THE QUEBEC CHAPTER OF THE CANADA COUNTRY STUDY : CLIMATE IMPACTS AND ADAPTATION

executive summary

Quebec has a varied climate. Many examples can be given of the considerable effects that climate fluctuations can have on the everyday lives of people living in the province. The increase in greenhouse gas concentrations, observed worldwide, is exerting additional pressure on the Earth's climate system. Very little is known about the mechanisms of climate response to recent anthropogenic factors of this type, and no precise data are available at present on the role that the oceans, polar regions, ecosystems and other components play, directly or indirectly, in this regard.

In its second assessment report, tabled in 1995, the Intergovernmental Panel on Climate Change (IPCC), which is composed of 135 countries and over 350 well-known scientists, stated for the first time that: "The balance of evidence suggests a discernible human influence on global climate". However, at the regional and local scales, controversy still exists regarding the magnitude, speed and nature of climate changes, and these issues will continue to be discussed and debated over the coming years. Shedding light on all these aspects of climate change will remain a major challenge for the scientific community.

To ensure that Quebec society is able to adapt and make suitable adjustments in the event of climate change, we need to gain a much better understanding of the characteristics of the province's climate, together with the positive and negative impacts that climate fluctuations, in some cases extreme, will have on all our resources, use patterns and activities as a whole. By more fully documenting the relationship between climate, nature and society, we will enhance our ability to adjust and adapt to even a slight modification in the range of future climate conditions. Therefore, the Canada Country Study: Climate Impacts and Adaptation is just what is needed at this time.

The Canada Country Study is divided into two phases. Phase I began in summer 1996 and will end in fall 1997. It consists in conducting an exhaustive review and evaluation of the existing literature on climate impacts and adaptation in Canada. Present gaps in our knowledge will be identified and recommendations will be made on avenues of research that should be pursued to remedy these deficiencies during the course of a second phase, slated to begin in late 1997 and continue for five years.

In Phase I, summary reports will be published, specifically a national summary for policy makers, a plain language national summary and six plain language regional summaries. The summaries will be prepared on the basis of information contained in 25 reports and articles published in 8 volumes, as follows:

- Volume I - British Columbia and the Yukon
- Volume II - The Arctic
- Volume III - The Prairies
- Volume IV - Ontario
- ***Volume V - Quebec***
- Volume VI - The Maritimes

- Volume VII - Climate change as examined from the perspective of a dozen or so strategic sectors of national interest, including agriculture, infrastructure, energy, forestry, fisheries, human health, recreation and tourism, transportation, ecosystems and wetlands and water resources.
- Volume VIII - Climate change examined with reference to seven crosscutting issues of national interest. The issues are changing land use patterns, internal trade, crossborder influences, extreme weather events, atmospheric issues, sustainable development and the two economies (north and south).

Environment Canada and ***the Association de climatologie du Québec*** are very pleased to present ***the Quebec Chapter of the Canada Country Study - Volume V***. Throughout this document, a special effort has been made to carefully situate the problem of climate change in the Quebec context by referring to past and present climate events, some of which are documented, in order to highlight the magnitude and significance of the associated impacts in Quebec.

A three-stage approach was adopted in designing and preparing the Quebec component of the Canada Country Study:

1) an exhaustive and rigorous inventory of scientific articles, studies, reports and initiatives was conducted, to quantify the links between past and present climate fluctuations in Quebec and their effect on 10 strategic sectors, and to summarize current knowledge of the potential impacts of climate change induced by an increase in greenhouse gas concentrations;

2) two forums were held, in Montreal and Quebec City, in April 1997. The purpose of the two workshops, which brought together specialists from various disciplines, was to raise participants' awareness of the issues, validate the information collected to date on the current knowledge base, and initiate collective thinking on the steps to be taken to develop effective measures for adapting to climate change;

3) the third stage involved drafting and revising the present document.

Without the active contribution and collaboration of the 100 or so experts from various fields who were contacted during the study, it would have been difficult to complete this report, which is intended as a first step toward ensuring more effective adaptation to a modification in climate variability.

REGIONAL CONTEXT

Quebec stretches more than 1 950 km from north to south, and more than 1 500 km from east to west at certain latitudes. The province's total land area is just under 1.5 million km2, of which 940 000 km2 is covered by forests and 184 000 km2 by fresh water. Quebec's population, estimated at 7.2 million in 1994, makes up 25.1% of Canada's total population.

The St Lawrence River is the jewel in the crown of the Quebec landscape. On a world scale, the river ranks 17th in length, 13th in watershed area, and 15th in discharge volume. It is fed by some 350 tributaries and contains more than 1250 islands. An estimated 97% of Quebecers live within its watershed, and two thirds of the population (69.5%) inhabits a 10-km strip of land on either side of the river.

Quebec's economy is based mainly on its strong tertiary sector, which generates $96.9 billion (1991) and represents 71.8% of the gross domestic product (GDP). The secondary sector (manufacturing industries, construction), worth $33.6 billion, accounts for 24.9% of the GDP. Finally, a large part of Quebec's economic activities centre on the use of natural resources (agriculture, forestry, mining), making up 3.2% of the GDP.

QUEBEC'S CLIMATE

Quebec has experienced significant climate fluctuations since the end of the last glacial epoch. It is estimated that 6 000 years ago, the mean temperature was about 1 oC higher than it is today.

Systematic recording of meteorological observations began only some 125 years ago, which means the province's climate history cannot be traced back very far. Nonetheless, geomorphological (fossils), ecological (pollen) and dendrochronological (tree rings) research has helped to shed light on the temperature regime and, in some cases, the humidity conditions that existed during the last millennium. The table below, although it must be interpreted with caution, is intended to give an overview of Quebec's recent climate history.

Climate history of Quebec over the past millennium

Period considered	900 to 1200	1200 to 1400	1400 to 1570	1570 to 1880	1880 to 1900	1900 to 1930	1930 to 1960	1960 to the present
Climate trend	Warm and humid	Cold and dry	Mild and humid	Cool, humid summers Cold, windy winters	Pronounced warming	Cold or cool	Mild	Near or slightly below normal
Source of data[1]	Geo Eco Dendro	Eco Dendro	Geo Eco Dendro	Eco Dendro	Meteo	Meteo	Meteo	Meteo
and	for	for	for	for	for southern Quebec Dendro	for southern Quebec	for	for
Area of Quebec considered	subarctic Quebec	subarctic Quebec	subarctic Quebec	subarctic Quebec	for subarctic Quebec		all of Quebec	all of Quebec

Reference period for normal conditions: 1951-1980
warm : more than 0.5 °C above normal
mild : 0.25 to 0.5 °C above normal
cool : 0.25 to 0.5 °C below normal
cold : more than 0.5 °C below normal

Note 1 : Indicates the type of data used to determine the climate trend :
Geo : geomorphological data (e.g. fossils)
Eco : ecological data (e.g. pollen)
Dendro : dendrochronological data (tree ring analysis)
Meteo : data from meteorological or climatological networks

FUTURE CLIMATE AS ENVISAGED IN CLIMATE CHANGE SCENARIOS(2xCO2)

The increase in concentrations of carbon dioxide and other greenhouse gases is now a recognized fact within the scientific community, in light of evidence that atmospheric CO_2 concentrations have risen from 280 ppmv in pre-industrial times to over 360 ppmv in 1996. Over the past 15 years, general circulation models (GCMs) have come into use as a tool for simulating the energy balance of Earth's atmosphere, and are now accepted around the world as a means of projecting the potential effects of increased greenhouse gas levels. The output from general circulation models is called « ***climate change scenarios or 2xCO_2 scenarios*** ».

General circulation models (GCMs) are mathematical representations of physical laws designed to simulate, as fully as possible and three-dimensionally, the global climate system. They include information on present and future concentrations of greenhouse gases, and the most recent versions have begun to incorporate atmospheric aerosols, particularly since the eruption of Mt. Pinatubo in 1991. About a dozen GCMs exist worldwide, including a Canadian model (CCC GCM II - 1992).

All the present GCMs have the ability to simulate and compare reference conditions ($1xCO_2$ concentrations, ranging from 300 to 330 ppmv) with an atmosphere in which the carbon dioxide concentration is doubled ($2xCO_2$, i.e. 600-660 ppmv). GCMs divide the Earth's surface into a grid containing a large number of spatial points, and calculate present climate conditions for all those points. Land use, bodies of water, topography, oceans and glaciers are examples of the variables included as parameters in the modelling, in view of the clear-cut role they play in the Earth's energy balance, both as part of recent ($1xCO_2$ scenario) and future ($2xCO_2$ scenario) conditions.

Simulations are performed using mathematical and physical formulas which may vary among the different GCMs. At present, for example, the spatial resolution of GCMs ranges from 200 to 300 km. Although the Canadian general circulation model has a higher spatial resolution (smaller distance between points) than many of the other existing models, it should be acknowledged that, intrinsically and given the high cost of performing simulations, GCMs as a whole can provide only a very crude representation of real environmental conditions.

It would not be wise to blindly compare scenarios generated by the different GCMs since they employ different mathematical formulas and representations of physical processes. There is a whole series of arguments that support a prudent approach in using GCMS; however, they do not negate or diminish the usefulness of this tool in identifying trends and indications on what the future climate would be like in the event of a doubling of CO_2 concentrations.

Although GCMs can be used to predict the magnitude of the climate's response to a substantial increase in greenhouse gas concentrations globally, a very high degree of uncertainty exists in applying the models on a regional scale. Differences in regional temperature and precipitation patterns explain why the models should not be used blindly. In view of this, advances in the development of regional climate models are being followed very closely. Once regional models have achieved a high enough resolution so they can more accurately represent the physical processes governing the air, water and soil, they will be able to interface with GCMs and support decision-making in the various sectors impacted by increased climate variability.

What does future climate change hold in store for Quebec?
From a comparative review of the different climate change scenarios that have been derived from GCMs and are applicable to Quebec, certain observations can be made about the temperature and precipitation regimes that might exist in a doubled-CO2 climate.

a) a general warming trend of +1 to +4 ^{o}C throughout southern Quebec and +2 to +6 ^{o}C in the northern part of the province. The warming will be amplified during the winter and more widespread and intense in Northern Quebec;

b) with a doubling of atmospheric CO_2, southern Quebec should receive amounts of precipitation that are near or slightly above the seasonal average (0% to +10%). More northerly regions in Quebec would receive 10 to 20% more precipitation than at present. Note, however, that spatial (considering the different regions in the province) and temporal (seasonal) differences are greater for the precipitation scenarios derived from GCMs than for the projected 2xCO_2 temperature regime.

No indications are provided in climate change scenarios on the frequency, duration and intensity of extreme climate events (drought, flooding, cold and heat waves, winter storms, etc.), nor on potential modifications in the mean track of weather systems that affect Quebec.

Variation in mean temperature and seasonal precipitation as projected by various climate change scenarios based on a doubling of CO_2

	Southern Quebec	***Northern Quebec***
Spring (March to May)	***Warming of 1 to 4 ^{o}C***	***Warming of 2 to 4 ^{o}C***
	0 to 20% more precipitation	***0 to 20% more precipitation***
Summer (June to August)	***Warming of 1 to 4 ^{o}C***	***Warming of 2 to 4 ^{o}C***
	Precipitation ranging within 10% of present values	***0 to 20% more precipitation***
Fall (Sept to Nov)	***Warming of 1 to 3 ^{o}C***	***Warming of 2 to 5 ^{o}C***
	GCMs disagree on the variation in precipitation, with projections ranging from +10% to -30% relative to current values	***0 to 20% more precipitation***
Winter (Dec. to Feb.)	***Warming of 2 to 6 ^{o}C***	***Warming of 2 to 9^{o}C***
	5 to 20% more precipitation	***0 to 20% more precipitation***

MAGNITUDE OF EXTREME CLIMATE EVENTS

Climate can be viewed as a statistical distribution representing all of the weather events affecting a given region. The frequency, magnitude, duration and sequence of these weather events can result in extreme climatic events that may in some cases be highly detrimental to Quebec society and to natural ecosystems.

The history of Quebec has been marked by naturally occurring climate events of drastic scope that are simply part of the province's climate regime. A striking example of this is the "year without a summer" or "the black summer" of 1816 which stands out in the climatology annals of North America. This event is believed to have been linked to the intense volcanic eruption of Tambora, near Java, Indonesia in April 1815, which ejected an estimated 150 million tonnes of volcanic dust into the atmosphere. The repercussions in summer 1816 were disastrous for Quebec.

Climate anomalies have occurred on other occasions in the past and are simply part of the intrinsic characteristics of past and present climate. But what will happen to the future climate given the ever-greater impact of human activities? Will there be more or fewer cold waves, tornadoes, floods and periods of drought in a future climate characterized by increased greenhouse gas concentrations? The answer to these questions is a matter of considerable controversy within the scientific community. Over the past 20 years, scientists have been trying to gain a better understanding of and predict the response of Earth's climate system to rising greenhouse gas levels, so as to evaluate the impacts on the frequency, duration and intensity of extreme climate events and on the track taken by weather systems that affect the province daily.

It is of paramount importance to have a clear understanding of the spatial and temporal distribution of abnormally intense climatic events, in addition to the most precise and accurate knowledge possible of the range of associated effects. If the global increase in greenhouse gas concentrations is bringing about changes in the frequency, duration and intensity of extreme climatic phenomena, it is imperative that we be able to detect this process rapidly and evaluate all of the consequences.

Five categories of extreme climate events are examined in the Quebec Chapter of the Canada Country Study: they are considered the most damaging and most typical of Quebec's climate. They are:

- *floods;*
- *drought;*
- *winter storms;*
- *intense cold waves and oppressive heat waves;*
- *severe convective summer weather systems (storms), speci and hailstorms.*

CHARACTERISTICS OF EXTREME CLIMATE EVENTS IN QUEBEC

FLOODS

- various causes: spring meltwater, ice jams, sudden cresting of rivers
- at least one major flood every year
- all regions of Quebec are affected, especially south of the 50th parallel
- appreciable increase in risks and damage during winters/springs with wide temperature fluctuations (freeze/thaw)
- growing problem of flooding associated with heavy rainfall
- major impacts on riverside populations, buildings and transportation infrastructure (highways, bridges, culverts)
- mean annual damage estimated at $10-15 million

DROUGHT

- an insidious phenomenon that is rarely foreseeable and affects mainly southwestern Quebec, with at least one period of drought every summer
- the earliest impacts are observed in agriculture (crop yields, irrigation); increased risk of forest fires; reduction in the quality and quantity of water; interruptions in drinking water supply
- prolonged drought (water shortage lasting a number of weeks) can affect water tables, water levels in the St. Lawrence River (impacts on shipping and pleasure boating), levels in hydro-electric reservoirs (impact on production) and wetland ecosystems (drying up of marshes)

HEAT WAVES

- occur at least once a year, especially in July
- affect mainly southern and southwestern Quebec, with a more drastic effect in large urban centres (urban heat islands)
- potential impact on the well-being and health of children, the elderly and people with cardio-respiratory problems
- a winter heat wave (temperature > 0°C) raises the risk of ice jam flooding, apple tree mortality, and can reduce maple syrup production.

WINTER STORMS

- occur in various forms (snow storms, blizzards, freezing rain) many times a year
- primarily affect the St. Lawrence corridor (where more than 2/3 of the population lives), and show increasing intensity from west to east
- have a pronounced adverse impact on land-based transportation (loss of life and injuries, material damage, mobility of users, cost of maintaining transportation networks)
- storms with freezing rain have the most serious impacts: power failures and associated consequences, destruction of trees and shrubs, severe transportation problems , etc.

SEVERE SUMMER WEATHER

- these phenomena vary over time and space, making forecasting and monitoring difficult
- concentrated in southern Quebec
- over 100 confirmed events on average every year
- marked adverse impact on a number of economic sectors (agriculture, infrastructure and buildings, recreational activities, safety of people and property)
- the costs associated with these events are enormous but not computed globally

COLD WAVES

- occur at least once a year, above all in January and February
- affect mainly areas north of the 48th parallel
- Quebecers have adapted well to cold waves (warmer clothing, reduction in travel and outings), but they present a potential problem for the homeless
- hydrological impacts (decline in temperatures, production of frazil ice in rivers) influence the health of fish populations

It seems important to reiterate that, although more and more research is being done on the link between climate change and extreme climatic events, present 2xCO2 scenarios do not provide any indication of the expected frequency, duration or intensity of such events, nor do they examine the impact on the mean track of weather systems that impinge on Quebec. However, some early studies done primarily in the United States show that severe climatic events might increase in a warmer climate.

OVERVIEW OF THE SITUATION

The Quebec Chapter of the Canada Country Study has provided the opportunity to systematically examine our knowledge of past, present and future climate fluctuations in relation to ten strategic sectors in Quebec. This review underscores the appreciable extent to which several of these spheres of activity are sensitive to extreme climate events.

Preparing the Quebec Chapter of the Canada Country Study: Climate Impacts and Adaptation has involved compiling a phenomenal amount of information, evaluating current knowledge and identifying potential solutions for information gaps and avenues for future research. Whereas some sectors are well-documented, only very sketchy information exists on other sectors and their links with climate. The challenge of this project consisted in identifying the existing gaps in knowledge in an objective and realistic manner, without losing sight of the possible imbalance in our current understanding of the effects of climate variability on Quebec resources, use patterns and activities.

For each sector examined, a summary table has been prepared in order to:

- evaluate present knowledge of the relationship between climate and the different sectors, based on 5 rating categories (sketchy, poor, average, good, very good);

- summarize current knowledge of the magnitude and intensity of the repercussions of climate change on the selected sectors, based on 5 rating categories (sketchy, poor, average, good, very good);

- identify, in order of priority, the existing knowledge gaps for the sectors;

- for each knowledge gap, suggest potential solutions and make specific recommendations aimed at remedying deficiencies in the short or medium term.

WATER RESOURCES		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (6)**	**RECOMMENDATIONS (7)**
sensitivity to climate: ***GOOD*** **Specific and single-purpose studies, mainly on the St Lawrence, showing the relationship between variations in water levels and use patterns, riparian ecosystems, and the different life stages of aquatic fauna**	**G.1** Systematic and comprehensive documentation of record high and low water levels and their effects on the St Lawrence as a whole (river, estuary and Gulf) is lacking and an urgent solution needs to be found.	**R.1** Compile, document and list all the impacts of record high and low water levels in the St. Lawrence in terms of particle transport, water quality, the salinity front, circulation of marine water masses and vertical stratification.
effects of climate change: ***AVERAGE*** **A quantitative estimate has been made solely of future water requirements in southern Quebec, flow levels in the fluvial stretch of the St Lawrence and the net water input from each watershed in northern Quebec**	**G.2** There is an obvious lack of suitable indicators for quantitatively assessing water quantity/quality in relation to abnormal and significant climate fluctuations.	**R.2** Develop, validate and quickly make available climate indicators for evaluating abnormal climate fluctuations that can influence the water use patterns and resources in Quebec.
	G.3 The link between decadal hydrologic cycles and climate systems is not well understood, particularly for northern Quebec.	**R.3a** Select 1 or 2 subbasins in Quebec where an integrated and comprehensive analysis of the hydrologic cycle can be conducted, taking into account the spatial and temporal constraints of the available climatological and hydrological data. **R.3b** Detailed analysis and monitoring of extreme flooding events (e.g. Saguenay in 1996)
	G.4 A more in-depth examination of water quality and supply in relation to extreme climate fluctuations is required in order to better assess future drinking water needs.	**R.4** Collate statistics on drinking water use patterns in the large urban agglomerations in Quebec and quantify the related sensitivity to extreme climate fluctuations and expected climate change
	G.5 The mechanisms linking shoreline erosion and the intensity/track of weather systems need to be better understood and quantified.	**R.5** Document and analyse the frequency, magnitude, track and duration of the weather systems that traverse Quebec, with a focus on precipitation and winds
	G.6 Little is known about Quebec's ability to export fresh water in a context of increased climate variability.	**R.6** Identify the comparative advantages of Quebec's water supply, versus that of adjacent regions, under a climate change scenario

HEALTH AND SOCIAL ASPECTS		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (3)**	**RECOMMENDATIONS (7)**
sensitivity to climate: ***POOR*** **Very few studies are available that identify links between the effects of extreme climate events and human health and social behaviour in Quebec, except only indirectly associated with climate or specific contaminants**	**G.7** Quantification of the direct and indirect sensitivity of human health and social behaviour to extreme climate events (floods, cold and heat waves, winter storms, etc.)	**R.7a** Initiate multidisciplinary studies to quantitatively assess the direct impacts of oppressive heat waves, intense cold waves and winter storms on morbidity and human mortality and on the social behaviour of people living in urban and semi-urban environments in Quebec **R.7b** Examine the indirect relationships that exist between climate variability, air/water quality and health. Monitor water-borne diseases. **R.7c** Closely monitor emerging infectious diseases and those associated with crops and nutrition
effects of climate change: ***SKETCHY*** **Aside from one study estimating the number of deaths caused by an increase in the number of oppressive heat waves in Montreal, no research has been done on this topic**	**G.8** We need to gain a better understanding of how increased climate variability here or elsewhere in the world can have an impact, in Quebec, on community identity, safety, integration, density, displacement of people, and the ability of existing social institutions to adapt.	**R.8a** By using $2xCO_2$ scenarios divided into 10-year periods in order to determine the trend in the number of extreme climate events (particularly intense cold waves and oppressive heat waves), provide a qualitative estimate of the first-order impacts on human health and social behaviour in Quebec **R.8b** Considering the present or future influx of climate change refugees, prepare a qualitative assessment of the pressure exerted by climate change on the social fabric and on cultural, food consumption and social habits, in a limited number of regions in Quebec
	G.9 The awareness of the medical/social community of the impacts of climate change on human health and social behaviour must be enhanced on a priority basis	**R.9a** Include a health-climate change program in medical and science curricula for professionals **R.9b** Support and promote interdisciplinary research on the links between health and climate; bring data banks up to date and make them more accessible to researchers, physicians and social service staff

AGRICULTURE		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (4)**	**RECOMMENDATIONS (7)**
sensitivity to climate: ***AVERAGE*** **The positive and negative effects of daily climate fluctuations on agriculture are known at the local or regional level. The sector has considerable ability to adapt in the short term**	**G.10** There is a lack of indicators that can be used to monitor and identify abnormal climate fluctuations that are responsible for positive or negative impacts on agriculture	**R.10a** Give priority to the continued operation of stations that have a lengthy data series and can help to detect any trends indicating a change in climate variability in Quebec **R.10b** Develop, validate and make accessible climate indicators that can be used to identify climatic seasons during which yields attain record levels
	L.11 Crop damage caused by extreme climate events has not been documented sufficiently or systematically	**R.11** By studying all periods of drought, hail and winter freeze/thaw conditions over the past 20 years, identify the quantitative link between the intensity of these events and crop damage
	L.12 There is a pressing need to train agricultural producers so they can more effectively manage climate information in their routine operations	**R.12** From the standpoint of farm plans, examine the climatic factors that are likely to optimize and facilitate water management, decision making, tillage, pest control treatments and building construction.
effects of climate change: ***AVERAGE*** **A large number of high-quality quantitative studies exist on the effects of doubled CO_2 on the yields of a number of Quebec crops and the response of some plants**	**L.13** Current models simulating the links between plants and climate parameters are too general and empirical, in addition to presenting frequent problems of scale (e.g. individual farm versus the resolution of GCMs, impacts of one-time events versus cumulative effects). The comparative advantage of Quebec's agricultural sector on the international level needs to be studied further.	**R.13a** Conduct studies to identify the relationships between water availability, plant growth, CO_2 levels and climate conditions by using models adapted to the local or regional scale **R.13b** Model the variation in plant yields based on the different types of climate-induced stimulation likely to occur with a $2xCO_2$ environment in Quebec (including the development of pest insects, parasites, and fungicide and pesticide use). Determine the crops that are most likely to be exported to countries hit by climate change **R.13c** Adapt the development of hybrids to a broader climate spectrum (e.g: grain corn)

ECOSYSTEMS AND WETLANDS		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (5)**	**RECOMMENDATIONS (10)**
sensitivity to climate: ***AVERAGE*** **For specific low water level events on the St Lawrence, the magnitude of the effects on ecosystems and wetlands is known fairly well. Little work has been done elsewhere in Quebec (except with regard to avian fauna) and almost none in Northern Quebec**	**G.14** We need a better understanding of the functioning of the St Lawrence and interactions between ecosystems and the present climate	**R.14a** Study and interpret the climate history of the St Lawrence and the related impacts on ecosystems / wetlands **R.14b** Conduct studies on the effect of an increase in CO_2 on the growth of plant species (riparian and aquatic)
	G.15 Few studies exist on adaptation to climate change for the area from Cornwall to Quebec City	**R.15** Initiate a multidisciplinary study to identify the links between past and present variations in water levels in the St Lawrence. The focus should be on Lake Saint Pierre.
	G.16 Wetlands and plant species have differing levels of tolerance for extreme climate events; these need to be better understood, particularly in the case of ecosystems at risk or at the edge of their geographic range	**R.16a** Develop, validate and make accessible climate indicators characterizing the extreme climate situations that have the greatest impacts on ecosystems and wetlands in Quebec **R.16b** Establish an ichthyological monitoring network that can be used to develop a baseline assessment and provide a better foundation for identifying changes in ecosystems and wetlands **R.16c** Set up sites for long-term monitoring of ecosystems in reference areas (e.g. Lake Saint Pierre) **R.16d** Complete the establishment of a limited number of multidisciplinary observation stations to provide a lengthy record (climate and ecological data)
effects of climate change: ***POOR*** **The only information available is qualitative evaluations of the potential impacts of climate change on ecosystems and wetlands**	**G.17** The factors responsible for natural variability in animal populations need to be better understood	**R.17** Identify the critical stages in the development of species and determine the physical and biological factors influencing the survival, growth and fecundity of individuals
	G.18 Means of evaluating ecological changes according to the most plausible $2xCO_2$ scenarios need to be established	**R.18a** Simulate and examine the likely effects on fauna of various $2xCO_2$ scenarios as they relate to decisions on controlling water levels in Lake Ontario and the St Lawrence **R.18b** Implement and test management strategies

FISHERIES		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (4)**	**RECOMMENDATIONS (7)**
sensitivity to climate: ***AVERAGE*** **Much is known about the climate factors that affect freshwater populations, primarily in southern Quebec. In contrast, the situation of marine species is not known well at all.**	**G.19** We need to learn more about the occurrence, magnitude and timing of fluctuations in water levels/flows in relation to the different lifestyles of many fish species. Studies should be initiated or continued to identify species' range of tolerance and to measure the strength of cohorts of certain fragile species during high and low water levels	**R.19a** Conduct systematic analyses of episodes of extreme water levels (both high and low) in the St Lawrence **R.19b** Examine the effects of such water levels on the strength of species cohorts (yellow perch, northern pike, walleye, tomcod) in key sectors of the St Lawrence by using fishing plans or an ichthyological monitoring network **R.19c** Monitor sport fishing in strategic locations for this activity (size, weight, catches, age)
effects of climate change: ***POOR*** **Impacts on freshwater species are assessed indirectly by using present knowledge related to extreme water levels. No quantitative analysis is available for a $2xCO_2$ environment, especially for marine and northern populations**	**G.20** Very little is known about the behaviour of freshwater and saltwater species in the more northerly regions of Quebec	**R.20** Identify zones where joint studies can be undertaken to survey populations of the most important fish species found in the bodies of water in Northern Quebec
	G.21 Little research has been done and little is known about the effect of factors such as seasonal changes in temperature and wind direction (phenomenon of upwelling) on the presence, vitality, recruitment and mortality of certain species.	**R.21a** By looking at specific conditions of intense cold and heat, determine the corresponding limits of tolerance and the mortality rates of species sensitive to such conditions (e.g. redfish) **R.21b** Gain an understanding of the chronological frequency and the meteorological, physical, biological and hydrological processes that explain variations in the presence or recruitment of certain species
	G.22 Coupled ocean-climate models should be used to estimate the temperature and circulation regimes in the estuary/Gulf of St Lawrence and Hudson Bay and to delineate the associated effects on the population status and health of fish species living in those waters.	**R.22** Water temperature, wind speed and direction, currents and freshwater discharges from the St Lawrence and the large rivers of the North Shore in Quebec should be included in developing predictive models of fish landings under a 2xCO2 scenario and for species that live in surface waters. Any effort to couple ocean, climate, hydrologic and ice modelling at a sufficiently fine scale should be encouraged.

FORESTRY		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (4)**	**RECOMMENDATIONS (6)**
sensitivity to climate: ***AVERAGE*** **For a limited number of forest species, the links between the forest ecosystem, and the air and soil are well known. It is difficult, however, to extrapolate this information over a long period or to the entire province**	**G.25** The current monitoring network shows signs of instability in tracking the state of health of forest populations in Quebec in response to increased climate stress	**R.25** Maintain a monitoring network that has a high enough spatial and temporal resolution to monitor the following in Quebec: • composition and change in populations; • regions where forests are particularly sensitive to climate perturbations; • interactions between growth, mortality, the water balance, carbon/nitrogen concentrations and climate
	G.26 The role of climatic factors in the distribution and migration of forest populations needs to be better understood	**R.26** In order to predict variations in stand types, biological and climate models need to be coupled in the short term, thereby integrating the process of carbon and nitrogen cycling in the forest ecosystem, the **water balance**, fauna and habitats **R.26b** Promote multidisciplinary projects that can be implemented in the short term and that establish contacts among forest managers and climate, biology and forest ecology specialists
effects of climate change: ***POOR*** **A number of climate-vegetation simulations have been conducted on the main forest biomes in Quebec, but they did not take into account soil and biological characteristics or the incidence of extreme climate events. Coupling of biological models and regional climate models has been initiated**	**G.27** Extreme natural perturbations (forest fires, freezing rain, etc.) need to be modelled in order to estimate the effects on forest populations in the medium term	**R.27** Considering that a higher frequency of "natural disturbances" might be a warning of climate change, there is an urgent need to better describe the biological and ecological interactions between extreme events (forest fires, freezing rain storm, etc.) and populations
	G.28 In light of the capacity of boreal and temperate forests to store carbon, it is important to enhance our understanding of the exchanges that occur between the forest ecosystem, the atmosphere and the soil.	**R.28a** If we want silvicultural operations to optimize both forest production and carbon sequestration in the forest ecosystem, specific studies need to be conducted on the link between climate conditions and carbon cycling by various forest populations **R.28b** Determine the cumulative effects on forest populations of various $2xCO_2$ scenarios; identify the impacts of an increase in CO_2 concentrations and temperature on the growth of species; adapt forest management techniques

ENERGY		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (2)**	**RECOMMENDATIONS (2)**
sensitivity to climate: ***GOOD*** **Although we understand the important influence of climate on energy supply and demand, the most commonly used climatic factors are of a general nature and not well developed**	**G.23** There are no effective methods for linking regional climate fluctuations to heating and air conditioning requirements, along with the net supply of water in the reservoirs of Northern Quebec, and to the capacity of hydro-electric power stations along the St Lawrence	**R.23** By drawing on data collected over the past 30 years in Quebec, develop and validate climate indicators that have a sufficiently high spatial and temporal resolution to correlate such indicators with actual data on energy use for heating and air conditioning, taking into account technological advances implemented to reduce energy consumption
effects of climate change: ***AVERAGE*** **Existing studies have been limited to estimating variations in water supply in hydro-electric reservoirs and the largest watersheds in Northern Quebec**	**G.24** The distribution of energy in Quebec in a $2xCO_2$ environment needs to be evaluated, with a view to meeting domestic energy needs, while estimating the potential for exporting energy to regions adjacent to Quebec	**R.24** By using regional climate models (resolution of 30-40 km) and climate indicators, indicate how Quebec's energy sector should strategically position itself in the North American context given the energy supply and demand characteristics under a $2xCO_2$ scenario

TRANSPORTATION		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (2)**	**RECOMMENDATIONS (2)**
sensitivity to climate: ***AVERAGE*** **A large number of technical studies exist which identify the relationships between modes of transportation and climate conditions. However, no overview exists of the influence of climate on transportation in Quebec**	**G.30** The effects of present and future winter conditions on road transportation should be quantified to a greater extent and properly documented	**R.30** The overall cost associated with the effects of winter storms and freeze/thaw conditions should be evaluated and documented until such time as regional climate models are able to provide reliable indications on the track and intensity of low pressure systems in a $2xCO_2$ environment
effects of climate change: ***SKETCHY*** **Marine transportation on the St Lawrence is the only sector that has been studied indirectly with reference to a $2xCO_2$ scenario**	**G. 31** Measures for adapting need to be developed for the marine environment to minimize the impacts of episodes (duration and intensity) of abnormally low water levels in the St Lawrence	**R.31** The use of coupled econometric and hydrodynamic models to forecast water levels/flows in the St Lawrence will be encouraged to determine the necessary modifications in future ship design and the cargo types that should be promoted to strategically position maritime ports in Quebec

INFRASTRUCTURE AND PERMAFROST		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (1)**	**RECOMMENDATIONS (4)**
sensitivity to climate: ***POOR*** **The ability exists to measure the relative importance of the thermal regime in the behaviour of permafrost in Northern Quebec. However, the available data do not allow us to quantify these processes on spatial and temporal scales** ***effects of climate change:*** ***SKETCHY*** **Only one specific study has been done in Quebec. There is a need to use and adapt research conducted elsewhere in Canada (e.g. Mackenzie River Basin)**	**G.29** Climate warming in Northern Quebec will increase the depth of the active permafrost, reduce its load-bearing capacity and increase the instability of slopes. All these aspects directly affect road, maritime, hydro-electric and government infrastructure.	**R.29a** Thermal measurement networks (air and soil) need to be maintained an automated to be able to track changes in climate and the permafrost in Northern Quebec **R.29b** Map the arctic and subarctic regions that have sensitive and ice-rich soils, in order to identify locations where there is a risk of major ecological changes in the event of permafrost melting **R.29c** Determine, for a $2xCO_2$ environment, the safety factors required in construction design to prevent costly damage resulting from subsidence of facilities built on soil containing permafrost that is undergoing melting **R.29d** Assess the present cost of infrastructure damage that is directly linked to extreme climate events

RECREATION AND TOURISM		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (1)**	**RECOMMENDATIONS (2)**
sensitivity to climate: ***POOR*** **Downhill skiing, golfing and pleasure boating (indirectly), are the only sectors that have been studied** ***effects of climate change:*** ***POOR*** **No work has been done aside from two studies on skiing and golfing**	**G.32** The only recreation and tourism studies dealt with downhill skiing and golfing, and touched indirectly on pleasure boating. In view of the importance of this sector in Quebec, it is essential that coverage be broadened to all recreational activities and potential tourism at the regional level	**R.32a** Identify the satisfaction criteria for staging recreational activities in Quebec, including the alternatives available for the different activities, by documenting them to as much as possible **R.32b** Evaluate the present economic spinoff from recreation in Quebec and link this sector to representative climate indicators

EXTREME CLIMATE EVENTS		
OVERALL EVALUATION OF THE KNOWLEDGE BASE	**PRESENT GAPS (2)**	**RECOMMENDATIONS (3)**
sensitivity to climate: ***POOR*** **In spite of the large number of reference documents, reports, and studies on extreme climate events, the majority of them have looked at the economic consequences of material damage and loss of life. Except in rare instances, social and biological aspects have not been discussed.**	**G.33** The record of extreme climate events that have occurred in Quebec is incomplete, and sometimes contradictory; these events are poorly documented and do not contain enough information to evaluate the overall impact on the physical, social and biological levels.	**R.33a** Information on the cost and the physical, biological and social effects of extreme climate events, specifically floods, drought, heat and cold waves, and episodes of severe weather events, that is, tornadoes, heavy hail and winter storms, needs to be compiled and made available to decision makers **R.33b** A methodology for analysing and evaluating the effects of extreme climate events on the basis of direct and indirect data needs to be developed and applied in a systematic fashion for planning purposes
effects of climate change: ***SKETCHY*** **No study is available in Quebec on changes in the frequency, intensity and duration of extreme events under a $2xCO_2$ scenario**	**G.34** Present climate change scenarios are not able to indicate whether the frequency, intensity or duration of extreme climate events will vary significantly in a $2xCO_2$ environment.	**R.34** Until climate change scenarios can give an adequate and valid indication of the influence of increased greenhouse gases on extreme climate events, work should be done to determine the sensitivity of the different sectors and the extent of the impacts of extreme climate events by varying the duration and intensity of such abnormal climate events according to a predetermined factor

CONCLUSION

From the Quebec Chapter of the Canada Country Study: Climate Impacts and Adaptation, the following conclusions can be drawn:

- an impressive quantity of scientific information exists on the links between the climate and economic sectors in Quebec, but coverage varies considerably among the sectors;

- water resources, agriculture and forestry are the sectors for which the most information exists, covering both present and past links to climate, as well as the largest number of studies on the possible effects of a $2xCO_2$ scenario;

- no work has as yet been done in the areas of human health and social aspects, fisheries, infrastructure maintenance, or recreation and tourism;

- studies have clearly shown the appreciable sensitivity that exists to extreme climate events; in view of their major impacts on Quebec, these events need to be documented more extensively and analysed both spatially and temporally.

By identifying 34 gaps in the knowledge base and providing 57 recommendations, the Quebec Chapter (Volume V) of the Canada Country Study is intended to serve as a starting point for developing and implementing rational and concrete measures for adapting to alterations in climate variability of natural or anthropogenic origin.