn are expected to decrease. But these results do not consider a host of complexities, such as regional/local effects, pests and weeds. The model also ignores extreme weather events such as flooding, which some researchers assert would significantly alter standard modelling results (Rosenzweig et al., 2002).

At the global level, in a study covering four major crops and five regions, Parry et al. (2004) predicted that climate change will probably exert a slight to moderate negative impact on yields, but this assumes no negative impacts from the types of disruptive stresses noted above. In scenarios involving high-end temperature increases, they found that cereal yields decreased much more in developing than in developed countries. Canada would experience slight increases in productivity, although local/regional effects are not well mapped.

Rosenzweig and Iglesias (1999), using models that similarly ignore many potential negative impacts, found that Canada's production of grains and protein feed could increase by a mean (across three models) of 15.7% and 20.7%, respectively, at 550 ppm of atmospheric CO_2 and with some adaptive actions; the corresponding figures for the United States are –4.7% and 0%, respectively. Wheat exports stand to do particularly well under most scenarios, with Canadian productivity increasing while most other countries would see declines. Only New Zealand's wheat production performs as well as Canada's in these models, with China and the Commonwealth of Independent States also experiencing large gains. Latin America and the Middle East experience huge losses, with Africa also losing significantly. More recent studies suggest that crop production increases in mid to high latitudes are likely to become decreases with average global temperature increases greater than 3°C (Intergovernmental Panel on Climate Change, 2007b).

A final layer of complexity is added to the agricultural sector results by the unpredictability of adaptive actions. Countries' capacity to adapt will significantly affect the results: for example, African yields in many scenarios drop, but poor adaptive capacity may mean that the impact there will be far worse than for other regions with similar projected declines in yield (Parry et al., 1999).

In Canada, the climate would become more favourable for fruit and vegetable production in several regions, potentially lessening dependence on imports. Canada's competitive advantage may increase in the growing of wine-producing grapes over hotter, drier regions of Australia and California, for example. In the end, most models predict increased productivity for Canadian growers across a range of crops relative to global competitors. Those models are limited in scope, however, and the survey by Lemmen and Warren (2004) probably yields the most reliable results, ending on a note of uncertainty. The impacts of a number of potentially negative influences are not well enough known to fully understand the productivity effects. Long-term price impacts will therefore be similarly difficult to predict.

In the final analysis, it is possible to predict with some certainty the broad-brush effects of climate change in the short term: increased Canadian agricultural productivity, particularly in cereals such as wheat, relative to trading partners in developing countries but to a lesser extent relative to United States producers. It is not yet known, however, to what extent these general trends will be moderated by disruptive negative influences, such as extreme weather events and pests.

Fisheries

Fisheries exports, valued at $4.3 billion in 2005 (Fisheries and Oceans Canada, 2005), contribute less to the Canadian economy than forestry and agriculture, but they are still significant and account for a disproportionate amount of income in certain communities. A little over half of the value in this sector is shellfish exports, dominated by lobster, crab and shrimp. Another 15% of the export value is salmon, with some two-thirds of that being Atlantic salmon.

The fisheries sector is addressed in detail in Section 3, and also in the regional chapters. Fish stocks are known to be vulnerable to climate change. However, they are also subject to a host of other influences that make climatic impacts difficult to isolate. Direct effects stem from increased water temperatures and altered oceanic circulation. Indirect climate effects include altered freshwater temperatures and runoff patterns, disruptions to other links in the food chain (i.e. changes in food and nutrient supply), contributions to toxic algal blooms, and the synergistic effects of climate change and such forces as human predation, pollution and ozone depletion.

Although the precise nature of the impact of climate change on Canada's global fisheries trade is not known, the potential for disruption is well illustrated by the collapse of the Atlantic cod fisheries — formerly a major export stock. There is evidence that climate change (in tandem with overfishing) played a significant role in that collapse (Rose, 2004). There is also concern that climate change–induced reductions in snowpack may reduce stocks of Pacific salmon (Mote et al., 2003). Section 3 notes the threats to sockeye salmon populations from a warming trend in the eastern North Pacific, and also the possibility that such anadromous species will alter their range to put them out of the reach of Canadian fishers. Fisheries, and particularly pelagic fisheries, are an international management issue; the dynamics of climate change–induced impacts, such as altered distribution and abundance of fish stocks, will make that management challenge much more difficult (Miller, 2000; Jurado-Molina and Livingston, 2002; Harley et al., 2006).

Other Issues

Trade in environmentally sound technologies for adaptation (Klein et al., 2006), such as disaster proofing and low–water usage techniques, as well as in low–greenhouse gas (GHG) technologies, is expected to increase. To take advantage, companies in Canada should be encouraged to develop such technologies for adaptation as well as for mitigation. The impact on Canada's auto sector, whose main market is the United States, may depend on the fuel efficiency of vehicles manufactured here, or on which parts are manufactured here. Although there may be concern regarding potential disputes over trade and environmental laws and agreements, surveys of the potential conflicts (Charnovitz, 2003; Cosbey et al., 2003; Magnusson, 2004) tend to agree that, for the most part, there are few conflicts that cannot be avoided by careful drafting of environmental measures.

Research Gaps

The uncertainties and data gaps relevant to this section's discussions on fisheries, agriculture and forestry are addressed elsewhere in this volume, as well as being touched upon above. It was noted that few global forestry studies managed to integrate a focus on productivity with a focus on disturbances, such as fires and pests. The same sort of gap exists in agriculture, where none of the global studies surveyed considered the impacts of extreme weather events or pests.

With respect to trade in these sectors and the economic impacts that climate change might have on Canadian interests, there are a few key research gaps. The few outputs from global-level models have not yielded information specifically relevant to Canada, tending to aggregate Canada and the United States into a single North American entity. Any assessment of the economic and trade impacts on Canada will necessarily involve a greater degree of complexity, and differentiation between Canada and the United States.

Conclusions

This section offers an overview of the potential impacts of climate change on Canada's international trade patterns. Although it seems clear that there will be significant effects, further analysis is needed to better understand the breadth of potential impacts. Furthermore, additional study is needed to clarify the nature of these impacts.

That said, there are good indications regarding the general direction of change. From an economic perspective, the impacts on the forestry sector are likely to be most significant, as productivity in Canada may decline relative to that of overseas competitors and prices could decline as a result of increased global supply. Agricultural impacts are also likely to be significant, as Canadian productivity in important export grain crops increases relative to world trends (but potentially less so relative to United States producers). It should be stressed that any predicted outcome makes assumptions about adaptive behaviour (even if implicitly assuming it does not take place) and that appropriate adaptation will be key in ensuring that the risks and opportunities identified above are adequately addressed in the Canadian context.

2.4 CLIMATE CHANGE IMPLICATIONS FOR CONFLICT

The impacts of climate change can make life in an affected region more difficult and even render areas uninhabitable. Regions may experience higher temperatures, changes in precipitation patterns, desertification, sea-level rise, and more frequent and/or severe extreme weather events due to climate change (Brooks, 2004). These impacts can, in turn, threaten food production, reduce freshwater supplies, lead to loss of land and infrastructure, and increase the incidence of disease (Barnett and Adger, 2003). Such changes can induce migration, which may occur peacefully or may generate conflict.

The causes of many conflicts are very difficult to isolate. Very few are considered to be mainly due to environmental stresses. Nevertheless, environmental stress and related issues of scarcity may contribute additional stress to political, social, economic, ethnic, religious or territorial conflicts, or conflicts over resources or national interests (cf. Gleick, 1990; Lonergan, 1998).

The number of active armed conflicts increased to more than 50 in the early 1990s, and then declined to fewer than 30 in 2003 (Human Security Centre, 2005). The increase and subsequent decline were entirely the result of conflicts within countries, which account for more than 95% of all armed conflicts. One of the major reasons for the decline in the number of armed conflicts is a dramatic increase in international activities designed to stop existing conflicts and prevent new ones (Human Security Centre, 2005). These activities include preventive diplomacy missions, peace-making missions, peace-keeping operations and sanctions by the United Nations and other groups (Ackermann, 2003; Human Security Centre, 2005). Canada has a history of contributing to such efforts.

Although future impacts of climate change could lead to new conflicts and/or exacerbate conflicts caused by non-climatic factors, this relationship is unclear. Empirical research confirms that environmental scarcity causes large population movements, which can, in turn, cause conflicts (e.g. Baechler, 1998). Where armed conflicts result, these tend to be persistent, diffuse and subnational rather than between states (Homer-Dixon, 1991; Baechler, 1998). There would be value in Canada and other countries giving further consideration to how foreign policy and development resources can best be used to mitigate the potential for such conflicts, in recognition that climate change may serve as a contributing factor.

2.5 IMPLICATIONS FOR INTERNATIONAL MIGRATION TO CANADA

Canada has been a destination for international migrants throughout its history. Immigration is governed by the *Immigration and Refugee Protection Act* of 2002 and its regulations. The act makes a clear distinction between the basic social, cultural and economic goals of the immigration program and the humanitarian goals of the refugee protection program. During the past decade, immigration to Canada has fluctuated between 175 000 and 250 000 per year, including between 22 000 and 33 000 refugees. In 2005, 32.0% of the refugees came from Africa and the Middle East, 33.1% from Asia and the Pacific, 21.3% from South and Central America and 11.2% from Europe (Citizenship and Immigration Canada, 2006).

Migration on all scales — rural to urban, between urban areas within a country and internationally — is driven by a combination of 'push' factors associated with the origin and 'pull' factors associated with the destination (Castles and Miller, 1993). The adverse impacts of climate change will exacerbate existing conditions of environmental degradation and contribute to internally displaced persons and migrants (Stern, 2006). Gradual changes, such as reduced crop yields or water supplies, induce migration because the affected area becomes less attractive. People will be drawn to locations with better opportunities, relatives and friends, and other perceived advantages (Cragg and Kahn, 1997; Deane and Gutmann, 2003). Historically, migration due to the impacts of climate change has been overwhelmingly within the same country (Baechler, 1998). There is no reason to expect this pattern to change. Friends and relatives within the immigrant community could make Canada an attractive choice for some international migrants.

Under international law, refugees are defined by the United Nations High Commissioner for Refugees (UNHCR) as individuals who flee their country because of fear of ethnic, religious or political persecution, or to escape conflict, and cannot rely on the protection of their own government (United Nations High Commissioner for Refugees, 2006). The UNHCR notes that "accurate use of the term 'refugee' implies a need for international protection" (United Nations High Commissioner for Refugees, 1993, Chapter 1, p. 3). The global number of refugees was about 14 million at the end of 2004: about 4.8 million Palestinian refugees and 9.2 million refugees of concern to the UNHCR in other countries (United Nations High Commissioner for Refugees, 2005).[3] The number of refugees of concern to the UNHCR has declined steadily from about 12.1 million at the end of 2001 (United Nations High Commissioner

[3] In addition, there were about 10 million asylum-seekers, returned refugees, internally displaced persons (IDPs), returned IDPs, stateless persons and others of concern to the UNHCR.

for Refugees, 2005). In Africa, there were just over 3 million refugees, mostly located in countries bordering countries with internal armed conflicts.

El-Hinnawi (1985) defined 'environmental refugee' as a person forced to leave his/her traditional habitat due to an environmental disruption that jeopardized his/her existence and/or seriously affected the quality of his/her life. Although the term 'environmental refugee' is used in some climate change literature, it is controversial. People displaced by environmental changes need assistance but generally do not need protection, and therefore do not fit the definition of refugee. It may be more appropriate to refer to persons displaced by environmental degradation.

Estimated recent numbers of persons displaced by environmental degradation, and future projections that consider impacts of climate change, are presented in Table 3. There is limited empirical support for these estimates (Black, 2001), although it is widely accepted that environmental change contributes to internal and international migration, and that the number of migrants may be large. Myers and Kent (1995) projected the number of 'environmental refugees' in 2050 at 150 million, with about 100 million being from low-lying coastal areas, 50 million from agriculturally dislocated areas and 1 million from island states. Myers (2005) has since increased his estimate of the total to 200 million. Most of the people displaced by environmental change are expected to be in Africa and Asia, geographically remote from, and hence less likely to migrate to, Canada. Closer to home, rural land degradation and desertification are a significant cause of migration within and from Mexico (Leighton, 1998).

TABLE 3: Estimates of 'environmental refugees' (persons displaced by environmental degradation).

Estimate of environmental refugees	Date(s) covered by estimate	Source
About 10 million	1980s	Jacobson (1988)
About 64 million	1980s	Lonergan (1998)
About 15 million	1990	Westing (1992)
Up to 25 million, of whom 25–33% are international and the balance internal: 16 million for Africa, 6 million for China and 2 million for Mexico	1990	Myers (1993)
About 150 million	2050	Myers and Kent (1995)
About 200 million	2050	Myers (2005)
8.6 million forced migrants due to 1 m rise in sea level		Tol (2002)

By making life in a region difficult or impossible, the impacts of climate change will cause internal and international migration (McLeman and Smit, 2005). These impacts are most likely to affect rural areas of poor countries geographically remote from Canada. The risk that 'waves of environmental refugees' will spill across Canada's borders, with consequent destabilizing effects on domestic order and international relations, is low (Homer-Dixon, 1991). Nevertheless, climate change could lead to pressure on Canada to accept more immigrants and refugees. [4]

2.6 HEALTH EFFECTS

Canadians are influenced by health issues abroad, including changes in abundance and virulence of diseases in countries with significant travel, tourism and trade to and from Canada. Other health issues, such as those due to a rise in the number and severity of natural disasters, result in increased calls on Canada for assistance (*see* Section 2.2).

In many regions of the world, malaria, hemorrhagic dengue fever, malnutrition and diarrheal diseases are on the rise for several reasons, including changing climate. Using data compiled by the World Health Organization (WHO), it has been estimated that climate warming to 2004 contributed to more than 150 000 deaths and 5 million illnesses per year (Patz et al., 2005). This same study projected a doubling of these tolls by 2030 as a result of climatic and other changes (e.g. population distribution, water pollution). The greatest threats are increased malnutrition and malaria in Africa, more diarrheal cases in southeast Asia and natural disasters in Latin America and the Caribbean. The following sections expand on some of these issues. Poorer countries of the world are the most vulnerable to such impacts (Intergovernmental Panel on Climate Change, 2007b). Technical assistance and humanitarian aid programs in Canada will likely be pressured by these trends.

Diseases

Diseases such as cholera follow warm spells, such as warm El Niño episodes in South and Central America, and would likely spread in a warming world. Some tropical and subtropical diseases transmitted by ticks, insects and wildlife are an increasing threat to Canada in a warming climate (*see* regional chapters in this report). Vector-borne diseases, including malaria, dengue fever and Lyme disease (transmitted by ticks) may expand their ranges in North America (Intergovernmental Panel on Climate Change,

[4] New Zealand has programs that grant residency to 1750 people each year from Pacific Island countries (New Zealand Immigration Service, 2005): Samoa (1100), Fiji (250), Tonga (250), Tuvalu (75) and Kiribati (75). Although climate change is not an official reason for the programs, all of these small island states are vulnerable to sea-level rise.

2001b). To date, active disease prevention programs have virtually eliminated diseases such as malaria from Canada, but continued vigilance will be needed, as will assistance to reduce impacts abroad.

Diarrheal diseases represent another significant health risk, resulting in thousands of premature deaths in poorer countries with inadequate food and water treatment and inspection, especially in Africa, southeast Asia and the eastern Mediterranean (Campbell-Lendrum et al., 2003). It has been estimated that, globally, a 5% increase in the number of cases of diarrhea occurs per degree Celsius of warming (Campbell-Lendrum et al., 2003).

Temperature Extremes

Increases in the length and intensity of heat waves will impact heat-related illnesses and mortality. Warm night-time conditions, which allow little relief from the heat, are an important component of heat waves. Global-scale analysis indicates that more than 70% of the global land area experienced a significant increase in the annual occurrence of warm nights during the period 1951 to 2003, with especially high increases in the number of warm nights per decade occurring in western Africa, Eurasia, northern South America and western North America (Alexander et al., 2006).

The heat wave in August 2003 resulted in the greatest climate impact on mortality in European history — from 27 000 to 40 000 excess deaths (Kovats and Jendritzky, 2005). Premature mortality and increased hospital admissions in heat waves are expected to be more frequent in many regions, although a reduction in severe cold-related deaths is anticipated in temperate and subpolar regions. Several cities around the world, including some Canadian cities, have instituted adaptation measures to reduce the impact of heat waves, including heat warnings and preparedness services, and 'green roofs' with vegetation on large buildings to reduce the heat-island effect of cities (*see* Chapters 5 and 6).

Food Security

Health problems and mortality due to more severe drought and famine are increasing in some regions and decreasing in others due to the changing climate. Although the relationships between crop productivity and climate are complex (Easterling et al., 2007), most studies project decreases in crop yield potential at low latitudes, even for very small increases in mean temperature (Intergovernmental Panel on Climate Change, 2007b). Concerns are raised by studies such as that of Peng et al. (2004), who, through controlled experiments, reported a 10% decline in rice production for each degree Celsius increase in night-time temperature.

Of particular concern are health impacts resulting from the unavailability of adequate food supplies in Africa. Figure 5 shows the trends in the Food Production Index of the United Nations Environment Programme (UNEP) for the world as a whole and in Africa (United Nations Environment Programme, 2002). The rapid decline in Africa began about 1970, roughly corresponding to the start of rapid global temperature warming. The trend in climate drivers and production decline is likely to continue, resulting in increasing demand for food production from countries such as Canada to help make up the shortfall. The majority of people at additional risk of hunger due to climate change are in Africa (Parry et al., 1999).

Flooding

There are both immediate health effects from coastal and inland flooding, including injuries and loss of life, and longer term impacts, resulting from contaminated water and food. Provision of clean water supplies as soon as possible after the disaster is essential for reducing health impacts.

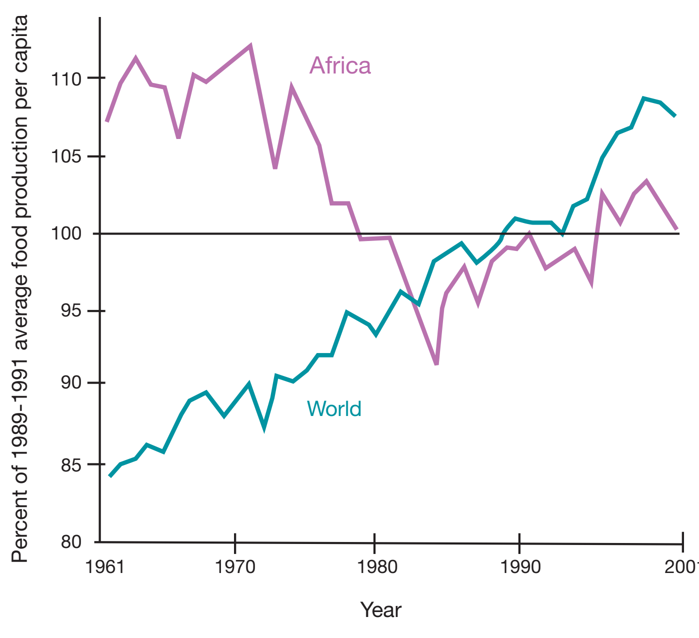

FIGURE 5: Food Production Index (net food production per capita, base line 1989-91) for Africa, contrasted with the rest of the world, for the period 1961 to 2001 (United Nations Environment Programme, 2002). *Source*: Food and Agriculture Organization (FAO) statistical databases, 1995.

A combination of sea-level rise, rapid population growth in coastal zones worldwide and more intense storm surges associated with more severe winter and tropical storms will increase the numbers of people at risk from coastal flooding. Regions likely to be especially affected by coastal flooding include small islands and Asian megadeltas, such as the Ganges-Brahmaputra and the Zhujiang (Adger et al., 2007). The low-elevation coastal zone (LECZ; <10 m above mean sea level) contains about 10% of the world's population while only accounting for 2.2% of total land area (McGranahan et al., 2006). Asia has by far the greatest population in the LECZ, and 19 of the 215 countries studied by McGranahan et al. (2006) have more than 50% of their population in the LECZ (*see also* McGranahan et al., 2007). The greatest impacts proportional to population size will likely be on low-lying small island states in the Caribbean, southwestern Pacific and Indian Ocean.

One-sixth of the world's population is subject to floods that are due in part to snowmelt, and may therefore experience lower flood peaks on average as a result of climate change (Barnett et al., 2005). Nevertheless, in regions affected by tropical cyclones (e.g. Central America, the Caribbean and the southwestern Pacific), observed increases in severity and duration of these events (Webster et al., 2005) have resulted in more floods and landslide disasters. It has also been shown that high-intensity rains have become more frequent and heavier in many parts of the world, including the eastern United States and southeastern Canada, northern Mexico, eastern South America, southern Africa, Europe, India and eastern Asia (Figure 2; Groisman et al., 2005). Such rains can result in flash floods, often without adequate warning to protect people and property, and increasingly frequent urban flooding due to overtaxing of drainage facilities. *Escherichia coli* (E. coli) and other contaminants in drinking water supplies are most often washed into wells or surface waters by high-intensity rains, which are becoming more frequent throughout much of the world. In the United States, it is estimated that 68% of all health outbreaks from contaminated water occurred after heavy rain events (Patz, 2001).

Potential Implications for Canada

Most of these trends affecting health and mortality abroad can be reduced by adaptation measures, both internationally and within Canada. Initial responses by Canada to these needs have been made (*see* Section 5).

Canada and other developed countries may be able to further reduce health-related vulnerabilities in other countries through programs that involve assistance to:

- strengthen public health services in affected regions;
- take actions to reduce standing waters, which breed dengue- and malaria-bearing mosquitoes;
- improve water treatment systems; and
- improve warning systems for coastal and riverine floods, heat waves and impending drought conditions.

Potential actions within Canada may involve:

- ensuring that immigration policies are designed to take into account refugees from these health- and disaster-related trends;
- improving surveillance programs on movement of climate-related diseases; and
- improving border health controls for climate-sensitive infectious diseases.

2.7 TOURISM IMPACTS

Tourism is one of the largest and fastest growing economic sectors in the world. In 2004, tourism represented 1.5 to 2.0% of Canada's GDP (Canada Tourism, 2005; World Tourism Organization, 2005; Statistics Canada, 2006). Over 19 million tourists (overnight visitors) came to Canada, more than 15 million of them from the United States (Canada Tourism, 2005; World Tourism Organization, 2005). In addition, there were 19.7 million day visitors. About 55% of the tourists came for leisure, recreation and holidays (World Tourism Organization, 2005). Foreign tourists spent an average of 6.4 nights per visitor in Canada and accounted for about 30% of the total nights in accommodation establishments (World Tourism Organization, 2005). In addition to their domestic travel, 19.6 million Canadians travelled to foreign countries, mainly the United States, for overnight stays. Foreign tourism to Canada peaks during the summer, whereas Canadian travel abroad peaks during the winter (Canada Tourism, 2005).

Most studies addressing the impacts of climate and climate change on tourism have been published since 2000 (Scott et al., 2005). Hamilton et al. (2005) distinguished three strands of literature:

- studies that build statistical models of the behaviour of certain groups of tourists as a function of weather and climate;
- studies that relate the fates of particular tourist destinations to climate change; and
- studies that try to define indicators of the attractiveness to tourists of certain weather conditions.

Available studies in the first category apply almost exclusively to warm-weather vacation choices by Europeans: the significance of weather and other amenities in the destination preferences of British, Dutch, German, Italian and other European tourists (Agnew and Palutikof, 2001; Maddison, 2001; Lise and Tol, 2002). No studies of the destination choices of Canadian tourists have been found that explicitly include weather or climate as a factor in the choice. However, winter travel to Hawaii, Arizona, Florida, the Caribbean and Mexico is clearly motivated by a desire for warmer conditions.

During the past two decades, numerous studies have been undertaken of the potential impacts of climate change on tourist destinations in Canada, covering various types of outdoor tourist activities across most of the country (Scott et al., 2004; Jones and Scott, 2006). These studies suggest that skiing and other winter activities will be adversely affected, despite additional snowmaking. The length and quality of the summer tourist season is expected to improve in most regions, although adjustments, such as better water management for golf courses, may be needed. Adaptation to lower flows and water levels for water-based activities will be required in some regions. Tourism impacts and adaptation are also discussed in the regional chapters.

Although such studies can provide important insights into the impacts of climate change on a specific destination, tourist traffic will depend on how climate change and associated environmental changes affect the attractiveness of that destination relative to its competitors.

The third strand of literature adopts the premise that travel behaviour is motivated by two sets of factors: one set that influences a person to consider travelling and another set that attracts that person to a particular destination (de Freitas et al., 2004; Scott et al., 2004; Amelung and Viner, 2006). Such analyses use various direct indicators, such as temperature and humidity, or indirect indicators, such as beaches, of the attractiveness to tourists of certain weather conditions.

A simulation model of global tourism, projecting arrivals and departures for 207 countries on the basis of population, per capita income and climate, suggests that tourism growth is driven by increases in population and income, and so is larger in Asia and Africa than Europe and North America (Hamilton et al., 2005). Global tourism increases at 3.2% per year between 1995 and 2075 in the base case.

Climate change shifts tourism toward the poles and from lowlands to highlands. As countries closer to the poles become more attractive to their own residents, they tend to generate fewer international tourists (Hamilton et al., 2005). In addition to the higher temperatures, countries nearer the equator may be rendered less attractive due to loss of beaches and coral reefs, and damage due to more intense tropical storms (Loftus, 2005).

Climate change is projected to benefit Canadian tourism more than any other country over the period to 2025 (Hamilton et al., 2005). Climate change would increase Canada's share of global arrivals (i.e. more tourists coming to Canada) and reduce Canada's share of global departures (i.e. fewer Canadians travelling abroad). Canadians would take more vacations at home, so domestic travel would grow relative to international travel (Hamilton et al., 2005). The authors caution that the model is very simplistic, with a crude representation of climate change, so the focus should be on the qualitative results. The model also excludes a number of variables likely to influence tourist flows (Gössling and Hall, 2006).

In summary, summer tourism in Canada is likely to benefit from climate change, although some activities may need to adapt. This will attract more foreign tourists and keep more Canadians at home. Winter tourism in Canada may suffer despite efforts to adapt, but the milder winters are projected to reduce travel by Canadians to warm destinations.

3 OCEANS

Canada is influenced in many ways by the three bordering oceans — Pacific, Arctic and Atlantic — and climate change impacts on the oceans affect Canada's people and economy. All of the world's ocean basins have been warming on average, due to greenhouse gas forcing (*see* Section 1.2), and this is expected to continue. The warming is resulting in rising mean sea level and changes in biological systems, including shifting distributions of fisheries and coral reef bleaching in tropical areas. Sea-level rise is projected to continue for several centuries, even if atmospheric greenhouse gas concentrations are stabilized, due to the lag time involved in thermal expansion of ocean waters and melting of land ice. At the same time, increased storminess has resulted in significant increases in wave heights in many parts of the world's oceans (*see* Section 1.2). Melting of ice on land is changing salinity as well as adding to sea-level rise, and increased CO_2 absorption is increasing the acidity of ocean waters.

The impacts on marine biological systems and fish distribution have been documented in the assessment reports of the Intergovernmental Panel on Climate Change, such that a "Growing recognition of the role of the climate-ocean system in management of fish stocks is leading to new adaptive strategies based on determination of acceptable removal percentages of fish, and stock resilience." (McLean et al., 2001, p. 345).

3.1 ATLANTIC OCEAN AND LABRADOR SEA

Ocean Changes

The atmosphere over the Atlantic Ocean has changed, and will continue to change, with observed and projected increases in storminess and more frequent occurrence of intense hurricanes (*see* Section 1.2). Climate warming, which will generally be more pronounced in northern regions, will lead to reductions in sea ice. The increased melting of the Greenland Ice Sheet and other land glaciers, and greater precipitation will result in more freshwater inflow to the North Atlantic, thereby reducing its salinity (Intergovernmental Panel on Climate Change, 2001a). The volume-averaged temperature increase at depths of 0 to 700 m depth in the North Atlantic from 1960 to 2000 has been 0.2°C, but there has been little trend in sea-surface temperature in the northern North Atlantic (Barnett et al., 2001; Pierce et al., 2006).

The strength of the meridional overturning circulation (MOC), also called thermohaline circulation, will be reduced if the waters of the Greenland, Norwegian and Labrador seas are warmed and/or freshened, both of which are projected to occur with climate change (Intergovernmental Panel on Climate Change, 2007a). Reducing the MOC results in reduced transport of warmer near-surface water from the subtropical gyre to high latitudes, counteracting overall global warming. As a result, the North Atlantic would warm less than other areas at corresponding latitudes, and it is possible that parts may cool in the next few decades, although there is uncertainty in the geographic distribution (Stocker et al., 2001). Although the MOC is expected to slow during this century, it is very unlikely to shut down (Intergovernmental Panel on Climate Change, 2007a). Adaptation to address the abrupt climate change that would occur with shutdown of the MOC, and implications for climate policy and decision-making, have not been researched (Hulme, 2003). Nevertheless, reducing the MOC will not cause the onset of the next ice age (Berger and Loutre, 2002; Weaver and Hillaire-Marcel, 2004).

With warming, there will be reduced sea-ice cover over the North Atlantic Ocean, which will make the ocean more open to atmospheric influences. Increased storminess (Lambert, 1996; Lambert and Fyfe, 2006) and possibly more intense hurricanes undergoing extratropical transition, such as Hurricane Juan (2003), will lead to higher ocean-wave conditions. There is now considerable evidence of increasing storminess and higher wave climates in the North Atlantic, including the Grand Banks (Gulev and Hasse, 1999; Gulev and Grigorieva, 2004) and, as the climate warms, most regions of the midlatitude oceans will see an increase in extreme wave heights (Wang et al., 2004; Wang and Swail, 2006a, b). In the near term, there could be more icebergs due to increased melting of the Greenland Ice Sheet and other calving glaciers.

These impacts are affecting fisheries, offshore oil and gas operations, exploitation of other natural resources of the ocean and marine transportation. Reduced sea ice will mean less of a hindrance to marine shipping and fisheries vessels, but storminess and higher waves will adversely impact fleets and energy exploration activities, and increase the risk of marine accidents. Sea-level rise will affect coastal zones around the Atlantic Ocean, with impacts on the habitat of fisheries and creation of new tidally inundated areas. Sea-level changes can also affect the usefulness of port facilities, both overseas and at home, and affect international competitiveness. There will likely be a need for increased search-and-rescue capacity for the North Atlantic Ocean.

Fisheries

Marine fisheries provide an important food source and are a vital part of the economies of Atlantic Canada (*see* Chapter 4) and other countries, especially in Europe, that border on the North Atlantic Ocean. Historic variations in fisheries across the North Atlantic, beyond Canada's traditional fishing areas, are well documented. In the early 1950s, for example, the stock of Norwegian spring-spawning herring was the world's largest herring stock and was important to Norway, Iceland, Russia and the Faroe Islands (Vilhjálmsson et al., 2005). In 1965, a sudden and severe cooling of these waters resulted in the decimation of the most important food for these herring. The stock was also severely overfished and collapsed. Restrictions on the fisheries and favourable climatic conditions later contributed to the stock's increase and the need for international agreements to set quotas. Such agreements may be an important management tool in the future as climate change alters fish stocks and their ranges.

The disappearance of the North Atlantic cod has demonstrated the social and economic costs of changing fish stocks on Atlantic Canada. The disappearance of the cod was, in part, due to colder waters in the Labrador Sea, as well as overfishing, and the stocks have not recovered as was originally assumed after fishing pressure was reduced (Drinkwater, 2002, 2005; Barange et al., 2003). The relationships with climate have been reviewed by Drinkwater (2002, 2005) and Barange et al. (2003). Generally, as stocks have reduced, they have become more sensitive to climate variability or change, due to shrinkage of the age distribution and geographic extent (Brander, 2005). Although warming waters are likely to promote the recovery of the northern cod stock (Drinkwater, 2005), an increase in abundance of the main forage fish, capelin, and a decline in seal abundance are likely necessary for recovery to occur. The northern cod situation demonstrates how fishing, climate change and other factors affecting marine ecosystems may interact strongly at the extremes of the range of a species. A lightly exploited stock may show few drastic changes as climate and other factors change; however, as in the case of northern cod, such changes may amplify the effects of overfishing, causing negative and sudden changes in vital survival rates and abundance, as well as distribution (Rose et al., 2000; Rose, 2004; Drinkwater, 2005).

As fish are international resources, competition in the open ocean and for species that straddle international borders has led to major disputes. The 1982 Law of the Sea Convention has provisions that enable coastal states to establish Exclusive Economic Zones (EEZs), extending up to 200 nautical miles (360 km) offshore, where they have sovereign rights over the natural resources. Countries are expected to manage these stocks in a sustainable manner. With the dramatic increase in fishing beyond the EEZs in the 1980s, and increases in catches within the EEZs due to rapidly growing fishing capacity, the 1995 UN Convention on Straddling Fish Stocks and Highly Migratory Fish Stocks mandated the application of a precautionary approach to fisheries management and emphasized the need for co-operation between countries. The Northwest Atlantic Fisheries Organization (NAFO) and the North East Atlantic Fisheries Commission (NEAFC) were formed and led to ecosystem-based approaches to the management of living marine resources, where natural factors such as climate change are taken into account in decision-making. The 2002 World Summit on Sustainable Development stated in its implementation plan that such ecosystem-based approaches to management are to be in place by 2010.

The Arctic Climate Impact Assessment provided a detailed analysis of Arctic and North Atlantic fisheries (Vilhjálmsson et al., 2005), concluding that it is not possible with present knowledge to provide precise forecasts of either changes in the fish stocks and fisheries or the effects on society, due to uncertainties in:

- identifying the reasons for historical changes in fish biology;
- predicting possible changes in the ocean climate under the scenarios of climate change; and
- understanding the relationships between socioeconomic factors and changes in fish stocks.

Further, since many of these fish stocks are heavily exploited, they are currently much lower in abundance than in the past and are exhibiting extreme changes in population characteristics. Nevertheless, some general conclusions can be drawn with respect to the impacts of climate change on fisheries and the related economies in North Atlantic–Arctic countries. Warming will be a benefit for some species, whereas it will create problems for others. Changes need to be seen in the context of an overall economy, its diversification and its ability to adapt — politically, socially and economically. It is important for Canadians to understand the impacts in other countries and to project how other countries may respond, so as to understand the consequent impacts on Canada. There is need for further analysis in this regard.

Another issue related to climate change in the marine environment is the altered risks of poisoning of fish and shellfish for human consumption and impacts on ecosystems. Warmer waters could result in an expansion in the ranges of toxins to higher latitudes and increase the occurrence of toxic algal blooms (Berner et al., 2005). There could be impacts on human health that will need to be accounted for in both domestic production and import of seafood.

Climate-related changes can also affect the competitive nature of fisheries systems globally. Impacts that reduce fish in other regions of the North Atlantic may result in additional pressures from their fishers to utilize Canadian waters. Impacts on commercial shellfish may be of most significance.

Atlantic Ocean Warming and Tropical Storms

Waters of both the North Atlantic and South Atlantic oceans have been warming since the 1950s, from near the surface to depths of >100 m, with much of the warming attributable to increasing greenhouse gas concentrations (Barnett et al., 2001; Pierce et al., 2006). Several analyses of the frequency of intense hurricanes and more long-lived storms indicate a significant trend towards more categories 4 and 5 storms in the past 30 to 35 years (Emmanuel, 2005; Webster et al., 2005). Some hurricane forecasters attribute the recent increases entirely to cyclic changes, but analysis of the relative importance of climate change and cyclic changes suggests that global warming trends account for two-thirds of the increase in categories 3 to 5 hurricanes (Faust, 2006). Thus, more intense hurricanes are to be expected on average in the future as the ocean continues to warm. This suggests the need for better disaster preparedness and management for hurricanes in the Caribbean, coastal areas of the United States and maritime Canada, and increased demand for disaster preparedness and recovery assistance (*see* Section 2.2).

3.2 PACIFIC OCEAN

Changing Conditions

Average warming off the British Columbia coast was minimal between 1901 and 1979, but occurred at a rapid rate of up to 0.25°C per decade between 1979 and 2004. Much of the warming in this recent period has occurred in June, July and August (data from the National Climatic Data Center; Smith and Reynolds, 2005). The trends observed in the North Pacific are, in part, related to the Pacific Decadal Oscillation (PDO), which is, in turn, linked to the El Niño Southern Oscillation (ENSO). These two circulation phenomena result in alternating warm periods (1935–1945 and 1975–2004), accompanied by a deeper Aleutian Low, and a cool period (1945–1975) in the eastern North Pacific. These major fluctuations and longer term warming trends appear to both be at work, reinforcing each other in warm phases. Some oceanographer-meteorologists think that anthropogenic climate change stimulates the warm phase of the PDO and ENSO (Corti et al., 1999; Timmermann et al., 1999).

At the same time, with the frequency of intense winter storms in parts of the Northern Hemisphere increasing (McCabe et al., 2001), changes in significant wave heights have been observed. From 1950 to 2002, significant wave heights have increased about 1 cm per decade off British Columbia's coasts (Gulev and Grigorieva, 2004). Such increases are projected to continue (Caires et al., 2006).

Sea-level rise and an increase in intense storms are resulting in flooding and erosion episodes and related water quality problems on the west coast, especially in the lower mainland (*see* Chapter 8).

Fisheries

With continued warming of the eastern North Pacific, the population distribution for sockeye salmon will be compressed, forcing them increasingly into the Bering Sea (Welch et al., 1998; Beamish et al., 1999). Figure 6 shows the current thermal limits for sockeye salmon in December (upper panel) and July (lower panel). The 2 x CO_2 climate projections show this thermal limit retreating to the Bering Sea (Welch et al., 1998), out of reach of most Canadian fishers. While it is expected that changes in total numbers may be small, changes in regions of occurrence will mean that a particular species will be caught by fishers from different countries. For anadromous fish, warming water in

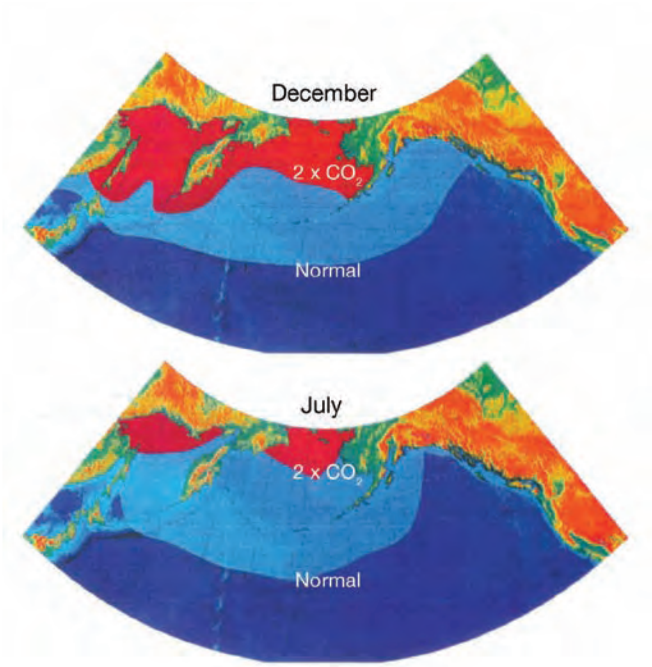

FIGURE 6: Current and projected (under a scenario of 2 x CO_2) distribution of thermal limits controlling the distribution of sockeye salmon in the north Pacific Ocean for December and July (Natural Resources Canada, 2000).

spawning rivers may also change the populations and ranges of certain fish stocks (*see* Chapter 8).

Aquaculture in coastal waters could benefit from warmer conditions, with increased growth rates and an increase in the geographic range of the activity. Higher water temperatures and related physical changes could, however, result in more intense and frequent disease outbreaks and algal blooms (Kent and Poppe, 1998). Bacterial contamination of oysters and other shellfish may be more frequent as water temperatures rise. The increased frequency of intense winter storms and the trend towards higher wave heights would also physically endanger aquaculture operations.

Fishers would be affected in several ways by the changing climate. They may need to go farther from home ports to catch their quota of a particular species. This exposes them to increasing hazards from the more frequent intense winter storms and higher waves off the west coast. In addition to such safety concerns, the changing fish populations may make it necessary to adapt by modifying the kinds of fish they catch and where they catch them (Beamish et al., 1999; *see* Chapter 8).

Tourism

Tourism in western coastal waters will be affected in similar ways. Generally, small recreational boats would require greater attention to safety because of higher waves and greater incidence of severe storms. Sea-level rise and severe storms would also have negative effects on marinas and other coastal infrastructure used for fisheries and boating, which may require expensive adaptation measures to maintain (*see* Chapter 8).

Shipping

Although the most favourable ship routings across the Pacific may change as circulation, winds and storm patterns change, the main impact on shipping is likely to be through ports and shore infrastructure. In Japan, for example, it has been estimated that a 1 m sea-level rise would require an expenditure of US$110 billion to maintain present functions and stability in their 1000 ports (McLean et al., 2001). In British Columbia, reinforcement and raising of breakwaters and wharves will likely be required to adapt to higher water levels and the greater wave regime, to ensure that Canadian ports remain internationally competitive (*see* Chapter 8).

3.3 ARCTIC OCEAN

Shipping

Little international shipping takes place in the Canadian Arctic at present. Port and docking facilities in the Canadian Arctic are rudimentary, with the exception of the Port of Churchill, Manitoba, on Hudson Bay, which has four deep-sea berths for grain, general cargo and tanker vessels. In 2002, Manitoba and the Russian province of Murmansk—the European gateway to the Northeast Passage—signed a letter of intent to develop a marine link between the two provinces. Dubbed the 'Arctic Bridge', this concept is to develop further the Port of Churchill as part of a North American trade corridor. This concept is deemed viable as a result of the longer sea ice–free shipping season in Hudson Bay and the Davis Strait. It has been suggested that there should be development of port facilities at Iqaluit to assist regional economic growth (Aarluk Consulting Inc. et al., 2005). The duration of ice cover in the Canadian Arctic Archipelago is projected to be reduced by one month by 2050 and by two months by 2090 (Dumas et al., 2006). However, there would still be significant ice hazards for ship transits (*see* Chapter 3).

Base-metal mines, including the Polaris lead-zinc on Little Cornwallis Island and the Nanisivik zinc mine on northern Baffin Island, were supplied by sea, and concentrate was shipped to smelters in Europe and elsewhere. However, these mines ceased operations in 2002 and 2003, respectively, leaving the Raglan nickel-copper mine in northern Quebec and the prospect of a huge nickel mine at Voisey's Bay in Labrador to be serviced by sea. The mining industry hopes to develop port and road facilities in or near Bathurst Inlet to service and supply exploration and development operations for precious and base metals and diamonds in the Kitikmeot region and northern Northwest Territories (*see* Chapter 3).

A considerable increase in international use of the Canadian portion of the Arctic Ocean seems likely. The Arctic Climate Impact Assessment (ACIA) concluded that:

> *"The continued reduction of sea ice is very likely to lengthen the navigation season and increase marine access to the Arctic's natural resources." (*Arctic Climate Impact Assessment, 2004, p. 11)

Further, the ACIA suggested that trans-Arctic shipping during the summer is likely to be feasible within decades. Diminished sea ice in summer in the Canadian Arctic could prompt the world's shipping community to seek expanded access to the Northwest Passage (Figure 7) to convey international cargos, taking advantage of the shorter sea route from eastern Asia and the west coast of North America to the eastern seaboard of North America and western Europe. Most climate models suggest that these sea ice changes will occur in the latter half of this century (Walsh et al., 2005), although recent trends suggest an earlier date. However, opening of the seas north of the Russian Federation is likely to occur earlier, and infrastructure to support marine traffic along that route will probably develop before that in Canadian waters.

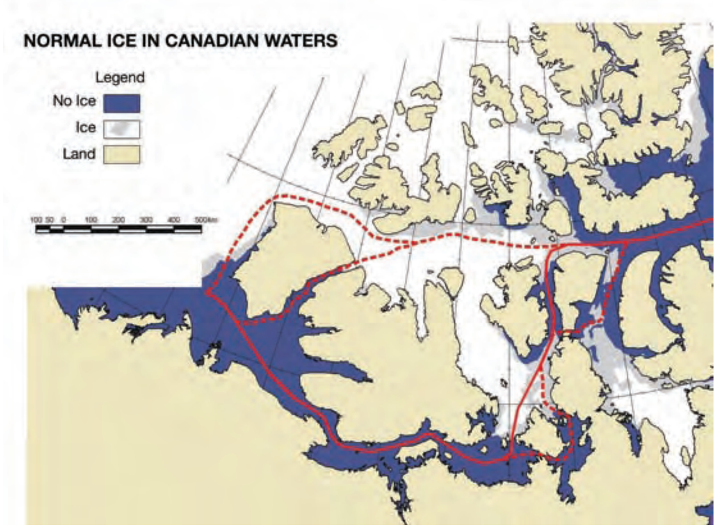

FIGURE 7: The primary (solid line) and alternative (dashed lines) routes for the Northwest Passage,shown on a map of historical average ice conditions for September 3 (1971-2000) (courtesy of Humfrey Melling, Fisheries and Oceans Canada, and Environment Canada).

To follow up on the ACIA, Arctic Council ministers in 2004 initiated an Arctic Marine Shipping Assessment (AMSA). To be presented to ministers in 2008, the AMSA will provide a 'snapshot' of Arctic shipping in 2004 and projections of the likely level of shipping in the circumpolar Arctic in 2020 and 2050, in light of sea-ice ablation, economic development scenarios, and risks such as the possibility of increased ice hazards in some regions.

Fisheries and the Food Chain

Water temperatures and ice cover influence the distribution of Arctic fish and marine mammals, as do changes in freshwater input from the major rivers of Russia and Canada (Arctic Monitoring and Assessment Program, 2002). Along the North American coast, important fish stocks, such as Atlantic cod and herring, are being displaced due to warming waters — moving northeastward where they will be more accessible to fishers from Scandinavia and Russia. Loss of estuarine ice may displace cisco. Loss of sea ice results in Arctic shelf seas looking more like temperate seas, with implications for food web structures that are difficult to predict. One surprise and warning sign was a massive bloom of jellyfish in the Bering Sea in the 1990s (Arctic Monitoring and Assessment Program, 2002).

Pupping of ringed seals, which provides a favourite food source for polar bears, requires extensive sea ice. A decrease in suitable habitat could affect the entire upper food chain, since the seals prey on Arctic cod. For Canadians of the Arctic, the catching of fish or seals for food requires longer voyages into the Arctic seas, which are increasingly hazardous because of the trend towards more severe winter storms (*see* Section 1.2). This leads to significant changes in the way of life for some Arctic communities (*see* Chapter 3).

Contamination of the food chain is also a concern. As permafrost melts, more mercury is released to rivers and the ocean, and accumulates up the food chain. Mercury and other contaminants from more southerly latitudes can have adverse effects on people of the Arctic, especially indigenous women. Women of Baffin Island, Nunavik and Greenland have been found to have very high mercury concentrations in their blood and breast milk. Seal meat and fish are significant food sources for these populations (Arctic Monitoring and Assessment Program, 2003).

Industrial development in the north is likely to add to contamination of the Arctic seafood chain. Development of natural gas and oil deposits at Hammerfest, Norway is proceeding apace with reduced ice. Oil reservoirs have been identified 320 km from the North Pole, and the Shtokman field in Russian parts of the sea is thought to be the largest offshore gas reservoir in the world. With global warming and loss of Arctic sea ice, development of these resources is becoming increasingly feasible (*see* Chapter 3).

Toxic Materials

Persistent organic pollutants (POPs), including hexachlorocyclohexane (HCH), dichloro-diphenyl-trichloroethane (DDT), toxaphene and polychlorinated biphenyls (PCBs) of industrial and agricultural origin, and some heavy metals, have been detected throughout the circumpolar world at unexpectedly high levels (Indian and Northern Affairs Canada, 1997). Sources of POPs within the Canadian Arctic, including PCBs from Distant Early Warning (DEW) line sites, are minor compared with long-range transport from the south (Europe, Asia and North America). Bioaccumulation and biomagnification of POPs in the Arctic environment have resulted in elevated levels of some POPs in lipid tissues of animals, particularly marine mammals, including beluga whales, narwhal, walrus, ringed seal and polar bears. As a result of eating marine mammals, some Inuit have levels of some POPs in their bodies that are known to have effects on the immune system and on neurobehavioural development and reproduction (Dewailley and Furgal, 2003).

Macdonald et al. (2003) noted that increased global temperatures will have direct effects on contaminants through enhanced volatility, more rapid degradation and altered partitioning between phases (Macdonald et al., 2003). Changes in the timing and length of seasons are likely to be particularly important in changing the spatial distribution and levels of contaminants in the Arctic through long-range transport. The ACIA noted that climate change and pollution in the Arctic are interrelated, and that:

> *"More extensive melting of multi-year sea ice and glacial ice can result in pulse releases of pollutants that were captured in the ice over multiple years or decades."*
> (McCarthy et al., 2005, p. 954)

Although the bilateral Canada–United States dimensions of contaminants are most critical for Canada, longer range atmospheric transport is becoming of increasing concern (Indian and Northern Affairs Canada, 1997). Pollutants due to emissions from the rapidly growing economies of China, Japan and southeast Asia are now being detected in Canada's north. Some of these contaminants come through volatilization from waters of lakes, such as the Great Lakes and Asian lakes, where the substances had been earlier deposited through long- and short-distance atmospheric transport. This volatilization occurs in the warm season, with the toxic contaminants gradually moving farther and farther north to where waters are too cold, year round, for the process to occur. This volatilization process will occur more readily as lakes warm in the changing climate. Thus, this contribution to Arctic contaminants from the above-mentioned sources in the Northern Hemisphere will gradually increase. It is presently unknown whether changes in atmospheric circulation patterns will occur that would either lessen or exacerbate the transport of contaminants to the Arctic.

Canadian Control and Security

Canada acquired sovereignty over the Arctic from the United Kingdom through legal and political measures that stretch back to the 1670 Charter granted by King Charles II to the Hudson's Bay Company. In 1870, the company transferred its title to the Hudson Bay watershed to Canada. Following an address by the Canadian Parliament to Queen Victoria expressing doubt as to Canada's northern border, the United Kingdom in 1880 transferred to Canada all territory in British North America and adjacent islands, with the exception of Newfoundland. Both Denmark and Norway challenged Canadian sovereignty on some islands from 1898 to 1910. However, Canada took several actions to reassert ownership and, with payment of compensation, Norway relinquished its Arctic claim in 1931. An issue remaining is the dispute with Denmark over tiny Hans Island between Greenland and Ellesmere Island.

With Canada's sovereignty to Arctic land secure, attention turned to the ocean, with specific reference to the Northwest Passage. The United States and European Union contend the passage is a strait used for international navigation through Canadian territorial waters, whereas Canada asserts the passage to be internal waters over which it has full jurisdiction and control (e.g. Rothwell, 1993; Charron, 2005). The degree of control that Canada can exercise over these waters depends upon whether they are considered internal waters, as Canada claims, or a strait for international navigation. The 1969 transit through the passage of the American supertanker 'Manhattan' crystallized Canadian concerns and prompted legislative action, including the Arctic Waters Pollution Prevention Act. A similar transit through the passage in 1985 by the American icebreaker 'Polar Sea' resulted in legal action by Canada to draw 'straight baselines' around claimed land and ocean. In 1988, Canada and the United States concluded an Arctic Co-operation Agreement through which future transits through the passage by icebreakers would be undertaken with the consent of Canada. This agreement had no bearing on the legal positions of the parties vis-à-vis the status of the passage. Increased shipping in Canadian Arctic waters will likely require increased surveillance, monitoring, maintenance of navigation signals and search-and-rescue services.

4 CONTINENTAL EFFECTS (NORTH AMERICA)

4.1 WATER IMPLICATIONS

Higher temperatures and a changing rainfall regime are affecting water supply, water demand and water quality in Canada, Mexico and the United States. Most of the observed trends of the past 35 years are expected to continue in the coming decades. Two major issues for Canada relate to managing the border and transborder basins shared with the United States (International Joint Commission, 1997) and responding to demands for export of water to the dry regions of the United States and northern Mexico (Bruce et al., 2003).

Canada–United States Border and Transborder Waters

There are a dozen large bilateral drainage basins, or groups of small basins, for which the International Joint Commission (IJC) has responsibility under the *Boundary Waters Treaty* of 1909. Many of these basins, and their subbasins, have water-sharing agreements where rivers flow north or south across the border or form the border. Also, in some basins, pollution control agreements are in place to protect ecosystems and water quality (e.g. Great Lakes–St. Lawrence River). Climate change is beginning to affect both the quantity and quality of these waters, and the ability of one country to meet its present obligations to the other (Bruce et al., 2003).

To illustrate the potential extent of the issue, Table 4 gives the linear trend (1970–2000) in annual flows and minimum and maximum flows for major bilateral rivers. Most are downwards except for the Red River, which flows northward from the Dakotas, where significant increases in precipitation have occurred (Bruce et al., 2003). These bilateral stresses are superimposed on domestic water management issues (Cohen et al., 2004).

On the Columbia River, the trend towards greater flow in winter and less flow in spring is expected to continue. Changing water demands in the United States, combined with climate change, could seriously compromise hydroelectric power generation and other uses in Canada, especially in drier regions in southern areas of the Canadian part of the basin (e.g. Okanagan and Osoyoos lakes, *see* Chapter 8; Cohen et al., 2000; Payne et al., 2004). Existing processes through which rules are being reviewed for possible changes in 2013 provide an opportunity for consideration of adaptation to climate change.

TABLE 4: Trends (percentage change) in annual flows for boundary river systems between Canada and the United States, 1970–2000 (Bruce et al., 2003).

River	Mean	Minimum (daily)	Maximum (daily)
St. John (Fort Kent)	-13	71	-16
St. Croix	-21	-23	-26
Niagara (Queenston)	-7	-8	-9
Rainy (Fort Frances)	-22	-12	-27
Lake of the Woods (western outlet)	-21	-59	-29
Red (Emerson)	124	159	63
Souris (Sherwood)	-82	-74	-94
Souris (Westhope)	-42	100	-60
Milk (eastern border crossing)	-22	47	-6
Milk (western border crossing)	-26	59	-41
St. Mary (border)	-7	15	-29
Kootenay (Fort Steele)	3	-4	-12
Columbia (International Border)	4	37	-25
Yukon	1	-1	-12

The Souris River flows out of Canada into North Dakota at Sherwood, SK, and back into Canada (Manitoba) at Westhorpe, ND. Under a ‘normal climate’, each country can use 50% of the natural flow up to the border crossing. Natural flow is calculated by a joint board reporting to the IJC, which takes the measured flow and adjusts for human withdrawals and reservoir evaporation upstream. At the Sherwood crossing, Canada is required to deliver half of the first 50 000 cubic decametres (40 500 acre-feet) of natural flow in the January 1 to May 31 period. With the downward trend from 1973 to 1998 in mean annual natural flow from 7 to 2.5 m^3/s, Canada’s obligation was not met in 5 years between 1988 and 2000 (Bruce et al., 2003). However, there is a clause in the agreement, which had to be invoked, to provide to North Dakota 40% of the natural flow in the critical period. Continuing and more acute problems with declining flows and increasing consumption for stock watering and irrigation due to climate change are expected to result in frequent inability to meet the initial quantitative goal (Bruce et al., 2003).

There have been serious problems in meeting the provisions of apportionment agreements, established in 1921, for the Milk and St. Mary rivers due to declining flows in southern Alberta and reduction of meltwater from headwaters in Glacier National Park[5] in the United States. These trends and increased demand for irrigation reached the point that, in 2003, the Governor of Montana called for reopening of the existing agreements. Bilateral discussions continue with the aid of the IJC.

In the Great Lakes basin, a critical agreement for sharing water is the *Niagara River Treaty* of 1950. An agreed amount, 100 000 cubic feet per second (cfs) in daytime and 50 000 cfs at night, is allowed to go over Niagara Falls for the benefit of the tourists. The balance is divided equally between Ontario and New York State for hydroelectric power generation. With the upper Great Lakes (Superior, Michigan, Huron) having progressively less ice and higher surface temperatures as the climate warms, winter-time evaporation losses have substantially increased and will continue to do so. This resulted in a 7% decline in the mean annual flow of the Niagara River between 1970 and 2000 (Bruce et al., 2003). Continuation of this decline is expected with climate change, and adjustments to the agreement and/or to operations may be needed (Mortsch et al., 2000; Bruce et al., 2003).

Water quality in the Great Lakes is affected by more intense rains in the watershed, which increase erosion and wash pollutants into the lakes; by higher water temperatures; and by earlier establishment of a thermocline, allowing bottom waters to become depleted of oxygen earlier in the warm season. There are questions as to whether the two countries can achieve their mutually agreed water quality objectives under these changing climate conditions (Great Lakes Water Quality Board, 2003). For example, an increase in the frequency of high-intensity rains, resulting in more erosion and diffuse sources of pollution to the lakes, causes increased problems associated with nutrients, pathogens (e.g. *E. coli*), turbidity and pesticide products (Bruce et al., 2006).

Although Canada and United States have an enviable record of settling water disputes amicably through the International Joint Commission and the *Boundary Waters Treaty*, climate change threatens to stress this relationship. In order to adapt to changes already occurring and projected future changes, the management and terms of some of these agreements may need to be adjusted (Bruce et al., 2003).

External Demands for Canadian Water

Although the flow of rivers in the southeastern United States has risen substantially in the past 60 years, flow has decreased in most rivers of the west, especially during the April to autumn period (Frederick and Gleick, 1999; Pulwarty, 2002; Barnett et al., 2005). In snowmelt regions, particularly for rivers fed by snowmelt in their headwaters in the Rocky Mountains, more winter depletion of the snowpack has occurred by melt and sublimation. This has resulted in a marked downward trend (1950–2000) in April snowpack water equivalent (Mote et al., 2003), and changes in seasonality of water supplies, with more flow in winter and less in the rest of the year. Drier conditions are occurring in the irrigation and stock-watering seasons of summer and fall. The longer term trend since 1900 in the southwestern United States and in Mexico has been an increase in the Palmer Drought Severity Index (Figure 3; Dai et al., 2004).

This change towards drier conditions in the western United States, especially during the growing season, has exacerbated overcommitment of the waters of the Colorado River to users in many states (Gleick and Chalecki, 1999). Seasonal decline in the flows of the Columbia and Sacramento rivers are also sparking conflicts over uses, including instream ecosystem and fish protection (e.g. Cohen et al., 2000). Overpumping of the Ogallala aquifer in Nebraska, Oklahoma and the high plains of Texas has seriously lowered levels and depleted supplies for agricultural and other uses. Conflicts are simmering over the sharing of reduced water in the border and transborder rivers between the United States and Mexico (Salman, 2006).

As a solution for these problems, some have looked to the north, to the apparently plentiful waters in British Columbia and the Great Lakes. Analysts have argued, however, that effective water conservation measures would permit meeting of all essential needs now and in the immediate future from supplies within the United States (Frederick and Gleick, 1999). In the longer term, if drying continues as projected, this may not be the case.

Recognizing the potential for interest in exporting of Great Lakes water, the governors of the eight Great Lakes states, in co-operation with Ontario and Quebec, have negotiated an agreement (2005) pursuant to the earlier Great Lakes Charter Annex (2001). This agreement calls for no diversions out of the Great Lakes basin, with some exceptions. A 'grandfather' clause exempts the substantial (3200 cfs) diversion of Lake Michigan waters into the Mississippi River system at Chicago. The amount of this diversion is governed by a United States Supreme Court ruling. The other exception to the Great Lakes Annex Agreement prohibition on diversions outside the basin is for straddling counties and communities, those whose borders, as of 2005, straddle the watershed boundary of the Great Lakes.

With the expectation that increased evaporation due to climate change will lower Great Lakes levels and flows of the rivers in the system, including the St. Lawrence, adverse impacts on shipping, hydroelectric power generation and water quality are projected (Great Lakes Water Quality Board, 2003). This is without further diversions out of the system. Canada and the provinces need to remain vigilant to this threat, as well as the promotion of conservation by all jurisdictions. A recent amendment to the *International Boundary Waters Treaty Act* by Canada prohibits bulk-water removals and diversions from border and transborder waters but does not deal with attempts to divert internal Canadian waters, an issue that a number of provinces have similarly addressed.

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[5] Glacier National Park had 150 glaciers in 1850; in 2005, it had 27; by 2050, it is expected to have none.

Mexico also has very limited and declining supplies in regions bordering United States and has, at times, looked north to Canada for additional supplies. There remains a debate among trade experts as to whether water export would be expected or required under the terms of the *North American Free Trade Agreement* (NAFTA). There is no specific prohibition on export of water under this agreement, nor is there an obligation for bulk export of water. However, bulk export in one region may set a precedent.

4.2 ENERGY ISSUES

Energy goods are an important part of Canada's export basket.[6] Energy exports to the United States (which accounts for over 95% of Canada's energy exports) increased at an average annual rate of almost 17% during the decade from 1996 to 2005 (Table 5). Canada exports natural gas, crude oil, non-crude oil, electricity and coal to the United States.

Climate change will alter the demand for energy in Canada and the United States, which will likely affect energy exports. Climate change will also affect Canada's supply of hydroelectricity and its electricity exports to the United States. Finally, efforts to reduce greenhouse gas emissions will likely change the export markets for different energy products.

Energy Demand

Climate change will lower space-heating demand in Canada, which will reduce natural gas and home heating oil consumption (Bhartendu and Cohen, 1987; Findlay and Spicer, 1988). It will also increase the air conditioning load, which will increase electricity demand during the summer months. The air conditioning demand rises faster than the annual average temperature. A 3°C increase in mean daily maximum temperature increases the mean peak power demand by 7% (1200 MW; Colombo et al., 1999). In Canada, however, the overall energy demand is expected to decline over the coming few decades.

In the United States, the larger impact will be on the air conditioning load, thus causing overall energy demand to rise (Edwards, 1991; Sailor and Muñoz, 1997; Considine, 2000; Sailor, 2001; Amato et al., 2005). A 5°C temperature rise by 2100 would lead to a $40 billion welfare loss due to increased energy demand (Mansur et al., 2005). Changes in the energy demand in Canada will affect the energy available for export, and the increased energy demand in the United States will affect its energy imports.

Coal

Canada has abundant coal resources, mainly in the west (National Energy Board, 2003). About 90% of the coal produced in Canada is used to generate electricity in Alberta, Saskatchewan and northwestern Ontario. Coal for electricity generation in southern Ontario, New Brunswick and Nova Scotia is imported. Coal exports are primarily metallurgical coal for Asian markets. Record demand due to increased air conditioner use and reduced supply of hydroelectric energy due to drought-like conditions contributed to Ontario's decision to delay shutdown of the coal-

TABLE 5: Canada's energy exports to the United States (Industry Canada, 2006).

	Value (millions of 2005 dollars)							Average annual growth [1]
	1996	1997	1999	2000	2002	2003	2005	
Natural gas and natural gas liquids	9 875	10 906	12 106	22 924	10 391	28 484	38 807	20.2%
Crude oil	10 970	11 390	10 121	19 334	18 015	20 414	29 913	15.4%
Non-crude oil	3 464	3 402	3 327	5 615	7 036	8 006	10 972	15.9%
Electrical energy	1 218	1 377	1 923	4 059	1 812	1 852	3 168	19.5%
Coal and coal-based solid fuels	88	66	55	120	162	150	260	19.9%
Other energy goods	418	515	541	643	722	678	897	9.3%
Total energy exports to the United States	26 032	27 657	28 073	52 693	48 139	59 584	84 017	16.9%
Total exports to the United States	223 177	243 888	308 076	359 289	345 366	326 700	365 741	5.9%
Energy exports as percentage of total exports to U.S.	11.7%	11.3%	9.1%	14.7%	13.9%	18.2%	23.0%	

[1] average of year-on-year growth over 10 years; overall average growth is higher

[6] Energy goods are defined here as those goods covered under NAFTA's Chapter 6: 'Energy and Basic Petrochemicals'. They include most refined and unrefined hydrocarbon products, uranium and electricity.

fired generating units in the province (Independent Electricity System Operator, 2006). Closing the coal plants would reduce coal imports from the United States.

Crude Oil

Crude oil resources are located mainly in western Canada, but also in northern Canada and offshore Newfoundland and Nova Scotia (National Energy Board, 2003). Production of conventional crude oil is declining in western Canada and is expected to peak within the next decade on the east coast (National Energy Board, 2003). Oil sands production is projected to rise rapidly during the next two decades, more than offsetting the declining output from conventional sources (National Energy Board, 2003).

Canadian crude oil supplies refineries in western Canada and the United States. Refineries in eastern Canada use imported crude oil. As a result, more than half of Canada's production is exported to the United States. American imports are forecast to increase, but Canada's share is expected to remain at about one-third (Energy Information Administration, 2006). American efforts to increase energy security could reduce imports, possibly including those from Canada.

The main effect of climate change on Canada's oil exports is likely to be the impact of reduced water supplies in northern Alberta on oil sands production (Bruce, 2006; Schindler and Donahue, 2006). Since bitumen extraction and upgrading uses substantial amounts of water, presently projected rates of oil sands development may have to be reduced if instream flow requirements for the Athabasca River are to be met downstream (Bruce, 2006). Improved efficiency in water use would be a valuable adaptation.

Natural Gas

Natural gas is produced in western Canada and offshore Nova Scotia, and there are extensive reserves in the Arctic (National Energy Board, 2003). Production is forecast to remain roughly constant, unless or until a pipeline to bring gas from the Arctic is completed (National Energy Board, 2003). About half of Canada's output is currently exported to the United States, but exports are expected to decline as production declines and domestic demand rises (National Energy Board, 2003). Although the space-heating demand in Canada is expected to decline due to climate change, other uses are expected to grow, leading to an increase in domestic demand for natural gas (National Energy Board, 2003).

Electricity

About 60% of Canada's electricity generation is hydro based and most of the balance is coal produced, but the mix varies significantly by province. Historically, 7 to 9% of Canada's electricity has been exported to the United States, mainly from hydro-rich regions: British Columbia, Manitoba and Quebec. Electricity imports average about a quarter of the exports. Imports are driven by cross-border differences in peak periods and opportunities for utilities with hydro storage capacity to buy off-peak power and sell more during peak periods.

In the United States, about half of the electricity is generated from coal, and electricity generation is responsible for almost 40% of CO_2 emissions (Energy Information Administration, 2006). Given the long lives of generating facilities, changes to the generation mix are likely to occur gradually (Morgan et al., 2005). Climate change is projected to reduce the hydroelectric generation potential of the Colorado and other western rivers, especially during the summer months when the electricity is most needed to meet the rising air conditioning load (Edwards, 1991; Christensen et al., 2004).

The availability of hydroelectricity in Canada to meet the rising air conditioning demand in the United States (and Canada) may be compromised by climate change as well. Although climate change is projected to increase hydroelectric generation potential in northern Quebec and Labrador (Mysak, 1994; Mercier, 1998), the experience over the period since 1970 is for reduced flows on most major rivers flowing to Hudson, James and Ungava bays, except the Nelson River (Déry et al., 2005). In Ontario and on the Prairies, hydroelectric generation potential would likely be reduced, except from the Winnipeg and Nelson rivers. In southeastern British Columbia, a projected small increase in precipitation, combined with increased reservoir evaporation due to higher temperatures, could reduce hydroelectric generation potential, especially if instream flow needs and irrigation needs downstream are to be met (Raban, 1991; Mercier, 1998; Payne et al., 2004). Declines in levels of the Great Lakes, and thus flows of the Niagara and St. Lawrence rivers, have been projected to reduce hydroelectric power generation by up to 17% by 2050 (Tin, 2006).

Meeting the increased air conditioning load in North America, while coping with reduced hydroelectric production in some regions and reducing greenhouse gas emissions, will pose a challenge for electric utilities. The simplest solution to this challenge would be to meet the higher demand with more gas-fired generation, which is well suited to serving peak loads. But the scope for this option is limited, due to the anticipated supply constraints and price increases for natural gas. Renewable energy sources, such as wind and solar, generate electricity when conditions are favourable and cannot be relied upon to meet the air conditioning demand when it occurs. Nuclear generating stations are best suited to providing a constant supply of electricity and are therefore less well suited to serving a variable load, such as air conditioning demand. Utilities in both countries will probably need to rely on a mix of demand-side measures, such as energy efficiency, and generation actions to cope with the changes in demand.

Uranium

Canada is the world's largest producer and exporter of uranium, the fuel for nuclear generators. Global efforts to reduce greenhouse gas emissions could lead to more nuclear power generation in some countries. That could lead to higher exports of uranium for Canada.

Summary

Climate change will reduce energy use for space heating, thus saving natural gas and home heating oil. The natural gas saved will simply moderate the expected North American shortage.

Utilities in Canada and the United States will need to rely on a mix of energy efficiency and generation options specific to their region to cope with the demand. The challenge will be greater in the United States due to its greater reliance on coal-fired generation and larger projected growth in air conditioning load. It does not appear that Canada will be able to substantially increase exports of electricity or natural gas to help meet the United States demand.

4.3 TRANSBORDER AIR QUALITY

Although the transborder transport of atmospheric pollutants between the United States and Canada has been well documented for acid rain and some contaminants, there has been little attempt to assess the potential impacts of climate change on these movements. Such impacts, positive or negative, can arise from:

- changes in average circulation patterns, especially in hot spells;
- increases in average air temperature and hot spells, and effects of sunlight on atmospheric chemical processes; and
- remedial actions to address air quality and emission reduction.

The regions of Canada currently most affected are southern Ontario and Quebec, southwestern New Brunswick and Nova Scotia, southern British Columbia and southwestern Alberta.

The main concerns are ground-level ozone concentrations, small particulate matter ($PM_{2.5}$), acid deposition, mercury and several other toxic chemicals. The human health and ecosystem effects of these atmospheric contaminants are addressed in the regional chapters, especially Ontario and Quebec. An estimate of premature deaths from these causes for a total of eight cities across Canada is 5900 per year (Judek et al., 2004).

For the critical Canada–United States transborder air-pollution issues, the two countries agreed on pollution control measures to lessen the impacts through the Canada–United States Air Quality Agreement of 1991 and its Ozone Annex of 2000 (Canada–United States Air Quality Committee, 2006). Areas of special concern are the Georgia Strait region of the Pacific Coast and the Great Lakes–St. Lawrence River area. The 2006 Progress Report notes that 3-year average ground-level ozone levels remained unacceptably high in 2002 to 2004. The highest daily maximum 8-hour average ozone concentration exceeded 95 ppm in southwestern Ontario and 80 ppm in a much larger area southwest of a line between the Ottawa Valley and the north end of Georgian Bay. This situation occurred in spite of successful programs in both countries that reduced the chemical precursors, volatile organic compounds (VOCs) and nitrous oxides (NOx). High ozone concentrations occur in smog episodes during hot spells, which are more frequent in the changing climate, when high temperatures and sunlight act upon the emitted precursor chemicals to create ozone.

The average annual number of smog advisories increased from 7 during 1993 to 1998 to 24 during 2000 to 2005, with a record of 53 in 2005 (Yap et al., 2005). The duration of 'warm spells' in the Great Lakes region increased between 1951 and 2003 (Alexander et al., 2006). Heat episodes (defined as temperature >30°C) are projected to double by 2050 and more than triple by 2080 (Cheng et al., 2005). More intense, more frequent and longer lasting heat waves are projected for both Europe and North America (Meehl and Tebaldi, 2004). Thus, the changing climate may prevent the air-pollution control efforts from having the desired effect of reducing ozone concentrations. Such warm-spell smog episodes are also periods of high particulate ($PM_{2.5}$) concentrations. It is estimated that transborder pollutants account for 99% of smog events in Windsor and 84% of events downwind of Toronto (Yap et al., 2005). In Quebec, pollutant sources in such events are estimated to be 30% from the United States and 30% from Ontario, with the balance locally generated. To reduce future health risks, it will be necessary to redouble efforts to reduce NOx and VOCs in Canada and the United States.

Acid deposition to Canada's lakes and forests has been somewhat ameliorated by reductions in SO_2 emissions in the United States and Canada (Canada–United States Air Quality Committee, 2006). Nevertheless, the effects of these improvements in aquatic ecosystems are influenced by lake characteristics and climate interactions (Canada–United States Air Quality Committee, 2006), and many lakes do not yet show signs of recovery. Work at the Experimental Lakes area in northwestern Ontario suggests that climate change is a factor in slowing the positive response of lakes (Schindler et al., 1996).

Further research and monitoring are required to address knowledge gaps with respect to the interaction in lake ecosystems between acid deposition and climate change, and the impacts of climate trends on transport of toxic chemicals.

5 CANADA'S INTERNATIONAL OBLIGATIONS ON ADAPTATION

> *"Climate change is a serious and long-term challenge that has the potential to affect every part of the globe."* (G8 Gleneagles, 2005, p. 1)

A global reduction of greenhouse gas emissions facilitates adaptation by slowing the rate of climate change. As signatories to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, Canada and other developed countries have committed not only to reduce greenhouse gas emissions, but also to:

- assist developing countries that are particularly vulnerable to the adverse effects of climate change in meeting the costs of adaptation to those adverse effects; and
- facilitate the transfer of environmentally sound technologies and know-how to developing countries.

With atmospheric concentrations of greenhouse gases continuing to rise due to increasing global emissions, greater adaptation efforts are required in most countries.

5.1 ADAPTATION NEEDS IN DEVELOPING COUNTRIES

Some key requirements for empowering the vulnerable to cope with the changing climate, and adapt in the long term, have been identified as follows (Zubair, 2004):

- enhancing capability in climate science and technology, including monitoring, greater use of remote sensing and strengthening the science structure;
- improving assessments of vulnerability, impacts and adaptation options;
- making greater use of lessons learned from coping with climate variability; and
- empowering citizens, especially the young, through information programs.

Article 12 of the Kyoto Protocol, which establishes the Clean Development Mechanism (CDM), states that a share of CDM proceeds is earmarked to assist developing countries that are particularly vulnerable to the adverse effects of climate change in meeting the costs of adaptation. The share has been set at 2% of the Certified Emission Reductions (CERs) issued for most CDM projects. The CDM is still in its infancy and the first CERs were not issued until 2006, so the revenue this will generate to assist adaptation is uncertain. It has been estimated at €325 million through 2012, with a range of €125 to €570 million (United Nations Framework Convention on Climate Change, 2006). It should be noted that vulnerability is a function of many factors, including income, education and access to resources (*see* Chapter 2).

Multilateral assistance for adaptation is also available, but the amounts contributed have been small. The estimated status (as of 2006) of funding for adaptation under the UNFCCC, the Kyoto Protocol and the Global Environment Facility, housed in the World Bank, is summarized in Table 6.

Among the more successful capacity-building efforts are those that have involved communities in projects to increase resilience. For example, the Hyogo Framework 2005–2015 is aimed at building resilience of nations and communities to disasters (International Strategy for Disaster Reduction, 2005b). In drought-prone parts of Maharashtra state in India, projects on sustainable management of watersheds involved reclaiming degraded lands and improving yields in monsoon rain–fed agriculture. This was achieved through projects to 'catch rain where it falls', which were undertaken by villagers following a training program. In Sudan, a similar project was directed towards rangeland rehabilitation. Both projects increased resilience in the face of more intense dry periods punctuated by heavy rains in the changing climate (International Union for Conservation of Nature, 2003). Undergraduate and graduate study programs on climate science and sustainable development have been promoted in the Caribbean and the southwestern Pacific islands, with very positive effects on national impacts and adaptation programs.

A major blueprint for sustainable development in developing countries is contained in the Millennium Development Goals adopted by 189 nations in 2000. It is now evident that many of these goals cannot be achieved without dealing effectively with the impacts of changing climate. Goal 1 is to eradicate extreme poverty, yet the poorest people live in regions subject to coastal flooding in storm surges, river floods and severe storms, or in drought-intensive regions — most of these conditions being exacerbated by the changing climate. For example, the February 2000 floods in Mozambique washed away years of development work (Reid and Alam, 2005). Goals 4, 5 and 6 deal with human health, and climate change is increasing mortality and morbidity associated with malaria, dengue, heat waves and natural disasters. The El Niño hot period in 1983, a foretaste of future higher temperatures, and accompanying floods resulted in a 103% increase in infant mortality in Peru (Toledo Tito, 1997). Environmental sustainability is goal 7, yet ecosystem boundaries are shifting and ecosystem health is being degraded by the changing climate, especially in the far north and on coral reefs.

TABLE 6: Estimated status of funds for assistance in adaptation under the United Nations Framework Convention on Climate Change (*from* Global Environment Facility, 2006; United Nations Framework Convention on Climate Change, 2006).

Name of fund	Funding source	Total funds mobilized (US$)	Operational criteria	Main activities of support
I. Funds established under the United Nations Framework Convention on Climate Change (Articles 4.1, 4.3, 4.4, 4.5, 4.8, and 4.9)				
(a) Special Climate Change Fund (SCCF)	Voluntary contributions from 11 developed countries (Canada, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Portugal, Sweden, Switzer-land and United Kingdom)	US$45.4M (contributions: US$36.7M pledged: US$8.7M)*	• Additional cost of adaptation measures • Sliding scale for co-financing	• Addresses adaptation as one of the four funding priorities
(b) Least Developed Countries Fund (LDC Fund)	Voluntary contributions from 13 developed countries (Canada, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Spain, Sweden, and Switzerland as of April 30, 2006)	US$75.7M (previous contributions: US$29.9M pledged: US$45.8M GEF allocation to date: US$11.8M)**	• Guiding principles: country-driven approach, equitable access by LDCs, expedited support and prioritization of activities • Provision of full-cost funding for adaptation increment as identified and prioritized in NAPAs[1] • Sliding scale for co-financing	• Implementation of NAPAs[1] (all projects for the preparation of NAPAs in 44 countries approved with a budget of US$9.6M)
II. Fund established under the Kyoto Protocol (Article 4.10)				
(a) Adaptation Fund	2% share of proceeds from Clean Development Mechanism (CDM)	Not yet operational – projected to levy between US$160M and US$950M until 2012 (Müller, 2007)	• Guiding principles: country-driven and a 'learning-by-doing' approach, sound financial management and transparency, separation from other funding sources	• Concrete adaptation projects and programs identified in decision 5/CP7
III. Global Environment Facility (GEF)–managed funds established in response to guidance from the Conference of Parties (COP)				
(a) Global Environment Facility Trust Fund	GEF		• Incremental cost to achieve global environmental benefits	• Vulnerability and adaptation assessments as part of national communications and enabling activities
(b) Strategic Priority on Adaptation (SPA)	GEF	US$50M, of which US$25M has been allocated	• Incremental cost guidance with some flexibility, especially for Small Grants Programme	• Pilot and demonstration projects on adaptation • Small Grants Programme (US$5M) to support com-munity-based adaptation

[1] NAPA- National Adaptation Programmes of Action

* GEF allocation of US$2.0M was used for projects and administrative support.

** GEF allocation of US$11.8M to LDCF was approved for projects, administrative budgets and special initiatives

Without attention to climate change, Millennium Development Goals will become increasingly distant (Intergovernmental Panel on Climate Change, 2007b). To date, however, only a few bilateral development assistance programs have made climate change adaptation an element of their efforts.

In 2002, participants at the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa adopted a Summit Plan of Implementation as part of the strategy to meet the Millennium Development Goals (United Nations, 2002). The signatories agreed to a series of actions, one of which included protecting and managing the natural resource base of social and economic development. In the report that followed the summit, strong connections were drawn between international development and natural hazards, and included the following call for action:

"38. Change in the Earth's climate and its adverse effects are a common concern of humankind. We remain deeply concerned that all countries, particularly developing countries, including the least developed countries and small island developing states, face increased risks of negative impacts of climate change and recognize that, in this context, the problems of poverty, land degradation, access to water and food and human health remain at the centre of global attention. …Actions at all levels are required to:

(a) Meet all the commitments and obligations under the United Nations Framework Convention on Climate Change…." (United Nations, 2002, p. 29)

Small island developing states (SIDS) have been pursuing, since 1994, the Barbados Program of Action towards sustainable development, with a high priority on responding to climate change. Progress was reviewed at an international meeting in Mauritius in 2005, with 114 countries participating. Emphasis was placed on coping with natural disasters associated with climate change, capacity building, health issues, and coastal and marine resource management and protection. The Mauritius strategy notes that SIDS are already experiencing adverse effects of climate change and sea level rise. Canada has supported adaptation studies, training and on-the-ground measures to increase adaptive capacity, in the Caribbean and southwestern Pacific. New Zealand has adopted a policy favouring immigrants from small islands, including some under stress from climate change and inundation (*see* footnote 4).

The Intergovernmental Panel on Climate Change (IPCC) has recognized the clear connections between climate change, adaptation and sustainable development with a full chapter of the third assessment report devoted to the linkages. The summary of that chapter contains the following statement:

"Clearly, adaptive capacity to deal with climate risks is closely related to sustainable development and equity. Enhancement of adaptive capacity is fundamental to sustainable development." (Smit et al., 2001, p. 899)

This is an important concept for all concerned with promoting sustainable development abroad.

5.2 ACTIONS TO DATE

The Canada Climate Change Development Fund (CCCDF) was established in 2000 to assist developing countries in tackling the challenge of climate change. It promoted activities in developing countries that address the causes and effects of climate change while at the same time contributing to sustainable development and poverty reduction. The CCCDF was a six-year, $110 million initiative administered by the Canadian International Development Agency (CIDA). The CCCDF had four themes, one specifically to reduce vulnerability of developing countries to the adverse effects of climate change. As the program developed, more emphasis was placed on adaptation, and included contributions to international adaptation funds and to the International Federation of Red Cross and Red Crescent Societies. Projects were undertaken in the Caribbean, southwestern Pacific, Indonesia and Nigeria, among others. In addition, Canada's International Development Research Centre (IDRC) is collaborating with the United Kingdom Department for International Development in a $65 million program for climate change adaptation in Africa, through research and capacity building.

Providing the scientific foundation for better climate change projections, as a basis for impact and adaptation studies, is an international effort. Discussions within the UNFCCC include consideration of co-ordinated and integrated approaches to scientific research and systematic observations for both adaptation and mitigation. The Nairobi work program on impacts, vulnerability and adaptation to climate change represents a significant new initiative under the UNFCCC to assist countries to make informed decisions on practical adaptation actions (United Nations Framework Convention on Climate Change, 2007). Canada has long been a participant in, and helped lead aspects of, many major international initiatives on global environmental change, such as the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP).

The Inter-American Institute for Global Change Research (IAI) is an intergovernmental organization supported by 19 countries, including Canada, in the western hemisphere. Its mission is to develop the capacity for understanding the integrated impact of present and future global change on regional and continental environments, and to promote collaborative research and informed action at all levels. The primary objective of the science agenda of the IAI is to encourage research beyond the scope of national programs by advancing comparative and focused studies based on scientific issues important to the region as a whole, including climate change adaptation (Fenech et al., 2005).

The global change SysTem for Analysis, Research and Training (START), cosponsored by the IGBP, WCRP and IHDP, provides an international framework for capacity building. It is a nongovernment, nonprofit organization that establishes and fosters regional networks of collaborating scientists and institutions in developing countries. These networks conduct research on regional aspects of environmental change; assess impacts and vulnerabilities to such changes; and provide information to policy-makers. The organization acts to enhance the scientific capacity of developing countries to address the complex processes of environmental change and degradation through a wide variety of training and career development programs. It mobilizes resources to support infrastructure and research programs on environmental change within developing regions.

Canadians have played active roles in international assessments of climate change impacts and adaptation measures through the Intergovernmental Panel on Climate Change and the Arctic Climate Impact Assessment. On issues of global health impacts of climate change, Health Canada has actively collaborated with the World Health Organization, the United Nations Environment Programme and the World Meteorological Organization (e.g., Kovats et al., 2003).

6 SYNTHESIS

The above analysis (Sections 1 to 5) leads to some conclusions of relevance to policy, program or investment decisions by Canada in response to changing climate abroad, as observed and projected for the future. Many of these conclusions are indicated in the text and summarized in the 'Key Findings' section.

- Resource conflicts, especially over water, will be exacerbated in some regions of the world, and sea-level rise and increasing natural disasters will force people to relocate both within countries and internationally, with implications for Canadian policies and activities related to aid, peace-keeping and immigration.
- Risks associated with many climate-sensitive diseases are likely to increase, so continued vigilance will be required to address the increasing risks to Canadians.
- Reduced sea-ice cover in the warming Arctic will result in greater marine traffic and development activities by many countries, and could present challenges for Canadian control and environmental protection. Circumpolar wildlife and indigenous ways of life are also threatened by loss of sea ice and melting permafrost (*see* Chapter 3).
- Intensification of smog episodes, associated with longer and more intense warm spells, is leading to an increase in health problems associated with ozone precursors and small particle emissions from American and Canadian sources. Reducing these health risks will require greater reductions in emissions of precursors in both countries.
- As a result of climate change, global prices for wood products may fall, and there may be some opportunities in Canada for increasing agricultural exports (grains, corn) and reducing imports (fruits, vegetables).
- Canada's warm-season tourism potential is expected to increase, whereas many winter activities will require significant adaptation of facilities to remain sustainable. Canadian travel to warm destinations may be reduced. Tourism promotion programs could help to realize economic and social benefits.
- Canada–United States border and transborder water agreements were developed without consideration of a changing climate, and some may not be appropriate to protect future Canadian interests or responsibilities in water apportionment and water quality agreements.
- Increasing aridity in southwestern North America is likely to increase pressures for bulk export of water from Canada, with implications for trade and transborder water policies, including protection of Canadian waters.
- Increased air conditioning loads, and probable reduced hydroelectric supply in the United States and parts of Canada, will have major implications for energy planning in Canada and energy export agreements.
- Weather-related disaster losses are increasing rapidly worldwide, in part due to increasing frequency of extreme events. Improved disaster preparedness and management assistance will be required, especially to developing countries.
- Although some climate and ocean change effects on fisheries have been identified, there are limited data on, and understanding of, changes in fish distribution and abundance in response to climate and related oceanic changes. This represents a significant knowledge gap to be addressed through monitoring and research.
- The need for international assistance programs for adaptation to climate change in developing countries is increasing. The wide range of adaptation issues to be addressed includes preparing for and coping with natural disasters, dealing with shortages of water and food supplies, and health-related issues.
- International programs in natural and social science (including economics), and research and science assessments on climate change, provide essential foundations for Canadian policy and program responses. Active involvement of Canadian experts in these activities contributes internationally and also helps enable input of globally current science to policies in Canada.

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MOVING FORWARD

CHAPTER 10
Moving Forward on Adaptation

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Recommended Citation:

Burton, I. (2008): Moving Forward on Adaptation; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, *edited by* D.S. Lemmen, F.J.Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. x-x.

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[2] Input and comments by the following chapter authors and advisory committee members substantially contributed to shape the structure, content and style of this chapter, and their help is gratefully acknowledged: Alain Bourque, Jim Bruce, Norm Catto, Don Forbes, Jenny Fraser, Erik Haites, Beth Lavender, Don Lemmen, Linda Mortsch, David Sauchyn, Robin Sydneysmith, Liette Vasseur, Fiona Warren, Elaine Wheaton and Leslie Whitby. The research assistance of Yvonne Howard and Thea Dickinson is also gratefully acknowledged. The scope of this chapter reflects the wide range of reviewer comments received.

CONTENTS

SUMMARY

The climate change debate has moved from questions about the reality of, and reasons for, change, to consideration of what can be done to address its causes and consequences. While reduction of greenhouse gas emissions is essential to reduce the rate and magnitude of climate change, it cannot prevent significant changes in climate. Therefore, adaptation is also necessary. Because climate will continue to change for many decades, adaptation is an ongoing process that involves building the capacity to undertake continual adjustments in response to changes in climate and other stresses. Adaptation involves a wide range of actors, including individuals, community groups, civil society, the private sector and all orders of government.

Canada has the capacity to adapt to the adverse impacts of climate change and to take advantage of the opportunities that climate change will bring. The effective deployment of this adaptive capacity will be facilitated by increased knowledge and awareness of the impacts of changing climate, and broader understanding of the role of adaptation. Some adaptation actions in the context of climate change are already being undertaken in Canada. Most of these were initiated in response to isolated events or circumstances, as the need became apparent and where the capacity existed. A more anticipatory and strategic approach to adaptation would help reduce social and economic costs, increase efficiency and further reduce vulnerability in Canada.

Moving adaptation forward in Canada involves building on the momentum gained through existing initiatives and considering additional steps to facilitate implementation of adaptation measures and policies. Building on present activities involves:

- maintaining and strengthening the knowledge base;
- synthesizing and sharing knowledge;
- removing barriers to action; and
- reviewing and contributing to international initiatives.

To achieve these goals, all of the actors involved in climate change adaptation will play a role. Possible near-term steps include:

- broadening engagement and collaboration;
- leading by example;
- enhancing institutional capacity; and
- promoting and, where appropriate, mandating adaptation measures.

1 INTRODUCTION

1.1 VISION FOR AN ADAPTIVE SOCIETY

The vision embodied in this chapter is one of an adaptable and adapting Canadian society that is coping well with climate change through both reducing greenhouse gas emissions and adapting, and is profiting and thriving in the process. Such a vision cannot be achieved with only a spontaneous or *laissez-faire* approach. Some deliberate and co-ordinated steps forward are necessary. As Canadians adapt to climate change, they require, as a minimum, access to the best scientific information and expert help and advice regarding the choice of adaptation options (Box 1). Successful future adaptation will depend upon maintenance and strengthening of the knowledge base, as well as mechanisms for sharing information. At the same time, efforts towards overcoming barriers to action are needed to create an environment that is more favourable for adaptation. Progress on these actions requires leadership from the public and private sectors, as well as changes in public attitudes and behaviour, and a greater awareness of the potential for adaptation.

There is every reason to be confident that Canadians are capable of achieving this vision. Canada has the wealth, technology, skills, social organizations and institutions that are necessary for success, and a strategic approach to adaptation would help to maximize efficiencies and cost-effectiveness. Additionally Canadians understand that we do not face the challenge of climate change alone. Although the climate is likely to change more in Canada, especially in the north, than in many other regions of the world, our adaptive capacity is great. We are therefore in a good position to adapt ourselves and to help others who are less fortunately positioned to cope with climate change. We also have the resourcefulness to learn from the lessons and experiences of other countries.

What could stand in our way? As the following text makes clear, given awareness and the will, existing barriers can be overcome. As climate change unfolds today, tomorrow and over the coming decades, a great deal of adaptation will be needed to complement efforts to reduce the rate of climate change through mitigation. It is important to recognize, however, that understanding of adaptation and the will to adapt come first. This chapter is an effort to contribute to the further development of that understanding and will.

BOX 1

What is adaptation to climate change?

(*modified from* Chapter 2)

Adaptation to climate change is any activity that reduces the negative impacts of climate change and/or positions us to take advantage of new opportunities that may be presented. There are many different types of adaptation (Table 1). Adaptation includes activities that are taken before impacts are observed (anticipatory) and after impacts have been felt (reactive; Smit et al., 1999). Both anticipatory and reactive adaptation can be planned (i.e. the result of deliberate policy decisions), while reactive adaptation can also occur spontaneously (i.e. autonomous, without planning). In most circumstances, anticipatory planned adaptations will incur lower long-term costs and be more effective than reactive adaptations. Other dimensions of adaptation include temporary or permanent adaptation measures, and reversible or irreversible adaptation.

Adaptation will usually not take place in response to climate change alone, but in consideration of a range of factors with the potential for both synergies and conflicts. Successful adaptation does not mean that negative impacts will not occur, only that they will be less severe than would be experienced had no adaptive action been taken. In deciding what adaptation option is most appropriate for a particular situation, attention must be paid to the feasibility and likelihood of uptake, as well as the mechanisms involved.

TABLE 1: Different types of adaptation (*modified from* Smit et al., 1999).

ADAPTATION			
Based on	Type of adaptation		
Intent *In relation to climatic stimulus*	Autonomous *(e.g. unmanaged natural systems)*		Planned *(e.g. public agencies)*
Action	Reactive *(post)* *(From observed modification)*	Concurrent *(during)*	Anticipatory *(ante)* *(Prior modification)*
Temporal scope	Short term *Adjustments, instantaneous, autonomous*		Long Term *Adaptation, cumulative, policy*
Spatial scope	Localized		Widespread

1.2 SCOPE OF THIS CHAPTER

This chapter explores how the developing momentum towards adaptation in Canada can be built upon and strengthened. It draws upon the preceding chapters in this assessment, reports of the Intergovernmental Panel on Climate Change (IPCC) and the growing body of research on adaptation, as well as steps being taken elsewhere in the world to move adaptation forward.

Section 2 of this chapter provides a brief summary of the current status and practice of adaptation in Canada; Section 3 focuses on the momentum towards adaptation and additional efforts required to support adaptation decision-making over the next decade or so; and Section 4 identifies some potential next steps.

2 STATUS OF ADAPTATION

2.1 ADAPTATION IMPERATIVE

Reducing greenhouse gas emissions alone is not enough to address the challenges associated with climate change. It is also necessary to adapt. Many impacts of climate change are now being observed across Canada (*see* Chapters 3–8) and around the world (*see* Chapter 9 and Intergovernmental Panel on Climate Change, 2007a, b). Moreover, further change is locked into the climate system — the Earth and its atmosphere are committed to centuries of changing climate, including associated sea level rise (Intergovernmental Panel on Climate Change 2007a).

> In anticipation of the impacts of climate change, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 with the fundamental objective of stabilizing greenhouse gas concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system. One of the important criteria for assessing what is 'dangerous' is the ability to adapt. The Convention therefore acknowledges that adaptation is necessary and provides for assistance to the most vulnerable countries in meeting costs of adaptation.

The question today is not whether adaptation will occur, but when and how it will occur. Some adaptation will occur spontaneously; examples of this are already apparent in Canada and around the world. In other cases, adaptation requires effective planning, co-operation and co-ordination. A proactive approach is likely to improve the success of adaptation initiatives and reduce the associated costs.

Adaptation and mitigation are complementary responses, and both are essential in addressing climate change. The role of adaptation and its relationship to mitigation have received less attention than mitigation alone (e.g. Klein et al., 2007), but it is clear that adaptation will be more feasible and effective if the rate of climate change is slower and the magnitude smaller. Although little is known about the costs of adaptation (e.g. Churchill et al. 2006; Stern, 2006), it is clear that the more the climate changes, the more difficult and costly adaptation is likely to become. Eventually there are limits to adaptation.

Momentum for adaptation to climate change is building among a few innovators. Individuals, communities, civil society, the private sector in industry, business, and commerce, and governments at all levels have roles to play in adaptation. The wide range of players highlights that adaptation can be complex, particularly at regional and national scales. Complexity also results from the unequal distribution of climate change impacts, costs and benefits by regions and localities, by economic sectors and by different social groups, as well as differences in the capacity of these players to undertake adaptive actions.

It is broadly recognized that there is a need to give greater attention to adaptation, and a positive start is being made. Understanding of the risks and opportunities arising from climate change, and the processes of adaptation, has been increasing significantly. For Canada, this progress is evident in the research results presented in the preceding chapters of this assessment. Although much of the focus has been on impacts, there are examples of practical on-the-ground adaptation, both in Canada and internationally, that are contributing to enhancing the understanding of adaptation processes.

There remain knowledge gaps. Examples of questions where further insights are needed include:

- How much adaptation can be expected to take place spontaneously by people and industry acting on their own, and in their own self-interest?

- What kind and quality of information about climate change risks is needed, and by whom and how should it be supplied?
- To what extent is guidance and promotion required?
- How can responses be co-ordinated, and how will the responsibilities and the costs be distributed?
- What level of adaptation is required in the interests of public safety?

Answers to such questions would help inform the identification of priorities for adaptation action. While the generation of more knowledge is important, it is also recognized that knowledge must be effectively communicated. Lack of understanding is one of the chief barriers to effective adaptation in Canada today.

2.2 ESTABLISHING THE FOUNDATION

The need for adaptation to 'normal' climate has always been present (Burton, 2004) and has a long history of professional and managerial practice in specific disciplines or professions. In the context of climate change, there has been rapid growth in research and writing on the subject of adaptation since the UNFCCC was opened for ratification in 1992 (e.g. Smit et al., 1999, 2000). Policy frameworks for adaptation have been developed (United Nations Development Programme, 2005), the concept of vulnerability has been elaborated upon (*see* Chapter 2), and initial quantitative measures of vulnerability have been proposed (Adger et al., 2004; Downing and Patwardhan, 2005). In addition, compendia of tools and methods for impact and adaptation assessment have been compiled (Feenstra et al., 1998; United Nations Framework Convention on Climate Change, 2005), and the need and potential for technology development and transfer have been explored (Klein et al., 2006). Thus, a strong foundation for the development of adaptation policy and the implementation of adaptation measures has been created.

Canada's approach to adaptation to climate change, like that of virtually every other developed country, remains in its early stages of development. Canadian experts have contributed substantially to the development of adaptation theory and practice through such organizations as the Intergovernmental Panel on Climate Change. Adaptation actions that make both the present and the future more sustainable, sometimes referred to as 'no-regrets' measures, are often cited as the key to moving forward despite uncertainty. Adaptations in building and infrastructure design, water and energy conservation, renewable energy generation, and diversification of economies are win-win strategies that provide useful starting points for communities to increase their adaptive capacity.

Professional, expert and management groups working within sectors are accustomed to using their own institutional processes and tools to manage risk, timing of capital stock turnover and business case presentation. These groups now share the need to factor climate change into their work, and face similar challenges in devising the best ways to achieve this. Past practices (that are still being used in many instances) make the assumption that climate 'normals' of the past will also apply to the future, and often rely on empirical analysis of the historical climate record. This assumption can no longer be considered correct, and such analysis therefore no longer provides an adequate basis for decision-making. Increasingly, efforts are being made to incorporate information on climate trends and future climate projections. Expert judgement will be increasingly required, and will be most accepted when trend analysis and climate scenarios point in the same direction. This is the case for most, but not all, climate impacts in Canada. For example, despite historical trends of decreased runoff in much of northern Quebec, climate models consistently project increasing runoff in future (*see* Chapter 5). However, for the foreseeable future, a combination of trend analysis and scenarios seems likely to offer the best strategy for incorporating climate change information into decision-making in many professional fields (Carter et al., 2007).

2.3 EXAMPLES OF CURRENT ADAPTATION ACTIVITIES

Policies and measures to cope with climate variability and extremes have long been used effectively in Canada. Indeed, much of Canadian history can be seen as the successful struggle to thrive within a harsh and varied climate. Adaptation to ongoing and future climate change will involve both a continuation of past initiatives and the introduction of new approaches. Many of the lessons learned from adapting (either successfully or poorly) to past climate, including variability and extremes, will inform future adaptation decisions. What differentiates past adaptation to 'normal' climate from adaptation to climate change are the high rate of change that is projected and the associated uncertainties. It needs to be understood that there will be no return to the previous 'normal'. Instead, we face an ongoing process of change that will continue for decades to centuries. It is therefore not a case of planning for a different stable future climate, but of building the capacity and flexibility to cope with whatever evolving climate may bring in the future.

Both implementation of operational adaptations and the facilitation of future adaptation by increasing adaptive capacity are required (Smit and Wandel, 2006). Ideally, climate change adaptation initiatives will be integrated with other programs and driven by goals that extend beyond preparing for climate change. This is just the beginning of a process of integrating (mainstreaming) climate risks into decision-making, such that adaptation decisions are based upon understanding of changes in both climatic and non-climatic factors (Klein et al., 2007).

The capacity to undertake adaptation varies greatly across Canada — between and within regions, communities and sectors — owing to a large number of economic, social, institutional and location factors (e.g. Smit and Wandel, 2006). As such, a range of motivations drive adaptation — from protecting health and safety during extreme weather events to making businesses more competitive, efficient and profitable, as well as sustaining economic development in the longer term. The examples presented in Table 2 illustrate that many actors, including individuals, community groups, the private sector and all orders of government, are involved in climate change adaptation and reflect ways that Canadians are now starting to adapt.

As noted by the Conference Board of Canada, there is considerable scope for adaptation in the private sector (Churchill et al., 2006). However, while there are indications of increasing awareness, the Conference Board report concluded that more preparations and precautionary measures are needed (Churchill et al., 2006). Industry and professional organizations, such as the Canadian Council of Professional Engineers and the Canadian Institute of Planners, are working to include climate change adaptation in their professional curriculum. Professional organizations, such as the Air and Waste Management Association and the Canadian Water Resources Association, are also placing climate change adaptation on their agendas. Obstacles to adaptation in the private sector include the perceived costs of innovation and associated competitive disadvantage in the absence of demands for higher standards from consumers or stricter codes and standards set by governments.

The role of governments in adaptation often involves finding a balance between protecting the safety of the public and facilitating and promoting adaptation without discouraging innovation, initiative and enterprise. Recent government program initiatives to facilitate adaptation are summarized in Canada's Fourth National Report on Climate Change (Environment Canada, 2006). There are some circumstances where regulation, such as revisions in the codes and standards for infrastructure, may be necessary in the interests of public safety, to ensure that changing climate risks are factored into design and construction. At the time of writing, initiatives by the Canadian Council of Professional Engineers, the Canadian Standards Association and the National Round Table on Environment and Economy are investigating various aspects of infrastructure adaptation in Canada.

The examples provided in Table 2 of adaptation by different actors are indicative of the types of responses that will be needed on a much larger scale as climate change unfolds. Exactly how such activities can best be expanded in a timely and effective manner is yet to be determined. It is clear, however, that co-operation within and between all levels of government, the private sector and civil society, as well as the research community, is essential. As in other public policy areas, serious consequences can flow from failures of integration and co-operation.

2.4 INTERNATIONAL DIMENSIONS OF IMPACTS AND ADAPTATION

The impacts of changing climate in Canada will have implications for other countries and vice versa (*see* Chapter 9). Some of this is related to competitive advantages and global trade supply-demand dynamics. For example, with a longer and warmer growing season, Canada may require less imported fresh fruits and vegetables. There are also issues associated with the impacts of climate change on human health and migration, and transboundary waters. A detailed discussion of potential direct and indirect effects on Canada arising from climate changes elsewhere in the world is presented in Chapter 9, which concludes that fully understanding the implications of climate change for Canada requires accounting for the international dimensions.

It is also important to consider international dimensions in adaptation decisions. For example, adaptation measures and policies adopted in one country could serve as trade barriers or subsidies, and thus attract attention under international trade agreements. Such possibilities lie in the future and are likely to unfold gradually. It is nevertheless important for policy-makers and industry in Canada to understand these broader economic implications of adaptation to climate change.

Many other nations, particularly those in the developing world, are likely to be more adversely affected by climate change than Canada. The higher frequency and severity of weather-related disasters are already significant obstacles to development, and create more demands for humanitarian aid (Red Cross Climate Centre, 2007). There is a growing need for technical and financial assistance to developing countries to help them adapt to climate change and associated extreme events (*see* Chapter 9). The increasing losses from weather-related disasters world-wide are also having impacts on insurance and reinsurance costs (Linnerooth-Bayer and Mechler, 2006).

TABLE 2: Selected examples of adaptation initiatives undertaken by individuals, community groups, industry and governments in Canada.

Adaptation example	References and/or chapter
INDIVIDUALS	
• Northerners are more frequently using insect repellents, bug nets and window screens to deal with the increased proliferation of insects.	Nickels et al. (2002) Chapter 3
• Hunters in the Arctic have increased the use of the global positioning systems to assist navigation in unpredictable or challenging weather.	Ford et al. (2006) Chapter 3
• Homes and cottages are being built farther back from the coast.	Chapters 4, 8
• Residents of remote coastal communities are better prepared for shortages (i.e. power, food, transportation) due to recent experience with inclement weather conditions.	Chapters 4, 8
COMMUNITY GROUPS AND ORGANIZATIONS	
• The community of Arctic Bay, NU has shifted a portion of its narwhal quota from spring to summer hunts to reduce risks associated with ice break-up conditions, and to increase chances of hunting success.	Armitage (2005); Community of Arctic Bay et al. (2006) Chapter 3
• Residents of Pointe-du-Chêne, NB organized an emergency shelter in response to increasing flooding risk, and lobbied elected officials for less vulnerable road access.	Chapter 4
• A community group in Annapolis Royal, NS undertook mapping of potential storm surges that has resulted in revision of emergency measures.	Medhi et al. (2006) Chapter 4
• The Mississippi Valley Field Naturalists published a report educating residents about the potential impact of climate change on ice safety conditions from year to year	Egginton et al. (2007) Chapter 6
INDUSTRY	
• Production barges have been used in the Mackenzie Delta rather than a land-based production facility, in recognition that higher temperatures and rising sea levels are exacerbating flood risk.	Chapter 3
• Thermosyphons have been used in the construction of several major infrastructure projects in the North to induce artificial cooling of permafrost under warming conditions.	EBA Engineering Consultants Ltd. (1995) Chapter 3
• Agricultural producers are purchasing crop insurance to offset losses caused by inclement weather.	Wittrock and Koshida (2005) Chapters 6, 7, 8
• Some forestry companies have started using high-flotation tires on their vehicles to help navigate wet or washed-out conditions, allowing them to work in a wider range of weather conditions.	Cline et al. (2006); Mellgren and Heidersdorf (1984) Chapter 7
• The forest industry in central BC is seeking to extract as much merchantable timber as possible from forests affected by the mountain pine beetle epidemic. The industry is also attempting to develop alternative markets for beetle-killed wood.	Pederson (2004)
• Producers have changed their final product (e.g., from fresh fruit to juice) when the season has not favoured original intentions.	Risbey et al. (1999); Belliveau et al. (2006)
• Ski resorts are diversifying activities offered to encompass as many seasons as possible.	Scott (2003)

Adaptation example	References and/or chapter
GOVERNMENTS	
• Municipalities along the Quebec eastern North Shore have introduced regulations to limit development in zones vulnerable to coastal erosion and flooding.	Chapter 5
• Westbank, BC has included climate change in the Trepanier Landscape Unit Water Management Plan.	Summit Environmental (2004) Chapter 8
• The town of Vanderhoof, BC is engaged in a vulnerability assessment pilot project with the Canadian Forest Service, with a specific goal of being able to plan adaptation to climate change.	Natural Resources Canada (2005) Chapter 8
• Water meters have been installed in the Southeast Kelowna Irrigation District and several Canadian cities (e.g. Kelowna, BC; Sudbury, ON; Moncton, NB) to reduce water consumption.	Chapters 4, 6, 8
• Regina, SK has increased urban water conservation efforts.	Cecil et al. (2005)
• Smog and heat-health warning systems have been implemented in Toronto, ON and Montréal, QC.	Rainham et al.(2005); Ministère de la Santé et des Services sociaux (2006)
• New Brunswick's Coastal Areas Protection Policy establishes set-backs for permanent structures and could facilitate planned retreat.	New Brunswick Department of the Environment and Local Government (2002)
• Alberta's Water for Life Strategy addresses climate change impacts in areas that are currently water-stressed.	Government of Alberta (2003)
• British Columbia's Future Forests Ecosystem Initiative incorporates climate change adaptation into forest management.	BC Ministry of Forests and Range (2007)
• Research and networking have been supported through a range of federal, provincial and territorial programs.	Environment Canada (2006)

3 BUILDING THE MOMENTUM

The role and importance of adaptation are becoming more widely recognized among scientists and governments (e.g. Intergovernmental Panel on Climate Change, 2007b; Pielke et al., 2007), and some media reports have cited the necessity for adaptation (e.g. CBC News, 2007; Graham, 2007; Harrison, 2007; Shimo, 2007). This is evident both within Canada and internationally. Current adaptation initiatives in Canada are promising indications of the determination of Canadians, from individuals to community groups, industry and government, to adapt to the changing climate.

Building on the momentum provided by these existing initiatives requires envisioning where we want and need to go. Although specific goals will vary based on their timeframe (e.g. short, middle and long term) and the groups involved, one of the commonly cited objectives is to have climate change integrated, or 'mainstreamed', into relevant decision-making processes (e.g. Klein et al., 2005, 2007). This means that climate change is not considered in isolation from the numerous other factors that influence decision-making, but rather is considered as one element of integrative analysis and policy development. One example of mainstreaming is the manner in which climate change is addressed in the environmental assessment process for major projects, such as mines and pipelines in northern Canada (*see* Chapter 3). Although this represents important progress, there are limitations to a project-by-project approach. While such an approach contributes to reducing the vulnerability of the person or agency implementing the action, it also has the potential to inadvertently increase the vulnerability of others. Therefore, it is important to think about adaptation to climate change in a more collective and strategic way in relation to Canada's future development (Office of the Auditor General of Canada, 2006).

The following four building blocks for strengthening the momentum to undertake adaptation are addressed in this section:

- maintaining and strengthening the knowledge base
- synthesizing and sharing knowledge
- removing barriers to action
- reviewing and contributing to international initiatives.

3.1 MAINTAINING AND STRENGTHENING THE KNOWLEDGE BASE

To cope effectively with climate change there must be a strong understanding of the issue. This requires knowledge of potential impacts and vulnerabilities, of projected changes in climate and of adaptation processes and decision-making. It is important to recognize key gaps in present knowledge, as well as the need to maintain sources of data.

A large component of the climate change impacts and adaptation literature is devoted to the concept of vulnerability, its assessment and qualitative or quantitative measurement. Vulnerability is a function of exposure, sensitivity and adaptive capacity (*see* Chapter 2), and is therefore influenced by both climatic and non-climatic factors. Vulnerability is generally considered greatest where adaptive capacity is low (due to limited economic resources, poor access to information and technology, or weak social networks; *see also* Chapter 2); where economic activities are highly climate sensitive; where present livelihoods are close to the limits of tolerance or viability; and where ecosystems, social systems and economies are fragile because they lack diversity or have limited resilience (e.g. Burton and van Aalst, 1999; Adger et al., 2004; Downing and Patwardhan 2005). Identifying systems, activities and populations that are currently vulnerable to climate impacts provides one basis for determining short-term priorities for adaptation measures.

Although knowledge of future climate change is based in part upon historical climate trends, it is primarily dependent on analysis using Atmosphere-Ocean General Circulation Models (AOGCMs), Regional Climate Models (RCMs) and statistical downscaling techniques (*see* Chapter 2). There have been significant advances in all of these methods in recent years, which have led to higher confidence in model projections, particularly those of mean temperature. There is, however, less confidence in projections of precipitation and other variables that are relevant to the development and selection of specific adaptation options. There is also less knowledge of likely changes in climate variability and extremes. Uncertainties will always be inherent in climate projections, as analyses are dependent upon assumptions of future development pathways and associated greenhouse gas emissions (*see* Chapter 2), as well as the relative strengths of positive and negative feedback effects and non-linear changes in biophysical systems. This is not uncertainty regarding whether climate will change, but rather about the speed and magnitude of climate change over time. Adaptation is about how to deal with an uncertain climate as well as a changing climate.

There is an ongoing need for research on climate impacts. While considerable progress has been made in modelling impacts, there remain gaps with respect to the sensitivity of physical, ecological and human systems to critical parameters and thresholds. An important recent development in impacts research is the derivation of probability density functions that capture the continuous distribution of impacts as a function of a range of future climate trends and variability (Carter et al., 2007).

With respect to adaptation decision-making, there are generic reasons to be confident that Canada can adapt well, although analysis of the costs associated with such adaptation remains a major knowledge gap. This confidence stems from the fact that Canada is comparatively well endowed with respect to the broad determinants of adaptive capacity: it is a wealthy society with a highly skilled population and access to technology, and has strong and effective institutions. However, there is a difference between having the capacity to adapt and having the will and motivation to adapt (Burton, 2003). High adaptive capacity does not necessarily translate into strong or effective adaptation (e.g. Field et al., 2007).

In any particular situation, there is a long list of possible adaptive response options (*see* Chapter 3, Table 14 for an example in the forestry sector). Such lists generally include technical, administrative and behavioural actions that could be implemented by different groups, including governments, industry and individuals. Which response, or combination of responses, is chosen depends upon costs, estimates of the risk, available technology, social and institutional constraints and opportunities, and expected benefits. For example, adaptation choices to deal with drought at the farm level are influenced by financial institutions, producers of farm inputs (seeds, fertilizers, machinery and equipment) and several kinds of government programs (e.g. crop insurance). Ultimately, the choices made will reflect the specific circumstances of the decision-makers, including how they perceive the risks and the opportunities.

Dealing with uncertainties and non-specific predictions can present challenges for gaining consensus on adaptation decision-making. Risk management techniques are often used to address decisions under uncertainty (Bruce et al., 2005). Generally speaking, the resolution to these challenges lies in strategies that will be robust against a range of different climate scenarios (e.g. Risbey, 1998; Cohen and Kulkarni, 2001).

3.2 SYNTHESIZING AND SHARING KNOWLEDGE

The rapidly evolving nature of the climate change issue and the large scope and quantity of research on climate change impacts and adaptation necessitate the undertaking of periodic science assessments and the effective transfer of knowledge to decision-makers. This report, *From Impacts to Adaptation: Canada in a Changing Climate 2007,* represents the second national-scale assessment of climate change impacts and adaptation in Canada, the first being the 1998 *Canada Country Study* (Environment Canada, 1998). The spatial scale of national assessments allows demonstration of the breadth and seriousness of the climate change issue, but limits their application to detailed adaptation planning. Therefore, it is also desirable to have assessments at local and regional scales, and assessments that focus on specific sectors. At present, there are ongoing assessments being undertaken in Quebec (Ouranos Consortium, 2007) and Alberta (Sauchyn et al., in press). A sectoral assessment for health (Seguin, in press) is also underway.

Consideration should be given to undertaking specific local and community-based assessments (places, sectors, risks) on a regular basis, with major integrating assessments more widely spaced in time. For example, the European Union (EU) has proposed undertaking semi-decadal syntheses based on results of EU and national research programs (European Commission, 2007a). Ongoing updates of relevant science and observational data and trends are also valuable for monitoring evolving climate and the first-order impacts against the projections that inform adaptation planning. Assessments can provide a foundation for the development of government, business and community adaptation strategies and measures. Assessments also help to direct future research, by identifying knowledge gaps and stimulating new ideas.

Although periodic assessments provide a vehicle for integrating large volumes of scientific information, the transfer of the resulting knowledge to a wide range of decision-makers, including the general public, is also critically important. Raising awareness of risks and opportunities that climate change presents to Canadians, and the role that adaptation can play in responding to climate change, represents the first communication task.

There is also much that can be learned through sharing of information and experiences outside of formal assessment processes. Places that are anticipating water stress in the future can look to places already experiencing such challenges, such as the Okanagan Valley (Cohen and Neale, 2006) or the Prairies, for ideas on how to adapt. Although there are relatively few examples of the effective sharing and transfer of such knowledge, there are considerable opportunities for improving the use of web-based interfaces for information dissemination and exchange.

3.3 REMOVING BARRIERS TO ACTION

Many barriers to adaptation have been identified in the preceding chapters of this assessment, including lack of awareness, regulatory or legislative barriers, and societal expectations. Limitations in access to relevant information, and the lack of tools to facilitate integration of existing knowledge into decision-making, prevent existing information from being used as effectively as possible. The focus of public and media interest on the reduction of greenhouse gas emissions has contributed to a lack of recognition of adaptation and an underestimation of its potential value.

A great deal of scientific knowledge about climate change in Canada is held and advanced by government departments and agencies, other government-supported centres and programs, universities, think-tanks, professional organizations and non-government organizations. This information could be made more accessible and user friendly and its use promoted more vigorously. Specific information is needed on potential impacts for localities and sectors, including the timing of expected changes. Interactive discussions on adaptation measures would also facilitate effective and timely choices. As with many other issues, informing key audiences and engaging them in a proactive way would likely lead to an expansion of adaptation. Ensuring widespread access to knowledge and experience, facilitated by different levels of government acting together, would be an effective way of enhancing Canada's resilience to a changing climate. Appropriate institutional mechanisms for making information on climate change available and engaging Canadians in consideration of their adaptation options could be devised.

Access to decision-support tools and data sets to support such analytical methods is also important. Climate scenarios, an area of active research in Canada, represent one important category of data delivery (Climate Change Scenarios Network, 2007; Ouranos Consortium, 2007). A recognized need with respect to scenarios is more detailed information on the probability distribution of impacts. In addition, although compilations of existing adaptation methods and tools at the international level are readily accessible (Feenstra et al., 1998; United Nations Framework Convention on Climate Change, 2005), the majority of these tools are directed towards the measurement and assessment of impacts, rather than facilitating adaptation decision-making.

As noted previously, risk management approaches are the basis for most current adaptation decision-support tools. Efforts highlighted in several of the regional chapters of this assessment (e.g. Chapters 4 and 8) could lead to prototypes for decision-making in communities across the country (Mehdi et al., 2006). Adaptation modelling, a concept that is currently in development by a number of research groups worldwide (Herrod-Julius and Scheraga, 2000; Hope, 2006; Burton, 2007; Dickinson, 2007) may eventually result in formalized, quantitative methods for evaluating potential adaptations for a particular location.

3.4 REVIEWING AND CONTRIBUTING TO INTERNATIONAL INITIATIVES

Much can be gained by reviewing and contributing to international initiatives, and through a conscious effort to draw upon such opportunities. Most of the challenges facing Canada are not unique to our country, and many regions of the world have experience dealing with climate impacts similar to those Canada is expected to see in the future. A 2006 review (Gagnon-Lebrun and Agrawala, 2006) concluded that the United Kingdom, United States, Australia, New Zealand and the Netherlands were the most advanced in implementing adaptation measures.

Workshops and conferences to share research results, experience and tools, and participation in international initiatives are all mechanisms for the transfer of knowledge. Such sharing is one of the primary goals of the Nairobi Work Program on Impacts, Vulnerability and Adaptation to Climate Change under the UNFCCC (United Nations Framework Convention on Climate Change, 2007). In addition, there are growing opportunities for the Canadian business community to play active and constructive roles outside our borders on issues of climate change adaptation (International Institute for Sustainable Development, 2003; Mitchell and Tanner, 2006). The same applies to those engaged in research and development and in technical and social innovation.

Canada also has a responsibility to help other countries (Gardiner, 2004), especially those most severely impacted by climate change and least able to adapt (Burton et al., 2006, *see* Chapter 9). This can take the form of engagement in multilateral negotiations and contributions under the UNFCCC and other forums, as well as direct bilateral assistance, and would complement efforts of multilateral agencies that highlight the importance of incorporating climate change considerations within development policy frameworks and programming (World Bank, 2006).

In addition to research initiatives and experience with implementing adaptation measures, Canadians can also learn from the experiences of other countries as they start to develop policy frameworks and tools to assist adaptation (Box 2).

BOX 2

Learning from others

European countries have generally been the most active with respect to adaptation policy initiatives, and a number now have adaptation plans in place or under development.

The European Union (EU) 'Climate Change Programme II: Impacts and Adaptation' has a mandate of "exploring its role and the scope for a policy strategy to adapt to the impacts of unavoidable climate change and how best to assist local, regional, and national efforts" (European Commission, 2007b). The program published a report entitled *Building National Adaptation Strategies* (European Climate Change Programme, 2006). A green paper examining options for EU actions emphasizes the need to develop a coherent policy response to reduce costs and enable complementary actions based on joint partnerships at the most appropriate level (European Commission, 2007a).

Within the EU, steps are being taken by several member countries, including the following:

France passed a national adaptation strategy in November 2006. The strategy takes a crosscutting approach involving initiatives based on sectors (agriculture, energy and industry, transport, buildings and habitat, tourism, banking and insurance), environment (urban, seashore and oceans, mountain, forest) and resources (water, biodiversity, health, risks). France is now implementing the recommended actions in this strategy.

The *Netherlands* has drafted a 'National Programme for Spatial Adaptation to Climate Change' (ARK) with a strong emphasis on spatial planning and addressing issues associated with sea-level rise. It contains several key elements, including the role of the government, the integration of adaptation decisions into financial processes and instruments, and the design of physical structures.

Finland completed an adaptation strategy in 2005. The strategy identifies impacts and adaptation measures for all key sectors. It identified six priorities for implementation in the period 2006–2015: 1) integrating climate change impacts and adaptation into sectoral planning; 2) improving capacities to address extreme weather events; 3) including climate change aspects into long-term investments; 4) enhancing observation and monitoring systems; 5) strengthening and focusing research and development; and 6) relating this work to the international development agenda.

The *United Kingdom* is developing an 'Adaptation Policy Framework' (APF) that incorporates feedback from public consultations held between November 2005 and January 2006. The APF will set out a structure for the roles and activities of different organizations (from central government to individuals) to ensure a comprehensive and coherent approach to adaptation and to prevent adaptation in one sector from having negative impacts upon another sector. This policy initiative complements work in the United Kingdom on tools to support adaptation decision-making (e.g. Willows and Connell, 2003; Shaw et al., 2007).

Spain has established a Climate Change Policies Co-ordination Commission, which in July 2006 approved a 'National Plan for the Adaptation to Climate Change' (PNACC). The plan provides a general reference framework for evaluation of impacts, vulnerability and adaptation to climate change.

4 NEAR-TERM STEPS

Building on the strong knowledge base summarized in the preceding chapters of this assessment, there are a number of potential steps that could help ensure that adaptation continues to move forward in Canada.

4.1 BROADENING ENGAGEMENT AND COLLABORATION

All chapters of this assessment conclude that a wide range of actors are involved in climate change adaptation (*see also* Table 2). In addition to implementing adaptation actions, community groups, industry and professional organizations, and all orders of government can help strengthen adaptive capacity.

Given the broad range of actors involved, recognition and articulation of the roles and responsibilities of each would facilitate co-operation. There is also likely to be a need for appropriate mechanisms to facilitate effective co-ordination and collaboration. Such steps form part of the development of a strategic approach to adaptation. Where adaptation is built onto existing activities, it will likely be clear who will carry out the adaptation measures or policies in question, under what authority they will act and how the costs will be distributed. Where new initiatives on adaptation are required, the situation might be more complex. Clarification of the responsibilities of individuals, industries and various orders of government will facilitate new and planned action on adaptation. Some evolution of responsibilities may need to occur as the need for adaptation to climate change becomes more apparent and more urgent.

4.2 LEADING BY EXAMPLE

Leaders, innovators and early adopters exist within all segments of Canadian society. With respect to climate change adaptation, federal and provincial governments have provided much of the leadership with respect to research and networking, while some industries, municipalities and professional organizations have led the way in implementation of adaptation measures or at least preparing to adapt. This leadership conveys to others the importance of adaptation and the benefits that can be gained through action.

This leadership could be enhanced through a more strategic approach to adaptation. Many governments and non-government organizations would benefit from undertaking reviews of existing policies and programs to assess their vulnerability to climate change, and their ability to facilitate adaptation. Such analyses have been undertaken in the United Kingdom (e.g. Department of Environment, Food and Rural Affairs, 2003) and could serve as a model for other governments concerned with climate change impacts. Similarly, industry and businesses would benefit from a review of how climate change is likely to influence their operations, planning processes and competitiveness in terms of trade and market share. Such reviews would identify areas for more detailed examination, and ultimately lead to revision of climate-sensitive operations, programs and policies that will enhance their sustainability under a changing climate.

4.3 ENHANCING INSTITUTIONAL CAPACITY

There is now a diffuse and generally unco-ordinated flow of information and advice with respect to climate change adaptation from several government agencies, the scientific community and others. Enhancing institutional capacity could help shape a more coherent and user-friendly process that would allow Canadians to access the most authoritative information about how climate change will affect them in their own businesses and localities, and to engage the appropriate expertise in discussion about adaptation options. Examples of new institutions developed to help address this gap in Canada include the Ouranos Consortium (Quebec), the Prairie Adaptation Research Collaborative and the Pacific Climate Impacts Consortium. There is also significant opportunity to enhance the capacity within existing institutions to provide information and guidance on adaptation. For example, agricultural extension services, public health authorities, water management authorities and many other such services could factor climate change into the guidance they provide.

4.4 PROMOTING AND MANDATING ADAPTATION MEASURES

In some circumstances, more than information and guidance may be required to move forward on adaptation action. This may be especially true where extra costs are involved, or where institutional or other barriers exist. In such circumstances, governments and industries may wish to take further action, such as the provision of incentives or penalties. For example, water rates could be modified for different users, and improvements in water-use efficiency could be promoted and rewarded. Insurance may also have a role to play in facilitating adaptive behaviour. A range of market-type instruments can be used to promote and persuade people to move towards effective adaptation within various sectors. In circumstances where climate change presents significant risks to the security and safety of Canadians, it may be appropriate to mandate or require adaptation actions. Prominent among these needs is the importance of ensuring that construction of buildings and other infrastructure is robust to the changes in climate, including extreme weather risks.

5 FROM VISION TO ACTION

This chapter has described current and potential adaptation options, policies and measures in the context of a vision for an adaptive and adapting society. It is intentionally non-prescriptive in the sense that no specific recommendations are directed to any one place or institution. Because adaptation is such a multistakeholder and place-specific process, heavily top-down or structured approaches would risk inhibiting the diversity of activities and innovations that are required. It is clear that, as more climate impacts are experienced, all sections of Canadian society will need to adapt. Co-operation, co-ordination and social solidarity will help ensure that this will happen, and that barriers and obstacles are removed. Moving from vision to action needs many steps by many motivated actors.

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GLOSSARY

Adaptation
Adjustment in natural or human systems in response to actual or expected climate stimuli and their effects, which moderates harm or exploits beneficial opportunities. There are various types of adaptation, including anticipatory, autonomous and planned adaptation.[1*]

Adaptation benefits
The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures. [1]

Adaptation costs
Costs of planning, preparing for, facilitating and implementing adaptation measures, including transition costs.[1]

Adaptive capacity
The whole of capabilities, resources and institutions of a country, region, community or group to implement effective adaptation measures.[2*]

Albedo
The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, whereas vegetation-covered surfaces and oceans have a low albedo.[3*]

Anthropogenic
Resulting from or produced by human activity.[1*]

Atmosphere-Ocean General Circulation Model
see Climate model

Barrier (to adaptation)
Any obstacle to reaching an adaptation goal that can be overcome or attenuated by a policy, program or measure.[2*]

Baseline (or reference)
The state against which change is measured. 'Current baseline' represents observable, present-day conditions. A 'future baseline' is a projected future set of conditions that excludes the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.[1]

Canada Country Study
Published in 1998, the Canada Country Study: Climate Impacts and Adaptation was the first Canadian assessment of the potential impacts of climate change and variability, including consideration of existing and potential adaptive responses. It focused on reviewing existing scientific and technical literature through a series of commissioned studies and regional workshops.[4]

Capacity building
In the context of adaptation to climate change, capacity building is developing the technical skills and institutional capabilities of stakeholders to enable their participation in all aspects of adaptation to, and research on, climate change.[1*]

Climate
Climate in a narrow sense is usually defined as the average weather or, more rigorously, as the statistical description in terms of the mean and variability of relevant variables over a period of time ranging from months to thousands or millions of years. Variables taken into account most often include surface temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.[1*]

Climate change
Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing factors, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.[1*]

Climate model
A numerical representation of the climate system based on the physical, chemical and biological properties of its components; their interactions and feedback processes; and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity. Coupled Atmosphere–Ocean General Circulation Models (AOGCMs) provide a comprehensive representation of the climate system. More complex models include active chemistry and biology.[1*]

Climate normal
Arithmetic calculations based on observed climate values for a given location over a specified time period and used to describe the climatic characteristics of that location. The World Meteorological Organization (WMO) considers 30 years long enough to eliminate year-to-year variations. Thus, the WMO climatological standard period for normals calculations is defined as consecutive periods of 30 years (e.g. January, 1 1901 to December 31, 1930) and should be updated every decade.[5*]

Climate projection
The calculated response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based on simulations by climate models. Because climate projections are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, they are therefore subject to substantial uncertainty.[1+2*]

Climate scenario
A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models. A 'climate change scenario' is the difference between a climate scenario and the current climate.[1]

Climate system
The climate system is defined by the dynamics and interactions of five major components: atmosphere, hydrosphere, cryosphere, land surface and biosphere. Climate system dynamics are driven by both internal and external forcing factors, such as volcanic eruptions, solar variations or human-induced modifications to the planetary radiative balance (e.g. via anthropogenic emissions of greenhouse gases and/or land-use changes).[1]

Climate variability
Variations in the mean and other statistics (e.g. standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or to variations in natural or anthropogenic external forcing.[1*]

Coping range
The variation in climatic stimuli that a system can absorb without producing significant impacts. Also known as coping ability or capacity.[6]

Critical infrastructure
Physical and information-technology facilities, networks, services and assets that, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of a population or the effective functioning of governments.[7*]

Cryosphere
The component of the climate system consisting of all snow, ice and frozen ground (including permafrost) on and beneath the surface of the Earth and ocean.[1]

Downscaling
A method that derives local- to regional-scale (10–100 km) information from larger-scale models or data analyses.[1]

Drought
The phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that often adversely affect land resources and production systems. Drought has been defined in a number of ways (e.g. agricultural drought, meteorological drought and hydrological drought). A megadrought is a long, drawn-out and pervasive drought, lasting much longer than normal, usually a decade or more.[1+2*]

Ecosystem
The interactive system formed from all living organisms and their abiotic (physical and chemical) environment within a given area. Ecosystems cover a hierarchy of spatial scales.[1*]

Ecosystem approach (ecosystem-based management)
The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It applies appropriate scientific methodologies focused on the essential structure, processes, functions and interactions among organisms and their environment, and recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.[1]

Ecosystem services
Ecological processes or functions having monetary or non-monetary value to individuals or society at large. There are 1) supporting services, such as productivity or biodiversity maintenance; 2) provisioning services, such as food, fibre or fish; 3) regulating services, such as climate regulation or carbon sequestration; and 4) cultural services, such as tourism or spiritual and aesthetic appreciation.[1]

Ecotone
Transition area between adjacent ecological communities (e.g. between forests and grasslands).[1]

El Niño–Southern Oscillation (ENSO)
El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Perú, but has since become identified with a basin-wide warming of the tropical Pacific east of the International Dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of 2 to about 7 years, is collectively known as El Niño–Southern Oscillation (ENSO). During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea-surface temperatures warm, further weakening the trade winds. This event has great impact on the wind, sea-surface temperature and precipitation patterns in the tropical Pacific, with effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña.[2*]

Emergency management
The management of emergencies concerning all hazards (natural and human-induced), including all activities and risk management measures related to prevention and mitigation, preparedness, response and recovery. Mitigation in this context refers to sustained actions taken to eliminate or reduce risks and impacts posed by hazards well before an emergency or disaster occurs, and is generally synonymous with 'adaptation' in a climate change context.[8*]

Emission scenario
A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g. greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (e.g. demographic and socioeconomic development, technological change) and their key relationships. Concentration scenarios, derived from emission scenarios, are used as input to a climate model to compute climate projections.[1*]

Evapotranspiration
The combined process of water evaporation from the Earth's surface and transpiration from vegetation.[1]

Exposure
The nature and degree to which a system is exposed to significant climatic variations.[6]

Extreme weather event
An event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as, or rarer than, the 10th or 90th percentile. By definition, the characteristics of what is called 'extreme weather' may vary from place to place.[1*]

Extirpation
The disappearance of a species from part of its range; local extinction.[1]

Feedback
An interaction mechanism between processes in a system, which results when an initial process triggers changes in a second process and that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.[1*]

Food security
A situation that exists when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development and an active and healthy life. Food insecurity may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution or inadequate use of food at the household level.[1]

Greenhouse effect
The process in which the absorption of infrared radiation by the atmosphere warms the Earth. In common parlance, the term 'greenhouse effect' may be used to refer either to the natural greenhouse effect, due to naturally occurring greenhouse gases, or to the enhanced (anthropogenic) greenhouse effect, which results from gases emitted as a result of human activities.[1]

Greenhouse gas (GHG)
Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, by the atmosphere itself and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. In addition, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances.[2*]

Grey literature
In the context of scientific and technical information, grey literature refers to electronic and print publications not published commercially or indexed by major database vendors. Some grey literature may be ephemeral and of questionable relevance or quality, but it is occasionally the sole source of information for specific research questions. Grey literature is usually not subject to peer review, and must be scrutinized accordingly.[9*]

(climate change) Impacts
The adverse and beneficial effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts.[1*]

Institutions
Rules and norms that guide how people within societies live, work and interact. Formal institutions are codified rules, such as the constitution, organized markets or property rights. Informal institutions are rules governed by social or behavioural norms of a family, community or society.[10]

Intergovernmental Panel on Climate Change (IPCC)
A panel established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988 to assess scientific, technical and socioeconomic

information relevant for the understanding of climate change, its potential impacts, and options for adaptation and mitigation.[11]

Kyoto Protocol
The Kyoto Protocol was adopted at the Third Session of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. The Kyoto Protocol entered into force on February 16, 2005.[1*]

Mainstreaming
In the context of adaptation, mainstreaming refers to the integration of adaptation considerations (or climate risks) such that they become part of policies, programs and operations at all levels of decision-making. The goal is to make the adaptation process a component of existing decision-making and planning frameworks.[12]

Maladaptation
Any deliberate adjustments in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead.[6*]

Mitigation
In the context of climate change, mitigation is an anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.[1]

'No regrets' policy/measure
A policy or measure that would generate net social and/or economic benefits irrespective of whether or not climate change occurs.[1*]

North Atlantic Oscillation (NAO)
The North Atlantic Oscillation (NAO) consists of opposing variations of barometric pressure near Iceland and near the Azores. It is the dominant mode of winter climate variability in the North Atlantic region.[1]

Pacific Decadal Oscillation (PDO)
A statistical measure of coupled decadal to interdecadal variability of the atmospheric circulation and underlying ocean in the Pacific Basin. It is most prominent in the North Pacific, where fluctuations in the strength of the winter Aleutian Low pressure system covary with North Pacific sea-surface temperatures and are linked to decadal variations in atmospheric circulation, sea-surface temperatures and ocean circulation throughout the Pacific Basin. Such fluctuations have the effect of modulating the El Niño–Southern Oscillation cycle.[3*]

Permafrost
Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years.[3]

Phenology
The study of natural phenomena that recur periodically (e.g. development stages, migration) and their relation to climate and seasonal changes.[1]

Policy instruments
The means to address a problem and achieve desired policy goals that governments can use to change socioeconomic structures and individual and collective behaviours. Instruments include provision of information, voluntary guidelines and codes and standards, regulations and market-based mechanisms (e.g. emissions trading schemes, and water pricing and allocation schemes).[12]

Proxy climate indicator
A local record that is interpreted, using physical and biophysical principles, to represent some combination of climate-related variations back in time. Climate-related data derived in this way are referred to as proxy data. Examples of proxies are tree-ring records, characteristics of corals, and various data derived from ice cores.[3]

Recurrence interval (return period)
The average time until the next occurrence of a defined event. When the time to the next occurrence has a geometric distribution, the return period is equal to the inverse of probability of the event occurring in the next time period (i.e. $T = 1/P$, where T is the return period, in number of time intervals, and P is the probability of the next event's occurrence in a given time interval).[13]

Resilience
The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the same capacity for self-organization and the same capacity to adapt to stress and change.[1]

Resource-reliant communities
Resource reliance is a measure of the relative importance of a resource sector (or sectors) to a particular community, specifically in relation to the employment income directly generated by the exploitation, processing and (in some cases) distribution of resources. Categories of resource-reliant communities range from

'moderately reliant' (30–49.9% of employment income derives from resource activity) to 'solely reliant' (80% and above).[14]

Risk
A combination of the likelihood (probability of occurrence) and the consequences of an adverse event (e.g. climate-related hazard).[12]

Risk management
A systematic approach to setting the best course of action under uncertainty, by applying management policies, procedures and practices to the tasks of analyzing, evaluating, controlling and communicating about risk issues.[15]

Salt-water intrusion
Displacement of fresh surface water or groundwater by the advance of saltwater due to its greater density. This usually occurs in coastal and estuarine areas due to reducing land-based influence (e.g. either from reduced runoff and associated groundwater recharge, or from excessive water withdrawals from aquifers) or increasing marine influence (e.g. relative sea-level rise).[1]

Scenario
A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline.[1]

Sea ice
Any form of ice found at sea that has originated from the freezing of seawater. Sea ice may be discontinuous pieces (ice floes) moved on the ocean surface by wind and currents (pack ice) or a motionless sheet attached to the coast (land-fast ice). Sea ice less than one year old is called first-year ice. Multi-year ice is sea ice that has survived at least one summer melt season.[2]

Sea-level rise
An increase in the mean level of the ocean. Eustatic sea-level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea-level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land-level subsidence. In areas subject to rapid land-level uplift, relative sea level can fall.[1]

Sensitivity
Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damage caused by an increase in the frequency of coastal flooding due to sea-level rise).[1]

Social capital
The aggregate of actual or potential resources that can be mobilized through social relationships and membership in social networks.[16]

SRES Scenarios
The storylines and associated population, GDP and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES), and the resulting climate change and sea-level rise scenarios. Four families of socioeconomic scenario (A1, A2, B1 and B2) represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns, and global versus regional development patterns.[1*]

Stakeholder
A person or an organization that has a legitimate interest in a project or entity, or would be affected by a particular action or policy.[1]

Storm surge
Generally used to refer to a temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. Negative storm surges also occur and can present significant problems for navigation.[3*]

System
An entity consisting of diverse but interrelated components that function as a complex whole. Examples include the climate system, ecosystems and market economies.[17]

Technologies (for adaptation)
Technologies that, when implemented or applied, work towards adaptation goals. They include 'hard' forms (e.g. new irrigation systems or drought-resistant seeds) and 'soft' technologies (e.g. insurance schemes or planning processes), or they can be a combination of hard and soft (e.g. early warning systems that combine hard measuring devices with soft knowledge and skills that can raise awareness and stimulate appropriate action).[18*]

Threshold
The level of magnitude of a system process at which sudden or rapid change occurs. It is also a point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.[1*]

Tools (for adaptation)
Methodologies, guidelines and processes that enable stakeholders to assess the implications of climate change impacts and relevant adaptation options in the context of their operating environment. Tools may occur in a variety of formats and have diverse applications: crosscutting or multidisciplinary (e.g. climate models, scenario-building methods, stakeholder analysis, decision-support tools, decision-analytical tools) to specific sectoral applications (e.g. crop or vegetation models, methods for coastal-zone vulnerability assessment).

Traditional knowledge
A cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment.[19]

Uncertainty
An expression of the degree to which a value is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g. a range of values calculated by various models) or by qualitative statements (e.g. reflecting the judgment of a team of experts).[1*]

United Nations Framework Convention on Climate Change (UNFCCC)
The Convention was adopted on May 9, 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It contains commitments for all parties. The Convention entered into force in March 1994. See also Kyoto Protocol.[1*]

Urbanization
The conversion of land from a natural or managed natural state (such as agriculture) to cities; a process driven by net rural-to-urban migration through which an increasing percentage of the population in any nation or region come to live in settlements that are defined as 'urban centres'.[1]

Vector-borne disease
Disease, such as malaria, dengue fever and lyme disease, that is transmitted between hosts by a vector organism (e.g. mosquito or tick).[1*]

Vulnerability
Vulnerability is the susceptibility to be harmed. Vulnerability to climate change is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability to climate change is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.[1]

Water stress
A region is water stressed if the available freshwater supply relative to water withdrawals acts as an important constraint on development. Withdrawal exceeding 20% of renewable water supply has been used as an indicator of water stress. A crop is water stressed if soil-available water, and thus actual evapotranspiration, is less than potential evapotranspiration demands.[1*]

Weather
State of the atmosphere at a given time and place with regard to temperature, air pressure, humidity, wind, cloudiness and precipitation. The term is mainly used to describe conditions over short periods of time.[20]

Winter road
A seasonal roadway constructed annually over frozen ground or frozen water bodies that provides access to and from communities and resource extraction sites not connected by permanent roads. Also referred to as seasonal road and, where built exclusively across frozen water bodies, ice road.

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* modified from source