World Resource Review Vol. 18 No. 1

Coping with the Impacts of Climate Change on Water Resources: A Canadian Experience

B.B. Mehdi, L. Connolly-Boutin, C.A. Madramootoo
Brace Centre for Water Resources Management
McGill University
21 111 rue Lakeshore
Ste-Anne-de-Bellevue, Québec H9X 3V9 CANADA

Keywords: Climate change, water resources, adaptation, institutional responses, Canada

SUMMARY

This paper presents some of the Canadian challenges related to water resources and climate, and describes the Canadian institutional responses that have been put in place to address adaptation mechanisms to cope with the impacts of a potentially changing climate. Recent extreme events in Canada are presented to provide an overview of some of the challenges being faced, after which the impacts of climate on four rather diverse sectors of water management are given, and current coping mechanisms are outlined. The federal and provincial governments have reacted proactively to the issue of climate change, and have recognized that in addition to mitigating greenhouse gases and reducing emissions, it is essential to understand the impacts of climate change and how to adapt. In general, adaptation assistance varies from monetary support for adaptation strategies, to providing access to expert-knowledge networks on adaptation. A continued concerted effort on behalf of the government is necessary to ensure that continued, and planned, adaptation is carried out.

INTRODUCTION

Global climate variation and change will significantly impact Canada’s hydrological cycle, and the systems and cycles which it nourishes. Some of the anticipated impacts brought about by global climate change will include changes in water quantity, such as water supply for ecological, domestic, agricultural, recreational, commercial, and industrial uses; changes to instream flows which support aquatic ecosystems, hydropower, navigation; changes in riparian, wetland and coastal boundaries and productivity, and changes in the frequency and severity of floods. Water quality will also be affected by the lack thereof, and these changes will affect ecosystems and wastewater assimilation.

Although several extreme events have played out over recent years it cannot be said for certain that they are a consequence of global climate change. However, it is known that climate change will bring about modifications to the hydrological cycle notably by increasing the frequency of extreme events (Trenberth, 1999), which consequently will have ramifications on ecological, social and economic systems. The impacts of such changes must be addressed by policy makers and decision makers who manage water resources, through appropriate adaptation mechanisms. For example, these adaptations can be policy related, monetary assistance, infrastructure building, sharing of knowledge, and in all cases governments can take a leadership role. In this regard, Canada has already taken steps in the direction of facilitating adaptation to climate change. This paper presents the Canadian challenges related to water resources and climate change, and describes the Canadian institutional responses that have been set up to address adaptation mechanisms to cope with the impacts of climate change.

RECENT CANADIAN HISTORICAL EXTREME EVENTS

Model predictions have been made that the Canadian climate, as a whole, will become more variable and for the most part warmer, as well as wetter on average; however some areas will experience more frequent incidences of drought in summer. Recent extreme weather events, such as the Red River flood (Manitoba, 1997), the ice storm (eastern Ontario-Quebec, 1998), widespread national drought (2001), Hurricane Juan (Halifax, 2004), and heavy rainfall resulting in landslides (British Columbia, 2005), have shown that climate can have a significant impact on Canadian water resources. Although no single extreme event can be definitively linked to climate change, incidents of these types of events can be expected to increase in the future (Kharin and Zwiers, 2000). A brief description of these recent extreme events and how they impacted societies and water resources follows.

The Red River Flood, Manitoba 1997

In the spring of 1997, the Red River rose 12 m above its normal winter levels and causing flooding of over 1840 km^2. This flood was the highest recorded flood of the 20th century (International Red River Basin Taskforce, 2000). The main cause of the flood was the greater than 200% of the normal average snowfall which fell on the southern part of the Red River basin (in the U.S.) from September 1996 - April 1997. Amounts exceeded 250 cm in some locations. This above-average snowfall was followed by a highly unusual snowmelt, which begun later in the season, and was followed by periods of freezing and additional periods of thawing (Todhunter, 2001). The frozen, saturated clay soils and a deep snowpack exacerbated the flooding, which caused an estimated $500 million in damages (Pietroniro et al., 2004).

The floods were responsible for the displacement of 28 000 rural Manitoba residents (Todhunter, 2001). Had there been no emergency dykes and flood control works already in place (the Red River Floodway completed in 1968), the flood damages were estimated to have cost several billion dollars more (Brooks et al., 2002).

The Ice Storm, Eastern Canada 1998

On January 4, 1998, an ice storm struck eastern Ontario, Québec and New Brunswick. Ice storms are rather common in the region as they occur 10 to 15 times a year (Meteorological Service of Canada, 2005). The peculiarity of this storm was the fact that freezing rain fell on the region for over 80 hours in total (non consecutive), almost doubling the annual total precipitation in one single storm (Meteorological Service of Canada, 2005). The equivalent of 100 mm of water fell in Montreal while Ottawa received 85 mm of total water equivalent precipitation. More than 2.6 million people, or 19% of Canada's workforce, were impeded from going to work during the storm (Statistics Canada, 1998), which lasted 5 days.

The extent of the damage caused by the storm left 1.4 million customers in Québec and 230 000 customers in Ontario without electricity (some for over 30 days), and 10 000 people left their homes for the safety of shelters. Besides toppling over 1 000 transmission towers, 30 000 wooden utility poles and several thousand kilometres of power lines, the storm affected the livestock, dairy, maple sugar and forestry industries (Statistics Canada, 1998). By early February of that year, insurance claims totaling $790 million had been made to cover damages made to homes, cars and other property (Statistics Canada, 1998).

National Drought, Canada 2001

In the spring and summer of 2001, Canada experienced a nation wide drought, as well as its third overall warmest year on record (1998 was the warmest year on record). According to the Meteorological Service of Canada, average temperatures for the month of August were 20.2^{o}C in Halifax, 22.5^{o}C in Montreal, 19.8^{o}C in Saskatoon and 23.2^{o}C in Toronto. Average temperatures for the same months are 18.4^{o}C in Halifax, 19.5^{o}C in Montreal, 17.3^{o}C in Saskatoon and 19.9^{o}C in Toronto (MSC, 2005). The growing season across southern Canada was the driest in 34 years. The Prairies were the hardest hit; some regions were suffering their second or third straight year of drought. The drought and already low grain prices are estimated to have cost Western producers $5 billion (Phillips, 2002).

British Colombia experienced its driest winter on record. Rain and snowfall were half of their historical average for the region. Snowpacks were at or below their lowest levels on record, consequently, in Victoria, at the end of the wet season, the main reservoir's drinking water levels were more than 30% lower than full capacity (Phillips, 2002).

Alberta declared a drought before the first day of summer and rationed irrigation water in the spring for the first time. Officials estimated that the region would need an unprecedented 50%-70% more precipitation the following winter and spring to replenish water levels for the 2002 growing season (Phillips, 2002).

The Great Lakes/St-Lawrence region endured its driest summer in 54 years of records. From March to August, the Lake Ontario region received only 256.0 mm of precipitation. Normally, it receives 413.7 mm during this period. Montreal experienced its driest April on record (only 13.7 mm of precipitation fell on the city compared to an average of 76.1 mm) followed by a record 35 consecutive days with no measurable rainfall (MSC, 2005).

Atlantic Canada was also affected by the drought. It experienced its third driest summer on record, totaling four dry summers out of the last five. Only a quarter of the normal rainfall fell on Charlottetown (49 mm compared to an average of 173.1 mm) and Moncton (47.6 mm compared to an average of 182.8 mm) in July and August, causing those months to be the driest recorded (MSC, 2005). As a result, it was estimated that potato yields in the Atlantic Provinces were 35-45% lower than average (Phillips, 2002).

Hurricane Juan, Atlantic Canada 2003

On September 29, 2003, Nova Scotia was hit with a Category 2 hurricane with maximum sustained winds of 158 km/hr. The storm, which caused over $150 million in damages, has been recorded as the most damaging in Halifax recent history (Fogarty, 2004). Strong hurricanes have an occurrence of once in 50 years in Nova Scotia. The reason hurricane Juan was so powerful was due to a combination of warmer ocean temperatures and an accelerating storm.

Normal temperatures on the Nova Scotia coast at the end of September are 15^{o}C. The water temperatures the day of the storm were at 18^{o}C, thereby slowing the rate at which the hurricane weakened. Compounding this was the fact that the hurricane accelerated as it neared Nova Scotia. This acceleration caused an increase in wind speeds relative to the ocean and ground. Hence, the storm itself was weakening, but the weakening effect was almost negated by its accelerating forward action. The acceleration also meant that the storm was spending less time weakening over cooler waters (Fogarty, 2004).

Hurricane Juan claimed at least eight lives in Atlantic Canada, and brought the strongest winds ever recorded since 1893 over the city of Halifax (Bowyer, 2004). A record storm surge was experienced at Halifax Harbour, and extensive wind damage (especially to trees) in Halifax was left for residents to clean up months after the storm had passed.

Flooding in British Columbia, 2005

On January 18, 2005 a rainfall event causing 320 mm of rain to fall in 48 hours wreaked havoc. A warming trend in British Columbia led to high rainfalls and early snowmelt, which caused destructive runoff. The runoff brought on landslides, road closures, avalanches, flooding and power outages throughout much of southern B.C., the lower Fraser Valley and Vancouver Island (MPSSG, 2005). In 48 hours, North Vancouver had received 320 mm of rain (NHER, 2005). The region usually receives 153.6 mm of precipitation in the entire month of January (MSC, 2005). The heavy rainfall in North Vancouver caused a massive landslide that destroyed two homes, caused one death and was responsible for the evacuation of over 70 homes. British Columbia announced a state of emergency in the area (NHER, 2005). The extreme weather also caused ice jams, avalanches and flooding in other parts of the province. A number of communities were affected by the ice jams and the flooding, and over 500 people had to evacuate their homes (MPSSG, 2005). The Ministry of Public Safety and Solicitor General estimates that total damages were in the order of $20 million (MPSSG, 2005).

CURRENT MANAGEMENT CHALLENGES

In this century, although extreme precipitation events (1-day duration with a 20-year return period) have not increased significantly in Canada (Zhang et al., 2001), the less extreme heavy events (those exceeding the threshold of an approximate 2–month return period) have become more frequent in Canada (Kunkel, 2003). In fact, using the global coupled model of the Canadian Centre for Climate Modeling and Analysis, simulation results shows increases in precipitation do not become significant until the end of 21st century (Kharin and Zwiers, 2000), suggesting that increases in extreme precipitation events may not be important now, but may only occur towards the beginning of the next century or so.

However, it is known that atmospheric water vapor content will increase due to the warmer air temperatures, and this will provide for a greater thermodynamic instability of the atmosphere, as a result it is highly likely that extreme precipitation events will increase (Kunkel, 2003). Using a coupled

Atmospheric-Ocean Global Climate Model (AOGCM), Kharin and Zwiers (2000) found that in the future, extreme precipitation increases almost everywhere on the globe in a warmer world. On average, return periods for extreme precipitation events that were expected once in 20 years in 1900, will be reduced to approximately 1 in 10 years by 2100. This leaves little doubt that in the future we can expect a more intense energy atmosphere, and more intense precipitation events to occur with global warming.

Given that extreme weather events, such as heavy rainfall, floods, and even more frequent dry spells are more likely to increase in occurrence in the future (IPCC, 2001), water managers will be required to make decisions affecting their operations under a new set of circumstances, which may no longer be directly applicable to their current management practices. As such, tools must be provided to help decision makers to make better informed decisions. If they are liable to undertake planned adaptation, guidelines and solutions to better cope with the challenges posed by climate change need to be provided.

Management challenges recently faced by water managers in various water sectors showcase some of the adaptation needs. Four important and diverse water resource systems that are vulnerable to climate in different regions of Canada are presented to highlight some of the more recent challenges faced (or being faced) in light of climate variation and potential change. The impacts of climate on the systems are outlined, and coping mechanisms are presented. Each example presents a unique set of adaptation responses.

Great Lakes – St. Lawrence Basin

The Great Lakes – St. Lawrence basin is home to over 42 million people and contains 20% of the world's fresh water (Brown et al., 1996). The St. Lawrence River is by far the most significant component of Quebec's water resources. The St. Lawrence flow is dominated by the five Great Lakes whose immense storage capacity reduces the river's sensitivity to short-term climate and flow fluctuations; however, this connection also exposes the river to the longer-terms effects of climate change that occur within the Great Lakes region (Bruce et al., 2000). The average flow in the St-Lawrence (6 910 m^3/s) represents approximately 1% of the total volume of water in the Great Lakes.

Water levels fluctuate naturally in the Great Lakes basin. The irregular long-term trends in water level fluctuations correspond to trends in precipitation and temperature. However, climate change scenarios developed for the region (Mortsch et al., 2000), predict lower flow volumes in the St-Lawrence (38% reduced flow under a $2xCO_2$ scenario, compared to 1900-1990) and lower water levels in the Great Lakes (of between 0.3m – 1m by 2050). The great Lakes receive water from inflows from the upper takes, rivers and from precipitation. Some of the more significant natural governing factors controlling levels in the Great Lakes are: changes to precipitation regimes (rainfall increasing in spring and autumn, and snowfall declining in spring) and ice cover duration (which will decrease) in the future (Mortsch, 2000; Hanson et al., 1992). For example, consecutive low precipitation amounts as were received during the summer of 2001 would significantly lower water levels in the Great Lakes. The Great Lakes lose water principally by evaporation, outflows (natural and diversions) and consumptive use.

The extent of the fluctuations in the Great Lakes- St. Lawrence Basin is also dependant on the flows of the St-Lawrence, which are determined primarily by the main tributaries, namely the Great Lakes basin and the Ottawa River. The flows on Lakes Superior and Ontario are regulated (since 1921 and 1960, respectively) to provide for the generation of hydroelectricity, for flood control and for commercial shipping.

Of great economic concern is the potential decreasing lake and water levels for commercial navigation, recreational boating and marinas, which are sensitive to water level and flow changes. During the 2003 navigation season, 40.982 million tonnes of cargo, mostly grain, iron ore, coal, steel and other bulk, passed through the Seaway representing a cargo value of $7 billion (Great Lakes St. Lawrence Seaway System, 2005). In the past, channels have been altered (enlarged, dredged) to allow for deep-draft shipping. There is however a check in place to maintain water levels at a sufficient height for navigation. The St-Lawrence River Board of Control was established by the International Joint Commission (IJC) in 1952 to monitor and regulate flow conditions in Lake Ontario and Lake St-Francis, and to maintain a minimum level of water in the Port of Montreal. The Board ensures sufficient water is present in the River systems for user needs (such as domestic and sanitary water uses, navigation, power and irrigation) and regulates to the extent possible minimal flooding occurrences. Currently, the IJC is looking at the effects of climate change on the Great Lakes basin and has identified research needs in a “white paper” (IJC, 2003).

Under climate change scenarios, management of water in the Great Lakes-St. Lawrence basin will have to focus increasingly on water scarcity issues (Mortsch, 2000). Furthermore, the competition between sectors would also require apportioning water for ecosystem needs as well as human needs. As such, a balance must be struck between the users of the resource so as to avoid conflicts. In the recent past, 2001 summer low flow levels have caused the cities of Montreal and of Rosemère in the province of Quebec to have their water levels reach critical thresholds for their surface water intakes, due to the intakes being nearly exposed, thereby potentially threatening intake water quality. Under a

$2xCO_2$ climate, such events may become more frequent. One adaptive solution may be to lower the water intakes so that they are able to cope with lower flow volumes, or to put in additional emergency water intakes.

Climate change will affect the flow regulations, and also highlight the demand that water for human health and ecosystems is met first. Currently, there is a study (by Milton) to assess the vulnerability of socio-economic issues (infrastructure, potable water intakes, boating and human habitats), and environmental areas (wetlands) on the St-Lawrence to determine how future water levels and flows will affect these (CCIAP, 2005).

Milot and Lepage (2004) have examined an integrated approach towards adaptation responses in the St-Lawrence with the input of affected stakeholder groups. They found it difficult to reach a consensus for an integrated approach because of the different objectives held by each of the user groups. Although some scientific data is missing to determine the extent of climate change taking place, due diligence should be used when adapting. Clarifying the role that science plays is a crucial next step to define adaptation priorities. The St-Lawrence is a vital part of the regions' economy and will continue to be so in the future.

Prairie Drought Responses

Drought conditions in the Prairie Provinces are a concern in terms of crop productivity and yields as well as in terms of rural development. The semi-arid climate of the southern portion of the Prairie Provinces normally has annual evaporation exceeding precipitation, thereby making the region vulnerable to droughts and soil moisture deficits (Bruce et al., 2000). Although the Canadian Plains are used to experiencing long lasting drought episodes (the last one occurred in 1961 (Sauchyn and Beaudoin, 1998)), coping strategies are still needed in the region, especially for agriculture which requires a reliable source of water supply. Coping strategies would include increasing the socio-economic resilience, upgrading infrastructure, developing and implementing more efficient irrigation, developing and/or utilizing drought resistant crops.

The Canadian Global Circulation Model (CGCM1) predicts changes for the Canadian Prairies, such as summer temperature will increase by 3 to 4^{o}C, and summer precipitation will decrease by 10-20%. These changes will result in warmer and more arid conditions over much of the present Prairie agricultural area in summer, mainly because increased evapotranspiration will not be offset by the predicted increase in precipitation (Nyirfa and Harron, 2001). Water management will remain a key issue in the Prairies.

The key water issues in the Prairie Provinces region revolve around low surface water flows in summer, controlling flooding risks, and ensuring sufficient water is available to maintain hydroelectricity power production. In most Prairie basins, the water resources are fully allocated so that drought periods pronounce the water shortages (Tollefson, 2004; Bruce et al., 2000; Byrne et al., 1989). In the South Saskatchewan River Basin (SSRB) which includes the city of Calgary, water is supplied via the major tributaries from snow and melting glaciers in the Rocky Mountains. Approximately 90% of the total South Saskatchewan River stems from the Rocky Mountains. In the SSRB, 83% of water is used for irrigation. A joint Climate Change Impacts and Adaptation Program and Prairie Adaptation Research Collaborative funded project is underway to examine the current sensitivity and future vulnerability of regional socio-economic systems to changes in water supply (PARC, 2005).

Despite the fact that irrigators in western Canada use 30% less water per area today than they did 15 years ago (Hill, 2004a), water for irrigation will become scarcer as water reserves become depleted, precipitation becomes less reliable, and lower surface flows occur. These impacts are especially pertinent in the Prairie Provinces which rely heavily on irrigation. In Alberta alone, over 580 000 ha are under irrigated agriculture, in Saskatchewan and Manitoba irrigated agriculture makes up approximately 30 000 ha in each province (Madramootoo, 2005). The main challenges for the irrigation sector in light of climate change are to conserve water as much as possible, and to expand irrigation to those areas which will require water for food production in the future.

To this effect, Alberta Irrigation Projects Association with its partners have developed decision support tools (computer models) to help with adaptation in on-farm water management, infrastructure management and forecast how these gains/adaptations translate into basin-wide cooperative water management solutions (Hill, 2004b). In Saskatchewan, alternative surface water supplies are being examined which can be tapped into if the use elsewhere is reaching full capacity or over allocation; for example, part of the province could use Lake Diefenbaker as a source of irrigation water (Tollefson, 2004).

Expanding irrigation necessitates consultation with the public as a partner, especially for large scale irrigation projects. Gaining the trust of the public will reduce adversity to large irrigation projects (Sawatsky and Chan-Yan, 2004) which have been steeped in controversy in the past. Using this approach, irrigation will be able to expand where it is economically and environmentally affordable as well as justifiable as an adaptation.

In the Prairies, knowledge needs for irrigation are still required with respect to knowing how mountain hydrological dynamics will change and how snowmelt and runoff patterns will change; examining whether the storage capacity and/or river diversions have the capacity to handle a more variable supply of water; developing a greater flexibility in measuring the variability in flows (Chinn et al., 2004). These knowledge gaps will help to address planned adaptation to more arid soil conditions and drought occurrences.

Under drought conditions, groundwater is the alternative water source to surface water (Thorleifson et al., 2002). The Prairie Adaptation Research Collaborative (PARC) has examined the potential impacts of climate change and variability on prairie groundwater (Sauchyn, 2002). Shallow aquifers are more vulnerable to climate change, since they are more closely linked to weather patterns than deep buried aquifers. Therefore, a drier climate will result in greater demand for more reliable groundwater sources and increased withdrawal.

To adapt to drought conditions, a Drought Watch program has also been set up by the Prairie Farm Rehabilitation Administration (PFRA) which monitors drought occurrences in the Prairies, and provides timely information of the impacts of climatic variability on surface water supplies and agriculture. They provide coping strategies and water management strategies to deal with water shortage to farms in the Prairies. Adaptation strategies to provide rural water supplies include sizing dugouts for a 3-year coping range, instead of 2-years; tapping into groundwater; stocking watering dams and reservoirs; and piping water to rural areas (Adkins, 2004). Some of these adaptation options are already being implemented on farms in the Prairie regions in conjunction with experts.

Municipal Water Supply and Infrastructure

Urban areas have to supply water for sanitation and also evacuate excess water from runoff generated in built up areas. Most existing and current water infrastructure is designed based on the premise that the historical climate is an accurate indication of the future climate, however this hypothesis may no longer hold true. If there should be an increase in the occurrence of extreme events, water infrastructure (such as drains, culverts, ditches, water treatment plants) will have to cope with excessive runoff volumes on a regular basis, and as a result may necessitate upgrading, replacing or redesigning. The intensity-duration-frequency (IDF) curves which are used by engineers for design of infrastructure are currently based on data from 1965-1990. The province of Québec is at present undertaking a project (led by Ouranos) to update its IDF curves to incorporate data until the year 2002. Deterministic modeling which is based on projected meteorological time series can also be used for upgrading infrastructure based on future climate projections, as this method does not use IDF curves (Kije Sipi Ltd., 2001).

Combined sewers may pose the largest threat under a changing climate as they carry both wastewater and stormwater runoff in the same pipe to the treatment plant, meaning that should a large precipitation event occur that exceeds the treatment plants' design capacity, the excess combined wastewater and stormwater will overflow, and be discharged into the receiving water body (i.e., river) untreated. Since combined sewer systems are older systems, most major Canadian cities have stopped building combined sewers (e.g., Edmonton) or are making improvements to the existing combined sewer systems (e.g., Vancouver) to reduce the volume of flow (GVRD, 2003). Some municipalities, such as Vancouver, are applying computer simulation models (e.g., MOUSE developed by they Danish Hydraulic Institute) to help in the planning process for reducing flows in combined sewers and adapting to climate change (Hajdukovic et al., 2004).

In Canada, stormwater management is generally under the authority of local municipal governments. However, under the Constitution Act, provincial governments still have a say in the design and construction of related works. Nevertheless, few provincial governments take a pro-active approach for managing stormwater (Kije Sipi Ltd., 2001).

Drinking water supplies to municipalities are also at risk under a changing climate, since 88% of all the water used by Canadian municipalities stems from surface water (Dore and Burton, 2001). With predicted diminishing water supplies in some regions, and/or predicted increases in intense precipitation in others, ensuring a reliable quantity of water and of a high quality is of great concern to municipalities. Problems have already been encountered with water intakes being almost exposed during the 2001 drought in the province of Québec. Some municipalities, such as in the Niagara region, have determined that their water intakes will reach lower than the predicted future (lower) Great Lake levels (Dore and Burton, 2001), making them vulnerable to climate change. The authors of the study have also conducted similar studies have been carried out for other municipalities across Canada, which show several other vulnerable regions. Action by the communities remains to be taken.

Currently, a project is underway in Quebec City to determine drinking water quantity supply under climate change predictions. Information is being collected on all surface water supply sites, the number and types of current users, and the mean daily withdrawal. The project plans to identify sites that had historic water shortages and which may be vulnerable to climate change (Mailhot et al., 2004) so as to better respond to changing conditions and target efforts to the most vulnerable areas.

Ecosystems/in Stream Flows

Maintaining adequate in stream flows is vital for safeguarding the health of ecosystems. Aquatic species rely on the quantity and timing of flows to live out their natural cycles, such as spawning. The pike fish depend on peak runoff for spawning in early spring, when the wetlands are flooded (Rasmussen, 2002). The timing and magnitude of peak flows are necessary to sustain certain ecosystems as well as for water resource management (Bruce et al., 2000; Schindler, 1997). Timing of peak snowmelt discharge is particularly important because it often contributes to a considerable portion of the annual flow. Since snow accumulation and snowmelt affect the timing and the volume of spring runoff, streams fed by snowmelt (partially or wholly) are particularly sensitive to temperature increases, especially to higher winter and spring temperatures. Most Canadian non-mountainous streams and rivers have an annual maximum flow in the spring as a result of snowmelt (Schindler, 2001). Whitfield and Cannon (2000) have found that even small variations in temperature and precipitation result in significant shifts in streamflow patterns, for all regions of Canada.

For example, the flows in the Fraser River (British Columbia) are dominated by snowmelt and winter runoff. As such, climate warming is likely to change the flow regimes as well as increase water temperatures, and hence affect the current distribution of current species, such as salmon, in the Fraser River (Levy, 1992). Several physiological and biological features will change in a warmer climate, where less precipitation falls as snow, or periodic melting decreases the size of the spring snowpack (Schindler, 2001) and these in turn may affect species habitats, fish and wildlife feeding patterns and landscapes.

In South-central British Columbia, spring runoff already occurs 20 days earlier than usual; and late summer flows were found to be lower from 1985-94 than from 1975-84 (Leith and Whitfield, 1998). This will entail challenges for the apportionment of interprovincial waters, which are already almost fully allocated in some provinces under drought conditions. In the future, the apportionment agreements may very well have to take into consideration water for ecosystems, and the natural environment.

The absence of water resources data (continuous empirical observations at national, regional and local spatial scales) for many areas will likely provide a substantive knowledge gap that needs to be addressed to better understand and better cope with climate change impacts and adaptation. Canada probably has the lowest station density compared to any "developed" country. This situation must be redressed if we are to adapt to the effects of climate change on ecosystems.

INSTITUTIONAL RESPONSES TO ADAPTING TO CLIMATE CHANGE

The challenges faced in the water resources sector are diverse and complex. Although Canada is a water rich country, the future provision of this resource should not be taken for granted. Changes to surface water flows, recharge rates in groundwater, cryosphere melting rates, and the changing water vapor content of the atmosphere, provide us with sufficient reasons to sound the alarm bells on the absolute need to manage and preserve the resource. Although future climate change projections may be laced with uncertainties, adaptation is necessary, especially in the water resources sector, to ensure sufficient supply for economic development, the environment, and recreation, and more importantly to preserve peace between user groups.

"Adaptation" refers to activities that minimize the negative impacts of climate change, as well as to activities that allow users to take advantage of new opportunities that may be presented. There are two types of adaptation: planned (or anticipatory) adaptation, and reactive adaptation. Planned adaptation is implemented before the impacts occur and is most effective where several options are considered, and typically involves collaboration among different groups. Usually, a number of meetings and long discussions are required to undertake planned adaptation. Whereas reactive adaptation usually occurs after the impacts have already been felt. Reactive adaptation most commonly takes place after an unforeseen natural disaster, or when dealing with unmanaged systems. In most cases, planned adaptation is the most cost effective and efficient type of adaptation as it involves a well thought out -and priced- process or plan of action.

In order to help water managers adapt to some of the challenges posed by climate, the federal and provincial governments are already providing assistance in various forms. They have reacted proactively to the issue of climate change, and have recognized that in addition to mitigating greenhouse gases and reducing emissions, it is essential that Canadians understand the impacts of climate change better and how to adapt. Assistance varies from monetary aid for adaptation strategies, to providing access to expert-knowledge networks on adaptation. Outlined below are some of the key federal and provincial initiatives that facilitate adaptation to climate change in the water resources sector.

Federal government responses to adapt to climate change

With the ratification of the Kyoto Protocol more attention has been drawn to the issue of climate change. Canada is committed to mitigate GHGs and to adapt to a changing and ever increasingly variable climate. Within the federal government, the climate change file is co-managed by two Ministries: the Ministry of Natural Resources and the Ministry of the Environment. Both Ministries are committed to make climate change a national priority and to work closely with Canadians and the global community to provide the public with the most up-to date resources, information, ideas and approaches to protect Canada's climate, and help Canadians to adapt.

Natural Resources Canada

Climate Change Impacts and Adaptation Program (CCIAP)

The overarching goal of the Government of Canada's Climate Change Impacts and Adaptation Program is to reduce Canada's vulnerability to climate change. The research program was set up in 2000 to support research that addresses gaps in the knowledge of Canada's vulnerability to climate change. One of the criteria for obtaining funding is to work with a stakeholder group, since the program also supports the provision of information for adaptation decision-making to stakeholders (water managers, water purveyors, hydrologists, engineers, etc.).

The Impacts and Adaptation Program mainly provides funding for research and activities to improve knowledge of Canada's vulnerability, to better assess the risks and benefits posed by climate change and to build the foundation on which appropriate decisions on adaptation can be made by decision-makers. To date, the program has funded over 100 projects on adaptation in Canada. The program also supports the Canadian Climate Impacts and Adaptation Research Network (C-CIARN) which is a network of researchers and stakeholders (see below).

Table 1 Examples of adaptation projects funded by CCIAP

TITLE	LOCATION
Climate Change Impacts on Low-Flow Characteristics of New Brunswick Rivers and Adaptation Strategies for Instream Flow Needs	New Brunswick
Preliminary Evaluation of the Potential Impacts of Climate Change on Ground Water Resources in Eastern Canada	Atlantic Canada and Quebec
Impacts & Adaptation of Drainage Systems, Design Methods & Policies	Ontario
Climate Change Impacts on Canadian Prairie Wetlands & Agricultural Adaptation Strategies	Saskatchewan
Climate Change and Water Resource Management in the Okanagan Region	British Columbia

As of 2005, all of the monies for the program have been allocated. Projects under the following broad themes were funded: Water Resources, Coastal Zones, Communities, Agriculture, Ecosystems, Forestry, Fisheries, Health, Landscape Hazards, Tourism, Transportation, and Cross-Cutting. The government is currently conducting a departmental evaluation which will measure how well the Program has met its stated objectives and to determine what the next steps will be with regards to the adaptation agenda in Natural Resources Canada.

Canadian Climate Impacts and Adaptation Research Network (C-CIARN)

The Canadian Climate Impacts and Adaptation Research Network is an initiative that was set up by the federal government (Natural Resources Canada) in response to the Kyoto Protocol which put emphasis on the need to adapt to climate change as well as to mitigate greenhouse gases. The C-CIARN offices are hosted by government departments, research institutions and universities. C-CIARN was created to foster increasing cooperation between stakeholder parties and researchers, to identify the potential impacts of climate change and to increase stakeholder approaches to adapting. The network promotes new climate change research techniques and methodologies, disseminates information on impacts and adaptation, and determines knowledge gaps in the adaptation community that need addressing. This information is used in part by the federal government to issue calls for research proposals.

The C-CIARN network is comprised of six regional offices (Atlantic, Quebec, Ontario, Prairies, British Columbia and the North) and seven sectorial offices (Water Resources, Agriculture, Fisheries, Coastal Zones, Landscape Hazards, Forestry, and Health) spread out across Canada, to help address these problems. Each sector focuses on issues that are pertinent across the country, while each region integrates the issues of particular relevance in each sector.

To date, the C-CIARN network has over 2500 members and has hosted over 60 workshops, and produced scores of reports and publications on climate change impacts and adaptation, all of which have been widely distributed amongst the impacts and adaptation community.

Environment Canada

Adaptation and Impacts Research Group (AIRG)

The Adaptation and Impacts Research Group was created as part of Environment Canada's Action Plan. This plan works towards securing a healthy environment, ensuring safety from environmental hazards and building a greener society. The main goal of the group is to ensure the availability of information for Canadian decision and policy makers on the environmental, social and economic impacts caused by vulnerabilities to atmospheric change, variability and extremes, as well as viable adaptive responses.

The AIRG has partnered with four Canadian universities (the University of Toronto, the University of British Columbia, York University and the

University of Waterloo). The partnerships were created to promote the interaction between the AIRG and the university's faculty and staff, and to undertake research in the AIRG's key research priorities which are: identifying the impacts of atmospheric change; identifying and assessing adaptive responses; strengthening the national and international research communities' capacity for impact assessment; developing the analytical capacity for integrated assessment of atmospheric issues; and identifying barriers to implementation of adaptive and mitigation measures. The research that is carried out by the partner universities is then made available to decision and policy makers.

Table 2 Examples of adaptation and impacts research group's research projects

TITLE	LOCATION	UNIVERSITY
The Impact of Climate Change on Regional Energy Systems	Saskatchewan, Toronto-Niagara Region, Ontario, Region of Waterloo	University of Toronto
Assessment of Natural Hazards and Disasters in Canada	Canada	University of Toronto
Canadian Agricultural Adaptations to 21st Century Droughts: Preparing for climate change?	Canada	University of Toronto
Historical and Future Climates for the Assessment of Energy Sector Impacts in Canada	Canada	University of Toronto
Great Lakes Coastal Wetland Communities: Vulnerabilities to climate change and response to adaptation strategies	Great Lakes	University of Waterloo
Climate Change and Transboundary Water Issues	Columbia River Basin	University of British Columbia

Provincial government responses to facilitate adaptation to climate change

Ouranos Consortium (Québec)

The Ouranos Consortium was created to amass experts to advance the understanding of regional climate change and its environmental, social, and economic impacts. To this end, Ouranos develops tools (such as regional climate models) for providing decision makers with detailed regional climate change scenarios. They also evaluate the anticipated impacts of climate change on sectors, such as hydropower, in order to optimize adaptation strategies. Ouranos is also responsible for developing detailed medium and long term scenarios of the future Québec climate.

The creation of Ouranos was a joint initiative of the Government of Québec, Hydro-Québec and the Meteorological Service of Canada. Its creation was prompted by a series of extreme events that took place in Quebec prior to the conception. These founding partners contribute staff and financial resources to support the organization and its work. The Quebec funding agency Valorisation-Recherche Québec was also closely involved with the establishment of Ouranos and contributes to its annual funding.

Several institutions and organizations actively participate in Ouranos' activities. The four universities that are most involved are: Université du Québec à Montréal, Institut national de la recherche scientifique, Université Laval, and McGill University. A number of other organizations (government ministries, universities, associations, foundations, and subsidizing bodies) are involved, and provide support either at the level of specific projects or for the overall operations.

Ouranos' activities link over two hundred researchers and specialists from several dozen organizations to ensure that their work consistently responds to the needs of decision makers. Ouranos functions as a catalyst for the research community's efforts to determine the principal vulnerabilities of different regions and sectors in Québec, in terms of the physical environment and of the impact on humans and the economy. Working in close collaboration with decision makers and users, it helps to establish priority areas of intervention and develop adaptation strategies to mitigate the impacts or to capitalize on economic opportunities.

Prairie Adaptation Research Collaborative (Alberta, Saskatchewan, Manitoba)

The Prairie Adaptation Research Collaborative (PARC) is a partnership between the governments of Canada, Alberta, Saskatchewan and Manitoba mandated to pursue climate change impacts and adaptation research in the Prairie Provinces. Their objective is to generate practical options to adapt to current and future climate change. They also foster the development of new professionals in the emerging science of climate change impacts and adaptation.

PARC housed at the University of Regina and offers funding for interns, graduate research, hosts several important conferences and workshops on the subject of climate change, and publishes their research findings. They collaborate with stakeholders (e.g., Manitoba Conservation, Manitoba Hydro and Climate Change Central) and researchers from different levels of government. Since its inception in 2000, PARC has been involved in dozens of interdisciplinary projects (mostly in the Prairie Provinces, but also internationally) that address climate change impacts and adaptation issues.

Manitoba Climate Change Action (Manitoba)

The Government of Manitoba has made a four-year $1 million commitment to support practical, Manitoba based, actions that respond to the issue of Climate Change. As a result, the Manitoba Climate Change Action Fund (MCCAF) was set up as a component of the Sustainable Development Innovations Fund (SDIF). The MCCAF has annual funds to support projects focusing on public education and outreach; on the scientific understanding of climate change impacts and potential adaptation practices; technological innovation (research and commercialization); and on alternative or "green" energy.

Climate Change Central (Alberta)

Government of Alberta set up Climate Change Central (C3) in 1999 to promote the development of innovative responses to global climate change and its impacts. Climate Change Central builds links and relationships between businesses, governments and other stakeholders interested in pursuing greenhouse gas reductions initiatives. Although the focus is mainly on reducing net greenhouse gas emissions while strengthening Alberta's economy and long-term competitiveness, C3 also focusing on adaptation in their programs, policies and actions to effectively deal with current climate trends. Climate Change Central is advising on adaptation activities within Alberta, and is part of provincial, Western Canadian, and national committees addressing the effects of climate change.

Water, Air and Climate Change Branch of the Ministry for Water, Land and Air Protection (British Columbia)

The Water, Air and Climate Change Branch works to maintain clean air and water supported by monitoring and reporting. It also works to ensure that BC responds to the challenges of climate change. It does this in part by developing legislation and policies and applying scientific expertise to protect climate change, air quality, water quality, drinking water sources and the land. The branch works with various levels of the BC Government, such as: regional offices of Ministry, other provincial agencies, federal and local governments, industry, stakeholder groups, nongovernmental agencies, the research community and the public.

Current strategies to encourage adaptation include organizing and providing funding for workshops (sometimes in collaboration with other groups); developing legislation and policies for climate change; and producing reports, posters and publications (such as *Indicators of Climate Change for BC*).

CONCLUSION

Several challenges are being faced by water managers across Canada, and these will be exacerbated under a changing climate. However, globally, Canada is at the forefront of adaptation. Two major federal government initiatives and several provincial strategies exist to promote and facilitate adaptation. Stakeholders are involved in these initiatives and are also undertaking adaptation measures using their own know how.

Overall in Canada, applied examples of adaptation measures that have been executed are not common in the water resources sector and many needs still exist. As climate change awareness increases, stakeholders are becoming informed about the consequences and impacts, and there is great potential for adaptation implementation to progress, however this will require continual encouragement, guidance and support from all levels of government.

Adaptation is an essential action to reduce vulnerability to climate change, and to increase the resilience of the water resources sector. The government plays a critical role in ensuring Canada is prepared to deal with the impacts that climate change may bring about. With continued funding for adaptation research and more programs which encourage adaptation actions, Canada will be able to continually preserve and manage its water resources.

REFERENCES

Adkins, P., Dealing with Drought, Presentation given at *Confronting Water Scarcity: Challenges and Choices*, (Drought and rivers session), Lethbridge, AB. July 13-16 (2004).

Bowyer, P., Classifying Hurricane Juan, *CMOS Bulletin* **32**(2), 37-39 (2004).

Brown, D., C. Southam, M. Maddock and B. Mills, Grand River Basin Water Supply and Demand, *Great Lakes-St. Lawrence Basin Project on Adapting to the Impacts of Climate Change and Variability,* Progress Report 1: Adapting to the impacts of climate change and variability, L. Mortsch and B. Mills (eds.), Environmental Adaptation Research Group, Atmospheric Environment Service, Burlington, Ontario (1996).

Brooks, G.R., S. St. George, C.F.M. Lewis, B.E. Medioli, E. Nielsen, S. Simpson and L.H. Thorleifson, Geoscientific contributions to understanding flood hazards in the Red

River Valley, Manitoba, *Canadian Water Resources Association Proceedings of the 55th Annual Conference (CD),* Session b7b, Winnipeg, Manitoba (2002).

Bruce, J., I. Burton, H. Martin, B. Mills and L. Mortsch, Vulnerability and Adaptation to Climate Change, *Final Report,* GCSI – Global Change Strategies International Inc. & Meteorological Service of Canada (2000).

Byrne, J. M., R. Barendregt and D. Schaffer, Assessing potential climate change impacts on water supply and demand in southern Alberta, *Canadian Water Resources Journal,* **14**(4), 18-29

(1989).

Chinn, W.R., R.V. Rieve, T.G. Helwig, An Assessment of the Effects of Projected Climate Change on the Intensively Irrigated Areas of Alberta, *Canadian Water Resources Association Proceedings of the 57th Annual Conference (CD),* Session 18, Montreal, Qc. (2004).

Dore, M.H.I. and I. Burton, The Costs of Adaptation to Climate Change in Canada: A Stratified Estimate by Sectors and Regions (Social Infrastructure), *CCAF project No. A209* (2001).

Fogarty, C., Why did a Category-Two Hurricane hit Nova Scotia? *CMOS Bulletin,* **32**(2), 41-42 (2004).

Great Lakes St. Lawrence Seaway System, Retrieved 2005-05-17, from http://www.greatlakes-seaway.com/en/aboutus/competitiveness.html (2005).

GVRD, Greater Vancouver Regional District's Collection: Sanitary and Combined Sewers, Retrieved 2005-04-13, from: http://www.gvrd.bc.ca/sewerage/collection_combined.htm (2003).

Hajdukovic, D., B. Burton, L. Yao-Hung, Vancouver Sewerage Area Combined System Model: From Conception to Implementation, *Canadian Water Resources Association Proceedings of the 57th Annual Conference (CD),* Session 21, Montreal, Qc. (2004).

Hanson, H., C. Hanson and B.Yoo, Recent Great Lakes ice trends, *Bulletin of the American Meteorological Society,* **73**(5), 577-84 (1992).

Hill, D., Irrigation in the 21st Century, Presentation given at *Confronting Water Scarcity: Challenges and Choices,* (Irrigation: Increased efficiency & productivity session) Lethbridge, AB, July 13-16 (2004a).

Hill, D., Irrigated Agriculture: Our Capability to Provide Leadership in Sustainable Water management Decision Making, *Canadian Water Resources Association Proceedings of the 57th Annual Conference (CD),* Session 10, Montreal, Qc. (2004b).

IPCC (Intergovernmental Panel on Climate Change), *Climate Change 2001: Impacts, Adaptation, and Vulnerability,* Chapter 4: Hydrology and Water Resources, pp. 191-235, Working Group II to the Third Assessment Report, J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, K.S. White (eds.), Cambridge University Press, Cambridge, United Kingdom (2001).

International Red River Basin Taskforce, *Living with the Red: A Report to the governments of Canada and the United States on reducing flood impacts in the Red River Basin,* International Joint Commission (2000).

Kharin, V.V. and F.W. Zwiers, Changes in the Extremes in an Ensemble of Transient Climate Simulations with a Coupled Atmosphere-Ocean GCM, *Journal of Climate,* **13,** 3760-3788 (2000).

Kije Sipi Ltd., Impacts and Adaptation of Drainage Systems, Design Methods and Policies, Climate Change Adaptation Project No. A330, p. 119, June (2001).

Kunkel, K.E., North American Trends on Extreme Precipitation, *Natural Hazards,* **29,** 291-305 (2003).

Leith, R.M.M and P.H. Whitfield, Evidence of climate change effects in the hydrology of streams in the south-central B.C., *Canadian Water Resources Journal,* **23**(3), 219-230 (1998).

Levy, D.A., Potential Impacts of Global Warming on Salmon Production in the Fraser River Watershed, *Canadian Technical Report of Fisheries and Aquatic Sciences, 1889,* Department of

Fisheries and Oceans, Vancouver, B.C. p. 96 (1992).

Madramootoo, C.A., S. Kulreshetha, G. Pearson, N. Visvanatha, G. Wilkes, Analysis of Issues Constraining Sustainable Irrigation in Canada and the Role of Agriculture and Agri-Food Canada, Policy/Research Paper, Agriculture and Agri-Food Canada/PFRA, Ottawa (2005).

Mailhot, A., A.N. Rousseau, E. Nantel, B. Lacroix-Vachon, J-P. Villeneuve, Quebec's Supply of Drinking Water: An Overview of the Amounts Withdrawn and a Historical Analysis of the Amounts Available, *Canadian Water Resources Association Proceedings of the 57th Annual Conference (CD),* Session 16, Montreal, Qc. (2004).

Meteorological Service of Canada (MSC), *Climate Summaries,* Retrieved 2005-05-19 from the MSC website: http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdn_climate_summary_e.html (2005).

Ministry of Public Safety and Solicitor General's (MPSSG) Landslide Incidents – January 2005, Retrieved 2005-04-06 from the MPSSG, Government of British Columbia website: http://www.pep.bc.ca/hazard_preparedness/Landslide_Incidents_2005-01.html (2005).

Mortsch, L., H. Hengeveld, M. Lister, B. Lofgren, F. Quinn, M. Slivitzky, L. Wenger, Climate Change Impacts on the Hydrology of the Great Lakes-St. Lawrence System, *Canadian Water Resources Journal,* **25**(2), 153-179 (2000).

Natural Hazards and Emergency Response's (NHER) North Vancouver Landslide: January 19, 2005, Retrieved 2005-04-06 from NHER, Natural Resources Canada website: http://landslides.nrcan.gc.ca/landslides_b1_x/index_e.aspx?ArticleID=747 (2005).

Nyirfa, W. and B. Harron, Assessment of Climate Change on the Agricultural Resources of the Canadian Prairies, PFRA Report, funded by PARC-QS3, Agricultural and Agri-Food Canada publication, p. 27 (2001).

PARC (Prairie Adaptation Research Collaborative) *South Saskatchewan River Basin Project,* Retrieved 2005-07-12 from the PARC website: http://www.parc.ca/ssrb/ (2005).

Phillips, D., The Top Ten Canadian Weather Stories for 2001, *CMOS Bulletin,* **30**(1), 19-23 (2002).

Pietroniro, Al, Robert Halliday, Nicholas Kouwen, Donald H. Burn, Charles Lin and Sal Figluzzi, Chapter 4: Floods, *Threats to Water Availability in Canada, National Water Research Institute Scientific Assessment Report Series Number 3,* Environment Canada, 27-33 (2004).

Rasmussen, J. B., Challenges facing St-Lawrence River Biodiversity in the 21st Century, *Managing the St-Lawrence,* McGill University, Brace Centre Symposium, Montreal, Qc. September 16 (2002).

Sauchyn, D., Water and Earth Science Research Projects, *Prairie Adaptation Research Collaborative PARC), Synthesis of research projects (Draft),* pp. 37-38 (2002).

Sauchyn, D.J. and A.B. Beaudoin, Recent Environmental Change in the Southwestern Canadian Plains, *The Canadian Geographer,* **42**(4), 337-53 (1998).

Sawatsky, L. and D. Chan-Yan, Negative Public Perception of Large Irrigation Projects: A Case Study, *Canadian Water Resources Association Proceedings of the 57th Annual Conference (CD),* Session 18, Montreal, Qc. (2004).

Schindler, D.W., The Cumulative Effects of Climate Warming and Other Human Stresses on Canadian Freshwaters in the New Millennium, *Can. J. Fish. Aquat. Sci.*, **58,** 18-29 (2001).

Schindler, D., Widespread effects of climatic warming on freshwater ecosystems in North America, *Hydrological Processes*, **11**(8), 1043-1067 (1997).

St. George, S. and E. Nielsen, Paleoflood Records for the Red River, Manitoba, Canada, Derived from Anatomical Tree-ring Signatures, *The Holocene,* **13,** 547-555 (2003).

Statistics Canada, *The St. Lawrence River Valley 1998 Ice Storm: Maps and Facts,* Catalogue No. 16F0021XIB, Statistics Canada, Ottawa (1998).

Thorleifson, H., H. Maathuis and J. Lebedin, Potential Impact of Climate Change on Prairie Groundwater Supplies: Review of current knowledge, *Praire Adaptation Research Collaborative (PARC), Synthesis of research projects (Draft),* pp. 39-40 (2002).

Todhunter, Paul E., A Hydroclimatological Analysis of the Red River of the North Snowmelt Flood Catastrophe of 1997, *Journal of the American Water Resources Association,* **37**(5), 1263-1277 (2001).

Tollefson, L., J. Linsley and S. Kulshreshtha, Developing the Irrigation Opportunity in Saskatchewan in Light of Climate Change, *Canadian Water Resources Association Proceedings of the 57th Annual Conference (CD),* Session 14,, Montreal, Qc. (2004).

Trenberth, K.E., The Extreme Weather Events of 1997 and 1998, *Consequences,* **5,** 3-15 (1999).

Whitfield, P.H. and A.J. Cannon, Recent Variations in Climate and Hydrology in Canada, *Canadian Water Resources Journal,* **25**(1), 19:66 (2000).

Zhang, X., W.D. Hogg and È. Mekis, Spatial and Temporal Characteristics of Heavy Precipitation Events over Canada, *J. Climate,* **14,** 1923-1936 (2001).