CHAPTER 9
Canada in an International Context

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KEY FINDINGS

Climate change is already affecting the residents, economies and environments of all regions of the world through higher temperatures, sea-level rise, more frequent heavy precipitation events, more intense storms, more severe droughts, melting glaciers, changes to river flows, more evaporation, permafrost degradation, less sea and lake ice, and more heat waves. These impacts, mostly adverse, are expected to continue and intensify in the future.

The impacts of climate change and the adaptation measures that other countries take to respond to them can affect Canada in a number of ways. The effects on Canada arise from impacts that occur elsewhere in North America, the surrounding oceans or globally.

NORTH AMERICAN ISSUES

- An increase in health problems and mortality is associated with ozone precursors and small-particle emissions, with extensive transborder effects. Although longer and more intense heat waves are likely to result in the intensification of smog episodes, further reductions of these emissions in both the United States and Canada would help reduce health risks.
- Declining flows in many southern Canadian rivers are resulting in increased problems over sharing and quality of water along the Canada–United States border, including the Great Lakes.
- Growing air conditioning loads, and probable reduced hydroelectric supply in the United States and some regions of Canada, are changing transborder transfers of electrical energy.
- With increasing drought projected for the southwestern United States and Mexico, growing demands for export of Canadian water can be anticipated.

OCEAN AND COASTAL ZONE ISSUES

- Warming of the Arctic will result in reduced sea ice and increased marine traffic and development activity in Canadian Arctic waters, likely increasing the resources needed for continued protection of Canada's safety, security, and environmental and Inuit interests in the Arctic.
- Rising sea levels, increased storminess and reduced ice cover regimes increase shoreline erosion and require adjustments to road locations, port facilities, navigation systems, vessels and search-and-rescue capability on the Atlantic, Pacific and Arctic coasts.
- Impacts on fish distributions and foreign fishing patterns are poorly understood but potentially of major significance to Canadian fishing communities, thereby representing a key knowledge gap.

GLOBAL ISSUES

Health

- Diseases currently prevalent in warmer climates will become increasingly greater threats in Canada as a result of greater incidence of disease and vectors in countries that are involved in trade and travel with Canada.
- Increased transmission of persistent toxics and pollutants to northern Canada will occur as more chemicals are volatilized from warming lakes in Eurasia and North America, thereby affecting the health of northern residents and ecosystems.
- Increased international assistance to developing countries will be needed for safe water supplies and food handling, in order to reduce deaths and illness due to diarrhea and other diseases.

Population Movement

- Many people will be forced to relocate internally within countries and internationally due to sea-level rise and growing water and food shortages in many countries, with implications for Canadian policies and activities related to aid, peace-keeping and immigration.

Increased Disasters

- Weather-related disasters, including drought, are projected to continue to increase in frequency and severity worldwide, resulting in increasing need for disaster relief and assistance from Canada, and losses for those Canadians with business and property abroad.

Canadian Tourism

- In the longer term, prospects are for greater warm-season tourism in Canada. Significant adaptation by winter tourism facilities will be needed for them to remain viable.
- Less travel by Canadians to warm destinations is projected because of longer warm seasons at home.

Canadian Trade

- Increased global forest productivity could contribute to lower prices for Canadian wood products if fire and insect infestation effects abroad are minimized.
- Canadian exports of grains and corn could find greater markets, and imports of fruits and vegetables could be reduced.

Canada is in a position to — and has an obligation to — assist developing countries to adapt to climate change. Canada, together with other developed countries, has committed to reduce greenhouse gas emissions, assist developing countries with adaptation to the adverse impacts of climate change, and assist transfer of environmentally sound technology and know-how. Canada's participation in international programs in natural and social sciences related to climate change contributes to international understanding and to Canadian science assessments. The knowledge gained by Canadian experts through this participation also benefits the development of domestic policies and programs.

Understanding these international issues contributes to development of Canada's foreign policy, stimulates and protects international trade, and protects Canadian resources, environment and health. The potentially significant effects and requirements need to be taken into account by all orders of government and by many businesses. Little research has been undertaken on these issues from a Canadian perspective, although studies elsewhere, including those cited here, have important implications for Canada.

1 INTRODUCTION

1.1 PURPOSE OF CHAPTER

Climate is changing the world's economy and environment. In a world of increasing interactions between citizens and companies of different countries through travel and trade, and with migration of species and transborder threats to ecosystems, the impacts of climate change are not confined by national borders. Key issues for Canada include changes in trade, immigration and tourism patterns; transborder effects on water, health and air pollution; increasing stresses over resources; and the need for international responses to more frequent and larger disasters. In a number of cases, stresses brought about by 'economic globalization' will be exacerbated by climate change.

Northern circumpolar countries are already experiencing major climate change effects, and adaptation by one nation can have consequences for others. In all three oceans bordering Canada, changes in currents and distribution of fish, more severe winter storms, and rising water temperatures and levels will trigger actions by other countries that could have significant effects in Canada.

In short, climate change impacts and adaptation in other countries may have profound effects on Canada. This chapter is an initial attempt to identify some key issues for Canada from an international perspective and discuss possible responses.

1.2 INTERNATIONAL CLIMATE CHANGE TRENDS AND PROJECTIONS

What climate changes have other countries experienced in recent decades, and what are the likely changes over the next four or five decades? Much of the information here is drawn from the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) and from scientific publications since 2000.

Temperature

Global mean temperature has increased about 0.74°C during the past century, with the rate of temperature rise being much greater after 1979 (Intergovernmental Panel on Climate Change, 2007a). Large departures from this average have been experienced in various regions, as illustrated in Figure 1. By 2050, the range of expected warming (1.3–1.7°C relative to 1980–1999) shows limited sensitivity to the choice of emission scenarios

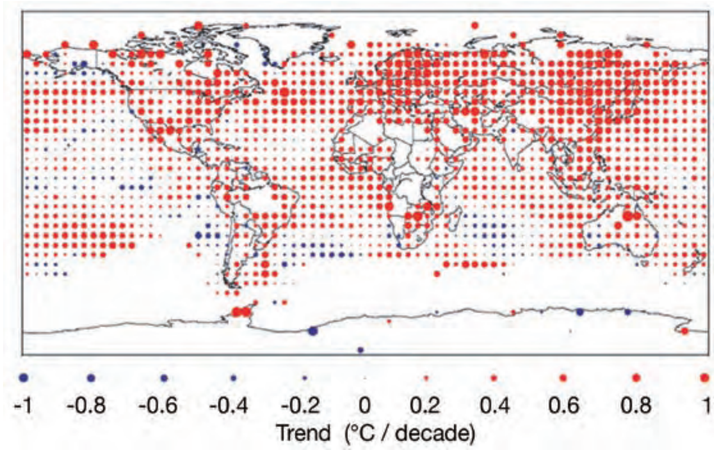

FIGURE 1: Annual temperature trends (°C/decade), 1976–2000. Red indicates warming trend, blue indicates cooling trend, and the size of circles is proportional to the magnitude of change (Folland et al., 2001).

(Intergovernmental Panel on Climate Change, 2007a). Again, large regional departures from these mean temperature values are expected. Evaporation rates will generally increase as air and especially water temperatures rise.

Precipitation

Globally averaged precipitation since the 1960s has remained largely unchanged (Gruber and Levizzani, 2006), although other estimates suggest an average increase of about 2% over land areas (Folland et al., 2001). Increases and decreases in annual precipitation for the past 3 to 4 decades are regionally variable (Groisman et al., 2005). Regions of declining rainfall include much of the Mediterranean basin and northern Sahara, southern Africa and Argentina, parts of the Middle East, northern Mexico and the southwestern United States. Global climate model projections of precipitation changes during the next few decades are somewhat inconsistent, although they suggest a continuation of the patterns observed since 1970. In many locations, it may be most useful to simply extrapolate the trends of the past few decades. In most regions, observed changes in heavy and very heavy precipitation are more significant than changes in mean precipitation (Groisman et al., 2005). The global distribution of trends in heavy precipitation is shown in Figure 2. Climate models project a continued increase in the intensity of rainfall events that have been observed in many parts of the world (e.g. Alexander et al., 2006).

FIGURE 2: Regions of disproportionate changes in heavy and very heavy precipitation. Thresholds used to define heavy and very heavy precipitation vary by season and region (*modified from* Groisman et al., 2005).

Sea-Level Rise and Oceans

Global mean sea level has increased about 18 cm during the past century, and at an accelerating rate of 3 mm/a since 1992. The further rise projected by the Intergovernmental Panel on Climate Change (2007a) for the years 2090–2099 relative to 1980–1999 ranges from 18 to 59 cm. However, these results do not include the full effect of potential changes in ice-sheet flow or breakup in Greenland and Antarctica (Intergovernmental Panel on Climate Change, 2007a). From 2001 to 2004, glacier melt contributed about 1 mm/a to sea-level rise and accounted for 20 to 30% of the total rise from 1991 to 2004 (Kaser et al., 2006). Many low-lying coastal plains and small island states are vulnerable to the rising seas, especially in storm conditions.

Globally averaged sea-surface temperatures have risen 0.4°C since 1970 and 0.6°C during the past century (Rayner et al., 2003; Pierce et al., 2006). The anthropogenic (greenhouse gas) warming signal is clearly evident in all ocean basins: Indian, Pacific, Atlantic and Arctic (Pierce et al., 2006). This has also contributed to sea-level rise through thermal expansion. Increased acidity of ocean surface layers, due to more CO_2 absorption, has also been detected and is projected to cause further reductions in pH of between 0.14 and 0.35 units by 2100 (Intergovernmental Panel on Climate Change, 2007a).

Extreme Events

Severe winter storms in the Northern Hemisphere have increased in intensity in some regions (McCabe et al., 2001), a trend that is projected to continue (Lambert, 1996; Lambert and Fyfe, 2006). This increase, combined with higher sea level, will lead to greater storm surges, shore erosion and flooding effects in many coastal areas.

The average annual number of tropical cyclones (hurricanes) has not changed, but intensities are increasing, with a greater proportion of category 4 and 5 storms observed since 1970 (Emmanuel, 2005; Webster et al., 2005). Models suggest that intensification is related to sea-surface temperatures and will continue in the future (Knutson and Tuleya, 2004).

Changes in other extreme events have been assessed by the Intergovernmental Panel on Climate Change (2001a, 2007a), and include increased frequency of high-intensity rainfall in many areas, more frequent and intense droughts in midcontinental and low-latitude regions, and an increase in areas subject to drought (Intergovernmental Panel on Climate Change, 2007a)

Other Trends and Impacts

- **Permafrost** is thawing in North America, Europe and Asia, a trend that will continue or accelerate, with resulting impacts on hydrology, wildlife and the built-environment (Intergovernmental Panel on Climate Change, 2001b; Arctic Climate Impact Assessment, 2004).
- **Snow cover** in the Northern Hemisphere at the time of spring melt (March–April) continues to decline, with more melting generally occurring during the winter months (Mote et al., 2005). Less flow in the summer and autumn dry seasons is affecting, and will continue to affect, water availability for irrigation and other uses.
- **Very dry areas** have increased globally in extent, from 12 to 30% of total landmass since 1970 (Dai et al., 2004). The Palmer Drought Severity Index (Figure 3) has shown widespread drying trends over large regions, including much of Africa. Increasing drought also characterizes many important food-producing regions, including the Great Plains of North America.
- **Wave heights** have increased by up to 1 cm/decade (1950–2002) in much of the North Pacific and North Atlantic, in the Mediterranean and along the east coast of South America (Gulev and Grigorieva, 2004), with consequent effects on shipping and drilling platforms. Recent studies indicate that these increases are expected to continue (Caires et al., 2006).
- **Greater variability in the summer monsoon rainfall** is likely causing more severe drought and flood events in India and southeast Asia (Lal et al., 2001). Monsoonal rainfall in Mexico and the northern Caribbean, the sub-Saharan grasslands and southeastern Africa has declined since 1975 (Chen et al., 2004).
- **Reduced lake-ice cover**, earlier spring algal blooms, higher spring surface-water temperatures and earlier stratification of lakes (by two to four weeks) have been observed in Europe and other temperate regions (Mortsch et al., 2003).

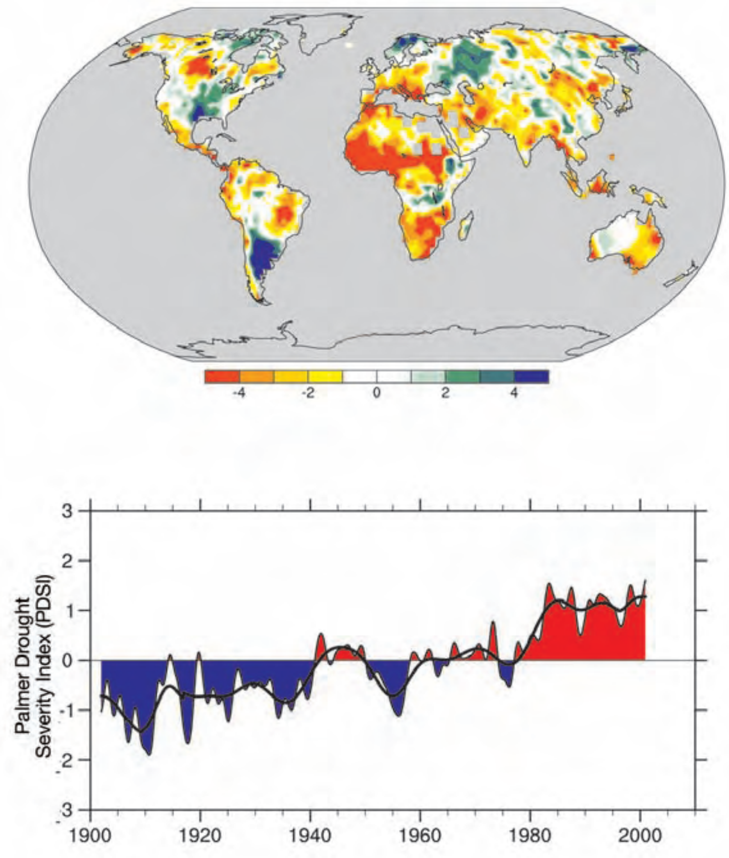

FIGURE 3: "The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. The PDSI is a prominent index of drought and measures the cumulative deficit (relative to local mean conditions) in surface land moisture by incorporating previous precipitation and estimates of moisture drawn into the atmosphere (based on atmospheric temperatures) into a hydrological accounting system. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (negative). The smooth black curve shows decadal variations. The time series approximately corresponds to a trend, and this pattern and its variations account for 67% of the linear trend of PDSI from 1900 to 2002 over the global land area. It therefore features widespread increasing African drought, especially in the Sahel, for instance. Note also the wetter areas, especially in eastern North and South America and northern Eurasia." (Trenberth et al., 2007 p. 263, which was adapted from Dai et al. 2004).

- **Phenological events** for land species are also now earlier in the year by 5 to 14 days, providing a longer growing season in the Northern Hemisphere since the 1950s for various plants and trees. Global terrestrial net primary production has increased 6% between 1982 and 1999, according to satellite measurements, especially over northern temperate latitudes (Nemani et al., 2003).
- **More heat waves** have been observed over most land areas. In addition to having major health implications and causing premature deaths (e.g. in Europe during the summer of 2003), heat waves can also result in agricultural losses, changes in ecosystems and wildlife, and increased energy demand for cooling. On the other hand, continuation of the current trend of fewer very cold days (Alexander et al., 2006) will reduce heating needs and the number of cold-related injuries and deaths.
- **Arctic sea-ice annual area** has decreased significantly (7.4%; Johannessen et al., 2004) in the 25 years prior to 2002. The year 2005 had the least Arctic sea-ice extent in September since satellite observations began in 1979. These changes, projected to continue, could accelerate the use of shipping channels and exploration for oil, gas and minerals, but have adverse effects on wildlife and hunting activities of Arctic people (*see* Section 3.3 of this chapter, as well as Chapter 3).
- **Widespread retreat of glaciers** is underway in the western Americas, the Alps and most of the Himalayas, threatening key water supplies in South American countries (Mark and Seltzer, 2003) and elsewhere. Total ice loss from the Greenland Ice Sheet in 2005 was double the 1996 value (Rignot and Kanagaratnam, 2006), contributing to freshening of northern North Atlantic waters, although the central ice cap has either remained unchanged or perhaps thickened due to greater snowfall. The freshening of the northern extension of the Gulf Stream may be weakening thermohaline (meridional overturning) circulation, including the Gulf Stream. If this persists as predicted, it would result in less warming than would otherwise occur in Europe and northeastern North America (Intergovernmental Panel on Climate Change, 2007a).

Based on these trends and impacts, as well as consideration of adaptive capacity, the regions assessed as being most vulnerable to the risks associated with climate change and sea-level rise are the Arctic, sub-Saharan Africa, small islands and Asian megadeltas (Adger et al., 2007). Nevertheless, all regions have vulnerable areas, communities and sectors (Adger et al., 2007).

2 GLOBAL ISSUES

2.1 OVERVIEW OF GLOBAL IMPACTS AND ADAPTATION — EQUITY ISSUES

Geographic Equity

Climate change involves a classic case of inequity between the rich and the poor of the world. The people and countries that have grown wealthy through economies driven by fossil fuels are visiting upon the poorest countries damaging changes in the form of disasters and threatened water and food supplies, due to a changing climate. These poorest and most vulnerable countries contribute least to the global greenhouse gas burden (Intergovernmental Panel on Climate Change, 1994; Stern, 2006). The disparity between rich and poor due to social and economic factors is likely to be exacerbated by climate change (Intergovernmental Panel on Climate Change, 2001c).

Coastal communities may also suffer disproportionately from climate change because some of the most pervasive impacts are those arising from warming of the global oceans. This contributes to sea-level rise, more intense and long-lived tropical cyclones, and redistribution of fish populations. Impacts on coastal areas and nearshore communities include erosion of beaches and shorelines, loss of coral reefs, and more frequent and severe flooding of low-lying areas during storms. Without significant adaptation measures, an additional 80 million people are at risk of flooding in coastal areas by the 2080s, and the problem is only going to increase with time (Parry et al., 2001).

Impacts on human health through changes in water availability and quality, spread of tropical diseases, impacts on food systems, and natural disasters also affect most seriously the poorest communities, those least able to adapt (Intergovernmental Panel on Climate Change, 2001b, 2007b). Subsequent sections outline some of the ways in which Canada can support adaptation in less developed countries. Sustainable development pathways can help significantly to reduce the impacts associated with climate change (Intergovernmental Panel on Climate Change, 2007b).

Intergenerational Equity

In addition to concerns over geographic inequity, the climate change issue is also characterized by inequity over time. Emissions now, will have impacts, mostly adverse, on many future generations. For example, if greenhouse gas concentrations were stabilized at 2006 levels (379 ppm CO_2), sea level would continue to rise for more than 500 years due to thermal expansion and for thousands of years due to melting of ice on land (Intergovernmental Panel on Climate Change, 2007a). Adaptation measures in coastal regions require long-term strategies.

2.2 NATURAL DISASTERS, INSURANCE AND REINSURANCE, AND HUMANITARIAN ASSISTANCE

Extreme weather events can become natural disasters when they strike vulnerable communities that are unable to manage the risk and unprepared to cope with the hazard. People in Canada can be affected by natural disasters in other countries through indirect impacts on the availability and cost of goods and services, changes in financial markets, and requests for donations of money, clothing and food. An example was the spike in oil and gas prices in Canada following Hurricane Katrina in 2005, and the storm's impact on Gulf oil production (Kovacs, 2005).

The potential impacts of climate-related trends, and their continuation under the changing climate, have important implications for the insurance industry, as well as human suffering. These trends also indicate an increasing need for humanitarian emergency assistance abroad, and the importance of assisting developing regions with disaster-loss-mitigation projects as an adaptation to climate change.

Changing Conditions

As the global population continues to grow, and exposure of infrastructure to weather-related disasters increases, economic losses are also expected to increase. However, there is evidence that losses from climate/weather events have been rising at a greater rate than would be expected from changes in exposure alone. It is also evident that the frequency of severe weather events resulting in major losses, such as storms, floods and droughts, has also been rising. The global number of severe damage-causing storms has increased from an average of 150 per year in the early 1980s to between 250 and 300 per year in the period 2000 to 2004 (Mills, 2005). Total property losses (excluding health impacts) have been rising twice as fast as would be expected due to growth in world economies and population (Mills, 2005). Thus, a portion of the growth in disaster losses is attributable to a changing climate, as demonstrated by the increase in climate extremes of various kinds (*see* Section 1.2), and is consistent with climate model projections (Intergovernmental Panel on Climate Change, 2001a, 2007a). This has occurred despite attempts in many countries to reduce losses through, for example, tougher building codes, better warning systems and flood-loss-reduction projects. Nevertheless, the improved warning systems have resulted in fewer fatalities in the 1990s than in the 1970s, even as affected populations have risen dramatically (Figure 4; World Meteorological Organization, 2006).

In 1975, worldwide economic losses due to severe weather disasters, adjusted for the effects of inflation, were US$4 billion; 30 years later, losses in 2005 were more than US$200 billion, representing a fifty-fold increase (Munich Reinsurance, 2006). Property damage payments by insurance companies also increased fifty-fold during this period, from US$1.6 billion to US$83 billion, again adjusted for the effects of inflation. Although the insurance industry has been in business for more than three hundred years, seven of the ten most costly disasters affecting the industry have occurred since 2001 (Mills, 2005). Data from the Centre for Research on Epidemiology of Disasters indicates that 80% of all natural disasters in the decade from 1996 to 2005 were meteorological or hydrological, and that more than 1.5 billion people worldwide were affected by weather- and water-related disasters between 2000 and 2004 (United Nations Educational, Scientific and Cultural Organization, 2006).

The International Federation of Red Cross and Red Crescent Societies (2004) studied 3000 natural disaster events that occurred around the globe between 1994 and 2003. More than 80% of these were high-impact weather-related events. During this period, 580 000 fatalities and economic losses of US$680 billion were recorded, and an average of 250 million people per year displaced from their homes. More than 95% of the damage to property was recorded in affluent or moderate-income countries, with the largest losses in the United States. In contrast, more than 90% of the disaster fatalities and 98% of the people displaced by disasters lived in moderate- or low-income nations, primarily in Asia and Africa (International Federation of Red Cross and Red Crescent Societies, 2004). High-impact weather is largely an economic shock in affluent countries like Canada, but severe weather in poorer countries is also a significant threat to life, health and safety.

In highly developed countries, the average number of deaths per disaster is 23, whereas the number increases dramatically to more than 1000 deaths per disaster in less developed countries (World Meteorological Organization, 2006). Although the absolute dollar costs of disasters in highly developed countries are large, they are usually much less than the gross domestic product (GDP) of the country (Handmer, 2003). Although Hurricane Katrina caused large losses, it was a small fraction of the United States GDP. In contrast, losses from the hurricane in 1998 in Honduras

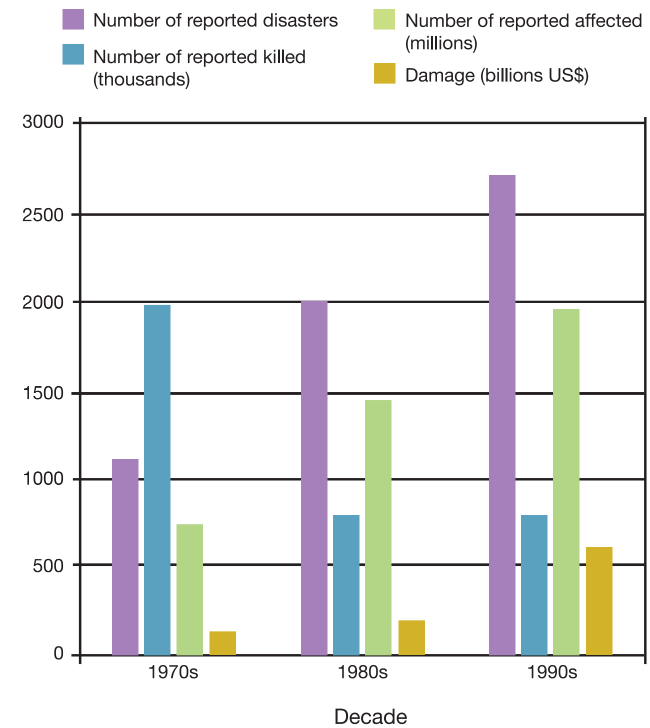

FIGURE 4: Global frequency of natural disaster impacts and associated human and economic losses from the 1970s to 1990s (World Meteorological Organization, 2006).

amounted to more than 75% of its GDP. In Central America and the Caribbean, damages from hurricanes can set back national economic development for years by diverting investments from growth to recovery (International Strategy for Disaster Reduction, 2005a).

International Assistance

Canadians have long supported international disaster-relief efforts, and this support has increased in recent years. The tsunami in south Asia, drought in Africa, and hurricane damage in the Caribbean, Central America and the United States are some recent events that have led to significant support from people across Canada.

International and Canadian assistance to disaster victims has been growing for several decades with the increase in extreme events. An important challenge is to look beyond disaster relief and begin to build resilient communities that are better able to cope with the threat of high-impact weather. The period of rebuilding following a natural disaster can be an ideal time to invest in disaster-resilient infrastructure and buildings, as well as relocation, rather than put people and infrastructure back in harm's way. In addition, this is a period appropriate for investment in non-structural disaster-risk-reduction activities, such as improved warning and preparedness systems and appropriate land-use changes. These concepts are important for disaster-loss-reduction assistance.

International Insurance

The global insurance industry provides the primary mechanism used to value and pool the threat of property damage due to high-impact weather.

The cost of insurance for homes and businesses has increased in recent years in regions where new research shows that the expected future damage is higher than historical damage. This has been evident in Florida and along the Gulf coast of the United States. In most markets, however, the cost of property insurance has been stable or declining when measured relative to the value of the property. Some severe weather events did not affect the cost of insurance. For example, the 1998 ice storm, the most costly event faced by Canadian insurers, did not result in higher rates because it was generally viewed by the industry as a risk that has not changed in likelihood. Moreover, more than 90% of the factors affecting the cost of insurance (e.g. frequency of theft or urban fires, or vehicle repair costs) are not related to weather, so increases in severe weather damage may have only a modest impact on the overall cost of comprehensive insurance policies.

Some companies insure insurance companies; this is called reinsurance. Much of the cost of repairing property damaged by severe weather events is borne by the reinsurance industry, through the payments it makes to insurance companies. The reinsurance business is volatile. Insurance companies are paying more for reinsurance in regions where there is a growing risk of severe weather events, such as the Caribbean and the Atlantic coastal region of the United States. This has placed the cost of insurance beyond the reach of many less well-off citizens of these affected regions. To date, however, the cost of reinsurance has been stable for insurance companies in Canada.

Supply of International Goods and Services

Extreme climate events affect the availability and cost of goods and services purchased by Canadians. The impact of Hurricane Katrina on gasoline supplies and prices was noted above (Kovacs, 2005). Severe weather has, at times, affected the harvest of such crops as coffee and oranges. Increased hurricane activity has disrupted Canadian vacation plans to Mexico, the Caribbean and the United States. Many Canadian individuals and companies own property at risk, especially in Florida, the Gulf States and the Caribbean, and have faced major increases in insurance premiums.

Large disasters can influence international financial markets, in which many Canadians invest. Such disasters have impacted certain sectors, particularly energy and food, as in the case of Hurricane Katrina. These shocks frequently have an immediate impact on the Canadian financial markets, even if the disaster struck in a distant location.

2.3 TRADE ISSUES

Canada, perhaps more than any country in the Organisation for Economic Co-operation and Development (OECD), has good reason to ask how climate change might affect its patterns of international trade, since trade occupies an exceptionally strong position in the national economy. Canadian exports and imports as a percentage of gross domestic product stood at 70% in 2006, and trade directly contributed 12.8% to GDP (Foreign Affairs and International Trade Canada, 2006).

The most likely impacts of climate change on international trade stem from its potential to fundamentally alter the basis for comparative advantage — one of the key drivers for trade. These impacts may manifest themselves by:

- altering the competitiveness of Canadian producers (for better and for worse);
- similarly altering the competitiveness of foreign firms that compete with Canadian producers, both in the Canadian market and in third-country markets; and
- leading to policies that will, in turn, impact competitiveness in foreign markets.

The third factor (impacts of policies) lies outside the scope of this analysis. The first two factors are illustrated below by exploring climate change implications for some of Canada's key export sectors: forestry, agriculture and fisheries. Energy is dealt with in Section 4.2.

It is not possible to say with certainty what the impacts of climate change will be for Canada's trade patterns in any of these sectors. In many cases, there is still some uncertainty regarding the regional and local changes in climate, and about the dynamics of the linkages between those changes and biophysical impacts (e.g. on net primary productivity). Moreover, some types of impacts (such as extreme weather events) can at best only be expressed in terms of probability. And, although the literature focuses most heavily on supply-side issues, highly speculative assumptions about mid- to long-term demand for Canada's exports are required to translate this research into price impacts. Finally, there is a range of climate change models, sectoral models and assumptions about mitigation and adaptation from which to choose, resulting in a range of plausible scenarios.

Forestry

Forestry is one of Canada's leading export sectors. Forest products amounted to more than 10% of Canada's total merchandise exports, averaging $45 billion per year in the five years ending

2005 (Table 1). The forest sector as a whole creates direct employment for more than 370 000 people (Natural Resources Canada, 2001) and an estimated 555 000 indirect and induced jobs (Natural Resources Canada, 2005).

The biggest export market by far is the United States, which takes some 85% of Canada's forest product exports and is where Canadian softwood producers compete directly with American producers. China, Japan and the European Union are the other important export markets. Pulp and paper products dominate the export picture, accounting for roughly half the value of merchandise trade (Table 2). Primary wood products and wood fabricated materials roughly split the remaining half. Most production is centred either in the east (Quebec and Ontario) or the west (British Columbia and Alberta), the former accounting for more of the processed exports and the latter accounting for more primary exports. Exports of wood paneling have steadily increased during the last decade, now displacing the once prominent newsprint exports that, along with wood pulp exports, have steadily declined during the same period (Natural Resources Canada, 2005).

TABLE 1: Canada's major global export sectors (millions of 2005 dollars; Industry Canada, 2006).

Sector	Value (millions of 2005 dollars)					Percentage (2005)
	2001	2002	2003	2004	2005	
Mineral products	61 560	53 826	64 996	72 373	92 651	21.3
Vehicles, aircraft, vessels and other transportation equipment	97 394	98 988	90 107	91 199	89 676	20.6
Machinery: mechanical, electrical, and electronic appliances or equipment	56 785	52 601	47 764	51 589	54 286	12.5
Base metals and articles of base metals	24 946	26 591	24 934	30 690	32 613	7.5
Wood pulp, paper	27 769	26 471	24 102	24 677	23 707	5.4
Products of the chemical or allied industries	16 275	16 890	16 877	20 106	22 881	5.3
Wood and wood articles	19 127	19 023	17 694	22 003	20 316	4.7
Plastics, rubber and articles made from these materials	15 628	16 180	15 791	17 088	18 210	4.2
Live animals and animal products	11 274	11 830	9 701	9 912	10 522	2.4
Vegetable products	10 284	9 013	9 118	10 258	9 480	2.2
Food products, beverages, spirits, tobacco products	8 436	8 912	9 207	9 523	9 176	2.1
Total exports	**404 085**	**396 381**	**381 000**	**411 840**	**435 641**	**88.0**

TABLE 2: Canada's forest products exports by region (Statistics Canada, 2004).

	Value in 2004(millions of current dollars) Percentage					
	Quebec	Ontario	Alberta	British Columbia	Other	Canada
Primary wood products (mostly softwood logs)	4 580	3 204	1 902	9 174	2 189	18 860
	24.3 (%)	17.0 (%)	10.1 (%)	48.6 (%)	10.4 (%)	
Wood-fabricated materials (lumber, plywood)	7 246	5 653	1 467	4 954	3 343	19 321
	37.5 (%)	29.3 (%)	7.6 (%)	25.6 (%)	14.8 (%)	
Pulp and paper products (pulp, paper, newsprint)	11 896	8 978	3 399	14 693	5 601	38 966
	30.5 (%)	23.0 (%)	8.7 (%)	37.7 (%)	12.6 (%)	

Climate change will affect the productivity, distribution and species composition of North American forests (Shugart et al., 2003; Lemmen and Warren, 2004). Studies tend to consider either the impacts on forest productivity (the results of temperature change and increased CO_2 fertilization) or the impacts of disturbances, such as fires, pests, drought and storms. There are, unfortunately, only a handful of studies that integrate these two research streams.

Studies of the first type tend to predict that more timber will be available during the next century as a result of increased productivity — the result of a longer growing season, increased precipitation (in places) and increased CO_2 fertilization (Medlyn et al., 2000; Irland et al., 2001; Sigurdsson et al., 2002), although there is still some uncertainty on whether the latter would have more than a short-term impact. Specific effects will vary by region as a function of differing climate changes, pre-existing conditions and forest type. For example, although increased temperature generally leads to greater productivity, it may mean more drought conditions for the western aspen parklands, resulting in significant dieback (Hogg et al., 2002).

Studies of forest disturbances frame predictions in terms of lost forest area. Modelling by Sohngen et al. (2001) estimated that some 1.6 million ha of the forest decline that occurs annually in North America is attributable to climate change. A number of insect pests expand their range as winter temperatures increase (Hogg et al., 2002; Williams and Liebhold, 2002; Carroll et al., 2004). The boreal forest, where insect damage may constitute up to twice the damage done by fires, is particularly vulnerable (Volney and Fleming, 2000). Fire hazard is also a significant problem, with a number of studies predicting longer, more severe Canadian fire seasons under climate change scenarios (Li et al., 2000; Flannigan et al., 2001, 2005; Brown et al., 2004; Gillett and Weaver, 2004). Most predict higher risks in western Canada and lower risks, due to projected increased precipitation, in the eastern boreal forests. Flannigan et al. (2005) saw the possibility of a doubling of annual area burned in Canada by 2100. Lightning strikes and forest area burned are projected to increase in the United States as well.

The combined effects of increased moisture stress, increased fire hazard and increased pest activity seem most likely to adversely affect British Columbia and Alberta. British Columbia's mountain pine beetle infestation is already affecting trade, causing accelerated salvage harvest and presaging a supply crunch in the medium term (Natural Resources Canada, 2005; *see also* Chapter 8). It has now begun to spread east, with about 2.8 million trees affected in Alberta as of spring 2007 (Alberta Sustainable Resource Development, 2007). Quebec and Ontario are the other two major producers of forest products, with a strength in pulp and paper, and they may experience the benefits of both increased precipitation and increased productivity in some subregions of the provinces. Potential gains in regions of Ontario, however, would be tempered by losses in other parts of the province resulting from reduced soil moisture and drought stress (*see* Chapter 6).

One of the few global analyses to include both the effect of increased productivity and that of disturbances is Sohngen et al. (2001). Although this study predicts a net expansion of Canadian (and North American) forests by 3 to 4%, it notes that dieback in North America will be more pronounced than that experienced by our global competitors (28–29% versus 6–14%, respectively). The economic result of increased North American supply is predicted to be lower prices for forest products, not compensated for by increased sales (Sohngen and Sedjo, 2005). Moreover, increases in productivity in North America will be less pronounced than for other producers (e.g. 17% versus 32–42% respectively; Sohngen et al., 2001). This single study suggests that there will be lower world prices (depending on assumed demand) and a smaller share of the global market for Canadian (and North American) producers.

In the final analysis, prices for Canada's exported forest products seem likely to fall as supply increases. In western Canada, this may be a short-term phenomenon, driven by accelerated salvage harvesting (*see* Chapter 8). The increased productivity of global competitors will add to this effect, particularly as it concerns non-American export destinations. The increased volumes exported may not be sufficient to compensate for lowered prices.

Agriculture

Agriculture is another important export sector for Canada, averaging 5% of total merchandise exports over the five-year period ending in 2005 and more than $20.2 billion in annual sales (Table 1). Canadian producers are keenly aware that they will be impacted not only by changing climate within Canada but also by climate events in other parts of the world, as reflected by the following headlines in *The Western Producer* (2006): 'U.S. wheat struggles in drought' and 'Australian drought alters auction business' (Duckworth, 2007).

Grains and oilseeds, and products thereof, dominate this sector in Canada, accounting for some 40% of the value of merchandise exports (Agriculture and Agri-Food Canada, 2005). Live animal and red meat exports, mostly to the United States, have traditionally also been strong in this mix at around 25%, but have dropped to 20% since the 2003 trade bans in key export markets resulting from bovine spongiform encephalopathy (BSE). The United States was the destination for more than 60% of Canada's agricultural exports in 2004, with Japan and the European Union the next most important markets at 9.4% and 6%, respectively.

Wheat is Canada's largest crop in terms of both area planted and export value; it is the single largest agricultural earner of export revenue, at $3.8 billion in 2004 (Agriculture and Agri-Food Canada, 2004).

As noted in the various regional chapters in this volume, the agricultural sector in Canada can expect both positive and negative impacts from climate change. Positive impacts include longer growing seasons, increased productivity from warmer temperatures and CO_2 fertilization and, in some areas, decreased moisture stress. Negative impacts include increased moisture stress in many areas, increased losses from pests, more difficult crop planning due to increased climatic variability (with wrong choices resulting in crop losses) and increased crop damage from extreme weather events (e.g. heat waves, hail, floods, drought). Impacts on water availability — a key issue in arid areas such as the Great Plains (the location of most wheat production) and the interior valleys of British Columbia — will be a function of small changes in rainfall and heat-induced increases in evapotranspiration.

The net impacts on Canadian agriculture are uncertain (Lemmen and Warren, 2004). At a general level, the effects of increased temperature and increased CO_2 concentrations are understood: they will bring increased net primary productivity and increased moisture loss. Less clear are other key variables: water availability and incidence of weeds, pests and disease. These uncertainties are largely a function of limitations in modelling of local/regional climate changes (e.g. changes in precipitation patterns, variability/predictability of climate behaviour, incidence of extreme weather events).

In the case of the United States, Thomson et al. (2005a, b, c) derived greater certainty from their assessments. Areas such as the American midwest and southwest, where water resources are a limiting factor, may experience problems as water becomes more scarce and interannual variability of water supply increases significantly. For example, wheat yield potential was adversely affected by the 2005 drought, when Oklahoma and parts of Texas had deficits of more than 50 cm from normal rainfall averages (The Western Producer, 2006). Irrigated winter wheat is expected to increase in acreage, while irrigated soybeans and corn are expected to decrease. But these results do not consider a host of complexities, such as regional/local effects, pests and weeds. The model also ignores extreme weather events such as flooding, which some researchers assert would significantly alter standard modelling results (Rosenzweig et al., 2002).

At the global level, in a study covering four major crops and five regions, Parry et al. (2004) predicted that climate change will probably exert a slight to moderate negative impact on yields, but this assumes no negative impacts from the types of disruptive stresses noted above. In scenarios involving high-end temperature increases, they found that cereal yields decreased much more in developing than in developed countries. Canada would experience slight increases in productivity, although local/regional effects are not well mapped.

Rosenzweig and Iglesias (1999), using models that similarly ignore many potential negative impacts, found that Canada's production of grains and protein feed could increase by a mean (across three models) of 15.7% and 20.7%, respectively, at 550 ppm of atmospheric CO_2 and with some adaptive actions; the corresponding figures for the United States are –4.7% and 0%, respectively. Wheat exports stand to do particularly well under most scenarios, with Canadian productivity increasing while most other countries would see declines. Only New Zealand's wheat production performs as well as Canada's in these models, with China and the Commonwealth of Independent States also experiencing large gains. Latin America and the Middle East experience huge losses, with Africa also losing significantly. More recent studies suggest that crop production increases in mid to high latitudes are likely to become decreases with average global temperature increases greater than 3°C (Intergovernmental Panel on Climate Change, 2007b).

A final layer of complexity is added to the agricultural sector results by the unpredictability of adaptive actions. Countries' capacity to adapt will significantly affect the results: for example, African yields in many scenarios drop, but poor adaptive capacity may mean that the impact there will be far worse than for other regions with similar projected declines in yield (Parry et al., 1999).

In Canada, the climate would become more favourable for fruit and vegetable production in several regions, potentially lessening dependence on imports. Canada's competitive advantage may increase in the growing of wine-producing grapes over hotter, drier regions of Australia and California, for example. In the end, most models predict increased productivity for Canadian growers across a range of crops relative to global competitors. Those models are limited in scope, however, and the survey by Lemmen and Warren (2004) probably yields the most reliable results, ending on a note of uncertainty. The impacts of a number of potentially negative influences are not well enough known to fully understand the productivity effects. Long-term price impacts will therefore be similarly difficult to predict.

In the final analysis, it is possible to predict with some certainty the broad-brush effects of climate change in the short term: increased Canadian agricultural productivity, particularly in cereals such as wheat, relative to trading partners in developing countries but to a lesser extent relative to United States producers. It is not yet known, however, to what extent these general trends will be moderated by disruptive negative influences, such as extreme weather events and pests.

Fisheries

Fisheries exports, valued at $4.3 billion in 2005 (Fisheries and Oceans Canada, 2005), contribute less to the Canadian economy than forestry and agriculture, but they are still significant and account for a disproportionate amount of income in certain communities. A little over half of the value in this sector is shellfish exports, dominated by lobster, crab and shrimp. Another 15% of the export value is salmon, with some two-thirds of that being Atlantic salmon.

The fisheries sector is addressed in detail in Section 3, and also in the regional chapters. Fish stocks are known to be vulnerable to climate change. However, they are also subject to a host of other influences that make climatic impacts difficult to isolate. Direct effects stem from increased water temperatures and altered oceanic circulation. Indirect climate effects include altered freshwater temperatures and runoff patterns, disruptions to other links in the food chain (i.e. changes in food and nutrient supply), contributions to toxic algal blooms, and the synergistic effects of climate change and such forces as human predation, pollution and ozone depletion.

Although the precise nature of the impact of climate change on Canada's global fisheries trade is not known, the potential for disruption is well illustrated by the collapse of the Atlantic cod fisheries — formerly a major export stock. There is evidence that climate change (in tandem with overfishing) played a significant role in that collapse (Rose, 2004). There is also concern that climate change–induced reductions in snowpack may reduce stocks of Pacific salmon (Mote et al., 2003). Section 3 notes the threats to sockeye salmon populations from a warming trend in the eastern North Pacific, and also the possibility that such anadromous species will alter their range to put them out of the reach of Canadian fishers. Fisheries, and particularly pelagic fisheries, are an international management issue; the dynamics of climate change–induced impacts, such as altered distribution and abundance of fish stocks, will make that management challenge much more difficult (Miller, 2000; Jurado-Molina and Livingston, 2002; Harley et al., 2006).

Other Issues

Trade in environmentally sound technologies for adaptation (Klein et al., 2006), such as disaster proofing and low–water usage techniques, as well as in low–greenhouse gas (GHG) technologies, is expected to increase. To take advantage, companies in Canada should be encouraged to develop such technologies for adaptation as well as for mitigation. The impact on Canada's auto sector, whose main market is the United States, may depend on the fuel efficiency of vehicles manufactured here, or on which parts are manufactured here. Although there may be concern regarding potential disputes over trade and environmental laws and agreements, surveys of the potential conflicts (Charnovitz, 2003; Cosbey et al., 2003; Magnusson, 2004) tend to agree that, for the most part, there are few conflicts that cannot be avoided by careful drafting of environmental measures.

Research Gaps

The uncertainties and data gaps relevant to this section's discussions on fisheries, agriculture and forestry are addressed elsewhere in this volume, as well as being touched upon above. It was noted that few global forestry studies managed to integrate a focus on productivity with a focus on disturbances, such as fires and pests. The same sort of gap exists in agriculture, where none of the global studies surveyed considered the impacts of extreme weather events or pests.

With respect to trade in these sectors and the economic impacts that climate change might have on Canadian interests, there are a few key research gaps. The few outputs from global-level models have not yielded information specifically relevant to Canada, tending to aggregate Canada and the United States into a single North American entity. Any assessment of the economic and trade impacts on Canada will necessarily involve a greater degree of complexity, and differentiation between Canada and the United States.

Conclusions

This section offers an overview of the potential impacts of climate change on Canada's international trade patterns. Although it seems clear that there will be significant effects, further analysis is needed to better understand the breadth of potential impacts. Furthermore, additional study is needed to clarify the nature of these impacts.

That said, there are good indications regarding the general direction of change. From an economic perspective, the impacts on the forestry sector are likely to be most significant, as productivity in Canada may decline relative to that of overseas competitors and prices could decline as a result of increased global supply. Agricultural impacts are also likely to be significant, as Canadian productivity in important export grain crops increases relative to world trends (but potentially less so relative to United States producers). It should be stressed that any predicted outcome makes assumptions about adaptive behaviour (even if implicitly assuming it does not take place) and that appropriate adaptation will be key in ensuring that the risks and opportunities identified above are adequately addressed in the Canadian context.

2.4 CLIMATE CHANGE IMPLICATIONS FOR CONFLICT

The impacts of climate change can make life in an affected region more difficult and even render areas uninhabitable. Regions may experience higher temperatures, changes in precipitation patterns, desertification, sea-level rise, and more frequent and/or severe extreme weather events due to climate change (Brooks, 2004). These impacts can, in turn, threaten food production, reduce freshwater supplies, lead to loss of land and infrastructure, and increase the incidence of disease (Barnett and Adger, 2003). Such changes can induce migration, which may occur peacefully or may generate conflict.

The causes of many conflicts are very difficult to isolate. Very few are considered to be mainly due to environmental stresses. Nevertheless, environmental stress and related issues of scarcity may contribute additional stress to political, social, economic, ethnic, religious or territorial conflicts, or conflicts over resources or national interests (cf. Gleick, 1990; Lonergan, 1998).

The number of active armed conflicts increased to more than 50 in the early 1990s, and then declined to fewer than 30 in 2003 (Human Security Centre, 2005). The increase and subsequent decline were entirely the result of conflicts within countries, which account for more than 95% of all armed conflicts. One of the major reasons for the decline in the number of armed conflicts is a dramatic increase in international activities designed to stop existing conflicts and prevent new ones (Human Security Centre, 2005). These activities include preventive diplomacy missions, peace-making missions, peace-keeping operations and sanctions by the United Nations and other groups (Ackermann, 2003; Human Security Centre, 2005). Canada has a history of contributing to such efforts.

Although future impacts of climate change could lead to new conflicts and/or exacerbate conflicts caused by non-climatic factors, this relationship is unclear. Empirical research confirms that environmental scarcity causes large population movements, which can, in turn, cause conflicts (e.g. Baechler, 1998). Where armed conflicts result, these tend to be persistent, diffuse and subnational rather than between states (Homer-Dixon, 1991; Baechler, 1998). There would be value in Canada and other countries giving further consideration to how foreign policy and development resources can best be used to mitigate the potential for such conflicts, in recognition that climate change may serve as a contributing factor.

2.5 IMPLICATIONS FOR INTERNATIONAL MIGRATION TO CANADA

Canada has been a destination for international migrants throughout its history. Immigration is governed by the *Immigration and Refugee Protection Act* of 2002 and its regulations. The act makes a clear distinction between the basic social, cultural and economic goals of the immigration program and the humanitarian goals of the refugee protection program. During the past decade, immigration to Canada has fluctuated between 175 000 and 250 000 per year, including between 22 000 and 33 000 refugees. In 2005, 32.0% of the refugees came from Africa and the Middle East, 33.1% from Asia and the Pacific, 21.3% from South and Central America and 11.2% from Europe (Citizenship and Immigration Canada, 2006).

Migration on all scales — rural to urban, between urban areas within a country and internationally — is driven by a combination of 'push' factors associated with the origin and 'pull' factors associated with the destination (Castles and Miller, 1993). The adverse impacts of climate change will exacerbate existing conditions of environmental degradation and contribute to internally displaced persons and migrants (Stern, 2006). Gradual changes, such as reduced crop yields or water supplies, induce migration because the affected area becomes less attractive. People will be drawn to locations with better opportunities, relatives and friends, and other perceived advantages (Cragg and Kahn, 1997; Deane and Gutmann, 2003). Historically, migration due to the impacts of climate change has been overwhelmingly within the same country (Baechler, 1998). There is no reason to expect this pattern to change. Friends and relatives within the immigrant community could make Canada an attractive choice for some international migrants.

Under international law, refugees are defined by the United Nations High Commissioner for Refugees (UNHCR) as individuals who flee their country because of fear of ethnic, religious or political persecution, or to escape conflict, and cannot rely on the protection of their own government (United Nations High Commissioner for Refugees, 2006). The UNHCR notes that "accurate use of the term 'refugee' implies a need for international protection" (United Nations High Commissioner for Refugees, 1993, Chapter 1, p. 3). The global number of refugees was about 14 million at the end of 2004: about 4.8 million Palestinian refugees and 9.2 million refugees of concern to the UNHCR in other countries (United Nations High Commissioner for Refugees, 2005).[3] The number of refugees of concern to the UNHCR has declined steadily from about 12.1 million at the end of 2001 (United Nations High Commissioner

[3] In addition, there were about 10 million asylum-seekers, returned refugees, internally displaced persons (IDPs), returned IDPs, stateless persons and others of concern to the UNHCR.

for Refugees, 2005). In Africa, there were just over 3 million refugees, mostly located in countries bordering countries with internal armed conflicts.

El-Hinnawi (1985) defined 'environmental refugee' as a person forced to leave his/her traditional habitat due to an environmental disruption that jeopardized his/her existence and/or seriously affected the quality of his/her life. Although the term 'environmental refugee' is used in some climate change literature, it is controversial. People displaced by environmental changes need assistance but generally do not need protection, and therefore do not fit the definition of refugee. It may be more appropriate to refer to persons displaced by environmental degradation.

Estimated recent numbers of persons displaced by environmental degradation, and future projections that consider impacts of climate change, are presented in Table 3. There is limited empirical support for these estimates (Black, 2001), although it is widely accepted that environmental change contributes to internal and international migration, and that the number of migrants may be large. Myers and Kent (1995) projected the number of 'environmental refugees' in 2050 at 150 million, with about 100 million being from low-lying coastal areas, 50 million from agriculturally dislocated areas and 1 million from island states. Myers (2005) has since increased his estimate of the total to 200 million. Most of the people displaced by environmental change are expected to be in Africa and Asia, geographically remote from, and hence less likely to migrate to, Canada. Closer to home, rural land degradation and desertification are a significant cause of migration within and from Mexico (Leighton, 1998).

TABLE 3: Estimates of 'environmental refugees' (persons displaced by environmental degradation).

Estimate of environmental refugees	Date(s) covered by estimate	Source
About 10 million	1980s	Jacobson (1988)
About 64 million	1980s	Lonergan (1998)
About 15 million	1990	Westing (1992)
Up to 25 million, of whom 25–33% are international and the balance internal: 16 million for Africa, 6 million for China and 2 million for Mexico	1990	Myers (1993)
About 150 million	2050	Myers and Kent (1995)
About 200 million	2050	Myers (2005)
8.6 million forced migrants due to 1 m rise in sea level		Tol (2002)

By making life in a region difficult or impossible, the impacts of climate change will cause internal and international migration (McLeman and Smit, 2005). These impacts are most likely to affect rural areas of poor countries geographically remote from Canada. The risk that 'waves of environmental refugees' will spill across Canada's borders, with consequent destabilizing effects on domestic order and international relations, is low (Homer-Dixon, 1991). Nevertheless, climate change could lead to pressure on Canada to accept more immigrants and refugees. [4]

2.6 HEALTH EFFECTS

Canadians are influenced by health issues abroad, including changes in abundance and virulence of diseases in countries with significant travel, tourism and trade to and from Canada. Other health issues, such as those due to a rise in the number and severity of natural disasters, result in increased calls on Canada for assistance (*see* Section 2.2).

In many regions of the world, malaria, hemorrhagic dengue fever, malnutrition and diarrheal diseases are on the rise for several reasons, including changing climate. Using data compiled by the World Health Organization (WHO), it has been estimated that climate warming to 2004 contributed to more than 150 000 deaths and 5 million illnesses per year (Patz et al., 2005). This same study projected a doubling of these tolls by 2030 as a result of climatic and other changes (e.g. population distribution, water pollution). The greatest threats are increased malnutrition and malaria in Africa, more diarrheal cases in southeast Asia and natural disasters in Latin America and the Caribbean. The following sections expand on some of these issues. Poorer countries of the world are the most vulnerable to such impacts (Intergovernmental Panel on Climate Change, 2007b). Technical assistance and humanitarian aid programs in Canada will likely be pressured by these trends.

Diseases

Diseases such as cholera follow warm spells, such as warm El Niño episodes in South and Central America, and would likely spread in a warming world. Some tropical and subtropical diseases transmitted by ticks, insects and wildlife are an increasing threat to Canada in a warming climate (*see* regional chapters in this report). Vector-borne diseases, including malaria, dengue fever and Lyme disease (transmitted by ticks) may expand their ranges in North America (Intergovernmental Panel on Climate Change,

[4] New Zealand has programs that grant residency to 1750 people each year from Pacific Island countries (New Zealand Immigration Service, 2005): Samoa (1100), Fiji (250), Tonga (250), Tuvalu (75) and Kiribati (75). Although climate change is not an official reason for the programs, all of these small island states are vulnerable to sea-level rise.

2001b). To date, active disease prevention programs have virtually eliminated diseases such as malaria from Canada, but continued vigilance will be needed, as will assistance to reduce impacts abroad.

Diarrheal diseases represent another significant health risk, resulting in thousands of premature deaths in poorer countries with inadequate food and water treatment and inspection, especially in Africa, southeast Asia and the eastern Mediterranean (Campbell-Lendrum et al., 2003). It has been estimated that, globally, a 5% increase in the number of cases of diarrhea occurs per degree Celsius of warming (Campbell-Lendrum et al., 2003).

Temperature Extremes

Increases in the length and intensity of heat waves will impact heat-related illnesses and mortality. Warm night-time conditions, which allow little relief from the heat, are an important component of heat waves. Global-scale analysis indicates that more than 70% of the global land area experienced a significant increase in the annual occurrence of warm nights during the period 1951 to 2003, with especially high increases in the number of warm nights per decade occurring in western Africa, Eurasia, northern South America and western North America (Alexander et al., 2006).

The heat wave in August 2003 resulted in the greatest climate impact on mortality in European history — from 27 000 to 40 000 excess deaths (Kovats and Jendritzky, 2005). Premature mortality and increased hospital admissions in heat waves are expected to be more frequent in many regions, although a reduction in severe cold-related deaths is anticipated in temperate and subpolar regions. Several cities around the world, including some Canadian cities, have instituted adaptation measures to reduce the impact of heat waves, including heat warnings and preparedness services, and 'green roofs' with vegetation on large buildings to reduce the heat-island effect of cities (*see* Chapters 5 and 6).

Food Security

Health problems and mortality due to more severe drought and famine are increasing in some regions and decreasing in others due to the changing climate. Although the relationships between crop productivity and climate are complex (Easterling et al., 2007), most studies project decreases in crop yield potential at low latitudes, even for very small increases in mean temperature (Intergovernmental Panel on Climate Change, 2007b). Concerns are raised by studies such as that of Peng et al. (2004), who, through controlled experiments, reported a 10% decline in rice production for each degree Celsius increase in night-time temperature.

Of particular concern are health impacts resulting from the unavailability of adequate food supplies in Africa. Figure 5 shows the trends in the Food Production Index of the United Nations Environment Programme (UNEP) for the world as a whole and in Africa (United Nations Environment Programme, 2002). The rapid decline in Africa began about 1970, roughly corresponding to the start of rapid global temperature warming. The trend in climate drivers and production decline is likely to continue, resulting in increasing demand for food production from countries such as Canada to help make up the shortfall. The majority of people at additional risk of hunger due to climate change are in Africa (Parry et al., 1999).

Flooding

There are both immediate health effects from coastal and inland flooding, including injuries and loss of life, and longer term impacts, resulting from contaminated water and food. Provision of clean water supplies as soon as possible after the disaster is essential for reducing health impacts.

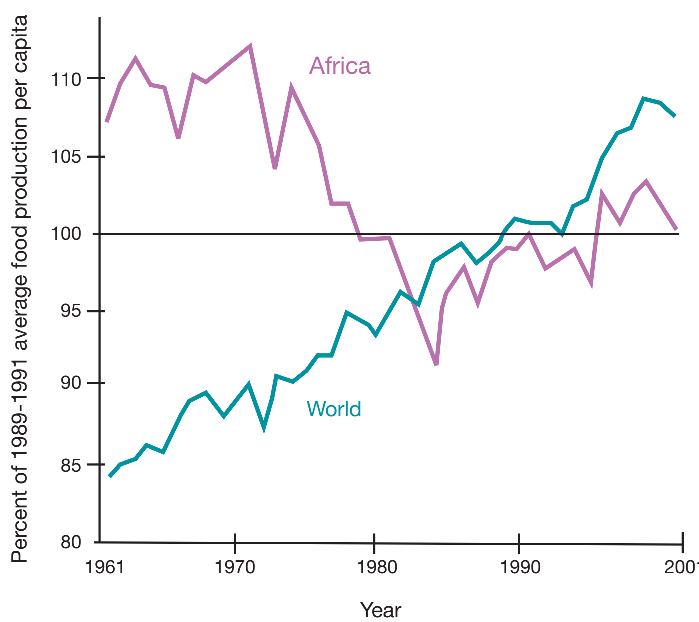

FIGURE 5: Food Production Index (net food production per capita, base line 1989-91) for Africa, contrasted with the rest of the world, for the period 1961 to 2001 (United Nations Environment Programme, 2002). *Source*: Food and Agriculture Organization (FAO) statistical databases, 1995.

A combination of sea-level rise, rapid population growth in coastal zones worldwide and more intense storm surges associated with more severe winter and tropical storms will increase the numbers of people at risk from coastal flooding. Regions likely to be especially affected by coastal flooding include small islands and Asian megadeltas, such as the Ganges-Brahmaputra and the Zhujiang (Adger et al., 2007). The low-elevation coastal zone (LECZ; <10 m above mean sea level) contains about 10% of the world's population while only accounting for 2.2% of total land area (McGranahan et al., 2006). Asia has by far the greatest population in the LECZ, and 19 of the 215 countries studied by McGranahan et al. (2006) have more than 50% of their population in the LECZ (*see also* McGranahan et al., 2007). The greatest impacts proportional to population size will likely be on low-lying small island states in the Caribbean, southwestern Pacific and Indian Ocean.

One-sixth of the world's population is subject to floods that are due in part to snowmelt, and may therefore experience lower flood peaks on average as a result of climate change (Barnett et al., 2005). Nevertheless, in regions affected by tropical cyclones (e.g. Central America, the Caribbean and the southwestern Pacific), observed increases in severity and duration of these events (Webster et al., 2005) have resulted in more floods and landslide disasters. It has also been shown that high-intensity rains have become more frequent and heavier in many parts of the world, including the eastern United States and southeastern Canada, northern Mexico, eastern South America, southern Africa, Europe, India and eastern Asia (Figure 2; Groisman et al., 2005). Such rains can result in flash floods, often without adequate warning to protect people and property, and increasingly frequent urban flooding due to overtaxing of drainage facilities. *Escherichia coli* (E. coli) and other contaminants in drinking water supplies are most often washed into wells or surface waters by high-intensity rains, which are becoming more frequent throughout much of the world. In the United States, it is estimated that 68% of all health outbreaks from contaminated water occurred after heavy rain events (Patz, 2001).

Potential Implications for Canada

Most of these trends affecting health and mortality abroad can be reduced by adaptation measures, both internationally and within Canada. Initial responses by Canada to these needs have been made (*see* Section 5).

Canada and other developed countries may be able to further reduce health-related vulnerabilities in other countries through programs that involve assistance to:

- strengthen public health services in affected regions;
- take actions to reduce standing waters, which breed dengue- and malaria-bearing mosquitoes;
- improve water treatment systems; and
- improve warning systems for coastal and riverine floods, heat waves and impending drought conditions.

Potential actions within Canada may involve:

- ensuring that immigration policies are designed to take into account refugees from these health- and disaster-related trends;
- improving surveillance programs on movement of climate-related diseases; and
- improving border health controls for climate-sensitive infectious diseases.

2.7 TOURISM IMPACTS

Tourism is one of the largest and fastest growing economic sectors in the world. In 2004, tourism represented 1.5 to 2.0% of Canada's GDP (Canada Tourism, 2005; World Tourism Organization, 2005; Statistics Canada, 2006). Over 19 million tourists (overnight visitors) came to Canada, more than 15 million of them from the United States (Canada Tourism, 2005; World Tourism Organization, 2005). In addition, there were 19.7 million day visitors. About 55% of the tourists came for leisure, recreation and holidays (World Tourism Organization, 2005). Foreign tourists spent an average of 6.4 nights per visitor in Canada and accounted for about 30% of the total nights in accommodation establishments (World Tourism Organization, 2005). In addition to their domestic travel, 19.6 million Canadians travelled to foreign countries, mainly the United States, for overnight stays. Foreign tourism to Canada peaks during the summer, whereas Canadian travel abroad peaks during the winter (Canada Tourism, 2005).

Most studies addressing the impacts of climate and climate change on tourism have been published since 2000 (Scott et al., 2005). Hamilton et al. (2005) distinguished three strands of literature:

- studies that build statistical models of the behaviour of certain groups of tourists as a function of weather and climate;
- studies that relate the fates of particular tourist destinations to climate change; and
- studies that try to define indicators of the attractiveness to tourists of certain weather conditions.

Available studies in the first category apply almost exclusively to warm-weather vacation choices by Europeans: the significance of weather and other amenities in the destination preferences of British, Dutch, German, Italian and other European tourists (Agnew and Palutikof, 2001; Maddison, 2001; Lise and Tol, 2002). No studies of the destination choices of Canadian tourists have been found that explicitly include weather or climate as a factor in the choice. However, winter travel to Hawaii, Arizona, Florida, the Caribbean and Mexico is clearly motivated by a desire for warmer conditions.

During the past two decades, numerous studies have been undertaken of the potential impacts of climate change on tourist destinations in Canada, covering various types of outdoor tourist activities across most of the country (Scott et al., 2004; Jones and Scott, 2006). These studies suggest that skiing and other winter activities will be adversely affected, despite additional snowmaking. The length and quality of the summer tourist season is expected to improve in most regions, although adjustments, such as better water management for golf courses, may be needed. Adaptation to lower flows and water levels for water-based activities will be required in some regions. Tourism impacts and adaptation are also discussed in the regional chapters.

Although such studies can provide important insights into the impacts of climate change on a specific destination, tourist traffic will depend on how climate change and associated environmental changes affect the attractiveness of that destination relative to its competitors.

The third strand of literature adopts the premise that travel behaviour is motivated by two sets of factors: one set that influences a person to consider travelling and another set that attracts that person to a particular destination (de Freitas et al., 2004; Scott et al., 2004; Amelung and Viner, 2006). Such analyses use various direct indicators, such as temperature and humidity, or indirect indicators, such as beaches, of the attractiveness to tourists of certain weather conditions.

A simulation model of global tourism, projecting arrivals and departures for 207 countries on the basis of population, per capita income and climate, suggests that tourism growth is driven by increases in population and income, and so is larger in Asia and Africa than Europe and North America (Hamilton et al., 2005). Global tourism increases at 3.2% per year between 1995 and 2075 in the base case.

Climate change shifts tourism toward the poles and from lowlands to highlands. As countries closer to the poles become more attractive to their own residents, they tend to generate fewer international tourists (Hamilton et al., 2005). In addition to the higher temperatures, countries nearer the equator may be rendered less attractive due to loss of beaches and coral reefs, and damage due to more intense tropical storms (Loftus, 2005).

Climate change is projected to benefit Canadian tourism more than any other country over the period to 2025 (Hamilton et al., 2005). Climate change would increase Canada's share of global arrivals (i.e. more tourists coming to Canada) and reduce Canada's share of global departures (i.e. fewer Canadians travelling abroad). Canadians would take more vacations at home, so domestic travel would grow relative to international travel (Hamilton et al., 2005). The authors caution that the model is very simplistic, with a crude representation of climate change, so the focus should be on the qualitative results. The model also excludes a number of variables likely to influence tourist flows (Gössling and Hall, 2006).

In summary, summer tourism in Canada is likely to benefit from climate change, although some activities may need to adapt. This will attract more foreign tourists and keep more Canadians at home. Winter tourism in Canada may suffer despite efforts to adapt, but the milder winters are projected to reduce travel by Canadians to warm destinations.

3 OCEANS

Canada is influenced in many ways by the three bordering oceans — Pacific, Arctic and Atlantic — and climate change impacts on the oceans affect Canada's people and economy. All of the world's ocean basins have been warming on average, due to greenhouse gas forcing (*see* Section 1.2), and this is expected to continue. The warming is resulting in rising mean sea level and changes in biological systems, including shifting distributions of fisheries and coral reef bleaching in tropical areas. Sea-level rise is projected to continue for several centuries, even if atmospheric greenhouse gas concentrations are stabilized, due to the lag time involved in thermal expansion of ocean waters and melting of land ice. At the same time, increased storminess has resulted in significant increases in wave heights in many parts of the world's oceans (*see* Section 1.2). Melting of ice on land is changing salinity as well as adding to sea-level rise, and increased CO_2 absorption is increasing the acidity of ocean waters.

The impacts on marine biological systems and fish distribution have been documented in the assessment reports of the Intergovernmental Panel on Climate Change, such that a "Growing recognition of the role of the climate-ocean system in management of fish stocks is leading to new adaptive strategies based on determination of acceptable removal percentages of fish, and stock resilience." (McLean et al., 2001, p. 345).

3.1 ATLANTIC OCEAN AND LABRADOR SEA

Ocean Changes

The atmosphere over the Atlantic Ocean has changed, and will continue to change, with observed and projected increases in storminess and more frequent occurrence of intense hurricanes (*see* Section 1.2). Climate warming, which will generally be more pronounced in northern regions, will lead to reductions in sea ice. The increased melting of the Greenland Ice Sheet and other land glaciers, and greater precipitation will result in more freshwater inflow to the North Atlantic, thereby reducing its salinity (Intergovernmental Panel on Climate Change, 2001a). The volume-averaged temperature increase at depths of 0 to 700 m depth in the North Atlantic from 1960 to 2000 has been 0.2°C, but there has been little trend in sea-surface temperature in the northern North Atlantic (Barnett et al., 2001; Pierce et al., 2006).

The strength of the meridional overturning circulation (MOC), also called thermohaline circulation, will be reduced if the waters of the Greenland, Norwegian and Labrador seas are warmed and/or freshened, both of which are projected to occur with climate change (Intergovernmental Panel on Climate Change, 2007a). Reducing the MOC results in reduced transport of warmer near-surface water from the subtropical gyre to high latitudes, counteracting overall global warming. As a result, the North Atlantic would warm less than other areas at corresponding latitudes, and it is possible that parts may cool in the next few decades, although there is uncertainty in the geographic distribution (Stocker et al., 2001). Although the MOC is expected to slow during this century, it is very unlikely to shut down (Intergovernmental Panel on Climate Change, 2007a). Adaptation to address the abrupt climate change that would occur with shutdown of the MOC, and implications for climate policy and decision-making, have not been researched (Hulme, 2003). Nevertheless, reducing the MOC will not cause the onset of the next ice age (Berger and Loutre, 2002; Weaver and Hillaire-Marcel, 2004).

With warming, there will be reduced sea-ice cover over the North Atlantic Ocean, which will make the ocean more open to atmospheric influences. Increased storminess (Lambert, 1996; Lambert and Fyfe, 2006) and possibly more intense hurricanes undergoing extratropical transition, such as Hurricane Juan (2003), will lead to higher ocean-wave conditions. There is now considerable evidence of increasing storminess and higher wave climates in the North Atlantic, including the Grand Banks (Gulev and Hasse, 1999; Gulev and Grigorieva, 2004) and, as the climate warms, most regions of the midlatitude oceans will see an increase in extreme wave heights (Wang et al., 2004; Wang and Swail, 2006a, b). In the near term, there could be more icebergs due to increased melting of the Greenland Ice Sheet and other calving glaciers.

These impacts are affecting fisheries, offshore oil and gas operations, exploitation of other natural resources of the ocean and marine transportation. Reduced sea ice will mean less of a hindrance to marine shipping and fisheries vessels, but storminess and higher waves will adversely impact fleets and energy exploration activities, and increase the risk of marine accidents. Sea-level rise will affect coastal zones around the Atlantic Ocean, with impacts on the habitat of fisheries and creation of new tidally inundated areas. Sea-level changes can also affect the usefulness of port facilities, both overseas and at home, and affect international competitiveness. There will likely be a need for increased search-and-rescue capacity for the North Atlantic Ocean.

Fisheries

Marine fisheries provide an important food source and are a vital part of the economies of Atlantic Canada (*see* Chapter 4) and other countries, especially in Europe, that border on the North Atlantic Ocean. Historic variations in fisheries across the North Atlantic, beyond Canada's traditional fishing areas, are well documented. In the early 1950s, for example, the stock of Norwegian spring-spawning herring was the world's largest herring stock and was important to Norway, Iceland, Russia and the Faroe Islands (Vilhjálmsson et al., 2005). In 1965, a sudden and severe cooling of these waters resulted in the decimation of the most important food for these herring. The stock was also severely overfished and collapsed. Restrictions on the fisheries and favourable climatic conditions later contributed to the stock's increase and the need for international agreements to set quotas. Such agreements may be an important management tool in the future as climate change alters fish stocks and their ranges.

The disappearance of the North Atlantic cod has demonstrated the social and economic costs of changing fish stocks on Atlantic Canada. The disappearance of the cod was, in part, due to colder waters in the Labrador Sea, as well as overfishing, and the stocks have not recovered as was originally assumed after fishing pressure was reduced (Drinkwater, 2002, 2005; Barange et al., 2003). The relationships with climate have been reviewed by Drinkwater (2002, 2005) and Barange et al. (2003). Generally, as stocks have reduced, they have become more sensitive to climate variability or change, due to shrinkage of the age distribution and geographic extent (Brander, 2005). Although warming waters are likely to promote the recovery of the northern cod stock (Drinkwater, 2005), an increase in abundance of the main forage fish, capelin, and a decline in seal abundance are likely necessary for recovery to occur. The northern cod situation demonstrates how fishing, climate change and other factors affecting marine ecosystems may interact strongly at the extremes of the range of a species. A lightly exploited stock may show few drastic changes as climate and other factors change; however, as in the case of northern cod, such changes may amplify the effects of overfishing, causing negative and sudden changes in vital survival rates and abundance, as well as distribution (Rose et al., 2000; Rose, 2004; Drinkwater, 2005).

As fish are international resources, competition in the open ocean and for species that straddle international borders has led to major disputes. The 1982 Law of the Sea Convention has provisions that enable coastal states to establish Exclusive Economic Zones (EEZs), extending up to 200 nautical miles (360 km) offshore, where they have sovereign rights over the natural resources. Countries are expected to manage these stocks in a sustainable manner. With the dramatic increase in fishing beyond the EEZs in the 1980s, and increases in catches within the EEZs due to rapidly growing fishing capacity, the 1995 UN Convention on Straddling Fish Stocks and Highly Migratory Fish Stocks mandated the application of a precautionary approach to fisheries management and emphasized the need for co-operation between countries. The Northwest Atlantic Fisheries Organization (NAFO) and the North East Atlantic Fisheries Commission (NEAFC) were formed and led to ecosystem-based approaches to the management of living marine resources, where natural factors such as climate change are taken into account in decision-making. The 2002 World Summit on Sustainable Development stated in its implementation plan that such ecosystem-based approaches to management are to be in place by 2010.

The Arctic Climate Impact Assessment provided a detailed analysis of Arctic and North Atlantic fisheries (Vilhjálmsson et al., 2005), concluding that it is not possible with present knowledge to provide precise forecasts of either changes in the fish stocks and fisheries or the effects on society, due to uncertainties in:

- identifying the reasons for historical changes in fish biology;
- predicting possible changes in the ocean climate under the scenarios of climate change; and
- understanding the relationships between socioeconomic factors and changes in fish stocks.

Further, since many of these fish stocks are heavily exploited, they are currently much lower in abundance than in the past and are exhibiting extreme changes in population characteristics. Nevertheless, some general conclusions can be drawn with respect to the impacts of climate change on fisheries and the related economies in North Atlantic–Arctic countries. Warming will be a benefit for some species, whereas it will create problems for others. Changes need to be seen in the context of an overall economy, its diversification and its ability to adapt — politically, socially and economically. It is important for Canadians to understand the impacts in other countries and to project how other countries may respond, so as to understand the consequent impacts on Canada. There is need for further analysis in this regard.

Another issue related to climate change in the marine environment is the altered risks of poisoning of fish and shellfish for human consumption and impacts on ecosystems. Warmer waters could result in an expansion in the ranges of toxins to higher latitudes and increase the occurrence of toxic algal blooms (Berner et al., 2005). There could be impacts on human health that will need to be accounted for in both domestic production and import of seafood.

Climate-related changes can also affect the competitive nature of fisheries systems globally. Impacts that reduce fish in other regions of the North Atlantic may result in additional pressures from their fishers to utilize Canadian waters. Impacts on commercial shellfish may be of most significance.

Atlantic Ocean Warming and Tropical Storms

Waters of both the North Atlantic and South Atlantic oceans have been warming since the 1950s, from near the surface to depths of >100 m, with much of the warming attributable to increasing greenhouse gas concentrations (Barnett et al., 2001; Pierce et al., 2006). Several analyses of the frequency of intense hurricanes and more long-lived storms indicate a significant trend towards more categories 4 and 5 storms in the past 30 to 35 years (Emmanuel, 2005; Webster et al., 2005). Some hurricane forecasters attribute the recent increases entirely to cyclic changes, but analysis of the relative importance of climate change and cyclic changes suggests that global warming trends account for two-thirds of the increase in categories 3 to 5 hurricanes (Faust, 2006). Thus, more intense hurricanes are to be expected on average in the future as the ocean continues to warm. This suggests the need for better disaster preparedness and management for hurricanes in the Caribbean, coastal areas of the United States and maritime Canada, and increased demand for disaster preparedness and recovery assistance (*see* Section 2.2).

3.2 PACIFIC OCEAN

Changing Conditions

Average warming off the British Columbia coast was minimal between 1901 and 1979, but occurred at a rapid rate of up to 0.25°C per decade between 1979 and 2004. Much of the warming in this recent period has occurred in June, July and August (data from the National Climatic Data Center; Smith and Reynolds, 2005). The trends observed in the North Pacific are, in part, related to the Pacific Decadal Oscillation (PDO), which is, in turn, linked to the El Niño Southern Oscillation (ENSO). These two circulation phenomena result in alternating warm periods (1935–1945 and 1975–2004), accompanied by a deeper Aleutian Low, and a cool period (1945–1975) in the eastern North Pacific. These major fluctuations and longer term warming trends appear to both be at work, reinforcing each other in warm phases. Some oceanographer-meteorologists think that anthropogenic climate change stimulates the warm phase of the PDO and ENSO (Corti et al., 1999; Timmermann et al., 1999).

At the same time, with the frequency of intense winter storms in parts of the Northern Hemisphere increasing (McCabe et al., 2001), changes in significant wave heights have been observed. From 1950 to 2002, significant wave heights have increased about 1 cm per decade off British Columbia's coasts (Gulev and Grigorieva, 2004). Such increases are projected to continue (Caires et al., 2006).

Sea-level rise and an increase in intense storms are resulting in flooding and erosion episodes and related water quality problems on the west coast, especially in the lower mainland (*see* Chapter 8).

Fisheries

With continued warming of the eastern North Pacific, the population distribution for sockeye salmon will be compressed, forcing them increasingly into the Bering Sea (Welch et al., 1998; Beamish et al., 1999). Figure 6 shows the current thermal limits for sockeye salmon in December (upper panel) and July (lower panel). The 2 x CO_2 climate projections show this thermal limit retreating to the Bering Sea (Welch et al., 1998), out of reach of most Canadian fishers. While it is expected that changes in total numbers may be small, changes in regions of occurrence will mean that a particular species will be caught by fishers from different countries. For anadromous fish, warming water in

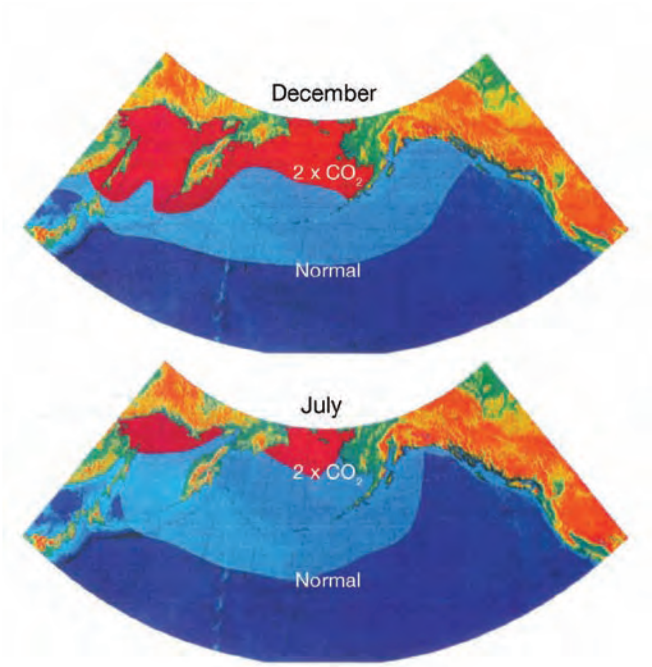

FIGURE 6: Current and projected (under a scenario of 2 x CO_2) distribution of thermal limits controlling the distribution of sockeye salmon in the north Pacific Ocean for December and July (Natural Resources Canada, 2000).

spawning rivers may also change the populations and ranges of certain fish stocks (*see* Chapter 8).

Aquaculture in coastal waters could benefit from warmer conditions, with increased growth rates and an increase in the geographic range of the activity. Higher water temperatures and related physical changes could, however, result in more intense and frequent disease outbreaks and algal blooms (Kent and Poppe, 1998). Bacterial contamination of oysters and other shellfish may be more frequent as water temperatures rise. The increased frequency of intense winter storms and the trend towards higher wave heights would also physically endanger aquaculture operations.

Fishers would be affected in several ways by the changing climate. They may need to go farther from home ports to catch their quota of a particular species. This exposes them to increasing hazards from the more frequent intense winter storms and higher waves off the west coast. In addition to such safety concerns, the changing fish populations may make it necessary to adapt by modifying the kinds of fish they catch and where they catch them (Beamish et al., 1999; *see* Chapter 8).

Tourism

Tourism in western coastal waters will be affected in similar ways. Generally, small recreational boats would require greater attention to safety because of higher waves and greater incidence of severe storms. Sea-level rise and severe storms would also have negative effects on marinas and other coastal infrastructure used for fisheries and boating, which may require expensive adaptation measures to maintain (*see* Chapter 8).

Shipping

Although the most favourable ship routings across the Pacific may change as circulation, winds and storm patterns change, the main impact on shipping is likely to be through ports and shore infrastructure. In Japan, for example, it has been estimated that a 1 m sea-level rise would require an expenditure of US$110 billion to maintain present functions and stability in their 1000 ports (McLean et al., 2001). In British Columbia, reinforcement and raising of breakwaters and wharves will likely be required to adapt to higher water levels and the greater wave regime, to ensure that Canadian ports remain internationally competitive (*see* Chapter 8).

3.3 ARCTIC OCEAN

Shipping

Little international shipping takes place in the Canadian Arctic at present. Port and docking facilities in the Canadian Arctic are rudimentary, with the exception of the Port of Churchill, Manitoba, on Hudson Bay, which has four deep-sea berths for grain, general cargo and tanker vessels. In 2002, Manitoba and the Russian province of Murmansk—the European gateway to the Northeast Passage—signed a letter of intent to develop a marine link between the two provinces. Dubbed the 'Arctic Bridge', this concept is to develop further the Port of Churchill as part of a North American trade corridor. This concept is deemed viable as a result of the longer sea ice–free shipping season in Hudson Bay and the Davis Strait. It has been suggested that there should be development of port facilities at Iqaluit to assist regional economic growth (Aarluk Consulting Inc. et al., 2005). The duration of ice cover in the Canadian Arctic Archipelago is projected to be reduced by one month by 2050 and by two months by 2090 (Dumas et al., 2006). However, there would still be significant ice hazards for ship transits (*see* Chapter 3).

Base-metal mines, including the Polaris lead-zinc on Little Cornwallis Island and the Nanisivik zinc mine on northern Baffin Island, were supplied by sea, and concentrate was shipped to smelters in Europe and elsewhere. However, these mines ceased operations in 2002 and 2003, respectively, leaving the Raglan nickel-copper mine in northern Quebec and the prospect of a huge nickel mine at Voisey's Bay in Labrador to be serviced by sea. The mining industry hopes to develop port and road facilities in or near Bathurst Inlet to service and supply exploration and development operations for precious and base metals and diamonds in the Kitikmeot region and northern Northwest Territories (*see* Chapter 3).

A considerable increase in international use of the Canadian portion of the Arctic Ocean seems likely. The Arctic Climate Impact Assessment (ACIA) concluded that:

> *"The continued reduction of sea ice is very likely to lengthen the navigation season and increase marine access to the Arctic's natural resources." (*Arctic Climate Impact Assessment, 2004, p. 11)

Further, the ACIA suggested that trans-Arctic shipping during the summer is likely to be feasible within decades. Diminished sea ice in summer in the Canadian Arctic could prompt the world's shipping community to seek expanded access to the Northwest Passage (Figure 7) to convey international cargos, taking advantage of the shorter sea route from eastern Asia and the west coast of North America to the eastern seaboard of North America and western Europe. Most climate models suggest that these sea ice changes will occur in the latter half of this century (Walsh et al., 2005), although recent trends suggest an earlier date. However, opening of the seas north of the Russian Federation is likely to occur earlier, and infrastructure to support marine traffic along that route will probably develop before that in Canadian waters.

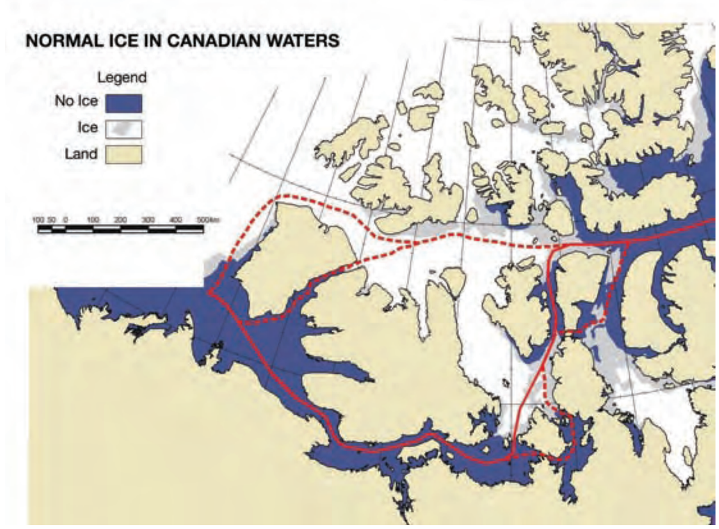

FIGURE 7: The primary (solid line) and alternative (dashed lines) routes for the Northwest Passage,shown on a map of historical average ice conditions for September 3 (1971-2000) (courtesy of Humfrey Melling, Fisheries and Oceans Canada, and Environment Canada).

To follow up on the ACIA, Arctic Council ministers in 2004 initiated an Arctic Marine Shipping Assessment (AMSA). To be presented to ministers in 2008, the AMSA will provide a 'snapshot' of Arctic shipping in 2004 and projections of the likely level of shipping in the circumpolar Arctic in 2020 and 2050, in light of sea-ice ablation, economic development scenarios, and risks such as the possibility of increased ice hazards in some regions.

Fisheries and the Food Chain

Water temperatures and ice cover influence the distribution of Arctic fish and marine mammals, as do changes in freshwater input from the major rivers of Russia and Canada (Arctic Monitoring and Assessment Program, 2002). Along the North American coast, important fish stocks, such as Atlantic cod and herring, are being displaced due to warming waters — moving northeastward where they will be more accessible to fishers from Scandinavia and Russia. Loss of estuarine ice may displace cisco. Loss of sea ice results in Arctic shelf seas looking more like temperate seas, with implications for food web structures that are difficult to predict. One surprise and warning sign was a massive bloom of jellyfish in the Bering Sea in the 1990s (Arctic Monitoring and Assessment Program, 2002).

Pupping of ringed seals, which provides a favourite food source for polar bears, requires extensive sea ice. A decrease in suitable habitat could affect the entire upper food chain, since the seals prey on Arctic cod. For Canadians of the Arctic, the catching of fish or seals for food requires longer voyages into the Arctic seas, which are increasingly hazardous because of the trend towards more severe winter storms (*see* Section 1.2). This leads to significant changes in the way of life for some Arctic communities (*see* Chapter 3).

Contamination of the food chain is also a concern. As permafrost melts, more mercury is released to rivers and the ocean, and accumulates up the food chain. Mercury and other contaminants from more southerly latitudes can have adverse effects on people of the Arctic, especially indigenous women. Women of Baffin Island, Nunavik and Greenland have been found to have very high mercury concentrations in their blood and breast milk. Seal meat and fish are significant food sources for these populations (Arctic Monitoring and Assessment Program, 2003).

Industrial development in the north is likely to add to contamination of the Arctic seafood chain. Development of natural gas and oil deposits at Hammerfest, Norway is proceeding apace with reduced ice. Oil reservoirs have been identified 320 km from the North Pole, and the Shtokman field in Russian parts of the sea is thought to be the largest offshore gas reservoir in the world. With global warming and loss of Arctic sea ice, development of these resources is becoming increasingly feasible (*see* Chapter 3).

Toxic Materials

Persistent organic pollutants (POPs), including hexachlorocyclohexane (HCH), dichloro-diphenyl-trichloroethane (DDT), toxaphene and polychlorinated biphenyls (PCBs) of industrial and agricultural origin, and some heavy metals, have been detected throughout the circumpolar world at unexpectedly high levels (Indian and Northern Affairs Canada, 1997). Sources of POPs within the Canadian Arctic, including PCBs from Distant Early Warning (DEW) line sites, are minor compared with long-range transport from the south (Europe, Asia and North America). Bioaccumulation and biomagnification of POPs in the Arctic environment have resulted in elevated levels of some POPs in lipid tissues of animals, particularly marine mammals, including beluga whales, narwhal, walrus, ringed seal and polar bears. As a result of eating marine mammals, some Inuit have levels of some POPs in their bodies that are known to have effects on the immune system and on neurobehavioural development and reproduction (Dewailley and Furgal, 2003).

Macdonald et al. (2003) noted that increased global temperatures will have direct effects on contaminants through enhanced volatility, more rapid degradation and altered partitioning between phases (Macdonald et al., 2003). Changes in the timing and length of seasons are likely to be particularly important in changing the spatial distribution and levels of contaminants in the Arctic through long-range transport. The ACIA noted that climate change and pollution in the Arctic are interrelated, and that:

> *"More extensive melting of multi-year sea ice and glacial ice can result in pulse releases of pollutants that were captured in the ice over multiple years or decades."*
> (McCarthy et al., 2005, p. 954)

Although the bilateral Canada–United States dimensions of contaminants are most critical for Canada, longer range atmospheric transport is becoming of increasing concern (Indian and Northern Affairs Canada, 1997). Pollutants due to emissions from the rapidly growing economies of China, Japan and southeast Asia are now being detected in Canada's north. Some of these contaminants come through volatilization from waters of lakes, such as the Great Lakes and Asian lakes, where the substances had been earlier deposited through long- and short-distance atmospheric transport. This volatilization occurs in the warm season, with the toxic contaminants gradually moving farther and farther north to where waters are too cold, year round, for the process to occur. This volatilization process will occur more readily as lakes warm in the changing climate. Thus, this contribution to Arctic contaminants from the above-mentioned sources in the Northern Hemisphere will gradually increase. It is presently unknown whether changes in atmospheric circulation patterns will occur that would either lessen or exacerbate the transport of contaminants to the Arctic.

Canadian Control and Security

Canada acquired sovereignty over the Arctic from the United Kingdom through legal and political measures that stretch back to the 1670 Charter granted by King Charles II to the Hudson's Bay Company. In 1870, the company transferred its title to the Hudson Bay watershed to Canada. Following an address by the Canadian Parliament to Queen Victoria expressing doubt as to Canada's northern border, the United Kingdom in 1880 transferred to Canada all territory in British North America and adjacent islands, with the exception of Newfoundland. Both Denmark and Norway challenged Canadian sovereignty on some islands from 1898 to 1910. However, Canada took several actions to reassert ownership and, with payment of compensation, Norway relinquished its Arctic claim in 1931. An issue remaining is the dispute with Denmark over tiny Hans Island between Greenland and Ellesmere Island.

With Canada's sovereignty to Arctic land secure, attention turned to the ocean, with specific reference to the Northwest Passage. The United States and European Union contend the passage is a strait used for international navigation through Canadian territorial waters, whereas Canada asserts the passage to be internal waters over which it has full jurisdiction and control (e.g. Rothwell, 1993; Charron, 2005). The degree of control that Canada can exercise over these waters depends upon whether they are considered internal waters, as Canada claims, or a strait for international navigation. The 1969 transit through the passage of the American supertanker 'Manhattan' crystallized Canadian concerns and prompted legislative action, including the Arctic Waters Pollution Prevention Act. A similar transit through the passage in 1985 by the American icebreaker 'Polar Sea' resulted in legal action by Canada to draw 'straight baselines' around claimed land and ocean. In 1988, Canada and the United States concluded an Arctic Co-operation Agreement through which future transits through the passage by icebreakers would be undertaken with the consent of Canada. This agreement had no bearing on the legal positions of the parties vis-à-vis the status of the passage. Increased shipping in Canadian Arctic waters will likely require increased surveillance, monitoring, maintenance of navigation signals and search-and-rescue services.

4 CONTINENTAL EFFECTS (NORTH AMERICA)

4.1 WATER IMPLICATIONS

Higher temperatures and a changing rainfall regime are affecting water supply, water demand and water quality in Canada, Mexico and the United States. Most of the observed trends of the past 35 years are expected to continue in the coming decades. Two major issues for Canada relate to managing the border and transborder basins shared with the United States (International Joint Commission, 1997) and responding to demands for export of water to the dry regions of the United States and northern Mexico (Bruce et al., 2003).

Canada–United States Border and Transborder Waters

There are a dozen large bilateral drainage basins, or groups of small basins, for which the International Joint Commission (IJC) has responsibility under the *Boundary Waters Treaty* of 1909. Many of these basins, and their subbasins, have water-sharing agreements where rivers flow north or south across the border or form the border. Also, in some basins, pollution control agreements are in place to protect ecosystems and water quality (e.g. Great Lakes–St. Lawrence River). Climate change is beginning to affect both the quantity and quality of these waters, and the ability of one country to meet its present obligations to the other (Bruce et al., 2003).

To illustrate the potential extent of the issue, Table 4 gives the linear trend (1970–2000) in annual flows and minimum and maximum flows for major bilateral rivers. Most are downwards except for the Red River, which flows northward from the Dakotas, where significant increases in precipitation have occurred (Bruce et al., 2003). These bilateral stresses are superimposed on domestic water management issues (Cohen et al., 2004).

On the Columbia River, the trend towards greater flow in winter and less flow in spring is expected to continue. Changing water demands in the United States, combined with climate change, could seriously compromise hydroelectric power generation and other uses in Canada, especially in drier regions in southern areas of the Canadian part of the basin (e.g. Okanagan and Osoyoos lakes, *see* Chapter 8; Cohen et al., 2000; Payne et al., 2004). Existing processes through which rules are being reviewed for possible changes in 2013 provide an opportunity for consideration of adaptation to climate change.

TABLE 4: Trends (percentage change) in annual flows for boundary river systems between Canada and the United States, 1970–2000 (Bruce et al., 2003).

River	Mean	Minimum (daily)	Maximum (daily)
St. John (Fort Kent)	-13	71	-16
St. Croix	-21	-23	-26
Niagara (Queenston)	-7	-8	-9
Rainy (Fort Frances)	-22	-12	-27
Lake of the Woods (western outlet)	-21	-59	-29
Red (Emerson)	124	159	63
Souris (Sherwood)	-82	-74	-94
Souris (Westhope)	-42	100	-60
Milk (eastern border crossing)	-22	47	-6
Milk (western border crossing)	-26	59	-41
St. Mary (border)	-7	15	-29
Kootenay (Fort Steele)	3	-4	-12
Columbia (International Border)	4	37	-25
Yukon	1	-1	-12

The Souris River flows out of Canada into North Dakota at Sherwood, SK, and back into Canada (Manitoba) at Westhorpe, ND. Under a ‘normal climate’, each country can use 50% of the natural flow up to the border crossing. Natural flow is calculated by a joint board reporting to the IJC, which takes the measured flow and adjusts for human withdrawals and reservoir evaporation upstream. At the Sherwood crossing, Canada is required to deliver half of the first 50 000 cubic decametres (40 500 acre-feet) of natural flow in the January 1 to May 31 period. With the downward trend from 1973 to 1998 in mean annual natural flow from 7 to 2.5 m^3/s, Canada’s obligation was not met in 5 years between 1988 and 2000 (Bruce et al., 2003). However, there is a clause in the agreement, which had to be invoked, to provide to North Dakota 40% of the natural flow in the critical period. Continuing and more acute problems with declining flows and increasing consumption for stock watering and irrigation due to climate change are expected to result in frequent inability to meet the initial quantitative goal (Bruce et al., 2003).

There have been serious problems in meeting the provisions of apportionment agreements, established in 1921, for the Milk and St. Mary rivers due to declining flows in southern Alberta and reduction of meltwater from headwaters in Glacier National Park[5] in the United States. These trends and increased demand for irrigation reached the point that, in 2003, the Governor of Montana called for reopening of the existing agreements. Bilateral discussions continue with the aid of the IJC.

In the Great Lakes basin, a critical agreement for sharing water is the *Niagara River Treaty* of 1950. An agreed amount, 100 000 cubic feet per second (cfs) in daytime and 50 000 cfs at night, is allowed to go over Niagara Falls for the benefit of the tourists. The balance is divided equally between Ontario and New York State for hydroelectric power generation. With the upper Great Lakes (Superior, Michigan, Huron) having progressively less ice and higher surface temperatures as the climate warms, winter-time evaporation losses have substantially increased and will continue to do so. This resulted in a 7% decline in the mean annual flow of the Niagara River between 1970 and 2000 (Bruce et al., 2003). Continuation of this decline is expected with climate change, and adjustments to the agreement and/or to operations may be needed (Mortsch et al., 2000; Bruce et al., 2003).

Water quality in the Great Lakes is affected by more intense rains in the watershed, which increase erosion and wash pollutants into the lakes; by higher water temperatures; and by earlier establishment of a thermocline, allowing bottom waters to become depleted of oxygen earlier in the warm season. There are questions as to whether the two countries can achieve their mutually agreed water quality objectives under these changing climate conditions (Great Lakes Water Quality Board, 2003). For example, an increase in the frequency of high-intensity rains, resulting in more erosion and diffuse sources of pollution to the lakes, causes increased problems associated with nutrients, pathogens (e.g. *E. coli*), turbidity and pesticide products (Bruce et al., 2006).

Although Canada and United States have an enviable record of settling water disputes amicably through the International Joint Commission and the *Boundary Waters Treaty*, climate change threatens to stress this relationship. In order to adapt to changes already occurring and projected future changes, the management and terms of some of these agreements may need to be adjusted (Bruce et al., 2003).

External Demands for Canadian Water

Although the flow of rivers in the southeastern United States has risen substantially in the past 60 years, flow has decreased in most rivers of the west, especially during the April to autumn period (Frederick and Gleick, 1999; Pulwarty, 2002; Barnett et al., 2005). In snowmelt regions, particularly for rivers fed by snowmelt in their headwaters in the Rocky Mountains, more winter depletion of the snowpack has occurred by melt and sublimation. This has resulted in a marked downward trend (1950–2000) in April snowpack water equivalent (Mote et al., 2003), and changes in seasonality of water supplies, with more flow in winter and less in the rest of the year. Drier conditions are occurring in the irrigation and stock-watering seasons of summer and fall. The longer term trend since 1900 in the southwestern United States and in Mexico has been an increase in the Palmer Drought Severity Index (Figure 3; Dai et al., 2004).

This change towards drier conditions in the western United States, especially during the growing season, has exacerbated overcommitment of the waters of the Colorado River to users in many states (Gleick and Chalecki, 1999). Seasonal decline in the flows of the Columbia and Sacramento rivers are also sparking conflicts over uses, including instream ecosystem and fish protection (e.g. Cohen et al., 2000). Overpumping of the Ogallala aquifer in Nebraska, Oklahoma and the high plains of Texas has seriously lowered levels and depleted supplies for agricultural and other uses. Conflicts are simmering over the sharing of reduced water in the border and transborder rivers between the United States and Mexico (Salman, 2006).

As a solution for these problems, some have looked to the north, to the apparently plentiful waters in British Columbia and the Great Lakes. Analysts have argued, however, that effective water conservation measures would permit meeting of all essential needs now and in the immediate future from supplies within the United States (Frederick and Gleick, 1999). In the longer term, if drying continues as projected, this may not be the case.

Recognizing the potential for interest in exporting of Great Lakes water, the governors of the eight Great Lakes states, in co-operation with Ontario and Quebec, have negotiated an agreement (2005) pursuant to the earlier Great Lakes Charter Annex (2001). This agreement calls for no diversions out of the Great Lakes basin, with some exceptions. A 'grandfather' clause exempts the substantial (3200 cfs) diversion of Lake Michigan waters into the Mississippi River system at Chicago. The amount of this diversion is governed by a United States Supreme Court ruling. The other exception to the Great Lakes Annex Agreement prohibition on diversions outside the basin is for straddling counties and communities, those whose borders, as of 2005, straddle the watershed boundary of the Great Lakes.

With the expectation that increased evaporation due to climate change will lower Great Lakes levels and flows of the rivers in the system, including the St. Lawrence, adverse impacts on shipping, hydroelectric power generation and water quality are projected (Great Lakes Water Quality Board, 2003). This is without further diversions out of the system. Canada and the provinces need to remain vigilant to this threat, as well as the promotion of conservation by all jurisdictions. A recent amendment to the *International Boundary Waters Treaty Act* by Canada prohibits bulk-water removals and diversions from border and transborder waters but does not deal with attempts to divert internal Canadian waters, an issue that a number of provinces have similarly addressed.

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[5] Glacier National Park had 150 glaciers in 1850; in 2005, it had 27; by 2050, it is expected to have none.

Mexico also has very limited and declining supplies in regions bordering United States and has, at times, looked north to Canada for additional supplies. There remains a debate among trade experts as to whether water export would be expected or required under the terms of the *North American Free Trade Agreement* (NAFTA). There is no specific prohibition on export of water under this agreement, nor is there an obligation for bulk export of water. However, bulk export in one region may set a precedent.

4.2 ENERGY ISSUES

Energy goods are an important part of Canada's export basket.[6] Energy exports to the United States (which accounts for over 95% of Canada's energy exports) increased at an average annual rate of almost 17% during the decade from 1996 to 2005 (Table 5). Canada exports natural gas, crude oil, non-crude oil, electricity and coal to the United States.

Climate change will alter the demand for energy in Canada and the United States, which will likely affect energy exports. Climate change will also affect Canada's supply of hydroelectricity and its electricity exports to the United States. Finally, efforts to reduce greenhouse gas emissions will likely change the export markets for different energy products.

Energy Demand

Climate change will lower space-heating demand in Canada, which will reduce natural gas and home heating oil consumption (Bhartendu and Cohen, 1987; Findlay and Spicer, 1988). It will also increase the air conditioning load, which will increase electricity demand during the summer months. The air conditioning demand rises faster than the annual average temperature. A 3°C increase in mean daily maximum temperature increases the mean peak power demand by 7% (1200 MW; Colombo et al., 1999). In Canada, however, the overall energy demand is expected to decline over the coming few decades.

In the United States, the larger impact will be on the air conditioning load, thus causing overall energy demand to rise (Edwards, 1991; Sailor and Muñoz, 1997; Considine, 2000; Sailor, 2001; Amato et al., 2005). A 5°C temperature rise by 2100 would lead to a $40 billion welfare loss due to increased energy demand (Mansur et al., 2005). Changes in the energy demand in Canada will affect the energy available for export, and the increased energy demand in the United States will affect its energy imports.

Coal

Canada has abundant coal resources, mainly in the west (National Energy Board, 2003). About 90% of the coal produced in Canada is used to generate electricity in Alberta, Saskatchewan and northwestern Ontario. Coal for electricity generation in southern Ontario, New Brunswick and Nova Scotia is imported. Coal exports are primarily metallurgical coal for Asian markets. Record demand due to increased air conditioner use and reduced supply of hydroelectric energy due to drought-like conditions contributed to Ontario's decision to delay shutdown of the coal-

TABLE 5: Canada's energy exports to the United States (Industry Canada, 2006).

	Value (millions of 2005 dollars)							Average annual growth [1]
	1996	1997	1999	2000	2002	2003	2005	
Natural gas and natural gas liquids	9 875	10 906	12 106	22 924	10 391	28 484	38 807	20.2%
Crude oil	10 970	11 390	10 121	19 334	18 015	20 414	29 913	15.4%
Non-crude oil	3 464	3 402	3 327	5 615	7 036	8 006	10 972	15.9%
Electrical energy	1 218	1 377	1 923	4 059	1 812	1 852	3 168	19.5%
Coal and coal-based solid fuels	88	66	55	120	162	150	260	19.9%
Other energy goods	418	515	541	643	722	678	897	9.3%
Total energy exports to the United States	26 032	27 657	28 073	52 693	48 139	59 584	84 017	16.9%
Total exports to the United States	223 177	243 888	308 076	359 289	345 366	326 700	365 741	5.9%
Energy exports as percentage of total exports to U.S.	11.7%	11.3%	9.1%	14.7%	13.9%	18.2%	23.0%	

[1] average of year-on-year growth over 10 years; overall average growth is higher

[6] Energy goods are defined here as those goods covered under NAFTA's Chapter 6: 'Energy and Basic Petrochemicals'. They include most refined and unrefined hydrocarbon products, uranium and electricity.

fired generating units in the province (Independent Electricity System Operator, 2006). Closing the coal plants would reduce coal imports from the United States.

Crude Oil

Crude oil resources are located mainly in western Canada, but also in northern Canada and offshore Newfoundland and Nova Scotia (National Energy Board, 2003). Production of conventional crude oil is declining in western Canada and is expected to peak within the next decade on the east coast (National Energy Board, 2003). Oil sands production is projected to rise rapidly during the next two decades, more than offsetting the declining output from conventional sources (National Energy Board, 2003).

Canadian crude oil supplies refineries in western Canada and the United States. Refineries in eastern Canada use imported crude oil. As a result, more than half of Canada's production is exported to the United States. American imports are forecast to increase, but Canada's share is expected to remain at about one-third (Energy Information Administration, 2006). American efforts to increase energy security could reduce imports, possibly including those from Canada.

The main effect of climate change on Canada's oil exports is likely to be the impact of reduced water supplies in northern Alberta on oil sands production (Bruce, 2006; Schindler and Donahue, 2006). Since bitumen extraction and upgrading uses substantial amounts of water, presently projected rates of oil sands development may have to be reduced if instream flow requirements for the Athabasca River are to be met downstream (Bruce, 2006). Improved efficiency in water use would be a valuable adaptation.

Natural Gas

Natural gas is produced in western Canada and offshore Nova Scotia, and there are extensive reserves in the Arctic (National Energy Board, 2003). Production is forecast to remain roughly constant, unless or until a pipeline to bring gas from the Arctic is completed (National Energy Board, 2003). About half of Canada's output is currently exported to the United States, but exports are expected to decline as production declines and domestic demand rises (National Energy Board, 2003). Although the space-heating demand in Canada is expected to decline due to climate change, other uses are expected to grow, leading to an increase in domestic demand for natural gas (National Energy Board, 2003).

Electricity

About 60% of Canada's electricity generation is hydro based and most of the balance is coal produced, but the mix varies significantly by province. Historically, 7 to 9% of Canada's electricity has been exported to the United States, mainly from hydro-rich regions: British Columbia, Manitoba and Quebec. Electricity imports average about a quarter of the exports. Imports are driven by cross-border differences in peak periods and opportunities for utilities with hydro storage capacity to buy off-peak power and sell more during peak periods.

In the United States, about half of the electricity is generated from coal, and electricity generation is responsible for almost 40% of CO_2 emissions (Energy Information Administration, 2006). Given the long lives of generating facilities, changes to the generation mix are likely to occur gradually (Morgan et al., 2005). Climate change is projected to reduce the hydroelectric generation potential of the Colorado and other western rivers, especially during the summer months when the electricity is most needed to meet the rising air conditioning load (Edwards, 1991; Christensen et al., 2004).

The availability of hydroelectricity in Canada to meet the rising air conditioning demand in the United States (and Canada) may be compromised by climate change as well. Although climate change is projected to increase hydroelectric generation potential in northern Quebec and Labrador (Mysak, 1994; Mercier, 1998), the experience over the period since 1970 is for reduced flows on most major rivers flowing to Hudson, James and Ungava bays, except the Nelson River (Déry et al., 2005). In Ontario and on the Prairies, hydroelectric generation potential would likely be reduced, except from the Winnipeg and Nelson rivers. In southeastern British Columbia, a projected small increase in precipitation, combined with increased reservoir evaporation due to higher temperatures, could reduce hydroelectric generation potential, especially if instream flow needs and irrigation needs downstream are to be met (Raban, 1991; Mercier, 1998; Payne et al., 2004). Declines in levels of the Great Lakes, and thus flows of the Niagara and St. Lawrence rivers, have been projected to reduce hydroelectric power generation by up to 17% by 2050 (Tin, 2006).

Meeting the increased air conditioning load in North America, while coping with reduced hydroelectric production in some regions and reducing greenhouse gas emissions, will pose a challenge for electric utilities. The simplest solution to this challenge would be to meet the higher demand with more gas-fired generation, which is well suited to serving peak loads. But the scope for this option is limited, due to the anticipated supply constraints and price increases for natural gas. Renewable energy sources, such as wind and solar, generate electricity when conditions are favourable and cannot be relied upon to meet the air conditioning demand when it occurs. Nuclear generating stations are best suited to providing a constant supply of electricity and are therefore less well suited to serving a variable load, such as air conditioning demand. Utilities in both countries will probably need to rely on a mix of demand-side measures, such as energy efficiency, and generation actions to cope with the changes in demand.

Uranium

Canada is the world's largest producer and exporter of uranium, the fuel for nuclear generators. Global efforts to reduce greenhouse gas emissions could lead to more nuclear power generation in some countries. That could lead to higher exports of uranium for Canada.

Summary

Climate change will reduce energy use for space heating, thus saving natural gas and home heating oil. The natural gas saved will simply moderate the expected North American shortage.

Utilities in Canada and the United States will need to rely on a mix of energy efficiency and generation options specific to their region to cope with the demand. The challenge will be greater in the United States due to its greater reliance on coal-fired generation and larger projected growth in air conditioning load. It does not appear that Canada will be able to substantially increase exports of electricity or natural gas to help meet the United States demand.

4.3 TRANSBORDER AIR QUALITY

Although the transborder transport of atmospheric pollutants between the United States and Canada has been well documented for acid rain and some contaminants, there has been little attempt to assess the potential impacts of climate change on these movements. Such impacts, positive or negative, can arise from:

- changes in average circulation patterns, especially in hot spells;
- increases in average air temperature and hot spells, and effects of sunlight on atmospheric chemical processes; and
- remedial actions to address air quality and emission reduction.

The regions of Canada currently most affected are southern Ontario and Quebec, southwestern New Brunswick and Nova Scotia, southern British Columbia and southwestern Alberta.

The main concerns are ground-level ozone concentrations, small particulate matter ($PM_{2.5}$), acid deposition, mercury and several other toxic chemicals. The human health and ecosystem effects of these atmospheric contaminants are addressed in the regional chapters, especially Ontario and Quebec. An estimate of premature deaths from these causes for a total of eight cities across Canada is 5900 per year (Judek et al., 2004).

For the critical Canada–United States transborder air-pollution issues, the two countries agreed on pollution control measures to lessen the impacts through the Canada–United States Air Quality Agreement of 1991 and its Ozone Annex of 2000 (Canada–United States Air Quality Committee, 2006). Areas of special concern are the Georgia Strait region of the Pacific Coast and the Great Lakes–St. Lawrence River area. The 2006 Progress Report notes that 3-year average ground-level ozone levels remained unacceptably high in 2002 to 2004. The highest daily maximum 8-hour average ozone concentration exceeded 95 ppm in southwestern Ontario and 80 ppm in a much larger area southwest of a line between the Ottawa Valley and the north end of Georgian Bay. This situation occurred in spite of successful programs in both countries that reduced the chemical precursors, volatile organic compounds (VOCs) and nitrous oxides (NOx). High ozone concentrations occur in smog episodes during hot spells, which are more frequent in the changing climate, when high temperatures and sunlight act upon the emitted precursor chemicals to create ozone.

The average annual number of smog advisories increased from 7 during 1993 to 1998 to 24 during 2000 to 2005, with a record of 53 in 2005 (Yap et al., 2005). The duration of 'warm spells' in the Great Lakes region increased between 1951 and 2003 (Alexander et al., 2006). Heat episodes (defined as temperature >30°C) are projected to double by 2050 and more than triple by 2080 (Cheng et al., 2005). More intense, more frequent and longer lasting heat waves are projected for both Europe and North America (Meehl and Tebaldi, 2004). Thus, the changing climate may prevent the air-pollution control efforts from having the desired effect of reducing ozone concentrations. Such warm-spell smog episodes are also periods of high particulate ($PM_{2.5}$) concentrations. It is estimated that transborder pollutants account for 99% of smog events in Windsor and 84% of events downwind of Toronto (Yap et al., 2005). In Quebec, pollutant sources in such events are estimated to be 30% from the United States and 30% from Ontario, with the balance locally generated. To reduce future health risks, it will be necessary to redouble efforts to reduce NOx and VOCs in Canada and the United States.

Acid deposition to Canada's lakes and forests has been somewhat ameliorated by reductions in SO_2 emissions in the United States and Canada (Canada–United States Air Quality Committee, 2006). Nevertheless, the effects of these improvements in aquatic ecosystems are influenced by lake characteristics and climate interactions (Canada–United States Air Quality Committee, 2006), and many lakes do not yet show signs of recovery. Work at the Experimental Lakes area in northwestern Ontario suggests that climate change is a factor in slowing the positive response of lakes (Schindler et al., 1996).

Further research and monitoring are required to address knowledge gaps with respect to the interaction in lake ecosystems between acid deposition and climate change, and the impacts of climate trends on transport of toxic chemicals.

5 CANADA'S INTERNATIONAL OBLIGATIONS ON ADAPTATION

"Climate change is a serious and long-term challenge that has the potential to affect every part of the globe." (G8 Gleneagles, 2005, p. 1)

A global reduction of greenhouse gas emissions facilitates adaptation by slowing the rate of climate change. As signatories to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, Canada and other developed countries have committed not only to reduce greenhouse gas emissions, but also to:

- assist developing countries that are particularly vulnerable to the adverse effects of climate change in meeting the costs of adaptation to those adverse effects; and
- facilitate the transfer of environmentally sound technologies and know-how to developing countries.

With atmospheric concentrations of greenhouse gases continuing to rise due to increasing global emissions, greater adaptation efforts are required in most countries.

5.1 ADAPTATION NEEDS IN DEVELOPING COUNTRIES

Some key requirements for empowering the vulnerable to cope with the changing climate, and adapt in the long term, have been identified as follows (Zubair, 2004):

- enhancing capability in climate science and technology, including monitoring, greater use of remote sensing and strengthening the science structure;
- improving assessments of vulnerability, impacts and adaptation options;
- making greater use of lessons learned from coping with climate variability; and
- empowering citizens, especially the young, through information programs.

Article 12 of the Kyoto Protocol, which establishes the Clean Development Mechanism (CDM), states that a share of CDM proceeds is earmarked to assist developing countries that are particularly vulnerable to the adverse effects of climate change in meeting the costs of adaptation. The share has been set at 2% of the Certified Emission Reductions (CERs) issued for most CDM projects. The CDM is still in its infancy and the first CERs were not issued until 2006, so the revenue this will generate to assist adaptation is uncertain. It has been estimated at €325 million through 2012, with a range of €125 to €570 million (United Nations Framework Convention on Climate Change, 2006). It should be noted that vulnerability is a function of many factors, including income, education and access to resources (*see* Chapter 2).

Multilateral assistance for adaptation is also available, but the amounts contributed have been small. The estimated status (as of 2006) of funding for adaptation under the UNFCCC, the Kyoto Protocol and the Global Environment Facility, housed in the World Bank, is summarized in Table 6.

Among the more successful capacity-building efforts are those that have involved communities in projects to increase resilience. For example, the Hyogo Framework 2005–2015 is aimed at building resilience of nations and communities to disasters (International Strategy for Disaster Reduction, 2005b). In drought-prone parts of Maharashtra state in India, projects on sustainable management of watersheds involved reclaiming degraded lands and improving yields in monsoon rain–fed agriculture. This was achieved through projects to 'catch rain where it falls', which were undertaken by villagers following a training program. In Sudan, a similar project was directed towards rangeland rehabilitation. Both projects increased resilience in the face of more intense dry periods punctuated by heavy rains in the changing climate (International Union for Conservation of Nature, 2003). Undergraduate and graduate study programs on climate science and sustainable development have been promoted in the Caribbean and the southwestern Pacific islands, with very positive effects on national impacts and adaptation programs.

A major blueprint for sustainable development in developing countries is contained in the Millennium Development Goals adopted by 189 nations in 2000. It is now evident that many of these goals cannot be achieved without dealing effectively with the impacts of changing climate. Goal 1 is to eradicate extreme poverty, yet the poorest people live in regions subject to coastal flooding in storm surges, river floods and severe storms, or in drought-intensive regions — most of these conditions being exacerbated by the changing climate. For example, the February 2000 floods in Mozambique washed away years of development work (Reid and Alam, 2005). Goals 4, 5 and 6 deal with human health, and climate change is increasing mortality and morbidity associated with malaria, dengue, heat waves and natural disasters. The El Niño hot period in 1983, a foretaste of future higher temperatures, and accompanying floods resulted in a 103% increase in infant mortality in Peru (Toledo Tito, 1997). Environmental sustainability is goal 7, yet ecosystem boundaries are shifting and ecosystem health is being degraded by the changing climate, especially in the far north and on coral reefs.

TABLE 6: Estimated status of funds for assistance in adaptation under the United Nations Framework Convention on Climate Change (*from* Global Environment Facility, 2006; United Nations Framework Convention on Climate Change, 2006).

Name of fund	Funding source	Total funds mobilized (US$)	Operational criteria	Main activities of support
I. Funds established under the United Nations Framework Convention on Climate Change (Articles 4.1, 4.3, 4.4, 4.5, 4.8, and 4.9)				
(a) Special Climate Change Fund (SCCF)	Voluntary contributions from 11 developed countries (Canada, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Portugal, Sweden, Switzer-land and United Kingdom)	US$45.4M (contributions: US$36.7M pledged: US$8.7M)*	• Additional cost of adaptation measures • Sliding scale for co-financing	• Addresses adaptation as one of the four funding priorities
(b) Least Developed Countries Fund (LDC Fund)	Voluntary contributions from 13 developed countries (Canada, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Spain, Sweden, and Switzerland as of April 30, 2006)	US$75.7M (previous contributions: US$29.9M pledged: US$45.8M GEF allocation to date: US$11.8M)**	• Guiding principles: country-driven approach, equitable access by LDCs, expedited support and prioritization of activities • Provision of full-cost funding for adaptation increment as identified and prioritized in NAPAs[1] • Sliding scale for co-financing	• Implementation of NAPAs[1] (all projects for the preparation of NAPAs in 44 countries approved with a budget of US$9.6M)
II. Fund established under the Kyoto Protocol (Article 4.10)				
(a) Adaptation Fund	2% share of proceeds from Clean Development Mechanism (CDM)	Not yet operational – projected to levy between US$160M and US$950M until 2012 (Müller, 2007)	• Guiding principles: country-driven and a 'learning-by-doing' approach, sound financial management and transparency, separation from other funding sources	• Concrete adaptation projects and programs identified in decision 5/CP7
III. Global Environment Facility (GEF)–managed funds established in response to guidance from the Conference of Parties (COP)				
(a) Global Environment Facility Trust Fund	GEF		• Incremental cost to achieve global environmental benefits	• Vulnerability and adaptation assessments as part of national communications and enabling activities
(b) Strategic Priority on Adaptation (SPA)	GEF	US$50M, of which US$25M has been allocated	• Incremental cost guidance with some flexibility, especially for Small Grants Programme	• Pilot and demonstration projects on adaptation • Small Grants Programme (US$5M) to support com-munity-based adaptation

[1] NAPA- National Adaptation Programmes of Action

* GEF allocation of US$2.0M was used for projects and administrative support.

** GEF allocation of US$11.8M to LDCF was approved for projects, administrative budgets and special initiatives

Without attention to climate change, Millennium Development Goals will become increasingly distant (Intergovernmental Panel on Climate Change, 2007b). To date, however, only a few bilateral development assistance programs have made climate change adaptation an element of their efforts.

In 2002, participants at the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa adopted a Summit Plan of Implementation as part of the strategy to meet the Millennium Development Goals (United Nations, 2002). The signatories agreed to a series of actions, one of which included protecting and managing the natural resource base of social and economic development. In the report that followed the summit, strong connections were drawn between international development and natural hazards, and included the following call for action:

> *"38. Change in the Earth's climate and its adverse effects are a common concern of humankind. We remain deeply concerned that all countries, particularly developing countries, including the least developed countries and small island developing states, face increased risks of negative impacts of climate change and recognize that, in this context, the problems of poverty, land degradation, access to water and food and human health remain at the centre of global attention. …Actions at all levels are required to:*
>
> *(a) Meet all the commitments and obligations under the United Nations Framework Convention on Climate Change…."* (United Nations, 2002, p. 29)

Small island developing states (SIDS) have been pursuing, since 1994, the Barbados Program of Action towards sustainable development, with a high priority on responding to climate change. Progress was reviewed at an international meeting in Mauritius in 2005, with 114 countries participating. Emphasis was placed on coping with natural disasters associated with climate change, capacity building, health issues, and coastal and marine resource management and protection. The Mauritius strategy notes that SIDS are already experiencing adverse effects of climate change and sea level rise. Canada has supported adaptation studies, training and on-the-ground measures to increase adaptive capacity, in the Caribbean and southwestern Pacific. New Zealand has adopted a policy favouring immigrants from small islands, including some under stress from climate change and inundation (*see* footnote 4).

The Intergovernmental Panel on Climate Change (IPCC) has recognized the clear connections between climate change, adaptation and sustainable development with a full chapter of the third assessment report devoted to the linkages. The summary of that chapter contains the following statement:

> *"Clearly, adaptive capacity to deal with climate risks is closely related to sustainable development and equity. Enhancement of adaptive capacity is fundamental to sustainable development."* (Smit et al., 2001, p. 899)

This is an important concept for all concerned with promoting sustainable development abroad.

5.2 ACTIONS TO DATE

The Canada Climate Change Development Fund (CCCDF) was established in 2000 to assist developing countries in tackling the challenge of climate change. It promoted activities in developing countries that address the causes and effects of climate change while at the same time contributing to sustainable development and poverty reduction. The CCCDF was a six-year, $110 million initiative administered by the Canadian International Development Agency (CIDA). The CCCDF had four themes, one specifically to reduce vulnerability of developing countries to the adverse effects of climate change. As the program developed, more emphasis was placed on adaptation, and included contributions to international adaptation funds and to the International Federation of Red Cross and Red Crescent Societies. Projects were undertaken in the Caribbean, southwestern Pacific, Indonesia and Nigeria, among others. In addition, Canada's International Development Research Centre (IDRC) is collaborating with the United Kingdom Department for International Development in a $65 million program for climate change adaptation in Africa, through research and capacity building.

Providing the scientific foundation for better climate change projections, as a basis for impact and adaptation studies, is an international effort. Discussions within the UNFCCC include consideration of co-ordinated and integrated approaches to scientific research and systematic observations for both adaptation and mitigation. The Nairobi work program on impacts, vulnerability and adaptation to climate change represents a significant new initiative under the UNFCCC to assist countries to make informed decisions on practical adaptation actions (United Nations Framework Convention on Climate Change, 2007). Canada has long been a participant in, and helped lead aspects of, many major international initiatives on global environmental change, such as the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP).

The Inter-American Institute for Global Change Research (IAI) is an intergovernmental organization supported by 19 countries, including Canada, in the western hemisphere. Its mission is to develop the capacity for understanding the integrated impact of present and future global change on regional and continental environments, and to promote collaborative research and informed action at all levels. The primary objective of the science agenda of the IAI is to encourage research beyond the scope of national programs by advancing comparative and focused studies based on scientific issues important to the region as a whole, including climate change adaptation (Fenech et al., 2005).

The global change SysTem for Analysis, Research and Training (START), cosponsored by the IGBP, WCRP and IHDP, provides an international framework for capacity building. It is a nongovernment, nonprofit organization that establishes and fosters regional networks of collaborating scientists and institutions in developing countries. These networks conduct research on regional aspects of environmental change; assess impacts and vulnerabilities to such changes; and provide information to policy-makers. The organization acts to enhance the scientific capacity of developing countries to address the complex processes of environmental change and degradation through a wide variety of training and career development programs. It mobilizes resources to support infrastructure and research programs on environmental change within developing regions.

Canadians have played active roles in international assessments of climate change impacts and adaptation measures through the Intergovernmental Panel on Climate Change and the Arctic Climate Impact Assessment. On issues of global health impacts of climate change, Health Canada has actively collaborated with the World Health Organization, the United Nations Environment Programme and the World Meteorological Organization (e.g., Kovats et al., 2003).

6 SYNTHESIS

The above analysis (Sections 1 to 5) leads to some conclusions of relevance to policy, program or investment decisions by Canada in response to changing climate abroad, as observed and projected for the future. Many of these conclusions are indicated in the text and summarized in the 'Key Findings' section.

- Resource conflicts, especially over water, will be exacerbated in some regions of the world, and sea-level rise and increasing natural disasters will force people to relocate both within countries and internationally, with implications for Canadian policies and activities related to aid, peace-keeping and immigration.
- Risks associated with many climate-sensitive diseases are likely to increase, so continued vigilance will be required to address the increasing risks to Canadians.
- Reduced sea-ice cover in the warming Arctic will result in greater marine traffic and development activities by many countries, and could present challenges for Canadian control and environmental protection. Circumpolar wildlife and indigenous ways of life are also threatened by loss of sea ice and melting permafrost (*see* Chapter 3).
- Intensification of smog episodes, associated with longer and more intense warm spells, is leading to an increase in health problems associated with ozone precursors and small particle emissions from American and Canadian sources. Reducing these health risks will require greater reductions in emissions of precursors in both countries.
- As a result of climate change, global prices for wood products may fall, and there may be some opportunities in Canada for increasing agricultural exports (grains, corn) and reducing imports (fruits, vegetables).
- Canada's warm-season tourism potential is expected to increase, whereas many winter activities will require significant adaptation of facilities to remain sustainable. Canadian travel to warm destinations may be reduced. Tourism promotion programs could help to realize economic and social benefits.
- Canada–United States border and transborder water agreements were developed without consideration of a changing climate, and some may not be appropriate to protect future Canadian interests or responsibilities in water apportionment and water quality agreements.
- Increasing aridity in southwestern North America is likely to increase pressures for bulk export of water from Canada, with implications for trade and transborder water policies, including protection of Canadian waters.
- Increased air conditioning loads, and probable reduced hydroelectric supply in the United States and parts of Canada, will have major implications for energy planning in Canada and energy export agreements.
- Weather-related disaster losses are increasing rapidly worldwide, in part due to increasing frequency of extreme events. Improved disaster preparedness and management assistance will be required, especially to developing countries.
- Although some climate and ocean change effects on fisheries have been identified, there are limited data on, and understanding of, changes in fish distribution and abundance in response to climate and related oceanic changes. This represents a significant knowledge gap to be addressed through monitoring and research.
- The need for international assistance programs for adaptation to climate change in developing countries is increasing. The wide range of adaptation issues to be addressed includes preparing for and coping with natural disasters, dealing with shortages of water and food supplies, and health-related issues.
- International programs in natural and social science (including economics), and research and science assessments on climate change, provide essential foundations for Canadian policy and program responses. Active involvement of Canadian experts in these activities contributes internationally and also helps enable input of globally current science to policies in Canada.

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