CHAPTER 6
Ontario

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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,

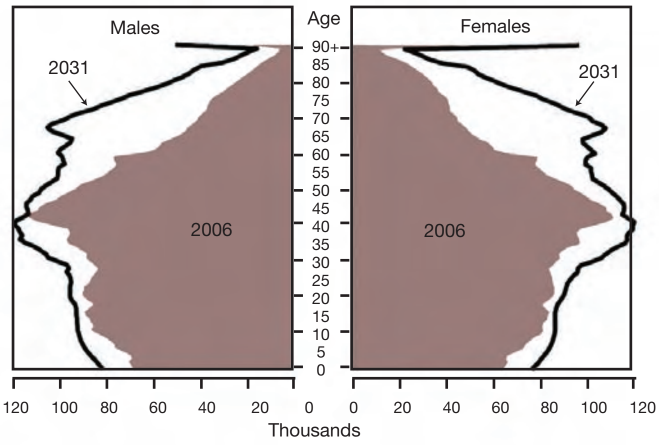


FIGURE 2: Ontario population pyramids, 2006 and 2031 (Ontario Ministry of Finance, 2006).

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.

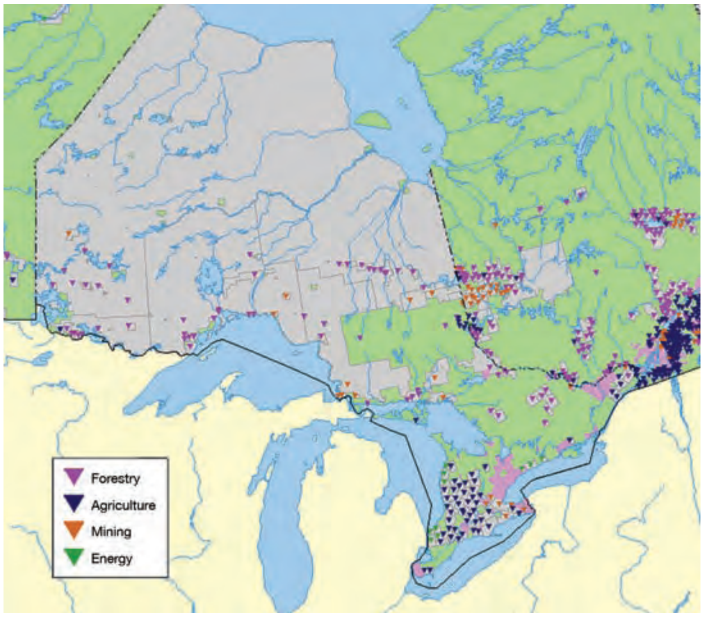


FIGURE 3: Communities in Ontario more than 30% reliant on resource-based industry (Natural Resources Canada, 2001).

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.

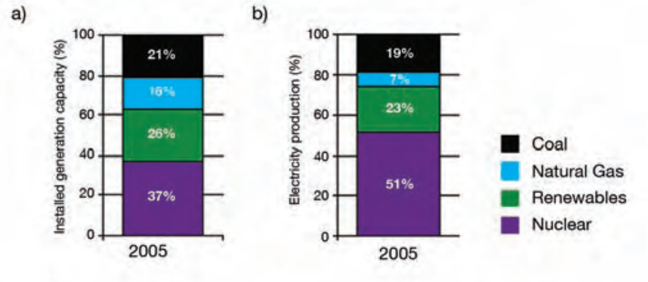


FIGURE 4: Ontario's electricity system, 2005 (Ontario Power Authority, 2005): a) installed generation capacity, and b) electricity production.

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

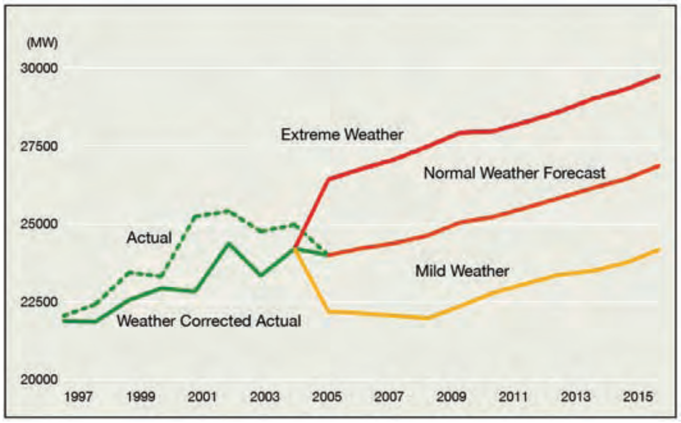


FIGURE 5: Hourly peak demand forecasts under three weather scenarios (Independent Electricity System Operator, 2005).

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).

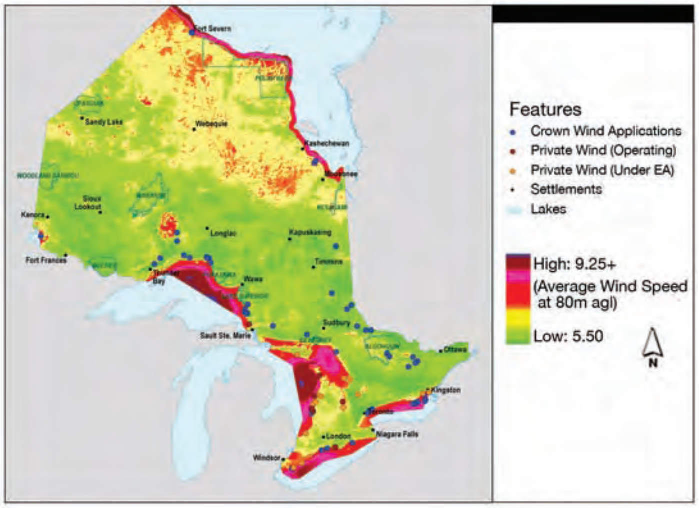


FIGURE 6: Wind power resources in Ontario (Ontario Ministry of Natural Resources, 2006a).

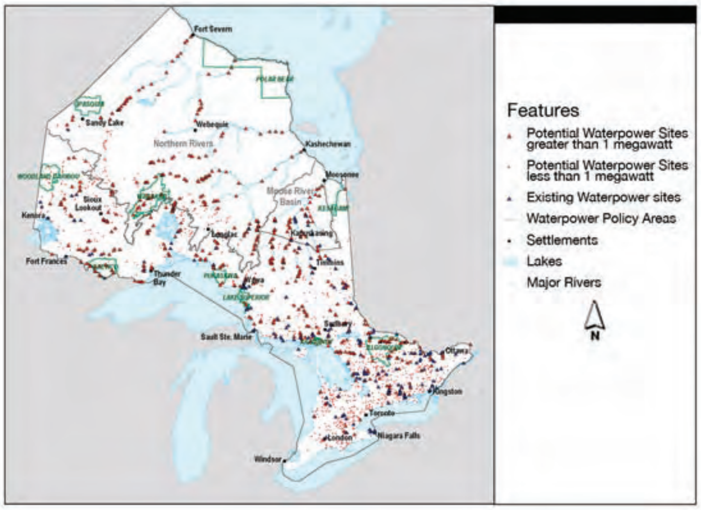


FIGURE 7: Water power resources in Ontario (Ontario Ministry of Natural Resources, 2006b).

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

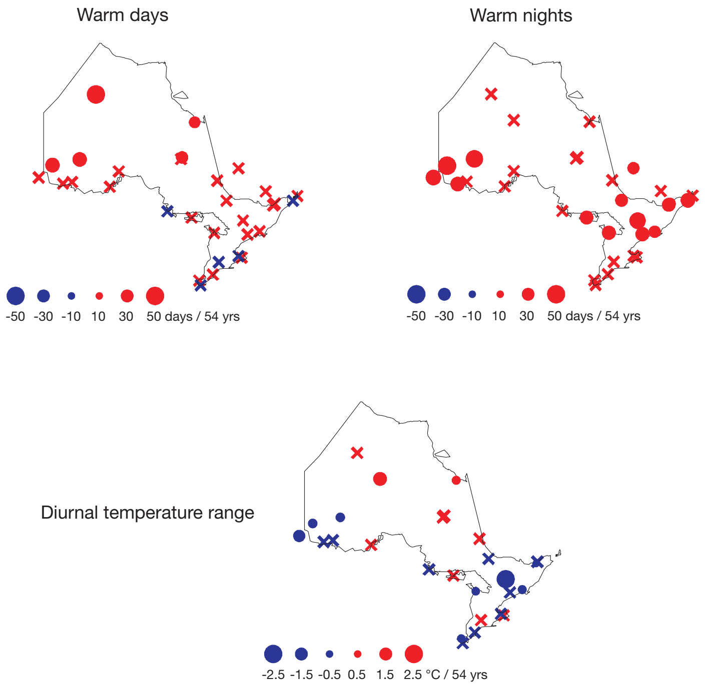
During the last half of the twentieth century (1948–2006), the period for which data are available for northern as well as southern Canada, national annual temperatures have increased by 1.3°C (Environment Canada, 2006a; *see* Chapter 2). During the same time period, annual average temperatures across 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, 2006). The largest decrease in diurnal temperature range occurred in the central subregion (Vincent and Mekis, 2006).

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, 2006). 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.

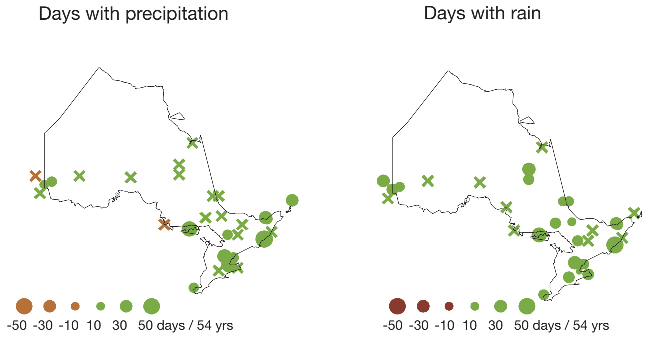
Between 1953 and 2001, days with freezing rain events occurred, on average, between 2 and almost 10 times per year, with Ottawa, North Bay and Sudbury having the highest annual averages and Thunder Bay, Kenora and Sioux Lookout the lowest. Risk of freezing rain has remained relatively stable during this 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).


Warm days

Warm nights

Diurnal temperature range

FIGURE 8: Trends for warm days, warm nights and diurnal temperature change, 1950–2003 (Vincent and Mekis, 2006). 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.


Days with precipitation

Days with rain

FIGURE 9: Trends in precipitation indices, 1950–2003 (Vincent and Mekis, 2006). 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

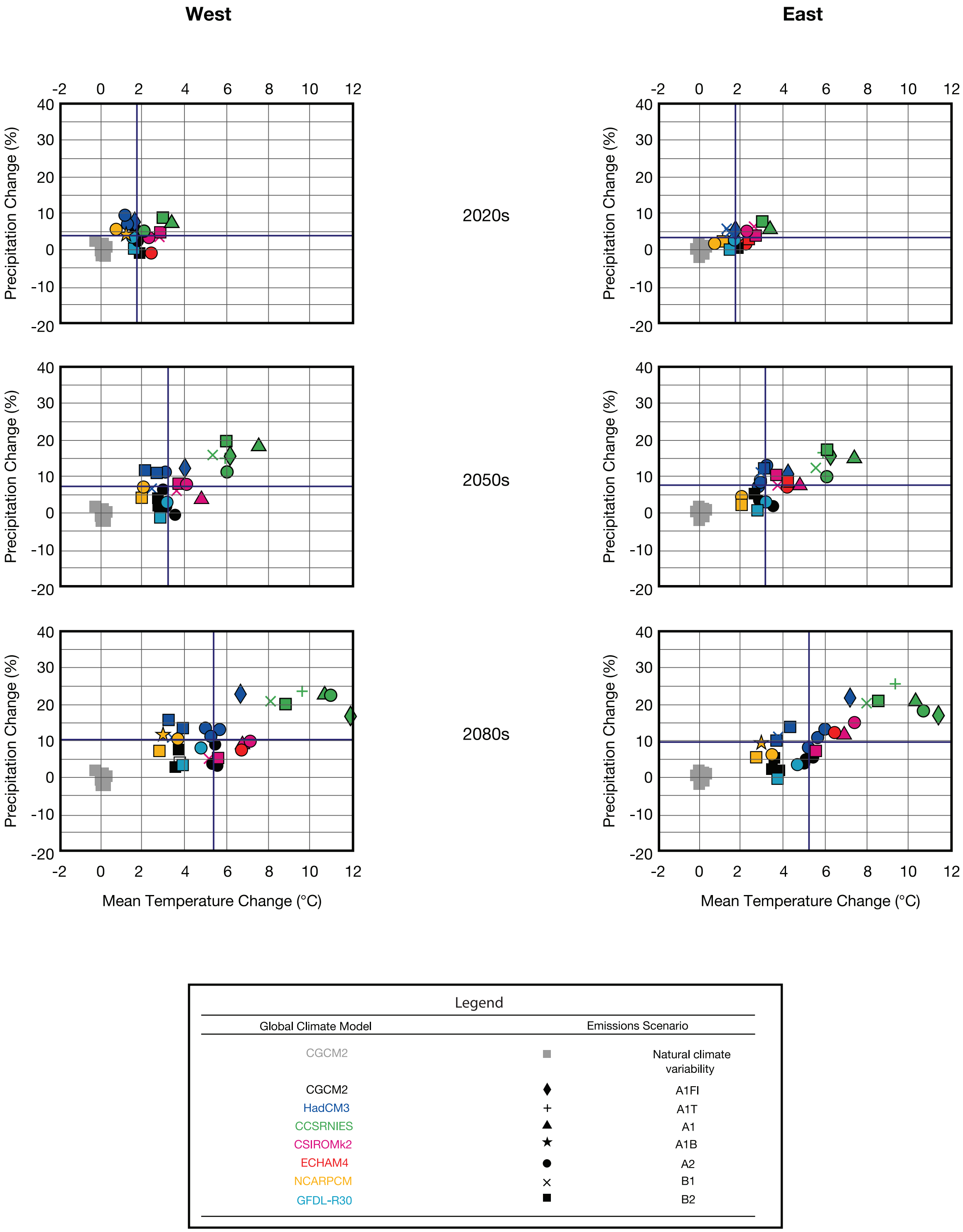


FIGURE 10: Scatterplots of projected change in annual mean temperature and precipitation. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot. (*see* Appendix 1 of Chapter 2 for details).

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.

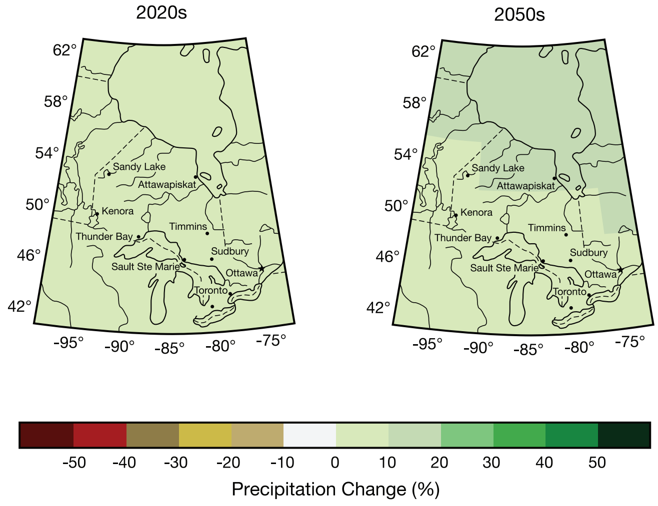


FIGURE 12: Projected annual change in precipitation (%) for the 2020s (left) and 2050s (right), relative to 1961–1990, based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

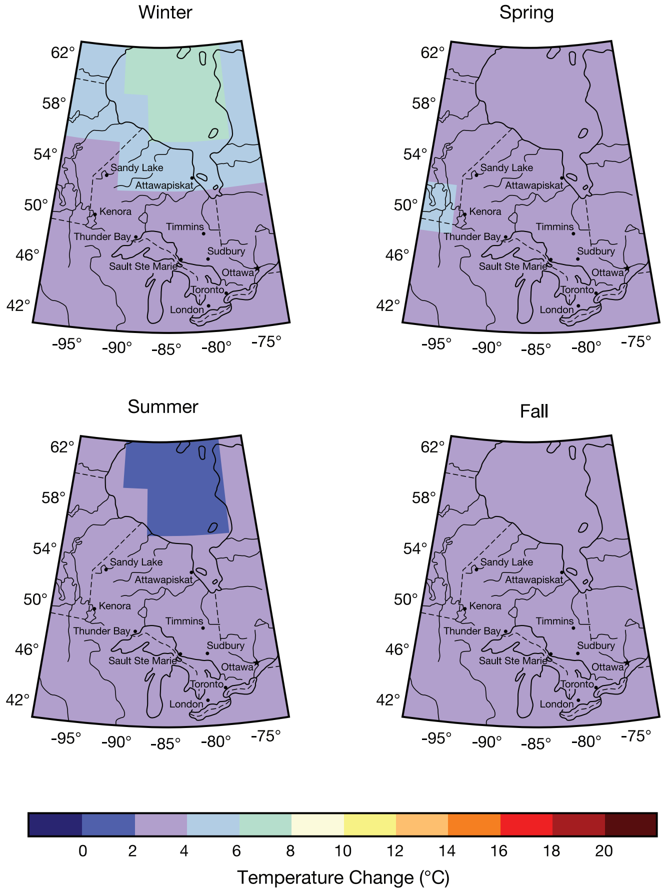


FIGURE 11: Projected seasonal change in temperature by the 2050s (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

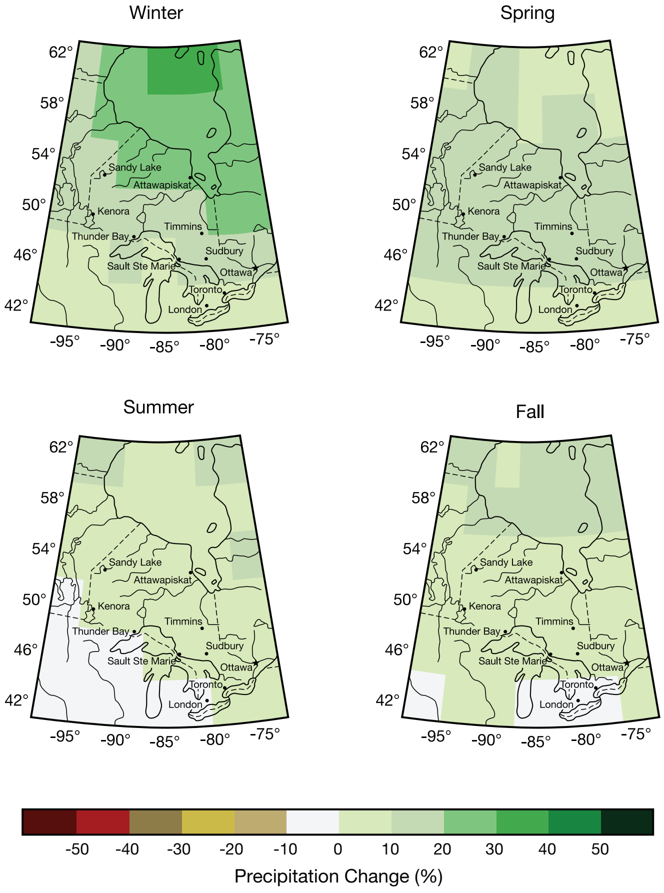


FIGURE 13: Seasonal change in precipitation (%) by the 2050s, relative to 1961–1990, based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

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).

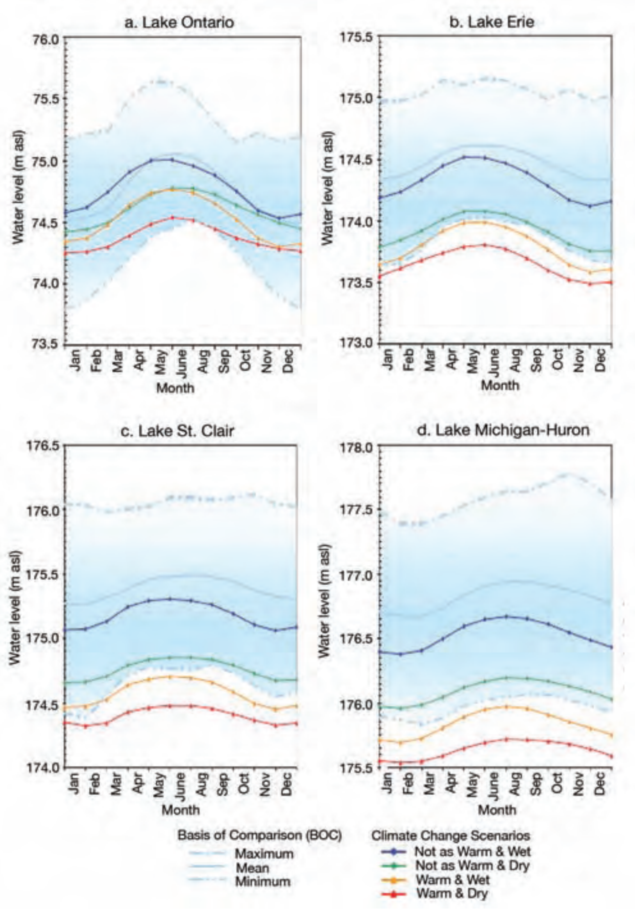


FIGURE 15: Projected changes in Great Lakes water levels (Morstch et al., 2006), based on a 101-year average for Lake Ontario (a) and a 50-year average for lakes Erie (b), St. Clair (c) and Michigan-Huron (d).

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 will likely

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).

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 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).

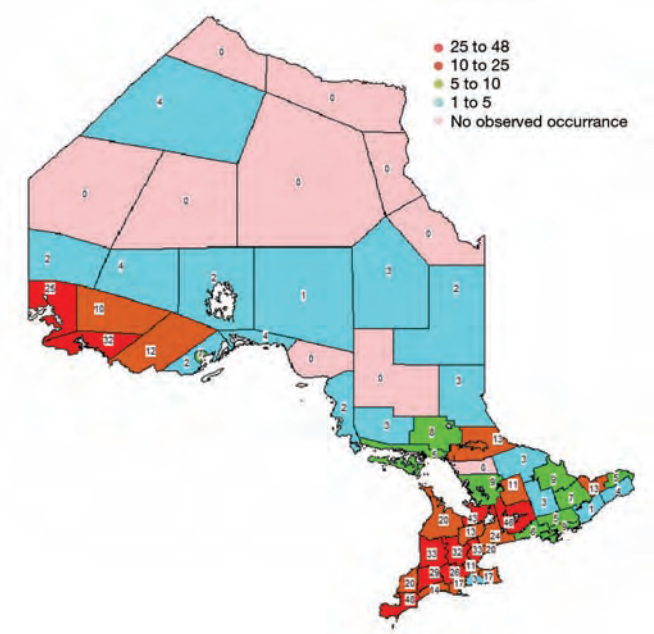


FIGURE 16: Occurences of heavy rainfall 1979-2004. Heavy rainfall is defined as rainfall that is greater or equal to 50 mm/hour or greater or equal to 75 mm in three hours (Environment Canada, 2005b).

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.

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 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).

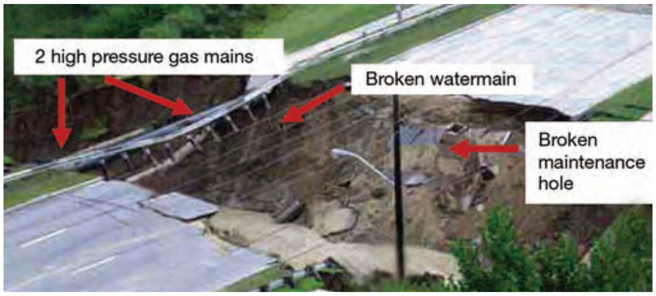


FIGURE 17: Damage at Finch Avenue and Black Creek, north Toronto flood, August 2005. Photo courtesy of City of Toronto).

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. Photo 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

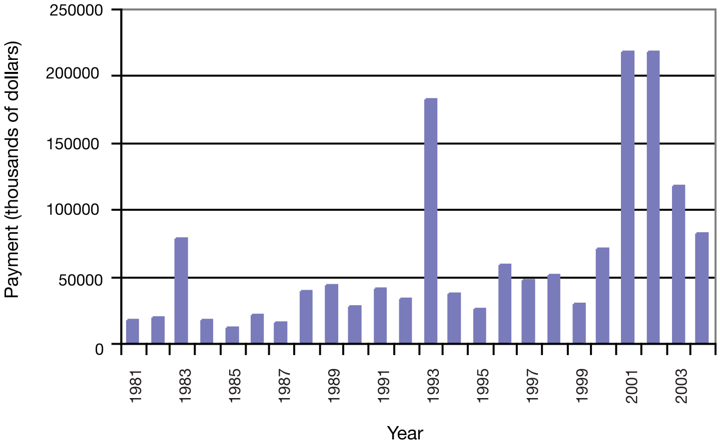


FIGURE 20: Ontario crop insurance payments, 1981–2004 (Statistics Canada, 2005).

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 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).

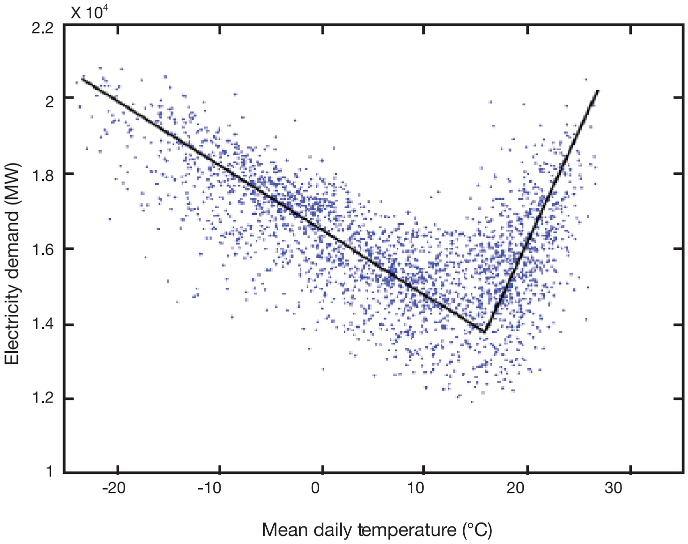


FIGURE 21: Impact of mean daily temperature on electricity demand in Ontario (Cheng et al., 2001).

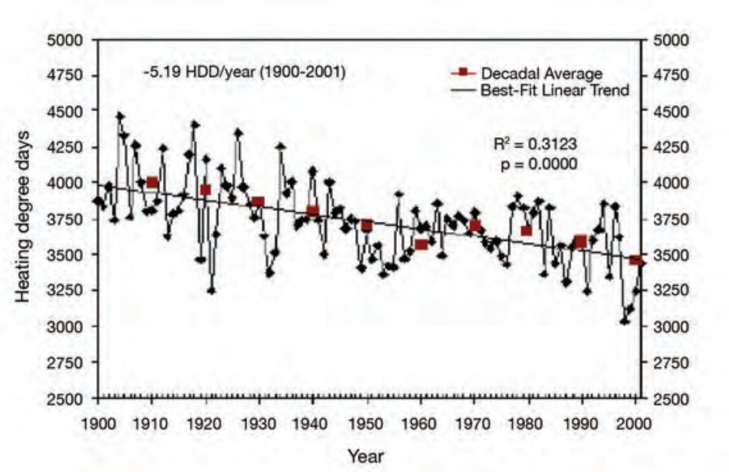


FIGURE 22: Annual heating degree days (HDD) in Toronto, 1900–2000 (Klaassen, 2003).

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).

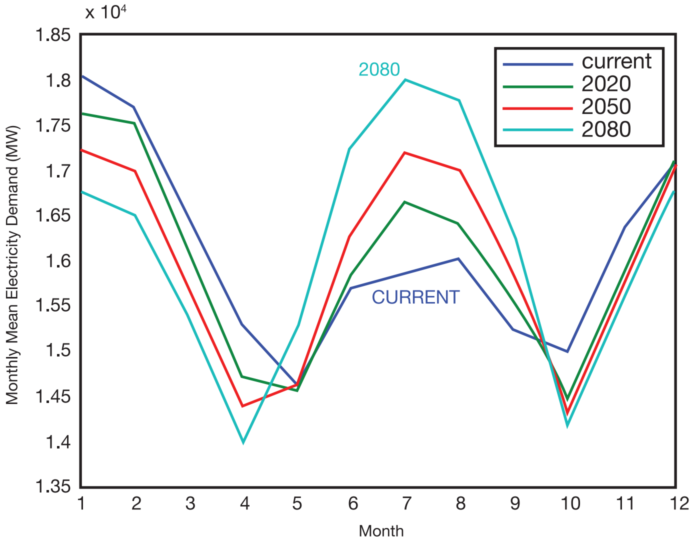


FIGURE 23: Projections of monthly mean electricity demand in Ontario as a result of climate change (Cheng et al., 2001).

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 pestmanagement, 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°C); 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.

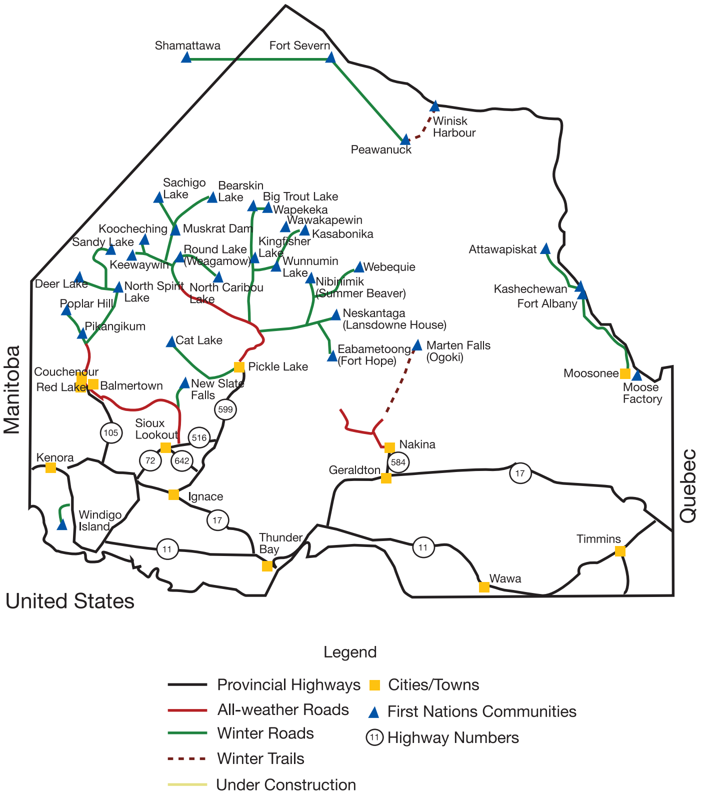


FIGURE 25: Communities and road networks in the north subregion and the western part of the central subregion (*see* Figure 1). Winter roads and trails are critical for accessing communities of the north subregion (Ontario Ministry of Northern Development and Mines, 2006a).

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	🟫	🟫	🟫
Fauna	🟫	🟦	🟫
Flora	🟫	🟦	🟦
Water			
Quality	🟩	🟪	🟫
Quantity (shortages)	⬛	⬛	🟫
Flooding	🟫	🟫	🟫
Health			
Heat	⬛	🟪	🟫
Insect/vector disease	🟩	🟪	🟫
Water quality	🟩	🟪	🟫
Air quality	⬛	🟪	🟫
Agriculture			
Drought	⬛	⬛	🟫
Energy			
Increased demand	⬛	⬛	🟫
Lower production	⬛	⬛	🟪
Forestry			
Fire	🟫	🟫	⬛
Pests and disease	🟪	🟪	⬛
Transportation			
Winter roads	🟫	⬛	⬛
Paved surfaces	⬛	⬛	🟪
Navigation	⬛	🟪	🟪
Tourism and Recreation			
Cold season	⬛	🟫	🟫

🟫 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.

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