Government of Canada Gouvernement du Canada

Climate Change Impacts and Adaptation:

A Canadian Perspective

Water Resources

Prepared by the Climate Change Impacts and Adaptation Directorate
Natural Resources Canada
July 2002

Canada

Preface

There is strong consensus in the international scientific community that climate change is occurring and that the impacts are already being felt in some regions (see, for example, the recent Third Assessment Report of the Intergovernmental Panel on Climate Change). It is also widely accepted that even after introducing significant measures to reduce greenhouse gas emissions, some additional degree of climate change is inevitable, and this will have economic, social and environmental impacts on Canada and Canadians.

It is possible to reduce our vulnerability to climate change. An effective response involves both the reduction of greenhouse gas emissions as well as adaptation to the impacts resulting from a changing climate. Reducing greenhouse gas emissions will decrease both the amount of climate change, as well as the rate of change, so that effective adaptation can occur. Adaptation refers to activities that minimize the negative impacts of climate change, and position us to take advantage of new opportunities that may be presented.

The report *"Climate Change Impacts and Adaptation: a Canadian Perspective"* presents a brief summary of research in this field over the past five years, as it relates to Canada. Results of research supported by the Government of Canada's Climate Change Action Fund (CCAF) are highlighted in boxes within each chapter of the report.

The Water Resources chapter focuses on the impact of climate change on the supply of water in Canada, the increasing demands for this critical resource, and options to deal with these impacts. At the same time, it must be recognized that adaptation decisions taken within the water resources sector will have important implications in many other areas, including agriculture, transportation, human health and industry. A complete assessment of impacts and adaptation options should therefore take into consideration issues raised within other chapters of this report.

Please direct inquiries to:

Climate Change Impacts and Adaptation Directorate
Natural Resources Canada
601 Booth Street
Ottawa, Ontario, K1A 0E8

or via e-mail to dlemmen@nrcan.gc.ca

Understanding the vulnerability of Canada's water resources to climate change is vitally important. Water is one of Canada's greatest resources. We depend on the availability of a clean, abundant water supply for domestic use; food, energy and industrial production; transportation and recreation; and the maintenance of natural ecosystems. It is estimated that water's measurable contribution to the Canadian economy reaches $7.5 to 23 billion per year[1].

Canada has a relative abundance of water, possessing 9% of the world's renewable freshwater, yet only 0.5% of the global population.[2] However, the water is not evenly distributed across the country, and water availability varies both between years and with the changing seasons. As a result, most regions of the country have experienced water-related problems, such as shortages (droughts), excesses (floods) and associated water quality issues. For example, the drought of 2001 affected Canada from coast to coast (Table 1), with significant economic and social impacts. In the 1990s, severe flooding in the Saguenay region of Quebec (1996) and Manitoba's Red River valley (1997) were two of the costliest natural disasters in Canadian history.

In its Third Assessment Report, the Intergovernmental Panel on Climate Change projects an increase in globally averaged surface air temperatures of 1.4 to 5.8°C by 2100. Changes of this magnitude would significantly impact water resources in Canada[4]. Climatic variables, such as temperature and precipitation, greatly influence the hydrological cycle, and changes in these variables will affect runoff and evaporation patterns, as well as the amount of water stored in glaciers, snowpacks, lakes, wetlands, soil moisture and groundwater. However, there remains uncertainty as to the magnitude and, in some cases, the direction of these changes. This is related to the difficulty that climate models have in projecting future changes in regional precipitation patterns and extreme events, and to our incomplete understanding of hydroclimatic processes.

TABLE 1: The 2001 drought across Canada.[3]

REGION	CONDITIONS IN 2001
British Columbia	• Driest winter on record, with precipitation half of historic average across coast and southern interior • Snowpacks in southern regions were at or below historic low
Prairies	• Saskatoon was 30% drier than 110-year record • Many areas experienced lowest precipitation in historic record • Parts of the Palliser Triangle experienced second or third consecutive drought
Great Lakes–St. Lawrence basin	• Driest summer in 54 years • Southern Ontario (Windsor–Kitchener) experienced the driest 8 weeks on record • Montreal experienced driest April on record and set summer record with 35 consecutive days without measurable precipitation
Atlantic	• Third driest summer on record • Large regions experienced only 25% of normal rainfall in July, and August was the driest on record • July, with 5 mm of rain, was the driest month ever recorded in Charlottetown

In addition to the expected shifts in hydrological parameters, potential changes in the economic, demographic and environmental factors that influence water resources must also be considered. The response of water users, as well as water management mechanisms, to climate change will greatly influence the vulnerability of water resources. Both the ability and the willingness of society to undertake appropriate adaptive measures are critically important.

The impacts of climate change on water resources will vary across the country, due to regional differences in climate changes, hydrological characteristics, water demand and management practices. Some of the major potential impacts are listed in Table 2.

From this table, it is evident that the potential impacts of extreme events, seasonal shifts in flow regimes and reduced winter ice cover are key issues for several regions of Canada.

TABLE 2: Potential impacts of climate change on water resources (derived from Figure 15-1 in reference [4]).

REGION	POTENTIAL CHANGES	ASSOCIATED CONCERNS
Yukon and coastal British Columbia	• Increased spring flood risks (BC), impacts on river flows caused by glacier retreat and disappearance	• Reduced hydroelectric potential, ecological impacts (including fisheries), damage to infrastructure, water apportionment
Rocky Mountains	• Rise in winter snowline in winter-spring, possible increase in snowfall, more frequent rain-on-snow events	• Increased risk of flooding and avalanches
	• Decrease in summer streamflow and other changes in seasonal streamflow	• Ecological impacts, impacts on tourism and recreation
Prairies	• Changes in annual streamflow, possible large declines in summer streamflow	• Implications for agriculture, hydroelectric generation, ecosystems and water apportionment
	• Increased likelihood of severe drought, increasing aridity in semiarid zones	• Losses in agricultural production, changes in land use
	• Increases or decreases in irrigation demand and water availability	• Uncertain impacts on farm sector incomes, groundwater, streamflow and water quality
Great Lakes basin	• Possible precipitation increases, coupled with increased evaporation leading to reduced runoff and declines in lake levels	• Impacts on hydroelectric generation, shoreline infrastructure, shipping and recreation
	• Decreased lake-ice extent, including some years without ice cover	• Ecological impacts, increased water loss through evaporation and impacts on navigation
Atlantic	• Decreased amount and duration of snow cover	• Smaller spring floods, lower summer flows
	• Changes in the magnitude and timing of ice freeze-up and break-up	• Implications for spring flooding and coastal erosion
	• Possible large reductions in streamflow	• Ecological impacts, water apportionment issues, hydroelectric potential
	• Saline intrusion into coastal aquifers	• Loss of potable water and increased water conflicts
Arctic and Subarctic	• Thinner ice cover, 1 to 3 month increase in ice-free season, increased extent of open water	• Ecological impacts, impacts on traditional ways of life, improved navigation, changes in viable road networks
	• Increased variability in lake levels, complete drying of some delta lakes	• Impacts on ecosystems and communities

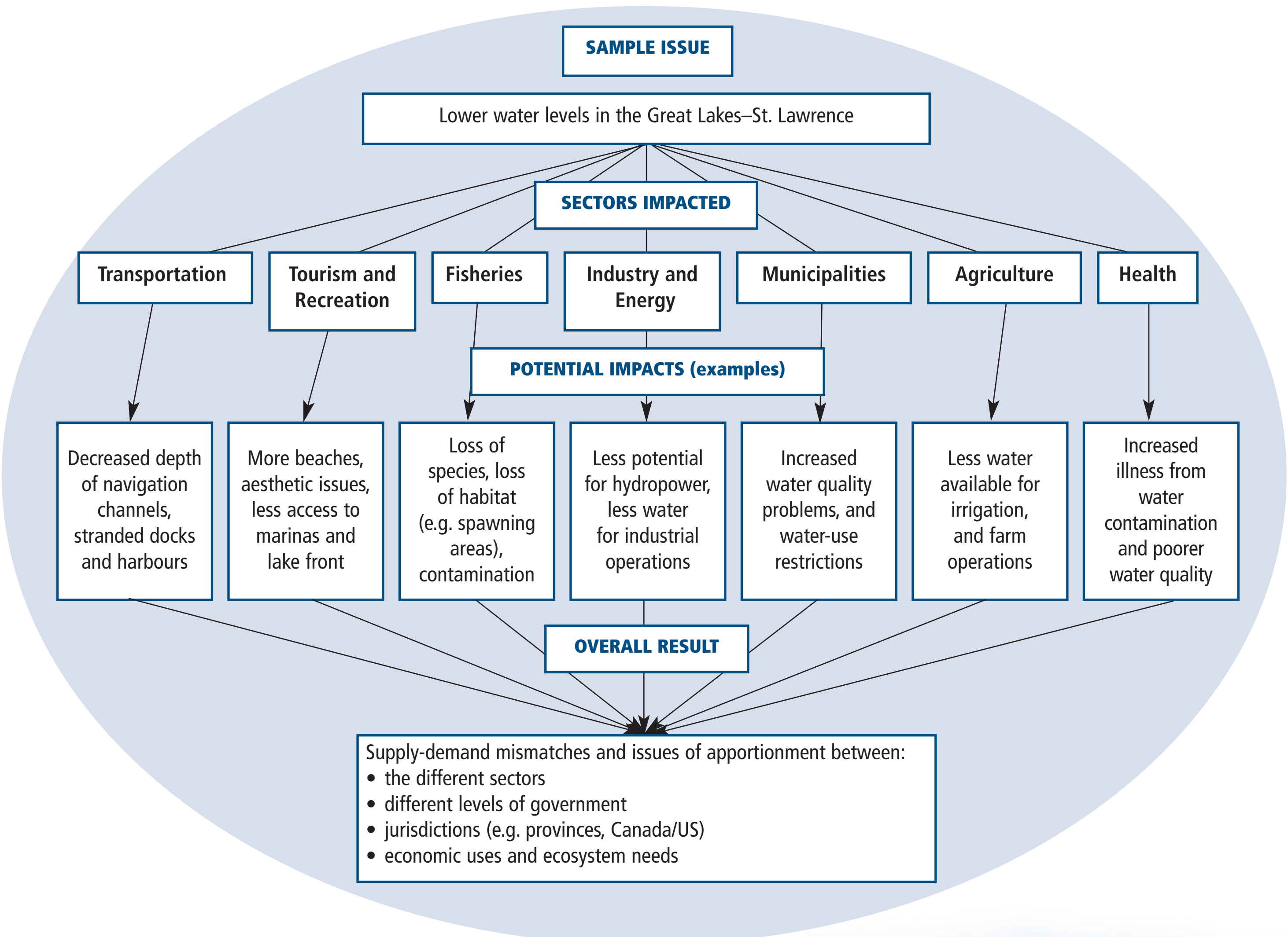
This chapter examines current research on these and other issues, as well as recent progress in adaptation research. Focus is placed on the impacts on water supplies and demand, and on options to adapt to these impacts. Many other aspects of water resources related to transportation, recreation, health and fisheries are addressed in other chapters of this report. While significant uncertainty remains in projecting future impacts, it does not limit our ability to take action to reduce our vulnerability to climate change. By understanding the range of possible impacts, as well as the intricate role of societal response to changing conditions, we will be better prepared to reduce losses and capitalize on potential benefits.

Previous Work

"The sensitivity of a water resource system to climate change is a function of several physical features and, importantly, societal characteristics." [5]

Numerous reports and workshops involving researchers and stakeholders have identified water resources as one of the highest priority issues with respect to climate change impacts and adaptation in Canada. This reflects both the climatic sensitivity of the resource and the crosscutting nature of water issues, where adaptation decisions in one sector will have significant consequences in several other sectors. Figure 1 illustrates some of these issues as they relate to decreasing water levels in the Great Lakes–St. Lawrence basin, and the impacts on sectors such as transportation, fisheries, agriculture and human health.

FIGURE 1: Water resources is a crosscutting issue.



In their summary of research as part of the Canada Country Study, Hofmann et al.[6] stated that climate change will have a range of impacts on both the hydrological cycle and water uses. For the nation as a whole, climate change will likely increase precipitation, evaporation, water temperatures and hydrological variability. These changes will combine to negatively impact water quality. Regional projections include declining Great Lakes water levels, decreasing soil moisture in southern Canada, and a reduction of wetlands in the Prairies. Another key concern is increased conflict between water users due to increasing mismatches between supply and demand.

Previous literature suggests infrastructure modification, management adjustment and development of new water policies as methods of adaptation in the water resources sector.[6] Uncertainties in impact projections have led many authors to advocate the implementation of 'no regrets' adaptation options. These measures would benefit Canadians, irrespective of climate change, as they address other environmental issues. The engagement of stakeholders, including the general public, is critical to the development of effective adaptation strategies. Perhaps most importantly, the literature notes that water managers must be encouraged to address climate change impacts in their long-term planning activities.

Much of the research on water resources and climate change has concentrated on the physical aspects of the issue, particularly hydrological impacts,[7] and less so on the economic and social aspects. This imbalance and the resulting knowledge gaps have been recognized in the literature, and in the reports and proceedings of numerous workshops and similar forums that have addressed climate change impacts and adaptation in Canada.

Impacts on Water Supply

Quantity of Freshwater

As flow patterns and water levels respond to the changing climate, our water supplies will be affected. Diminishing surface-water and groundwater supplies, coupled with increasing demands for these resources, would challenge all aspects of water resource management.

It is difficult to predict future changes in the availability of freshwater. While there is confidence that warmer temperatures will affect variables such as evaporation and snow cover, uncertainties concerning the nature of regional changes in precipitation patterns, as well as the complexity of natural ecosystems, limit our ability to project hydrological changes at the watershed scale. However, it is reasonable to generalize that, for many regions of Canada, climate change will likely result in decreased summer flows, warmer summer water temperatures and higher winter flows. This is particularly true for the snowmelt-dominated systems that are found across most of the country.[4]

Some of the most vulnerable regions of Canada with respect to the impact of climate change on water resources are those that are already under stress, with demand approaching or exceeding supply. This is most apparent in the driest regions of the southern Prairies, commonly referred to as the Palliser Triangle, where drought and severe annual soil moisture deficits are recurrent problems.[8] Even Ontario, perceived to be an especially water-rich province, suffers from frequent freshwater shortages,[9] and more than 17% of British Columbia's surface-water resources are at or near their supply capacity for extractive uses.[10]

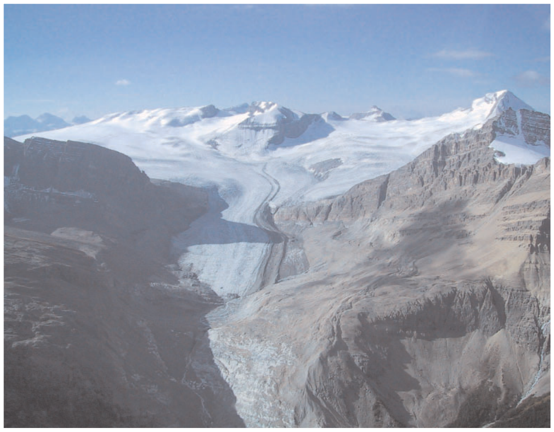
For much of western Canada, snowmelt and glacier runoff from mountainous areas are primary sources of water supply for downstream regions. With warmer conditions, the seasonal and long-term storage capacity of alpine areas may decrease, due to thinner snowpacks, more rapid spring runoff, and decreased snow and ice coverage.[11] This, in turn, would result in lower summer river flows and therefore greater water shortages during the period of peak demand. Recent trends observed on the eastern slopes of the Canadian Rocky

Mountains suggest that the impacts of diminishing glacier cover on downstream flows are already being felt (*see* Box 1). Across southern Canada, annual mean streamflow has decreased significantly over the last 30–50 years, with the greatest decrease observed during August and September.[12] Continued decreases are projected to occur as a result of climate change.

BOX 1: Diminishing flows in Prairie rivers.[13]

Glacial meltwater is a key source of water for rivers in western and northern Canada. Along the eastern slopes of the Canadian Rocky Mountains, glacier cover has decreased rapidly in recent years, and total cover is now approaching the lowest experienced in the past 10 000 years. As the glacial cover has decreased, so have the downstream flow volumes.

This finding appears to contradict projections of the Intergovernmental Panel on Climate Change that warmer temperatures will cause glacial contributions to downstream flow regimes to increase in the short term. However, historical stream flow data indicate that this increased flow phase has already passed, and that the basins have entered a potentially long-term trend of declining flows. The continuation of this trend would exacerbate water shortages that are already apparent across many areas of Alberta and Saskatchewan owing to drought.



Peyto Glacier *(photo courtesy of Mike Demuth)*

The Great Lakes basin is another region where there are significant concerns over the impact of climate change on water resources. More than 40 million people live within the basin, most of whom depend on the lakes for their water supply.[14] Many studies have suggested that climate change will result in lower water levels for the Great Lakes, with consequences for municipal water supplies, navigation, hydroelectric power generation, recreation and natural ecosystems.

Although summer stream flows are generally expected to decline, many researchers project a corresponding increase in winter flows. This is because warmer winters would increase the frequency of mid-winter thaws and rain-on-snow events, a trend that is already evident on the upper Saint John River.[15] This, in turn, would increase the risk of winter flooding in many regions as a result of high flows and severe ice jams.[16] For example, on the Grand River of southern Ontario, researchers project that warmer temperatures and increased precipitation will extend the risk of severe flooding to the months of January and February.[17] However, since snow accumulation will likely be reduced by frequent, small melt events throughout the winter, the magnitude of spring flooding will likely decline. Similar patterns are anticipated for snowmelt-dominated rivers across much of southern Canada.

Climate change affects not only the quantity of surface water but also that of groundwater. Every region of Canada is reliant, to some degree, on groundwater. For example, the entire population of Prince Edward Island relies on groundwater for potable water, while approximately 90% of the rural population in Ontario, Manitoba and Saskatchewan depend on groundwater resources.[18, 19] Despite its importance, recharge rates for groundwater across the country are virtually unknown, groundwater dynamics are poorly understood,[20] and research on the impacts of climate change remains limited.[6]

The depth and nature of the groundwater affects its sensitivity to climate change. In general, shallow unconfined aquifers will be impacted most significantly. This is clearly demonstrated by historic variability, in which shallow wells in many parts of Canada run dry during drought periods. In many regions, unfortunately, these shallow aquifers also contain the highest quality groundwater and are a critical source of potable water and water for livestock. Although deeper aquifers are less sensitive to the direct impacts of climate change, the failure of shallow aquifers could encourage their exploitation. These deep aquifers can take decades to recover from pumping, due to slow recharge rates.[20]

Local factors, such as the permeability of the material (e.g., soil, rock) above the aquifer, and the timing of precipitation, strongly affect the rate of groundwater recharge and therefore sensitivity to climate change.[18] An increase in winter precipitation is expected to benefit groundwater levels more than an increase in summer precipitation. This is because snowmelt tends to recharge groundwater, whereas summer precipitation is primarily lost through evapotranspiration.[20]

Quality of Freshwater

Water quality would suffer from the projected impacts of climate change. Poor water quality effectively diminishes the availability of potable water, and increases the costs associated with rendering water suitable for use.

Changes in water quantity and water quality are inextricably linked. Lower water levels tend to lead to higher pollutant concentrations, whereas high flow events and flooding increase turbidity and the flushing of contaminants into the water system. Box 2 lists some of the main water quality concerns facing different regions of the country.

Warmer air temperatures would result in increased surface-water temperatures, decreased duration of ice cover and, in some cases, lower water levels. These changes may contribute to decreased concentrations of dissolved oxygen, higher concentrations of nutrients such as phosphorus, and summer taste and odour problems (e.g., references 22, 23).

River flows are expected to become more variable in the future, with more flash floods and lower minimum flows. Both types of hydrological extreme have been shown to negatively affect water quality. During low flow events, increased concentrations of toxins, bacterial contaminants and nuisance algae are common. For example, when flow dropped in the St. Lawrence and Ottawa rivers, noxious odours became a problem due to an increase in a particular type of phytoplankton.[24] Heavy flow events have been shown to increase soil erosion and chemical leaching, whereas intense rainfalls increase the risk of runoff of urban and livestock wastes and nutrients into source water systems.[25]

BOX 2: Main water quality concerns across Canada.[21]

REGION	WATER QUALITY CONCERN
Atlantic	• Salt water intrusion in groundwater aquifers • Water-borne health effects from increased flooding
Quebec	• Upstream shift in saltwater boundary in the Gulf of St. Lawrence • Water-borne health effects from increased flooding and sewer overflow
Ontario	• Degradation of stream habitat • Water-borne health effects • Volatilization of toxic chemicals
Prairies	• Summer taste/odour problems in municipal water supply • Stream habitat deterioration
British Columbia	• Saltwater intrusion due to rise in sea level and increased water demands • Water-borne health effects from increased floods • Increased water turbidity from increased landslides and surface erosion
Arctic and the North	• Rupture of drinking water and sewage lines from permafrost degradation • Rupture of sewage storage tanks from permafrost degradation, and seepage from sewage storage lagoons • Increased turbidity and sediment loads in drinking water

Climate change may also affect the quality of groundwater. For example, reduced rates of groundwater recharge, flow and discharge may increase the concentrations of contaminants in the groundwater. Saltwater intrusion into groundwater aquifers in coastal regions is another concern, although Canadian research on this topic is limited.[26] In southern Manitoba, future changes in precipitation and temperature may cause groundwater levels in some parts of the Red River basin to decline faster than others.[27] These changes would affect the flow in the aquifer, and possibly shift the saline-freshwater boundary beneath the Red River valley, so that the groundwater in some areas may no longer be drinkable.[27]

Ecological Impacts

"Water is also a critical, limiting factor in the existence and distribution of our natural ecosystems."[6]

Wetlands, important natural modifiers of water quality, are highly sensitive to climate change.[28] As water flows through a wetland, contaminants such as metals, nutrients and sulphates are often filtered out. Lower water table levels, however, decrease the assimilative and purification abilities of wetlands. Drier conditions have also been associated with acid pulses (which can cause fish kills) and the formation of highly toxic methyl-mercury.[29, 30] In the Canadian Prairies, wetlands (sloughs) are of tremendous hydrological importance, and provide vital habitat for birds and aquatic species. The persistence of these wetlands depends on a complex interaction between climate, geology and land use patterns, and their extent is controlled by the balance between water inputs and outputs.[31] The greatest impact of future climate change on Prairie wetland coverage would result from changes in winter snowfall, whereas changes in evaporation would have a smaller impact.[31] Coastal wetlands of the Great Lakes are likely to suffer from decreased lake water levels and from shifts in surface-water and groundwater flow patterns.[32]

River ecosystems are also an important component of the Canadian landscape. Their sensitivity to climate change is influenced by the characteristics of the river and its location. Northern rivers may be impacted by permafrost degradation and changes in flood regimes.[33] Ice-jam flooding is a key dynamic of the Peace–Athabasca Delta in northern Alberta, particularly for rejuvenation of riverside ecosystems. A decrease in ice-jam flooding due to climate change would significantly impact this ecologically sensitive region.[34] In southern Canada, seasonal shifts in flow regimes projected for rivers could have major ecological impacts, including loss of habitat, species extinction, and increased water contamination. Drainage basins containing large lakes or glaciers are generally less sensitive to changes in climate, at least in the short term, as these features help buffer the impacts of climate change.

Forests cover almost half of Canada's landmass and are important regulators of the hydrological cycle. Changes in forest extent and distribution, due to climate change or other factors, impact the storage and flow of water. An increase in forest disturbances, such as fires and insect defoliation, would also affect the ability of the forest to store and filter water. The impacts of climate change on forest ecosystems are covered in greater detail in the forestry chapter.

Water Demand

"The consequences of climate change for water resources depend not only on possible changes in the resource base (supply)…but also on changes in the demand, both human and environmental, for that resource."[5]

Future water demand will be affected by many factors, including population growth, wealth and distribution. Globally, it is estimated that between half a billion and almost two billion people are already under high water stress, and this number is expected to increase significantly by 2025, due primarily to population growth and increasing wealth.[35] Warmer temperatures and drier conditions due to climate change would further increase future water demand in many regions.

Where climate change is associated with increased aridity, it would directly affect water demand with respect to agricultural and domestic uses. For example, outdoor domestic water uses (e.g., gardening and lawn watering) and drinking-water demand tend to increase in warmer, drier conditions. In some cases, technological and management changes may sufficiently increase water use efficiency to address the increased demand. Management changes that work to reduce the demand for water will also be important. Warming of surface waters would have a direct impact on industrial operations by decreasing the efficiency of cooling systems, which could in turn reduce plant outputs.[36]

Another major demand on water resources is hydroelectric power generation, which fulfills approximately two-thirds of Canada's electricity requirements.[2] Studies suggest that the potential for hydroelectric generation will likely rise in northern regions and decrease in the south, due to projected changes in annual runoff volume.[37] For example, lower water levels are expected to cause reductions in hydro generation in the Great Lakes basin.[14] An increase in annual flows, however, will not always lead to increased hydro production. Increases in storms, floods and sediment loading could all compromise energy generation. In western Canada, changes in precipitation and reduced glacier cover in the mountains will affect downstream summer flows and associated hydroelectric operations.[13] Moreover, changes in the ice regimes of regulated rivers will likely present the hydro industry with both opportunities, in terms of shorter ice seasons, and challenges, from more frequent midwinter break-ups.[16]

The seasonality of the projected changes, with respect to both the availability and demands for water resources, is another important factor. For example, during the summer months, lower flow levels are projected to reduce hydroelectric generation potential, while more frequent and intense heat waves are expected to increase air-conditioner usage and therefore electricity demand. Demand for hydroelectric power exports is also likely to increase in the summer, due to increased summer cooling needs.

Increased demand in any or all of these sectors would increase the conflict between alternative water uses, including in-stream needs to retain ecosystem sustainability. Improvements in water use efficiency may be required to prevent the extinction of some aquatic species and the degradation of wetlands, rivers, deltas and estuaries.[38]

Adaptation in the Water Resources Sector

"Water managers are beginning to consider adapting to climate change…[however], the extent of adaptation by many water managers is uncertain."[5]

Several studies indicate that managers are generally complacent toward the impacts of climate change.[36, 39] In a survey of American water resource stakeholder organizations, no groups indicated the intention to conduct future work regarding climate change, and all ranked the level of attention given to climate change as low.[40] This may be because managers generally believe that the tools currently used to deal with risk and uncertainty will be sufficient for dealing with any increased variability induced by climate change.

BOX 3: Commonly recommended adaptation options.[21]

The most frequently recommended adaptation options for the water-resources sector include:

- Water conservation measures;
- Improved planning and preparedness for droughts and severe floods;
- Improved water-quality protection from cultural, industrial and human wastes;
- Enhanced monitoring efforts; and
- Improved procedures for equitable allocation of water.

Each of these recommendations would be considered a 'no-regrets' option that would benefit Canadians irrespective of climate change impacts.

Another important factor could be the lack of standards for incorporating climate change into design decisions. The reactive, rather than proactive, nature of water management may also play a role.

There are, however, exceptions to these general trends. For example, water managers in the Grand River basin of southwestern Ontario, have begun to develop contingency plans for future droughts,[41] and a series of workshops has been held to evaluate decision analysis methods for dealing with shifting Lake Erie water levels under climate change.[42] These initiatives contradict the often-cited opinion that climate change will have minimal influence on water management operations until there is better information regarding the timing and nature of the projected changes. Researchers point out that the scientific uncertainty associated with climate change is not very different than the other sources of uncertainty that water managers are trained to consider, such as population growth and economic activity.[43] Therefore, uncertainty should not preclude the inclusion of climate change as part of an integrated risk management strategy.

Structural Adaptations

In contemplating structural adaptations, one should consider whether the system will be capable of dealing with the projected hydrological changes, as well as the economic, social and ecological costs of the adaptation.

Physical infrastructure, such as dams, weirs and drainage canals, has traditionally served as one of the most important adaptations for water management in Canada. There are conflicting opinions, however, on the potential of building new structures for climate change adaptation. Given the substantive environmental, economic and social costs associated with these structures, many experts advocate avoiding or postponing the construction of large-scale infrastructure until there is greater certainty regarding the magnitude of expected hydrological changes.

On the other side of the coin is the fact that water infrastructure improves the flexibility of management operations, and increases a system's capacity to buffer the effects of hydrological variability.[5] In the Peace River, for example, stream regulation will allow operators to potentially offset the effects of climate change on freeze-up dates by reducing winter releases.[44] Similarly, communities in the southern Prairies can use small-scale water infrastructure to increase water storage through snow management, and reduce regional vulnerability to drought.[45]

Most existing water management plans, as well as water-supply and -drainage systems, are based upon historic climatic and hydrological records, and assume that the future will resemble the past. Although these systems should be sufficient to handle most changes in mean conditions associated with climate change over the next couple of decades, management problems are likely to arise if there is an increase in climate variability and the occurrence of extreme events. Case studies in Ontario indicate that increases in the intensity of precipitation events have the potential to increase future drainage infrastructure costs and decrease the level of service provided by existing systems (Box 4).

BOX 4: How vulnerable is our infrastructure?[46]

Since the majority of urban water drainage systems are designed based upon historical climate records, a change in precipitation patterns may cause these systems to fail. More intense precipitation events are expected to decrease the level of service that existing drains, sewers and culverts provide, and increase future drainage infrastructure costs. While making the necessary changes (e.g., increasing pipe sizes) would be expensive, the overall costs are expected to be lower than the losses that would result from not adapting. For example, insufficient pipe sizes would lead to an increase in sewer backups, basement flooding and associated health problems.

Several studies suggest that the design of water management systems should focus on thresholds, such as the point at which the storage capacity of a reservoir is exceeded, rather than mean conditions (e.g., references 47, 48). Thresholds can induce nonlinear and therefore less predictable responses to climatic change, which would significantly stress the adaptive capacity of water resource systems.[43]

In many cases, modification of existing infrastructure operations, rather than the introduction of new structures, will be an effective adaptation option.[49] For example, models indicate that the Grand River basin will be able to adapt to all but the most severe climate change scenarios through modifications in operating procedures and increases in reservoir capacity.[50] A drainage infrastructure study of North Vancouver suggests that the system can be adapted to more intense rainfall events by gradually upgrading key sections of pipe during routine, scheduled infrastructure maintenance.[51] Adaptations such as these can be incorporated into long-term water management planning.

Institutional Adaptations and Considerations

"The ability to adapt to climate variability and climate change is affected by a range of institutional, technological, and cultural features at the international, national, regional, and local levels, in addition to specific dimensions of the change being experienced."[5]

Demand management involves reducing water demands through water conservation initiatives and improved water use efficiency. Demand management is considered to be an effective, and environmentally and economically sustainable, adaptation option. As a result, programs based on water conservation and full water costing are being increasingly used in the municipal sector. In the Grand River basin, for example, municipalities have begun to develop programs to make water use, storage and distribution more efficient. At the same time, however, many municipalities are unable to adopt demand management programs due to insufficient legal or institutional provisions.[41] The lack of public awareness of the need for water conservation and avoidance of wasteful practices is also an obstacle. Some other factors that affect a community's ability to adapt are outlined in Box 5.

BOX 5: What affects a community's capacity to adapt? [52]

In a study of the Upper Credit River watershed in southern Ontario, the following were identified as important factors in determining a community's capacity to adapt to climate change:

- stakeholders' perceptions and awareness of the issues involved
- level and quality of communication and coordination between stakeholders and water managers
- level of public involvement in water-management decision-making and adaptation implementation
- quality and accessibility of resources (e.g., sufficient financial resources, adequately trained staff and access to high-quality data)
- socio-economic composition (more affluent communities can dedicate more money to adaptation)

Some of these factors could be enhanced through such mechanisms as public information sessions and increased networking, whereas others, such as socio-economic structure, can be significant barriers to adaptation.

Community water conservation initiatives can be extremely successful at reducing water demands and minimizing the impacts of climate change on regional water supplies.[53] In a study of sixty-five Canadian municipalities, sixty-three were found to have already undertaken water conservation initiatives.[54] Similarly, most rural property owners surveyed in Ontario had practiced some form of water conservation, such as shortening shower times and reducing water waste in homes.[9] Factors that influenced the adoption of conservation methods included program awareness and participation, level of formal education, and anticipation of future water shortages. A successful community approach to water management problems was documented for North Pender Island, British Columbia.[55] Water management on the island is the responsibility of five elected trustees who oversee the water use act, which specifies volume allocations per household and the acceptable and unacceptable uses of the community's water supply. Failure to comply with the water act results first in warnings, then potential disconnection from the town's water supply.

The institutional capacity of the community or system is key in implementing effective adaptation. In Canada, introducing adaptation measures can be challenging, simply due to the fact that many different levels of government administer water management activities. Even within one level of government, several separate agencies are often involved in water legislation.[46] Clear definition of the roles and responsibilities of each agency involved is an important first step in building adaptive capacity,[52] as is the development of mechanisms to foster interagency collaboration (e.g., the Canadian Framework for Collaboration on Groundwater). Another key requirement is the willingness of the water management agencies to provide appropriate assistance to communities in support of adaptation implementation.[52] The community's perceptions of the different adaptation options are also important (Box 6).

Although institutional changes represent an important adaptation option in water resource management, it must be recognized that some current legislation may also present barriers to future adaptation. For example, the Niagara River Treaty may restrict the ability of power utilities to adapt to low flow conditions, as the treaty apportions water for hydroelectric power generation and the preservation of Niagara Falls scenery.[43] Another example is the Boundary Waters Treaty of 1909, which determines the priority of interests in the Great Lakes (e.g., domestic and sanitary purposes first, then navigation, and then power and irrigation) and does not recognize environmental, recreational or riparian property interests.[43] However, the Great Lakes Water Quality Agreement, signed in 1978, does strive to protect physical, chemical and biological integrity in the Great Lakes basin.[14]

Economics, pricing and markets are fundamental mechanisms for balancing supply and demand. In the future, water demands may be increasingly controlled through pricing mechanisms, as has been seen in the Grand River basin over recent years.[57] Although increasing the cost of water would act as an incentive to limit use, there are still many issues that need to be addressed, including an improved understanding of the environmental justice and equity consequences of water pricing.[39]

BOX 6: Perceptions of adaptation options.[56]

Focus group interviews in the Okanagan Valley revealed that structural changes (e.g., dams) and social measures (e.g., buying out water licences) were adaptation options preferred by these small groups to address water shortages in that region. Structural adaptations designed to intervene and prevent the impacts of climate change, such as dams and snow making, were especially favoured. The focus groups were also able to identify the implications of different adaptation choices (e.g., the high economic and environmental costs of dams). Overall, the interview process revealed a strong stakeholder interest in climate change adaptation and the need for continuing dialogue.

(photo by Wendy Avis, March, 2001)

Diminishing water supplies are expected to increase competition and conflict over water and increase its value.[41] Resolving these issues may sometimes involve changing current policies and legislation. At present, most water laws do not take climate change into account, and would therefore be challenged by the projected impacts on water resources. For example, transboundary water agreements may require updating and careful consideration must be given to potential changes in flow regimes and levels.[58] Water transfers, which are becoming increasingly important mechanisms for water management in some parts of the world, often generate new problems of their own. For example, the transfer of water between two parties often impacts on a third, uninvolved party, such as a downstream water user. Policy mechanisms capable of taking these third parties into account are necessary.

Within the Great Lakes basin, significant supply-demand mismatches and water apportionment issues are expected under most climate change scenarios.[59] Although the traditional cooperation between legal groups involved in such conflicts has been impressive, there is no fully consistent approach to water law and policy, and the historic success would likely to be challenged by the impacts of climate change.[60] International laws must also evolve to avoid future conflict, as few of them allow for the possible impacts of climate change.

Knowledge Gaps and Research Needs

Although progress has been made over the past five years, many of the research needs identified within the Canada Country Study with respect to the potential impacts of climate change on water resources remain valid. For example, continued improvements are required in the understanding and modelling of hydrological processes at local to global scales, such as the role of the El Niño–Southern Oscillation (ENSO) in controlling hydrological variability.

From a regional perspective, studies based in the Atlantic Provinces, eastern Arctic, and high-elevation mountainous regions are still lacking. The same applies to studies of groundwater resources across most of the country, as emphasized in a recent synthesis for the Canadian prairies.[20]

A primary goal of impacts and adaptation research is to reduce vulnerability to climate change and, as such, there is a need for studies that focus on the regions and systems considered to be most vulnerable. In Canada, this includes areas presently under water stress, such as the Prairies, the interior of British Columbia, the Great Lakes–St. Lawrence basin and parts of Atlantic Canada, as well as regions where climate change impacts on water resources may have large ramifications for existing or planned activities. In some cases, studies may have to initially address fundamental knowledge gaps with respect to either processes or data (e.g., the paucity of data on groundwater use in most areas) before meaningful analyses of adaptation options can be undertaken.

Needs identified within the recent literature cited in this report include the following:

Impacts

1. Research on the interactive effects between climate change impacts and other stresses, such as land use change and population growth
2. Improved understanding of the economic and social impacts of climate change with respect to water resources
3. Improved access to, and monitoring of, socio-economic and hydrological data
4. More integrative studies, which look at the ecological controls and human influence on the vulnerability of water to climate change
5. Studies that focus on understanding and defining critical thresholds in water resource systems, rather than on the impacts of changes in mean conditions

6. Research on the vulnerability of groundwater to climate change and improved groundwater monitoring
7. Research on the impacts of climate change on water uses, such as navigation, recreation/tourism, drinking-water supplies, hydroelectric power generation and industry, as well as on ecological integrity
8. Studies that address the impacts of climate change on water quality

Adaptation

1. Integrative studies of water resources planning, which address the role and influence of water managers on adaptive capacity
2. Understanding of the current capacity of water management structures and institutions to deal with projected climate change, and the social, economic and environmental costs and benefits of future adaptations
3. With respect to adaptation via water pricing and policy/legislation, better understanding of the environmental justice and equity consequences, and mechanisms to assess the impacts of water transfers on third parties

Conclusion

Future changes in climate of the magnitude projected by most global climate models would impact our water resources, and subsequently affect food supply, health, industry, transportation and ecosystem sustainability. Problems are most likely to arise where the resource is already under stress, because that stress would be exacerbated by changes in supply or demand associated with climate change. Particular emphasis needs to be placed on the impacts of extreme events (drought and flooding), which are projected to become more frequent and of greater magnitude in many parts of the country. These extreme events would place stress on existing infrastructure and institutions, with potentially major economic, social and environmental consequences.

A relatively high degree of uncertainty will likely always exist regarding projections of climate and hydrological change at the local management scale. Focus must therefore be placed on climate change in the context of risk management and vulnerability assessment. The complex interactions between the numerous factors that influence water supply and demand, as well as the many activities dependent upon water resources, highlight the need for integrative studies that look at both the environmental and human controls on water. Involvement of physical and social scientists, water managers and other stakeholders is critical to the development of appropriate and sustainable adaptation strategies.

References

Citations in bold denote reports of research supported by the Government of Canada's Climate Change Action Fund.

1. Environment Canada (1992): Water conservation – every drop counts; Supply and Services Canada, Freshwater Series A-6.
2. Environment Canada (2001): Water; available on-line at http://www.ec.gc.ca/water/ (accessed April 2002).
3. Environment Canada (2002): Dave Phillip's top 10 weather stories of 2001; available on-line at http://www.msc.ec.gc.ca/top_10_e.cfm (accessed March 2002).
4. Cohen, S. and Miller, K. (2001): North America; *in* Climate Change 2001: Impacts, Adaptation and Vulnerability, (ed.) J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, p. 735–800; also available on-line at http://www.ipcc.ch/pub/reports.htm (accessed July 2002).
5. Arnell, N. and Liu, C. (2001): Hydrology and water resources; *in* Climate Change 2001: Impacts, Adaptation and Vulnerability, (ed.) J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, p. 191–233; also available on-line at http://www.ipcc.ch/pub/reports.htm (accessed July 2002).
6. Hofmann, N., Mortsch, L., Donner, S., Duncan, K., Kreutzwiser, R., Kulshreshtha, S., Piggott, A., Schellenberg, S., Schertzerand, B. and Slivitzky, M. (1998): Climate change and variability: impacts on Canadian water; *in* Responding to Global Climate Change: National Sectoral Issue, (ed.) G. Koshida and W. Avis, Environment Canada, Canada Country Study: Climate Impacts and Adaptation, v. VII, p. 1–120.
7. Chalecki, E.L. and Gleick, P.H. (1999): A framework of ordered climate effects on water resources: a comprehensive bibliography; Journal of the American Water Resources Association, v. 35, no. 6, p. 1657–1665.
8. Herrington, R., Johnson, B.N. and Hunter, F.G. (1997): Responding to global climate change in the Prairies; Environment Canada, Canada Country Study: Climate Impacts and Adaptation, v. III. 75 p.
9. Dolan, A.H., Kreutzwiser, R.D. and de Loë, R.C. (2000): Rural water use and conservation in southwestern Ontario; Journal of Soil and Water Conservation, v. 55, no. 2, p. 161–171.
10. British Columbia Ministry of the Environment, Lands and Parks (1999): A water conservation strategy for British Columbia; available on-line at http://wlap-www.gov.bc.ca/wat/wamr/water_conservation/index.html (accessed June 2002).
11. Ryder, J.M. (1998): Geomorphological processes in the alpine areas of Canada: the effects of climate change and their impacts on human activities; Geological Survey of Canada, Bulletin 524, 44 p.
12. Zhang, X., Harvey, K.D., Hogg, W.D. and Yuzyk, T.R. (2001): Trends in Canadian streamflow; Water Resources Research, v. 37, no. 4, p. 987–998.
13. **Demuth, M.N., Pietroniro, A. and Ouarda, T.B.M.J. (2002): Streamflow regime shifts resulting from recent glacier fluctuations in the eastern slopes of the Canadian Rocky Mountains; report prepared with the support of the Prairie Adaptation Research Collaborative.**
14. International Joint Commission (2000): Protection of the waters of the Great Lakes: final report to the governments of Canada and the United States; International Joint Commission, February 22, 2000, 69 p.
15. Beltaos, S. (1997): Effects of climate on river ice jams; 9th Workshop on River Ice, Fredericton, New Brunswick, Proceedings, p. 225–244.
16. Prowse, T. and Beltaos, S. (2002): Climatic control of river-ice hydrology: a review; Hydrological Processes, v. 16, no. 4, p. 805–822.
17. **Bellamy, S., Boyd, D. and Minshall, L. (2002): Determining the effect of climate change on the hydrology of the Grand River watershed; project report prepared for the Climate Change Action Fund, 15 p.**
18. **Piggott, A., Brown, D., Moin, S. and Mills, B. (2001): Exploring the dynamics of groundwater and climate interaction; report prepared for the Climate Change Action Fund, 8 p.**
19. Remenda, V.H. and Birks, S.J. (1999): Groundwater in the Palliser Triangle: An overview of its vulnerability and potential to archive climate information; in Holocene climate and environmental change in the Palliser Triangle: a geoscientific context for evaluating the impacts of climate change on the southern Canadian Prairies, (ed.) D.S. Lemmen and R.E. Vance, Geological Survey of Canada, Bulletin 534, p. 57–66.
20. **Maathuis, H. and Thorleifson, L.H. (2000): Potential impact of climate change on Prairie groundwater supplies: review of current knowledge; Saskatchewan Research Council, Publication No. 11304-2E00, prepared with the support of the Prairie Adaptation Research Collaborative, 43 p.**
21. **Bruce. J., Burton, I., Martin, H., Mills, B. and Mortsch, L. (2000): Water sector: vulnerability and adaptation to climate change; report prepared for The Climate Change Action Fund, June 2000; available on-line at http://iss.gsc.nrcan.gc.ca/cciarn/WaterResourcesImpacts-workshopreports.pdf (accessed June 2002).**

22. Nicholls, K.H. (1999) Effects of temperature and other factors on summer phosphorus in the inner Bay of Quinte, Lake Ontario: implications for climate warming; Journal of Great Lakes Research, v. 25, no. 2, p. 250–262.

23. Schindler, D.W. (1998): A dim future for boreal watershed landscapes; BioScience, v. 48, p. 157–164.

24. Hudon, C. (2000): Phytoplankton assemblages in the St. Lawrence River, downstream of its confluence with the Ottawa River, Quebec, Canada; Canadian Journal of Fisheries and Aquatic Sciences; v. 57(SUPPL. 1), p. 16–30.

25. Adams, R.M., Hurd, B.H. and Reilly, J. (1999): Agriculture and global climate change: a review of impacts to U.S. agricultural resources; Pew Center for Global Climate Change, Arlington, Virginia; available on-line at http://www.pewclimate.org/projects/env_agriculture.cfm (accessed June 2002).

26. Mehdi, B., Hovda, J. and Madramootoo, C.A. (2002): Impacts of climate change on Canadian water resources; *in* Proceedings of the Canadian Water Resources Association Annual Conference, June 11–14, 2002, Winnipeg, Manitoba.

27. **Chen, Z. and Grasby, S. (2001): Predicting variations in groundwater levels in response to climate change, upper carbonate rock aquifer, southern Manitoba: climatic influences on groundwater levels in the Prairies, including case studies and aquifers under stress, as a basis for the development of adaptation strategies for future climatic changes; project report (Phase II) prepared with the support of the Prairie Adaptation Research Collaborative, 18 p.**

28. Schindler, D.W. (2001): The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium; Canadian Journal of Fisheries and Aquatic Science, v. 58, no. 1, p. 18–29.

29. Devito, K.J., Hill, A.R. and Dillon, P.J. (1999): Episodic sulphate export from wetlands in acidified headwater catchments: prediction at the landscape scale; Biogeochemistry, v. 44, p. 187–203.

30. Branfireun, B.A., Roulet, N.T., Kelly, C.A. and Rudd, J.W. (1999): In situ sulphate stimulation of mercury methylation in a boreal peatland: toward a link between acid rain and methyl-mercury contamination in remote environments; Global Biogeochemical Cycles, v. 13, no. 3, p. 743–750.

31. **Van der Kamp, G., Hayashi, M. and Conly, F.M. (2001): Controls on the area and permanence of wetlands in the northern Prairies of North America; report prepared with the support of the Climate Change Action Fund, 10 p.**

32. Mortsch, L. (1998): Assessing the impact of climate change on the Great Lakes shoreline wetlands; Climatic Change, v. 40, no. 2, p. 391–416.

33. Ashmore, P. and Church, M. (2001): The impact of climate change on rivers and river processes in Canada; Geological Survey of Canada, Bulletin 555, p. 58.

34. **Prowse, T., Beltaos, S., Bonsal, B., Pietroniro, A., Marsh, P., Leconte, R., Martz, L., Romolo, L., Buttle, J.M., Peters, D. and Blair, D. (2001): Climate change impacts on northern river ecosystems and adaptation strategies via the hydroelectric industry; evaluation report prepared for the Climate Change Action Fund.**

35. Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B. (2000): Global water resources: vulnerability from climate change and population growth; Science, v. 289, no. 5477, p. 284–288.

36. Frederick, K.D. and Gleick, P.H. (1999): Water and global climate change: potential impacts on U.S. water resources; prepared for the Pew Center on Global Climate Change; available on-line at http://www.pewclimate.org/projects/clim_change.cfm (accessed June 2002).

37. Filion, Y. (2000): Implications for Canadian water resources and hydropower production; Canadian Water Resources Journal, v. 25, no. 3, p. 255–269.

38. Jackson, R.B., Carpenter, S.R., Dahm, C.N., McKnight, D.M., Naiman, R.J., Postel, S.L. and Running, S.W. (2001): Water in a changing world; Ecological Applications, v. 11, no. 4, p. 1027–1045.

39. Gleick, P.H. (senior author) (2000): Water: the potential consequences of climate variability and change for the water resources of the United States; report to the Water Sector Assessment Team of the National Assessment of the Potential Consequences of Climate Variability and Change, for the U.S. Global Change Research Program, 150 p.

40. Seacrest, S., Kuzelka, R. and Leonard, R. (2000): Global climate change and public perception: the challenge of translation; Journal of the American Water Resources Association, v. 36, no. 2, p. 253–263.

41. de Loë, R., Kreutzwiser, R. and Moraru, L. (1999): Climate change and the Canadian water sector: impacts and adaptation; report prepared for Natural Resources Canada, May 1999.

42. Chao, P.T., Hobbs, B.F. and Venkatesh, B.N. (1999): How climate uncertainty should be included in Great Lakes management: modelling workshop results; Journal of the American Water Resources Association, v. 35, no. 6, p. 1485–1497.

43. de Loë, R. and Kreutzwiser, R. (2000): Climate variability, climate change and water resource management in the Great Lakes; Climatic Change, v. 45, p. 163–179.

44. Andres, D. and Van der Vinne, G. (1998): Effects of climate change on the freeze-up regime of the Peace River; *in* Ice in Surface Waters, (ed.) Hung Tao Shen, Proceedings of the 14th International Symposium on Ice, New York, July 27–31, 1998, v. 1, p. 153–158.

45. Gan, T.Y. (2000): Reducing vulnerability of water resources of Canadian Prairies to potential droughts and possible climatic warming; Water Resources Management, v. 14, no. 2, p. 111–135.

46. **Kije Sipi Ltd. (2001): Impacts and adaptation of drainage systems, design methods and policies; report prepared for the Climate Change Action Fund, 119 p.**

47. Arnell, N.W. (2000): Thresholds and response to climate change forcing: the water sector; Climatic Change, v. 46, p. 305–316.

48. Murdoch, P.S., Baron, J.S. and Miller, T.L. (2000): Potential effects of climate change on surface-water quality in North America; Journal of the American Water Resources Association, v. 36, no. 2, p. 347–366.

49. Lettenmaier, D.P., Wood, A.W., Palmer, R.N., Wood, E.F. and Stakhiv, E.Z. (1999): Water resources implications of global warming: a U.S. regional perspective; Climatic Change, v. 43, no. 3, p. 537–579.

50. Southam, C.F., Mills, B.N., Moulton, R..J. and Brown, D.W. (1999): The potential impact of climate change in Ontario's Grand River basin: water supply and demand issues; Canadian Water Resources Journal, v. 24, no. 4, p. 307-330.

51. Denault C., Millar, R.G. and Lence, B.J. (2002): Climate change and drainage infrastructure capacity in an urban catchment; *in* Proceedings of the Annual Conference of the Canadian Society for Civil Engineering, June 5–6, 2002, Montreal, Quebec.

52. **Ivey, J., Smithers, J., de Loë, R. and Kreutzwiser, R. (2001): Strengthening rural community capacity for adaptation to low water levels; report prepared for the Climate Change Action Fund, 42 p.**

53. Boland, J.J. (1998): Water supply and climate uncertainty; in Global Change and Water Resources Management, (ed.) K. Shilling and E. Stakhiv, Universities Council on Water Resources, Water Resources Update, Issue 112, p. 55–63.

54. Waller, D.H. and Scott, R.S. (1998): Canadian municipal residential water conservation initiative; Canadian Water Resources Journal, v. 23, no. 4, p. 369–406.

55. Henderson, J.D. and Revel, R.D. (2000): A community approach to water management on a small west coast island; Canadian Water Resources Journal, v. 25, no. 3, p. 271–278.

56. **Cohen, S. and Kulkarni, T. (2001): Water management and climate change in the Okanagan basin; report prepared for the Climate Change Action Fund, 43 p.**

57. Kreutzwiser, R., Moraru, L. and de Loë, R. (1998): Municipal water conservation in Ontario: report on a comprehensive survey; prepared for Great Lakes and Corporate Affairs Office, Environment Canada, Ontario Region, Burlington, Ontario.

58. Bruce, J.P. (2002): Personal communication.

59. Mortsch, L., Hengeveld, H., Lister, M., Lofgren, B., Quinn-F.H., Slivitzky, M. and Wenger, L. (2000): Climate change impacts on the hydrology of the Great Lakes–St. Lawrence system; Canadian Water Resources Journal, v. 25, no. 2, p. 153–179.

60. Saunders, J.O. (2000): Law and the management of the Great Lakes basin; Canadian Water Resources Journal, v. 25, no. 2, p. 209–242.