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Water Sector:

Vulnerability and Adaptation to Climate Change

Final Report

Support from:

[The Government of Canada Climate Change Action Fund](#)



Workshop Organized by:

Provincial Chapters of the [Soil and Water Conservation Society](#)
[International Institute for Sustainable Development](#) – Prairies
Canadian Water Resources Association – Quebec

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June 2000

Water Sector:
Vulnerability and Adaptation to Climate Change

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Executive Summary and Recommendations

Water, in its liquid and solid forms, and its multitude of uses and ecosystem values, is the component of the environment most vulnerable to climate change. Economic and environmental impacts on the water sector will be serious. The more than 330 water resource managers and scientists across Canada who were consulted through project workshops, and the published literature suggest a number of adaptation measures that could reduce vulnerability. However, at this critical juncture, Canadian actions appear to be moving towards greater rather than less vulnerability

- **Climate Scenarios**

In Chapter 1, the nature and reliability of the new generation of climate models is examined, with the model from the Canadian Centre for Climate Modelling and Analysis (University of Victoria) emerging as a valuable “middle of the road” guide to the future. It is shown that the observed trends to date, in a large number of climate and water related parameters, are consistent with model projections of the future. This lends more confidence to the projections. Uncertainties in future emissions of greenhouse gases and aerosols are more significant than remaining uncertainties in the modelling.

- **Vulnerabilities**

Among the most important projected effects of the climate scenarios on Canadian water resources are:

1. declines in low season river flows and lake levels and higher water temperatures in most of southern Canada, with potentially serious implications for water supplies, water allocation, hydro-power production, waste assimilation and pollution concentrations, and for freshwater ecosystems,
2. ground water levels and quality are also likely to be under greater stress with levels declining in populated southern regions,
3. greater frequency of high intensity rainfalls that would increase soil erosion, flash floods and storm sewer overflow,
4. average annual flood peaks are expected to be lower in most regions, but occasional very large floods are likely to occur in vulnerable river systems, (e.g. Fraser, Red, tributaries of St. Lawrence),

5. sea level rise, combined with more severe winter storms, poses major flood and erosion risks in coastal areas, particularly in Atlantic Canada (Bay of Fundy, Northumberland Strait),
 6. melting of permafrost poses difficult problems for roads and infrastructure of northern regions, and
 7. changing flow patterns and ice conditions have direct effects on wildlife distribution and survival, and in turn on subsistence communities of the north.
- **Adaptation Needs**

A large number of specific adaptation measures were identified in each region and documented in Chapter 3 and the Annexes (workshop reports). Among those most frequently identified were:

1. water conservation measures by all users
2. greater emphasis on planning and preparedness for droughts and severe floods
3. expanded efforts at water quality protection from agricultural, industrial and human wastes
4. renewal of national (federal-provincial) monitoring efforts for water quantity, quality and climate, and
5. improved procedures for fair allocation of water within basins, provinces, and between jurisdictions, taking in-stream ecosystem needs into account.

It will be immediately noted that these measures would be wise ones even if climate did not change much from the variability of the past few decades. They are “no regrets” or “worth doing anyway” adaptation measures.

- **Increasing Vulnerability**

However, the view of most workshop participants was that Canadian water resources and the people and ecosystems dependent upon them are becoming more vulnerable to climate change impacts, rather than less. With reductions in monitoring, technical support and scientific research by both senior levels of government, the knowledge and database has been eroding. These are essential to permit timely decisions on pollution, water supply and flood and drought issues. As well, water infrastructure is decaying. We are reaching a critical turning point in water management in Canada. Analyses of the present and probable future effects of climate change make constructive response urgent.

While much needs to be done at local and provincial levels, the framework for appropriate adaptation and management must be provided at a national level (federal and federal-provincial).

Recommendations:

Adaptation measures for consideration by provinces and at the local level are contained in Chapter 3. The following recommendations are directed towards the federal government.

- 1. Create an inter-agency coordination mechanism to develop a national strategy for water resources and climate change, and to implement federal actions (e.g. transboundary issues, monitoring, science, etc.)**
- 2. Create a mechanism for federal-provincial and multi-stakeholder coordination to advise on and implement the strategy.**
- 3. In light of water sector vulnerability and uncertainties associated with climate change, work with provinces to prevent or limit interbasin diversions or bulk transfers of water, especially out of Canada.**
- 4. Support research and studies on regional scale climate and hydrological prediction and on adaptation measures.**
- 5. Organize a broad-based national conference involving all stakeholders on water resources and climate change to help set agenda and priorities.**
- 6. Challenge the Canadian Climate Program Board to provide guidance on research priorities for climate science, water sector vulnerability and adaptation studies, particularly for new and renewed research funds.**
- 7. As part of Recommendation # 1, place a high priority on restoring, with the provinces, the essential monitoring of water quantity, water pollution and freshwater ecosystem health.**

Preface

The project Water Sector: Vulnerability and Adaptation to Climate Change was made possible only by contributions from a number of partners. First of all, essential funding was provided through the Climate Change Action Fund administered through the Adaptation Liaison Office of Natural Resources Canada. Global Change Strategies International, Inc. led and managed the overall project contributing through reductions in the normal fees for their senior associates (Jim Bruce, Ian Burton, Hans Martin). Meteorological Service (formerly Atmospheric Environment Service) of Environment Canada contributed the time of two experts on climate vulnerability and adaptation (Linda Mortsch, Brian Mills). These five from GCSI and MSC constituted the writing team for the overall project.

Five regional water sector workshops were organized as part of the project. Advantage was also taken of a multi-sectoral vulnerability and adaptation workshop in Yellowknife, which provided input on issues in the north. In all, some 330 water managers, consultants, engineers, scientists, and those affected by water issues participated in the five workshops. Participants in each workshop were provided with a copy of the Background Document prepared by the writing team. In each case, a workshop report highlighting the main outcomes was produced by the local organizers, in collaboration with members of the writing team. Workshop participants were all provided with a copy of the report of the event they attended. A complete set of workshop reports appears as an Annex to this report. Highlights of the regional vulnerability and adaptation assessments, undertaken through the workshops and the Background Document, have been summarized in Chapter 3 of this report.

The Regional Workshops 2000 were held as follows:

- | | |
|-----------|---|
| 23 March | Cambridge, Ontario: Soil and Water Conservation Society, Ontario Chapter (John Parish) and Grand River Conservation Authority. |
| 14 April | Vancouver, B.C.: Soil and Water Conservation Society, B.C. Chapter (Peter Friz) |
| 12-13 May | Moncton, N.B.: Soil and Water Conservation Society, Atlantic Chapter and 11th Hydrotechnical Conference (Gordon Fairchild) |
| 18 May | Winnipeg, Manitoba: International Institute for Sustainable Development and partners (Allen Tyrchniewicz) |
| 3 June | Ste. Foy, Quebec: Canadian Water Resources Association, Quebec Chapter and partners (Michel Slivitzky, Gerald Vigeant, Environment Canada and Ralph Silver, CWRA) |

The Yellowknife Workshop, 27-29 February, 2000, was sponsored by Natural Resources Canada. Two members of the writing team (Mortsch, Martin) participated.

The following report, compiled by the writing team, is organized to provide first a general overview of expected and observed climate and hydrologic change over Canada and its implications for the water sector. Special issues and adaptation needs in each region are then examined in Chapter 3. Some broader conclusions and proposals for follow-up actions especially at the federal or national level are given in Chapter 4.

This was indeed a highly cooperative venture and much of the credit for successful completion must go to the partner organizations and individuals named. However, if any errors or biases have crept into this final report, they are the responsibility of the writing team.

James P. Bruce, Ottawa, 26 June 2000

1. Recent Developments in Climate Change

-Projections and Observations

1.1 The Changing Climate

There is increasingly strong evidence that global and Canadian climates are changing and that at least part of that change is due to human activities. It is not contested that the natural greenhouse effect, in which certain gases in the atmosphere prevent some of the energy that otherwise goes from earth to space, have for millennia warmed the earth's surface. In addition, from Fig. 1, it can be seen that since the beginning of the industrial revolution in the 19th century, one of the most important of those greenhouse gases, carbon dioxide (CO₂) has risen sharply in concentration in the global atmosphere. This has paralleled the burning of fossil fuels (Fig. 1 inset). The changes were augmented somewhat by reduction of forests on every continent. Other greenhouse gases such as methane, nitrous oxide, the chlorofluocarbons have also increased greatly due to human activities. In Fig. 2, the average temperatures in the Northern Hemisphere are shown, with a remarkable warming trend since 1900. This, plus much other evidence, led the large number of scientists from around the world, collaborating in the UN's Intergovernmental Panel on Climate Change (IPCC), to conclude in 1995 that, "The balance of evidence suggests a discernible human influence on global climate." Greenhouse gas concentrations continue to increase in the atmosphere and are projected to do so for many decades. There is uncertainty about how rapidly human actions might be modified in the future to reduce or arrest the increases in greenhouse gases, and there are lesser uncertainties about the rates of change of climate that will result from a given scenario of greenhouse gases. The climate changes for a scenario of future emissions and concentrations of such gases are estimated by means of mathematical models which simulate the behaviour of the global climate system, based on well established equations describing heat and water vapour exchanges, movement of the atmosphere and interactions with the underlying ocean and land surfaces.

1.2 Models

The mathematical models generally used to project future climate with forcing by greenhouse gases and aerosols are known as GCMs (General Circulation Models or Global Climate Models). Over the past decade, the sophistication of such models has increased and their ability to simulate present and past climates has substantially improved. In particular, a number of GCMs developed in Canada, U.S.A., U.K. and Germany have combined models of ocean circulation and behaviour, with atmospheric models, in an interactive way, and are usually labelled AOGCMs. This is to distinguish them from earlier models with prescribed and non-interactive ocean conditions. This discussion of likely future climates in Canada is based primarily on the output of such AOGCMs. However, much of the research on climate change impacts in the water sector

is based on outputs of earlier generation of models. Recent observed climate trends are also cited in order to assess the degree to which experience over recent decades, as greenhouse gas concentrations increase, correspond with model projections. Special attention is paid to observations and modelling of the climate parameters, which are key parts of the hydrologic cycle, precipitation, temperature (as a surrogate for evaporation), and as a derived quantity, soil moisture.

1.3 Global Projections

Seven of the leading AOGCMs have been inter-compared for temperature and precipitation changes, annual, winter and summer over Canada. (E. Barrow 2000) These model outputs were compared for 2020, 2050 and 2080 with “business as usual” greenhouse gas and aerosol increases. The models in the comparison were CGCM1 (Canadian), HadCM2 and HadCM3 (Hadley Centre U.K.), CCSR-98 (Japanese Centre for Climate Research Studies), GDFL-R15 (Princeton, U.S.A.), CSIROmk2b (Australia) and ECHAM4 (MaxPlanck Inst., Germany). The HadCM2 generally has the lowest temperature increase for summer, winter and annual values (2050 and 2080). The CCCma’s CGCM1 projects temperature increases in the mid range, but about 3% lower annual precipitation increases by 2050 than the average of the others. The HadCM2 and 3 models gave similar results to each other for winter and annual values but in summer, the later HadCM3 gives warmer and drier conditions than HadCM2. The Canadian model and the HadCM3 model give similar results for summer. The agreement between all models was, of course, greatest for the 2020s for which mean annual temperature increases from 1990 ranged from 1.2 to 2.2°C and precipitation, averaged over Canada, increased 3 to 7%.

As a check on reliability, the average global warming to date simulated by the models, due to observed anthropogenic increases in greenhouse gases and aerosols, is given as 0.6 ° C (average of 4 models) with a range of 0.5 to 0.7 ° C. The World Meteorological Organization (WMO) reported in July 1999 that global mean warming over the past century has been 0.7°C. Since the CCCma results are close to being “in the middle” and they have been used to drive some Canadian smaller area models, hydrologic and meteorological, it will be most frequently cited here. It should be noted that the recently released U.S. country study was based on the CCCma and HadCM2 (cooler, wetter) model results.

For the global mean of annual precipitation, CCCma AOGCM projected increases of 1% by 2050 and 4% by 2100. However, evaporation increases, in many regions would be greater than precipitation and the CCCma suggests that the June-July-August precipitation minus evaporation difference would be increasingly negative over time and be about 30% by 2050 averaged over global land areas – i.e. a significant decline in average soil moisture. Sea ice extent in the Arctic is projected to be reduced by about one-half in June-July-August by 2050 and to virtually disappear by 2090. (Boer et al 1998) All of these projections assume a so-called “business as usual” scenario in future

emissions of greenhouse gases and aerosols. Full achievement of Kyoto protocol targets for emission reductions would delay the changes by 1 to 2 decades.

1.3 Projections for Canada

But, of course, it is not the global mean temperature change that will influence Canada's water, but the changes in temperature and other climatic factors over Canada. For a doubled CO₂ atmosphere, by the second half of the coming century, temperature increases for summers, over Canada, as projected by CCCma, would average about 4 °C. For winter months (Dec.,Jan.,Feb.) increases of 6 °C or more are projected for most of central Canada, with slightly lower values in the Atlantic Region and far west. A winter warming of as much as 10 °C is projected for parts of the high Arctic. A winter precipitation decline of from 0 to 20% is projected for the 2050s for much of western Canada with an increase of 0 to 20% from the Great Lakes eastward. In summer the projected area of precipitation decline of 0 to 20% is larger, including Ontario and southern Quebec – but small increases are indicated for northern Quebec and Atlantic Provinces. The higher temperatures and evaporation and these small changes in precipitation would lead to summer soil moisture declines of 0 to 20% over most of Canada. Smaller regions in the southern Prairies and in U.S.A. in the southern Great Lakes basin would experience minus 20 to minus 40% declines in average soil moisture. (Boer et al. 1998). For comparison, the Hadley Centre 3 model suggests increases in precipitation year round in the north but in southern Canada, increases in winter precipitation and small declines in summer rains.

Zwiers and Kharin used the CCCma – GCM2 model to examine changes in some extremes. They estimated that over Canada, a doubled CO₂ world would increase 20 year return period one day rainfall values by about 14%, i.e. the return period would be reduced by about a factor of 2. A 20 year return period, one day heavy rainfall, would become a 10 year return period event.

Mean sea level is projected to rise 2 to 5 times as fast in the next century as the 10 to 20 cm rise in the last (IPCC 1996). In Atlantic coastal regions, the Fraser Delta and some parts of Vancouver Island, this could result in more coastal erosion, more frequent flooding and salt water intrusion into groundwater and estuaries. However, in Hudson Bay and the Arctic Ocean where land is still rebounding from the last ice age, the **relative** sea level rise would be much less or even negative. Nevertheless, the reduction in ice cover expected would permit greater open water fetch to increase wave and storm surge effects on coasts in these northern areas.

1.5 Comparisons of Projected Changes with those observed to date

1.5.1 Average temperatures over Canada have increased more than 1°C in the past century, with the largest increases in central, northwest and northern regions. This is a similar pattern, in a broad scale, of projections from the models. In coastal areas of eastern Canada and over the waters off Labrador, cooling has been observed in the past 3 decades. This too is consistent with model projections of cooler conditions in this area in a greenhouse forced world, due to changes in ocean circulation and ice conditions.

1.5.2 Precipitation changes have been only moderately consistent with modelled outputs. Nationally, precipitation has increased 1.7% of the mean per decade over the period 1948 to 1995, with slightly larger increases north of 55 °N due to more snow. (Mekis and Hogg) The greatest national increase has occurred in autumn (3.4%). Only on the Prairies was the projected small decline in summer rainfall observed in Southern Canada. (projected decline in summer). The largest increasing trends have been in the north, northwest, Pacific Coast and South B.C. mountains.

1.5.3 Permafrost has been retreating northward in the Mackenzie Basin resulting in many landslides. (Cohen, S.J., Mackenzie Basin Impact Study 1997) Permafrost is present where ground temperatures are below 0°C all year. About one half of Canada's land area is underlain by permafrost. A large portion of this permafrost area, (about 53%) where communities of significant size exist, has an average temperature higher than minus 2°C. Ice rich permafrost in these areas is at risk of thawing from global warming. Increased landslides, landslips and sinking of terrain is already occurring. Increased thaw and settlement is likely to occur beneath buildings, utility systems, roads, railroads, pipelines, dams and dykes. The wide band at risk is between James Bay and Inoucdjouac on the east, north end of Lake Winnipeg, and Churchill in the middle, and between Lesser Slave Lake and Great Bear Lake or Dawson City in the northwest. (Natural Resources Canada 1999)

1.6 Severe Weather Events

The observed changes in the past few decades, and the climate model projections for a number of kinds of extreme events are outlined here.

a) Short Duration Heavy Rains

Observations - No analyses of Canadian data are available of trends in very short duration (minutes to hours) heavy rain events except for Vancouver. The Vancouver airport results show an increased frequency of short duration high intensity falls, although these trends are not evident in other nearby stations (e.g. Abbotsford). These heavy falls

can cause city street flooding, sewer overflows, erosion and flash floods, and landslides. Some analyses of heavy one-day events have been undertaken. Daily data show that a small increase in percentage of precipitation in heavy events (90th percentile) has occurred in some areas in the period 1940-1995. This is especially true for larger population centres on the west coast, the Winnipeg area, the Montreal-Ottawa area, southwestern Ontario and the Atlantic provinces. In some other regions such as the rest of the Prairies and northern Ontario, there has been a negative trend. (Mekis & Hogg, 1999). In the adjacent U.S.A., the frequency of heavy one-day rainfalls (>50 mm) has increased by about 20% over the past 90 years (Karl et al., 1995). Stone, et al., 1999 have determined that in spring and early summer heavy rain event frequency from 1950 to 1990 have increased as much as 8% in southeastern Canada, and about 3% in southwestern Canada.

Projections – As noted above, model results indicate there will be an increased frequency of heavy one-day rains in a doubled CO₂ climate (last half of the 21st century), with return periods halved, e.g. a 20 year return period rainfall becomes a 10 year event. (Zweirs and Kharin, 1998)

b) Severe winter storms

Observations - The frequency of Northern Hemisphere severe winter storms (central pressure lower than 970 kpa) has nearly doubled since the mid 1970s, (Lambert 1996)

Projections - The Canadian GCM indicates that in a doubled CO₂ world, the number of weak to moderate winter storms in the northern hemisphere would decrease but the number of very severe storms would increase. (Lambert 1995)

c) Heat waves

Observations - There are no available analyses of trends in Canada of 3 to 10 day hot spells. However, it has been shown that there is a high correlation between much warmer average conditions such as those projected for Canada, and heat waves which last several days or more. (Karl et al., 1996)

Projections - With a generally warming climate, more heat waves of several days' duration are projected but this has not been quantified. Estimates have been made of increases in numbers of days when the temperature would be above 30°C with doubled CO₂ climate. For example, for London, Ontario, these would increase from 10 to 50 per year and for Winnipeg, from 13 to 32 per year. With increases in night-time temperatures projected to be greater than increases in day-time maxima, there would be less nighttime relief in such events. More intense and prolonged heat waves would lead to increased frequency and intensity of health and life threatening smog episodes in and near population centres, and to periods of high water demand.

d) Wildfires and other Forest Disturbances

Observations - With a maximum warming in Canada having occurred in the central and northwest regions over the past several decades, boreal forests have experienced a doubling of areas affected by fires and insect infestations especially in northwestern Ontario, northern Manitoba and Saskatchewan and the Northwest Territories (Kurtz and Apps, 1995). The average age of the trees as well as climate, have influenced these occurrences. Such fires have frequently threatened communities in the boreal forest region. Little change in fire occurrences has been observed in Quebec and eastern Canada, where warming has been less pronounced or cooling has even occurred.

Projections – With additional warming of 5°C plus in central, western and northern boreal forest regions with a doubled CO₂ atmosphere, higher fire weather indices and greater insect infestations can be expected. Lightning strikes, which set off most fires in more remote regions, are projected to increase by 44% in the U.S.A. with CO₂ doubling (Price and Rind 1994). While specific projections for Canada are not available a similar or larger increase is probable since, in general, it has been found that an increase of 1°C in average wet-bulb temperature is accompanied by a 40% increase in lightning. (Reeve & Toumi, 1999) Reduction of ground cover by fire can lead to more severe flooding and erosion if heavy rain or snowmelt events follow.

e) Severe Thunderstorms and Tornadoes

Observations – These events are often not well observed especially in less populated regions. However, it has been recognized that warmer springs and summers tend to bring more severe thunderstorms, damaging downbursts, hail and tornadoes. (Etkin, 1995)

Projections – While climate models do not have the fine scale spatial resolution to resolve thunderstorm/tornado events, they do project increases in atmospheric conditions, warmer springs and summers, more moisture in lower atmosphere, which lead to these damaging weather events. Tornado events in the prairies, particularly in central Alberta, southern Ontario and near the Ontario/Quebec border are likely to increase.

Table 1-1, summarizes some of the key projections of the climate models and observed trends to date.

Table 1-1**CLIMATE CHANGE PROJECTIONS AND OBSERVATIONS**

	<i>Projected</i>	<i>Observed to date</i>
Global mean temperature	1.7 to 4.0 °C (1990-2100)	0.7 - 0.8 ⁰ C (WMO 1900-1999)
Mean Temperature – Canada (2040-2060)	2 to 4 °C	1+ °C
Temperature–Canada N. and N.W. (2040-2060)	5 to 10 °C	1.7 °C
Temperature – Coastal Labrador (2040-2060)	0 to - 1 °C	Slightly negative
Total Precipitation – Canada (2040-2060)	0 to 20% more in north slightly less in South-Summer	++ at high latitudes, + at mid latitudes slightly negative southern Prairies – summer
Extreme Precipitation – Canada (2 x CO ₂)	2 x frequency of heavy rains	+ 8% SE Canada +3% SW Canada Spring/Summer (heavy one day falls)
Water Vapour in Troposphere	Increase	Increase over N. America except N.E. Canada
Sea Level Rise	50 cm (mean projections) 1990-2100	10 – 20 cm (1900-1999)
Streamflow (or soil moisture) – 2050s	- 30%	- 10%
Date of Spring Breakup	Earlier	Earlier 76% of basins (1947-1996) Earlier 82% of basins (1967-96)

Number of days with ice cover	Fewer	Fewer 38% of stations (3 decades) 40% of stations (4 decades)
	Projected	Observed to date
Arctic Sea Ice extent – 2050	- 30%	- 14% (year round ice)
Snow Cover extent – 2050 DJF	- 15% N. America	- 10% Northern Hemisphere
Late season snow pack Rockies – April 1	Less (more melt over winter)	31% less since 1976
Glacier retreat – e.g. Glacier National Park	None left (by 2030)	2/3 reduction in numbers (from 150 to 50)
Permafrost (discontinuous areas)	Retreat northward	Retreat Mackenzie Basin
Severe winter storms frequency	15% - 20% 2 x CO ₂	50% - 60% 1975 to present

1.7 Disaster Considerations

Catastrophe Scenarios:

Major disasters usually require the coincidence of a combination of factors. Since such coincidences are rare, their likely frequency is impossible to predict. However, it can be instructive to envisage worst-case scenarios. Several examples of infrequent but increasingly plausible scenarios have been suggested which would affect Canadian regions. With sea level rise continuing, such catastrophes could occur on both coasts. For Vancouver, Richmond and nearby communities, major floods on the Fraser River under possibility of heavy rains with rapid snowpack melt are increasingly likely. If such a flood was combined with a significant storm surge along with a higher mean sea level or seasonal tides, many dykes could be overtopped and great devastation could occur.

For communities along the Bay of Fundy, rising sea levels, and an increasingly likely very severe winter storm, could result in overtopping the salt-marsh dykes, inundating and salinating large areas of valuable agricultural land and inundating many near-shore municipalities. An intense storm in January 2000 resulted in a storm surge of 2 metres at Shediac N.B. pushing the blocks of ice to damage buildings well inshore, and raising water levels to record highs in Charlottetown.

With the possibility of greater evaporation with higher temperatures, and little or no increase in summer rains, large-scale, intense drought scenarios are also plausible for much of southern Canada.

Weather-Related Disaster Losses in Canada (storms, floods, droughts)

Economic losses due to weather-related events in Canada are increasing rapidly. It is difficult to determine a comprehensive estimate of all losses because of the large number of data sources and differing methods of computation. These include: insured losses, federal and provincial governments' financial assistance, individual and farm-borne losses (deductibles, uninsurable or non-eligible items etc.), provincial, municipal, community and not-for-profit organizations' social services costs and general community economic losses. It will, of course, be recognized that much of the increase in losses is due to greater exposure to the risk. However, with the above analysis of trends and their own analyses, many spokespersons of the insurance industry are convinced that increases in frequency of extreme climate events is a contributing factor.

The data shown in **Table 1-2 and Figure 3** are neither comprehensive nor complete, but they serve to show the dramatic increase in some of the recent losses associated with extreme weather-related events in Canada. It must be recognized that most flood and drought losses are not insured commercially in Canada. These types of loss are better reflected in **Figure 3**, where government compensation is included.

Table 1-2. Insured Disaster Losses in Canada, 1984-1998

YEAR	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
LOSS \$million	39	101	12	170	87	14	16	484	94	255	200	376	760	205	1450

Note: Figures are insured losses only, and do not include all economic losses such as residential losses in floods which are not insurable (from Angus Ross, Sorema Reinsurance).

1.8 ENSO and other Climate System Changes with Greenhouse Forcing

-Implications for Canada

A critical issue, in considering the extent to which weather variability affecting water resources is likely to increase with increasing greenhouse gas forcing of climate, lies in whether natural modes of the climate system such as the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the Arctic Oscillation (AO) and the North Atlantic Oscillation are influenced by the increased radiative forcing. Many severe weather events accompany strong El Niños and La Niñas. This is particularly evident in tropical zones, but has been shown to affect as well severe events in temperate zones. For example, Barsugli et al. (1999) used medium term forecast models with and without El Niño and concluded that the devastating freezing rain storm in eastern Canada and U.S.A. of Jan. 1998, and the heavy rains in central California in Feb. 1998 bore the signs of “substantial impacts” of the strong 1997-8 El Niño.

Several recent studies have shown that the period of intense warming over North America appears to be associated, at least in significant measure, with a major change in the Pacific circulation in the mid 1970s. This too marked a time when the interval between El Niño events decreased from about 6 ½ years to about 3 ½ years. Some scientists (e.g. Schrag, 2000) suggest that these changes may have been brought about by an external force, such as the increased radiative forcing by the greenhouse gases, triggering the changes in the Pacific, but this is not unanimously agreed. The Decadal and Interdecadal Pacific Oscillation (PDO and IPO) states modify the manner and extent to which ENSO events affect conditions in Canada.

Elsewhere, changes in the Arctic Oscillation and its closely linked North Atlantic Oscillation have also been related to shifts in climate conditions in Europe and elsewhere. Indeed, there is a growing view amongst climate scientists that the main way in which the enhanced greenhouse effect will be felt is through changes in the frequency of the “warm” state of these large-scale modes of the climate system. (Palmer, 1999, Fyfe, 1999)

In this connection many AOGCMs including CCCma now project more El Niño like climatic patterns in a greenhouse gas forced climate system.

Coupled AOGCMs have given these results, beginning with Meehl and Washington (1996). Boer et al (1998) indicate that the latest modelling runs from the CCCma model shows “enhanced warmth in the tropical eastern Pacific, which might be termed “El Niño-like” and “an El-Niño-like signal in precipitation”. These results were from the more advanced coupled ocean-atmosphere model, but were absent in CCCma’s previous equilibrium mixed-layer ocean model. The model projections to 2100 in all cases were based on projected greenhouse gas and aerosol increases similar to those in the IPCC 92a scenario, so called “business as usual”.

Knutson & Manabe (1998) of Geophysical Fluid Dynamics Lab (GFDL), Princeton concluded that the predominance of El Niño Conditions over the past two decades is “not likely attributable to internal (natural) climate variability” and is likely due at least in part to “sustained thermal forcing, such as the increase of greenhouse gases in the atmosphere”. However, this result is still being debated since reconstruction of probable El Niño conditions before 1920 suggest that the high frequencies and intensities of El Niños since 1970 may have also occurred early in the century. The GFDL AOGCM projects that the warming of the tropical Pacific due to increased greenhouse gases will tend to make the mean climate more “El Niño-like” since the warming projected by the model is enhanced in the model’s El Niño region relative to surrounding regions. The UKMO models also show intensification of El Niño like temperature and precipitation patterns in equatorial Pacific by 2050 compared to the 1961-90 means, with greenhouse and aerosol forcing.

These models have been criticized by some as being too coarse in resolution to really simulate well the ENSO events. However, Timmerman et al. (1999) from Max Planck Inst., Hamburg, have used an AOGCM with much finer resolution in the tropics. They conclude that greenhouse forcing will result in “more frequent El Niño-like conditions and stronger cold events (La Niña)”.

Thus, most, but not all modelling studies tend to reinforce theoretical work by Sun (1997) that suggests a continued increase in El Niño-like precipitation and temperature conditions, in a greenhouse gas enhanced world. This, in turn, suggests in general, increased frequency of heavy rains and storms in some regions interspersed with short dry spells, and more prolonged droughts in other parts of the world, punctuated by heavy rain years.

ENSO implications **for Canada** have been well studied (Shabbar and Khandekar, 1996, Shabbar et al., 1997). A consistent response to El Niño for southern Canada from interior B.C., as far east as Ontario, is significantly drier and warmer conditions and droughtiness. For La Niñas, abnormally wet conditions in winter are usually experienced from interior B.C. through to southern Quebec and significantly cooler weather in western, especially northwestern regions. The typical winter precipitation patterns are shown in Fig. 4.

A further graph (Fig. 5) illustrates the historical differences in precipitation in southern Canada (Southern B.C. through the Prairies to western Great Lakes basin) following year-end peaks in El Niño and La Niña conditions. The data indicate that drier than normal weather will prevail in winter and spring in an El Niño year. Conversely, wetter than normal weather will prevail during the same period in a La Niña situation. El Niños generally bring higher than normal temperatures in southern Canada, augmenting the drought-inducing effects of lower than normal precipitation. If the recent research results cited above are confirmed, El Niño (*dry*) conditions are likely to continue to become more frequent with greenhouse gas forcing of climate change. These recent research results also suggest stronger La Niñas, punctuating the El Niños. This suggests that

prevalent dry conditions may be interspersed with wet, flood-producing years such as experienced in the central prairies in 1999. Fluctuations in climatic conditions in northern parts of Canada, particularly the northeast, are affected by trends and variations in the Arctic Oscillation and its cousin the North Atlantic Oscillation. These effects are just beginning to be understood. (Fyfe et al. (1999).

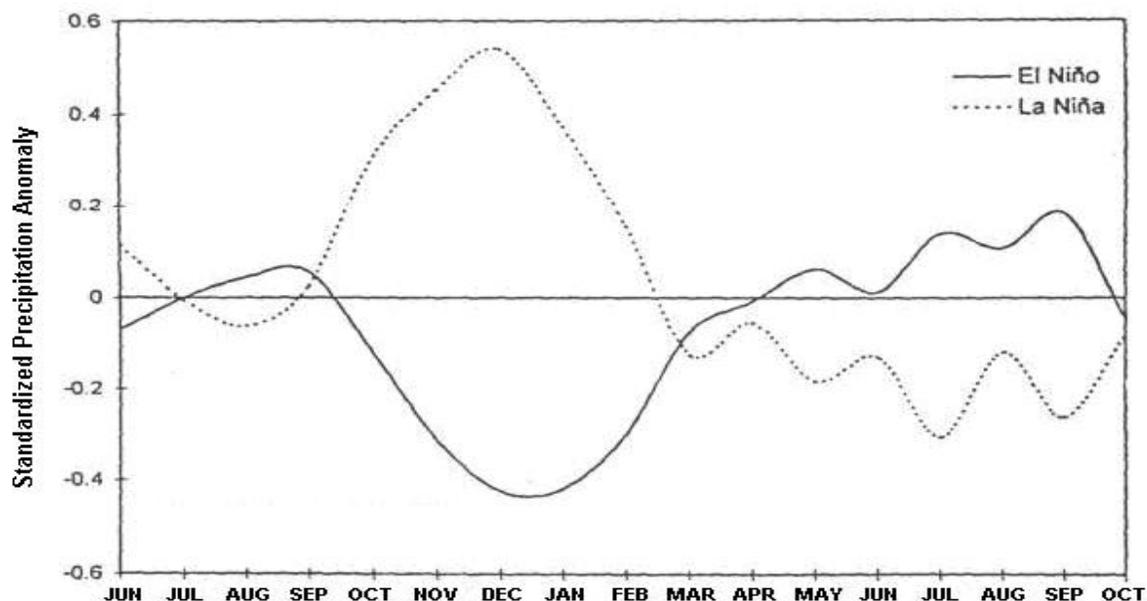


Figure 5. ENSO Events and Precipitation for Southern Canada. (Shabbar et al.(1997).

1.9 Observed Hydrologic Trends

With the changes in climate observed to date, generally consistent with projections for the future, has any trend in hydrologic characteristics been observed? Two recent papers provide valuable analyses. Zhang et al. (1999) analyzed the hydrometric data from a number of rivers in Canada with fairly long records. (from 1947-96) The annual mean streamflow for almost all of southern Canada has shown a downward trend, increasingly so since 1967. The exception is southern Ontario where the longer records show slightly increasing flows, but the most recent period (1967-96) indicates little trend. More than 2/3 of the rivers across Canada had declining monthly flows in July to September with only 6% (average of 3 months) having increasing flows. For Feb.-March and April 41% (average of 3 months) had lowering mean annual flows and 15% (average of 3 months) had increasing amounts. Annual minimum flows from 1967-96 went down in 65% of rivers and up in 13%, and annual peak flows declined in 60% of rivers, but increased in 28% of cases over the longer period (1947-96).

In southern Canada these flow changes are an obvious response to increased evaporation with higher temperatures and only small changes in precipitation. River flow volumes tend to remain large in winter and spring but peak discharges lower on average due to winter period thaws and snow-melt. Lower summer/autumn flows and minimum flows also reflect the increased evaporation effect and on the Prairies and slightly lower precipitation. Whitfield and Cannon's study (1999) noted the importance of the "leverage effect of small variations in climate, particularly temperature, on different hydrologic systems".

In the Northwest Territories, Yukon and Northern B.C. mean annual flows from 1967-96 increased, except for the Mackenzie system affected by drier conditions in the northern Prairies. These increases reflect the significantly higher precipitation in northern regions.

It seems likely from climate projections that these observed trends are likely to continue.

2. Water Resource Vulnerabilities and Adaptation Needs

- A National Perspective

2.1 Climatic Scenarios

It is evident that if the above cited climate projections are realized, there are important implications for Canada's water resources, and for boundary and transboundary waters shared with U.S.A. It must also be realized that the uncertainties surrounding the model projections work in both directions. The changes could be smaller than projected or larger. Thus application of the precautionary principle calls for development of adaptation measures. The models also cannot simulate sudden "surprises" in the climate system that are theoretically possible but unlikely over the next century, such as significant changes in ocean currents like the Gulf Stream which would greatly disrupt regional climate or rapid collapse and melting of Antarctic ice which could trigger major sea level rise.

The following discussion of potential vulnerabilities in the water sector is based upon the model projected changes to year 2050, outlined above, or where 2050 estimates are not available to a climate with doubled CO₂ equivalent atmosphere (between 2050 and 2080 depending on assumptions about future emissions). As noted above, the model projections used are ones which give results consistent with observed changes over the past several decades, and are based upon the most recent analyses from coupled atmosphere-ocean GCMs.

2.2 Water Supply

In most of southern Canada, higher temperatures and little change in precipitation will probably accentuate observed trends of the past 3 decades, i.e. lower total flow, lower minimum flows and lower average annual peak flow. If the projections are verified, of more prolonged and pronounced El Nino-like conditions, winter dryness from southern B.C. across the southern Prairies and the Lake Superior and Lake Michigan-Huron basin would increase. In addition, the higher temperatures and evaporation would overcome any slight increase in summer season rainfall. This suggests more prolonged and intense droughts to come and lower water supplies to Upper Great Lakes. With wetter winter conditions and cooler summers associated with La Ninas being somewhat intensified but less frequent, such prolonged dryer periods could well be punctuated by high runoff or flood producing years. Earlier work by the Geophysical Fluid Dynamics Lab, suggests that the greatest deficits of moisture (precipitation minus evaporation) are likely to occur in a band around 50°N. (Wetherald & Manabe, 1995). In a downscaled regional climate simulation for the southern Prairies, soil moisture declines of 10-30% were projected. (Laprise et al. 1998) for a doubled CO₂ climate. Melt water from the retreating glaciers in the Rockies would eventually result in a gradual decline in flows in the eastward flowing rivers on the Great Plains.

The implications for river flow, ground water, water supply in the Columbia Basin on the Great Plains and for levels of the Great Lakes are readily evident. Many of the lake and river systems that would have lower levels and flows, on average, are among the most heavily used in Canada and also shared with U.S.A. This suggests that water conservation measures will be important especially in high consumptive uses such as irrigation. It also suggests that caution should reign in connection with permitting significant water-taking or diversions from watersheds near and along the Canada-U.S. border. Groundwater resources in southern Canada are also likely to experience long term declines in recharge rates suggesting that careful husbanding of these resources will be important as well as development of equitable sharing arrangements in boundary groundwaters. Such arrangements are not in place at present between Canada and U.S.A.

Hydropower production in British Columbia, on the Saskatchewan-Nelson System, and in the Great Lakes-St. Lawrence basin could be significantly reduced. In particular, the projected average drier conditions in the southern Great Plains and the Upper Great Lakes basins could significantly reduce water available on the Nelson, at Sault Ste Marie, Niagara and on the St. Lawrence for electricity production. This would result in increased use of alternative generation methods, which at least over the coming few decades would be fossil fuels. This would make achievement of Canada's GHG emission reduction targets (e.g. Kyoto) more difficult and could further exacerbate local air pollution problems in heavily populated regions.

2.3 Water Quality

Several aspects of a changing climate can have an impact on water quality. Williamson, (Prairies Workshop) has pointed out that high concentrations of pollutants in Prairie Rivers occur:

- (i) at low flows when point sources from municipalities and industry are important, and
- (ii) at high flows when runoff from agriculture and urban areas dominate.

Moderate flow periods have lower concentration of nutrients and toxics. If the frequency of short duration high precipitation intensities increases as projected, increased risk of biological contamination, of water supplies especially from animal wastes, can occur as well as greater soil erosion and sedimentation accompanied by pesticides. On the other hand, more extended drier conditions in agricultural areas could reduce nitrogen leaching into groundwater and nitrate contamination.

In coastal regions, both east and west, salt water intrusion into aquifers and estuaries is likely to be increasingly observed as mean sea level rises, especially where aquifers are heavily pumped for water supplies.

2.4 Floods

With greater frequency of high intensity rains, **small watershed** runoff, especially storm sewer drainage, is likely to have higher peak discharges. This could result in more frequent storm sewer backup unless design criteria are modified, and greater field and bank erosion.

In large basins, warmer conditions are likely to reduce the frequency of annual high spring flows and flood risks in south and western Canada. However, with Spring rains becoming more intense the possibility of a very occasional, very large floods from snowmelt and Spring rains is likely. With the general warming, however, snowmelt freshets will likely continue to be earlier in the year. Eastern Canada would be expected to experience, on average, higher spring freshets but lower late summer flows.

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3.1 Regional Vulnerabilities And Impacts: Atlantic

3.1.1 Regional Characteristics

Atlantic Canada includes the Maritime provinces of New Brunswick, Prince Edward Island and Nova Scotia as well as the province of Newfoundland. Together, these provinces contain almost 300,000 surface water bodies and over 40,000 km of coastline (Shaw 1997). The region's 2.37 million people (Statistics Canada 1996) and economic activities are concentrated along the ocean coastline and large rivers such as the Saint John. A description of the climate of Atlantic Canada is provided by Canavan (1997). Two climate regions cover most of Atlantic Canada (Atlantic and Northeastern Forest) while a third (Arctic Mountains and Fjords) includes only the extreme northern portion of Labrador. Within these regions one finds some of the wettest and most temperate locations in eastern Canada. Regional climate variations are largely controlled by differing latitude and proximity to the Atlantic Ocean or Gulf of St. Lawrence. Since the upper wind flow is westerly, maritime influences on temperature and precipitation are much more prominent along the immediate coastlines, with more of a continental climate apparent in western New Brunswick and Labrador (Canavan 1997; Phillips 1990).

3.1.2 Key Water Issues

The key water resource issues affecting Atlantic Canada include the collapse of marine fisheries, coastal inundation, riverine flooding and occasional drought. While extremely important, the first issue is beyond the primary 'fresh water' scope of this report although it is undoubtedly related to climate variability and change. Flooding is perhaps the most pervasive water issue in Atlantic Canada. For example, over 57 communities in Newfoundland have experienced flooding during the past 15 years that in total caused over \$40 million in damage (Newfoundland and Labrador Department of Environment and Labour 1999). Flooding is also a common experience in the Saint John River basin (Hare et al. 1997) and along the Bay of Fundy coast and Northumberland Straits (e.g., January 2000). The Maritimes have also experienced significant summer droughts (e.g., 1984, 1989) most recently in 1998 (Hofmann et al. 1998).

3.1.3 Observed Trends in Climate and Hydrology and Projected Climate Change and Sea-level Rise

Observed Trends

Seasonal temperature trends over the 1895-1992 period are listed in Table 3.2-1. With the exception of autumn temperatures in the Atlantic region, seasonal and annual trends are positive for most of the area. Annual increases are small relative to changes in many other parts of Canada. One exception to this pattern is the Saint John River basin in western New Brunswick, which has experienced greater warming more consistent with

that observed in the Great Lakes and northern New England regions (Hare *et al.* 1997). If only the 1948-1995 period is considered, then a different trend emerges with Atlantic Canada actually cooling by 0.7°C over this period. (Shaw 1997) Precipitation has been increasing in all three climate regions over the past century, almost entirely due to greater winter, spring and autumn snowfall (Mekis and Hogg 1999).

Table 3.1-1. Seasonal Temperature Trends in Atlantic Canada Climate Regions (1895-1992)

Climate Region	Winter	Spring	Summer	Autumn	Annual
Atlantic	0.3	0.2	0.8	-0.1	0.3
Northeastern Forest	0.5	0.9	0.5	0.1	0.5
Arctic Mountains and Fjords (1946-1992)	-0.7	-1.6	0.0	-0.7	-0.8

Bold indicates a statistically significant trend. Source: (Environment Canada 1995)

Based on a limited analysis of eight climate stations in the Maritime provinces over the period 1944-90, Lewis (1997) noted trends in extreme temperature and precipitation:

- decreasing trend in the number of days per year with a maximum temperature greater than 25°C;
- increasing trend in the number of days per year with a minimum temperature below -15°C;
- increasing trend in the number of daily precipitation events above 20mm; and
- very slightly increasing trend in the number of daily snowfall events above 15cm.

Mekis and Hogg (1999) also observed an increase in the fraction of total precipitation falling in heavy events (>90th percentile) for much of Atlantic Canada over the 1940-95 period.

A few studies have identified changes in regional hydrology. For instance, runoff in Nova Scotia streams has decreased during the past 25 years, particularly during winter (Clair *et al.* 1997, Brimley and Sandford 1999). Zhang *et al.* (1999) indicate that annual mean flows and September (low season) flows in Atlantic Canada have mostly declined (1967-96) while April flows have increased. In comparing streamflows between 1976-85 and 1986-95, Whitfield and Cannon (2000) observed that many Atlantic Maritime rivers experienced lower flows in late summer and higher flows in early winter and spring. Zhang *et al.* (1999) in their analysis of trends in river flow indicate that mean annual flows and September flows in the Atlantic region declined in the 1967-96 period but spring flows (April) increased. Preliminary analyses in Nova Scotia and on the Island of Newfoundland indicate a trend towards more days with ice in rivers since 1952 (Shaw 1997). In western New Brunswick, Saint John River streamflow and basin precipitation appears to have become more variable and higher on average since 1950 (Hare *et al.*

1997). This variability has coincided with earlier and more frequent spring freshets and greater flooding and ice jam damage, particularly since 1972 (Hare et al. 1997). Several participants in the Atlantic workshop (2000) felt this trend may be more generally applicable, observing that the timing of extreme events, especially floods and spring breakup, was changing.

Future Climate Change and Sea-level Rise

Results from the CCCma coupled ocean-atmosphere model (CGCM1) (Boer et al. 1998) suggest that mid-21st century mean annual temperatures in Atlantic Canada, relative to the 1961-90 average, will be reduced by up to one degree Celsius over the Labrador Sea off of the Newfoundland coast. Over land areas, mean annual temperature will increase by 1-4°C (CCCma 1999). Winter (December-February) temperatures may cool slightly (less than one degree) along the coast and increase up to 4°C in northern Labrador while summer (June-August) temperatures would generally rise by about 2°C and up to 4°C in northern Labrador. A cooling of up to 3°C may occur off of the northeast coast. By the end of the century, the warming is expected to become even stronger over land (general increase of 3-5°C) however a cooling anomaly will remain over the ocean off of the northeast coast. Modest increases in annual precipitation are expected to accompany the temperature change by mid-century in northern areas with no change or slight decreases expected in the southern and western Maritimes. Results in Boer et al. (1998) suggest that winter and summer precipitation and soil moisture will remain within 20% of the 1975-95 average, even by the end of the 21st century.

Sea-level is also expected to continue to rise in Atlantic Canada. The Intergovernmental Panel on Climate Change (IPCC 1995) estimates that climate change will increase levels by an average of 50 cm over the next century which, in parts of Atlantic Canada, will be compounded by up to 30cm of sea-level rise due to crustal subsidence (Forbes et al. 1997).

3.1.4 Potential Regional Vulnerabilities and Adaptation Needs

The temperature and precipitation scenarios derived from the latest climate models are more moderate than scenarios developed from climate modeling experiments conducted in the late 1980s and early 1990s. Much of our quantitative knowledge of impacts was generated using the older, more drastic model results.

System Responses to Climate Change

Hydrology

Temperature and precipitation changes in the regional climate as outlined above may have important implications for many components of the hydrologic cycle. Unfortunately, there are few published analyses of the impacts of climate change on specific Atlantic Canada watersheds. The following implications were drawn primarily from reports of historic sensitivities and research from other regions. As for the climate scenarios noted previously for Atlantic Canada, several of the suggested effects run counter to recent hydrometric observations and trends.

Runoff and streamflow. Ng and Marsalek (1992) examined the sensitivity of a small Newfoundland watershed by simulating the effects of hypothetical changes in climate. Temperature increases barely affected total annual streamflow, led to larger and earlier winter runoff when precipitation was stored in the snowpack, and increased winter/spring streamflow peaks. Effects of precipitation fluctuations were more direct with annual and seasonal streamflow changes being directly proportional to precipitation changes and monthly peaks increasing about twice as much as precipitation (Ng and Marsalek 1992 as reported in Hofmann et al. 1998). Clair and Ehrman (1996) examined the implications of a 3°C rise in temperature coupled with various scenarios of precipitation using historical climate and hydrologic data for 15 wetland influenced Atlantic Canada rivers. The temperature change combined with precipitation changes of -20%, 0% and +20%, yielded discharge estimates of -29%, -10% and +9.5%, respectively.

Changing river ice. Ice cover is expected to become intermittent or disappear entirely in southern Atlantic Canada rivers. Ice that does form will likely be less thick. Meanwhile, permanent winter ice cover on northern rivers may occasionally break-up (Clair et al. 1997).

Icebergs and sea ice. Higher temperatures could reduce the southern extent of sea ice (Arctic Sciences Limited 1993). It is speculated that greater snow accumulation on Arctic ice caps and longer, warmer seasons at their edges might increase the calving of icebergs.

3.1.4.2 Extreme Events

Atlantic Storms. The frequency of severe storms and Atlantic hurricanes (or their remnants) is a great concern for Atlantic Canada. Research by Lambert (1995) as referenced earlier suggests that while fewer extra-tropical cyclones might be expected under climate change, the number of intense storms would increase. This trend has been observed in a study of storms along the eastern coast of North America where, over the last fifty years, seven of the area's eight most destructive storms have occurred in the most recent twenty-five years (Hengeveld and Francis 1998). It is unclear how climate change will influence future Atlantic hurricane behaviour. A recent increase in activity

has been noted since 1988 although this was significantly tempered by the El Nino La Nina events. This increase is much more likely to be a function of natural variability than anthropogenic climate change (Goldenburg et al. 1997).

Flooding and coastal erosion. Climate change is likely to affect the frequency and severity of riverine and coastal flooding. Reduced ice cover may enhance the potential for coastal erosion by allowing greater wave action and energy to reach the shore during winter storms. Ice-jam floods such as have occurred in the Saint John River (e.g., 1987 event that destroyed the C.P. Rail bridge at Perth-Andover and the 1973 event that caused over \$12 million damage (Phillips 1990, Hare et al. 1997)) may eventually become less of a problem in southern Atlantic Canada. Rivers in northern areas that usually remain ice-covered throughout the winter may begin to experience winter break-ups and associated flooding (Clair et al. 1997). It was noted that smaller watersheds are more affected by extreme heavy rain events that may become more common under climate change (Atlantic workshop 2000).

Forest fires. Reduced summer soil moisture may support more frequent forest fires, as indicated by slightly higher Fire Weather Index values estimated under climate change for the southern Maritimes, Cape Breton and eastern Newfoundland (Cox 1997). Others studies report that a less severe fire climate should exist in eastern Canada (Canadian Forest Service 1999).

Water Quality

Salt water intrusion. Salt water intrusion could contaminate groundwater aquifers (the main source of regional water supplies), disturb sensitive estuary ecosystems, and displace freshwater fish populations (Environment Canada - Freshwater Series A-9 1999).

Water-borne health effects. Should flooding become more of a problem under climate change, exposure to water-borne disease may also become more common, particularly in agricultural areas.

3.1.5 Management Implications and Adaptation Needs

The previous discussion illustrates some of the potential effects of climate change on the supply and distribution of Atlantic Canada's water resources. Layered onto this are a series of water management implications and possible adjustment strategies that have not been thoroughly investigated or re-examined using the latest climate change scenarios. Coastal flooding from sea-level rise and storm surges appears to be the most significant concern, based on the available literature and media reports (e.g., Schneiderei 1999).

3.1.5.1 Coastal Zones, Floodplains and Soil Erosion

Coastal flooding. Rising sea-level combined with storm surges and reduced sea ice cover may put coastlines at greater risk of erosion (Forbes et al. 1997). A one-metre rise in sea-level, the upper-range of IPCC estimates, would threaten residential, transportation, and industrial facilities with flooding in low-lying communities along the coast, such as Charlottetown and possibly Courtenay Bay (Stokoe et al. 1988). Drowned-valley estuaries of Prince Edward Island, Gulf coasts of Nova Scotia and New Brunswick, and the dyked areas of the salt marsh coast of the Bay of Fundy have also been identified as being susceptible to a combination of sea-level rise, high tides and storm surges (Forbes et al. 1997). It is not a question of if a Saxby gale event, which resulted in near total flooding from Amherst to Sackville in October 1869, will occur – it is only a question of when (Atlantic workshop 2000). Increased temperatures and reduced sea ice may also make the Gulf of St. Lawrence more susceptible to storm surges (Parkes and O'Reilly 1997).

The traditional response to coastal flooding along the Bay of Fundy has been the construction of aboiteaux and dykes. These were built to drain and protect fertile agricultural land located in the coastal marshes but now serve to protect many other land uses and investments, including residential and commercial development, that are far more susceptible to occasional flooding (Robichaud and Kolstee, Atlantic workshop 2000). If more frequent large rainfall events occur and sea level continues to rise, flooding of these lands will be more frequent resulting in greater damage and potential loss of life. Should summer and early autumn flows decline as suggested by some climate scenarios, the aboiteaux control structures may fail more often during the subsequent autumn storm season due to silt accumulation (i.e., lack of flow would prevent flushing of system). Fresh water could flood behind the structure and, by not accommodating some of the storm surge flow from the sea, the pressure of sea water against surrounding dykes would be magnified possibly leading to overtopping or dyke breaches – a recipe for significant damage.

An obvious **adaptation** would be to restrict land development in floodplains, however the tax base represents a large incentive for municipalities to maintain the status quo, especially since the costs of severe flooding are disproportionately borne by other agencies relative to either the municipality or landowners. Ultimately this should be addressed through provincial planning legislation that restricts new floodplain development while maintaining an even 'playing field' for all municipalities (Atlantic workshop 2000). Other measures to manage future flood risk include necessary improvements (upgrades) to dykes and other flood protection infrastructure, preparation/re-tooling of Emergency Measures Organizations and preparedness plans, improvements to tidal gauges/other monitoring tools, floodplain mapping, additional research (e.g., risk assessment) and increasing awareness of the issue among planners, bank officials, developers, politicians and regulators (Atlantic workshop 2000).

Soil Erosion. More intense rainfall, a possibility under climate change, may exacerbate soil erosion in agricultural areas leading to poorer soil and water quality. A range of **adaptive soil conservation tools** were offered during the Atlantic workshop, including the development of Environmental Farm Plan initiatives, Best Management practices, use of precision agriculture and environmental geomatics, research (e.g., soil erosion prediction models) and tax and other incentives to modify farm behaviour (Daigle, Atlantic workshop 2000). Soil conservation, through low tillage for example, also has the potential ancillary benefit of sequestering carbon.

3.1.5.2 Extractive Water Uses

Agriculture. Changes in the frequency and severity of flooding, heavy rain and drought stress are potential concerns to farmers. Each form of agriculture is sensitive to climate in very different ways. Excessive rainfall (>0.25mm/day) in May has been shown to significantly reduce pollination of apple trees while prolonged drought conditions may affect production several seasons after the drought has ended (Privé, Atlantic workshop 2000). It should be noted that the primary limiting factor for agricultural production in Atlantic Canada is heat, thus climate change may provide some benefits to farmers provided there is sufficient moisture during the growing season. One of the possible adjustments to warmer and drier conditions during the growing season by farmers is increased irrigation (Bootsma 1997). Irrigation withdrawals may seasonally stress local groundwater aquifers or streams. Unlike flooding, it is often much more difficult to bring political focus to drought conditions. A longer term approach of developing awareness of drought and coordination of affected interests may be a desirable first step adaptation strategy. This may be best regionally exemplified through the efforts of the Valley Water Group that formed after 3 years of drought in the Annapolis Valley (Webster, Atlantic workshop 2000). Their primary goals are to create a multi-stakeholder water management committee or board (representing many water interests) for the Annapolis Valley, identify agricultural water problems and implement solutions.

Municipal and rural domestic water use. Coastal and riverine flooding, if more frequent and severe under climate change, may place municipal water infrastructure (e.g., treatment and distribution facilities, pumps, wastewater collection and treatment systems) at greater risk of failure and contamination (water-borne disease, saltwater intrusion). Higher demand, but less water availability is what Atlantic Canada will likely have to face in the near future (Grosko, Atlantic workshop 2000). Atlantic Canada municipalities are among the highest consumers of water in Canada (Environment Canada 1996) which may lead to greater impacts should supplies become seasonally unreliable. **Water demand management** (e.g., metering, leak detection, water pricing) and improved levels of wastewater treatment (especially upstream of municipal water intakes) are **possible adaptation strategies** that may reduce the vulnerability to climate change while offering many other economic, health and ecosystem benefits.

3.1.5.3 Non-Consumptive Water Uses

Natural ecological functions. Salt water intrusion, sea-level rise and increased erosion may threaten coastal wetlands. This in turn may affect the ability of coastal marshes to support staging migratory waterfowl and seabirds. While purposeful adaptation options are limited, maintaining or expanding existing buffers around wetlands may assist in their evolution inland.

Fisheries. (note only freshwater impacts considered) Shuter et al. 1998 suggest that if climate change reduces freshwater discharge in the dry season one would expect consequent declines in ecosystem productivity and a decrease in overall sustainable harvests for coastal and estuarine fish populations. Productivity of coldwater freshwater species may also be reduced in southern Atlantic Canada should climate change lower lake levels, streamflow rates, and reduce nutrient loading and recycling for many Canadian shield lakes and streams. Cool and warmwater fish species may constitute a higher percentage of future harvests. The sustainable harvests for most fish species in northern regions may increase with longer, warmer growing seasons and relatively small changes in water levels. A greater diversity of harvestable species might also be expected (Shuter et al. 1998).

Hydro-electric power generation. Hydro-electric power accounted for 95.5%, 9.6% and 20.9% of all 1994 electricity production in Newfoundland, Nova Scotia and New Brunswick, respectively (Sawyer 1997). Sawyer (1997) crudely estimated that for every 10% increase or decrease in annual run-off in Labrador, a corresponding \$73 million increase or decrease could be expected in the value of exported hydro-electric power. Similarly, Stokoe et al. (1988) reported the potential for increased power production if climate change supports greater run-off in Labrador. Concern was expressed that flows in the Churchill River may be lower during summer when the demand for electricity is the greatest (Atlantic workshop 2000). Perhaps more significant is the potential for increased hydro-electric power production to offset more expensive and environmentally harmful carbon-based electricity generation. **Adaptation alternatives** include modifying reservoir operations to capture more water earlier in the season and developing additional storage capacity. Both of these options must be assessed in the context of other uses of water in the system, especially environmental considerations.

3.1.5.4 Water Management Policy and Interjurisdictional Apportionment

Browne et al. (1997) examined the fresh water implications of climate variability and change for several transboundary (Canada-U.S.) watersheds, including the Saint John River that stretches into Maine and Quebec. Although the authors noted the considerable uncertainty in future climate change scenarios and current knowledge of possible impacts, it was felt that the Saint John River would eventually benefit from climate change presumably due to reduced ice cover, ice thickness and associated ice-jam flooding (Browne et al. 1997). However, this benefit may not be fully realized for many

years as recent trends suggest a continued occurrence of flooding albeit through earlier winter break-ups and peak flows (Browne et al. 1997, Hare et al. 1997). Such trends may have implications for future flood risk and mapping programs on both sides of the border. It is unclear how other water concerns such hydropower production and Atlantic salmon fisheries will be affected by climate change.

While other examples of climate change implications for specific water management policies were not found in the literature, one might expect to see the issue incorporated into provincial flood plain and coastal management policies and building code standards.

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3.2 Regional Vulnerabilities and Impacts: Quebec

3.2.1 Regional Characteristics

Quebec is Canada's largest province and over 10% of its 1.5 million km² surface area is covered by freshwater. This represents 3% of the world's freshwater reserves (Government of Quebec 1999). It is thus not surprising that water continues to play an important role in the economy, culture and history of Quebec. The St. Lawrence River is by far the most significant component of Quebec's water resources as over 95% of the population lives within the watershed and almost 70% reside in a 10-km strip on either side of the river's shore (Bergeron et al. 1997).

Descriptions of the Quebec climate are provided by Bergeron et al. (1997) and Phillips (1990). Parts of four climate regions may be found in Quebec: Arctic Tundra, Arctic Mountains and Fjords, Northeastern Forest and Great Lakes/St. Lawrence. Annual precipitation generally increases from north to south and west to east, peaking in elevated areas surrounding the Gulf of St. Lawrence in southeastern Quebec. Climatic variation is a function of latitude, proximity to maritime influences (Gulf of St. Lawrence, Hudson Strait, Ungava Bay and Hudson Bay to a lesser extent), topography (Laurentians, Appalachians) and storm tracks of extra-tropical cyclones and remnants of tropical storms.

3.2.2 Key Water Issues

The key water issues affecting Quebec include riverine flooding, hydro-electric power production and the importance of the St. Lawrence River system and its tributaries to meet multiple in-stream and extractive water demands.

3.2.3 Observed Changes in Climate and Hydrology

Seasonal temperature trends over the 1895-1992 period are listed in Table 3.3-1. Temperatures have generally increased over the past century in all seasons over much of Quebec. The exception to this trend is in northeastern areas where cooling has occurred, as indicated for the Arctic Mountains and Fjords climate region. Ice cover data further illustrates this pattern of warming. Knob Lake in northeastern Quebec has experienced virtually no change or a slight increase in the length of its ice cover season since the mid-1950s while a reduction is apparent for Lac St. Jean in southern Quebec (Environment Canada 1995). With respect to precipitation, Mekis and Hogg (1999) report relatively large increases in rainfall and especially snowfall during the last century in virtually all seasons and climate regions in Quebec. Snowfall has trended downwards however in the Great Lakes-St. Lawrence region. Table 3.3-2 illustrates trends in total precipitation for specific climate regions based on varying observation record lengths.

Table 3.2-1. Seasonal temperature trends in Quebec climate regions (1895-1992)

Climate Region	Winter	Spring	Summer	Autumn	Annual
Arctic Tundra (1922-1992)	1.3	0.1	0.7	0.2	0.6
Northeastern Forest	0.5	0.9	0.5	0.1	0.5
Arctic Mountains and Fjords (1946-1992)	-0.7	-1.6	0.0	-0.7	-0.8
Great Lakes/St. Lawrence	1.1	0.8	0.1	0.4	0.6

bold indicates a statistically significant trend

Source: (Environment Canada 1995)

Table 3.2-2. Total precipitation trends in Quebec climate regions*

Climate Region	Winter	Spring	Summer	Autumn	Annual
Arctic Tundra (1948-1996)	5.6	7.7	0.5	7.4	5.1
Northeastern Forest (1918-1996)	3.1	2.5	1.7	2.6	2.4
Arctic Mountains and Fjords (1948-1996)	0.3	6.2	2.1	1.5	2.4
Great Lakes/St. Lawrence (1895-1995)	-0.3	1.0	1.1	2.6	1.1

*Total precipitation expressed as (mm change/mean) over 10 years [%]

bold indicates a statistically significant trend while underline indicates correlated residuals (Durbin-Watson test failed)

Source: Mekis and Hogg 1999, p. 72.

Mekis and Hogg (1999) have also investigated the occurrence of heavy precipitation events. observed an increase in the fraction of total precipitation falling in heavy events (>90th percentile) over the 1940-95 period for all but the central and extreme northeastern areas of Quebec.

Annual St. Lawrence River streamflow has generally increased over time with significant drops in the 1930s and 1960s and higher flows since the mid-1970s (Hofmann et al. 1998) until late in the 1990s. Much of our knowledge of climate change impacts in the St. Lawrence is derived from studies examining the effects of these historical fluctuations. A dampened interannual and seasonal variation has been noted since the 1960s for the fluvial section of the river (Environment Canada and Government of Quebec 1998a).

Trends in mean annual flows of rivers tributary to the St Lawrence have been generally downwards from 1967-1996 (Zhang et al. 1998). April mean flows tend to be higher and September mean flows are on a lowering trend over this period.

3.2.4 Projected Climate Change

The following discussion is based upon output from experiments conducted by the Canadian Centre for Climate Modeling and Analysis (CCCma 1999) using its coupled ocean-atmosphere model (CGCM1) to determine the effects of rising atmospheric concentrations of CO₂, other greenhouse gases and aerosols on global climate (Boer et al. 1998). Relative to the 1961-90 average, results for Quebec indicate a general warming of 2-3°C in southern regions and a 3-6°C increase in the north and northwest by the middle of the 21st century. A slight cooling trend is projected for the coastal regions of Labrador and north eastern Quebec. Winter (December-February) mid-century temperatures may increase from 2°C along the Gulf of St. Lawrence coast up to 9°C in the extreme northwest. Summer (June-August) mid-century temperatures will generally rise by 2-3°C over the province with increases up to 5°C in the extreme north and north west.

Slight changes in annual precipitation are expected by the middle of the 21st century relative to 1961-90 averages. A small reduction is shown for extreme southern areas while precipitation over the remainder of the province may increase somewhat (trend less than 1mm/day in both instances). These changes in annual precipitation do not shift appreciably in projected magnitude or pattern by the end of the century. The greatest seasonal change occurs in northeastern Quebec where increases approaching 1mm/day may occur during the summer period (2050s and 2080s). Mid-century summer precipitation decreases slightly (0 to 0.2 mm/day) in southwestern Quebec and this trend extends to southeastern areas by century's end. Modest changes in winter precipitation are also expected with all parts of the province showing zero change or nominal increases by the 2080s. Results in Boer et al. (1998) suggest that winter and summer precipitation and soil moisture will remain within 20% of the 1975-95 average, even by the end of the 21st century.

3.2.5 Hydrologic Implications

Several studies have been completed over the past decade that illustrate the potential effects of various climate change scenarios on the hydrology of specific watersheds:

Runoff. Slivitzky and Morin (1996) applied several GCM-based scenarios to determine potential hydrologic implications for the Moisie River. Temperature and precipitation changes ranging from 0.5 to 4.2°C and -4 to +110%, respectively, resulted in rather minor runoff differences of -5 to +11.3% from the base control run. Relative to the base case, total runoff tended to increase due to greater winter precipitation and earlier snowmelt, while decreases in runoff during summer and autumn were attributed to reduced summer precipitation and greater evapotranspiration (Hofmann et al. 1998). A similar pattern has been observed in the past three decades in most of the tributaries of the Ottawa – St. Lawrence system.

Using earlier and cruder versions of GCMs (GISS 1984, GFDL 1980), Singh (1988) estimated changes in runoff for three James Bay area watersheds that are important sources of hydro-electric power. Runoff increases were reported for La Grande River (15.6-16.5%), Caniapiscou River (13.0-15.7%) and the Opinaca-Eastmain River (6.7-20.2%). Such increases are within the current range of interannual variability in net basin supplies (Bornhold 1993). However, a slight decline in flows in the Ungava Bay drainage was observed from 1967-96.

St. Lawrence River streamflow and water levels. The St. Lawrence River is much larger than other Quebec watercourses. It is also different in that its headwaters are dominated by the five Great Lakes whose large storage capacity serve to reduce the river's sensitivity to short-term climate fluctuations. However, this connection also exposes the St. Lawrence River to the longer-term effects of climate change several hundred kilometres west of the Quebec border. Output from the CCCGCMII 2xCO₂ scenario suggests that this more western region of the upper Great Lakes basin could become drier under climate change. Hydrologic studies using output from this GCM indicate that mean flows at Montreal could drop as much as 3,100m³/s from the 1900-1990 average of 8,200m³/s (IJC 1993). Maximum flows would change from 12,800m³/s to 7,600m³/s while minimum flows would drop from 5,900m³/s to 3,300m³/s. Based on the mean annual streamflow reductions, Montreal Harbour water levels could potentially be lowered by approximately 1.25m.

Reduced sea, lake and river ice. Warmer temperatures may reduce the length and severity of the ice seasons in the Gulf of St. Lawrence, St. Lawrence River and further upstream in the Great Lakes (Arctic Sciences Limited 1993; Sanderson 1987). However, warming in the Gulf region is expected to be much less than further west and south.

Permafrost. The depth of the active permafrost layer in northern Quebec will increase, reducing the stability of slopes and infrastructure (Bergeron et al. 1997).

High water levels in the St. Lawrence produce significant benefits for certain uses and environmental components and sometimes yield extreme losses for others. Low water levels have few positive impacts on uses and environmental components and produce negative impacts which can sometimes be significant or extreme (Environment Canada and Government of Quebec 1998a, p. 2).

3.2.6 Extreme Events/Hazards

Flooding. Urban and riverine flooding have historically been significant problems in Quebec with over 167 major floods having occurred between 1865 and 1996 (Bergeron et al. 1997). Federal payouts for Quebec floods since the 1970s, under disaster assistance arrangements have totalled over \$300 million (Environment Canada 1999) and costs assumed by provincial and municipal agencies and individuals are much higher. Few Canadians will forget the compelling and staggering television images of a rampaging Saguenay River that caused over \$1 billion in damages in 1996. Almost 500,000 homes in Quebec are located on or beside one of the province's 4500 rivers or one-half million lakes (Government of Quebec 1999). Rivers in northern Quebec that usually remain ice-covered throughout the winter may begin to experience winter break-ups and associated flooding (Clair et al. 1997) while this may eventually become less of a problem for rivers in extreme southern Quebec. Greater winter precipitation and potential rain-on-snow events may also contribute to additional flooding. As noted in an earlier section, the models project and recent data suggest that climate change may generate more frequent and intense one-day heavy rainfall events. This would translate into more frequent storm sewer overflow in cities and flash floods in small watersheds.

Coastal Erosion. Shaw et al. (1998) estimated the sensitivity of Canada's marine coastlines to inundation and erosion that may stem from sea-level rise. Except where deltaic sediments occur along the Gulf of St. Lawrence, such as those at Rivière Portneuf, Rivière aux Outardes and Rivière Manicouagan, much of Quebec's coastline was classified as having low to moderate sensitivity. Lengthy ice cover periods limiting potential wave fetch and falling relative sea-levels due to isostatic rebound were cited as reasons for the lower sensitivity, especially along the Hudson Bay and Hudson Strait shores (Shaw et al. 1998). Nevertheless, roads in some eastern coastal areas are threatened by erosion (Morneau, Quebec Workshop)

Landslides. Landslides and sinkholes are current features of the southern Quebec landscape, especially where thick, weakly structured glacial sediments exist. Since the occurrence of these slides is strongly related to the presence of saturated ground, changes in precipitation may also alter the frequency of this hazard, with a trend towards heavier one-day rainfalls likely to induce more slides.

3.2.7 Storms

With observations and projections indicating that severe winter storms are likely to be more frequent in a changing climate, preparedness for very heavy snowfalls and freezing rain events should be enhanced.

3.2.8 Water Quality

Salt water intrusion. Projected substantive reduction in freshwater flowing from the St. Lawrence River and a rising mean sea level may allow further upstream penetration of salt water from the Gulf of St. Lawrence with attendant impacts on ecosystems.

Water-borne health effects. Duncan et al. (1998) allude to the potential for increased outbreaks of enteric pathogens such as *Cryptosporidium* and *Giardia*, as well as *e.coli*, as increases in ambient temperatures, prolonged summer seasons and increased heavy rainfall and/or run-off events become more common in watersheds with mixes of intensive agriculture and urbanization. Although much of Quebec's municipal water infrastructure is less than 35 years old, sewer overflow during flood events and infiltration of untreated water into the supply system represent possible pathways for such organisms to affect the urban population. Between 1989 and 1995, 24 epidemics of similar type affecting 800 people via surface water-based municipal systems were reported; over the same period 45 epidemics affecting over 1800 people were noted for groundwater-based collection systems. In both instances it is suspected that only a fraction of actual cases were reported (Government of Quebec 1999). Other concerns relate to reduced summer streamflows and the ability of receiving waters, particularly the St. Lawrence River, to assimilate municipal and industrial wastewater and pollutants from non-point agricultural runoff. More frequent storm water overflow flooding waste water treatment plants, with heavier one day rains, may exacerbate health risks. (Simoneau, Coté, Quebec Workshop)

3.2.9 Water Management Implications and Adaptation Needs

Any hydrologic changes resulting from climate change will be manifested in some form of impact to water-related activities and interests. Many factors contribute to the sensitivity of each interest to climate variability and change. Although a few studies have attempted to outline implications of specific climate change scenarios, most research has only begun to expose the sensitivities and nature of climate-society or climate-ecosystem interactions. Slivitzdy (Quebec Workshop) suggests considering effects under the headings of:

- (i) resource use of water (e.g. energy, withdrawals for industry, municipalities and agriculture), and
- (ii) life support uses for ecosystems.

3.2.9.1 Water as a Resource

Agriculture. Quebec irrigated only about 1% of its cropped area in 1988 and future likely increases in precipitation and soil moisture are generally expected to reduce the need for additional supplementary irrigation of crops (Hofmann et al. 1998). The exception might be in southwestern Quebec where warmer and drier conditions as suggested by some climate change scenarios would limit crop growth unless countered

with irrigation (Singh 1988). Clearly crop choice and value will also be important influences on future irrigation requirements. Irrigation is currently only a major contributor to reduced surface water flows in a few areas, such as the Bécancour River and the Yamaska River where water demands can exceed supplies by up to 160% of the available streamflow during very dry conditions (Government of Quebec 1999).

Forestry management. Drought years are highly correlated with bad forest fire seasons such as 1983 and 1991 when over 230,000 and 375,000 hectares of forest were burned, respectively (Bergeron et al. 1997). Other sources suggest that a less severe fire climate may result from climate change in eastern Canada (Canadian Forest Service 1998).

Municipal and rural domestic water use. Approximately one-half of all surface water abstractions in Quebec are for municipal water systems that supply water to over 5.5 million residents (Government of Quebec 1999). Although consumptive uses have negligible impacts on the St. Lawrence (Environment Canada and Government of Quebec 1998b) and conflicts occur very infrequently in such a water-rich landscape, reduced flows have been identified as a problem in a few systems, including the Saint-Charles River that provides water to the City of Quebec. (Coté, Quebec Workshop) Municipal systems or private wells that are reliant on groundwater service the remaining Quebec population. Though not widespread, evidence of emerging conflicts and impacts of groundwater withdrawals on surrounding wells, springs, wetlands, and rivers or lakes has become apparent in recent years in the Saint-Omer, Baie des Chaleurs, and Sainte-Thérèse-de-Blainville regions (Government of Quebec 1999). Under climate change, Lamothe and Périard (1989) estimate that the demand for lawn watering will increase by 20-30% thus increasing general municipal water use and abstractions from surface and groundwater sources. On Iles de la Madeleine groundwater supplies are under stress in spite of initial demand management efforts. Any decline in precipitation or salt water intrusion could cause serious problems (Nadeau, Quebec Workshop). **Greater efforts at demand management and water conservation measure would be useful adaptation strategies.**

3.2.9.2 Non-Consumptive Water Uses - Ecosystems

Natural ecological functions. Salt water intrusion, sea-level rise and increased erosion may damage certain coastal wetlands. Reduced flows and restricted flow ranges may threaten wetlands along the shores of the St. Lawrence River that require periodic inundation and drying to remain productive. In the fluvial section and fluvial estuary portions of the St. Lawrence (up to Quebec City), the stress of climate change would be coupled with significant urban sprawl and development (Environment Canada and Government of Quebec 1998b). **Adaptation needs include reduction of other stresses on wetland ecosystems.**

Freshwater fisheries. Shuter et al. (1998) suggest that if climate change reduces low flow season freshwater discharge one would expect consequent declines in ecosystem

productivity and a decrease in overall sustainable harvests for coastal and estuarine fish populations. Productivity of coldwater freshwater species may also be reduced in southern Quebec, particularly if climate change caused lower lake levels, and summer streamflow rates. Abundance of Atlantic salmon parr was shown to be related to seasonal streamflow for a sampled Quebec river (Regier and Meisner 1990 as reported in Hofmann et al. 1998). Cool and warmwater fish species may constitute a higher percentage of future harvests. The sustainable harvests for most fish species in northern regions may increase with longer, warmer growing seasons and relatively small changes in water levels. A greater diversity of harvestable species might also be expected (Shuter et al. 1998). **Adjustments of fishing quotas by species could be a valuable adaptation.**

Hydro-electric power generation: Quebec Hydro's 49 hydroelectric generating stations (plus Churchill Falls) account for over 94% of the Province's available electricity generating capacity (Hydro Quebec 1999). Hydrologic variability can affect Quebec Hydro's bottom line in a range of loss of \$1 billion to a gain of \$426 million over two years. Mercier (1998) notes that hydroelectricity production in northern Quebec (James Bay) and Labrador (Churchill Falls) could benefit from climate change through the availability of additional water supplies although Fortin noted that current supply levels are below normal over much of their region. Singh (1988) estimated the increased James Bay capacity could provide an additional 9 TWh of electricity generation. However, the Beauharnois power development at the outlet of Lake Saint-François, which represents about 7% of Hydro-Quebec's production, is dependent upon St. Lawrence River flows. If St. Lawrence flows fall under climate change as indicated previously, production at Beauharnois could be reduced by as much as 38% (Hofmann et al. 1998) and, coupled with losses at other St. Lawrence plants, this may offset gains in other areas. Quebec may also reap the benefits of additional energy exports should other provinces (most notably Ontario) and U.S. states lose some capacity to produce hydro-electric power. Comprehensive, system-wide adaptation strategies will await more reliable climate projections at a scale that can be linked to hydrologic models.

Port and transportation facilities. The Ports of Montreal and Quebec generate over \$1.7 billion and \$350 million in annual revenues (Government of Quebec 1999). The Port of Montreal is particularly sensitive to harbour water levels. During the 1988-1991 period, a 30 centimetre reduction in water levels resulted in a 15% decrease in the tonnage handled by the Port (Hofmann et al. 1998). Lower levels under climate change would exert similar effects as well as induce additional dredging requirements (Environment Canada and Government of Quebec 1998a). Reduced ice cover on the Great Lakes and St. Lawrence may allow for an extension of the shipping season by 1-3 months (Sanderson 1987). Together, these possible climate change effects may alter the competition among Great Lakes-St. Lawrence ports. **Increased dredging may become a necessary adaptation**

3.2.9.3 Interjurisdictional Water Management Policy and Potential Conflicts

Water regulation and binational management. The Great Lakes-St. Lawrence system is partly regulated and many of the institutional mechanisms currently in place reflect a need to address excessive supplies, water levels and flows (Browne et al. 1998). Mortsch and Quinn (1996) suggest that this management paradigm may need to shift to accommodate concerns over water scarcity and significant declines in future water supplies associated with potential climate change. Mechanisms such as Criterion (k), an emergency provision in the IJC regulation plan for Lake Ontario-St. Lawrence River operations that accommodates both exceedingly high and low supplies (Bourget and Clamen 1998), are examples of what may be needed under climate change conditions to protect both upstream and downstream interests. Future amendments must be coordinated with other regulation criteria, such as for the Ottawa River and Beauharnois-les Cédres complex. With the uncertainties associated with water resources in a changing climate and the distinct possibility of lower levels in the Great Lakes and flows on the St. Lawrence, **great caution should be exercised in connection with major diversions or bulk transport of water from basins in and affecting Quebec.**

3.2.10 Initial Approaches to Adaptation

It is evident that in connection with managing for a number of water uses, and with preparedness for extreme climate and water events, society in Quebec is not yet well adapted to the variability already experienced. As the workshop participants concluded, “If we are prepared for extremes in natural variability in weather events, we should be prepared for climate change. The fact that we have not been prepared up to now shows that we are presently not prepared for climate change.”

Adaptations that should be considered of high priority are:

- a) **a contingency plan for coping with reduced flows on the St. Lawrence,**
- b) **improved preparedness measures for floods and storms including long term disaster mitigation actions, and**
- c) **careful control of sources (agricultural and municipal) of potential bacterial and chemical contamination of water supplies in the face of higher temperatures and more intense rain events.**

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3.3 Regional Vulnerabilities and Impacts: Ontario

3.3.1 Regional Characteristics

Southern Ontario is an highly urbanized, heavily industrialized region but also a significant agricultural base. Conversely, northern Ontario is a sparsely settled region with a resource-based economy (mining, forestry, pulp and paper). Two ecoregions span Ontario – Great Lakes/St. Lawrence and Northeast forest. In Ontario, snow accumulation and melt play an important role in the hydrology of the region.

3.3.2 Key Water Issues

Water management issues are very complex in the south. Issues include: flooding and erosion protection, water apportionment, protection and securing of surface and ground water supply, and water quality protection and remediation (urban runoff, agricultural non-point source pollution, nutrient enrichment and toxic chemicals). Within the Great Lakes basin there are major hydro-power developments and significant consumptive uses including irrigation, public water supply, industrial processes, fossil fuel and nuclear thermoelectric generation and livestock watering. Many competing interests including human and ecosystem health and economic development must be balanced. In the north, ecosystem effects of resource development especially forest harvesting and hydro-power dominate water resources management concerns.

3.3.3 Observed Changes in Climate and Hydrology

Temperature and Precipitation

Seasonal temperature trends for the period 1895-1992 are listed in Table 3.3-1. 1998 was the warmest year in the Great Lakes / St. Lawrence Lowlands (+2.3°C) and Northeastern Forest (+2.1°C) ecoclimatic regions. There is a significant increase in total annual precipitation for most ecoregions of Canada (including the Northeastern Forest and the Great Lakes/St. Lawrence Lowlands); snow also shows a significant upward trend (see Table 3.3-2). However, in the Great Lakes/St. Lawrence Lowlands there are statistically significant declines in annual and spring snow combined with statistically significant increases in annual and spring rain.

Evaporation

Twenty years (1970-1990) of data for the Experimental Lakes Area (ELA) in northwestern Ontario illustrate the relationship between temperature and evaporation in small boreal lakes and streams. During this period, air temperature increased by 1.6°C, precipitation decreased and average annual evaporation increased by approximately 50%. The ELA region is in the extreme western part of Northern Ontario near Kenora. Thus,

temperature and precipitation trends are more typical of the Prairies than of the Northeastern forest ecoregion. Evaporation increased by an average of 35 mm/1°C increase in annual air temperature or 68 mm/1°C increase in summer air temperature (Schindler *et al.*, 1990; Schindler *et al.*, 1996). For the twenty-year record, evaporation increased by an average of 9 mm/year. This had significant effects on physical, biological and chemical process in lakes and streams because of reduced flow through the system and higher water temperatures.

Lake Levels

Historically, annual mean water levels in the Great Lakes have had a range of about 1.8 m from record maximum to minimum levels. Low levels occurred in the mid-1920s, mid-1930s, and early 1960s. High levels occurred in 1929–30, 1952, 1973–74, 1985–86, and 1997–98. Since the 1970s, the Great Lakes have been relatively high culminating in record water levels in 1986. A drought from 1987-1990 caused major declines in lake levels but most lakes remained above their long-term averages. A more severe drought in 1998-99 caused all the Great Lakes to fall below average by mid-1999, to their lowest levels in 30 years. Great Lakes levels declined dramatically; Michigan-Huron dropped 57 cm in one year.

Streamflow

Forty-one hydrometric stations in Ontario with a minimum of 30-years of data ending in 1990 were analysed by Ashfield *et al.* (1991). Mean monthly flows increased for the period September to January in over 50% of the stations while approximately 25% of the stations show a downward trend in flow for the April to September period. Increasing low flows were shown in 35% of the stations. Anderson *et al.* (1991) analysed low, average and maximum flow time series for 27 stations (unregulated flow) across Canada; the data indicated a decrease in summer low flow, an increase in winter average and low flows but little trend in maximum flows.

Lake Ice

Ice breakup dates for 20 Wisconsin lakes from 1968 to 1988 were examined (Anderson *et al.* 1996). There was a general trend toward earlier breakup dates, 9 days for northern lakes and 14 days for southern lakes, suggesting recent warming. Interannual variation in breakup dates was related to the warm phase of El Niño; breakup days were 5 to 14 days earlier in the mature phase of these events when winter air temperatures were warmer than normal. Schindler *et al.* (1990) found a 20-day decrease in ice duration on Lake 239 in the ELA for the period 1969 to 1988 while Schindler *et al.* (1996) found an overall 15-day decrease in the ice duration since 1970 in the ELA. These recent trends have been attributed to earlier breakup, higher spring air temperatures and below average snow cover (Schindler *et al.*, 1996; Skinner, 1993). Williams (1971) identified a trend toward earlier ice break-up and shorter ice duration for the Great Lakes from 1870-1940,

but found no significant trend from 1940-1971. Hanson *et al.* (1992) detected a significant trend toward earlier break-up from 1965-1990 on the Great Lakes (except Lake Ontario, which experienced a less significant trend).

**Table 3.3-1. Selected Regional Temperature Trends (change in temperature over period of analysis)
Environment Canada, 1995**

Region	Period	Annual	Winter	Spring	Summer	Autumn
Great Lakes Basin/St. Lawrence Lowlands	1895-1992	+0.6	+1.1	+0.8	+0.1	+0.4
Northeastern Forest	1895-1992	+0.5	+0.5	+0.9	+0.5	+0.1

Bold field: trend is statistically significant.

Table 3.3-2. Precipitation Trends* in Ontario (Mekis and Hogg, 1997; 1999)

Region	Period	Annual			Winter			Spring			Summer			Fall		
		Total	Snow	Rain	Total	Snow	Rain	Total	Snow	Rain	Total	Snow	Rain	Total	Snow	Rain
Great Lakes / St. Lawrence Lowlands	1895-95	1.1	-1.8	2.2	-0.3	-1.5	2.6	1.0	-3.8	2.6	1.1	-	1.1	2.6	-0.1	2.9
Northeastern Forest	1918-96	2.4**	4.3	1.3	3.1	3.0	6.2	2.5	4.6	0.5	1.7	-	1.6	2.6	6.2	0.9

*Unit: (mm change / mean) over 10 years

If mean < 5 mm, trend not computed

Bold fields: Trend is significant

Gray area: Residuals are correlated (Durbin-Watson test failed)

**Note – denoted as significant in Mekis and Hogg, 1997 and not significant in Mekis and Hogg, 1999

3.3.4 Projected Climate Change

The Great Lakes are one of the few regions in Canada that have had scenarios from transient runs of GCMs used for climate impact assessment. Tables 3.3-3 and 3.3-4 summarize temperature differences and ratios of precipitation changes relative to the base period of 1961-90 from the ensemble transient runs of the CCCma (CGCM1) and Hadley (HadCM2). The CCCma model appears to be much warmer and a little drier than the Hadley model. The HadCM2 model scenarios are wetter in the critical summer and autumn periods. Although as presented in Chapter 1, CCCma scenarios are actually in the mid range for temperature increase and have less precipitation increase than other recent climate models. The HadCM2 results are very conservative in temperature increase relative to the other scenarios and have more precipitation increase. The later HadCM3 temperature and precipitation changes, in summer, are similar to the CCCma scenario particularly in 2050 and 2080. This lends support to the result of a lowering of Great Lakes levels as in the CCCma scenario rather than minor increases given for that from HadCM2.

Table 3.3-3. Scenarios of Temperature Change (°C) for GCM Transient “Enhanced Greenhouse Effect with Aerosol Runs” in the Great Lakes – St. Lawrence Basin

GCM	Winter	Spring	Summer	Autumn
CCCma 2030	1.3-4.0	1.1-3.2	1.2-2.9	1.1-2.3
CCCma 2050	1.8-5.0	1.7-4.4	1.7-4.0	1.7-3.1
HadCM2 2030	1.2-2.0	0.8-1.1	0.6-1.0	0.9-1.3
HadCM2 2050	1.7-2.7	0.8-1.3	1.0-1.4	1.4-1.6

Note: 2030 – represents average of 2021-2040; 2050 – represents average of 2041-2060

Table 3.3-4. Projected Changes in Precipitation in Transient GCM ‘Enhanced Greenhouse Effect with Aerosols’ Scenarios (Ratio of Change)

GCM	Winter	Spring	Summer	Autumn
CCCma 2030	0.9-1.1	0.9-1.1	0.9-1.1	0.9-1.0
CCCma 2050	0.9-1.1	0.9-1.2	0.8-1.1	0.9-1.1
HadCM2 2030	1.0-1.1	0.9-1.1	1.0-1.2	1.0-1.2
HadCM2 2050	1.0-1.2	0.9-1.1	1.0-1.2	1.0-1.3

Note: 2030 – represents average of 2021-2040; 2050 – represents average of 2041-2060

Evaporation

In the Great Lakes Basin, Cohen (1986), Sanderson (1987) and Croley (1990, 1992) found that evapotranspiration significantly increases due to the warming in the 2xCO₂ climate change scenarios. Higher evapotranspiration offsets higher precipitation in climate change scenarios for the Great Lakes Basin (Croley, 1990). Sanderson and Smith (1993) applied Thornthwaite's empirical technique and three climate change scenarios to the Grand River watershed and found a 20-30% increase in potential evapotranspiration and an average evapotranspiration increase of 16.7% in the Basin for these scenarios much larger than any projected precipitation increases.

3.3.5 Hydrologic Implications

Runoff

Two studies have assessed the hydrological impacts of climate change scenarios on two southern Ontario watersheds using the older equilibrium 2xCO₂ scenarios. Runoff in the Grand River Basin decreased -11%, 21% and 22% (GISS87, GFDL87, and CCC92, respectively) (Sanderson and Smith, 1993; Smith and McBean, 1993). In the Bay of Quinte watershed, annual runoff decreased by 12% with temperature changes from 1.6 to 9.6 °C. The runoff in this watershed shifted from a typical pattern of cold-frozen low flow winter with snow stored on the ground followed by a rapid snowmelt and spring freshet to a 2xCO₂ pattern where snowfall was partly replaced by more winter rain, frequent runoff events and a minor spring freshet. Snowcover in the basin decreased. Drought frequencies increased but the extreme high flow rates remained the same in the projection. (Walker, 1996)

Groundwater

McLaren and Sudicky (1993) examined possible climate change impacts on groundwater (using 2xCO₂ GISS87, GFDL87, and CCC92 scenarios) in a portion of the Grand River basin. The modeling indicated that a reduction in the rate of recharge of 15% to 35%; projected drawdowns ranged from 2 to 7 m. Climate change is expected to exacerbate recharge, drawdown and groundwater supply problems. Rural domestic water could be seriously affected particularly those uses reliant upon shallow dug wells (McLaren and Sudicky, 1993). During dry spells, competition and conflict between rural users of ground water and surface water emerge. Ground water supplies are particularly vulnerable (Kreutzwiser, 1996). There has been conflict over rural water supplies for use in urban areas in Ontario (Hofmann, 1996, Leadlay, 1996).

Ground water management is hampered by a lack of inventories on ground water quantity, quality and withdrawals.

Great Lakes Levels

The hydrologic impacts of scenarios of climate change for the Great Lakes – St. Lawrence Basin suggest lower Great Lakes levels and outflows (see Table 3.4-5) except the older Hadley 2 model scenarios which suggest little change in levels and flows by 2090. For Lake St. Clair, the CCC GCMII 2xCO₂ scenario projected a mean water level decline of 1.6 m and a displacement of the shoreline 1-6 km lakeward. The surface area decreased 15 percent and lake volume 37 percent (Lee *et al.*, 1996). Also of concern is the exposure and dredging of toxic sediments and their remediation (Rhodes and Wiley, 1993).

Responses to adapt to large changes in lake levels in developed areas would be costly. Changnon (1993) estimated the costs for dredging, changing slips and docks, relocating beach facilities, extending and modifying water intake and sewage outfalls for a 110 km section of the Lake Michigan shoreline including Chicago to range from \$US 298 to \$US 401 million for a 1.3 m decline and \$US 605 to \$US 827 million for a 2.5 m decline in water levels.

Commercial navigation, recreational boating and marinas, municipal water supply, hydroelectric generation, shoreline infrastructure, and ecosystem functioning (wetlands) aquatic habitat and ecosystem protection are sensitive to water level and flow changes (Changnon, 1989, 1993, 1994; Hartmann, 1990; Lee *et al.*, 1994; Marchand *et al.*, 1988; Mortsch, 1998; Rissling, 1996; Sanderson, 1987). Record low water levels occurred in the 1960's and 1930's but since the 1970's, water resources management in the Great Lakes basin has focused on extreme high water level and flow issues instead of the impacts of extreme low levels and flows. **Drought contingency plans should be developed.**

Great Lakes Ice Cover

Assel (1991) applied a freezing degree-day and ice cover model to Lake Erie and Lake Superior under 2xCO₂ warming scenarios (U.S. EPA, 1989). A lack of significant mid-lake ice formation and a reduction in the ice cover duration of 5-13 weeks on Lake Superior and 8-13 weeks on Lake Erie was projected.

Table 3.3-5. General Circulation Model (GCM) Scenario Impacts on the Great Lakes (see notes para 3.3.4 & Chapter 1 concerning CCCma, HadCM2 and later HadCM3 model results)

Lake/River	Equilibrium 2xCO ₂ GCM scenarios				Transient GCM scenarios			
	CCC	GFDL	GISS	OSU	CCCma 2030	CCCma 2050	HadCM2 2030	HadCM2 2050
Change in mean annual runoff (%)								
Superior	-12	-26	-2	-8	-5	-8	0	0
Michigan	-38	-27	-24	-14	-12	-15	+4	+4
Huron	-36	-19	-29	-9	-7	-10	+2	+2
Erie	-54	-22	-41	-19	-23	-28	+4	0
Ontario	-34	-28	-33	-7	-10	-15	+3	+1
Mean annual outflow changes (%) from base case								
Superior	-13	-	-2	-19	-11	-17	+1	0
Michigan-Huron	-33	-	-25	-20	-16	-22	+3	+2
Erie	-40	-	-32	-23	-19	-25	+4	+2
Ontario	-39	-	-	-	-18	-25	+4	+2
St. Lawrence at Montreal	-40	-	-	-	-	-	-	-
Mean annual water level changes (m) from base case								
Superior	-0.23	-	-0.46	-0.47	-0.22	-0.31	+0.04	+0.02
Michigan-Huron	-1.62	-2.48	-1.31	-0.99	-0.72	-1.01	+0.14	+0.10
Erie	-1.36	-1.91	-1.16	-0.87	-0.60	-0.83	+0.11	+0.06
Ontario	-1.30	-	-	-	-0.35	-0.53	+0.25	+0.15
St. Lawrence at Montreal	-1.30	-	-	-	-	-	-	-

(sources: Quinn and Lofgren, 1999; Mortsch and Quinn, 1996; Croley, 1990;1992; Hartmann, 1990)

CCC – Canadian Climate Centre - Equilibrium 2xCO₂ run. Boer *et al.*, 1992; McFarlane *et al.*, 1992

CCCma – Canadian Centre for Climate Modelling and Analysis – **Transient Run**. Boer *et al.*, 1998a,b; Flato *et al.*, 1998

GFDL – Geophysical Fluid Dynamics Lab - **Equilibrium 2xCO₂ run** - Manabe and Wetherald, 1987

GISS – Goddard Institute for Space Studies - **Equilibrium 2xCO₂ run** - Hansen *et al.*, 1983, 1984

HadCM2 – Hadley Centre – **Transient run**.

OSU – Oregon State University - **Equilibrium 2xCO₂ run** - Schlesinger and Zhao, 1988

3.3.6 Water Quality

In a region where population growth, urbanization and industrial development currently stress water quality, climate change will be an additional stressor. Lower stream flows reduce assimilative capacities of streams and while pollutant loadings may remain constant their concentrations in water will increase. Warmer air temperatures lead to an increase in water temperature, a reduction in the frequency of water column turnover, a reduction in dissolved oxygen, and changes in nutrient cycling. Fish and other aquatic organisms are affected. Algal blooms become more frequent leading to taste and odour problems in municipal water supply. Changing water conditions may allow the increased growth and survival of certain opportunistic micro-organisms. **The potential emergence and resurgence of infectious diseases such as cholera and toxic E. coli mean that there is a need for investment in better barriers and water treatment** (Heathcote, Ontario Workshop).

Volatilization of toxic chemicals from the water surface may become an issue with warmer temperatures allowing widespread airborne transport over long distances (Mortsch and Mills, 1996). Lower lake levels expose sediments and necessitate dredging of shipping lanes and ports and harbours. Disposal of contaminated dredge material is a contentious issue (Rhodes and Wiley, 1993).

Through the Great Lakes Water Quality Agreement (GLWQA) 43 Areas of Concern (AOCs) have been identified in the Great Lakes Basin. Remedial Action Plans (RAPs) are being developed and implemented to restore lost beneficial uses of the AOCs. The success of the RAP efforts will be affected by hydrologic impacts of climate change. For example, reduction in seasonal flow and winter rainfall and erosion events make it difficult to meet Quinte RAP phosphorus loading targets in some catchments of the Bay of Quinte watershed (Walker, 1996). Water quality improvement (e.g. phosphorus concentrations) was due to investments in effluent treatment, agricultural conservation practices, and urban stormwater management. Under climate change scenarios these phosphorus improvements could be neutralized. **RAPs and Lakewide Management Plans (LaMPs) must take into account climate change effects.**

3.3.7 Water Management Implications and Adaptation Needs

Within the Great Lakes basin and the wider North American, and global context, lakes Superior, Michigan-Huron, Erie and Ontario are perceived as an abundant, high-quality source of water. In the region, a growing population, economic development and water quality problems (surface and groundwater) and water supply and demand mismatches, will lead cities and regions to increasingly explore the Great Lakes as sources of long-term, reliable supplies of water.

Water Diversions

Diversion and bulk transport of water from the Great Lakes is contentious. However, projected lower Great Lakes levels (see Table 3.3-5) due to climate change, will affect security of supply and increase the need for caution. Concerns include the long-term environmental and jurisdictional implications of transfer of water from one lake watershed of the basin to another, and to outside the basin. The City of London and Chatham-Kent, Ontario currently use a pipeline to Lake Huron for water supply; Alliston, Ontario is completing a pipeline from Georgian Bay to secure high quality drinking water. Waterloo and Halton Regions have investigated the feasibility of a pipeline to the Great Lakes as a solution for long-term, sustainable water supply (Sanderson, 1991; Thompson, 1999). Pleasant Prairie, Wisconsin, and Akron, Ohio, are located outside the Great Lakes Basin and return flows would be lost to the Great Lakes. But these communities have obtained permission, under U.S. law, to take water from the Great Lakes. Diversion proposals have included bulk transport of water from Lake Superior to international markets (Toronto Star, 1998); increasing flow of the Chicago diversion to augment low flow in the Mississippi river during the 1988 drought (Changnon, 1994; Changnon and Glantz, 1996); and withdrawal of water from Lake Huron for the Mud Creek irrigation district in Michigan (IJC, 1999). Climate change and its implications for significant changes in water supply reinforces the need for caution and policies on bulk transfers and diversions of water.

The 1985 Great Lakes Charter is a non-binding, arrangement between the Great Lakes states and the provinces of Ontario and Quebec to foster cooperative planning and management of the water resources of the Basin. According to the Charter, major diversions and consumptive uses (greater than 19 million liters per day in any 30-day period) should not be undertaken without prior notification of and consultation with other parties. However, the Charter does not require the consent of all Great Lakes states and provinces before allowing a new diversion or consumptive use to proceed and it does not establish criteria for when consent should be given or withheld (IJC, 1999). **The stresses of climate change make coordinated binational management of Great Lakes waters (as well as other boundary waters) more imperative.**

Water Apportionment and Allocation

Water resources in Ontario have many potential uses; trade-offs must be made between various uses. What are the mechanisms for allocating water, monitoring use and addressing conflicts? For example, there are competing preferences for water release or storage between upstream and downstream interests in the regulation of Lake Ontario. Recreational boating and cottaging interests in Lake Ontario want to maintain lake levels while the Port of Montreal

and other downstream interests want to maintain minimum flow requirements to ensure draft for vessels in the Port of Montreal and for ecosystem protection in the Estuary and Gulf of St. Lawrence. The Lake Ontario Board of Control of the International Joint Commission is proposing reexamination of the Lake Ontario regulation plan to include additional interests as well as the inability of the regulation plan to accommodate the low lake level and flow conditions presented by climate change scenarios (Lee et al., 1994). Significantly reduced lake levels and flows may require changes to the Niagara Treaty and to the Lake Superior and St. Lawrence River Orders of Approval and is virtually certain to generate the need for new regulation plans, including public hearings and environmental impact assessments (Cuthbert and Moulton, 1999).

Low-flow conditions are particularly difficult to manage because of the many competing interests of waste assimilation, municipal drinking water supply, recreation, water taking for irrigation and industrial needs as well as instream environmental needs that must be accommodated (Brown et al. 1996; Southam et al., 1997). Some watersheds do not have the infrastructure of reservoirs and control structures whereas others can use these structures to manage for low and high flow. **The climate change scenarios suggest that water managers will have to develop contingencies for more extremes in climate and hydrology.** They should commit to ongoing drought and flood preparedness and continually invest in the planning for these extreme “events” (Minshall, Ontario Workshop).

Agricultural demand for livestock watering and irrigation water increase in climate change scenarios. Brklacich (1990) assessed the moisture stress of 3 crops with climate change scenarios and reported an increase in irrigation demand for SW Ontario to maintain yields. Municipal water demand often peaks in the summer due to lawn and garden watering; climate change scenarios suggest an increase in municipal demand (Lamothe and Périard, 1989).

Water allocation arrangements (e.g., permit to take water) and policy guidelines need to be evaluated. In Ontario, at present, there are no legally binding set of priorities and methods for allocating water among the various water uses. Smaller municipalities, especially those reliant on ground water and rivers, may not have the capacity to respond. Instream ecological uses (e.g., fisheries habitat) are vulnerable to being overshadowed by economically beneficial uses. Climate change suggests that Ontario will be more vulnerable to drought; provincial and municipal drought preparedness needs to be assessed and responses developed (Kreutzwiser, Ontario Workshop).

3.3.8 Navigation and Recreational Boating

With low lake levels and less flow, Great Lakes shipping costs could increase significantly because of reduced drafts in shipping channels, extended waits at locks and increased dredging costs. Problems with reduced draft are expected in the St. Lawrence River and Montreal harbour. The viability of the St. Lawrence Seaway operation may be at considerable risk. Some of the costs may be offset by a longer shipping season with less ice (Marchand et al., 1988; Cuthbert and Moulton, 1999). Dredging of shipping channels and harbours may be required.

Recreational boating and fishing are significant economic activities in the lower Lakes that would be adversely affected by an increased frequency of low levels. Private docks may need to be extended, and some marinas, launching ramps, boat storage facilities and fishing areas may become unusable for periods of time. Damage to boats from hitting shoals and channel bottoms would increase. Inadequate depths in channels and problems with dock access would require expenditures for dredging or acceptance of loss of use (Rissling, 1996; Cuthbert and Moulton, 1999).

For the Bay of Quinte watershed, using transient CCCma scenarios, annual average flow in selected watersheds would decrease in 2030 by 7-12%, in 2050 by 12-22%, and in 2090 by 9-21%. Summer declines in flow are greater. They are 16-30% in 2030, 24-51% in 2050, and 28-63% in 2090. Recreational boating in the Trent-Severn Waterway would be seriously affected. **Much more investment in infrastructure and ongoing management would be required to allow intensifying recreational use.**

3.3.9 Hydroelectric Generation

Hydroelectric power generation capability is affected by streamflow reductions in the connecting channels of the Great Lakes and inland rivers. For example, record low levels and flows in the 1960s caused hydropower losses of between 19 percent and 26 percent on the Niagara and St. Lawrence Rivers (IJC, 1999). Niagara production is sensitive because of Niagara Treaty requirements for fixed scenic flow requirements over the Falls. There may be pressures to revise this Treaty and reduce scenic flow allocations.

Reduction in hydropower generation capability would affect regional electricity rates and cause reductions in air quality and a rise in greenhouse gas emissions as fossil fuel power generation facilities are used offset these reductions.

3.3.10 Wetlands

Although periodic water level fluctuations and cycles of wet and dry years are necessary to maintain wetland diversity, climate change could disrupt the functioning of wetland ecosystems and impair their multifunctional values (Mortsch, 1998; Poiani and Johnson, 1991,1993a,b). Great Lakes wetlands are vulnerable to a decline in mean lake levels and a change in the seasonal progression of high and low periods. Marshes, for example, adapt more readily to lower levels than swamps because their dominant vegetation could colonize quickly. Enclosed and barrier shoreline wetlands and inland wetlands would be vulnerable to drying. Open shoreline wetlands are not constrained from migration but colonization is limited by suitable substrate, shoreline slope and seed banks. Wetland securement and remediation planning need to consider implications of climate change.

3.3.11 Initial Approaches to Adaptation

The general agreement of participants at the Workshop was that Ontario is more vulnerable now to climate change effects in the water sector than 10 years ago because of changes in policy and funding at senior government levels.

Workshop participants were asked to consider how we might adapt to the impacts of climate change in order to secure water quality and supply in the future. The discussion groups generated numerous adaptation ideas although none were prioritized. Many of these actions are proactive and can be done today to adapt to the anticipated impacts of climate change. All adaptation measures identified are “no regrets” measures, i.e. worth doing anyway. Climate change is one more reason for doing them. These ideas include:

- **Reviewing the standards for floodplain management given changing flood risks, include “naturalizing” flood plains and headwater areas**
- **Preparing water budgets for watersheds to identify the connections between surface and groundwater, areas of vulnerability to water takings and to determine limits for water extraction**
- **Introducing water reuse and efficiency policies, encouraging new technologies which reduce water consumption, and decreasing subsidies to industries that promote high water use**
- **Introducing water conservation programs to assist landowners in protecting and enhancing the landscape’s ability to hold water**
- **Redefining water quality standards and improving waste water treatment**
- **Improving contingency plans for extreme events (drought and flood)**

- **Encouraging best management practices in rural areas to reduce sources of pollution and to re-vegetate riparian corridors**
- **Protecting existing wetlands and creating new wetlands to retain and filter water**
- **Encouraging community-based environmental stewardship**
- **Developing areas of excellence where programs and projects illustrate sustainable use of water**

References: See at end of Section 3.5

Changnon, S. A. and M. H. Glantz, 1996. "The Great Lakes diversion at Chicago and its implications for climate change," *Climatic Change*, 32:199-214.

Sanderson, M. (ed.), 1991. *Water pipelines and diversions in the Great Lakes Basin*, Department of Geography publication series. Occasional paper No. 13, University of Waterloo, 119pp.

See also References at the end of Chapter 3, Section 3.6.

3.4 Regional Highlights - The Prairies

3.4.1 Context

The climate of the southern portion of the Prairie Provinces is such that the annual evaporation normally exceeds precipitation and the region is vulnerable to droughts and soil moisture deficits. Streamflow is variable from year-to-year and except for the Red/Assiniboine River system, much of the source is glacier melt and melting of snow in the foothills and mountains. Peak flows occur in early summer and low flow in winter.

The central and northern portion of the Prairie Provinces receives more precipitation and generally has adequate soil moisture. In addition to drinking water and waste assimilation, a large portion of water is used for irrigation, power generation (thermal), ecological functions and recreation.

3.4.2 Key Water Issues

The key water issues in the region include low river flows in the summer, flooding, especially in the Red/Assiniboine River basin, and hydroelectric power production.

In many basins, the water resources are fully allocated and drought periods exacerbate supply-demand conflicts. Under these circumstances the management of the supply becomes a critical issue, locally, interprovincially and internationally.

3.4.3 Climate Change Projections and Observed Climate and Hydrologic Trends

3.4.3.1 Climate Change Projections

Climate change projections from the CCCma model (CGCM1) show a region of significant warming in the continental interior of North America. For the southern Prairies, the annual average temperature increase in 2040-60 relative to 1970-1990 is 3-5 °C while the increase in the northern part of the Prairies is 5-10 °C. The winters in particular are expected to be much warmer.

There is not much overall change in the outlook for precipitation in the Prairies. In the south the projections are for more rain in the spring with little change during the summer. Combined with higher temperatures the result is likely to be lower total flow, lower minimum flows and lower average-annual peak flow, a trend that has been observed over the past 3 decades. In the north, both winter and summer rain may increase but combined with temperature and evaporation increases, the result may be little change in flow. However, the balance between

precipitation, temperature and flow is very delicate. It was noted at the Winnipeg workshop that in the absence of a change in precipitation, a small increase in the average annual temperature can lead to large flow losses.

Though the total precipitation may change little, the nature of precipitation events is expected to change with more small rain event interspersed with the occasional very large event. With the prospect of spring rains becoming more intense, the possibility of very occasional, very large floods from snowmelt and spring rains is likely.

In his assessment of the impact of climate change on water supplies to the year 2050, A. Warkentin (Winnipeg workshop) concluded that there will be a large increase in evapotranspiration (February to October), lower soil moisture (May to September), reductions in the recharge of aquifers, the drying up of private wells, reduced stream flows and poorer water quality. He is predicting serious drying.

3.4.3.2 Observed Climatic and Hydrologic Trends

Temperature and Precipitation

Annual and seasonal temperature trends for two ecoregions included in the Prairies are listed in Table 3.4-1. Temperatures have increased in the period 1895 to 1992; winter and spring warming trends are the largest.

Annual precipitation trends for the region are summarized in Table 3.5-2 with small increases in southern areas and somewhat larger increases in the north. Summer rainfall has declined slightly in the south. However, Akinremi et al., 1999 analyzed precipitation trends at 37 Canadian Prairie stations with at least 75 years of record. Their results suggest a significant increase in the number of precipitation events primarily due to low-intensity events and not an intensification of precipitation. However, over more recent decades Darthi et al. (1999) shows a slight increase in frequency of heavy rains in spring and early summer. Precipitation and rainfall increase over 75 years (0.62 mm/yr. and 0.60 mm/yr., respectively, from linear regression analysis). For the most recent period, 1961-1995, snow showed a significant decrease of 0.95 mm/yr. The decreasing snowfall trend is opposite to the trend of increasing rainfall.

Runoff

The timing of hydrologic events is important to ecosystems (wetlands, deltas and sloughs) and for water resource management (e.g. reservoir filling). Time of peak snowmelt discharge is particularly important because it often contributes a considerable portion of total annual flow. Since snow accumulation and melt

affect the spring freshet, it may be sensitive to temperature increases particularly higher winter and spring temperatures. Burn (1994) analyzed the long-term record of 84 unregulated river basins from northwestern Ontario to Alberta for changes in the timing of peak spring runoff. The more northerly rivers exhibited a trend to earlier spring snowmelt runoff. The trend was more prevalent in the recent portion of the data.

One of the overriding parameter in Prairie hydrology is the permeability of the soil. A. Pietrniro (Winnipeg workshop) has noted the soil is freezing deeper because of a reduction in the insulating snow cover. As a result, less of the spring runoff is penetrating the soil leading to a reduction in the amount of water stored in the soil.

Yulianti and Burn (1999) analyzed 77 stations for varying periods from 1912 to 1993 for air temperature and low streamflow trends. Two periods emerge: before the 1970's temperature was decreasing and streamflow was increasing but from the 1970's to 1993 temperature showed an increasing tendency and the magnitude of the low flows showed a decreasing tendency. Linear and non-parametric correlation tests show a negative correlation between temperature and monthly and seasonal low flow. June had the highest percentage of rivers with a strong decreasing trend in low flow. Earlier spring runoff and smaller peak flow due to more frequent winter and spring melt may contribute to low flow in the summer.

One notes that in the past 30 years, climatic and hydrological trends have become more significant when compared with trends over the past 75 years or so. Things are changing more rapidly now.

3.4.4 Potential Vulnerability and Adaptation Needs

Before discussing the vulnerability of the Prairies to climate change, it should be acknowledged that not all the changes will be negative. There are benefits to warmer weather, human comfort and lower heating cost, for example. In agriculture there will be the prospect of planting a wider variety of crops and of expanding the arable region northward. The longer ice-free period should offer new opportunities to the shipping facilities at Churchill given the potential for a longer shipping season. However, in spite of these and other examples, on balance, the impacts will be negative, particularly in certain vulnerable areas, and the need for adaptation strategies is urgent.

From the outset it seems apparent that drought will accompany climate change. In this situation, one fundamental over-riding adaptation need will be paramount, water conservation. To this end stakeholders, particularly governments, should compile and analyze past adaptation practices and assess

their benefits, **collaborate to increase efficiency of water use, land-use zoning to avoid: 1) exposure to extreme events, 2) contamination of water supplies 3) development of areas with inadequate water supplies and, finally, reflect projections of climate change in the planning and implementation of all management decisions relating to water.**

3.4.4.1 System responses

Hydrology

Our ability to model climate impacts on hydrological systems remains embryonic. Consequently, the impacts derived from modeling scenarios are uncertain. Yet, one of the most pressing needs is a better understanding of the impacts of climate change on hydrology, particularly on the Prairie river systems that depend largely upon the snowfall and snowmelt regimes in the mountains. At present it is difficult to make water-resource planning decisions until studies are conducted with more reliable and recent model scenarios. The development of this knowledge base and appropriate hydrological models is a pressing adaptation need.

For effective water-resources management, we must better understand the implications of climate change on:

- the form and amount of winter precipitation,
- the snow pack accumulation and duration,
- glacier accumulation and ablation and
- changes to the magnitude, timing and duration of mountain runoff.

Then using improved hydrological models it would be possible to make quantitative estimates of the vulnerability of the water resources of the Prairies. The potential vulnerability of the hydrological regimes is profound and widespread. Three areas of concern are:

- Increased temperatures suggest more **glacier** melt. Initially, this melting causes higher runoff, however, after a number of years, decreasing amounts of water would come from the diminished glaciers (IPCC, 1996; Brugman *et al.*, 1997). Once the glacier has largely melted there will be no glacial water input in the late summer and fall reducing streamflow significantly. However, there is not a full consensus on the projected changes in runoff from the Rocky Mountains though the disappearance and retreat of glaciers is already evident.
- If annual **snowpack** in the mountains is reduced because of more rain and less snow there will be significant reductions in the water that flows through the rivers and is available to multiple users, or in the timing of the runoff.

- The **timing** of snowmelt is also important. If it is early and rapid, runoff may exceed the storage capacity of reservoirs and lead to release of water, greater potential for floods and shortages of water later in the year.

Contributions from glacial melt are particularly important in the transition from summer peak flows to base flow in these systems. River and reservoir systems that are snow-fed or rely on glacier melt for spring and summer flow during the critical periods of high agricultural and municipal demand and low precipitation may have critical supply-demand mismatches (Cohen *et al.*, 1989).

Water Quality

The quality of Prairie water resources is vulnerable to climate change and is closely linked to the changes in hydrology discussed in the previous section.

Many of the surface water bodies (lakes, rivers and reservoirs) in the Prairies are shallow, saline and eutrophic. With warmer weather, when there is a greater need for good quality drinking water for livestock, wildlife and humans, water quality often deteriorates. One of the reasons for the deterioration is that increases in evapotranspiration and higher water temperatures have negative consequences for the chemistry and biology of prairie water resources, including wetlands, closed-basin saline lakes and water-supply reservoirs. At the same time, rural populations rely on untreated water from shallow dug wells, farm ponds and dugouts for domestic and agriculture use. During the drought of 1988 there was an increase in consumptive use of water and an increase in water quality problems that required government assistance to farmers. It is not only the rural communities that are vulnerable to water quality deterioration. In urban communities, summer taste and odour problems can occur in municipal water supplies due to algae growth. Finally, recreational potential is reduced by warmer water temperatures, less runoff, lower lake and reservoir levels as well as deteriorated water quality and algae problems (Herrington *et al.*, 1997).

In a study of the relationship between stream flow and water quality, D. Williamson (Winnipeg Workshop) identified an unexpected phenomenon, when the river flows drop below their normal level and also when they increase above this level, the water quality deteriorates. The reason for this bimodal character is that at low flows the river cannot dilute or assimilate continuous effluents (point sources) adequately, while at high flows, due to surface runoff, large amounts of agricultural pollutants and sediments, and contaminated urban runoff (diffuse sources) are flushed into the stream. This occurs in largely agricultural areas that have point sources.

There is another feature of low flow. When low flows occur and the waste assimilation capabilities of a river decreases, sewage treatment costs increase in order to meet water quality standards. May to August is the most critical period.

Floods

While the average annual peak flow is likely to decline, and has done so recently, due in part to more frequent winter melt and rains, spring rains may become more intense. When coupled with snowmelt, very large floods may occur. The Red/Assiniboine drainage system has experienced these types of floods in the past and a flood channel was constructed around Winnipeg and ring dykes built elsewhere to deal with these events. The May 1997 “Flood of the Century” was such an event. On this occasion the Red River Floodway prevented serious disaster. This 48 km-long channel diverts floodwater out of the Red River around the east side of Winnipeg to return the water to the river north of the city. On May 3, 1997, the Red River crested at 24.5 ft. above City datum; without the Floodway, the crest would have been 34.3 ft. above City datum. Damage prevention in 1997 was estimated to be worth between \$4.5 billion and \$7 billion.

The construction of flood channels and ring dykes are only two of the flood abatement strategies that are considered to deal with the increased risk of flooding throughout the Prairies. **Other options include, improving flood forecasting and flood warnings, establishing and enforcing appropriate building codes, evacuation planning, land-use zoning to avoid exposure to extreme events and measures to reduce contamination of water supplies.** Concerning this final point, experience has shown that flooding brings with it the high risk of contamination of water resources, for example, wells, reservoirs and the ground water supply. (see IJC report 1999 on Red River floods.)

Groundwater

The Canadian Prairies’ water supply is mainly surface (river) water controlled by snow and ice melt in the Rockies (Bjonback, 1991). In areas where there is more reliance on ground water, the watersheds are not as well defined and the interrelationship between the land surface characteristics and the water resource are not well documented or monitored. Here, it will be difficult to define and to respond to the effects of climatic change and variability (Bjonback, 1991). In many jurisdictions, though surface water is legally apportioned, ground water is not. In the past the lack of control was not an issue but with decreasing surface-water resources, ground water will likely become more important and the need for domestic allocation and a Canada-US ground water apportionment agreement may arise. Already the overuse/mining of ground water is a growing problem in some areas. Given that Montana, Wyoming, North and South Dakota and parts of Nebraska are rather reliant on ground water **it seems appropriate to start planning immediately for the shared use of this poorly defined resource in the context of climate change.**

3.4.4.2 Management Implications and Adaptation Needs

Apportionment

The Saskatchewan/Nelson River system is an important, reliable, high-quality, alpine-water resource that is shared by the Prairie Provinces. There have been formal arrangements on water in place since 1948 but in 1969 the federal and provincial governments signed the Master Agreement on Apportionment. The upstream location of a large group of users in addition to climate change scenarios has the potential to significantly reduce flows entering the province of Saskatchewan. The evolving situation has major implications for Alberta's responsibilities to Saskatchewan under the Master Agreement on Apportionment (Bjonback, 1991, 168-169). The Agreement's "...major provision commits Alberta to allow one-half of the natural water flow arising in or flowing through Alberta to pass into Saskatchewan. Saskatchewan has a similar commitment to Manitoba..." (Pearse *et al.*, 1985 in Wittrock and Wheaton, 1992). The droughts of the 1980s put the Agreement to the test. Individual jurisdictions had to make difficult choices to meet inter-jurisdictional commitments (Bjonback, 1991). Irrigated agriculture and reservoir evaporation are primary consumers of surface water in the Canadian Prairies (Bauder, 1991).

Climate change scenarios where runoff decreases, evaporation increases, and consumptive use of water increases, have the potential to lead to disagreements over water apportionment. The issue extends far beyond irrigation. There is the potential for growing conflict over upstream and downstream use in hydroelectric generation, recreation, municipal and industrial use, waste assimilation and in-stream ecological requirements as and provinces are inclined to use more of their share. The Master Agreement of Apportionment "...is fragile since any of the parties could unilaterally pass legislation that would exempt it..." (Pearse *et al.*, 1985 in Wittrock and Wheaton, 1992). The role of such an institution in future economic development and environmental management is critical since many major rivers of the Prairies cross inter-jurisdictional boundaries.

Montana and North Dakota (e.g. Souris-Red Rivers, St. Mary-Milk Rivers). Surface water in Alberta, Saskatchewan and Manitoba currently is sufficient to meet present and some future growth in demand but water demand in the international tributaries is beginning to approach full apportionment (Bauder, 1991). Recently significant problems were encountered in meeting irrigation and international flow apportionment requirements (Bjonback, 1991). The 1980's experience could become the norm under the low water supply conditions of some climate change scenarios.

Adaptation to the decrease in shared water resources will require careful enforcement of national and international agreements, both existing ones and those that need to be developed.

Agriculture

Agriculture is highly sensitive to reduced water supplies. At present the South Saskatchewan River supports some 500,000 hectares of irrigation in southern Alberta, the largest portion of the approximately 650,000 hectares of irrigation in all of the Canadian Great Plains. Dealing with a reduced supply will be extremely difficult. On the positive side, it is recognized that the agricultural sector has adapted to drought in the past. **Effective watershed management, on-farm water management, alternate production systems, more efficient irrigation practices and the prevention of wetland loss are valuable adaptation measure that should be assessed and applied where appropriate.**

Hydro Electric Generation

Climate change could significantly affect hydropower production through more frequent droughts, reduction in river flow and reservoir levels, and warmer water temperatures. For example, Manitoba Hydro hydroelectric production is sensitive to diminished river flows, decreased base flow and changes in timing. During the drought of 1988, hydroelectric power generation decreased by 4% (Herrington et al., 1997). The thermoelectric generating plants of Alberta and Saskatchewan rely heavily on groundwater, streamflow and reservoirs for cooling water (Stolte and Sader, 1999). Warmer air temperatures increase cooling demand but also decrease the efficiency of the source water by raising its temperatures. The electricity industries will compete for water with demands for irrigation, municipal water supply, and in-stream biological uses.

There is a further problem with energy supply, a seasonal shift in electrical energy requirements is likely due to a higher summer demand (irrigation pumps and air conditioning) when seasonal low flows reduce generating capacity, confounded by an increased demand for irrigation water (Herrington et al, 1997).

Ecosystem Function - Wetlands

Only the spring snowmelt and precipitation feed many ephemeral Prairie sloughs. During a drought they dry out and in a season with high precipitation they persist. Semi-permanent sloughs are fed by groundwater in addition to precipitation and spring snowmelt and only dry out in serious drought when groundwater storage is depleted. Vegetation in these sloughs ranges from predominantly open water conditions with little vegetation in very wet years to

dense emergent vegetation during prolonged drought. These prairie sloughs provide critical waterfowl staging and breeding habitat. Drought reduces the area of sloughs, reduces their value for waterfowl habitat and makes them vulnerable to conversion to agricultural land. Waterfowl populations have been shown to correlate well with the number of prairie potholes, drought reduces waterfowl populations (Whitrock and Wheaton, 1989).

References: See at end of Section 3.5

3.5 Regional Vulnerabilities – The Arctic and The North

3.5.1 Context

The Arctic and northern region including the Yukon, Northwest Territories and Nunavut is characterized by dispersed communities and low population densities. At the same time, with an area of over 3, 800,000 square kilometer it comprises nearly 40 % of the area of Canada. Aboriginal subsistence lifestyles are intermingled with southern economic development associated with resource extraction and national defense. Water is important to the region for drinking, food, and transportation. Most communities are located near or on water.

3.5.2 Key Water Issues

Water issues in the region include changes in river flows and lake levels, melting of permafrost and sea ice, the conditions of roads, water quality changes and coastal erosion.

3.5.3 Climate Change Projections and Observed Climate and Hydrologic Trends

3.5.3.1 Climate Change Projections

Climate change projections from the CCCma model (CGCMI) and all other models suggest that the most significant increases in annual temperature will occur in northern regions. For the Canadian Arctic, the annual average temperature increase in 2040-60 relative to 1970-1990 is projected as 3-5 °C for much of the region with increases of 2-3 °C for the Mackenzie and 5 - 10 °C in the high Arctic and a small portion of Hudson Bay. However, there is retarded warming or even cooling at the eastern edge of the Canadian Arctic, near Greenland. Polar warming is magnified in the winter season. Precipitation is expected to increase in the mid and high latitudes in the winter with little change or small increase in summer.

3.5.3.2 Observed Climatic and Hydrologic Trends

It was clear at the Yellowknife Workshop that climate change is not an academic topic. It has been experienced already. In communities across the Arctic, inhabitants are noting widespread and serious changes in snow cover, ice cover duration, permafrost stability, the ranges of caribou herds, and abundance and health of other subsistence food species. There is growing certainty to them that climate change is a reality.

Table 3.5-1 Selected Regional Temperature Trends (change in temperature over period of analysis)
Environment Canada, 1995

Region	Period	Annual	Winter	Spring	Summer	Autumn
Yukon/North BC Mountains	1901-1992	+0.8	+1.4	+1.5	+0.5	-0.2
Mackenzie District	1895-1992	+1.7	+2.3	+2.4	+1.5	+0.7
Arctic Tundra	1922-1992	+0.6	+1.3	+0.1	+0.7	+0.2
Arctic Mountains & Fjords	1946-1992	-0.8	-0.7	-1.6	0.0	-0.7

Bold fields: Trend is statistically significant

Table 3.5-2 Precipitation Trends* in the Arctic Region (Mekis and Hogg, 1997; 1999).

Region	Period	Annual			Winter			Spring			Summer			Fall		
		Total	Snow	Rain	Total	Snow	Rain	Total	Snow	Rain	Total	Snow	Rain	Total	Snow	Rain
Yukon/North BC Mountains	1939-95	3.0	4.8	1.6	5.8	5.6	-	4.9	2.8	7.3	0.2	-	0.1	3.9	5.3	2.6
Mackenzie District	1927-96	1.2	1.3	1.1	1.6	1.5	-	0.2	1.0	-1.3	1.0	-	1.3	1.9	2.2	1.6
Arctic Tundra	1948-96	5.1	9.5	-1.1	5.6	5.9	-	7.7	9.2	-2.7	0.5	13.9	-1.4	7.4	11.3	0.3
Arctic Mountains & Fjords	1948-96	2.4	3.3	0.2	0.3	0.4	-	6.2	6.1	-	2.1	11.5	-1.2	1.5	0.8	5.2

*Unit: (mm change / mean) over 10 years

If mean < 5 mm, trend not computed

Bold fields: Trend is significant

Gray area: Residuals are correlated (Durbin-Watson test failed)

It is important to recognize the invaluable contribution, which indigenous observers are making to the assessment of the changes that are occurring. Their observations augment our understanding, which would otherwise have to rely on inadequate formal scientific study and very little observational data. Unfortunately little of their knowledge has been assembled and published except to some extent the Mackenzie Basin Study (Cohen et al. 1997).

Temperature and Precipitation

Significant warming has been detected for the period 1895-1992 for the Mackenzie district (Table 3.6-1). Warming in winter (+2.3 °C) and spring (+2.4 °C) has been most pronounced. However, there has been cooling in the eastern Arctic; the most pronounced is -1.6 °C in spring in the Arctic Mountains and Fjords region. Total annual precipitation and snowfall show a significant increase in all regions (Table 3.6-2).

At the Yellowknife workshop, both trained scientists (e. g. J. Bullas, Env. Canada) and native observers (S. Joss and B. Inuktalik, Holman, NT) reported less snow cover and warmer winters and springs. A later freeze-up has also been observed. One participant reported that Churchill is experiencing not only earlier springs and later falls but also, in recent times, there have been mid-winter thaws that last 3 to 5 days; plants and trees start to grow. The summer dry period occurs more quickly and earlier; there are fewer mosquitoes. The Coral Harbour fishing derby usually scheduled for March has now been rescheduled to February because of unsafe ice conditions due to warmer temperatures.

Storms

There are reports of more frequent storms in Coral Harbour (northern Hudson Bay) and on the McKenzie delta, for example. At Tuktoyuktuk, coastal erosion is increasing rapidly. Storm surges are washing across beaches and destroying buildings along the coastlines. These fall storms, which are most frequent, are causing far more shoreline wave damage than in the past because the ice cover occurs much later in the year. A 5/10 th, or greater, ice cover dampens waves and has been an important protection against storm surge and coastal erosion

Snow Cover

In spite of greater total snowfalls, winter and early spring snow depth (particularly February and March) were observed to have decreased significantly from 1946-1995. Significant decreases in spring and summer snow cover duration for most of western Canada and the Arctic accompanied these decreases.

In the mid-1970's there was a shift in the average atmospheric circulation of the Pacific-North American section of the Northern Hemisphere, which corresponds to the timing of the abrupt transition in snow, cover (Brown and Braaten, 1998). Research is still very active on the linkages between such shifts in modes of the climate system and greenhouse gas forcing of climate. (Ch.1)

Permafrost

Kwong and Gan (1994) conducted surveys of permafrost along the Mackenzie Highway south of Great Slave Lake. They found that the southern limit of the sporadic discontinuous permafrost zone has migrated northward by about 120 km. To determine if this migration was caused by warming, a detailed trend analysis (non-parametric Kendall's test) of monthly air temperature records for nine weather stations was conducted. The results show a regional warming trend for the period 1949-1989. It has been suggested that large areas of mid-Canada, including much of the Mackenzie Basin, Yukon, Northern Ontario and Quebec, with an annual mean temperature of -2 °C or more could have permafrost disappear completely (NRCan, 1999). Some portions of the globe, such as Siberia, have already witnessed retreat rates of 60-80 kilometres /1 °C (Prowse, 1996). Many of the workshop report by native observers, for example, from Sachs (NWT) Harbour and Holman (NT), confirmed these observations.

The widely reported deterioration of permafrost is a serious threat to transportation and water supplies in the region (discussed in the next section).

3.5.4 Potential Vulnerability and Adaptation Needs

3.5.4.1 System responses

Hydrology

Climate impact assessment studies on hydrology and water resources have focused on the Mackenzie River Basin (Cohen, 1993; 1994; 1997). There have been no formal impact assessments in the high arctic or the eastern arctic. The main results are given in Table 3.5-3. Although the temperature and precipitation predictions are consistent with increases in both cases, the hydrological impacts are either positive or negative depending on which model is used. The development of good hydrological model remains a serious challenge. It should be noted that the observed trend in most Arctic rivers has been (1967-96) towards increased annual mean flow except for the Mackenzie River where the headwaters extend well into the drier Prairies.

Table 3.5-3 Climate Change Impacts on Mackenzie Basin Hydrology

River Basin	Climate Scenario	Annual T&P Scenario Changes	Hydrologic impacts	Reference
Mackenzie River.	◆ composite	◆ +3.5°C, +10%	runoff: ◆ +7.1%	Soulis <i>et al.</i> , 1994
	◆ GFDL(R30)	◆ +6.0°C, +3%	◆ -7.1%	
	◆ CCC92	◆ +3.5°C, +3%	◆ -3.7%	

At the same time, the vulnerability of permafrost to climate change is a great threat to the Arctic. The region is underlain by continuous or discontinuous permafrost that has an important influence on hydrology. In 2 x CO₂ GCM scenarios, discontinuous and continuous permafrost boundaries move pole-ward about 500 km (Woo *et al.*, 1992) and the area of permafrost is reduced to less than 80% of its present coverage. Impermeable permafrost limits water storage and seasonally frozen soil inhibits infiltration of snowmelt. In this region, runoff is more important than subsurface ground water flow (Maxwell, 1997). Warming of the active layer and lengthening of the thaw season allows for deepening and thickening of the active layer, more water infiltration and enhanced active layer water storage (Hinzman and Kane, 1992; Kane *et al.*, 1992). This allows subsurface flow and drainage of the active layer to the groundwater flow network. Many patchy wetlands, peatlands and small northern lakes could drain because there would no longer be an impermeable permafrost barrier (Prowse, 1996). Peak flows from snow melt and rainfall events are likely to decrease or remain the same (Rouse *et al.*, 1997). Subsistence fishing, trapping and guiding activities are affected.

There is already a general trend towards water moving off of the land. The drying of lakes and ponds in the McKenzie delta has been observed. Communities are starting to worry about the risk of fires in the summer.

3.5.5 Management Implications and Adaptation Needs

In many ways the impacts of climate change are and will be most severe for the people of the north. For this reason it is urgent that general adaptation strategies should be considered now, including:

- **reflect projections of climate change in the planning and implementation of all management decisions relating to water**
- **collaborate to increase the efficiency of water use**
- **use land-use zoning to avoid 1) exposure to extreme events, 2) contamination of water supplies 3) development of areas with inadequate water supplies, 4) exposure to land slump**

- **compile and analyze past adaptation practices and assess their benefits**

3.5.5.1 Water Quality - Water Supplies

In urban communities, drinking water and sewage lines, buried in or above the permafrost, are subject to buckling and rupture as a result of permafrost degradation and thaw slump. The risk of loss of the delivery system or contamination problems due to broken sewage lines is increasing. The ground is unstable and slumps are not predictable. In addition, overall water supplies in lakes and rivers are lower than they have been in the past.

Sewage storage areas are at risk when tanks on permafrost are subjected to thaw slump due to the warming and melting of the permafrost. Tanks can shift, rupture and cause widespread contamination. No incidences were reported but the prospect of such an accident becomes greater as the warming proceeds.

Northern communities are experiencing more turbidity and higher sediment loads in drinking water supplies. The degradation of permafrost, with resultant bank collapses, and higher extreme flows are believed to be the causes. In communities near the ocean, lower summer/autumn river flows in some basins may lead to saltwater intrusion.

Some adaptation strategies are outlined in 3.5.5 above.

3.5.5.2 Land Transportation

The negative impact of climate warming on transportation is already serious. In the NWT, the Department of Transportation maintains about 1230 km of winter roads while there are approximately 900 km of private or special use winter roads. These roads are built over frozen lakes and tundra and are an alternative to air supply in areas not accessible by a year-round road system. Ice bridges, constructed at five locations, allow transportation after the ferry season ends on the year-round road system. Winter roads and ice bridges are an inexpensive transportation alternative to air supply for remote communities, resource exploration activities, and mine supply (Fairburn, Yellowknife Workshop) Air temperature affects ice thickness which influences load bearing capacity (size of vehicles, their load and speed allowed) and duration of the winter road season.

At the time of the Yellowknife meeting (February 28, 2000), winter roads out of Yellowknife were not yet able to carry the large tractor-trailers, forty-ton vehicles. Smaller vehicles were traveling out of Yellowknife but the bulk of the transport is conducted with large vehicles. There were only two or three tractor-trailers in the marshaling yard that normally contains forty to sixty vehicles waiting to move out in convoys at this time of year. The situation was bleak

since winter roads cannot be used much after the end of March. As it turned out, following the meeting, there was some very cold weather and the roads were able to carry all the supplies required. Thirty-eight hundred (3800) trucks made the trip before the road was closed on April 5, 2000.

About ten years ago these natural ice roads were in use with heavy traffic by December 1. Now it is more typical for the traffic to start moving six weeks later, around mid-January. In 20 years of record of ice roads, the last 4 to 5 years have been more difficult to maintain (Fairburn, Yellowknife Workshop). The winter hauling season usually operates continuously 24 hours per day. Near the end of the winter road season, transportation may be limited to nighttime travel only. Trucks travel slowly, often through a half a metre or more of water overlying lake ice. The risk to drivers increases.

In urban areas, many roads are constructed over permafrost soils that are ice-rich organic peat, clay or silt that have little bearing strength in an unfrozen state. The thawing of the permafrost has led to a phenomenon called thaw slump. When this occurs along a highway there can be sudden breaks in the surface where a part of the surface drops down or falls off on the side. For this reason, highway maintenance costs have gone up and highways are becoming more dangerous, posing a risk to driver safety.

Off-road snowmobile travel, particularly in remote uninhabited areas, is also becoming more dangerous because of more frequent unexpected slumps due to the deterioration of the permafrost.

3.5.5.3 Water Transport

Water transport is vital in this region with few roads. The rivers are vulnerable to climate change related impacts. Increasing numbers of land slides, due to permafrost deterioration, and low flow rates are causing the silting. Navigation on the Mackenzie River supports re-supply of many small northern communities. Lower low-season flows could limit navigation. It was reported at Yellowknife that an unexpected increase in river silt is causing difficulties with barge traffic between some of the river communities. On the other hand, the shipping season on the Mackenzie River and in the Beaufort Sea may be easier with a longer ice-free period. For the same reason, the shipping facility at Churchill Manitoba has the potential to carry increased traffic.

3.5.5.4 Mining

Resource extraction activities are an important economic activity in the north. The mining industry is confronted with two climate change risks related to water, the containment of mine tailing in ponds and the availability of adequate clean water supplies for waste assimilation.

Here again we are confronted with the deterioration of permafrost. The industry is greatly concerned about permafrost stability under their private roads and in their reservoirs which contain mine effluent. Deterioration of permafrost could damage supply roads and lead to the rupturing of tailings-pond containment dikes (often developed as frozen core dams) allowing contaminated water to flow freely into the environment. Tailing ponds were also designed with historical IDF curves that could change in the future. Mine site reclamation, decommissioning and Environmental Impact Assessment guidelines do not address the issue of climate change.

The second concern relates to water supply. Placer mining activities on the Forty-mile, Porcupine and Yukon rivers, for example, have substantial water use and there are concerns for water quality degradation from siltation and turbidity (Environment Canada, 1995b). There are other gold, copper, lead, and zinc mining and processing mills in northern BC and the Yukon where rivers are used to assimilate wastes and no assessment has been undertaken to determine the impacts of climate change.

On the positive side, the mining community is receptive to warmer conditions because it is easier to work in the winter and machinery breaks down far less in warmer weather, the equipment is more reliable and maintenance is easier.

3.5.5.5 Water Apportionment

Inter-jurisdictional water management may become more of an issue in the north due to climate change. For example, in the Mackenzie River basin, the NWT is downstream from the Yukon, BC, Alberta and Saskatchewan, which use the water for hydroelectricity generation, irrigation, oil sands extraction processes, municipal water supply and waste assimilation. If southern, populated regions experience water shortages, diversion of water may be seen as a solution. **This would raise questions of balancing apportionment of water to take into account economic interests of the south and environmental and aboriginal interests of the north.** Institutional mechanisms are required to deal with resource management, apportionment and security of supply issues. The Mackenzie River Basin Transboundary Master Agreement may be a suitable mechanism (Mortsch, 1997). Changes in the flow regime of the Yukon River may result in management issues with downstream interests in Alaska.

3.5.5.6 Hydro Electric Generation

Increased variability in flow is being experienced in certain regions (e.g., Snare River). Some water resource managers were concerned that reservoirs, dams and spillways were designed for historical climatic conditions. Changing

precipitation intensities have implications for design IDF curves and they may need reassessment.

There have already been occasions when hydropower was no longer adequate to meet community needs. As a result, some communities are shifting to diesel generators more frequently. The shift results in more expensive power, increases in air pollution and more noise. In the town of Whitehorse there is growing concern over health stress among members of the community, due to the increased use of diesel generators.

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3.6 Regional Vulnerabilities, Impacts and Adaptations: British Columbia

3.6.1 Regional Characteristics

Perceptions of vast coastal areas, inlets, fjords and glacier-fed lakes and mountain streams perpetuate the dominant public view that B.C. has an abundance of water and, for the most part, this vision is true. More than 24,000 streams and lakes yield water for domestic use, agriculture, industry, power production, wastewater assimilation and passive ecological (including fisheries), recreation and transportation functions (B.C. Ministry of Environment, Lands and Parks 1999a). Much of the human use of water occurs in the extreme southwestern and southern Interior portions of the province. Almost 60% of B.C.'s population is concentrated in the Vancouver and Victoria Census Metropolitan Areas (Statistics Canada 1999).

A description of the B.C. climate is provided by B. Taylor (1997). Four main climate regions have been identified in British Columbia: Pacific Coast, South B.C. Mountains, Yukon/North B.C. Mountains, and Northwestern Forest. Within these regions one finds some of the wettest (coastal mountains) and the driest (southern interior) places in southern Canada. A great variety of ecosystems are supported by the diverse conditions. Regional climate variations are largely controlled by differing proximity to the Pacific Ocean, topography (elevation, slope, and aspect), latitude, and seasonal patterns of the dominant westerly upper winds.

3.6.2 Key Water Issues

Flooding, drought and binational water management are among the important water issues facing B.C. During certain times and in certain regions there is too much water, as coverage of flooding problems along the Fraser and other rivers demonstrated as recently as spring 1999. Virtually all of the Canadian records for daily, seasonal and annual precipitation amounts have been set in British Columbia (Phillips 1990). While not pervasive in all regions, evidence of limited water availability also exists especially in the interior. For instance over 17% of surface water sources are at or nearing their capacity to reliably supply water for extractive uses (B.C. Ministry of Environment, Lands and Parks 1999a). Groundwater-surface water conflicts have been identified in a few interior aquifers. In the absence of any significant climate change, concerns over water availability, water quality and flooding will be magnified through an aging infrastructure and population and economic growth, which historically have generated greater demands for water and placed more people and investments in hazard-prone areas. However, it is important to place these issues in the context

of a variable and changing climate since any shift in the resource base will impact on many water management decisions.

3.6.3 Observed Trends in Climate and Hydrology and Projected Climate Change and Sea-level Rise

Observed Trends

Seasonal temperature trends over the 1895-1992 period are listed in Table 3.6-1. With the exception of autumn temperatures in the Yukon/North B.C. Mountain region, all of the trends are positive. As in most of Canada, much of the observed warming can be attributed to rising nighttime temperatures. A decreasing ice cover season since the mid-1950s at Dease Lake in northern B.C. is further evidence of general warming (Environment Canada 1995). With respect to precipitation, Mekis and Hogg (1999) report that snowfall and rainfall have increased with time in virtually all seasons and climate regions in B.C. Table 3.6-2 illustrates trends in total precipitation for specific climate regions based on varying observation record lengths.

Table 3.6-1. Seasonal Temperature Trends in B.C. Climate Regions (1895-1992)

Climate Region	Winter	Spring	Summer	Autumn	Annual
Pacific Coast	0.5	0.6	0.2	0.4	0.4
Yukon/North B.C. Mountains (1901-1992)	1.4	1.5	0.5	-0.2	0.8
Northwestern Forest	1.7	2.1	1.2	0.4	1.7
South B.C. Mountains	0.8	0.7	0.7	0.4	0.6

Bold indicates a statistically significant trend

Source: Environment Canada 1995

Table 3.6-2. Total Precipitation Trends in B.C. Climate Regions*

Climate Region	Winter	Spring	Summer	Autumn	Annual
Pacific Coast (1898-1995)	0.7	0.1	1.9	1.2	0.9
Yukon/North B.C. Mountains (1939-1995)	5.8	4.9	0.2	3.9	3.0
Northwestern Forest (1938-96)	-2.7	0.6	3.0	<u>3.5</u>	<u>1.9</u>
South B.C. Mountains (1895-1995)	2.4	1.6	1.0	0.8	1.4

*Total precipitation expressed as (mm change/mean) over 10 years [%]

Bold indicates a statistically significant trend while underline indicates correlated residuals (Durbin-Watson test failed) Source: Mekis and Hogg 1999, p. 72.

Mekis and Hogg (1999) have also examined changes in heavy precipitation events. They observed an increase in the fraction of total precipitation falling in heavy events (>90th percentile) over the 1940-95 period for much of B.C. Other research suggests that extreme precipitation events are not becoming more common in southwestern B.C., with the exception of Vancouver. (E.Taylor, B.C. workshop 2000).

Glacial ice and snowpack make important contributions to the hydrology of B.C., particularly in supplying the snowmelt freshet and maintaining streamflow during summer and early autumn. Most glaciers in southern British Columbia and the southern Rocky Mountains (e.g. Sentinel, Helm and Illecillewaet) have ablated considerably since the 1920s as temperatures have warmed (Brugman et al. 1997). However glaciers located in regions receiving high snow accumulations (northwestern B.C.) have gained mass and advanced (Brugman et al. 1997). Moore (1996) documented a statistically significant decrease in snowfall, April 1 snowpack and summer runoff since 1976 for the Capilano River in southern B.C. that may be related to a shift toward the strong phase of the PNA winter pattern. This Spring snowpack reduction appears to have occurred throughout the south coast mountain region (E. Taylor, B.C. workshop 2000), possibly due to more rain and less snow in winter.

Leith and Whitfield (1998) examined selected south-central B.C. streamflow records and observed a relationship between warmer climate conditions and ?delayed? spring runoff, lower late summer-early fall streamflows, and higher early winter flows. Taylor and Whitfield (1999) reported similar findings for several Pacific coast streams in their comparison of streamflow and climate records during the 1946-55 and 1986-95 periods. A more recent study by Whitfield and Cannon (2000) comparing temperature, precipitation, and streamflow across Canada between the decades of 1976-85 and 1986-95 also supports these findings, with mean annual flows in decline in the southern interior including the upper Columbia basin.

Future Climate Change and Sea-level Rise

Results from the CCCma coupled ocean-atmosphere model (CGCM1) (Boer et al. 1998) suggest that mid-21st century mean annual temperatures in B.C., relative to the 1961-90 average, will increase from 1°C in the extreme southwest to over 3°C in northern areas (CCCma 1999). A 2-5°C increase might be expected by late in the next century again with the greatest increase in the extreme north. Winter (December-February) mid-century temperatures may increase by 1-2°C along the coast and from 2-5°C in the interior with maximum warming expected in the northeast. Summer (June-August) temperatures will generally rise by 2-3°C over the province. A further increase of 1-2°C in each of these seasons is suggested by late in the century.

Slight changes in annual precipitation are expected by the middle of the 21st century relative to 1961-90 averages. A small reduction is shown for northern coastal areas while precipitation may increase a little in other areas (less than 1mm/day in both instances). These changes in annual precipitation are not amplified appreciably by the end of the century. Seasonal patterns are stronger with a substantive 'ENSO-like' increase in winter precipitation along the U.S. Pacific Northwest spilling into southwestern B.C. (up to 1.5mm/day by 2050s and 2.3mm/day by 2080s). Winter precipitation generally increases across much of the province with slight decreases only apparent in extreme northwestern sections of B.C. Results in Boer et al. (1998) suggest that winter and summer precipitation and soil moisture will remain within 20% of the 1975-95 average, even by the end of the 21st century. Local and even regional precipitation changes and patterns will likely be much less homogenous than climate scenarios suggest because of difficulties in resolving topographic variation in climate models.

Sea-level is also expected to rise to varying degrees along the B.C. coast. Allowing for thermal expansion of oceans, melting of land-based ice, oceanic and coastal winds, isostatic rebound and tectonic processes, Thomson and Crawford (1997) estimate that relative sea-level will change from -1 to 2mm/year along the south coast and from -1 to 6mm/year along the north coast.

3.6.4 Potential Regional Vulnerabilities and Adaptation Needs

System Responses to Climate Change

3.6.4.1 Hydrology

Precipitation and temperature variations exert a tremendous influence on the amount of water that reaches the surface, evaporates or transpires back to the atmosphere, becomes stored as snow or ice, infiltrates into the groundwater system, runs off the land, and ultimately becomes streamflow. The changes in regional climate outlined above have important implications for all of these aspects of the hydrologic cycle:

Glacier melt. Many southern B.C. glaciers at relatively low altitudes would continue to retreat while most in northern B.C. would expand or remain stable with increased snowfall (Brugman et al. 1997).

Earlier snowmelt. This will be especially significant in southern B.C. where the spring freshet may occur up to one full month earlier (Coulson 1997).

Greater runoff. Annual, winter and spring runoff are expected to increase although the additional precipitation would be offset somewhat by greater

evapotranspiration associated with rising temperatures and longer growing seasons (Coulson 1997).

Lower summer streamflows. The summer low flow period would be characterized by even lower streamflows in southern B.C. though slightly greater flows could be expected in northern B.C..

Peak streamflows may increase. The potential exists for increased peak flows in coastal and southern B.C. (Coulson 1997).

Altered groundwater aquifers. Changing patterns in spring recharge and fall water table decline, coupled with large withdrawals, may affect local flows of groundwater and contaminant plumes in the Abbotsford aquifer (Hii 1997).

3.6.4.2 Extreme Events

Flooding and coastal erosion. Urban, riverine and coastal flooding may become greater concerns for British Columbians. Warmer winter temperatures will result in a greater proportion of precipitation falling as rain that may lead to higher winter flows and more frequent flooding, especially in rain-dominated systems along the coast (Whitfield and Taylor, B.C. workshop). While much of the Pacific Coast has a low sensitivity to sea-level rise, Shaw et al. (1998) characterized the heavily populated Fraser Delta, parts of Eastern Graham Island (Queen Charlotte Islands), and many small fjord-head deltas (e.g., Squamish area) as being highly sensitive.

Landslides. The frequency of debris flows and other forms of landslide may be expected to rise if precipitation increases (Evans and Clague 1997). Rock avalanches and outburst floods might also become more common as glacial ice melts, debulking mountain slopes under rising temperatures; occurrences would peak and decrease as naturally-dammed reservoirs decrease in number and size (Evans and Clague 1997).

3.6.4.3 Water Quality

Salt water intrusion. Salt water intrusion into aquifers is already recognized as an issue in areas such as the Gulf Islands and southern Vancouver Island (B.C. Ministry of Environment, Lands and Parks 1999a). Climate change-induced sea-level rise and increased water demands may make the situation even worse.

Water-borne health effects. A recent extreme precipitation event was partly responsible for a 1995 outbreak of toxoplasmosis in the Capital Regional District of British Columbia. It was suspected that the feces of infected domestic, feral or wild cats entered the Humpback Reservoir or its feeder

streams and resulted in oocyst contamination of the water supply (Duncan et al. 1998). Other water-related health concerns include parasites (Giardia, Cryptosporidium) and increased survival of harmful bacteria in either surface or drinking water.

Water turbidity. A greater frequency of landslides and surface erosion may lead to increased turbidity in B.C. streams and reservoirs, particularly during the fall and winter seasons (E. Taylor 1997).

3.6.5 Management Implications and Adaptation Needs

The previous discussion illustrates some of the potential systemic effects of climate change on the supply and distribution of British Columbia's water resources. Layered onto this are a series of water management implications and possible adjustment strategies that have not been thoroughly investigated or re-examined using the latest climate change scenario information.

3.6.5.1 Coastal Zones, Floodplains and Landslide Hazards

The Province has experienced significant flooding, coastal erosion and landslides in the past with large floods occurring along the Fraser River in 1948 (9800 homeless) and Squamish River in 1980 (\$13 million damage). Minor coastal flooding and erosion were problems during the 1982-83 ENSO event. The October 1982 rainstorm-induced landslide in Howe Sound caused direct damages over \$1 million and stimulated a greater level of investment in preventative measures (Dalglish 1998; Smit, 1993). Emergency preparedness measures and other adaptations (e.g., property insurance, land use controls) are in place in response to these hazards and this adaptive capacity will be called upon should climate change increase event frequency. **Other possible adaptation measures include:**

- **reduction of impervious areas (e.g., asphalt, concrete);**
- **increasing the number of detention and infiltration ponds;**
- **construction of larger structures with greater storage capacity or resilience to extremes; and**
- **improved identification, monitoring and warnings for areas prone to floods and landslides (B.C. workshop 2000).**

However, it is also possible that climate change coupled with population and economic growth will greatly increase both the magnitude of the event and its potential impact. Several researchers have noted the vulnerability of the Fraser River delta (e.g., Richmond) and its protective dyke system to a combined threat of sea-level rise, storm surge, and snow-melt riverine flood (E. Taylor 1997; Andrey et al. 1999). Flooding of low lying agricultural and urban areas from high runoff and/or sea surges is compounded in certain areas (e.g., Nooksack)

where high water levels in the Fraser River prevent drainage (B.C. workshop 2000). Proactive research and planning to understand, manage and accommodate future flooding, as is being completed for Vancouver International Airport, should be instituted within all relevant land use, infrastructure and flood-related planning mechanisms within the Lower Fraser valley area. The results of sensitivity analyses should be used to support public education and awareness programs (B.C. workshop 2000).

3.6.5.2 Extractive Water Uses

Agriculture. Approximately 5% of the total cropped area in B.C. was irrigated in 1988, the highest ratio in all of Canada (Hofmann and Mortsch 1998). Under climate change improved production of existing and new high-value crops may be realized if sufficient water is available for irrigation. The agricultural industry will have to make significant adjustments given that approximately 99% of water used for irrigation in agriculture is supplied by surface sources, many of which are fed by snowmelt systems whose long-term reliability is questionable under climate change scenarios (Nyvall, B.C. workshop 2000). On the demand side, a change to warmer and drier summers, coupled with a longer growing season, will very likely intensify the water demand from both agricultural and non-agricultural users (Zebarth et al. 1997, Nyvall, B.C. workshop 2000). Greater competition for limited supplies will undoubtedly raise the price of water (delivery and treatment costs). Nyvall (B.C. workshop 2000) identified **a range of adaptation options, both structural (e.g., drip irrigation equipment, metering) and operational (e.g., water application scheduling), that could reduce water demands by approximately 40% if widely and properly adopted by farmers.**

Municipal and rural domestic water use. The primary concerns for municipal water use are depletion of groundwater reserves and the ability of existing reservoirs to capture enough water to satisfy a longer demand season associated with climate warming. Over 600,000 people depend on groundwater aquifers for water supply and several in each of the following regions have already been identified as having limited groundwater availability: Lower Mainland (3), Vancouver Island (8), Kamloops area (3); Penticton area (7); Williams Lake area (2); Smithers area (2) (B.C. Ministry of Environment, Lands and Parks 1999a). Should a greater proportion of rainfall occur in extreme events, less water would be available for infiltration and groundwater recharge, a particularly important concern in the Gulf Islands where groundwater is the primary domestic supply (B.C. workshop 2000). **Measures should be taken to protect groundwater recharge areas from excessive development and unsustainable use (B.C. workshop 2000).**

The remaining population is dependent upon surface water supplies. The Greater Vancouver Regional District relies on three main reservoirs for municipal water and has access to another three alpine lakes to supplement the primary reserves (E. Taylor 1997). Reservoirs have already been occasionally drawn down to 50% of capacity. Should the snowline lift from its present 900m level to 1300m or even 1700m as suggested by some climate change scenarios, there will be no snowpack storage left to fill the reservoirs (Hicks, B.C. workshop). Climate change, in addition to a growing Lower Fraser Valley population, may necessitate the development of expanded reservoir capacity and/or **continued water conservation programs**. While reservoir development may be premature, the latter adaptation, **which may include some combination of rational water permitting, metering, pricing and conservation (e.g., recycling water) measures, is cost-effective regardless of climate change** (B.C. workshop 2000). Similarly, research is a relatively risk-free response to climate change, and the GVRD is working with Environment Canada to better assess the potential impacts of climate change on its water supply and distribution system (B.C. workshop 2000). Support for conducting similar exercises in smaller B.C. municipalities who do not possess the necessary resources should be provided by higher levels of government.

3.6.5.3 Non-Consumptive Water Uses

Natural ecological functions. Salt water intrusion, sea-level rise and increased erosion may threaten many coastal wetlands and the species that depend upon them. Blais et al. (1998) noted the concern over high concentrations of persistent organochlorine compounds found in glacial ice and snow in western Canada. The rapid melting of glaciers and release of such pollutants deposited over decades via air transport may be of concern to aquatic ecosystems dependent on glacial meltwater for streamflow augmentation. **Provision for adequate monitoring of ecological functions may be the most prudent adaptation measure at this stage.**

Fisheries. Decreased seasonal streamflow, changing water quality (temperature, sedimentation/organics leading to reduced available oxygen) may affect the stream habitat for many andromadous species that use B.C. rivers for spawning and rearing young. McBean *et al.* (1992) suggest that climate warming could cause the successful migration of non-salmonid warm-water species from southern portions of the Columbia River system. Climate change is not expected to eliminate existing species in British Columbia, but it could cause southern latitudinal margins to move northward and shift elevational limits upward (McBean *et al.*, 1992). A stronger Aleutian low, predicted by climate change models, is thought to promote ocean upwelling thus increasing productivity over a large area of the North Pacific, adding uncertainty to the findings of other research that suggest predicted warmer sea surface temperatures will greatly

limit the southward extent of Sockeye salmon (Beamish, B.C. workshop 2000, Beamish et al. 1997, Pynn 1999). Climate (e.g., wind direction, Fraser River flows), not overfishing, is also thought to be the primary factor behind the collapse of Coho salmon fisheries in the Strait of Georgia and northwest U.S. (Beamish, B.C. workshop 2000). **If they are to be adaptable, future fisheries management strategies, including the establishment of quotas, must account for climate fluctuations and effects in both the ocean and spawning rivers.**

Hydro-electric power generation. B.C. Hydro operates several of the Province's 129 major water control structures to provide approximately 43,000 GW-hours of electricity annually to its 1.3 million residential, commercial and industrial customers (B.C. Hydro 1999; B.C. Ministry of Environment, Lands and Parks 1999a). Generally it is expected that climate change will not significantly affect hydro-electricity production except for potentially reducing capacities in southeastern B.C. where decreased runoff in the Columbia River Basin may become a problem (Ross and Wellisch 1997, Snover 1997). **Modifying reservoir operations to capture water earlier in the season and construction of additional storage are among the adaptation options available to power producers.** However such decisions must be rationalized against the needs of other users and instream uses to protect ecosystems and fisheries. Where economically feasible, decentralization of power generation (e.g., small-scale hydro close to demand centres) may be able to partially compensate for production losses at larger plants.

Tourism and Recreation. Reduced reliability of snowfall for ski resorts and implications for other recreation industries/pursuits (e.g., canoeing) were also identified as concerns (B.C. workshop 2000).

3.6.5.4 Water Management Policy and Interjurisdictional Apportionment

Greater potential for conflicts between uses. Water resources are already being stressed in a few southern B.C. locations. Changes in water resources due to climate change may further complicate management through instruments such as the provincial Water Protection Act (1995) which contains provisions for limiting bulk removal of water outside of the province and prohibiting large-scale diversions between major watershed within B.C. (B.C. Ministry of Environment, Lands and Parks 1999b). Over 20% of streams have been fully allocated in several B.C. water precincts, particularly southern Vancouver Island and the southern Interior (B.C. Ministry of Environment, Lands and Parks 1999a). Meanwhile conflicts between groundwater and surface water needs have already been experienced over several aquifers including those in the Kamloops area (Cherry Creek, Salmon River Valley), Penticton area (Marron Valley, Summerland, Kalamalka Lake) and Williams Lake area (Chimney Creek) (B.C. Ministry of Environment, Lands and Parks 1999a). **Prohibiting all inter-basin**

water transfers and offering rewards for not exceeding water-permit licenses were identified as adaptation strategies that could ameliorate potential water conflicts (B.C. workshop 2000).

Binational water management. Binational management of the Columbia River system may become more difficult in the future should climate change reduce winter snowpack and summer flows as a few analyses and recent trends have suggested (Snover 1997, Browne et al. 1998; Zhang et al. 1999). Water availability to meet multiple-use demands (e.g., fisheries, hydro, irrigation, recreation) is projected to decrease by mid-century (Browne et al. 1998). **Formal and informal criteria and legal instruments used for managing binational water resources** such as those under the Columbia River Treaty and those established by the International Joint Commission under the Boundary Waters Treaty (1909) **may have to be adjusted to consider changes in future climate and hydrology** (see Bourget and Clamen 1998 for discussion of Osoyoos Lake Board of Control). Similar investigations may be needed to explore implications of climate change for binational groundwater aquifers and possible management regimes.

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4. An Adaptation Strategy for Canadian Water Management

4.1 A Growing Vulnerability to Climate Change

There is evidence to show/suggest that the climate is changing and the vulnerability of Canada's water resources and supply is increasing. The security of our national water resources is under growing threat that affects both quantity and quality. There is also a threat of growing variability and a risk of more severe droughts and floods. All sectors of the national economy and all regions and communities are dependent for their health and prosperity on safe and adequate supplies of water. Canada is well endowed with water resources. Canadians have tended to take their water resources for granted. There has been a tradition of benign neglect and inefficient use. The role that water resources have played in Canada's health and prosperity is now at risk in new ways. These new risks pose unprecedented challenges to the hydrologic, climate and atmospheric sciences; to water management in both public and private sectors and to policy makers at all levels of government.

We base this conclusion on our synthesis of recent scientific literature, and on the collective expert judgment of the 330 water resource scientists and managers that participated in five workshops held across the country in the past four months. In these workshops a strong consensus emerged that our water resources are vulnerable and a turning point is approaching for management of Canadian water. It has to be recognized however that the quantitative analytical basis for this judgment is weak. There is insufficient reliable data on the quantity and quality of our water resources. And at a time when knowledge is needed more than ever the data collection and observation systems have been allowed to deteriorate. The feeling of foreboding about Canada's water is compounded by the sense that to a large extent decisions are being made in the absence of adequate understanding of their likely consequences. In other cases lack of data results in the delay or indefinite postponement of decisions that need to be made now to protect future health and security.

Such decisions also include withdrawal of much scientific and engineering support to communities by both federal and some provincial levels of government.

Ground water is a vital, high-quality water source that is ineffectively managed because in many regions of Canada basic information on water quantity, quality of the resource and its use and extraction are not available.

Lack of preparedness planning for drought and low lake levels is evident in most regions.

The failure to launch a federal-provincial disaster loss mitigation program and the curtailment of the previous flood damage reduction program, has occurred in the face of a mounting toll of losses from weather and water related disasters.

These examples lend support to the conclusion that vulnerability is increasing, but the lack of data and analysis means that we have little knowledge of how rapidly this vulnerability is growing. The situation might not be as serious as the expert judgments suggest. On the other hand it might be much worse.

A more complete diagnosis is urgently needed, and an approach to this is suggested in the recommendations.

The means to reverse the growing risks to Canadian water supply do exist. How best to design and deploy this response capacity depends upon an understanding of the underlying causes. There are three main groups of causes.

1. The climate/atmosphere/hydrological regime is changing and is set to change more in the next few decades. Significant uncertainties about the amount and rate of change exist, but since economic activities and physical infrastructure are adapted to present days climate norms, deviations beyond what has been normally expected will necessarily result in some losses. In fact, we are not coping well with the climate variability of the recent past – e.g. Saguenay flood, Red River flood, droughts and low water elsewhere.
2. Changes in the social/economic and political situation are placing new and enlarged demands on all natural resources, and this applies especially to water. For example the growth of population and industrial activity, and their concentration in urban areas is creating higher and more spatially concentrated demands for water for domestic and industrial use (and for assimilation of wastes). In addition the demand for water for irrigation is growing and is likely to increase more with climate change. Water quality in rivers and lakes is also under threat as the volume of waste grows and as chemical and biological effluents from homes, industry, and agriculture are released into the environment. These increases in demand are occurring in circumstances where supply is diminishing in most populated regions.
3. Reductions in budgets for monitoring, capital improvements and operational water resource management in both public and private sectors has led to a reduction of the scientific and technical information available to local water managers in their struggle to keep pace with changes in water resources and pollution and the demands placed upon them.

4.2 Regional Differences

As Canadians move into the long and difficult process of coping with climate change considerations of regional fairness and equity necessarily arise. In dealing with the reduction of greenhouse gas emissions concerns have been expressed that no region should be especially disadvantaged [the exact quote would be helpful here] by bearing a greater or unequal share of the costs of mitigation. Much the same argument can be applied to vulnerability and adaptation. If there is a case to be made for helping the high emissions regions of Canada bear the costs of emission reductions, there is a similar case to be made for helping the most vulnerable regions with the costs of adaptation. At present two significant obstacles lie in the way of such an approach. First the vulnerabilities in the different regions of Canada are difficult to compare in a quantitative way. The previous sections of this report spell out in some detail the nature of the different problems in the various regions. They do not yet provide any comparative framework or analysis by which these diverse problems and needs might be evaluated. There is an emerging sense of where the water sector in Canada is most vulnerable to climate change, but more work is needed to deepen this understanding and place it on firmer ground. The second obstacle has to do with the policy and decision making context. As in the case of mitigation costs, so with adaptation costs there is no commonly understood or agreed mechanism through which the winners or those less adversely affected can assist the most vulnerable. Political “horse trading” has been a common way to resolve such difficulties in the Canadian policy process, but reliance solely on such mechanisms is likely to be contentious at best, and very probably frustrating and ineffective. Two new approaches are worth exploring. First ways should be explored to soften or remove the profound schism in response to climate change between mitigation and adaptation. Second a better coordination mechanism needs to be in place between the various Federal Departments with an interest in water issues, and also between Federal and Provincial governments. In accordance with recent practice such new coordinating mechanisms should involve the private sector and civil society organizations.

4.3 Adaptation Needs and Strategy

In the face of growing vulnerability and the complexity posed by regional differences, careful expert judgment and serious political attention should be directed to the creation of a water resources/climate change adaptation strategy for Canada. The literature review and workshop consultations carried out in this study do not yet provide a sufficient basis for the design of such a strategy. Further steps are needed. Nevertheless the broad range of adaptation needs has been identified, and these have been listed and described in the previous

sections. The climate/water resources scientific community and the water managers (public and private) know in general terms what needs to be done. The task is to weave this long list of needs into a coherent strategy with appropriate priorities and evaluation criteria, and to provide the vehicles for the implementation of the strategy.

These are complex questions and lie beyond the scope of this study. It is appropriate however to suggest what sort of actions are needed, while recognizing that the choice of actions and the implementation process require leadership from elsewhere. We suggest that at the Federal level a new inter-agency body is required to develop the new coherent strategy for responding to climate change in the water sector. This body, whatever its form, should command sufficient resources to enable it to obtain inputs to the policy process in the form of analytical studies of vulnerability, adaptation needs and priorities. Such a body would be linked in some way to a new coordinating mechanism at the national level in which Provincial and Territorial governments, the private sector and civil society would be involved. The National Air Issues Coordinating Committee might serve as an example of the sort of mechanism that is required.

In suggesting the need for new coordination mechanisms for the water sector we do not mean to imply the replacement of existing programmes and capacity. Indeed the success of the mechanisms would depend upon their ability to entrain the contributions of a wide array of exiting bodies which now play a role in the water management and adaptation process. We have not attempted to compile a complete list but the following examples serve as illustrations:

The Federation of Canadian Municipalities and the new federal Infrastructure Fund, along with some provincial funds,

- The Climate Change Action Fund (might also play a role in stimulating the creation of Federal coordination)
- Canadian Foundation for Climate and Atmospheric Sciences (Canadian Meteorological & Oceanographic Society – Science)
- Emergency Preparedness Canada (more disaster mitigation efforts?)
- The Federal Department of Agriculture and Agri-Food.
- Health Canada
- Natural Resources Canada

- Environment Canada (water policy) including the Meteorological Service of Canada (climate, hydrometric), Department of Foreign Affairs and International Trade (Boundary & Transboundary Waters)
- Fisheries and Oceans Canada
- The Provincial and Territorial governments....

In addition to making effective use of the existing capacities consideration might be given to the creation of new capacity where it is now lacking, and also to the revitalization of needed capacities that have fallen into disuse such as water quality laboratories and monitoring.

For example the Federal-Provincial flood damage Reduction Programme played a vital role designating flood plain lands and limiting development on them for purposes of flood plain management. While the majority of the nation's flood plains have now been mapped and defined there is need for an ongoing process of keeping this information up to date and relevant to future growth of cities and municipalities. With climate change, as well as with the growth of population and the economy new vulnerabilities are being created. The excellent work under this programme must be maintained in an up to date form.

4.4 Objectives of the Water Resources/Climate Change Strategy

The integration of the long list of adaptation needs which emerges from this study into a coherent strategy requires a clear articulation of objectives. While such a formulation is another task beyond the scope of this study, the following elements should probably be included as a minimum:

- present patterns of water use in Canada are wasteful and inefficient. Such practices were more acceptable in the past in part because of the abundant supplies available in the natural environment and low population and development. Since this abundance is more and more under threat and demands are growing, steps are needed to increase the efficiency of water use. There are a number of mechanisms available for this purpose including regulatory and market approaches. Some such methods are now in use in some places, but the whole issue of efficiency in water use should now be revisited in the light of climate change.
- there are signs that water quality standards are at risk with potentially severe consequences for human health. The protection and enhancement of water quality is another objective that should be included in the strategy, taking climate change into account.

- water resources are an essential element in the protection of wetlands, flood plains and biodiversity. A new national water management strategy for climate change should therefore also include a strong watershed conservation objective.
- since floods and droughts are likely to become more frequent and extreme with climate change the reduction of vulnerability to atmospherically driven extreme events is an important objective to be included in the strategy.
- sea level rise poses special problems in coastal regions. This needs to be addressed by more effective coastal zone management and planning.

Characteristics of a Successful Strategy

In moving towards the creation of a national strategy for water resources and climate change, several characteristics seem to be essential for success:

- consultation with water management practitioners
- recognition and respect for the different roles and responsibilities of the many actors and stakeholders involved from water users and consumers, to government bodies, the private sector, the climate/water scientific and technical community, and civil society
- building upon and use of existing capacities wherever they may be found to achieve the objectives such as described above. Wherever possible existing instruments and programmes should be utilized (see 4.3 Adaptation Needs and Strategy above).
- -new instruments might be introduced in special cases but much can be achieved with existing capacity, strengthened as appropriate in order to respond to climate change risks.
- the most pressing need is for new and improved modes of coordination specifically designed to facilitate the adaptation of the water sector to climate change.

4.6 The Benefits of Adaptation Now

Uncertainties about the rate and magnitude of climate change arise because of uncertainties in future emissions of greenhouse gases and aerosols as well as limited capabilities of climate models to make regional projections needed for hydrologic studies. These have led to some temptation in the water sector to

postpone serious response to the threat until more precise and confident projections are available. There are at least six reasons why adaptation to climate change makes good sense in the short term:

1. Climate change cannot be avoided. It is already underway. The world is committed to some changes due to past actions. Even the most optimistic forecasts of emission reductions recognize that greenhouse gas concentrations in the atmosphere will continue to increase for some decades at least.
2. Anticipatory and precautionary adaptation can be more effective and less costly than forced, last minute emergency response. This is not necessarily the case, but economic analysis reveals cases in which precautionary action is less costly. Much depends upon the assumptions made about the rate of climate change and the frequency of extreme events.
3. Climate change may be more rapid and more pronounced than present models and estimates suggest. There is the possibility of nasty surprises.
4. There are immediate benefits to be gained from better adaptation to climate variability and change, and extreme events, even in the climate being experienced now.
5. There are immediate benefits to be gained from the removal of maladaptive policies and practices.
6. Climate change brings opportunities as well as threats. There are future benefits to be gained from climate change and these can be captured by beginning the process of adaptation now.

4.7 A Win-Win Strategy

The many conclusions of this study can be summarized in one important and overriding lesson. Many of the actions needed to adapt to the threat of climate change in the water sector are needed to deal with the present situation. Actions to protect Canadian water resources; improve efficiency in water use; conserve watersheds and wetlands, flood plains and biodiversity; safeguard water quality, and reduce vulnerability to floods and droughts, and coastal storms and sea level rise, all need to be strengthened now in the short term. The more successfully this can be achieved the better adapted Canada and Canadians will be to whatever the future of the climate and the hydrologic cycle holds in store.

Better management of Canadian water resources now means less vulnerability to climate change in the future. It is a win-win situation. In the interests of human health and economic prosperity there is no reason for delay.

4.8 Recommendations for Next Steps

1. Take steps to create a national strategy for water resources and climate change.
2. Create an inter-agency coordination mechanism at the Federal level to help develop and implement the strategy.
3. Create a mechanism for Federal-Provincial and multi-stakeholder coordination to help develop and implement the strategy
4. Initiate further studies on adaptation priorities as an input to the policy process
5. Challenge existing agencies and use existing instruments to develop contributions to the strategy.
6. Organize a national conference on water resources and climate change, to generate debate and raise awareness and to help in agenda and priority setting [something on the scale of the Montreal Conference on Resources for the Future of 1962]
7. Challenge the Canadian Climate Program Board to provide guidance on research priorities for climate science, vulnerability and adaptation assessments
8. Strengthen the Meteorological Service of Canada, modelling, monitoring, re-invigorate water quality monitoring in collaboration with the Provinces.

ANNEX A.1 - WORKSHOP REPORT - ATLANTIC

Soil and Water Conservation Society – Atlantic Chapter Workshop

Water Sector: Vulnerability and Adaptation to Climate Change
(11th Atlantic Region Hydrotechnical Conference)

May 12-13, 2000 – Université de Moncton, Moncton, New Brunswick

Meeting Summary

OBJECTIVES, VENUE AND PARTICIPATION

The workshop was in co-operation with Global Change Strategies Inc., the Meteorological Service, Environment Canada and was supported by the Climate Change Action Fund, Natural Resources Canada. Each of the Canadian Chapters of the Soil and Water Conservation Society were asked to put on a workshop on this topic in their regions. The workshops were intended to stimulate discussion and awareness of the subject and provide some feedback on regional issues and potential adaptation measures.

The workshop was held as concurrent sessions with the 11th Atlantic Region Hydrotechnical Conference, a joint conference of the Canadian Society for Civil Engineering, Canadian Water Resources Association and the Atlantic Chapter of the Soil and Water Conservation Society. Sixty-four people attended the conference; out of this, 28 attended the first day of the SWCS workshop presentations and discussions and 25 the second day. The participants were mainly professional engineers from diverse sectors of the government, with a few academics, students and NGO's. The first day panel discussion topics were mainly agriculture, environment, drought, soil erosion and floods. The second day topics were mainly coastal zones, hydropower and environment. Potential implications of climate change and variability were examined within the context of current and future adaptive management practices.

NOTES FROM THE PRESENTATIONS

(NB : the abstracts of the presentations may be found in the appendices)

One of the two plenary session keynote speakers of the conference was Jim Bruce. He introduced the SWCS workshop topic with a background paper: *Water Sector: Vulnerability and Adaptation to Climate Change*. He discussed the possible changes in climate and the implications they could have. In the discussion following his presentation, the audience raised the possibility that a climate change could bring some

positive implications that we could take advantage of. There was also concern that although we can adapt, nature can't necessarily and there could be some adverse effects on some species. A lot can be done to modify our energy use (natural gas, efficient cars, etc.) but the government and the public have to be interested first. An *Overview of the Atlantic Canadian Sensitivities to Climate Change* was presented by Wayne Groszko (Env. Can.)

and Bill Brimley (Env. Can.). presented the *Possible Impacts on Atlantic Canadian Water Resources* of climate change, based on the predictions of modern models. From these, he showed a portrait of the past and future demand for water. Higher demand, but less water available is what we will likely have to face in the near future.

The *Weather conditions associated with apple production in the Annapolis Valley of Nova Scotia and the Okanagan Valley of BC* was presented by Jean-Pierre Privé, (Agric. Can.). With a mathematical analytical method, the effects of daily weather conditions were compared to annual variations in apple production for both Annapolis and Okanagan Valleys over an 80 and 72 year period, respectively. This study is useful to develop genotypes that tolerate or avoid stressful weather. This could also help to develop management strategies as an adaptive response to a climate change.

A global climate change would *Increase needs for Soil and Water Conservation according to Jean-Louis Daigle* (Eastern Canada Soil and Water Conservation Centre) He identified some challenges and issues regarding:

- Water and food production
- Regional climate variability
- Agro-environmental indicators
- Soil quality and cropland protection
- Water quality and water supplies
- Biodiversity in agroecosystems

Good examples of soil and water conservation programs were cited from NB and PEI and the challenge of ensuring a proper balance between policies and programs was presented. A need to review national and provincial programs was noted. The tools for change and adaptation proposed in this presentation were:

- Environmental farm plan initiatives
- BMP development
- Codes of practices
- Agri-conservation Clubs
- Promoting economic benefits of soil and water conservation
- Use of precision agriculture and environmental geomatics
- Program incentives (tax, etc.)

In the past, aboiteaux and dykes were built to drain and protect fertile agricultural land located in the coastal marshes. Now many stakeholders use these lands for purposes other than agriculture. Claude Robichaud and Hank Kolstee introduced us to the

Impacts on New Brunswick and Nova Scotia Dykelands Design and Construction of a global climate change. If more frequent large rainfall events occur and a rising sea level, flooding of these lands will be more frequent. A need to have a land-use planning policy for the use of flood plains was presented, especially in a context including climate change. Case per case design should be considered (different location, different requirement, different criteria).

The second day of the SWCS workshop opened with a presentation by Brian Mills. Various Adaptation *Options in the Water Sector* were introduced in this presentation and evaluation and implementation considerations of these options were discussed. It was mentioned that we adapt to impacts, not to the increasing temperature and that we should prevent the effects of this increasing temperature to adapt efficiently. Research and education may be key.

Stephen Hawboldt's presentation was on *Storm and Tidal Surge Impacts on Land Resources, Russian Roulette: The Odds are Changing*. Once in one hundred years, the Bay of Fundy has been subjected to a major storm that coincides with the very high tides that occur in the spring and fall depending upon the moon's cycle. Human induced climate change and sea level rise are suggesting that the game of Russian roulette that all Fundy residents have been playing may change. This presentation presented some adaptive measures or needs of the residents of the Bay of Fundy in a global climate change context. A need for more research, new partnerships and the participation of the community were some of the issues identified.

Finally, Trent Webster's presentation was about the *Nova Scotia Response to 3 years Drought*. Solutions sought for drought in the Annapolis Valley were presented. These solutions came from the Valley Water Group Meeting. The Group formed after 3 years of drought in this region. This meeting had two goals: 1) to create a water management committee or board for the Annapolis Valley and 2) to identify agricultural water problems and implement solutions. The principal issues were around water quantity, quality, allocation and wise use. Partnerships between the stakeholders were also an important way to solve the problems.

ISSUES RAISED FROM THE TWO PANEL DISCUSSIONS

Following each of the two days presentations, a panel discussion was held to discuss the implications of a potential climate change. Adaptive measures, economics of adaptation, education, research and options were the foci of the discussions. Other issues related to climate change or related to the water sector in the Atlantic Canada were also raised in these panel discussions and are included at end of this summary.

Adaptation:

Some points that have to be considered when looking at adaptive measures:

There has been a change in the timing of occurrence of extreme events especially floods and spring breakup

Smaller watersheds are more affected by extreme heavy rain events;

There could be potential benefits of climate change (longer growing season, etc).

The adaptive measures mentioned in the panel discussion were:

- We think differently than 20 years ago, so we should modify our actions if we don't want to make the same mistakes, which consequently means changing our habits;
- Monitoring should be improved and/or modified including new technologies;
- Improve soil erosion control (soil erosion would increase with the higher frequency of intense rains predicted)
- Soil conservation can be used to encourage adaptation to climate change and simultaneous sequestration of C (e.g. companion cropping in lowbush blueberries, low tillage);
- Floodplain mapping and zoning; we should limit future developments in these areas with a review of criteria.
- Store more water to increase stream flows in dry season;
- Reduce impacts from a "Saxby gale" in Bay of Fundy – prepare dikes, prepare EMO, prepare government, predict/assess economics losses
- Use resources and information already available and use them efficiently;

Economics of adaptation:

- Cost and size of projects : big structures versus small structures (big structures are more expensive but may be cheaper to maintain);
- The cost of projects versus the societal demand also has to be considered;
- "Free-market economics" impacts on soil and water conservation economics;
- The economic feasibility, the cost of agriculture land, the value of agricultural products and the trade policy are all interrelated issues;
- The tax base represents an advantage for municipalities – therefore, they support building on floodplains; should we persuade banks not to loan money to people that want to build on floodplains? Who should bear the risk?
- Costs of developing irrigation are high but it is also an issue of agricultural security, food security / societal investment and economic benefits downstream in economy ;
- Estimate of the cost of doing nothing; what would be the economic loss? There should be a linkage between cost/benefit (e.g. the cost of an increase in floods versus a floodplain policy).

Education:

- Setting common goals;
- Little understanding of climate change issues in most of the government, most industries or institutions;
- The Forestry industry has an understanding of the situation; they are planting trees to respond;
- Monsanto is an example of one industrial company that is responding to climate change issues, re: chemical development and use ;
- We are not learning to avoid building on floodplains ;
- We are re-building with the same structures, same designs, at the same places – we are not responding to adaptation requirement ;
- Developers should consider/include costs of adaptation;
- Educate planners, zoners, banks, developers, regulators so they can make good decisions (some regulators don't want to know about the problem because they are the ones who would have to fix it) ;
- Educate politicians/government to obtain legislation;
- Understanding who is bearing the risk, who is bearing the end-costs downstream in the economy;
- Education on water quality issues;
- At what level can we make a difference? Everyone has the same goals, but they are all fighting or competing amongst themselves. We should bring the stakeholders together ;
- Personalise the problems to raise the concern and awareness of the people.

Research:

- Testing response models (realistic scenarios from EMO);
- Ecological and in-stream value of water needs should be evaluated (we should not put all our eggs in the engineering basket, re: irrigation, in particular) ;
- Fall silt accumulation in aboiteaux will increase; sealing aboiteaux in fall – how to manage this? (we should not manage the same way as in the past) ;
- Impact of existing hydrotechnical infrastructure ;
- Impact of climate change on groundwater ;
- Study groundwater and surface water flows and quantity (there is enough water in a year cycle... what we need is to be able to retain it in reservoir for drought season. There is also a huge potential in groundwater that could bring a partial solution to drought (but just how “renewable” groundwater reserves are needs to be studied);
- Tide gauges and tidal research (the impacts of rise of sea level could be exaggerated by human action) ;
- Dikes need to be studied (can dykes resist projected floods?);

- Link soil and water conservation, water quality and climate change adaptation ;
- We need research that includes socio-economic impacts.

Options:

- Return some dykeland to wetland. Why maintain dykes if 50% of the land is not used for agriculture?
- Marshland has less dollar value than agricultural land does, so we could revise/change the land ownership patterns.
- Floodplain mapping and zoning; we should limit future development in these areas.

Other issues:

- There are water quality questions that need to be resolved too, which may or may not be linked to climate change: bacteria, viruses, parasite contamination... what happens if crops are contaminated? There will be impacts on sale of food produce. There's a need for research to know if there's a problem or a vulnerability;
- Identify sources of water contamination (ex: climate changes impacts);
- Avoid anthropocentric view of water sector impacts;
- Wildlife and agriculture water use conflicts may be growing;
- Natural tidal siltation of riverbeds; seasonal changes may affect;
- Surface water versus groundwater – use as source, and impacts of climate change need to be better understood;

There is a need for a positive approach to the problem. It was also raised that we should show solidarity and work together toward an adaptation strategy to probable climate change. We can do the work... or nothing. Do we have to wait for crisis as we always did in the past?

ANNEX A.2 - WORKSHOP REPORT - QUEBEC

Water Sector- Vulnerability and Adaptation to Climate Change in Quebec, Sainte-Foy Workshop.

On Thursday, June 8th, 2000, 96 participants representing NGO's, government, the private sector, universities and concerned citizens, met at the Hotel Quebec, Sainte-Foy to discuss climate change and the impacts (social and economic) it might have on the quantity and quality of Quebec's water resources. The workshop supported by Natural Resources Canada Climate Action Fund, was hosted by the Quebec Branch of the Canadian Water Resources Association in collaboration with Environment Canada, and in cooperation with GCSI-Global Change Strategies International Inc. After an introduction by André Carpentier (president of the Quebec Branch), Gérald Vigeant (Environment Canada) reviewed recent events in Quebec, including water- and climate-related disasters (e.g. ice storm, Saguenay flooding, water exports) and public consultations on water (BAPE's- Bureau d'audiences publiques sur l'environnement-recent report, May 2000). He then went on to provide a brief summary of the Working Document (Bruce, Burton, Martin, Mills, Mortsch).

Morning Session

The morning session of the workshop began with a series of half-hour presentations that were made by a variety of experts:

- Alain Bourque (Environment Canada) provided a review of climate change models, scenarios and modeling needs (e.g. issue of variability), and application on the regional scale for Quebec. Although regional predictions are more difficult to estimate due to higher uncertainties (e.g. influence of initial conditions in modeling), there is a general time-trend of effects due to the influence of the main forcing factors. There is a need to use results concretely, such as for impact studies and sensitivity analysis.
- Jacinthe Lacroix (Sécurité Publique) underlined the nature of climatic extremes and their trend over time (temperatures and precipitation, either in quantity or frequency; winter thaws; dry spells).
- Michel Slivitzky (INRS-Eau) separated the resource use aspects of water (e.g. energy, withdrawals) from its place in the environment more generally (life support for ecosystems). He provided some examples of vulnerability and the role adaptation can play not just in relieving the constraint on the availability of the water resource, but also how it may be geared towards reducing demand. Credible scenarios are required for developing effective adaptation strategies, which includes understanding of sensitivity and vulnerability of hydrological systems.

Afternoon Session

The afternoon section of the workshop focused on case studies in impacts and possible adaptation strategies for Quebec. It was divided into two parts, along the lines highlighted by Michel Slivitzky earlier.

First part: 'Eau comme milieu'

Christiane Hudon (Centre St. Laurent) looked at water levels and trends in the St. Lawrence river:

- A marina near Montreal (Pointe aux Trembles) was examined to see the effects of a lower water level, including nearby animal and plant impacts, and actions that were taken by the marina to adapt. The drop in water level in this case was greater than its natural variability. Over time, this extremely low level may fall within the 'natural' variability as the average level over time drops due to climate change.
- Flow and other physical characteristic of the water also change, which have impacts on both wildlife and humans. Some human activities are more sensitive than others to the changes, e.g. hydro and navigation.
- Management priorities must be in human health, avoiding risks and solving the issues of property and infrastructure damages (who pays?), and in their maintenance.

Marc Mingelbier (Faune et Parc Québec) focused on the rivers and lakes of Quebec.

- The large differences in their scale (water height, flow, physical environment, thermal inertia) means that climate change effects will differ widely, e.g. degree of erosion and sedimentary flow, impact on fish habitat.
- Some species of aquatic wildlife are more adaptable to the changes in habitat conditions than others. In order to assess changes in species numbers and diversity, scenarios are developed from models that describe the 'preferred' habitat for each species. Strategies that reduce environmental stresses are then examined.
- Winter precipitation was also examined to see how changes in the height of snow may affect the vulnerability of some wildlife to predators.

François Morneau (Transports Québec) looked at the possible impacts of climate change on Quebec's road networks:

- Impacts include increased frequency of thaw/freezing events, which deform and crack roads; increased temperatures, which soften roads and leads to deformation by the weight of heavy loads; increased amounts of freezing rain; increase in extreme events, with concomitant flooding; increase level of sea.
- Occasionally, there are some large 'surprises', like the flooding of the Saguenay river, but typically each year there are small 'surprises', e.g. a bridge collapse. Transports Québec has assigned to different type of bridges throughout the province, design criteria based on expected frequencies of extreme events. However these empirical design criteria do not take into account possible changes in the variability of such events. The question is: how will climate

change affect the design frequencies of such extreme events, when future conditions may change?

- Mr. Morneau discussed the problem of erosion, which threatens many roads near the sea. There are budgetary constraints which hamper the ability to deal with this problem, however.
- Cutbacks in Transports Québec have resulted in a much less centralized organization. There is less exchange of expertise and it is now more difficult to raise awareness. The typical reaction is that climate change is 'not a problem'.

Marc Simoneau (Environnement Québec) talked about the various pollution problems which could arise from climate change. Flooding of waste water treatment plants, sewers, and agricultural fields will have an impact on water quality. There are two concurrent extremes in the climate change scenario: (1) dry summers, hot temperatures; (2) sudden precipitation flashes. This means that there will be two concurrent extremes in impacts and risks, each requiring their own response strategy.

Key comments from the audience on the first part include:

- There seems to be a truncation between the science, the work of the specialists (meteorologist, hydrologists), and adaptation, the work of governmental ministries. The two groups of people must be brought together, with regular meetings held. With better prediction and communication thereof, there can be better prevention. It is acknowledged, however, that there is a lack of resources and/or time to design climate change adaptation strategies. The issue is not high on the political agenda and the feeling is that the divide is great between politicians and the concerned groups.
- Drops in water levels has implication for property law: who will have legal titles to the new land ? When does one revise the maps? Also, who's responsible for damages? The civil code will have to adapt to this new situation.
- There is a concern that commercial priorities will take precedence over environmental ones if the effects of climate change become a reality. Adaptation strategies for wetlands ecosystems could include: reduction of other stresses on the system, new man made habitats that can relieve some stresses in critical periods, reduce fishing quota to relieve pressure on the species, reintroduction of vanished species capable of adapting to the potential habitats.
- Some possible response strategies to climate change effects on water include: users of a common water resource should try to sort out the problem together; improve water quality standards; reduce waste in aqueducts; water charges; agricultural waste must be addressed by to the Ministry of the Environment.
- Even when adapting design and construction standards, it is difficult to get consensus on what is to be done to prevent erosion and maintain the road system on the island, given the experience of the Madeleine islands.

Part two: Eau comme ressource

Pierre-André Coté (Ville de Québec) made a presentation about the St. Charles river, whose basin supplies water to over 350,000 people illustrating population pressures and demands for water. The city of Québec itself supplies water to a population of 240,000, people in eight municipalities; with important upstream withdrawals and sewers overflow downstream, management poses serious water quantity and water quality problems. He proposed an approach for minimizing risks from climate-change impacts:

- 1) figure out what the pressure points are (e.g. in Quebec city it is the sewer overflow during frequent storms;;
- 2) options for additional control, e.g. dam;
- 3) examine options to avoid pressures in the first place (e.g. water demand management).

Vincent Fortin (Hydro-Québec) outlined the impacts of climate change on his company's hydraulic system and its adaptation strategy:

- Sensitivity: compared to changes in financial (e.g. interest rate, exchange rate), temperature, and electricity demand factors, hydrological variability have a much greater impact on Hydro-Quebec's bottom line (- \$1 billion to + 426million, depending on the scenario {based on sensitivity of the bottom line for 1999 and 2000 combined}).
- Impacts will vary across the province Quebec. Depending on the region, this will affect hydraulics either positively or negatively. On the whole, Hydro-Québec expects to benefit, according to the model scenarios. However, at present, they are suffering since water levels are below historic ones.
- Adaptation strategy: (1) evaluate climate change impacts; (2) produce scenarios; (3) study impact on planning of electricity production (e.g. adapt planning tools); (4) adapt the plan for electricity production. Efforts are now focused on coupling global models with hydrological models. There are still many unknowns and strategies will have to be flexible.

Yves Michaud (Centre Géoscientifique du Québec) examined the impacts of climate change on underground water resources in the Portneuf area of Quebec:

- As there is plenty of above-ground water, underground water resources are not seen as a problem in Quebec. Reservoirs are generally being charged at a faster rate than being depleted. Only in a few areas is there a problem.
- Extreme events get dampened as water filters into the underground reservoirs, so it is the average amount of precipitation that counts.
- Roger Nadeau (Ville de Cap-de-la-Madeleine) looked at the water shortage problem in the city on the Madeleine islands, where all water supply is drawn from a local aquifer: Demand management in the past ten years has stabilized the total withdrawal from the aquifer; yet the total volume is limited and the risk of lower rainfall will affect future groundwater supplies.
- Presently, water charges are applied to commercial and industrial users. Residential users pay essentially a low, fixed charge; the various implications of further limits to individual demand need to be examined.

Louise Rémillard (Alcan) provided an overview of the Alcan hydraulic power network and highlighted items that need to be considered in a climate change strategy:

- 1) public security- ensuring that the infrastructure is sound, flooding risks are evaluated, and emergency measures prepared.
- 2) management of hydraulic network- since the energy demand is little influenced by climate changes, the company feels it has adequate management processes to deal with fluctuations, and can depend on historic trends to forecast supply in the medium-term.
- 3) long-term capacity- would need to be evaluated. Possible adaptation measures include: adjust electricity production as required, e.g. new sources of energy, inter-exchange of electricity within the power network.

Key comment from the audience for the second part:

- If we are prepared for extremes in natural variability in weather events, we should be prepared for climate change. The fact that we have *not* been prepared up to now shows that we are presently *not* prepared for climate change. We still have much to learn from the impact of present and past vulnerabilities and previous disasters in Quebec.

ANNEX A.3 - WORKSHOP REPORT - ONTARIO

Water Sector: Vulnerability and Adaptation to Climate Change in Ontario Cambridge, Ontario Workshop

On Thursday, March 23, 2000, over 60 water managers and scientists met at the Grand River Conservation Authority Administrative Centre to discuss climate change and the impacts it might have on the quantity and quality of Ontario's water resources. The workshop was supported by Natural Resources Canada Climate Change Action Fund and hosted by the Soil and Water Conservation Society (Ontario Chapter) in cooperation with Global Change Strategies International, Inc. and Meteorological Service, Environment Canada. After presentation of some highlights of the Background Document (Burton, Mortsch) a series of 6 papers by Ontario experts were presented, covering floods and droughts, water quality, water supply and demand.

Future Climate Scenarios and Recent Trends

Climate change scenarios for 2050 by the Canadian Centre for Climate Modelling and Analysis (CCCma, U. Vic) suggests that mean annual temperatures in the Great Lakes-St. Lawrence Basin will increase by 1.7 to 4.1⁰C with the largest increases in spring and summer. The Hadley CM 2 UK model gives somewhat lower projections but its successor Hadley CM 3 is similar to CCCma. Precipitation projections are in the range of 10% less to 10% more on annual basis and in all seasons except spring (up to 20% more). Hadley CM 2 is a little wetter, but Hadley CM 3 similar to CCCma. Observed upward temperature trends, from 1895 to 1992, are 0.6⁰C winter and spring. An upward trend in total precipitation was also observed, concentrated in autumn. Further warming and somewhat drier conditions occurred from 1993-1999. Short duration (1 day) high intensity rainfalls are projected to increase in frequency (e.g. 20 year rain becomes 10 year event) – CCCma. Dartha, et al. indicate an increase in high intensity falls to date in spring – summer.

Water Impacts

How might these changes impact Ontario's water regime? More intense local rainstorms could increase flash flooding. At the same time evaporation will increase. Increases in both drought and flooding are expected. There could be, in general, less water to recharge aquifers resulting in lower base flows in watercourses. Shallow aquifers will be vulnerable. Lake levels will drop on average by a large amount in some projections

The impacts of increased variability in rainfall and temperatures will lead to greater uncertainty in managing our water resources with increased frequency of high intensity rainfalls. Water quality issues will become more prevalent as fields and riverbanks become more vulnerable to erosion, water temperatures increase and the capacity of

streams to assimilate pollutants decreases. These changes will have implications for allocating water, treating waste water, managing floods and drought and associated capital infrastructure, hydro-generation, irrigation, shipping on Great Lakes, outdoor recreation, fisheries, and public health and safety. There will be growing challenges around water management as competing interests vie for water. There will be a need to find mechanisms for allocating water more carefully, monitoring uses, and mediating conflicts. The issue of inter-basin water transfers and diversions from areas of abundant supply will become more pronounced.

Adaptation

Participants were asked to consider how we might adapt to the impacts of climate change in order to secure water quality and supply in the future? Five discussion groups were asked to discuss adaptation opportunities around public policy, programs, planning and pricing; community economic development; agriculture; fisheries and aquatic sciences; and, public health and safety.

A wealth of ideas were identified by the discussion groups and summarized at the end of the day. It was suggested that there are many proactive actions that can be taken today to adapt to the anticipated impacts of climate change. Some of these ideas include:

- ❖ Review the standards for floodplain management given changing flood risks, including “naturalizing” flood plains
- ❖ Preparing a water budget for watersheds to identify the connections between surface and groundwater and areas of vulnerability to water takings and to determine sustainable limits for water extraction
- ❖ Introducing water reuse and efficiency policies and encouraging new technologies which reduce water consumption
- ❖ Introducing water conservation programs to assist landowners in protecting and enhancing the landscapes ability to hold water
- ❖ Redefining water quality standards and improve waste water treatment
- ❖ Improved contingency plans for extreme events
- ❖ Encouraging best management practices in rural areas to reduce sources of pollution and to re-vegetate riparian corridors
- ❖ Protect existing wetlands and create new wetlands to retain and filter water

- ❖ Encourage community-based environmental stewardship
- ❖ Decrease subsidies to industries that promote increases in water use
- ❖ Develop areas of excellence – programs and projects that illustrate sustainable use of water
- ❖ Better and more extensive public education on water and climate

It is clear that although there is much uncertainty surrounding the nature and extent of climate change, we must be prepared to adapt to changes that appear to be inevitable. Ignoring the signs will be like burying our heads in the sand. There is an urgent need for scientists and water managers to exchange information and to develop adaptation strategies now. This is particularly true for the whole of the Grand River watershed, which is currently dependent almost solely on surface and groundwater with the basin for water supply and on surface water for wastewater discharge.

While there were many potential adaptation measures identified, there was neither time nor procedures in place to set priorities. All adaptation measures identified for climate change are “no regrets” measures, i.e. worth doing anyway. Climate change gives one more reason for doing them. There was, however, a view that Ontario is more vulnerable now than 10 years ago to climate change effects in the water sector because of changes in policy and funding at senior government levels.

ANNEX A.4 - WORKSHOP REPORT – PRAIRIE PROVINCES

WATER SECTOR: VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE

Background

The Water Sector: Vulnerability and Adaptation to Climate Change workshop was held May 18, 2000 at the Lombard Hotel in Winnipeg, Manitoba. The goal of the workshop was to raise the awareness of climate change in the water sector and to promote the development of adaptation strategies for water management in the Prairies. More precisely, the workshop was designed to: foster discussions for dealing with climate change and water issues using existing and future scientific knowledge; identify and strengthen linkages between water managers, public policy, and adaptation strategies relating to climate change and water issues; facilitate communication, consultation, and negotiation among interested parties, and where appropriate, create mechanisms for achieving practical solutions relating to climate change and water in the Prairies; and contribute to a national assessment of water sector vulnerability to climate change and potential adaptation measures.

The 95 participants came from across the Prairies, with representation from Alberta, Saskatchewan and Manitoba. The participants were decision-makers ranging from landowners, to local officials, to government officials.

Presentations were heard from experts in climate change and water management. Dr. Jim Bruce provided a background to climate change, and highlighted the need for adaptation. Linda Mortsh took participants through the work of the Canadian Climate Change Impacts Scenarios Project, highlighting who was involved, and how data was being made available in different formats. Al Pietroniro provided a background on hydrology modeling with a particular emphasis on the variables relating to climate change. Following the general presentations, regional presentations were made to provide a background of the issues in the Canadian Prairies. Alf Warkentin provided a flood and drought perspective and the implications of climate change. Betty Collins outlined the potential of wetlands to assist in adapting to climate change and their role for wildlife. Dave McGee concluded the regional perspective component of the workshop with a presentation of how Alberta is increasing their flexibility to deal with the changing aspects of the climate. The final presenter was Lawrence Martz, who outlined the GEWEX project, which combines the climate models with the hydrology models to get a better understanding of the impacts of climate change in the MacKenzie basin.

Following the morning presentations, the workshop participants divided into working groups to discuss: agriculture, wildlife, energy, community economic development, and public health and safety. The workshop groups were asked to address the vulnerabilities of the sector and potential adaptations.

Climate Change Scenarios for Prairie Provinces

Speakers from the 3 provinces outlined the most plausible scenarios for water, drawing upon the global climate model projections under “business as usual” & recent trends. Most of the attention was focused on the Saskatchewan – Nelson system and the Red River Lake Winnipeg drainage where scenarios to 2050 were reasonably similar. The Mackenzie and Churchill River systems were addressed less thoroughly but will likely experience somewhat different changes.

For the southern Prairie a plausible scenario involved large temperature increases (~7°C winter, ~3°C summer); more spring rain, with little change in summer; higher vapour pressures but still significant increases in potential evaporation in spring-summer; lower soil moisture except early spring; earlier spring breakup but, on average lower peak flows because of snowmelt episodes during the winter; however occasional very severe floods could occur with heavier earlier spring rains with snowmelt, winter flows higher, summer and autumn flows lower, annual discharge lower; aquifer recharge reduced; increased potential for flash floods on small watersheds, although average conditions would be drier, any change in frequency of severe long drought (every 30-50 years in past) is very uncertain. For water quality contaminants (eg. Phosphorus) increase as flows increase (floods, non-point sources) above a certain threshold (eg. 125 m³/sec for Red River at Selkirk), and increase with lower flows below this threshold (point sources).

In more northern basins both winter and summer precipitation may increase, which combined with temperature / evaporation increases may result in little change in flows. However, it was noted that small changes in average annual temperature can lead to large flow losses with no precipitation changes.

Agriculture Working Group

Vulnerability

The key vulnerability was the diminishing water resources, including surface, groundwater and aquifers. The increasing possibility of droughts could have impacts on decisions about pasture or croplands, irrigation, controls for new pests and soil quality, and use of wetlands. The group felt that some government policy and agencies as well as the lack of data and/or research was also a vulnerability to climate change.

Adaptations

The working group pointed out the agriculture has been able to adapt to droughts to a certain extent, citing the drought of the 30's compared to the 80's. Watershed management was seen as one of the key adaptations to climate change. This ranged from on farm water management to aquifer recharge, to prevention of wetlands loss. The group decided it would be necessary to adapt policies to be more flexible in water management. More information is required to make informed decisions, such as improved forecasting and modeling.

Wildlife Working Group

Vulnerability

The working group thought there would be significant changes in the biodiversity and species distributions. This would be due to the increase of temperature, eutrophication, salinity, as well as the greater disease spectrum. Water birds are especially sensitive to these types of changes. Cold water species of fish will decrease, while the warm water species will predominate. Spring spawning fish are also at risk. Perhaps the biggest vulnerability in our predictive ability is the limited knowledge or information gaps on vulnerabilities and likely changes.

Adaptations

The Wildlife working group suggested that two preconditions are required for adaptation, broad buy-in by all decision makers, and that “no-regrets” options are initiated first. The group felt it was necessary to adopt a set of numerical standards for H₂O quality. Increased head water storage will be required, but it will also require incentives for landowners to participate. Conservation farming practices will be necessary, to reduce nutrient loading, and control effluents.

The group also raised concerns about the possibility of more large reservoirs, more irrigation and the operation of reservoirs as potential hazards to wildlife. It was thought that there should be more emphasis on enacting / enforcing current regulations (e.g. drainage), ecological services payments to landowners, better allocation & licensing and giving “wildlife” a place at the decision making table.

Public Health and Safety working Group

Vulnerabilities

Two key areas were discussed, floods and droughts. The flooding concerns were: pollution from animal waste / lagoons, contamination of wells and aquifers, slope

stability concerns, and flash floods on smaller streams. The drought concerns were: insufficient supply leading to increased competition, groundwater mining and quality, intensive livestock operations and their water requirements, potential damage to riparian zones, erosion leading to reduced air and water quality and silting, and increased bacteria and algae due to warmer streams. The group did point out that the increased temperature would lead to less brutal cold winters.

Adaptations

The Public Health and Safety working group broke the adaptation measures into three categories, short-term, medium-term and long-term.

Short-term adaptations

- use common sense approaches, remember to think beyond just one issue.
- decrease reliance on water and incorporate meters and effective water rates
- establish apportionment guidelines that are clear on quantity and quality
- increase education of climate change, discuss in K-12

Medium-term adaptations

- increase use of small dams for flood control
- guarantee minimum flows of streams and rivers
- maintain and enhance riparian zones
- provide better predictive information

Long-term adaptations

- restrict flood plain development, particularly people and intensive livestock
- plan for hydrologic extremes
- establish a network for drought proofing

Community Economic Development Working Group

Vulnerabilities

The working group were concerned that communities and businesses perceive water as abundant and inexpensive. There was also a concern about increased migration to urban centers if dryer conditions prevailed in farm regions. One particular vulnerability raised by the working group, was that a vocal minority claimed there is no threat from climate change and that there is little media coverage.

Adaptations

The Community Economic Development working group indicated that a holistic approach to education/communication was required to successfully adapt to climate change. This would include incentives and disincentives. Water recycling needs to be used more extensively, and water labeling of products (analogues to energy labeling) could provide users with more information about their products. The group felt more research on regional and community impacts was required and that opportunities already known should be capitalized, such as longer shipping season at Churchill and the potential for greenhouses to supply produce locally.

Energy Working Group

Vulnerabilities

The group felt that the infrastructure needs to be assessed from a climate change perspective, citing examples of operational difficulties especially transmission lines due to winds and ice storms, dam operations with possibly more severe ice jams, and the increased conflict over cooling water supplies for thermal plants (AB & SK), particularly with warmer water. In Manitoba, concern was raised over lower hydro production and export revenues. Oil fields were also a concern because of methods using water would be restricted for steam or water injections. The overall concern was higher prices and more volatility.

Adaptations

The key adaptation focused on greater conservation and increased demand side management. There is a possibility to increase hydro capacity and add more alternative energy, especially natural gas, wind, solar. Improving operations to take changes into account was also suggested, but there is an increased potential for a Sask-Nelson system-wide severe drought. Another key adaptation was to take advantage of opportunities, such as a longer ice free season, which would make reservoir operation easier and a shift in seasonal demand helps to even out demand peaks.

ANNEX A.5 - WORKSHOP REPORT – BRITISH COLUMBIA

Water Sector: Vulnerability and Adaptation to Climate Change in British Columbia

Vancouver Workshop

On Friday, April 14, 2000, approximately 45 water-sector professionals, academics and students met at the Harbour Centre Campus of Simon Fraser University to discuss climate change and the impacts it might have on the quantity and quality of British Columbia's water resources. The BC chapter of the Soil and Water Conservation Society (SWCS) sponsored the workshop in co-operation with Global Change Strategies International, Inc. (GCSI) and the Meteorological Service of Environment Canada. The Climate Change Action Fund and Natural Resources Canada provided financial support. After a presentation of highlights from the Background Document (Martin), a series of five papers were given on historical and recent climate changes in British Columbia and the management of climate change in fisheries, agriculture and urban environment. The afternoon was devoted to two breakout sessions which discussed vulnerability, impacts and adaptation.

Future Climate Scenarios and Recent Trends

Atmospheric concentrations of carbon dioxide and other greenhouse gases have risen by over 30% since the industrial revolution, a trend that has occurred concurrently with a 0.5C increase in global mean temperature over the past century. Assuming a doubling of equivalent carbon dioxide concentrations by about 2050, the climate models predict an increase in global mean temperature of 1-4C with a 5-10C warming during winter in parts of northern Canada. Accompanying the temperature change will likely be a redistribution of precipitation, with less snowfall in southern Canada, sea-level rise of 20-90 cm and more frequent intense winter storms. In British Columbia, there have been several compelling trends in regional climate and hydrology over the past century including:

- Increasing temperatures with much of the change due to greater minimum (overnight) and winter temperatures
- Increasing precipitation and snowpack until 1976, then decreasing thereafter
- retreating glaciers since 1900
- earlier spring flood and lower flows in summer
- annual low flows now occurring in September or October rather than February or March
- recent shifts in some flow regimes – dependant upon location.

Based on climate model projections, B.C. winters are expected to become warmer and wetter. Summers in the southern areas will be warmer and drier, with warmer and wetter conditions in the north. Warmer winter temperatures will result in a greater proportion of precipitation falling as rain that may lead to higher winter flows and more frequent flooding, especially in rain-dominated systems along the coast. Trends toward

lower summer and early autumn flows and earlier spring peak flows are likely to continue. However, it was stressed that regional model-based estimates of climate change are highly uncertain, especially for precipitation, particularly in British Columbia where the local variations in topography give rise to distinct local climates that are not resolved by current climate models.

Water Impacts:

Even with the uncertainty in predicting future regional conditions, changes in the volume and seasonal distribution of water are likely. The key concern is the potential for a substantially reduced snowpack and, thus, limited replenishment of storage reservoirs, lakes and streams. Should the snowline lift from its present 900m level to 1300m or even 1700m as suggested by some climate change scenarios, there will be no snowpack storage left to fill the reservoirs. The agricultural industry will have to make significant adjustments given that approximately 99% of water used for irrigation in agriculture is supplied by surface sources. On the demand side, a change to warmer and drier summers, coupled with a longer growing season, will very likely intensify the water demand from both agricultural and non-agricultural users. In addition, summer water quality may decline if temperatures increase and reservoirs are drawn down while heavier winter rainfall may increase the frequency of landslides and thus reservoir turbidity. Expected growth in the population of the Greater Vancouver Regional District (GVRD) and in the Okanagan, only magnifies the issue.

Other potential impacts include:

- flooding of low lying agricultural and urban areas from high runoff and/or sea surges (e.g., area flooded by Nooksack has nowhere to drain if water levels are high in the Fraser River)
- human health concerns associated with sanitary sewer overflows
- inadequate groundwater recharge in the Gulf Islands where it is the primary domestic supply and where a greater proportion of rainfall occurs in extreme events leading to runoff and not infiltration
- reduced reliability of snowfall for ski resorts and implications for other recreation industries/pursuits (e.g., canoeing)
- a deterioration of wetland health and a reduced distribution caused by lower river flows.

The relationship between climate and Pacific fisheries is significant, complex and species specific. Key findings include:

- Historical catches of anchovies for three different regions show a startling correlation between fish abundance and decadal climate variations.
- Historic salmon catches exhibited major step changes that could be largely explained by key indexes of large-scale atmospheric processes (the Aleutian low, Pacific-Decadal Oscillation -PDO and Pacific Circulation Index -PCI).
- A stronger Aleutian low, predicted by climate change models, is thought to promote ocean upwelling thus increasing productivity over a large area of the North Pacific, adding uncertainty to the findings of other research that suggest predicted warmer sea surface temperatures will greatly limit the southward extent of Sockeye salmon.

- Climate, not overfishing, is thought to be the primary factor behind the collapse of Coho salmon fisheries in the Strait of Georgia and northwest U.S.
- Changes in the dominant wind direction and dramatic fluctuations in Fraser River flows have combined to alter both the salinity and food availability of the Strait of Georgia which in turn has led to much greater fish mortality.

Adaptation:

The discussion of adaptation measure included specific and general measures to be used in the development of strategies for the region. Specific measures that were mentioned included:

- supply and demand management
 - develop rational water permitting, metering, pricing and conservation (e.g., recycling water) measures
 - implement stronger groundwater protection
 - offer rewards for not exceeding water-permit licenses
 - prohibit inter-basin water transfers
 - reduce impervious areas
 - construct larger structures with greater storage capacity or resilience to extremes
 - increase the number of detention and infiltration ponds
- monitoring and research
 - map evaporative systems for crops, water requirements and land use
 - conduct sensitivity analyses
 - improve the quantity, quality and access to environmental information
 - use qualitative estimates while pursuing more rigorous quantitative assessments (i.e., adopt the precautionary principle while improving modelling capability and sophistication)
- increasing public education and awareness (get information describing potential impacts out to the public)

A number of general considerations were proposed for consideration in the selection, adoption and implementation of adaptation strategies, including:

- choose options that make sense regardless of climate change ('no regrets') and relate options to non-climate issues (i.e., co-benefits)
- use incentives rather than penalties to change behaviour
- use low risk/low tech options wherever possible
- support options that are derived through 'grass roots' processes/commitment
- implement a total-cost accounting approach when evaluating options that spans generations
- impact issue needs immediacy and relevance to people's lives to invoke action (e.g., Y2K)
- communities where water is scarce are more water conscious as they are directly affected (e.g., Gulf Islands where there is no possibility of inter-basin transfer)
- though disasters can act as catalysts for public action, yet there is also a need for strategic decisions from public officials and scientists

- pursue proactive planning since it is necessary to be prepared to take advantage of any opportune political environment
- assemble a chain-of-events path that motivate people to take action; model results and scenarios are pessimistic
- acknowledge progress along the way to provide some hope or a cause that may galvanize people

FOOTNOTE: There has been a recent outbreak of a spruce pathogen (insect of some kind) in B.C. The infestation is attributed to a **warm** winter and the survival of 80% of the insects. This event was not reported at the meeting perhaps because the infestation had not yet been detected.

ANNEX A.6 – WORKSHOP REPORT – NORTHERN CANADA

REPORT OF WATER SECTOR AUTHORS ON WORKSHOP: NORTHERN CANADA

The Workshop:

The workshop was held at the Explorer Hotel, Yellowknife, NWT, from Sunday, February 27 to February 29. The Sunday session was a half-day session starting at noon.

Approximately one hundred people attended the meeting. The mixture included all levels of government, the native community (about 20 representatives) and representatives from the private sector, notably Mining and Transportation. About forty of the participants were scientists or science managers.

The Sunday program featured six background papers and an evening panel discussion. Monday morning was one long session with ten papers on Impacts and Adaptation. After lunch, there was a Round Table discussion and breakout groups addressing the topic Attitudes and Experience of Practitioners. Later in the afternoon the breakout groups reported to the Plenary. In the evening there was a public meeting on, Becoming Aware of Climate Change with three guest speakers. The Tuesday sessions started with a Plenary discussion entitled “Responding to Climate Change. This was followed by a Round Table discussion in breakout groups on the topic, Establishing a Capacity for Adapting to Climate Change. The discussion groups reported to the Plenary before lunch. In the afternoon there was the last breakout group session addressing the topic Requirements for Promoting Adaptation. Towards the end of the afternoon the breakout groups reported to the Plenary. The workshop was closed with final comments at 4 p.m.

The Nature of the Discussions:

One of the most striking features of the meeting was the sense of urgency associated with climate change. This is not an academic topic in the Arctic. The communities from east to west are experiencing widespread and serious impacts. There is very little good news. No one needs to be convinced that climate change is a reality.

The mood was dynamic with a fair degree of solidarity and respect shared among the participants with their different agendas. There was a high level of understanding of the issue. The participants knew something was wrong and they had been involved in observing the changes. Traditional knowledge was

valued as a natural contribution to the discussion. At least five of the native representatives had had discussions with their leaders in preparation for this meeting. They, therefore, were able to bring a broader and perhaps historic perspective to the meeting.

The Content of the Discussion:

The first few topics were covered in the breakout session on Communities and Infrastructure.

Roads: The impact of climate change, warming, on infrastructure has been extremely serious, particularly in the case of roads and water supply.

At the time of the meeting, the 900 miles of winter roads out of Yellowknife were not yet able to carry the large tractor-trailers, forty-ton vehicles. Smaller vehicles were traveling out of Yellowknife but the bulk of the transport is conducted with large vehicles. The situation is bleak since winter roads cannot be used much after the end of March. Therefore, only about five weeks of winter transport remains. At the time of the meeting there were only two or three tractor-trailers in the marshaling yard where convoys are organized for travel over the winter roads. Normally the marshaling yard contains forty to sixty vehicles waiting to move out.

About ten years ago these natural ice roads were in use with heavy traffic by December 1. Now it is more typical for the traffic to start moving six weeks later, around mid-January. (As it turned out, since the meeting there has been considerable cold weather and the roads were able to carry all the supplies required, most notably fuel. The night time temperature on April 9 was - 25 degrees Celsius.)

The thawing of the permafrost has led to a phenomenon called thaw slump. When this occurs along a highway there can be sudden breaks in the surface where a part of the surface drops down or falls off on the side. For this reason, highway maintenance costs have gone up and highways are becoming more dangerous, posing a risk to driver safety.

Water Supplies: Water supplies buried in or above the permafrost are subject to rupture as a result of thaw slump. In addition, overall water supplies in lakes and rivers are lower than they have been in the past. Although it was not discussed, in the transport of wastewater, sewage, etc., there is also the risk of rupturing of the transport pipes due to thaw slump.

Sewer storage areas are at risk when tanks on permafrost are subjected to thaw slump due to the warming and melting of the permafrost. Tanks can shift, rupture and cause wide spread damage. No incidences were reported but the prospect of such an accident becomes greater as the warming proceeds.

Power Supplies: As water supplies decrease, hydropower is no longer adequate to provide communities. As a result, some communities are shifting to diesel generators more frequently. The result is more expensive power and increases in air pollution and noise. In the town of Whitehorse there is growing concern for health stress among members of the community due to the increased use of diesel generators.

River Silting: An unexpected increase in river silt is causing difficulties with barge traffic between some of the river communities. Land slides and low flow rates are causing the silting.

Mining: Not all the communities involved had negative reports about climate warming. For example, the mining community is receptive to warmer conditions because it is easier to work in the winter and machinery breaks down far less in warmer weather. However, the mining community is greatly concerned about permafrost stability for both their private roads and for their dams which contain mine effluent. Any deterioration of permafrost could damage roads and lead to the rupturing of wastewater containment dikes allowing contaminated water to flow freely into the environment.

Wildlife: The following characteristics were recorded by the native community and by the scientists doing research on flora and fauna:

- a) There are reports of skinny caribou or the total absence of caribou.
- b) Caribou are having difficulties finding food because there is no longer adequate snow cover on the surface. Instead, the surface is covered with ice. It requires more energy to break through the ice than the animal obtains from the food it is able to dig out.
- c) New species are appearing in the Arctic, for example, salmon in some rivers, grizzlies out on the ice, strange birds (such as robins), and musk ox moving into the southern regions.
- d) Young seals are no longer able to remain on the ice for their normal period of time. As a consequence, the young are undernourished when they leave the deteriorating ice surface.

The ice is melting prematurely.

- e) Caribou cannot migrate across traditional ice bridges between islands. The migrations occur at the same time as always. However, the ice isn't forming in advance of the migration. The animals build up in large herds, milling around on the shore waiting for the crossing. Finally, some panic and try to cross the ice; they break through and die. This migration is the fall migration after the rut when the animals are going south to winter grazing areas.

Coastal Erosion: In some areas, including Tuktoyuktuk, coastal erosion is increasing rapidly. Storm surges are washing across beaches and destroying buildings along the coastlines.

The Elders: Some elders have commented that they can no longer give good weather forecasts. "Everything has changed. Things (the weather) change so fast".