Climate Change: Practising Adaptive Management for Sustainability of Canadian Water Resources

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SUSTAINABLE DEVELOPMENT AND WATER RESOURCES

Sustainable development became prominent with the publication of the Brundtland Report in 1987. In 1992, leaders of some 150 countries at the United Nations Conference on Environment and Development (UNCED) agreed on two conventions with implications for water: Climate Change and Biodiversity. These leaders also adopted a blueprint for sustainable development called Agenda 21, which contained a chapter devoted to water (Bruce and Mitchell, 1995).

In Canada, virtually all governments have identified sustainable development as the overriding framework for water management. At the same time, considerable ambiguity exists regarding sustainable development, both at conceptual and operational levels (Mitchell and Shrubsole, 1994a; Biswas, 1996). Mitchell and Shrubsole (1994a; 1994b) have identified a number of themes to achieve water management consistent with sustainable development objectives. This chapter will focus on how one of these themes, adaptive management, can be used to address the threat of global climate change.

GLOBAL CLIMATE CHANGE

Scientists have recognized that concentrations of greenhouse gases in the atmosphere such as water vapour (H₂O), carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) are transparent to solar energy which reaches the Earth’s surface where it is absorbed, but trap, in return, most of the heat radiation re-emitted by the Earth’s surface into the atmosphere. Together with clouds, these gases provide an insulating blanket around the Earth, keeping it warm. Without this natural Greenhouse Effect, the Earth’s temperature would be -18°C, or 33°C colder than it is now (Hengeveld, 1995).

The Balance of Evidence

However, since the beginning of the Industrial Revolution 200 years ago, a rapidly expanding human population has added more greenhouse gases
(GHG) to the atmosphere. Increases in GHG concentrations raise global temperatures by "enhancing" the natural Greenhouse Effect (i.e., increasing the radiative forcing).

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations organization responsible for developing consensus assessments of the scientific and technical aspects of climate change. The IPCC concluded in its Second Assessment Report that observed trends over the past 100 years are beyond those expected from natural variability, such that "The balance of evidence suggests a discernible human influence on global climate" (IPCC, 1995). There is clear evidence that human activities are increasing GHG concentrations with measured increases of CO₂ (+30%), CH₄ (+145%), and N₂O (+15%) since pre-industrial levels (IPCC, 1995). Mean global temperatures have increased by 0.3°C to 0.6°C, with the greatest warming in the Northern Hemisphere and in high latitudes (IPCC, 1995). Together with recent evidence from aerosol effects, these patterns of change agree with climate model results suggesting that human activities are in part responsible for the recent warming trend (Santer et al., 1996).

CLIMATE CHANGE, HYDROLOGY AND CANADIAN WATER RESOURCES

Climate change will significantly impact hydrology and water resources on global, national and regional scales. The following section identifies possible climate change impacts for Canada.

Climate Change Impacts on Hydrology and Water Resources in Canada

Climate and water are closely linked since the global energy balance drives the distribution of moisture through precipitation and evaporation. As a result, direct climate change impacts are expected in the hydrologic cycle. Past climate change impact assessments suggest significant regional and temporal changes in evapotranspiration, runoff, lake levels, soil moisture, groundwater, snow and ice storage, and sea level rise. These changes are highlighted in Table 5.1.

The greatest impacts of climate change will likely be caused by increased frequency and intensity of extreme events, rather than gradual temperature changes (Hengeveld et al., 1995). During the past decade, insured economic losses due to major weather-related disasters have increased dramatically around the world. Climate change is expected to exacerbate extreme conditions that can lead to flooding and drought. Recent studies suggest an overall decline in the number of lows or cyclones which cause precipitation but an increase in the frequency of intense cyclones. Thus, a larger percentage of rain may fall as heavy downpours (Whetton et al., 1993; Lamb. 1995).

Wetlands in Canada are rapidly disappearing due to land use changes and their quality is also being affected by pollution. Climate change is another stressor which can affect wetlands through increases in air temperatures and a rise in sea level (Rizzo and Wiken, 1992; Vitousek, 1994). Wetland location, areal extent, productivity and diversity are vulnerable to changes to the hydrologic cycle.

Table 5.1: Summary of Hydrologic Impacts Assessed in Canadian Impact Studies using Various Climate Change Scenarios*

<table>
<thead>
<tr>
<th>Component</th>
<th>Impact</th>
<th>Area Studied</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation/ Evapotranspiration</td>
<td>increases</td>
<td>Great Lakes; Mackenzie R. Basin; Grand R., Ont.</td>
<td>Croley, 1990, 1993; Cohen, 1987; Soulis et al., 1994; Sanderson and Smith, 1993</td>
</tr>
<tr>
<td>• minimum increases duration and frequency earlier; maximum not as high</td>
<td>Great Lakes; Saskatchewan R.; Mackenzie R.</td>
<td>Croley, 1990, 1993; Cohen et al., 1989; Cohen, 1986, 1987; Soulis et al., 1994; Singh, 1987; Ng and Marsalek, 1992; Morin and Slivitzky, 1992; Smith, 1991; McBean and Smith, 1993; Hues and Marta, 1998; Kerr, 1996</td>
<td></td>
</tr>
<tr>
<td>Lake level</td>
<td>• minimum increases duration and frequency; attain all-time lows decreases; earlier seasonal maximum; amplitude decreases</td>
<td>Great Lakes; Great Slave and Great Bear Lakes</td>
<td>Hartmann, 1990; Croley, 1990, 1992; Kerr and Loewe, 1995; Kerr, 1996</td>
</tr>
<tr>
<td>• maximum</td>
<td></td>
<td>Grand R., Ont.; Saskatchewan; Southern Ontario</td>
<td>Sanderson and Smith, 1993; Woo, 1992; Cohen et al., 1998; Bliklach, 1990</td>
</tr>
<tr>
<td>• annual cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil moisture</td>
<td>decreases; summer deficit</td>
<td>Great Lakes; Great Slave and Great Bear Lakes</td>
<td>Hartmann, 1990; Croley, 1990, 1992; Kerr and Loewe, 1995; Kerr, 1996</td>
</tr>
<tr>
<td>Groundwater</td>
<td>• recharge decreases</td>
<td>Grand R., Ont.</td>
<td>McIver and Sudicky, 1991</td>
</tr>
<tr>
<td>• discharge to streams decreases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snowcover</td>
<td>• decreases more intermittent</td>
<td></td>
<td>Cooley, 1990</td>
</tr>
<tr>
<td>Ice</td>
<td>• lake ice ice cover reduced or eliminated; ice cover season reduced</td>
<td>Great Lakes; Mackenzie R.; numerous northern lakes</td>
<td>Assel, 1991; Andres, 1994; Skinner, 1992; Sanderson, 1987</td>
</tr>
<tr>
<td>Saltwater intrusion</td>
<td>sea level rise affects coastal rivers</td>
<td>St. Lawrence R. and Saint John R.</td>
<td>Slivitzky, 1993; Martec, 1987</td>
</tr>
</tbody>
</table>

* Methods of climate scenario development include General Circulation Models (GCMs), historical analogues, hypothetical conditions, climate transposition; various types of models (empirical, water budget) were used to assess hydrological impacts.

Climate change is expected to alter regional hydrologic processes and thus modify the timing as well as decrease the quantity and quality of water supplied to wetlands. Although periodic water level fluctuations are necessary to maintain wetland diversity, the rate of change, the frequency of
extreme events, as well as a decline in water storage associated with climate change could disrupt the functioning of wetland ecosystems and impair their multi-functional values (Mortsch, 1990; Bardecki, 1991; Martinello and Wall, 1993; Poiani and Johnson, 1993a; 1993b).

Permafrost in northern Canada is a major factor in the drainage of water, in the growth of vegetation and in land stability. Woo et al. (1992) summarize a number of environmental consequences of permafrost degradation as a result of climate change. Increases in the erosion of lake, river and reservoir shorelines may be expected as a result of permafrost thawing and a longer open water season. An increase in sediment transport in rivers may also be expected. Sea level rises accompanying climate change could lead to accelerated rates of coastal retreat in permafrost regions, and combined with thaw settlement as permafrost melts, could also result in the inundation of low-lying areas. Permafrost loss due to climate change could also lead to significant disruptions and impacts on northern engineered developments (Nixon, 1990; Lonergan et al., 1993).

ADAPTATION OF CANADIAN WATER RESOURCES MANAGEMENT TO CLIMATE CHANGE

As a concept, adaptation originated in the disciplines of biology and ecology where it is defined as a means of ensuring future survival. In recent years, social scientists have recast adaptation in climatic terms. International organizations such as the IPCC and national climate change action plans recognize the value of adaptation in protecting societies against the vagaries of climate change. One reason for pursuing adaptive responses to climate change is that adaptation makes sense now and is consistent with broader environment-economic sustainability goals (Mortsch and Mills, 1996).

Climate change impacts on water resources will be significant. The question for water resource managers is whether the impacts of climate change will be large enough and will occur rapidly enough to require measures undertaken explicitly to adapt to their effects (Nuttall, 1993). The following case studies illustrate how the principles of adaptive management can be incorporated.

Case Study: Urban Water Use in Canada

Urban water use refers to demands rising from communities which are served by a municipal water supply and distribution system. Canada’s per capita water use is the second highest in the world (Statistics Canada, 1994). Tate (this volume) highlighted characteristics of Canadian urban water use and showed that existing municipal water service practices are not sustainable. Climate change will exacerbate conditions and will require managers to adopt a proactive, adaptive approach in order to achieve sustainable water use in Canada.

An adaptive approach is one which embodies flexibility to deal or adjust to unexpected or uncertain conditions, whether environmental, economic or social in nature. Smit (1993) and Nuttall (1993) define characteristics of “adaptive systems.” The question remains how to actually incorporate climate change into urban water use management practices. Carter et al. (1994) have offered a process for assessing climate impacts and adaptations which could be used by urban water use managers, in consultation with stakeholders. The process consists of seven steps:

1. define objectives,
2. specify important climatic impacts,
3. identify adaptation options,
4. examine constraints,
5. quantify measures and formulate alternative strategies,
6. weigh objectives and evaluate trade-offs, and
7. recommend adaptation measures.

Define Objectives

While it can be assumed that “sustainability” is the vision for urban water management, the term is of little practical use unless specific objectives are identified for a watershed, municipality or region. It is against such objectives that the possible impacts of climate and other variables are assessed. Urban water use objectives may be found within various land use planning documents, servicing master plans, and water management strategies. For example, excerpts from the Grand Strategy Watershed Management Plan for Ontario’s Grand River Basin provide a number of measurable objectives for the year 2021:

The Grand River provides reliable sources of clean, potable water which support urban and rural growth within the watershed.... Fluctuating river flows are controlled to minimize flooding and drought.... The Grand River is now considered a “world-class” recreational fishing river. An ever growing number of visitors enjoy a diversity of water sports such as canoeing, boating and swimming...(GRCA, 1996, 6).

Specify Important Climate Change Impacts on Urban Water Use

Climate change will affect three aspects of urban water use in Canada: the long-term availability of water supplies, future levels of demand, and the longevity and robustness of water supply and distribution infrastructure.

Any changes in the quantity, quality or timing of water supplies could restrict the ability of municipalities to meet future water demands. McLaren and Sudicky (1993) demonstrated that groundwater levels in a southern Ontario watershed could drop significantly in response to climate change. The DPA Group (1986) and FitzGibbon et al. (1993) noted concerns for water quality as reduced supplies increase the relative concentration of pollutants in surface water resources. Managing the supply to increase water quantity or improve water quality could require costly infrastructure upgrades in the form of reservoirs, dams or upgrades to water treatment plants.
Fluctuations in short-term water use may be caused by the occurrence of holidays, water use restrictions (e.g., lawn watering bans), changes in temporary resident populations, tourist visitations, consumer behaviour and changes in climate variables. Together, these variables determine the peak demand which can be expected in any given system, a critical infrastructure design factor. Increases in average and maximum temperature have been associated with increased water use, while greater total rainfall and an increased number of days with rainfall have been related to reduced water use levels (Miaout, 1990; Akuoko-Asibey et al., 1993). Other variables such as potential evapotranspiration, moisture deficit and degrees above a certain threshold temperature have also been examined (Cohen, 1987; Robinson and Cereese, 1993). Cohen (1987) examined the implications of two climate change scenarios on monthly municipal water use for several Great Lakes Basin municipalities. Using regression analysis, the study showed that summer (May-September) water use could increase by approximately 5% to 6%.

Water and sewer infrastructure are designed to endure the climate of a particular region. Mortsch (1995) has identified concerns related to the effect of climate change on extreme events. Under a changing climate, extreme events such as flooding may become more severe or frequent. As a result, damages to water and sewage infrastructure could occur more often than the design limits of such systems are exceeded. This sensitivity is heightened given that much of the water supply infrastructure in large Canadian centres is more than 50 years old (Tate, 1990).

Most importantly, water and sewer infrastructure have been planned and designed to accommodate present ranges of supply and demand. Climate change threatens to alter the basis on which the infrastructure was designed. On the supply side, Lee et al. (1995) have shown that climate change could lower Lake St. Clair and western Lake Erie water levels such that water intake pipes could be exposed. Lamont and Périard (1989) estimated that climate change could increase the water demand for lawn watering requirements in Québec City and Montréal from 20% to 30%, and that this greater requirement for water could not be met by the existing water supply infrastructure.

Identify Adaptation Options

Adapting to climate variability is not a new concept. Historical adjustments, such as implementing lawn watering restrictions to curb peak seasonal water demands, offer a range of tested options which can be examined under climate change scenarios. Potential adaptation response strategies fall into two broad categories: those designed to augment water supplies and those geared to manage demand. Until recently, supply management options have been the preferred solution to meet municipal water needs. Such measures include the development of new reservoirs, well fields and the infrastructure necessary to distribute water to consumers. As recently as 1991-92, local governments were estimated to have spent $2.6 billion on water purification and supply (Statistics Canada, 1994). However, supply options alone will not guarantee reliable water resources under climate change. For example, under severe climate change scenarios tested in Ontario’s Grand River Basin, even large-scale manipulation of water resources may not be able to accommodate future in-stream water needs (Southam et al., 1997).

Rivers and Tate (1990) have made the case for demand management and water conservation in response to climate change. Substantial water use reductions and financial savings can be realized through economic (e.g., realistic pricing) and structural/operational (e.g., metering, retrofitting plumbing fixtures) techniques (Tate, 1990). Tate (this volume) specifies changes to water pricing, such as full cost pricing, which would facilitate sustainable resource management and will often also reduce sensitivity to climate impacts. Kreutzwiser and Feagan (1989) have identified a wide variety of pricing structures which are currently in practice or could be used to curb water demand in Ontario. Many options make sound economic sense even without climate change.

Assessment of Adaptation Options

Steps four through seven taken from Carter et al. (1994), focus on an assessment of adaptation options. Constraints to possible adaptation options can be weighted to become evaluation criteria and used to assess the adequacy of each measure. Criteria could include technical feasibility, economic feasibility, social and legal acceptability, environmental sustainability and, perhaps most importantly given the uncertainty associated with the risks of climate change, flexibility to reverse a measure if climate change scenarios and impacts either fail to materialize or become much more severe than initially envisioned (Mortsch and Mills, 1996). Constructing a large reservoir to provide water to a community may be technically achievable to address reduced supplies in the future, but may not be acceptable due to associated environmental, economic or social impacts. A reservoir is also a much less flexible option than demand-side measures such as plumbing fixture retrofits or the distribution of water conservation education packages. A wide variety of tools and techniques, such as surveys, policy delphis, and simulation modelling, is available to assist water managers in evaluating options.

Trade-offs will inevitably result from the evaluation exercise, most likely between municipal uses and competing water interests (e.g., maintaining environmental or ecological functions). Since trade-offs are resolved by prioritizing uses, goals and objectives, it is essential to involve all of the potential stakeholders in the evaluation exercise to establish a set of recommended adaptation measures.

Implementing Options and Monitoring Results

A final step not explicitly defined by Carter et al. (1994) consists of implementing chosen options and monitoring results. The adaptive approach recognizes that a process be instituted which acknowledges that humans learn through trial and error exercises (Mitchell and Shrubslove, 1994a), that comprehension of climate change is gradual, and that it is a disservice to hide uncertainties associated with climate change impacts from decision makers. The process should be able to accommodate ever-changing visions, priorities, objectives
and knowledge concerning climate change into the future and thus contribute
to a sustainable urban water use sector in Canada.

Case Study: The Great Lakes/St. Lawrence River Basin
The Great Lakes/St. Lawrence River watershed encompasses a drainage
basin of more than one million square kilometres and is populated by more
than 35 million people (Figure 5.1). Each of the five major lakes, Superior,
Michigan, Huron, Erie and Ontario, and the four major connecting river
systems, the St. Marys, the St. Clair/Detroit, the Niagara, and the St. Lawrence
Rivers represent individual and varied hydrologic parts of a complex ecological
system. The St. Lawrence River itself can be further subdivided into four
hydrographic and sub-ecological sectors, each with its own characteristics,
a fluvial section, a fluvial estuary, an upper estuary and a lower estuary.

Hydrologic Impacts of Climate Change
Climate change impacts under transitional and 2xCO₂ climate conditions for
the Great Lakes/St. Lawrence River system can be characterized by two main
elements: (1) significant changes in water supplies to the basin with resultant
reductions in levels of the lakes and flows in the rivers; and (2) increased sea
elevations in the Gulf of St. Lawrence and St. Lawrence River estuaries.

Several climate change studies found that net basin water supplies to the
Great Lakes could decrease by 23% to 51% under 2xCO₂ scenarios. As a
result, water levels in the lakes could decline by more than one metre and
flows in the connecting rivers could be significantly decreased (i.e., by 20%
to 40%) in the St. Lawrence River at Montreal (Smith et al., 1995). Table 5.2
presents mean, maximum and minimum water levels of the Great Lakes and
annual discharges of the St. Lawrence River at Montreal for 20th century
historical conditions and the Canadian Climate Centre GCM climate change
scenario (Levels Reference Study Board, 1993).

Impacts on Interests and Possible Adaptation Measures
A 15 to 30 centimetre drop in Lake Superior water levels will have a signifi-
cant impact on the commercial shipping that uses Superior harbours and
transits the lake, the relatively shallow entrance to the navigation locks at
Sault Ste. Marie and dredged channels through the St. Marys River to Lakes
Michigan-Huron. Other impacts of lower lake levels will be felt by riparians,
habitats, fish, wetlands, spawning spawning rivers, and summer plants on the
St. Marys River at the Soo. As an adaptation response, Lake Superior inter-
ests and the lake level regulation plan will undoubtedly call for outflow
reductions to and below the minimums called for by the current regulation
plan. This would cause significant water level reductions and resultant phys-
ical, social and environmental impacts throughout the St. Marys River and
further reduce water supplies to Lakes Michigan-Huron and the lower lakes.
Additional channel dredging and another control dam and lock structure on the lower St. Marys River may also be called for.

More severe water level and outflow decreases for Lake Superior have been projected by some climate change researchers. Under one climate change scenario, water supplies to Lake Superior may be reduced to the point that evaporation and other losses would exceed inflows, thereby causing Superior to become a terminal lake—that is one without an outlet! (Crole et al., 1995). This extreme condition is unlikely in the short term. However, extremely dry years during transition to 2xCO₂ conditions may generate a call for zero outflow lake regulation actions for over periods of a few months or even a year in order to maintain Superior levels within the 20th century historic range.

Water level decreases of a metre or more on Lakes Michigan-Huron will cause considerable impacts on all shoreline interests. Municipal and industrial infrastructure (e.g., water intakes, sewage outfalls, docks) will require modification to accommodate lower water levels. Commercial and recreational harbour facilities will require significant dredging, dock modification and redesign, and shoreline wetlands and tributary river estuaries over 8,800 kilometres of shoreline will be transformed. The lower lake levels will most certainly generate renewed interest and pressure to construct a water level control dam and/or outflow restricting weirs in the St. Clair River; to reduce or eliminate water diversions out of the lakes (i.e., at Chicago) (Changnon, 1994); and, to consider once again the interbasin transfer of water into the Great Lakes from Hudson Bay tributaries.

The St. Clair River, Lake St. Clair and Detroit River will be severely impacted by reduced water levels and flows. Channel dredging will be demanded by commercial shipping unless this activity is no longer considered viable. As a shallow riverine lake, Lake St. Clair will be particularly hard hit. New shorelines consisting of mud flats several kilometres wide will appear, the sports fishery and the lake’s huge recreational boating community will be decimated, and the lake’s biological productivity and complete ecosystem will be transformed.

Reduced Lake Erie levels will eliminate most concerns about shoreline flooding and erosion and generate low water level problems similar to those experienced on Lakes Michigan-Huron. The call for water diversions and expanded water supplies for municipal, industrial and agriculture uses can be expected. As an adaptive measure, extreme pressure to construct an outflow limiting weir or dam at the head of the Niagara River can be expected. As well, the diversion of water via the Welland Canal for hydropower production at the DeCew plants in St. Catherines, and via the Lake Erie Barge Canal at Tonawanda, will probably cease.

In the Niagara River, the huge Ontario Hydro and New York State hydropower generation plants will operate at significantly reduced loads, and pressure will no doubt be placed on re-negotiating the International Niagara Treaty to reduce scenic flows over Niagara Falls. Lake Ontario interests will probably lobby for changes in seasonal and maybe interannual outflow regulation patterns into the St. Lawrence River through changes to International Joint Commission Orders governing regulation of Lake Ontario levels and St. Lawrence River Seaway flow control structures.

In the St. Lawrence River from Lake Ontario to Quebec City, significant impacts will result from the considerable decreases in flows and water levels. Again, municipal and industrial infrastructure will have to be modified. Recreational boating, which is very important to the local economy of all the St. Lawrence and especially the Thousand Islands region near Lake Ontario, is highly sensitive to low water levels now and would be totally transformed by 2xCO₂ climate change levels and flows. Bergeron (1995) has shown an increase in boating accidents during years of low water levels in 1988 and 1989.

The reduction in St. Lawrence River flows will have a direct and major economic impact on hydroelectric power production at the Moses-Saunders Hydroelectric power plant at Cornwall and the Beauharnois power development at the outlet of Lac Saint-François. Average annual power production at Beauharnois for the 1943-1991 period was 12.4 TWh, representing about 7.2% of the total power production of the Hydro-Quebec power grid. Under climate change scenarios, a 38% reduction in power equating to 4.7 TWh has been projected.

The St. Lawrence Seaway will have to adapt to lower levels in the St. Lawrence from Lake Ontario to Montreal and while currently not sensitive to low levels below Montreal, new navigation works in the lower River may be required (Bergeron, 1995). The Port of Montreal generates about $1.2 billion in commercial activity annually and the economic success of the Port is closely linked to the frequency of low water levels (Bergeron, 1995). An average annual reduction in river flow of about 3,100 m³/s would potentially reduce the range of Montreal Harbour levels by about 1.25 metres. This would have a catastrophic effect on overseas commercial navigation into the Port of Montreal. An analysis of the historical low flows of the 1930s and 1960s, under present Lake Ontario regulation conditions, shows that during five years in the 1930s and four years in the 1960s the mean weekly level at the Port was below chart datum for as long as 28 and 32 weeks, respectively. Under a 2xCO₂ condition, the average annual flows and water levels could be lower than the historical minimums. The impacts and adaptation measures could be dramatic, including unprecedented channel dredging, and structural dams and navigation locks below Montreal that could totally transform the River.

Downstream of Montreal, Lac Saint-Pierre currently supports a large commercial freshwater fishing industry, with 1992 landings of 572 tonnes and a commercial value of $1,700,000 which represented 60% of total fresh water catches in the St. Lawrence corridor (St. Lawrence Center, 1996). High water levels in the spring helps fish to swim upstream to their spawning grounds at mouths of rivers and ensures sustained productivity. Decreases in spring flows of about 5,000 m³/s will reduce the high water levels by about 1 to 1.4 m and prove very damaging to the productivity of freshwater fisheries.

Below Quebec City, in the upper and lower estuaries and in the Gulf of St. Lawrence, the main impacts will come from the reduction of freshwater inflows as large as 3,000 to 5,000 m³/s and the projected rise in sea level. The first area which will be affected is the mixing zone, in the upper estuary, where the freshwater inflow plays an important role in the circulation and
sedimentation regimes. In the lower St. Lawrence estuary and Gulf of St. Lawrence, some studies have pointed to the importance of the freshwater inflows to circulation patterns and biological productivity. However, no specific studies have examined possible impacts of the large freshwater inflow reduction on an annual and seasonal variation basis. Before thinking in terms of adaptation strategies for this region, more detailed knowledge of the various physical and biological impacts of these climate change effects, and identification of species that might be affected and monitoring of possible effects, is needed.

Case Study: Mackenzie River Basin

The Mackenzie River Basin, including parts of British Columbia, Alberta, Saskatchewan, Yukon and Northwest Territories, covers an area of 1.8 million square kilometres and is Canada's largest drainage basin (Figure 5.2). This area has experienced a warming trend of 1.5°C this century and there is some evidence that this has led to permafrost thaw and lower lake levels in some areas. This does not necessarily mean that the "signal" of human-induced "global warming" has been detected, but it does demonstrate that the Mackenzie region is sensitive to current climate variation. Some have suggested that this region, with its current warming trend, may provide an early indicator of climate change impacts, analogous to the "canary" in the mine.

Impacts of Climate Change

When compared to the observed warming trend, scenarios of climate change from increased greenhouse gas concentrations suggest a more rapid increase in temperature. Outputs from GCMs of the atmosphere indicate that this region would warm by 4 to 5°C by the middle of the 21st century (Cohen, 1993). What impacts would result from these scenarios? If science could provide some answers to this "what if" question, how would stakeholders respond to the "so what" and "what should be done" questions?

The objective of the Mackenzie Basin Impact Study (MBIS) was to produce an integrated regional assessment of climate change scenarios for the entire watershed, including terrestrial and freshwater ecosystems and the communities that depend on them. This 6-year research collaborative was initiated by Environment Canada in 1990. The MBIS attracted research participants from many disciplines, and provided full or partial support for 19 projects, while another 11 projects were contributed by Environment Canada, B.C. Hydro and the University of Victoria. MBIS also benefited from research and data sets originating from other programs. MBIS was steered by a working committee composed of representatives from governments, aboriginal organizations and the private sector (Cohen, in press).

Some key findings are the following climate change scenario effects for the MBIS region, assumed to occur over the next 50 years (Cohen, 1994; in press):

1. basin runoff is projected to decline slightly (increases are projected for some sub-basins) with an earlier start to the spring peak;
2. Lake levels at Great Slave and Great Bear Lakes are projected to decline to below current minimum levels during the fall and winter months;
3. Ice on the Peace River is projected to form later in the fall, break up sooner in the spring, and its upstream advance could be reduced;
4. Increased permafrost thaw and accompanying landslides are projected to occur in the Mackenzie Valley and Beaufort Sea coastal zone, particularly in ice-rich and sloping terrain;
5. Peatlands are projected to disappear from areas south of 60°N and expand in northern areas, though the rate and timing of change have not been determined;
6. Forest growth rates are projected to change, with fire frequency and severity increasing, which could adversely affect commercial forestry potential (especially softwoods) and some wildlife species;
7. Caribou could be adversely affected by projected increases in summer temperatures accompanied by increased insect harassment;
8. The potential for wheat production would be improved so long as new technology is developed that is adapted to higher latitudes, and provision is made for expanded irrigation services;
9. Despite the longer summer, impacts on tourism would be mixed rather than generally positive;
10. There would be increased uncertainty and risk associated with the planning, design and operation of non-renewable resource extraction activities, including transportation and other infrastructure; and
11. Community impacts would vary depending on permafrost thaw rates and landslide risk, changes in ecosystems and resource potential, and the nature of future economic development patterns, which could also be affected by climate change; vulnerability of communities would vary with changing institutional relationships, access to all-season roads, and the nature of their economies.

Some of these results are consistent with the current warming trend observed in this region. The climate change scenario, however, could extend these and other possible changes beyond the limits of historical experience, and so may have implications for various resource management policies, plans, and agreements. Identification of these implications will require consultation with the region’s stakeholders.

Adaptation Responses

Participants at the round table discussions held during the MBIS Final Workshop, May 5-8, 1996 in Yellowknife, took the first step by providing comments on climate change from a wide range of regional perspectives. One of these round tables focused on interjurisdictional water management. There was recognition that recent trends towards lower streamflow and water levels, along with reduced spring flooding in the Peace-Athabasca Delta, could not be attributed solely to the operations of the W.A.C. Bennett Dam, located on the Peace River in northeast British Columbia. The recent climate warming trend had accelerated the effects of the dam on the river system.

When asked if the scenario of climate change impacts made a difference to their visions of the future, most round table panelists said “yes,” or “yes in the long term.” Some of them indicated that the scenario results were new to them, thereby raising new questions that would need to be addressed.

In the warming scenario noted earlier, what would be an appropriate response? Would artificial ice dams or new channels be able to preserve the Peace-Athabasca Delta’s ecosystem? Could changes in dam operations bring back the spring floods in the Delta without increasing risks to upstream communities? Or, should the Delta be allowed to “adapt” to a warmer climate by becoming a different kind of ecosystem, with reduced areas of surface water (lakes, perched basins, etc.) and more aspen and birch trees?

At the MBIS Final Workshop, some had expressed the opinion that there was little the region could do other than adapt in a reactive fashion. Aboriginal stakeholders said that adaptation would be possible so long as the rate of change was not too rapid. Others stated that a proactive response would be developed, and pointed to the Mackenzie River Basin Transboundary Waters Master Agreement as a mechanism that would enable the region to respond. Aboriginal land claims agreements, including the establishment of co-management boards for renewable resources, would also contribute towards developing a response. If it becomes more difficult to maintain downstream flows at historic levels, certain assurances of supply may need to be given. In aboriginal lands, regional land use planning may become oriented towards ecological zones rather than fixed areas of use so as to reduce vulnerability to future water level fluctuations. Beyond adaptation, the region could do its part to control greenhouse gas emissions and raise its voice to other governments so that greater momentum is given to national and international efforts (Cohen, in press).

Case Study: The Prairies

The Canadian Prairies, which include the provinces of Alberta, Saskatchewan and Manitoba, are a sub-humid to semi-arid continental region known for climatic extremes. Water is a critical natural resource in the Prairies since this region has a small population base primarily dependent upon agriculture, the agri-food business and energy development. For example, winter and early spring snowfall are relied on heavily to provide the spring runoff that replenishes the water reserves. Late spring and summer precipitation are required to provide most of the moisture needed to produce a wide range of field crops. Questions that need to be addressed include: (1) is the Prairie population well adapted to their current climatic conditions?; (2) are water resources being managed in a sustainable way?; (3) how will climate change affect the region? and; (4) do existing policies and agreements support or hinder the sustainable future of the Prairies?

Impacts of Climate Change and Possible Adaptation Measures

Climate change is expected to increase climatic variability in the Prairies. Most of the major rivers originate in the Rocky Mountains, which constitute the western boundary of the Prairies. These rivers, fed mostly by snowmelt,
glacial runoff and precipitation, flow in an easterly direction across the Prairies. Seasonal shifts in precipitation and the time of freeze-up and breakup, along with long-term changes in temperature and evaporation, will contribute to changes in annual discharges of rivers (Government of Canada, 1996).

For example, one study found that even if precipitation remained constant, a mean annual temperature increase of 1°C could decrease annual runoff volumes by between 5-15% (Nkemdirim and Purves, 1994). Another study found that as the climate warms, glaciers will melt until they reach a new equilibrium state (Nikolaichuk, 1990). This will initially increase annual stream flow, for the rivers originating in the mountains, and then reduce it, thus forcing water managers and users to adapt to wide variations in water supplies (Nuttie, 1993).

Another issue to be considered is changes in water quality. Many rivers on the Prairies already have high nutrient levels, salts and oxygen-consuming substances which cause water quality problems. Climate change is expected to cause reduced flows, thus leading to even higher nutrient concentrations.

Historically, the Prairies have had between two and seven million wetlands. The greatest number of wetlands are found along the sub-humid northern grasslands and adjacent aspen parkland, where 25-50% of the land surface is wetlands (Morrison and Kraft, 1994 in Government of Canada, 1996). These wetlands represent critical breeding habitat for waterfowl, producing between 50-80% of North America’s duck population (Batt et al., 1989; Gates, 1993). However, land use changes have led to the loss of 70% of the original wetlands and climate change may lead to further habitat changes.

Dams and reservoirs are present on most major drainage basins in the Prairies. They are used primarily for hydroelectric power generation, to manage extremes in water supply predominantly in the region commonly known as Palliser’s Triangle, and for recreation. The main developments of the 1980s have been the completion of the Rafferty Dam in 1992 and the Alameda Dam in 1994, both in southeastern Saskatchewan, and the Oldman Dam in 1993 in Alberta (Government of Canada, 1996).

Agriculture is the largest industrial user of water in the Prairies. Water is drawn for irrigation, as well as for livestock, dairy, feedlot and other farm operations, and is responsible for making otherwise marginal lands very productive (Government of Canada, 1996). Under climate change, northern marginal lands could become more productive, depending on soil suitability, while current productive farmland in the south could become drier, thereby increasing irrigation demands. The sustainable management of irrigation water will be dependent upon two factors: (1) the efficient management of water resources, the reduction of water lost to evaporation and leakage, and (2) a return to crops which have less water requirements.

**Political and Institutional Framework**

The issue of sustainable water management must be considered within the current political and institutional framework. Besides the international conventions on climate change and biodiversity mentioned earlier in this chapter, several bilateral, trilateral and multi-lateral trade agreements have implications for the Prairies, such as the Canada-United States Trade Agreement (CUSFTA), the North American Free Trade Agreement (NAFTA) and the General Agreement on Tariffs and Trade (GATT).

Under these trade agreements, Prairie agriculture is facing the challenge of becoming more integrated within the global agri-food system. If Prairie agriculture becomes more extensive and intensive, it will likely be to the detriment of regional sustainability due to the increased concentration of actual farms and processors, and the further marginalization of peripheral areas for production and processing (Chiotto, 1995).

The implications of climate change for the Prairies, combined with shifting political and institutional arrangements, are significant. First, farmers adversely impacted by climatic extremes have tended to rely on government support programs (Smit, 1994). Crop insurance and other government assistance have insulated farmers from the adverse financial effects of reduced yields or crop failure, thereby distorting their response to climate variations. With crop insurance deregulation, farmers will be forced to become more responsive to climate variability, and more astute at risk management.

Second, changes in government policy may further stress Prairie soils and water resources. For example, the elimination of the Western Grain Transportation Act (WGTA) may lead to the removal of some marginal lands from production, while in other areas, more intensive production can be anticipated. Increases in soil and water conservation practices would be required in areas where intensive and extensive production is likely to be the greatest. Lastly, it is unclear if the combination of government policy reform and the trend towards more industrialized agriculture will produce an agri-food system that is more or less vulnerable and adaptable to the effects of climate change.

**Future Progress Towards Sustainable Management of Water Resources**

Future progress towards sustainable management of water resources in the Prairies should be addressed on two fronts. First, the water user must understand and be able to choose the most appropriate use for the available water and to adapt to changes as they arise. Second, water managers have to choose areas of priority within the constraints of current legislation. Current limits to sustainable water use are:

- under-valuation of water,
- lack of knowledge about factors affecting water availability in the future, and
- cultural fixation of a short-term commodity-producing economic system (Willhite et al., 1995).

Scientific research on how climate change will impact the Prairies has been on-going, and the process to start a new study was initiated in April 1995 (Herrington, 1996, pers. comm.). The Prairies Climate Impact Study is expected to provide some useful information on the implications of climate change on future water resource management in the region.
KNOWLEDGE GAPS

Most climate change studies related to water have focused on water quantity and demand issues. Few studies have been done in Canada on the impacts of climate change on water quality. The effects of rising sea levels on most coastal communities along the Atlantic and British Columbia coasts have not been assessed. Climate change impacts on aquatic ecosystems such as wetlands and fisheries have also been sparsely covered, especially offshore fisheries which are largely influenced by ocean currents. Further work also needs to be done on evaluating and selecting adaptation measures for water resources in Canada.

CONCLUSIONS

In developing future water management policies, water managers can no longer assume that the climate will remain constant. Climate change scenarios suggest that the long-term availability and quality of water in Canada, and the frequency, duration and severity of extreme events such as floods and droughts will change due to an “enhanced” Greenhouse Effect. The application of adaptive management principles recognizes the additional uncertainty and risk brought on by climate change, and will encourage the building of flexible provisions to modify policies and activities when climate “surprises” are encountered.

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INTRODUCTION

Frank Lake provides a prime example of sustainable development at work. Through the cooperation of several partners, substantial economic benefit are realized while avoiding numerous detrimental environmental impacts. This innovative partnership arose from the realization of multiple use benefits identified through thoughtful environmental impact assessment (EIA). At the same time, the project enhanced and revitalized an entire ecosystem. This paper focuses on the major themes of sustainable development attained through partnerships and EIA.

SUSTAINABLE DEVELOPMENT

The collaboration of the various partners for the Frank Lake project shows how differing interests can be combined to provide social, economic and environmental benefits which facilitate developments that are sustainable. The essence of sustainable development encompasses three main elements: (1) ecological integrity combined with biological diversity, (2) a dynamic economy and, (3) social or intergenerational equity. Information sharing and integrated decision making by the various stakeholders binds these various elements together. Any element isolated from the rest would not constitute sustainable development which can only result from the close interaction of those three key elements.

Defining sustainable development appears an elusive concept as it can be seen either as a destination or a journey. The Brundtland Report certainly provides an initial starting point using the well known definition of “Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WCED, 1987). The Brundtland Report also defines the concept of integrated decision making. “The common theme throughout the strategy for sustainable development is the need to integrate economic and ecological considerations. They are all being integrated in the workings of the real world. This will require a change in attitudes and objectives and in institutional arrangements at every level.” Therefore, sustainable development governs economic development to either a rate or a level which is sustainable over time.