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Adaptation options for the near term: climate change and the Canadian water sector

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Abstract

Climate change poses significant challenges for the Canadian water sector. This paper discusses issues relating to the selection of proactive, planned adaptation measures for the near term (next decade). A set of selection criteria is offered, and these are used in three cases to illustrate how stakeholders can identify measures appropriate for the near term. Cases include municipal water supply in the Grand River basin, Ontario; irrigation in southern Alberta; and commercial navigation on the Great Lakes. In all three cases, it is possible to identify adaptations to climate change that also represent appropriate responses to existing conditions; these should be pursued first.

Keywords: Climate change; Adaptation; Water; Canada; Selection criteria

1. Introduction

Climate change presents both significant challenges and potential opportunities to the water sector in Canada. While water users and managers always have had to cope with climate, climate change presents a different kind of challenge (Burton, 1996). Even small long-term changes in temperature and precipitation are likely to have significant impacts on the hydrologic cycle — especially at the basin scale, which is most pertinent for water managers (Frederick and Major, 1997). Perhaps more significantly, predicted climate changes include not only shifts in means for temperature, precipitation, and evaporation, but also potentially increased variability. In other words, beyond concerns such as increases or decreases in precipitation, scenarios suggest that there are likely to be more frequent and more severe events such as storms (Francis and Hengeveld, 1998). Finally, planning responses to climate change in the water sector is difficult because considerable uncertainty still exists regarding the timing and magnitude of predicted changes (Frederick and Major, 1997).

Taking all of these factors into consideration, it remains far from clear how the Canadian water sector should respond to the challenge of climate change. While complacency is not warranted, it also seems premature at this time to consider drastic measures, such as extensive construction programmes and draconian regulations. Fortunately, there is an appropriate middle ground. Numerous potential adaptation options for various regions have been identified in other studies (e.g., Sanderson, 1993; Mortsch and Mills, 1996; Hofmann et al., 1998; de Loë and Kreutzwiser, 2000). Among these are adjustments in practices that could be appropriate initial steps. Therefore, a key task for people involved in water management is identifying and implementing these kinds of measures.

The purpose in this paper is twofold: first, to highlight adaptation options for the water sector in Canada; and second, to propose a set of criteria that can be used to identify appropriate options from within the broad range of choice that exists. The criteria are attuned to the near future (approximately the next decade). While we recognize that climate change is a long-term phenomenon, we argue that there is an urgent need to begin consideration of responses now, and therefore we emphasize anticipatory, cost-effective adaptations that can and should be implemented in the near future.

The paper is organized as follows. In the next section, the concept of adaptation to climate change that we

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advocate is explored briefly. This is followed by an overview of adaptation options, in general, and for three sectors, in particular: municipal water supply in Ontario, irrigation in southern Alberta, and commercial navigation on the Great Lakes. Together these quite disparate sectors highlight the challenges facing water managers in Canada. In the final section, criteria for selecting adaptation options for each of the three specific sectors are identified and applied.

2. Adaptation to climate change and variability

Mitigation of climate change has been the focus of considerable national and international research and policy activity. However, increasingly it is recognized that some climate change is inevitable. Hence, recognition of the need to be ready for anticipated changes has become widespread (e.g., Smit, 1993; Carter et al., 1994; Feenstra et al., 1998; Tol et al., 1998). As Feenstra et al. (1998, p. iii) note "since we are already committed to some climate change and since it is unlikely that the reduction of greenhouse gas emissions will be sufficient to prevent climate change, it is better to be prepared than to leave it for future generations to live with". *Adaptation* is an important way to increase readiness and address the impacts of climate change.

The concept of adaptation has been variously defined in the literature (e.g., Smit, 1993; Smithers and Smit, 1997; Burton et al., 1998). In essence, adaptations are adjustments in response to climate stimuli. These adjustments may be planned or unplanned. They may take the form of institutional, technological, or behavioural changes. Decisions to adapt can be made by individuals, communities, corporations, governments, and international and transnational bodies (Smithers and Smit, 1997; Feenstra et al., 1998). Finally, while adaptation normally is thought of in terms of adjustments that reduce vulnerability to climate change, it is worth noting that some adaptations can increase vulnerability; these are referred to as *maladaptations* (Burton et al., 1998).

The focus in this paper is on planned, anticipatory, positive adaptations of all types (i.e., institutional, technological, and behavioural) and at various scales (i.e., local, provincial, national, and international). While it is acknowledged that autonomous adaptations are likely to take place, this does not reduce the need for stakeholders (especially governments) to consider proactive adaptations now.

3. Adaptation opportunities in the water sector

The number of adaptation opportunities for the water sector is vast. For each of the many ways in which water is important, there exists a range of approaches that have been used to adapt to *existing* climate variability, along with numerous options for adapting to anticipated climate changes. (Frequently measures fit in both categories.) A key challenge for the *near term* (i.e., the next decade) is identifying adaptation options that represent appropriate adjustments to anticipated climate changes, but which also make good water management sense on their own. Focusing on these kinds of "no regrets" measures is appropriate for the near term because these are the ones that are most likely to be implemented.

A commonly used framework for classifying adaptation measures is based on the study of extreme events such as floods and droughts (e.g., Kates, 1985). This framework places adjustments to extreme events in three main categories:

1. *Accepting losses:* This involves bearing losses and sharing losses. Loss bearing typically is an individual adaptation. However, it also may be pursued by groups or communities that have no other choices, or which find all of the other choices to be too costly. Losses can be shared within wider communities (friends and neighbours assisting each other), or via mechanisms such as insurance and public relief.
2. *Preventing effects:* The aim of these adaptations is to prevent the consequences of climate change from occurring. These measures often involve the construction of structural works that will reduce the impacts of climate change. Dams and reservoirs that store water are common examples in this category. Typically, the aim is to allow pre-impact behaviour and activities to continue.
3. *Changing uses and/or locations:* Changing uses involves accepting that pre-impact behaviour and activities no longer can be pursued, because they are too risky, too expensive, or simply no longer possible. Hence, the adaptation involves switching to a different use strategy (e.g., from a cooling process that uses water once, to one that recycles cooling water). Adaptation strategies that involve a change of location are a more extreme response. An example might be a marina operator who is forced to relocate his marina due to reduced water levels at an existing site.

This framework is widely used in the context of adaptation to climate change (e.g., Feenstra et al., 1998; Hofmann et al., 1998). In both of these documents, research and education also are identified as categories of adaptations. However, in this paper it is assumed that these will take place, where appropriate, in the context of the three main types of adaptations.

Table 1 uses the three-part framework to present selected *example* adaptation opportunities for various Canadian water use sectors. To emphasize the way in which options will vary with decision-making scale, an *example* stakeholder is listed for each water use sector considered. While the pertinent climate change stimuli

Table 1
Example adaptation options for key water use sectors[a]

Water use sector	Example climate change stimulus	Example stakeholder	Example adaptations		
			Accepting losses	Preventing effects	Changing uses and/or locations
Municipal	Supply is reduced and demand increases	Municipal officials	Drought contingency planning	Increase water intake pumping capacity	Promote water conservation
Agriculture	Supply is reduced	Individual farmers	Supplement income by seeking off-farm employment	Construct or enlarge farm ponds to store more water	Switch to low-water-using sprinklers
Industry	Supply is reduced	Individual industries	Seek government subsidies for increased operating costs	Increase water storage capacity	Recycle cooling water
Rural domestic	Ground water supply is reduced, and demand increases	Households	Allow lawns and gardens to deteriorate	Deepen wells	Conserve water in the home and yard
Recreation and tourism	Lake levels decline	Marina owners	Temporarily close marinas	Install floating docks at marinas	Relocate marinas
Commercial navigation	Lake levels decline	Shipping companies	Contingency plans for interruption of shipping	Adapt shipboard loading and unloading facilities for lower lake levels	Reschedule shipments to coincide with seasonal peak water level periods
Energy	Lake levels decline	Power generation utility	Substitute energy sources to replace lost generation capacity	Increase pumped storage capacity	Encourage energy conservation by consumers
Commercial fishery (freshwater)	Stream flow reductions reduce habitat quality	Government regulators	Close the fishery	Construct reservoirs to increase flows	Reduce the number of licensed fishers

[a]Note: These examples illustrate the range of choice of options. Stakeholders will have to select the most appropriate options for their situations.

vary among the sectors, in all cases it is assumed that *less* water is available from both surface and ground water sources; this is a common assumption of climate change scenarios for most parts of Canada (e.g., Hofmann et al., 1998).

Significantly, many of the examples listed in the table already are used to adapt to existing climate variability. However, they also can be used to adapt to anticipated climate changes. The measures run the gamut from institutional (e.g., contingency planning, insurance, regulations) to structural (e.g., constructing reservoirs) to changes in behaviour (e.g., adopting water conservation).

Local conditions and circumstances will influence the specific adaptations that are, or can be, used for each sector, and by each stakeholder. This reinforces the need to develop criteria that can be used by stakeholders to select measures that are appropriate for their local circumstances. To highlight this, three case studies are developed below. Each case study emphasizes a particular use sector in a certain region, and links options to specific stakeholders. The regions selected emphasize different scales, from a local watershed (Grand River basin), to a large region (southern Alberta), to a regionally significant watershed (Great Lakes basin). The three sectors (municipal water supply, agricultural irrigation, and commercial navigation) were chosen because they highlight a broad range of problems and issues relating to the selection of adaptation options.

4. Adaptation in the municipal sector: water supply in the Grand River basin, Ontario

The Grand River basin is located in southern Ontario (Fig. 1). This watershed covers an area of 6790 km^2, and has approximately 600,000 inhabitants. It contains numerous small communities, along with five large urban centres (Brown et al., 1996). Municipalities play a central role in public water supply. However, another important actor in this region is the Grand River Conservation Authority, a watershed management agency which regulates rivers in the basin.

Demand for municipal water in the Grand River basin is being met primarily from ground water (80%) and surface (20%) water sources (Lacelle, 1993). Two municipalities in the watershed are heavily dependent on ground water, the Regional Municipality of Waterloo and the City of Guelph — although both take water from rivers to recharge ground water aquifers. The City of Brantford depends on surface water from the Grand

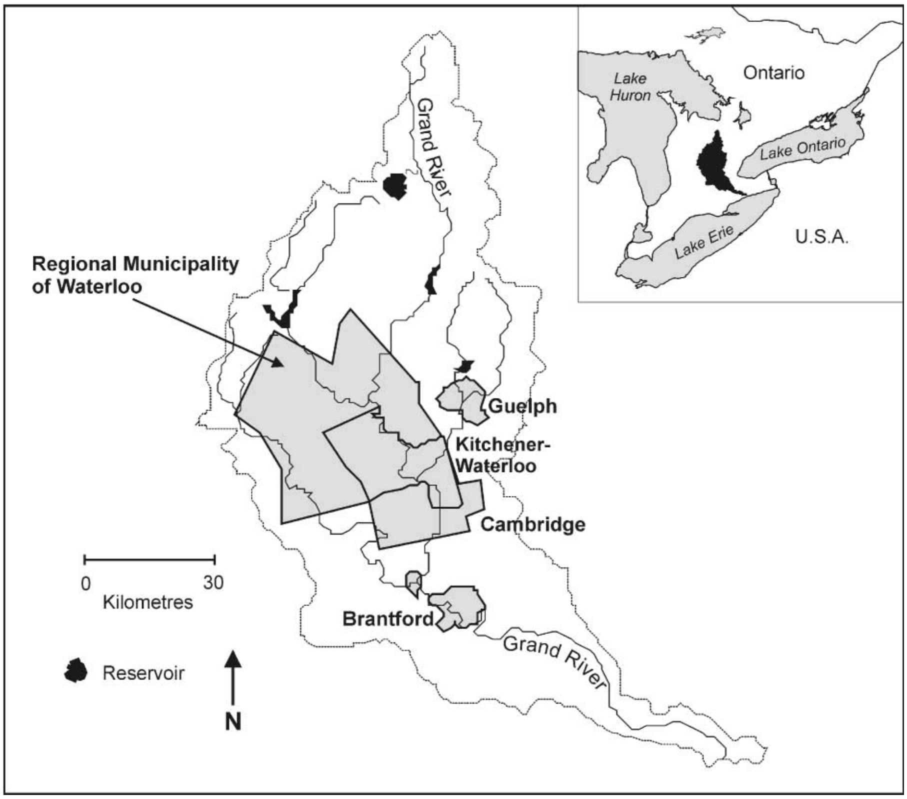

Fig. 1.

River. While the option of constructing a pipeline has been discussed for decades, none of these municipalities currently has access to the bountiful supplies of the Great Lakes. Consequently, these communities are likely to feel the impacts of climate change directly and significantly.

4.1. Anticipated climate change impacts

Several studies have generated scenarios of climate change impacts in the Grand River basin. Sanderson and Smith (1993) indicate that the basin may experience temperature increases of 4.7–5.7°C. Following from this, Smith and McBean (1993) suggest that stream flow reductions of between 19.2 and 40% could be expected. Ground water, the source of municipal water supply for a large number of basin communities, also may be vulnerable to changes in recharge rates brought on by climate change (Nuttle, 1993). McLaren and Sudicky (1993) estimated the impact of climate change on ground water recharge for a subregion of the basin. They predicted that a reduction in the rate of recharge of 15–35% can be expected, and that this will result in a drop in ground water levels, at existing municipal wells, in the range of 5–20 m. Finally, FitzGibbon et al. (1993) found that climate change will impact the flow as well as the quality of the Grand River. They estimate that a 10% reduction in peak discharge of the spring flood will occur which, in turn, will decrease the flushing action required to remove accumulated sediment and sludge from the Grand River, thus affecting water quality.

Many municipalities within the basin have faced short-term water shortages in recent years. And, increasingly, drought and population growth are sources of additional stress — making water and wastewater treatment systems more sensitive. System sensitivity or vulnerability is reflected in the type and frequency of system problems or failures that occur. Water sources, reservoirs and dams, intake pipes, pumps, and treatment processes are some of the most common components that will experience problems of one kind or another (Moraru et al., 1999).

Basin cities such as Cambridge, Kitchener, Waterloo, and Guelph have faced difficulties meeting their summer peak water demand and, as a result, have imposed lawn watering restrictions (Robinson and Creese, 1993; Johnson, 1999). Indeed, the City of Guelph imposed an outright lawn watering ban for part of the summer of 1999. For all municipalities in the basin, climate change raises the spectre of more frequent drought-induced shortages in the years to come. To make matters worse, if climate-induced shortages persist in the future, municipal water supply will face increased competition from other sources (e.g., industry, recreational activities such as golf, agriculture).

Table 2
Example adaptation options for stakeholders in the municipal water supply sector, Grand River basin, Ontario[a]

Stakeholders	Example adaptation options		
	Accepting losses	Preventing effects	Changing uses and/or locations
Municipal officials	Establish contingency plans for sharing water during shortages	Seek alternative water sources (e.g., Great Lakes pipeline)	Official Plan policies that disallow new residential growth and additional water-intensive industries
	Accept reduced levels of street cleaning (dirtier streets)	Construct new wells or deepen existing wells	Voluntary water conservation programme directed to residential and other water users
		Increase intake capacity (for municipalities taking from surface sources)	Leak detection and system optimization
			Upgrade wastewater treatment facilities to improve effluent quality
Households	Tolerate increased inconvenience	Construct cisterns and install rain barrels to store rain water	Adopt water conservation practices in the home
	Allow lawns and gardens to wither		Replace lawns with xeriscaping (low-water-using plants, rock gardens)
Industries, commercial firms and institutions	Tolerate increased inconvenience and production losses	Increase on-site storage capacities	Recycle water used in cooling and processing
		Make arrangements for alternative water supplies	Upgrade wastewater treatment facilities to improve effluent quality
			Relocate from municipalities where water is restricted to those where water supplies are more secure
Provincial government (Ontario)	Enhance conflict resolution mechanisms in the water allocation system	Regionalize water supply and wastewater treatment systems within the basin	Change *Building Code* to require the use of water-efficient fixtures in new construction, and retrofitting in existing structures
	Provide subsidies to assist municipalities and industries with increased operating costs	Construct Great Lakes pipeline to headwaters of Grand River to augment flow	Establish legal priorities to regulate withdrawals during times of shortage
			Deny water withdrawal permits to high water users
Grand River Conservation Authority	Trade habitat off against water for municipal supply	Construct additional storage reservoirs	Modify operational plans for reservoirs
Federal government	Provide subsidies to assist municipalities and industries with increased operating costs	Subsidize municipal infrastructure improvements	Impose conservation standards as a condition of receiving mortgage insurance (via Canada Mortgage and Housing Corporation)
	Tax write-offs for business losses due to water shortages		Promote water conservation

[a] Note: These examples illustrate the range of choice of options. Stakeholders will have to select the most appropriate options for their situations.

4.2. Adaptation options

Table 2 identifies a range of adaptation options that stakeholders in the municipal water supply sector in the basin can pursue. (The climate change stimulus is assumed to be reduced water supply, and increased demand.) The examples illustrate a range of choice of adaptation options. Stakeholders will have to select appropriate options from among a range such as this. Some of the options can be further sub-divided. For instance, water conservation programmes can include institutional measures (e.g., water conserving rate structures), technological adjustments (e.g., leak detection programmes, installation of low-water-using plumbing fixtures), and behavioural changes (e.g., reducing the length of showers). The table also illustrates the fact that the range of stakeholders within the municipal water supply sector is very broad. Not all of these stakeholders currently play a significant role. For instance, the federal government at present plays a diminished role compared to past decades.

There are signs that water managers in the basin are beginning to adapt to climate change at the local and watershed levels. Specifically, some larger municipalities are in the process of preparing contingency plans to address future droughts and their impacts on water supplies. Management of scarce water supplies at the watershed level, and coordination and cooperation among municipalities, are three issues that can be addressed during the preparation of drought contingency plans. At the provincial level, Ministry of Environment policies, plans, and regulations can be clarified to establish water taking priorities during periods of insufficient supply, and to establish conflict resolution mechanisms.

Some anticipatory adjustments to diminished water supply already are in place in cities such as the Regional Municipality of Waterloo and the City of Guelph. These involve demand management programmes to make water use, storage, and distribution more efficient. Demand management measures such as voluntary and mandatory outdoor water use restrictions, water rationing, public education, water pricing, and installation of water-saving equipment, among others, increasingly are being adopted in the municipal sector (Kreutzwiser et al., 1998). However, many municipalities still do not have the necessary legal or institutional provisions for demand management and water conservation.

5. Adaptation in irrigation agriculture: Southern Alberta

Southern Alberta contains a large semi-arid region with excellent agricultural potential (Fig. 2). Average annual precipitation varies widely, from around 250 mm in the area north of Medicine Hat, to 1500 mm in the mountains along the British Columbia–Alberta border (Alberta Environment, 1991). Dry years are common, with consequent drought and crop failure. Encouraged by government policy and railway company propaganda near the turn of the century, an agricultural economy developed in this region.

Agriculture remains an important component of the Alberta economy today. A considerable portion (some 16%) of agricultural production occurs using irrigation (Klassen and Gilpin, 1999). In fact, over 60% of the irrigation that takes place in Canada occurs in southern Alberta (Government of Canada, 1991) — most of it in irrigation districts (Fig. 2). Created under provincial legislation starting in 1915, these districts are organized to collect and distribute water to irrigation farmers (Klassen and Gilpin, 1999).

Irrigation in Alberta is a major water user, withdrawing approximately 2.8 billion m^3 per year (almost entirely from rivers and streams), and consuming most of that (approximately 82%) (Alberta Environment, 1991). The irrigation sector in Alberta is especially sensitive to climate change because stream flows are limited and extremely variable from year-to-year, as well as from season-to-season. Average annual discharge of the South Saskatchewan River below the confluence with the Red

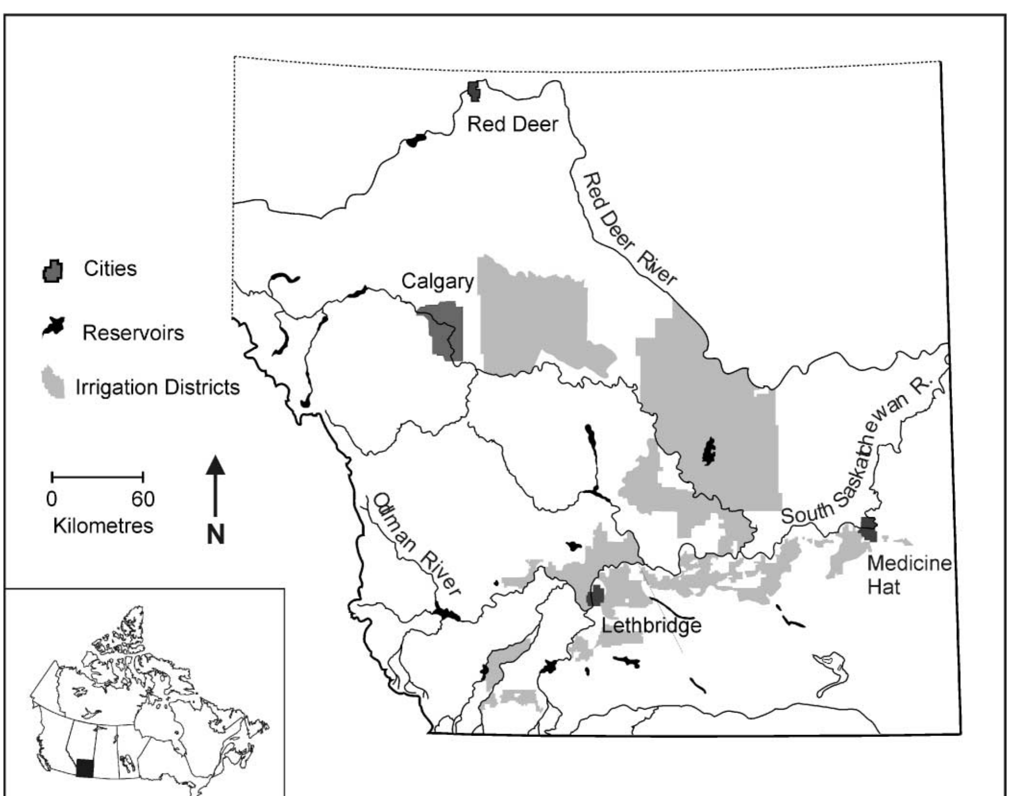

Fig. 2.

Table 3
Example adaptation options for stakeholders in the agricultural irrigation sector, Alberta[a]

Stakeholders	Example adaptation options		
	Accepting losses	Preventing effects	Changing uses and/or locations
Irrigation farmers (district or private)	Supplement income by seeking off-farm employment	Acquire additional rights to water	Switch from low- to high-efficiency irrigation systems
	Purchase additional crop insurance	Construct farm ponds and dugouts to store water (especially private irrigators)	Switch to crops that require less water
		Increase pumping capacity and relocate intakes (especially private irrigators)	Improved irrigation water use to reduce wastage (e.g., scheduling and other irrigation management techniques)
Irrigation districts	Contingency planning for water shortages	Upgrade canals and storage infrastructure to increase capacity and to reduce losses during transportation and storage	Adjust operation of district water control structures and water distribution systems (e.g., automation, system optimization)
		Relocate water intakes to accommodate changes in river channels	Promote efficiency and proper water use practices among water users
			Encourage transfer of water rights from less efficient to more efficient water users
Provincial government (Alberta)	Enhance crop insurance, stabilization, and relief programmes	Construct additional on-stream reservoirs to increase storage capacity and control river flows	Promote efficiency and proper water use practices among *all* licence holders
		Interbasin transfer (from northern river systems to southern)	Adjust operation of provincial water control structures (e.g., automation, system optimization)
		Subsidize irrigation district infrastructure improvements	Encourage shift from marginal lands to more productive lands
		Relocate diversion structures to accommodate changes in river channels	Promote research into new cultivars, new practices, new technologies
Federal government	Enhance crop insurance, stabilization, and relief programmes	Promote construction of farm ponds and dugouts (Prairie Farm Rehabilitation Administration)	Promote research into new cultivars, new practices, new technologies
		Subsidize infrastructure improvements (individuals and district/provincial)	

[a] Note: These examples illustrate the range of choice of options. Stakeholders will have to select the most appropriate options for their situations.

Deer River (Fig. 2) is approximately 9.5 billion m^3 — a small fraction of the vast quantities of water flowing in Alberta's northern rivers. Furthermore, between 1912 and 1982, the flow in the South Saskatchewan River has ranged from a low of about 4.9 billion m^3 per year to a high of just over 16 billion m^3 per year (Alberta Water Resources Commission (AWRC, 1986). Because the region's rivers and streams are fed primarily by melting snow in the western foothills and mountains, the bulk of stream flow — approximately 60% — occurs between the months of mid-May and mid-July (AWRC, 1986).

Irrigation itself is an adaptation to climate change and variability. It was adopted in southern Alberta prior to the turn of the century specifically to address the uncertainty associated with the natural precipitation regime. Using the three-part framework referred to above, it falls under the category of "Preventing Effects." However, in this subsection, opportunities for adaptation to climate change *within* the irrigation sector are identified.

5.1. Anticipated climate change impacts

In common with arid and semi-arid areas that are dependent on irrigation (Dudek, 1989), agriculture in southern Alberta is particularly vulnerable to climate change. Estimates of the impacts of climate change for the Oldman River basin in southern Alberta (Fig. 2) suggest that soil moisture is likely to decline, and that runoff will be reduced (Byrne et al., 1989; Nkemdirim and Purves, 1994). Using estimates produced by three general circulation models (GCMs), Nkemdirim and Purves (1994) suggest that under a $2 \times CO_2$ scenario, temperature is likely to increase by between 2.8 and 6.2°C, while precipitation is likely to increase by between 2 and 11%. Predicted increases in precipitation will not compensate for increased evaporation and evapotranspiration. Thus, average decreases in stream flow under the three scenarios were estimated to be 31.8% (Nkemdirim and Purves, 1994).

Given that Alberta's irrigation sector is almost entirely dependent on stream flow, climate change is likely to have severe impacts. These impacts will be magnified by changes in soil moisture requirements that result from climate change. Byrne et al. (1989) suggest that as temperatures increase, and as humidity decreases, irrigation water demand will rise dramatically as soil moisture deficits increase.

Any increase in irrigation water demand will lead to heightened competition and conflict with other water users. Recent restrictions on the expansion of irrigation in the region have been partly due to a desire on the part of the provincial government to maintain aquatic habitat through the preservation of instream flows (AWRC, 1986) — a relatively new concern that competes with irrigation. However, as the headwaters province for the Prairies, Alberta's ability to expand its irrigated area also is constrained by an agreement entered into in 1969 by the three Prairie provinces (Alberta, Saskatchewan, and Manitoba) and the federal government. Under this Master Agreement on Apportionment, Alberta has agreed to allow 50% of stream flow, as measured at the Alberta–Saskatchewan border, to pass to the downstream provinces (Prairie Provinces Water Board, 1989). Hence, under the current climate regime considerable competition for water resources exists. Climate change is likely to intensify this competition.

5.2. Adaptation options

Table 3 lists key stakeholders in the irrigation sector in Alberta, and identifies adaptation options. As in the municipal water case, the options listed are not necessarily feasible, appropriate or desirable during the near term; they represent a broad "range of choice". Many of these measures have already been pursued in this sector as a response to existing variability and increases in demand; this is especially true of the measures in the "Preventing Effects" column. For example, Alberta's water managers have constructed reservoirs to capture stream flow in spring for use later in the summer since the early years of the century (de Loë, 1994). The Oldman River Dam is the most recent major water storage project constructed by the provincial government (de Loë, 1997), but numerous smaller projects are ongoing. Similarly, recognition in the early 1960s that the efficiency of irrigation and water management works was unacceptably low led to an extensive programme of rehabilitation. Since the 1960s, irrigation districts, the federal government (up to 1973), and the Government of Alberta have spent hundreds of millions of dollars to upgrade irrigation canals and water control structures and to increase water storage capacity (de Loë, 1994). Behavioural changes, such as promoting proper irrigation management practices, also are being pursued as a response to increased demand, and growing awareness of supply limitations.

Some of the measures listed in Table 3 represent new, as-yet untested adaptations. For instance, water rights transfers have become feasible only recently under changes established by Alberta's new *Water Act*. Under the previous legislation, the *Water Resources Act*, the right to use water was vested in a licence that was tied to a particular parcel of land, and could not be transferred separately from the land, or easily to another purpose (Percy, 1988). The new law continues the use of licences, but permits the transfer of the right to use water from one type of use, such as irrigation, to another, such as industrial processing. This is a loss bearing strategy for irrigators because it amounts to a reduction in irrigation if water licences are transferred to some other purpose. Of course, from the point of view of Alberta's water sector, this represents "Changing Uses".

6. Adaptation in the commercial navigation sector: the Great Lakes basin

The Great Lakes (Fig. 3), with a surface area of 246,000 km^2, and almost one-fifth of the world's fresh surface water, are an immense, multi-faceted water resource. Commercial navigation, one of the oldest uses of the Great Lakes, contributes billions of dollars and thousands of jobs annually to the Canadian economy (Canadian Shipowners Association, 1997). Over the years, the governments of Canada and the United States have expended considerable sums of money in developing and maintaining navigation infrastructure. Improvements first began in 1680, with initial work on the Casson (Lachine) Canal in Montréal. Major advances in commercial navigation on the Great Lakes occurred in 1829, with the opening of the Welland Canal linking Lake Ontario with the upper lakes, and in 1959, with the opening of the St. Lawrence Seaway. Today, the Great Lakes–St. Lawrence waterway spans 3740 km, from the Gulf of St. Lawrence to the head of Lake Superior.

While the volume of shipments on the Great Lakes has declined over the past two decades, it remains significant. In 1996, the Canadian fleet hauled 67 million tonnes and the United States fleet shipped 106 million tonnes (Canadian Shipowners Association, 1997). When international carriers are included, about 250 million tonnes of cargo is transported annually within and through the Great Lakes–St. Lawrence waterway. For bulk cargo, such as grain, iron ore, and coal, there is simply no more efficient alternative than marine shipping. Consequently, commercial navigation will continue to be a significant use of the Great Lakes water resource.

6.1. Anticipated climate change impacts

Climate change, with anticipated lower Great Lakes water levels and flows in connecting channels, will impact commercial navigation in several ways. Water depths in connecting channels, e.g., the St. Clair River, and in harbours, will mean that ships will have to reduce their cargo weight to avoid grounding and, thus, unit shipping costs will increase. If more ships are required to carry the same volume of cargo, then increased delays may be experienced at locks. Some loading and unloading facilities and some smaller, regional ports may even become temporarily inaccessible during extreme low water periods. On the other hand, climate change may result in an 11-month or year-round navigation season, which may offset, to some extent, the costs of lower water levels.

Using an earlier $2 \times CO_2$ GCM-based hydrologic scenario, Sanderson (1987) estimated that operating costs to Canadian commercial shippers on the Great Lakes would increase almost 5%. This scenario assumed lake level reductions of from 21 cm on Lake Superior to 85 cm on Lake Ontario, and an 11-month shipping season. Sanderson (1987) estimated that, 69% of the time, annual operating costs would be similar to those experienced during the low water conditions of 1963–1965. A hydrologic scenario, based on the more sophisticated Canadian Climate Centre GCM (Levels Reference Study Board, 1993b), suggests substantially lower mean levels on several of the Great Lakes (e.g., 1.62 m lower on Lakes Michigan–Huron and 1.30 m lower on Lake Ontario) than those assumed by Sanderson. Thus, shipping cost increases could be substantially higher.

6.2. Adaptation options

Table 4 identifies the key stakeholders in the Great Lakes commercial navigation sector, and lists some example adaptation options. Again, the options are not necessarily desirable or recommended. As in the case of the municipal water supply sector in the Grand River basin, and irrigation in southern Alberta, many of these measures already have been pursued, or at least contemplated, in the context of previous low water level periods. For example, shippers historically have accepted losses due to reduced cargoes or, more often, have passed some of these costs on to their customers. Federal governments periodically have dredged connecting channels and harbours to maintain adequate drafts. Other options in the "Preventing Effects" column include a variety of hydrological interventions to reduce the frequency and severity of low water periods. Construction of vessels with shallower drafts, and various measures to change the timing and location of activities, are found in the "Changing Uses and/or Locations" column.

The International Joint Commission, a bi-national body established by the federal governments of Canada and the United States to address issues concerning boundary waters, such as the Great Lakes, evaluated a wide range of measures that potentially could be undertaken in response to high and low water conditions on the Great Lakes. Various hydrological interventions were given considerable scrutiny. One of these options would involve the placement of sills in the outlet channels of the Lakes, to raise the water level regime. The cost of this measure has been estimated at 25–50 million dollars, depending on the costs of environmental studies and remedial actions (Measures Working Group, 1989). Ironically, dredging of the St. Clair and Detroit Rivers during the 1930s and 1960s lowered the mean level of Lakes Michigan–Huron by 40 cm. Channel filling, to

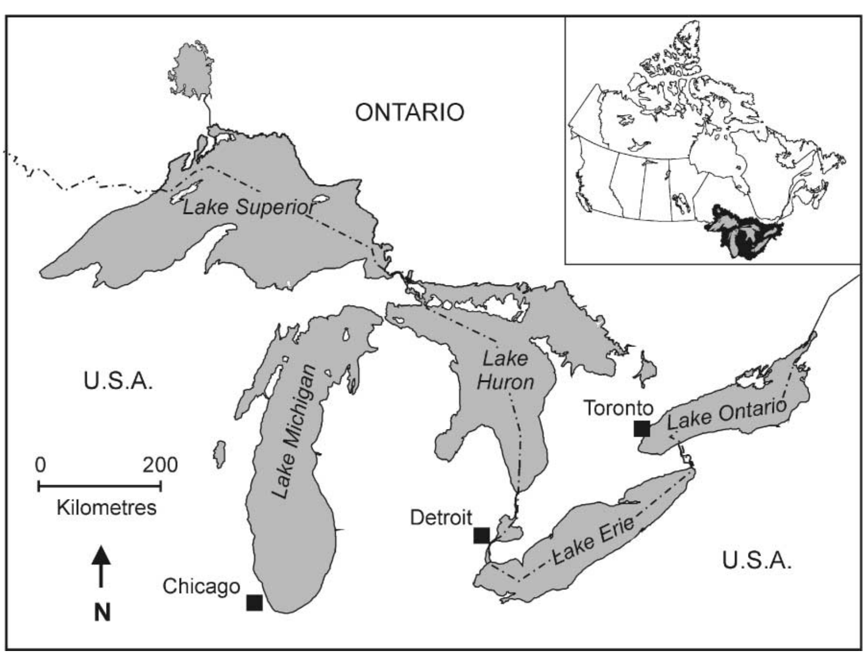

Fig. 3.

Table 4
Example adaptation options for stakeholders in the commercial navigation sector, Great Lakes basin[a]

Stakeholders	Example adaptation options		
	Accepting losses	Preventing effects	Changing uses and/or locations
Shipping companies	Establish contingency plans for interruption of shipping	Adapt shipboard loading and unloading facilities for lower lake levels	Construct vessels with shallower drafts
	Voluntarily reduce cargo loads		Reschedule shipments to coincide with seasonal peak water level periods
Federal governments (Canadian and US)	Increase rescue capability to deal with increased vessel groundings	Improve navigation and warning systems to reduce risk of grounding	Manage lock traffic to increase capacity
	Provide subsidies for increased operating costs	Increase dredging of harbours and connecting channels to deal with lower levels	Improve navigation and warning systems to allow selection of alternative routes
		Optimize operational plans for regulation of Lakes Superior and Ontario to stabilize or increase channel flows	Regulate vessel speeds and cargo limits
		Increase diversions into the Great Lakes and reduce diversions out of the Lakes	Relocate harbour facilities
		Regulate Lakes Michigan–Huron and Erie	
		Construct outlet channel sills to raise lake levels	
Provincial and state governments	Subsidize local businesses dependent on the shipping industry	Regulate encroachments in connecting channels that impact lake levels	Encourage optimization of provincial transportation system to support viable harbours

[a] Note: These examples illustrate the range of choice of options. Stakeholders will have to select the most appropriate options for their situations.

compensate hydrologically for the dredging, was planned but never undertaken.

Another option, co-ordinated regulation of Lakes Superior, Erie, and Ontario (only Superior and Ontario presently have outlet control structures), would slightly lower the mean levels of Superior, Michigan–Huron, and Erie, while raising the level of Lake Ontario and increasing flows in the St. Lawrence River. This measure was estimated to cost 3.38 billion dollars, including mitigation works in the St. Lawrence River (Levels Reference Study Board, 1993a). In its report to the Commission, the Board estimated a small annual net gain to commercial navigation, resulting from a 3.8 million dollar annual gain to Canadian shippers and a 3.3 million dollar loss to US shippers on the Great Lakes. Losses to the port of Montréal also were anticipated, but these could not be fully quantified. This raises an interesting issue concerning the distribution of impacts (i.e., who benefits and who bears the costs) of major hydrological interventions. The challenges associated with these kinds of potential adaptations to climate change are further illustrated by the case of diversions into and out of the Great Lakes basin. A key diversion out of the basin, at Chicago, is limited to 91 m^3/s by a US Supreme Court decree. It is unclear what authority the International Joint Commission, or federal governments, would have in reducing this diversion to help raise the level of Lakes Michigan–Huron. Indeed, further major hydrological interventions may require renegotiation of the *Boundary Waters Treaty* between Canada and the United States.

While implementation of many of the hydrological interventions that represent potential adaptations to climate change would be costly from an economic and environmental perspective, as well as institutionally complex, the options in the “Changing Uses and/ or Locations” column are generally more feasible. Rescheduling of shipping to coincide with seasonal peaking of lake levels, during lower water years, and more effective management of traffic in locks and connecting channels, are examples.

7. Discussion

Throughout the paper, a number of potential adaptation measures have been suggested that can be pursued by the various stakeholders in the Canadian water sector. These include a selective but broad list for the water sector as a whole, presented in Table 1, and various measures for three specific areas, presented in Tables 2–4.

The measures were identified as being part of a broad "range of choice". A key challenge confronting the water sector in Canada is moving beyond identification and categorization of measures, as in these tables, to actually selecting appropriate ones for the near term.

Guidance can be found in various forms. For example, attempts to systematize the selection process exist (e.g., Carter et al., 1994; Smith, 1996; Feenstra et al., 1998; Smith et al., 1996). And, numerous authors have proposed sets of selection criteria (e.g., Mortsch and Mills, 1996; Frederick and Major, 1997). Smith et al. (1996) propose a combination approach, involving a set of screening criteria, and a more involved follow-up approach, using tools such as multi-criteria evaluation.

It is argued here that an appropriate first step — whether or not a more sophisticated evaluation methodology ultimately is used — is *screening* the options in the broad range of choice so that implementation of clearly appropriate options can begin immediately. Application of the criteria discussed below should highlight measures that represent appropriate adaptations to climate change, *and* which comprise responses to existing problems. We suggest that in many cases, more involved evaluation techniques of the appropriateness of measures as adaptations to *climate change alone* are not needed. Ultimately, we argue, decisions to use or not use measures likely will be based on the merits of the measure *relative to existing problems*. For this reason, the first criterion suggested is the one commonly referred to as "no regrets".

8. Criteria for selecting adaptations

The following criteria are proposed here as appropriate for screening the broad range of available options, to identify measures that can be implemented in the near term (i.e., the next decade). They are drawn from a wide variety of sources, including the ones listed earlier:

- no regrets;
- reversibility;
- minimize environmental impacts;
- cost effectiveness;
- equity;
- reduce vulnerability — or at least do not increase it;
- ease of implementation (feasibility);
- effectiveness.

8.1. No regrets

Adaptation options that fall into the "no regrets" category are most appropriate. For example, Smith et al. (1996) suggest that measures should be selected that generate other benefits to the economy or the environment — and which are justifiable under current conditions. As noted earlier, we argue that — at least for the near term — options most likely implemented will be of the "no regrets" variety.

8.2. Reversibility

While a consensus has formed in the scientific community suggesting that human activities are producing climate change, considerable uncertainty remains regarding the impacts of the anticipated changes. As noted in the introduction to this paper, uncertainty is particularly strong at the basin or watershed scale — where most water management activities take place (Frederick and Major, 1997). Consequently, it is suggested here that measures that are most appropriate during the near term are those which are reversible. Consistent with the concept of "flexing" (Collinridge, 1983), it is not wise at this time to become locked into courses of action that cannot be altered in a decade should new information suggest a more appropriate direction.

8.3. Minimize environmental impacts

The focus in this paper has been on human-economic uses of water. Rather than being a rejection of the intrinsic and environmental importance of water, this reflects two considerations: (1) the orientation of water management in Canada today (which remains strongly anthropocentric), and (2) the fact that *adaptation* to climate change invariably deals with human activities and human behaviours. A key challenge for the Canadian water sector is ensuring that adaptations do not stress natural systems unnecessarily.

8.4. Cost effectiveness

It is wise for measures pursued in the near term to be inexpensive to implement. As Smith et al. (1996) note, "Given the long time frame and uncertainty about climate change, it is difficult to justify significant costs that provide benefits only if climate changes." This is especially true in the context of selecting adaptation options for the near term. Additionally, it is appropriate that all measures pursued as adaptations to climate change should meet the test of economic efficiency, in other words, their benefits should exceed their costs. Unfortunately, as Tol et al. (1998) note, there has been insufficient attention to the cost of many measures as potential adaptations to climate change. This will make application of this criterion more difficult, unless the cost of the measure has been evaluated in some other context.

8.5. Equity

While it is important for measures to be inexpensive and economically efficient, there is another pertinent dimension of cost that should be taken into account. The distinction between *costs to society* and *costs to individuals* should be recognized. We suggest that the most appropriate measures are those where beneficiaries accept the costs. This is the concept of "user pay", which is expressed as full cost pricing in the context of municipal water supply: the amount that consumers pay for water should capture the full cost of providing the service. However, it also is captured by the idea that some water management strategies represent a subsidy by society of individuals. Flood protection works to protect people who have knowingly located in a flood plain are an example. These kinds of measures are not appropriate, as a rule, and should certainly be discouraged when it is known that they are maladaptive.

8.6. Reduce vulnerability

Some kinds of behaviour, on the part of individuals, companies, and governments, increase vulnerability (or sensitivity to impacts), while others either reduce vulnerability, or, at a minimum, are neutral. Common sense dictates that given recognition of the likely impacts of climate change, measures that increase vulnerability should not be pursued. For example, government policies that encourage water consumptive industries or population growth in areas that currently experience constraints in water supplies, and which are likely to have an increased frequency of shortages due to climate change, should not be adopted.

8.7. Ease of implementation (feasibility)

Measures that are most appropriate in general, but especially in the context of a short time frame (e.g., 10 years), are those that do not require major financial outlays, dramatic changes in institutional arrangements, or immediate radical shifts in behaviour. In other words, the emphasis should be on feasible measures (Mortsch and Mills, 1996; Smith et al., 1996). This does not represent acceptance of the status quo. Rather, it represents recognition of some ongoing trends, and some hard realities. Throughout Canada, governments at all levels are being challenged to balance budgets and cut spending. This is reflected in the withdrawal of the federal government from many water management activities (Bruce and Mitchell, 1995), severe cuts in funding to environment and natural resources agencies in provinces such as Ontario (Kreutzwiser, 1998), and a trend to increased responsibility for water management at the local level. Therefore, it is important to identify as appropriate adaptation measures options that can be implemented relatively easily.

8.8. Effectiveness

Finally, the relative effectiveness of measures clearly is an important consideration that must be balanced against the other criteria. However, in the context of the near future, there seems to be limited value in suggesting, for instance, highly effective but extremely costly measures. Ultimately such measures may be required, especially if they are the ones that best meet criteria such as reducing vulnerability, equity, and reversibility. Consequently, we suggest that it may be more appropriate to examine the relative effectiveness of measures *after* considering the other criteria.

9. Applying the criteria

The criteria outlined here can be used to quickly screen available options and select suitable ones for the near term, without having to make use of an involved evaluation technique (e.g., benefit–cost analysis, multi-criteria evaluation). In large part, this is due to the fact that virtually every option listed in Tables 2–4 already has been considered in the context of existing climate variability. For instance, the options listed for commercial navigation (Table 4) already have been evaluated by the International Joint Commission, in the context of previous low water level periods on the Great Lakes (e.g., Measures Working Group, 1989; Levels Reference Study Board, 1993a, b). By drawing on prior evaluations of available options, we suggest that all of the stakeholders in the Canadian water sector should be able to screen pertinent options, and should be able to identify appropriate candidates for further consideration.

To illustrate this screening process, for each stakeholder in the three cases, Table 5 presents example adaptation measures — one that satisfies the criteria, and one that does not. For example, water conservation and improvements in efficiency of water use already have been identified as important in the municipal sector in Ontario, and in irrigation agriculture in southern Alberta. Water conservation and demand management promote efficient use of water and the user-pays principle, reduce stress on the environment and reduce vulnerability to predicted changes, and are consistent with existing initiatives by municipalities, irrigation districts, provincial governments, and the federal government. Therefore, water conservation is an appropriate adaptation option that should be high on the agenda of these stakeholders. In contrast, major capital projects such as pipelines or new storage reservoirs are expensive, increase vulnerability (by promoting maladaptive behaviours), have the potential for significant environmental impacts, and represent a form of subsidy. Therefore, in terms of the near future (and perhaps even the long-term), such measures are inappropriate.

Table 5
Applying the criteria — selecting adaptation options that can be implemented in the near term (next decade)

Stakeholders	Appropriate measures	Inappropriate measures
Municipal water supply in the Grand River Basin		
Municipal officials	Establish contingency plans for reduced water supplies	Seek alternative water sources (e.g., Great Lakes pipeline)
Households	Adopt water conservation practices in the home	Allow lawns and gardens to wither
Industries, commercial firms and institutions	Recycle water used in cooling and processing	Tolerate increased inconvenience and production losses
Provincial government (Ontario)	Enhance conflict resolution mechanisms in the water allocation system	Change *Building Code* to require mandatory retrofitting in existing structures (e.g., water-efficient fixtures)
Grand River Conservation Authority	Examine operational plans for reservoirs	Construct additional storage reservoirs
Federal government	Promote water conservation	Tax write-offs for business losses due to water shortages
Irrigation in Southern Alberta		
Irrigation farmers (district or private)	Improve irrigation water use to reduce waste (e.g., scheduling)	Increase pumping capacity and relocate intakes (private irrigators)
Irrigation districts	Promote efficiency and proper water use practices among water users	Upgrade canals and storage infrastructure to increase capacity
Provincial government (Alberta)	Encourage shift from marginal lands to more productive lands	Construct additional on-stream storage reservoirs
Federal government	Promote research into new cultivars, new practices, new technologies	Subsidize infrastructure improvements
Commercial navigation on the Great Lakes		
Shipping companies	Establish contingency plans for interruption of shipping	Adapt shipboard loading and unloading facilities for lower lake levels
Federal governments (Canadian and US)	Improve navigation and warning systems to allow selection of alternative routes	Regulate Lakes Michigan–Huron and Erie
Provincial and state governments	Regulate encroachments in connecting channels that impact lake levels	Subsidize local businesses dependent on the shipping industry

Once stakeholders have identified suitable options, consideration of one other issue is appropriate: coordination. Smith et al. (1996) have suggested that coordination — ensuring that measures selected are consistent with mitigation and adaptation measures pursued in other sectors, or that they make it easier to pursue mitigation or adaptation in other sectors — should be a selection criterion. We argue, instead, that stakeholders within each sector will have sufficient difficulties screening options using the criteria outlined above — without adding the need simultaneously to monitor the choices being made by all stakeholders in other sectors. Therefore, the kind of coordination that Smith et al. (1996) advocate may be more appropriate for many stakeholders *after* they have tentatively identified options appropriate to their own needs.

10. Conclusion

While the emphasis in this paper has been on practical measures for the near term, it is appropriate to end with consideration of a longer time horizon. It is desirable for stakeholders in all water sectors to anticipate possible consequences of climate change, and to consider these consequences in decisions that influence the way water is used, and where it is used. A desirable long-term objective is for all stakeholders to make decisions that reduce vulnerability to climate change and variability. This means, for example, that economic development decisions should be evaluated not just in terms of short-term political gain, or in the context of job creation, but also in recognition of their implications for water. For instance, a decision to attract a water consumptive industry to a water short area has significant long-term consequences. Not only will that industry potentially be in that location for a long time, but also that industry may attract ancillary development that places additional stress on water resources. This moves consideration of the impacts of decisions on water resources out of the realm of the immediate stakeholders discussed in this paper, to a broader range of people who do not currently take account of the impact of their decisions on current water resources, let alone probable climate-induced changes in these resources.

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