CLIMATE VARIABILITY, CLIMATE CHANGE AND WATER RESOURCE MANAGEMENT IN THE GREAT LAKES

ROB C. DE LOË AND REID D. KREUTZWISER

Department of Geography, University of Guelph, Guelph, Ontario, Canada, N1G 2W1

Abstract: Water managers always have had to cope with climate variability. All water management practices are, to some extent, a response to natural hydrologic variability. Climate change poses a different kind of problem. Adaptation to climate change in water resource management will involve using the kinds of practices and activities currently being used. However, it remains unclear whether or not practices and activities designed with *historical* climate variability will be able to cope with *future* variability caused by atmospheric warming. This paper examines the question of adaptation to climate change in the context of Canadian water resources management, emphasizing issues in the context of the Great Lakes, an important binational water resource.

1. Introduction

While the emphasis in the climate change policy field remains predominantly on mitigation, issues relating to adaptation are receiving much more attention and credibility. Important steps along the way include reports from the Intergovernmental Panel on Climate Change (IPCC) (Carter et al., 1994), and the recent *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies* (Feenstra et al., 1998). Given that a scientific consensus has formed around the idea that some level of climate change is inevitable, this attention to adaptation is appropriate. The challenge for individuals, corporations, and governments is to determine what kinds of adaptations are warranted. The range of choice in most areas is extensive, and includes changes in behaviour, technological developments, and changes in laws and policies — each with associated costs and benefits. Not all possible adaptations are desirable, as the costs of using them may exceed the benefits that will be derived.

The purpose in this paper is to examine adaptation in the context of water resources. Changes in the characteristics of water resources due to climate change will have dramatic impacts on both human and natural systems. Considerable progress has been made in recent years in identifying issues, exploring alternatives and specifying criteria for the investigation and adoption of adaptation measures for water resources management. This paper brings together key themes reflected in the literature and highlights important issues. The emphasis moves from a broad examination of adaptation in water management to a more focused exploration of climate change and water management in the Great Lakes basin. Along the way, issues, frameworks, and criteria for adoption are discussed.

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2. Adaptation to Climate Change in Water Resources Management

Any discussion of adaptation to climate change should begin by acknowledging two key points: (1) climate always has been variable, and (2) human societies always have had to deal with this variability. In other words, adaptation of human activities to predicted changes in climate caused by atmospheric warming will be, at some level, like existing adaptations to climate. As Burton (1996) and Smithers and Smit (1997) note, examples of adaptation to climate are all around us, in the form of building codes, transportation system design standards and agricultural practices.

Acceptance of these points does not constitute a basis for complacency. First, Burton (1996) reminds us that there is a difference between adaptation to climate (which is ages old), and adaptation to climate change (which is relatively new). He notes that commonplace adaptations to climate such as building codes usually treat climate as being stable over decades. Therefore, existing adaptations may not be adequate for anticipated climate changes. Second, Frederick and Major (1997) note that considerable uncertainty exists regarding not only the timing and magnitude of global changes, but also the impacts of these changes at the basin and watershed scales — which are most pertinent for water resources managers. Even small changes in temperature and precipitation are likely to have significant impacts on the hydrologic cycle.

These two considerations lead to a critical question: are existing practices and standards for water management already capable of dealing with anticipated future conditions, or should some proactive modification of current practices, and pursuit of additional adaptation measures, occur? As the Task Force on Climate Adaptation notes, "Even in the event of sudden changes or surprises in climate, perhaps relating to the reaching of some critical threshold or shift to a new equilibrium, ecosystems and human activities are sure to adjust somehow— *but in what forms and at what costs are essentially unknown*" (Smit 1993, 6; emphasis added).

Adaptation can take many forms (Smithers and Smit 1997). Smit et al., (this volume) propose an anatomy of adaptation which highlights key issues and concerns. These include the difference between "adaptations" and "adjustments"; the kind of adaptation (i.e., institutional, technological); the scale of adaptation; and the extent to which adaptation is reactive versus anticipatory.

For the purposes of this paper, the broad vision of adaptation advocated by Smit et al., (this volume) is adopted: any adjustment in a system in response to climate stimuli. For purposes of organizing adaptations in the context of Great Lakes water management (below), a framework used by researchers who have studied adaptation in extreme events (e.g., Kates 1985) is used. This framework is widely used by those interested in adaptation to climate change (e.g., Burton et al., 1998; Hofmann et al., 1998). It places adjustments to extreme events in three main categories: (1) loss bearing (bear the loss or share the loss), (2) reducing the loss (prevent the effects or modify the effects), and (3) avoiding danger (change locations or uses). These categories are used later to organize adaptations in the context of Great Lakes water management.

2.1. WATER RESOURCES MANAGEMENT AND CLIMATE VARIABILITY

Water users and managers understand that climate is variable, both spatially and temporally. In Canada, mean annual precipitation ranges from less than 100 mm in the high Arctic, 500 mm in parts of the Prairies, 900 over much of southern Ontario, to over 3,500 mm along the Pacific coast. Mean annual runoff generally corresponds to this pattern, ranging from less than 50 mm on the southern Prairies, 200 to 450 mm across southern Ontario, to over 2,000 mm along portions of the Pacific coast (Ontario Ministry of Natural Resources 1984; Laycock 1987). While no national inventory of groundwater yield exists, most aquifers are small and relatively shallow (Pearse et al., 1985), and yields are highly variable (Singer et al., 1997).

Considerable temporal variability in streamflow is also evident. Reliable annual flow (flow equaled or exceeded, on average, in 19 years out of 20) ranges from about 32% of mean flow on the southern Prairies to about 75% to 80% of mean flow in the northern, Atlantic and Pacific regions of Canada (Pearse et al., 1985). Reliable seasonal flow (flow which is equaled or exceeded, on average, in all but one season out of 20 years) ranges, across the country, from less than 5% to about 70% of mean annual flow (Pearse et al., 1985). High annual flows are typically about one-third higher than mean flow, but monthly, daily and instantaneous flows can be many times higher. During the June 1964 flow on the Oldman River, in southern Alberta, instantaneous discharge was 2,090 cms — over six times the June mean flow, twenty-four times the mean annual flow, and close to one thousand times the minimum daily flow recorded (Environment Canada 1973; 1989).

Recognition of this *normal* variability is evident both in the technological and institutional dimensions of water management. On the institutional side, allocation systems have been tailored — usually after considerable trial and error — to reflect local circumstances. Hence, on the Canadian prairies, the unsuitability of the riparian system was recognized early; riparian rights were abolished before the turn of the century and replaced with a prior appropriation system. In humid Ontario, in contrast, riparian rights continue to exist, but alongside a legislated permit system (Percy 1988).

On the technological side of water management, structures are built and operated according to engineering standards that take into account variability in precipitation and runoff (Riebsame 1988). Thus levees that protect flood-vulnerable developments are built to withstand a certain "design flood"; dams and reservoirs for irrigation water supply are designed according to certain expected levels of streamflow; and municipal water supply systems are built with particular drought frequencies in mind. The operation of these structures typically can be altered to adjust to changes in hydrologic conditions— but only up to a point.

In the context of climate change, the key question is: to what extent are current practices and standards in water management appropriate for adaptation to *future* changes in the hydrologic cycle caused by atmospheric warming, in particular, changes in *variability*? Some analysts are confident that current practices and standards may be adequate in certain areas. For instance, Boland (1997) argues that water conservation measures will be able to address the impacts of climate change by 2030 in the Washington Metropolitan Area. Stakhiv (1996, 261), also referring to the United States, concludes that water resources management is "relatively robust and resilient to the range of anticipated effects of climate change." This reflects the fact that the U.S. has a relatively well-integrated water management system — something which cannot be said for all regions of the world (Frederick and Major 1997).

While optimism about the ability of certain aspects of well integrated water management systems to adapt to climate change may be appropriate, concern— and attention to the range of possible adaptation measures — is warranted for two reasons. First, as Burton (1996) points out, historical adaptation to climate has proceeded on the assumption that climate is relatively stable from decade to decade. Variations in temperature, precipitation, runoff, etc., are considered variations about a relatively stable mean. Hence, in planning and designing both infrastructure and institutional arrangements, water managers tend not to have addressed the possibility of different climate regimes— especially ones that occur not gradually, over many decades, but rapidly due to threshold changes or shifts to new equilibria. Consequently, dams and reservoirs designed with current variability in mind may be over- or under-capacity relative to future variability. On the institutional side, the same is true for water allocation systems. Second, in Canada, at least, and most likely in other countries around the world, water management is not fully and satisfactorily adapted to climate variability now. It is true, as Stakhiv (1996) points out, that measures counted as adaptations to climate change are being implemented in some places simply as improvements to water management — without regard to climate change. However, in Canada the implementation of these measures is not occurring everywhere. Recent cut-backs in federal and provincial water management activities suggest that, for the foreseeable future, the capacity to implement these measures is in question.

Therefore, it remains appropriate to consider the need to adapt specifically to climate change in the area of water management. A wide range of adaptation options exists (Nuttle 1993; Riebsame 1988; de Loë and Mitchell 1993; Smit 1993;

Smith 1996; Smith and Lenhart 1996; Stakhiv 1996; Hofmann et al., 1998). A few of these measures include the following:

- For flooding: restricting development on floodplains; constructing or upgrading flood storage reservoirs; and providing flood insurance.
- For drought: changing reservoir operating rules; making marginal increases in the size of planned infrastructure; and preparing contingency plans.
- For water quality: controlling point and non-point discharge of wastes; and augmenting streamflow during low flow events.

A detailed examination of adaptation measures relating to water management is provided in section 3, where the Great Lakes case is examined. However, at this point it is important to emphasize that none of these "adaptations" represents an adaptation to climate change, *per se*. Every one of the measures has been used to respond to "normal" hydrologic variability.

2.2. SELECTING APPROPRIATE ADAPTATIONS

Identifying a range of possible adaptations is only the first step. Vastly more challenging is deciding which, if any, of the adaptation measures identified should be implemented. Various efforts to systematize a process for selecting adaptations exist, such as the IPCC Guidelines (Carter et al., 1994) and related approaches (e.g., Smith 1996; Feenstra et al., 1998). Other approaches also exist. Frederick et al. (1997) adapt standard water planning criteria. From a policy perspective, de Loë and Mitchell (1993) use a survey of water users and managers in the Grand River basin, Ontario, to identify and assess measures that could be adopted now to adapt to future climate changes. Smith et al., (1996) bring together, under one cover, various assessments of adaptation options in developed and developing countries.

Many writers emphasize the importance of developing criteria for the selection of adaptation measures. For instance, Smith (1996) proposes that anticipatory adaptation measures should be emphasized now. Often an anticipatory adaptation implemented now can lay the foundation for subsequent reactive adaptations. For example, moving towards full-cost pricing for municipal water supply now will allow for adjustments in reaction to changes in water availability in future. Smith and Lenhart (1996) propose that anticipatory adaptations should be flexible, and that the potential for benefits should exceed costs. They add that the net benefits of adaptations should occur independent of climate change. Adaptations such as these are referred to as "no regrets" measures. They are sensible measures which can be justified with respect to *existing* circumstances, but which also constitute adaptations to climate change. Water conservation measures are an excellent example. They respond to an existing problem (e.g., supply limitations, the need to defer construction of new plants)— and reduce vulnerability to future climate changes. Mortsch and Mills (1996) suggest a broad range of useful criteria, which address these kinds of considerations, but include others (see, for example, Table 1). These are used in section 3 to examine water management adaptations in the Great Lakes Basin.

Table I
Criteria for assessing climate adaptations [Source: Mortsch and Mills (1996)]

Economic feasibility and efficiency	How much will it cost? Who pays? Who benefits? What is the net benefit? Is there efficient use and allocation of resources? What is the economic risk and who bears it?
Technical feasibility	Is the technology available? Can the technology be developed? How much time is required to develop the technology and implement the adaptation?
Social acceptability	Is there consensus? Does it reflect societal wants, goals, values? Is the social capacity there? What is the net social benefit? Who will be affected? What are the distributional effects?
Legal ceptability	What is the statutory and regulatory framework? Are there any ac- laws, agreements, regulations or policies promoting maladaptive behaviour or preventing the adaptation?
Political realism	Are there the necessary political conditions? Are elected political representatives supportive? Is the electorate supportive?
Environmental sustainability	Will environmental resources and services be protected? Will the environment be impaired to the detriment of future generations? Will the complexity and resilience of ecosystems be maintained?
Institutional acceptability	Does the required institutional structure exist? Can existing institutions implement it? Is there sufficient Jurisdictional authority and power? Is there institutional responsibility and interest?
Flexibility	Are a wide range of alternative responses left open? Does this option prevent adoption of other corrective actions in the future? Is the adaptation measure irreversible?

3. Adaptations for Water Resources in the Great Lakes Basin

The Great Lakes are a vast, multifaceted, binational water resource. They contain almost 20 percent of the world's fresh, surface water. The five Lakes, and their connecting channels, are bounded by 18,000 km of shoreline. In addition to numerous ecosystem functions performed, including fish and wildlife habitat, the Lakes provide drinking water for millions of Canadians and Americans, processing and cooling water for industries and thermal generating plants, and are used for commercial navigation and recreational boating. Connecting channel flows generate hydropower. Beach and wetland recreation, riparian residential development, sport and commercial fishing, and waste assimilation are other significant uses. All of these resource uses are impacted by current fluctuating levels and flows — and will be impacted by changes produced by atmospheric warming.

Binational body constituted under the *Boundary Waters Treaty* of 1909. It plays a major role in the resolution of transboundary water disputes and issues.) Government and IJC studies have recommended non-structural adaptations to fluctuating lake levels, including shoreline management or emergency measures, rather than major additional hydrologic interventions, such as diversions or lake regulation structures. It should be noted that the levels of Lakes Superior and Ontario have been regulated by control structures on their outlets since 1921 and 1960, respectively. These control works are for hydropower and navigation purposes. Additionally, limited volumes of water are diverted into the Great Lakes, at Ogoki and Long Lac (Lake Superior), and out of the Lakes at Chicago (Lake Michigan). These interventions are important in that, among other things, they represent infrastructure that have been used to bring a *modest* degree of mitigation of extreme levels on a portion of the Great Lakes system, and, from the perspective of *some* resource users, possible justification for additional hydrologic intervention as an adaptation to climate change.

3.1. IMPACTS OF CLIMATE CHANGE ON GREAT LAKES WATER USES

The possible impacts of climate change on Great Lakes levels and flows have been a concern for more than a decade (Bruce 1984; Cohen 1986; Sanderson 1988). Various scenarios have suggested considerably lower mean Great Lakes levels, and an increased frequency of extreme low levels, due largely to higher rates of evaporation and evapotranspiration with warmer temperatures (Sanderson 1988).

The Canadian Climate Centre General Circulation Model (CCC GCM) has been used to generate climate scenarios for the Great Lakes basin under $2xCO_2$ conditions, which could arise by the year 2030. This second generation model, with greater spatial resolution than earlier models, suggests the following changes: over land precipitation down 2%; evapotranspiration up 22%; basin runoff down 32%; and, over lake evaporation up 32% (Croley 1991). As a consequence, net basin supply could decline 46%.

Under these conditions, long-term mean lake levels would decline 0.23 m on Lake Superior, about 1.3 m on Lakes Erie and Ontario, and 1.6 m on Lakes

Michigan-Huron (Working Committee 3 1993). To put these changes into perspective, the maximum monthly level expected would be only 0.5 to 0.6 m higher than the minimum monthly level recorded for lakes Michigan-Huron and Erie. Significantly, extremely low levels and flows would be experienced much more frequently, with the frequency increasing markedly on downstream Lakes. Calculations based on Working Committee 3 (1993) suggest that while the frequency of extreme low monthly mean levels is expected to increase only slightly on upstream Lake Superior, monthly lows that have been experienced historically about 1% to 2% of the time could be experienced about 42% of the time on downstream Lakes Erie and Ontario. The implications of a substantially lower water level regime would be most pronounced in the shallower areas of the Great Lakes, such as western Lake Erie, Lake St. Clair, and the St. Clair and Detroit Rivers. The surface area of Lake St. Clair, for instance, would be 15% smaller and the shoreline would migrate up to 6 km lakeward (Lee and Hibner 1996).

Changes to the seasonal water level regime can also be expected under $2xCO_2$ conditions. Lavender et al., (1998) suggest that the seasonal variation in levels, historically ranging from an average of 30 cm on Lake Superior to 49 cm on Lake Ontario, would increase considerably on the downstream lakes, but only slightly on Lake Superior. All lakes are likely to experience increased variability in these seasonal fluctuations. The timing of seasonal peaks and troughs may change only on Lakes Michigan-Huron. Peak levels, for instance, may occur more frequently in June than in August.

These hydrologic impacts will, in turn, affect a variety of water resource uses. Despite a lengthened shipping season under a $2xCO_2$ climate, 11 months ice-free on average, Sanderson (1987) estimated that more frequent lower lake levels could increase Canadian commercial navigation costs by 30%. A lower water level regime would adversely impact recreational boaters and marina operators, rendering some marinas temporarily or permanently inaccessible (Lee and Hibner 1996). Increased seasonal variability likely would make it more difficult to predict navigational hazards. Canadian hydropower plants could lose 4,165 gigawatt-hours of relatively inexpensive and environmentally-benign generating capacity, about 25% of Canadian Great Lakes generation (Sanderson 1987). Lower levels and flows would diminish water quality and increase pumping and treatment costs for municipal and industrial water users. Wetland and fishery resources also would be adversely impacted. On the other hand, the capacity of many recreational beaches would be increased and, in some shore reaches, flood and erosion damages to buildings and other structures would be substantially reduced (Levels Reference Study Board 1993). Table II sets out a range of predominantly negative consequences of lower Great Lakes levels and flows on selected water resource uses.

Table II
Impacts of low Great Lakes levels and flows on selected water resource uses

Water Use	Impact of Low Water Levels and Flows	Reference
Municipal and industrial water supply	• reduced intake capacity and increased - International Great pumping costs with loss of head • cost of extensions to water intakes and sewer outfalls • increased water treatment costs due to turbidity from wave action in shallower water • increased risk of frazil ice at intakes cost of substitute water sources	• International Great Lakes Levels Board (1973) • Functional Group 3 (1989)
Commercial navigation	• increased harbour and channel dredging costs • increased navigation hazards and risk of grounding • increased shipping costs due to reduced loads • dry rot of piers and other structures extended shipping season	• International Great (1973) • Sanderson (1987) • Functional Group 3 (1989)
Recreational boating	• increased harbour, marina and channel dredging costs • loss of access to moorings and marinas increased navigation hazards • dry rot of pier and other structures increased boating congestion in deeper waters	• International Great Lakes Levels Board (1973) • Functional Group 3 (1989) • Rissling (1996)
Hydro power generation	• reduced generating capacity • cost of alternative energy sources	• Sanderson (1987) • Irvine et al. (1995)

3.2. ADAPTATIONS TO VARIABILITY AND CHANGE

As noted earlier, adaptations to climate variability in the water resources sector have been commonplace. This is evident for several Great Lakes water uses. Hydropower and commercial navigation have adapted reasonably well to historic variability in water levels and connecting channel flows (Functional Group 3 1989). Power utilities, for example, have extensively interconnected grids and can substitute energy sources when necessary (Irvine et al., 1995). Larger municipal and industrial water users generally have had the resources to design,

Table III

Adaptations to variability and change in Great Lakes levels and flows, for selected water resources uses [Sources: Functional Group 3 (1989); Measures Work Group (1989); Levels Reference Study Board (1993); Smith (1993); Irvine et al. (1995); Rissling (1996)]

Water Use	Change Use (Location, Use)	Reduce loss (Prevent, Modify Effects)	Accept Loss (Share, Bear Loss)
Municipal and industrial water supply	• encourage water conservation (e.g,. low flow fixtures, pricing) • improve efficiency in use of cooling water • relocate major water using industries • recycle water for various uses • regulate water withdrawals	• increase water intake pumping capacity • extend water intakes and sewer outfalls • increase water storage capacity • regionalize water supply and sewer systems	• contingency plan for interruption of shipping • government subsidies for increased operating costs
Commercial navigation	• reduce cargo loads • reschedule shipments to seasonal peak water level • periods manage lock traffic to increase capacity	• install floating docks • dredge harbours and channels • improve navigation markers	• temporarily close marinas • government subsidies for increased operating costs
Recreational boating	• relocate marinas • regulate boating (e.g., zone restricted areas) • switch to shallower draft boats	• install floating docks • dredge harbours and channels • improve navigation markers	• temporarily close marinas • government subsidies for increased operating costs
Hydro power	encourage energy conservation (efficient fixtures, pricing) use peak load shifting introduce drought surcharges	• increase pumped-storage capacity • interconnect power grids	• Contingency plan for brown-outs and scheduled black-outs • Government compensation for power interruption • substitute energy sources and shift cost to consumers

build and modify, if necessary, infrastructure to accommodate variability. On the other hand, individual shore property owners and smaller water users, such as marina operators, have been less resilient to variability (Functional Group 3 1989; Levels Reference Study Board 1993).

Table III sets out examples of adaptation measures for several water uses. It is organized according to the hazards adjustment framework promoted by Burton and others (e.g., Burton 1996; Burton et al., 1998) and described earlier. For instance, municipal water suppliers can change water use by applying various conservation measures; improved navigation markers would reduce losses through ship groundings; and power utilities could share lost hydropower generation through contingency plans that might involved scheduled power black-outs.

Not shown in Table III are various hydrologic interventions that would modify the effects of climate change on levels and flows and, hence, work to reduce losses to all the water uses shown in this Table. These interventions include the following: water diversions into the Great Lakes basin; revised regulation (operating) plans for Lakes Superior and Ontario; and, sills and control structures in the outflow channels of Lakes Michigan-Huron and Erie (Measures Work Group 1989). Sills are structures that raise the bed of a connecting channel, thereby creating a higher water level regime on the upstream lake.

3.3. EVALUATING ADAPTATION MEASURES

The measures shown in Table III, and the various hydrologic interventions described above, have been used or could be used to adapt to fluctuating Great Lakes levels and flows. However, it is important to ask whether or not these adaptations are capable of dealing with a substantially altered hydrologic regime similar to that suggested by the CCC GCM 2xCO_2 scenario. This question has not been explored extensively in the literature. Stakhiv (1996), in reviewing the implications of several climate change scenarios, suggests that municipalities and other jurisdictions in the Great Lakes basin have the capacity to adapt incrementally and cost-effectively to climate change, because change will be gradual. As noted earlier, it is not yet clear that change will be gradual; a rapid shift to a new regime is possible. Furthermore, review of work for the International Joint Commission's six-year Levels Reference Study, and consideration of institutional and other constraints to adaptation, leads us to be less optimistic that stakeholders in the basin have the capacity to adapt incrementally and cost-effectively. The Levels Reference Study provides some insights into water use adaptiveness to fluctuating levels and flows.

Despite the resiliency of power utilities to historic hydrologic variability, Price et al., (1989) found no evidence of any proactive adaptation to climate change. Irvine et al., (1995) noted that none of the structural hydrologic interventions evaluated in the Levels Reference Study would do much to maintain hydropower generation capacity. They suggested that attention should be focused on drought contingency planning and conservation measures.

Many investment decisions related to recreational boating, such as marina construction and expansion, have been made since the late 1960s, during above average lake level conditions, in response to the increased popularity of sailing and other boating (Functional Group 3 1989). Many of these decisions were not mindful of historic variability, and certainly not anticipatory of the possibility of substantially lower lake levels — especially if these occur precipitously.

Some previous commercial navigation investments not only ignored the possibility of an altered hydrologic regime, but also can be viewed, in hindsight, as significant maladaptations to climate change. Dredging of the St. Clair and Detroit Rivers in the 1930s and 1960s, for instance, was not compensated for with fill or other channel obstructions. The net effect of navigation improvements has been a permanent lowering of Lakes Michigan-Huron by about 40 cm (Levels Reference Study Board 1993).

A climate change scenario was developed for the Levels Reference Study (Working Committee 3 1993). However, the Study's evaluation of measures that could be adopted in response to fluctuating Great Lakes levels and flows did not explicitly assess the impacts of measures under climate change conditions. Rather, level and flow conditions under various lake regulation schemes were compared to historical variation in levels and flows, and criteria of distribution of impacts, economic benefits and costs, environmental effects, and feasibility were applied (Levels Reference Study Board 1993).

The evaluation criteria set out in Table 1 can be applied to any adaptation measure to yield critical insight into the consequences of the adoption of that measure. Because of the complexity of the Great Lakes as a hydrologic system, the diversity of water resource uses and ecosystem functions, and the distribution and varying sensitivities of these uses and functions throughout the Great Lakes, the assessment of adaptation measures is a daunting task. The Levels Reference Study Board (1993) undertook a major assessment of a wide range of measures to alleviate the adverse consequences of fluctuating water levels. Included were a number of water level regulation schemes, various shore protection alternatives, and a variety of land use planning measures.

For example, the assessment of three lake regulation (Superior, Erie and Ontario), in the context of historic variability in levels and flows, revealed that this measure, while technically feasible, would be grossly inefficient and environmentally damaging, particularly to shore wetlands (Levels Reference Study Board 1993). Riparian property owners on the Lakes would benefit substantially, but hydropower interests would lose. Inequitable distributions of benefits and costs within specific resource use sectors also would occur. Canadian commercial shippers, for instance, would be winners, while American shippers overall would lose. Climate change, which will have a greater impact on downstream

Lakes, would sharpen some of these inequities. These distributional inequities challenge the social acceptability, and even the political realism, of further regulation of lake levels (Table I). The flexibility of hydrological interventions to respond to a changing hydrologic regime also warrants scrutiny. Deviations from current operational plans for control structures on the outlets of Lakes Superior and Ontario, and adjustments to diversions into and out of the Great Lakes basin, are technically feasible responses to water level extremes of varying effectiveness. However, inequities in the distribution of impacts and institutional constraints to implementation, especially concerning inter-basin water diversions, have been cited (Levels Reference Study Board 1993).

In its report to the International Joint Commission, the Levels Reference Study Board (1993) developed a set of guiding principles to be used by the Commission to enhance management of future water levels issues. These included respecting the full range of interests of affected parties, and full recognition of the potential for reduced water supplies due to climate change. The Commission did not accept these guiding principles in its report to the federal governments, noting that the principles differed in "some fundamental respects from those found in existing international agreements such as Article VIII of the Boundary Waters Treaty" (International Joint Commission 1993, 4). This represents further evidence of important concern about institutional and other constraints to adaptation.

3.4. CONSTRAINTS TO ADAPTATION

Numerous constraints to adoption of adaptation measures are embedded in the evaluation criteria set out in Table I. Scale is one of several characteristics of adaptation measures, described by the Task Force on Climate Adaptation (Smit 1993), which has implications both for the assessment and implementation of measures. The Task Force noted that adaptations accepted by individuals may in fact constrain adaptation by society. In terms of institutional arrangements, measures feasible at a senior government level may be infeasible adaptations at a local government level, for reasons such as insufficient jurisdictional or legal authority.

While technical and economic constraints may be overcome, given sufficient resources, some of the more challenging constraints to climate adaptation may relate to perceptions and attitudes, and to institutional arrangements. With uncertainty surrounding anticipated climate change, the historic hydrologic regime may be a more powerful influence on decision-making. And, because the Great Lakes are a binational water resource, jurisdictional constraints will make certain basin-wide measures very difficult to implement. The following examples serve to illustrate this point.

- The role of the Boundary Waters Treaty of 1909 has already been noted. This Treaty empowers the International Joint Commission (IJC) to regulate works, on either side of the boundary, which would adversely impact interests on the other side. Additional diversions of water into or out of the Great Lakes, for instance, may be very difficult to achieve. In its decisions, the IJC is bound by a priority of interests set out in the Treaty — domestic and sanitary purposes first, followed by navigation, and then by power and irrigation purposes. Environmental, recreational and riparian property interests are not recognized in the Treaty.
- The Chicago Diversion, an existing work exempted in the Boundary Waters Treaty, is controlled by a U.S. Supreme Court decree and, as such, is largely out of the hands of both federal governments and the IJC.
- The Niagara River Treaty of 1950, which apportions water for hydropower and preservation of the scenic character of the Niagara Falls, limits the ability of power utilities to adapt to low flow conditions.

4. Conclusion

Water management always has been concerned with adapting to climate *variability*. The challenge now is to address climate *change*. A key question is: to what extent are current practices and standards in water management appropriate for adapting to *future* changes in the hydrologic cycle caused by atmospheric warming? Many of the current practices constitute appropriate kinds of adaptations. At issue, though, is whether or not additional proactive measures are required. Recent studies suggest that highly integrated water management systems, such as are found in the U.S., may be capable of adjusting to predicted changes (Stakhiv 1996; Boland 1997). However, it is less certain that this is the case in Canada, especially in a binational system such as the Great Lakes. Furthermore, optimistic scenarios for adaptation typically assume gradual changes, when in fact rapid shifts also are possible.

Some adaptation can occur by adjusting the operating rules of structural works, and by continuing to promote the use of non-structural approaches, such as demand management. However, legal, political and technical problems exist, which constrain the amount of adaptation that can take place within the existing system. Consequently, it is appropriate to address climate change in current and future activities. A key challenge is determining the nature and type of adaptation that is appropriate, relative to particular water management contexts. Numerous criteria for evaluating adaptations exist, including flexibility, economic efficiency, legal acceptability, etc. Related to this, it is necessary to determine when certain adaptations should be pursued. The inherent uncertainty associated with climate change complicates this process, but this uncertainty is not significantly different from other sources of uncertainty (e.g., changes in population, demand, economic activity) (Frederick et al., 1997). In the context of the Great Lakes basin, major structural adaptations do not appear warranted or desirable at this time. However, it certainly is appropriate to plan for reduced levels and flows. It is especially appropriate to pursue the "no regrets" adaptations, which can produce benefits regardless of the nature of climate-induced changes that affect the hydrologic cycle.

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