ADAPTING

to Climate Change

ISBN 2-923292-01-4
Legal deposit - Bibliothèque nationale du Québec, 2004
Legal deposit - National Library of Canada, 2004

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OURANOS • 2004

Ouranos, a research consortium on regional climatology and adaptation to climate change, is a joint initiative of the Government of Québec, Hydro-Québec, and the Meteorological Service of Canada with the participation of UQAM, Université Laval, McGill University, and the INRS. Valorisation Recherche Québec collaborated on the establishment and financing of Ouranos. The opinions and results presented in this publication are the sole responsibility of Ouranos and do not reflect in any way those of the aforementioned organizations.

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FOREWORD

We, human beings, coexist with other living species (beings) on a telluric planet revolving around a star in one of the innumerable galaxies of the universe. Without the sun's energy, which makes all life possible here, our earth's climate would be frozen and the sky an endless night. For thousands of years, fragile and complex processes have maintained a comfortable balance in the climate. This has allowed achievement of a level of development that only a part of humanity has been able to benefit from, and to which the majority still aspires.

Suddenly, we are waking up to the fact that the climatic path our only planet will follow is determined by our values, our technological choices, and our economic behaviour. Certainties that were once unassailable are rapidly becoming obsolete, and will be revised in light of the magnitude of climate changes already in progress and yet to come. "Before seeking happiness, quality of life, or the preservation of the beauty of this earth, human beings need to meet the basic needs of life, in the strictest sense of the term: to provide for sustenance and adapt to their environmental milieu.[1]"

Ouranos, a god of Greek mythology, personified the heavens as a symbol of fertility. This myth provided a metaphor, representing its influence on humans and its interaction with the earth. Today it is the name of a consortium on regional climatology and adaptation to climate change, bringing together a team of over 200 researchers and professionals originating from numerous institutions and scientific disciplines. Its mandate consists of providing precise, reliable and forward-looking information to those whose job is to anticipate and prevent.

The following document sketches the current state of the little that is known, and the much that is yet unknown, of the impacts of the climate and its eventual changes on Québec. Scientific jargon has been set aside, inasmuch as possible, so as to render accessible the answers available today and the questions that require further documentation.

I wish to thank everyone who contributed to the production of this document. We are in their debt for the heart and talent they have invested, bringing together the elements of an expertise indispensable for adopting behaviour that will bear fruit for us and our children.

May your reading be enjoyable and stimulating,

Georges Beauchemin
Chairman of the Board, Ouranos

1 Pascal Acot: Histoire du Climat, Editions Perrin, 2003 (our translation).

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INTRODUCTION

The OURANOS consortium was born of the need for greater knowledge and a deeper understanding of the climatic phenomena that will affect the territory of Québec during the upcoming decades. To accomplish this, the consortium's research program has been grouped under two broad themes: *Climate science and hydrology* and *Impacts and adaptation strategies*.

Research into *Climate science and hydrology* seeks to further our understanding of the determinants of various aspects of climate and their evolution over time, including temperature, freezes and thaws, precipitation in the form of rain, snow, or ice, and wind. An examination of historical data, a statistical analysis of their variability, and the perfecting of climate models and scenarios will serve to generate climate forecasts. In the absence of a thorough understanding of climatology to underpin the analysis of the impacts, it is impossible to quantify and detail adaptation strategies. This provides the rationale for the considerable research efforts into climate and hydrology conducted at Ouranos. However, the purpose of this document is limited to describing the expected impacts, and it only touches on the science of climate to the extent that explanations are required to clarify the analysis of the impacts.

As to the research into *Impacts and adaptation strategies*, its primary goal is to assist the elaboration of strategies for adapting to the climate changes that will affect Québec over the course of the 21st century. The information thus gathered will be used to support the decision-making processes of the consortium's partners, whose activities in Québec could be affected by unprecedented climatic conditions that may positively or negatively impact on the natural and human environment—which has, all in all, been fairly stable for hundreds of years.

Before addressing this rich harvest of diverse facts and data, which will provide us with a greater appreciation of the climate changes that would result from a warming of the Northern Hemisphere, it seemed logical to release an initial document having a broad appeal that would, to some extent, draw a picture of the state of knowledge in terms of climate change affecting the territory of Québec. The result is this paper, called *Adapting to Climate Change* and developed around the following themes:

- the evolution of the climate,
- the territory and regions of Québec for purposes of this study,
- expected sectorial impacts.

1

Chapter 1 presents an analysis of changes to the climate observed in the Northern Hemisphere over the course of the last hundred years and their causes. The evidence gathered here seems to indicate that rising temperature is a phenomenon that is well under way, and that it is vital to understand as clearly as possible the impacts on our natural and human environment. This chapter also draws a global portrait of what is in store for the climate over the coming hundred years. Moreover, it presents scenarios for the evolution of Québec's climate during this same period, drawn from forecasts generated by the principal general climate models.

2

Chapter 2 presents the territory of Québec in terms of certain features that are useful for understanding ongoing climatic phenomena and sets up a framework for analysis based on the division of this territory into four zones: Québec's Arctic Region, Resources Region, Maritime Region, and Southern Québec Region.

For each of these regions, we consider the elements that are most likely to suffer shocks of varying intensity owing to the evolution of the climate. These elements are permafrost, forests, hydroelectricity, coastal erosion, Québec's ecosystems, and the Saint Lawrence River, as well as human activities that are most closely tied to the use of Québec's territory, such as water management, agriculture, energy demand, transportation, human health, and tourism.

All parts of this chapter are developed around the following three axes:

- a summary description of the situation,
- expected direct and indirect impacts,
- potential adaptation strategies and the necessary studies.

The current document lays out a synthesis, as complete and concise as possible, of the principal climatic phenomena at play in the Northern Hemisphere and their impacts on the territory of Québec. Only a more detailed analysis, spanning both space and time, of the various manifestations of climate change will permit a proper evaluation of the issues that current and future generations will need to confront.[2] Ouranos seeks to address exactly that need for knowledge of both the actual phenomenon of climate change and its impact.

2 For more information about Ouranos and the fourteen priority projects, visit our web site: www.ouranos.ca.

1

The Science of Climate

An Inevitable Increase in Temperatures

CHAPTER 1
The Science of Climate—An Inevitable Increase in Temperatures

The *United Nations Framework Convention on Climate Change*, adopted in 1992, recognized the importance of greenhouse gas (GHG[3]) emissions to climate change. It also pointed out the need to stabilize concentrations of GHGs in the atmosphere at a level that would not create a dangerous disruption of the climate by human activities, so as to ensure sustainable development.[4] Finally, it emphasized the importance of developing the means to adapt to changes that are already ongoing, believing that these would inevitably be amplified over time.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

ARTICLE 2

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

A RAPID RISE

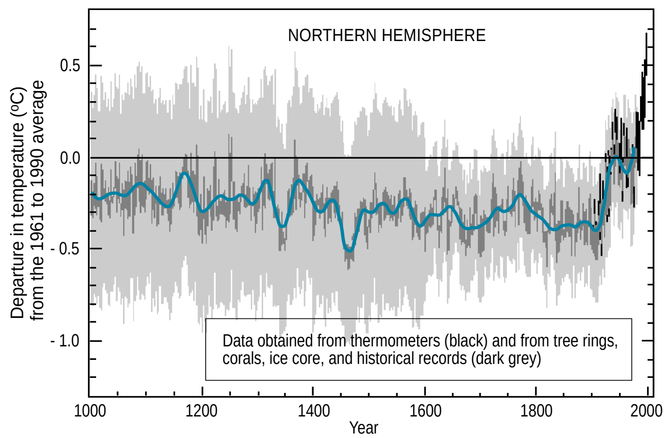
Between 1961 and 2000, mean temperatures observed in the Northern Hemisphere were decidedly higher than those recorded over the last thousand years. As Figure 1 reveals, this period clearly stands out from the preceding centuries, which were characterized by a slow cooling of a few hundredths of a degree Celsius.

In the light of this data, we see that the climate of the Northern Hemisphere has warmed by an average of nearly 0.6° ± 0.2°C since the beginning of the 20th century. Unlike some other warming phases that have occurred over the course of the past thousand years, this one is observable across the entire planet. Since people started measuring temperatures with instruments, the decade of the 1990s has proven to be the hottest on record, with 1998 its hottest year. Moreover, minimum temperatures (usually nighttime) increased twice as much as maximum temperatures (usually daytime) on average, having a direct impact on the range of daily, monthly, and seasonal temperature fluctuations and the freeze/thaw alternation.

Overall, precipitations have increased in the Northern Hemisphere, though with considerable regional variation—some areas experiencing declines. In the medium and higher latitudes of the Northern Hemisphere, an increase of five to ten per cent has been observed, alongside a slight rise in intense precipitation events.

Figure 1

Variation of the earth's surface temperature in the Northern Hemisphere between the years 1000 and 2000 (IPCC, 2001)



As to snow cover, it has decreased by ten per cent since the end of the 1960s, while the duration of ice cover on lakes and rivers is now about two weeks shorter than at the beginning of the 20th century. Sea ice cover in the Northern Hemisphere is now between ten and fifteen per cent less than during the 1950s, and the arctic ice is 40 per cent thinner in the summer. Permafrost is also 2° to 4° C warmer. Finally, sea levels have risen between 0.1 and 0.2 meters in the 20th century, or about ten times faster than during preceding millennia. This increase is essentially attributable to the expansion of ocean water, the surface temperature of which has increased by about 0.5° C since 1860.

3 The greenhouse gasses targeted by the protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorinated hydrocarbons (HFCs), perfluorinated hydrocarbons (PFHs), and sulphur hexafluoride (SF_6).

4 *United Nations Framework Convention on Climate Change*, United Nations, 1992, Article 2.

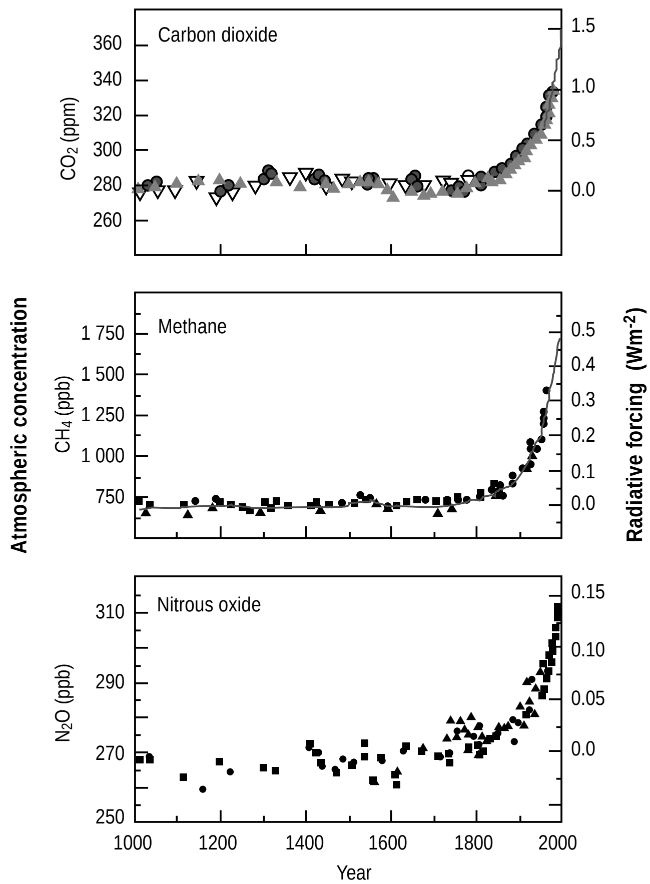
INCREASED GHG CONCENTRATIONS

According to the Intergovernmental Panel on Climate Change (IPCC)[5], this rise in temperatures is essentially attributable to the increased greenhouse effect caused by greater atmospheric concentrations of GHGs resulting from human activities starting with the beginning of the industrial revolution. Though water vapour remains the primary greenhouse gas in the earth's atmosphere, its impact is now amplified by the contributions of other gases added by us. Figure 2 clearly reveals the magnitude of the increased concentration of carbon dioxide, methane, and nitrous oxide between the years 1000 and 2000. Between 1750 and today, the concentration of CO_2 rose by 30 per cent—from 280 to 367 ppm[6]—owing to the use of fossil fuels.[7] Concentrations of CO_2 have not been as high as their current levels in 420,000 years, and the rate at which they are presently growing, relative to emissions, is unprecedented in the last 20,000 years.

Seventy-five per cent of emissions growth is attributable to the use of fossil fuels (coal, oil, and natural gas), and the remainder to changes in land-use patterns, for example deforestation. Though this varies from one year to the next, about one-half of anthropogenic CO_2 emissions are absorbed by the oceans and land, while the other half accumulates in the earth's atmosphere. We observe considerable variation in the rate of growth of CO_2 concentrations from one year to the next owing to the effect of climatic events, such as El Niño, on the rate at which gas is absorbed by forests and oceans.

Figure 2

Evolution of CO_2, CH_4, and N_2O concentrations between the years 1000 and 2000
(IPCC, 2001)



5 The Intergovernmental Panel on Climate Change was established in 1988 as a joint undertaking of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP).

6 ppm: number of molecules of a gas per million molecules of dry air.

7 Changes in the composition of atmospheric CO_2 isotopes clearly reveal the rising share of fossil fuels in the increase of this gas in the atmosphere, each source of emissions has a characteristic footprint in its isotope composition.

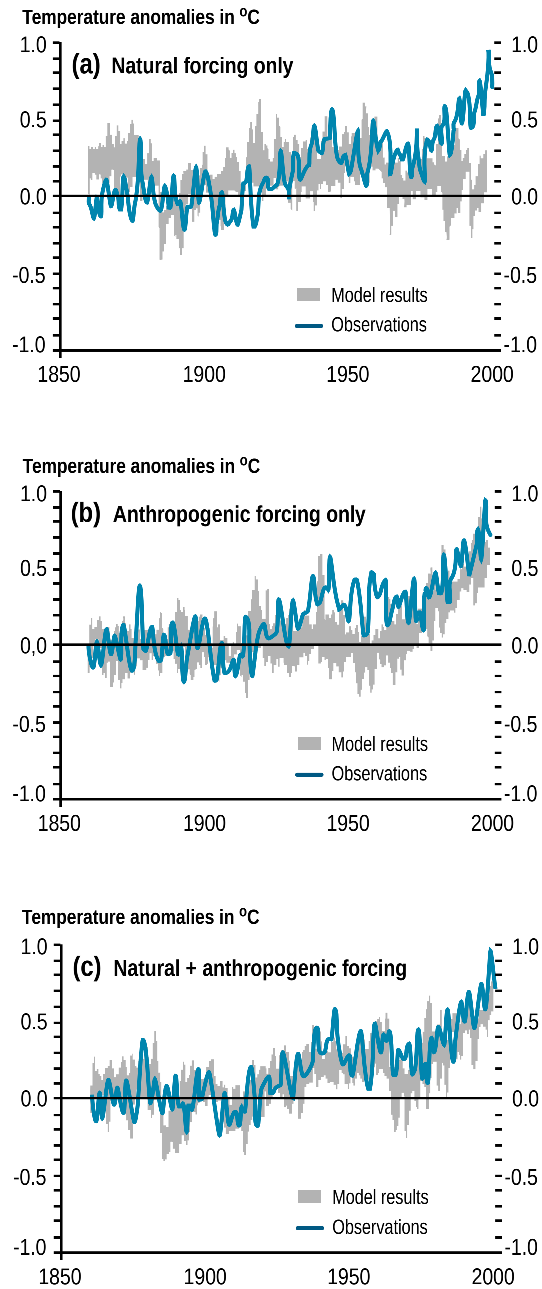
GHGs, which are naturally present in the atmosphere, contribute to retaining heat and maintaining conditions on earth that are suitable to life. However, their rising concentrations are driving a climate forcing that amounts to a disturbance in the earth's energy balance. Indeed, the earth's energy essentially comes from solar radiation, at about 340 W/m^2 (at the top of the atmosphere) averaged over time and space. About one-third directly bounces back into space owing to reflection off clouds, the atmosphere, and the surface of the earth. Another part is absorbed by the atmosphere and redirected into space in the form of infrared radiation. Increased concentrations of GHGs have the effect of holding a larger proportion of this energy in the form of infrared close to earth. This creates a slight disequilibrium, or positive forcing, of the earth's energy balance amounting to several watts per square metre (or megawatts per square kilometre).

In addition to the GHGs targeted by the *United Nations Framework Convention on Climate Change* and the Kyoto Protocol, many factors impact on the earth's climate. Indeed, tropospheric aerosols, land use changes, aerosols originating from volcanic eruptions, as well as variations in solar radiation and the concentration of ozone also impact on the climate. Climate models account for most of these factors when simulating the evolution of climate over time and space.

We see in Graph ***a*** of Figure 3 that the evolution of modelled temperatures, when only natural factors of radiative forcing are considered, lies well below the most recent observations. On the other hand, Graph ***b***, in which only increases in greenhouse gasses attributable to human activities are modelled, also fails to reproduce observed variations. However, when variations in both natural and human-induced radiative forcing mechanisms are factored in, these models reproduce the observations much more accurately, as is illustrated in Graph ***c***.

Figure 3

Temperature changes observed and modelled on natural and anthropogenic inputs
(IPCC, 2001)



RISING EMISSIONS

The primary source of GHG emissions is the use of fossil fuels (natural gas, coal, and oil). Now, as the identity below states (Kaya, 1990), the expanding use of fossil fuels is to a very large extent the direct outcome of population growth and economic development—almost inevitably associated with increases in energy consumption. This demand for energy extends to both electric and thermal power and, depending on the available natural resources, brings an increase in the production and consumption of renewable and fossil fuels.

CO_2 Emissions
*= GDP **X** energy intensity **X** carbon intensity*
*= [(GDP/population) **X** population] **X** (energy/GDP) **X** (CO_2 emissions/energy)*

Even if the range of population growth forecasts is reasonably well known, a great deal of uncertainty still surrounds both economic growth and the evolution of the carbon intensity. Consequently, the range of forecasts for the evolution of CO_2 emissions is extremely broad—which is true on the global, but even more on the regional, scale.

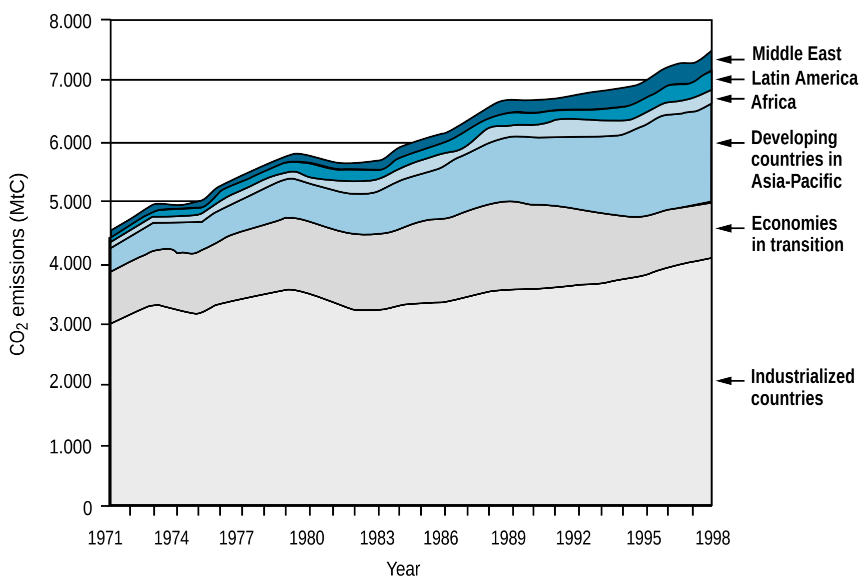
In developed countries, which have seen a marked decrease in their population growth rates, increasing emissions are essentially linked to higher per capita energy consumption for certain electricity uses as well as for transportation. In developing countries, we simultaneously observe high population growth rates and improvements to living standards, leading to a considerable expansion in energy consumption and GHG emissions.

The growing volume of GHG emissions in developing countries, and more particularly in the nations of Asia and the Pacific, must be accounted for. As we see in Figure 4, the relative contribution from member countries of the OECD[8] and economies in transition is declining, while that from countries in Asia-Oceania is increasing. Now, over the coming decades, these countries, which bear a substantial demographic weight, will clearly have a lot of catching up to do in terms of living standards.

In order to evaluate the expected evolution of GHG emissions, the IPCC modelled a small number of scenarios, starting today and extending until the end of the century, as functions of various assumptions on population growth, economic growth, technological developments, and fossil fuel use. Details of these scenarios are presented in the *Special Report on Emissions Scenarios* (SRES) published in 2000 by the Working Group III of the IPCC.

Figure 4

World CO_2 emissions by country group, 1971-1998
(IPPC, 2001)



8 OECD: Organisation for Economic Cooperation and Development.

EMISSIONS SCENARIOS IN THE *SPECIAL REPORT ON EMISSIONS SCENARIOS*

A1. The **A1 scenarios** are based on:
- very fast economic growth;
- population growth peaking in the middle of the 20th century and falling afterwards;
- rapid penetration of new, more efficient, energy technologies.

Greater convergence is expected between the regions of the earth with increased trade and declining income gaps. Within this group we distinguish between three scenarios depending on the energy sources used:
- fossil fuels: A1FI scenario,
- non-fossil energy: A1T scenario,
- technological improvements affecting all supply sources. A1B scenario.

A2. The **A2 scenarios** envisage a world in which convergence occurs more slowly, with fertility rates remaining high in some regions and a global population that continues to grow throughout the entire time horizon of the forecasts. Here economic and technological growth is more divergent and slower.

B1. The **B1 scenarios** foresee developments similar to those in the A1 scenarios, though with a greater emphasis on the services and information sectors. This type of evolution is accompanied by a reduction in consumption of raw materials and the introduction of clean technologies that use resources more efficiently.

B2. The **B2 scenarios**, like the A2 scenarios, assume ongoing population growth, but at a slower pace. In this scenario, economic development falls in a mid-range and technological change is more eclectic, so as to better satisfy local and regional needs.

None of these scenarios accounts for implementation of the Kyoto Protocol or other initiatives arising from the *United Nations Framework Convention on Climate Change.*

Graphs ***a*** and ***b*** in Figure 5 show CO_2 emissions and the associated concentration levels. Graph ***a*** reveals that total CO_2 emissions could rise from 8 GT (billions of tonnes) per year in 2000 to 28 GT/year in 2100 under the A1FI scenario, in which the bulk of new growth is driven by fossil fuels. Conversely, a more optimistic outlook such as B1, which counts on rapid stabilization of populations and the adoption of technologies that curtail carbon emissions, allows them to be reduced to about 5 GT/year in 2100.

As an example, the *International Energy Outlook 2003* of the U.S. Department of Energy's Energy Information Agency (EIA) forecasts an annual growth of 1.9 per cent in GHG emissions until 2025. A 2 per cent growth rate until 2050 is compatible with scenarios A2 and A1B in Figure 5. At 2 per cent annually, CO_2 concentrations will double between now and 2055 and quadruple by about 2100.

Graph ***b*** in Figure 5 reveals that the atmospheric concentration of carbon dioxide will increase in any case, since even 5 GT/year exceeds the absorption capacity of the earth's ecosystem. According to these scenarios, CO_2 concentrations will rise from 360 ppm in 2000 to level off at between 540 and 970 ppm in 2100, equivalent to an increase ranging from 90 per cent under the most optimistic scenario (B1) and 250 per cent (A1FI) with respect to the reference scenario—280 ppm observed during the pre-industrial period (before 1850).

Figure 5

Growth in emissions and concentrations under various scenarios from the IPCC
(IPCC, 2001)

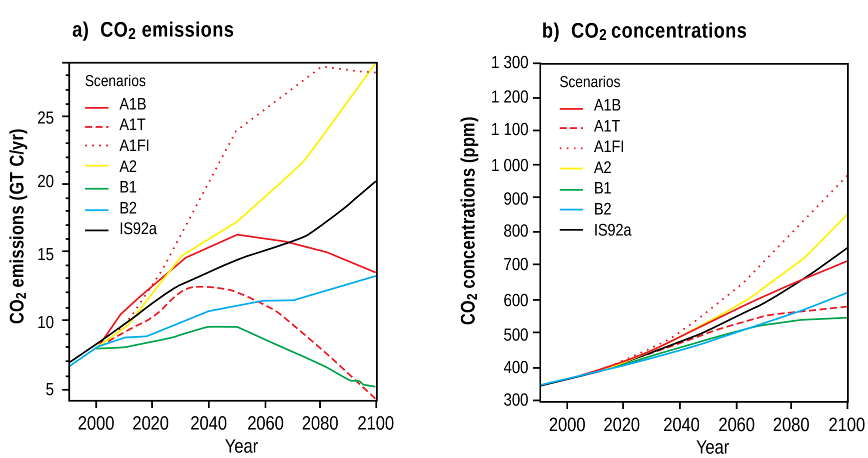
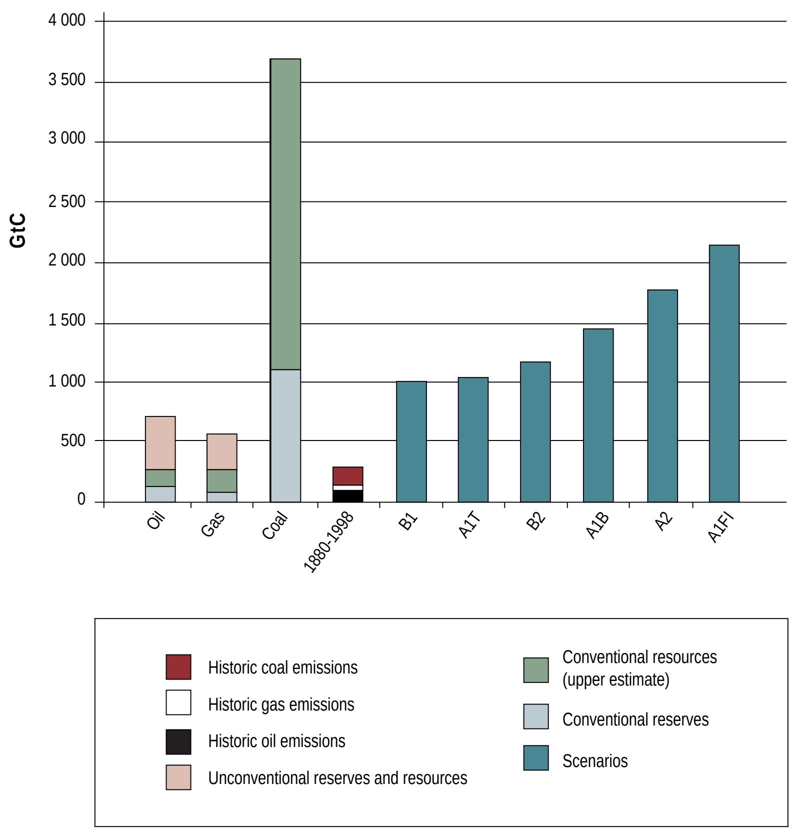


Figure 6 compares projected emissions attributable to human activities over the upcoming century with those emitted since 1880. Whatever scenario is retained, we recognize that future emissions will far exceed total historical emissions. This is altogether plausible, given that fossil fuel reserves are sufficiently abundant to ensure realization of the afore-mentioned high energy use demand scenarios associated with demographic and economic growth.

The IPCC scenarios make no explicit assumptions regarding the implementation of policies such as the Kyoto Protocol. It is implied, however, that significant commitments will be required if the more optimistic scenarios are to be achieved. In fact, considerably more far-reaching undertakings than those represented by the Kyoto Protocol would be required, as they only account for a little more than 5 per cent of 1990 emissions levels from industrialized economies and those in transition, and will lead to at most a 3 to 4 per cent reduction in total emissions. Reductions on the order of 30 to 40 per cent need to be envisaged to reach the goal of limiting atmospheric CO_2 concentrations to twice their pre-industrial levels by the end of the century. Consequently, reductions of about 10 times the magnitude of those that Kyoto provides for must be achieved to avoid dangerous climate regimes. As a corollary it will also be necessary to develop scenarios for adapting to a climate corresponding, between now and the end of the current century, to CO_2 concentrations at least twice as high as pre-industrial era levels.

Figure 6

Comparison of historical emissions and the IPCC emissions scenarios with levels of reserves and hydrocarbon resources, in billions of tonnes of carbon (Gt C)
(IPCC, 2001)

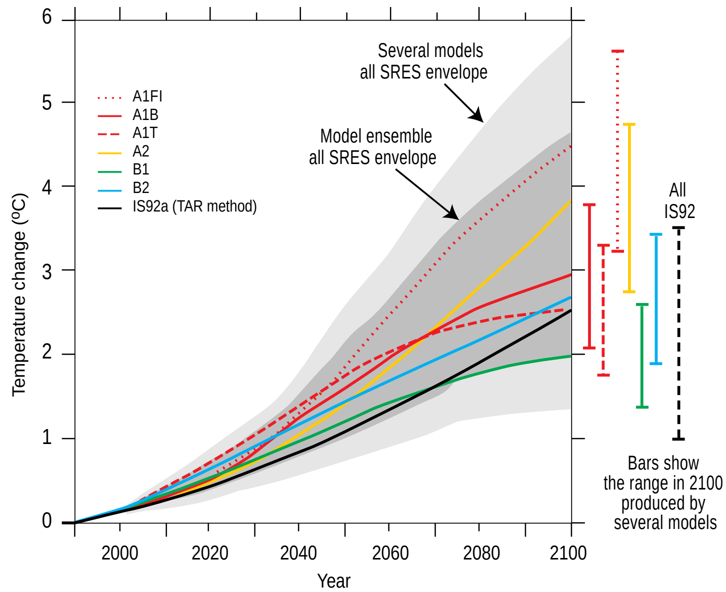


Under the various scenarios, global temperatures will rise by an average of 1.5° to 6 °C over the course of the century. Figure 7 illustrates the range of forecasted temperature increases between 2000 and 2100 based on the IPCC scenarios and various general climate simulation models. In northern latitudes, the increase could be about 40 per cent higher than the average for the hemisphere. Moreover, in the medium and higher latitudes of the North, precipitations are expected to increase over the course of the second half of the 21st century, accompanied by greater annual variations.

In the case of Québec, according to Hulme *et al*. (1999), global climate models suggest that by the end of the century Québec's summer temperatures will rise by an average of 2° to 3° C in the south (below the 50th parallel) and precipitation by 0 to 5 per cent. In the north (above the 50th parallel), the same increase in temperatures will yield additional precipitation on the order of 5 to 10 per cent. Winter temperatures will rise more, by about 3° to 4° C in the south, accompanied by a substantial jump in precipitation of 10 to 20 per cent, falling in the form of either rain or snow, while in the north temperature increases of 4° to 5° C will be associated with 10 to 25 per cent more precipitation. This average climate change scenario is based on the use of four scenarios from the *Special Report on Emissions Scenarios* (SRES), to wit, the B1, B2, A1, and A2 scenarios, which range from the most optimistic to the most pessimistic, or from a 4 per cent emissions decline to a 320 per cent increase by the year 2100.

Figure 7

Temperature increases between 1990 and 2100, according to the IPCC and various simulation models (IPCC, 2001)



Drawing on global climate change models, Figure 8 presents the range of changes to temperatures and precipitation that could result from one or the other of the four aforementioned emissions scenarios.

Figure 8

Temperature and precipitation increase scenarios for Québec, for the period from 2080 to 2100 relative to 1960–1990
(Hulme *et al*., 1999)

	SOUTHERN QUÉBEC			NORTHERN QUÉBEC		
	Optimistic scenario	Average scenario	Pessimistic scenario	Optimistic scenario	Average scenario	Pessimistic scenario
Summer (June to Aug.)						
Temperatures	+1.5°C	+2 to +3°C	+4.5 to +5°C	+1 to +1.5°C	+2 to +3°C	+4 to +4.5°C
Precipitation	0 %	0 to +5 %	0 to +10 %	0 to +5 %	+5 to +10 %	+10 to +20 %
Winter (Dec. to Feb.)						
Temperatures	+2°C	+3 to +4°C	+6 to +7°C	+2 to +3°C	+4 to +5°C	+7 to +9°C
Precipitation	+10 %	+10 to +20 %	+25 to +35 %	+5 to +15 %	+10 to +25 %	+20 to +40 %

Theoretically, any change in the climatic average is also accompanied by changes in its variability and extremes. However, generating scenarios for the extremes of climatic variability is much more demanding than for changes to average conditions. On one hand, the low horizontal resolution of global models, approximately 400 km, limits the degree of confidence that we can have in forecasts on a regional scale, especially in the case of extreme phenomena strongly dominated by local effects. On the other hand, extremes appear at the frontier of the variability simulated by the models—which frequently underestimate the observed variability (Covey *et al*., 2000).

In any event, the expected changes to monthly temperature extremes will essentially take the form of higher maximum and milder minimum temperatures than those observed today. As to expected monthly precipitation extremes, these are characterized by greater uncertainty than temperatures, as results vary widely between the different models. For example, the Canadian Coupled General Circulation Model suggests that daily precipitation extremes will increase in Canada, with 24-hour maximums rising about 14 per cent with respect to their 20-year values (Zwiers and Kharin, 1998; Kharin and Zwiers, 2000). Furthermore, along with this rise in precipitation, increased evaporation associated with higher temperatures must also be considered in evaluating impacts on various sectors of activity, such as forestry, agriculture, or hydroelectricity generation.

HAS QUÉBEC EXPERIENCED WARMING IN THE LAST CENTURY?

The answer to this question is not simple, since the climate system presents a great deal of natural variability. This variability occurs over both space and time, ranging from day-to-night temperature changes to shifts in the means across years, decades, or even centuries.

Country-wide studies of temperature and precipitation trends conducted by Environment Canada in recent years (Zhang *et al*., 2000) have revealed that between 1900 and 1998 the average annual temperature increased by 0.9° C in Canada below the 60th parallel.

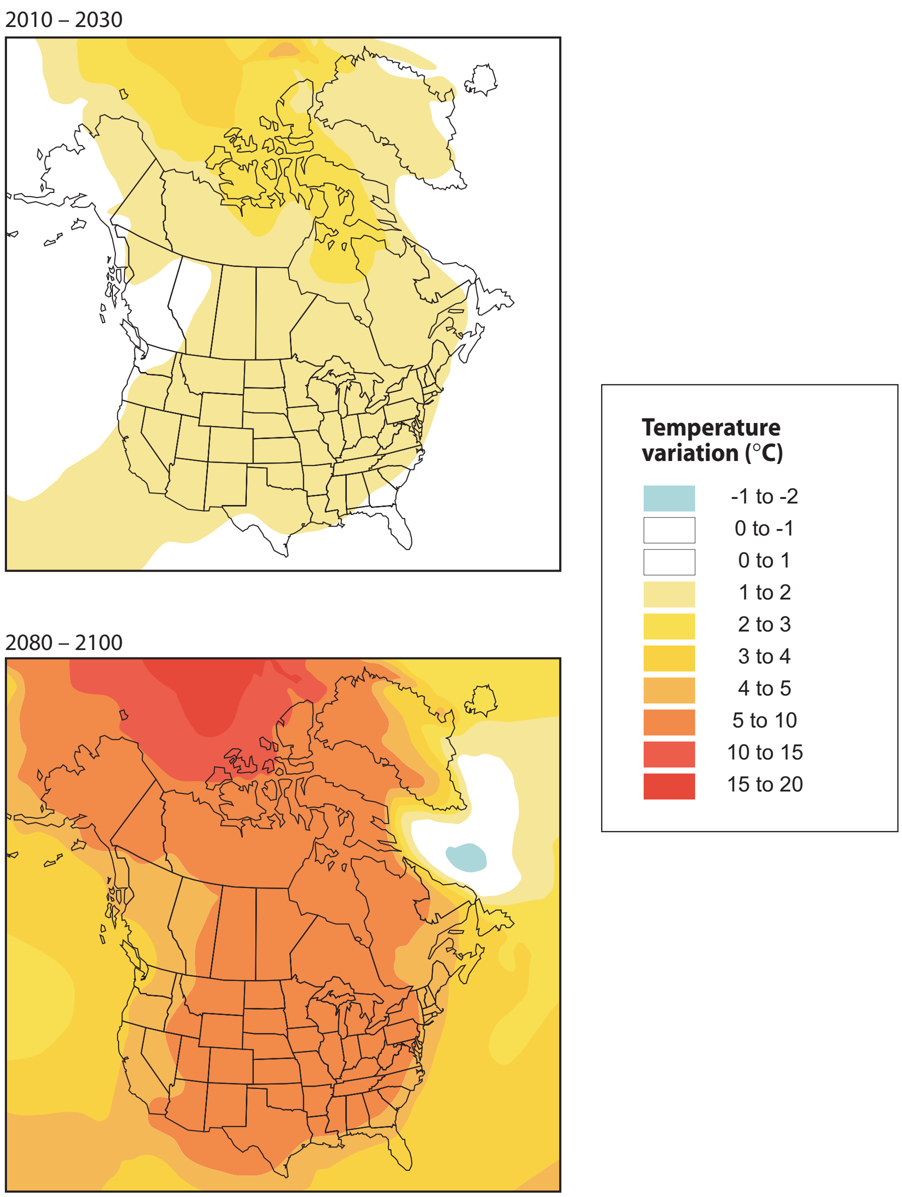
As to Québec, overall, a warming trend was observed from the beginning of the century until the early 1940s, then a slight cooling set in until the mid-1970s, followed by a pronounced warming that persists until today and which, over the entire period, amounts to 0.6° C.

Analysis of temperature-trend profiles indicates an increase in daily maxima and minima for all of Québec. However, the increase is much steeper for minima than for maxima, especially in the south, leading to a diminution of the diurnal temperature range (DTR). The impact of warming is felt more at night than during the day. Another way to put this is that Québec has not become hotter, but less cold (Henderson-Sellers, 1989; McGuffie and Henderson-Sellers, 1988).

Figure 9 reveals the differences in mean temperatures, in ° C, for the winters 2010–2030 and 2080–2100 relative to 1975–1995. These results are from the Canadian Coupled General Circulation model and based on a scenario under which GHG emissions grow by one (1) per cent annually, one of the more conservative scenarios presented in Figure 7 (IS92a). Temperature increases of 2° to 3° C are already foreseen for the extreme north of Québec between 2010 and 2030. By the 2080–2100 period, the Hudson's Bay region and the entire north (arctic and subarctic regions) will experience temperature changes of between 5° and 10° C, which are quite substantial.

Figure 9

Differences in mean temperatures, in ° C, for the periods 2010–2030 and 2080–2100 relative to 1975–1995
(Meteorological service of Canada, Environment Canada, 2000)



2

Impacts and Adaptation Strategies

A Regional Approach

CHAPTER 2
Impacts and Adaptation Strategies—A Regional Approach

The impacts of climate change, some beneficial and others adverse, are numerous and affect both the natural and the human environment. Although, globally, climate change will have serious and irreversible impacts, especially on natural ecosystems but also on some human habitats and productive activities, its distribution across the regions of the globe could be very uneven. Indeed, temperature increases will be greater in northern regions, while the lower latitudes will be vulnerable to more severe droughts.

Furthermore, developed economies should be better placed than other regions to react effectively to temperature changes. The impacts will also be very different, depending on whether the temperature changes only amount to a few degrees or are more substantial, and changes that prove beneficial at first may well turn out to be harmful in the long run. In any case, the extent and efficacy of the adaptation, whether planned or spontaneous, will have a determinant impact on the ultimate cost of climate change. With the help of good planning, modern economies that have learned to adjust to far-reaching commercial and technological changes should be able to considerably reduce the costs associated with climate change, and even to capitalize from the opportunities that arise.

An exact evaluation of the consequences of climate change requires a detailed analysis on the regional scale, accounting for both the geographical features unique to each natural environment and the area's economic and demographic characteristics. Moreover, the development of adaptation strategies must be based on an exact knowledge of the particularities of each climate region and its evolution over time.

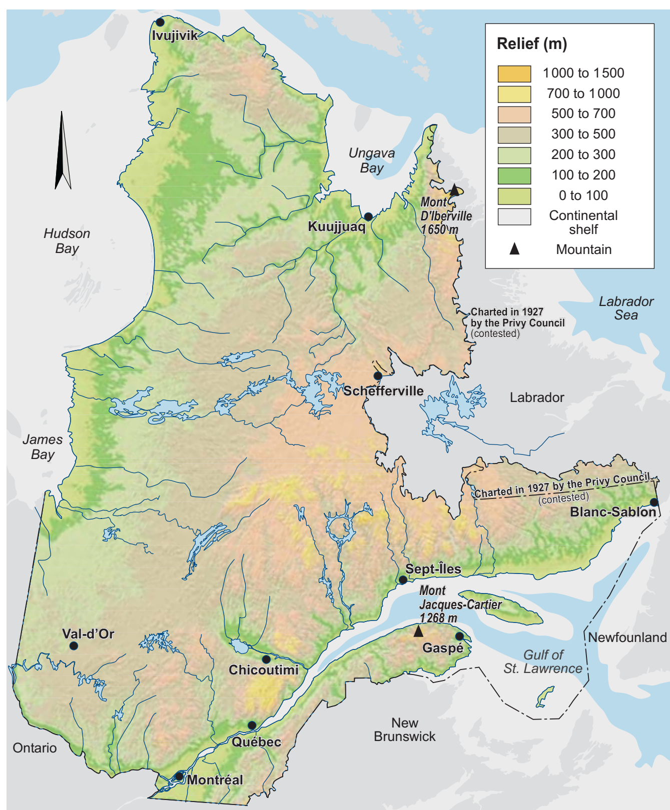
THE TERRITORY

Covering about 1,700,000 km^2, Québec is immense. It could hold France three times or Japan five times. From south to north, Québec stretches from 45° to 62° latitude north (about 2000 km) and, from east to west, from 57°to 79° longitude west (about 1500 km). Its population density is very low—4.7 inhabitants per square kilometre.[9] Fresh water bodies, in the form of over one million lakes and rivers, cover 10 per cent of Québec. The biggest, the Saint Lawrence River, crosses Québec from west to east for over 1000 km before emptying into the Atlantic.

Québec is subdivided into three main geographical regions associated with three types of relief. The Laurentian Plateau underlies nearly 95 per cent of the area of Québec. Part of the Canadian Shield—one of the planet's oldest geological formations—it consists mostly of granitic rock. It features low mountains with rolling crests covered with scenic forests and dotted with countless lakes. The second formation is the Saint Lawrence Lowlands, which border the river of the same name and are characterized by clayey soils. This area hosts a high concentration of agricultural activity. Finally, the Appalachians, a range of mountains with long, forested summits separated by valleys, rise in the south. In general, Québec's relief is not very high, featuring few elevations exceeding 900 m.

Figure 10

Relief (Natural Ressources Canada, 2002)

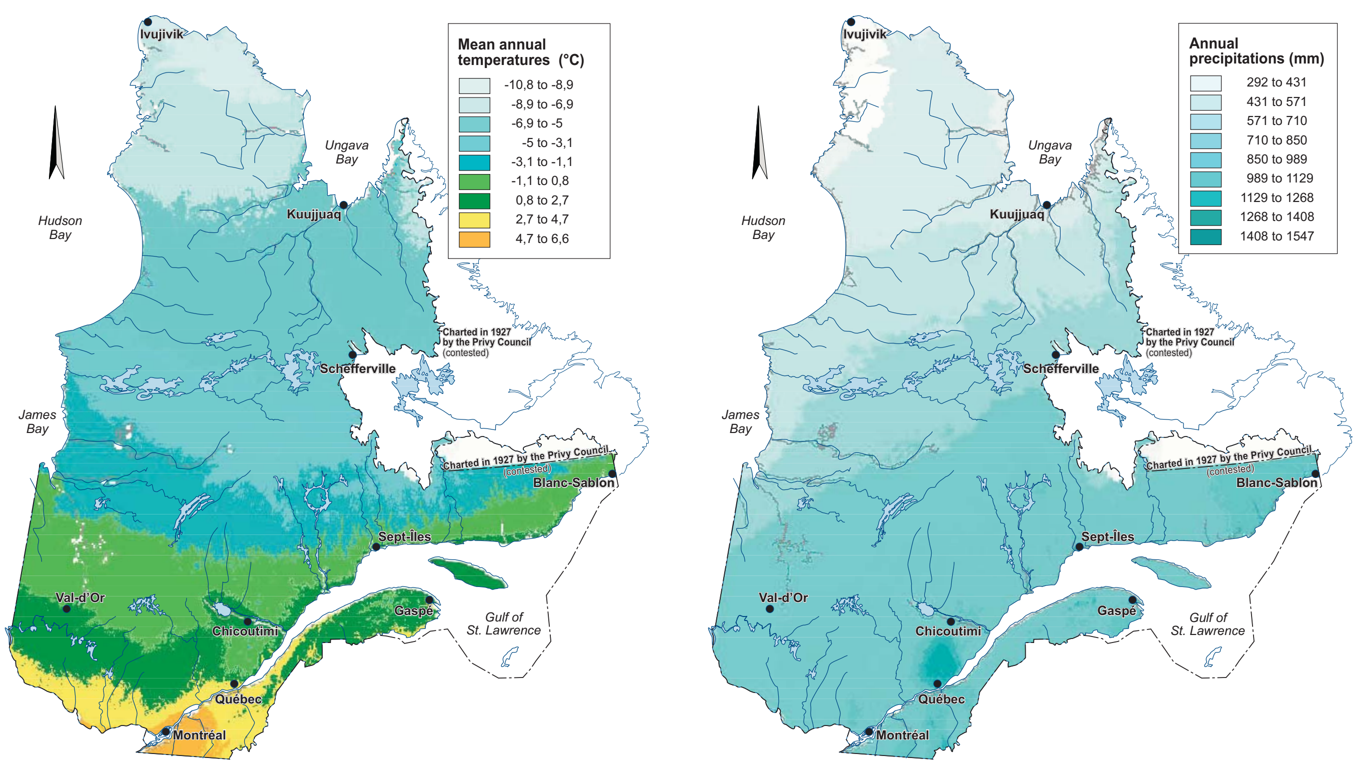


9 The significance of this number is tempered, however, by the immensity of the territory and the fact that northern Québec is scarcely inhabited—the vast majority of the population living near the banks of the Saint Lawrence River.

Given the vastness of this territory, it is not surprising to find substantial differences in temperature and precipitation. The mean summer temperature lies between 5° and 20° C, while in winter, which lasts from five to eight months depending on the region, this range is from –25° to –10° C. Total annual precipitation (snow and rain) varies between 300 and 900 mm, depending on the year, and can be as high as 1500 mm in some mountainous areas. South of 50° N latitude, the climate, continental and humid, is temperate. Here, each of the four seasons succeeds the other: a mild spring, a summer that is often hot, a colourful but sometimes cool autumn, and a white and cold winter with which Quebeckers have learned to cope. The inhabited zones border the deciduous and mixed forests. In the subarctic area, winters are colder and summers shorter and cooler, and there is less precipitation—here the flora is dominated by a coniferous forest frequently called the boreal forest or taiga, which becomes less dense toward the north. In the far north, the territory is subject to the rigour of the arctic climate and hosts the vegetation of the tundra. Finally, in the region of the Gulf of Saint Lawrence, the climate is maritime.

Figure 11

Mean annual temperatures and precipitations in Québec, 1966 to 1996
(Env. Québec, 1997)



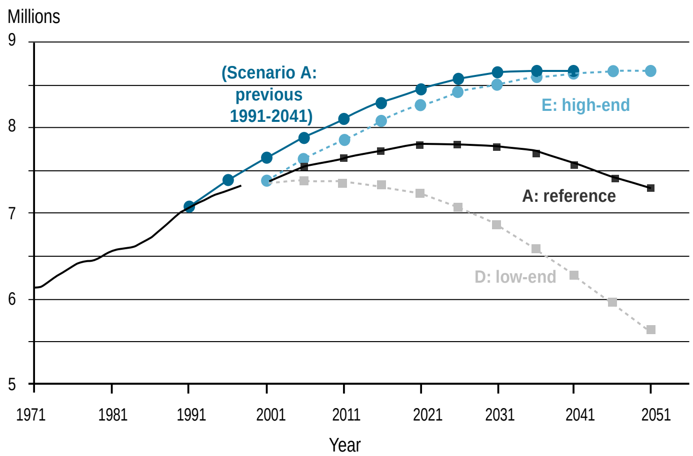
THE POPULATION

Québec's population is distributed very unevenly, the vast majority (80 per cent) living in the Saint Lawrence Lowlands. The rest of the territory, in which the economy is mostly based on natural resource exploitation, is home to the remainder, while only about ten thousand people inhabit the Arctic Region.

According to the reference scenario of the *Bureau de la Statistique du Québec* (1999), Québec's population (7.4 million individuals in 2001) will rise to 7.8 million in 2026 before falling to 7.3 million in 2051. The high- and low-end scenarios range from a population decline to 5.6 million to a slight increase to 8.6 million by 2051 (depending on the assumptions retained concerning birthrates and immigration).

Figure 12

Evolution of the population 1991–2041
(*Bureau de la Statistique du Québec*, 2000)



Even though, in the reference scenario, the actual level of the population will remain fairly stable over the course of the upcoming decades and will begin to decline around 2026, its composition and distribution will be markedly different. Scenarios from the *Bureau de la Statistique du Québec* reveal a highly differentiated regional distribution. Twelve of Québec's seventeen administrative regions will experience population loss between now and 2026. In the longer term, this depopulation will be more severe, ranging from –16 to -32 per cent. During the same period, the population of the Montréal region will increase by nearly 450,000 individuals (+13 per cent), who will primarily move into the northern and southern suburbs. The Outaouais region will also see strong population growth, reaching 364,000 inhabitants in 2041 (+13 per cent). In light of the particular issues it raises, it is worth noting that the population of Québec's arctic will grow from 10,000 to 13,000, or about 30 per cent, between 2001 and 2021.

Population shifts by age group will be even more pronounced than changes in the total populations of the regions. When we consider the ratio of those aged 65 and over to younger cohorts, Québec's demographic portrait is completely transformed. In 2051, there will be over 2 million Quebeckers aged 65 and over. The regional distribution of this age group reveals that their demographic weight will exceed 20 per cent of the population nearly everywhere, except in northern Québec. In 1996, they were at less than 15 per cent in the region with the oldest population, Mauricie. By 2026, only a crescent-shaped area centred on metropolitan Montréal and stretching from the Outaouais to the Centre-du-Québec will show some demographic vigour.

The aging of the population, a slowdown in the growth of metropolitan populations, and the depopulation of areas remote from large urban centres are the three conclusions yielded by demographic forecasts.

THE ECONOMY

The Québec economy is diversified and substantially outward oriented, ensuring a very high standard of living to its residents. In total, Québec's 2001 gross domestic product exceeded $230 billion in current dollars. Over the course of recent decades, while pursuing its evolution toward a services-based economy, a growing part of Québec's economy has been built on emerging new technology sectors (biotechnology, aeronautics, and information technologies).

The sensitivity and vulnerability of Québec's economy to climate change is a function of the size of the sectors most liable to be affected, either positively or negatively, by changes to temperature and precipitation. Obviously, these sectors include forestry, agriculture, and hunting and fishing, the exercise of which may be directly affected by the climate, either in the short term or cumulatively. In total, these industrial activities represent output worth over $3.8 billion. One must also account for electricity generation, which depends largely on precipitation in the form of snow and rain, and amounted to $7.8 billion in 2001, and energy consumption for heating and air conditioning that represent several billions of dollars annually. We must also consider industries based on the transformation of natural resources, such as agro-industry, wood products, pulp and paper, as well as the primary processing of metals—which could also be affected to some extent owing to changes in the availability and cost of commodity inputs and energy—with output worth over $13 billion annually.

As to industries providing services to the population, they are liable to operate under altered circumstances and be faced with greater and different needs. Thus, winter and summer recreation and tourism activities, for which restaurants and lodging represent sales in excess of $4 billion, could benefit or be hurt depending on their ability to build on the changing climatic conditions in Québec. Health and sanitary services could also be substantially affected. Other industries may be impacted, especially road and maritime transportation. Finally, financial services—notably insurance—will need to adjust to a greater frequency of some types of extreme meteorological events, which will translate into greater uncertainty and higher costs for claim compensation.

In summary, a significant part of Québec's economy will be directly or indirectly affected by climate change. In those regions in which the extraction of natural resources plays a large role, an even greater share of economic activity will be threatened. Nonetheless, it should be borne in mind that these impacts will also be felt in neighbouring, and competing, economies, which may bear on the direction and the magnitude of the anticipated changes' real incidence on Québec.

THE REGIONS FROM THE PERSPECTIVE OF CLIMATE CHANGE

The characteristics of the topography and geological formations, of the climate and vegetation zones, and of the population, the economy, and employment lead us to consider the issue of climate change in Québec from the perspective of four distinct regions: Québec's Arctic Region, the Resources Region, the Maritime Region, and the Southern Quebec Region (see Figure 13). In each of these regions the impact of climate change is liable to be felt differently, owing in part to variations in its extent, but also to the distinct manner in which the natural and human environment will react to it.

The **Arctic Region** will probably experience the greatest changes in terms of the climate and alterations to the environment, especially with the expected melting of a large proportion of the permafrost. Even though the affected population is small, constraints inherent in their remoteness, geographic dispersal, and the climate will render the adaptation process complex.

Further south, in the **Resources Region** of the Laurentian Plateau blanketed by coniferous forests, the potential impact of climate change on large reservoirs and extensive forestry operations will be far-reaching, for Québec as a whole and for the inhabitants of this region. The vastness of this territory makes it necessary to account for climate phenomena unique to each sub-region or watershed.

As for the **Maritime Region**, rising sea levels, the shortening of the freeze-up season, and the possibility of more intense storms could exacerbate the problem of coastal erosion. Like the population, the transportation axes and economy of this region are highly concentrated on the rim of the Saint Lawrence Estuary and Gulf, thus multiplying anticipated impacts.

Québec's Southern Region, located in the lowlands of the Saint Lawrence and the Appalachians and home to the vast majority of the population and a very diversified economy, will be affected in various manners. The rich and complex ecosystems of the Saint Lawrence are liable to be significantly impacted. The health of humans will be challenged by more frequent and intense heat waves, new vector-borne infectious diseases, changes to air quality, and increased risks in the provision of water. Some industries, such as agriculture, transportation, and tourism, will need to re-examine how they do business so as to reduce costs brought on by climate change and to take advantage of opportunities that may arise.

Figure 13

The regions of Québec from the perspective of climate change
(Ouranos, 2002)

(Ministère des Ressources naturelles, de la Faune et des Parcs)

QUÉBEC'S ARCTIC REGION

Québec's Arctic Region, which extends north of the 55th parallel, includes about 20 per cent of the area of Québec. It is entirely located within Nunavik. The population—mostly native and numbering approximately 10,000 individuals—lives in about fifteen villages dispersed along the shores of Hudson Bay and the Arctic Ocean. This is probably the region that will most strongly feel the effects of climate change and environmental modification, notably because of the likely melting of most of the permafrost, which is continuous north of 60° N.

PERMAFROST

Permafrost exists because of the climate which also affects its thermal regime. Present in rocky and various loose soils, and consisting mostly of an unstable mineral, ice, permafrost is also a geological phenomenon.

Permafrost is defined as: *all soil or rocks whose temperature remains below 0° C for at least two consecutive years* (*Associate Committee on Geotechnical Research*, 1988). Indeed, this thermal state nearly always lasts several hundred years. Each year, the upper level of the soil, called the active layer, thaws and freezes again during the cold season. The depth of the active layer in any given year (the maximum depth of thaw penetration) depends on the degree of warming of the atmosphere in the summer. The interface between the active layer and the permafrost is called the *ceiling* of the permafrost.

Within the frozen soil temperatures fluctuate with the seasons. Collectively, the temperature changes affecting the active layer and the permafrost are called the *permafrost thermal regime*. For permafrost to persist, the mean annual temperature on the soil's surface must be equal to or below 0° C. Depending on surface conditions, which reduce heat lost from the soil through contact with the atmosphere (a snow cover that partially isolates the soil in winter, plant cover, the organic horizon, and humidity), the mean air temperature must generally be several degrees below 0° C for the mean annual temperature of the soil to be 0° C.

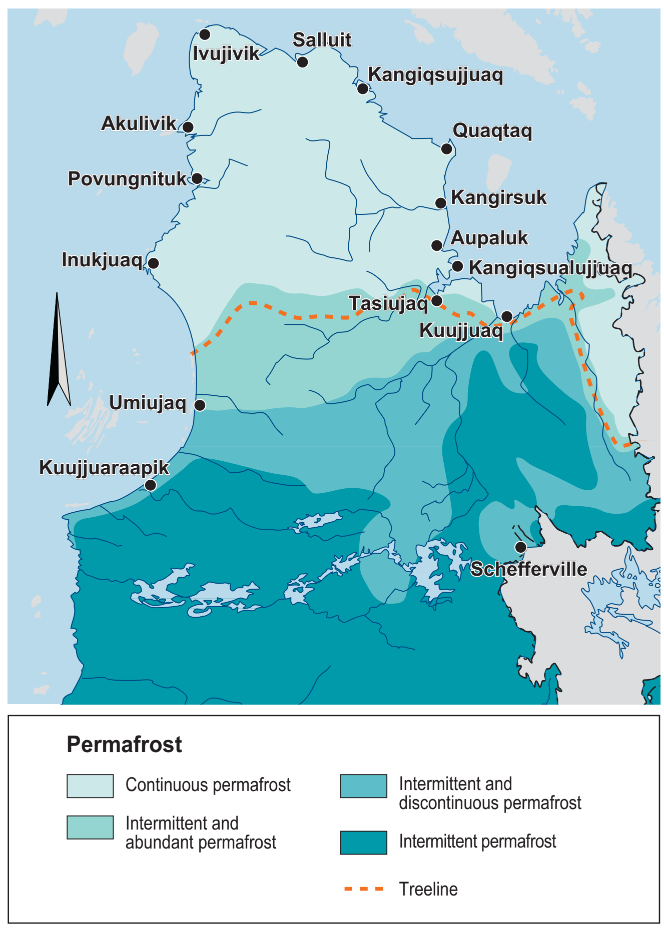
As a foundation material, permafrost is very solid: The ice and the soil-ice mixture are able to support very large loads. To date, the principles of building and laying foundations for infrastructure have mostly been based on keeping the soil frozen. For example, raft foundations are constructed to raise the ceiling of the permafrost, the space under buildings may be ventilated to keep the heat emitted by the building from being absorbed by the neighbouring soil and, sometimes, specialized refrigeration techniques are used to cool the soil under the building (*Associate Committee on Geotechnical Research*, 1988).

The situation in Québec

Permafrost covers a vast area of Québec's territory (Figure 14). At its southern edge it is discontinuous, i.e. appearing in variably-sized patches, since the temperature is slightly less cold and the surface features are highly irregular.

Figure 14

Permafrost (Allard et Séguin, 1987)



These intermittent stretches, in which permafrost is near 0° C and relatively thin (at several tens of meters), essentially coincide with the ecological zone of forest tundra, but spread beyond a little into the north of the boreal forest (Allard and Séguin, 1987). In the continuous zone, which globally corresponds to the tundra, there is a strong north-south gradient (thus, mean annual air temperatures range from –4.5° C at Kuujjuaq to –9° C at Salluit, approximately). The thickness of the permafrost varies between several tens of meters in the south to several hundred meters in the north. This gradient is reflected in soil temperature measurements (see Figure 15).

Figure 15 illustrates soil temperature profiles in two northern villages, Salluit and Kangiqsujuaq. It also reveals that the profiles measured in 2001 and 2002 were warmer than those observed during the 1990s—the last decade featuring a significant warming (Allard *et al*. 2002).

In terms of geology, the northern area mostly lies on the rocks of the Canadian Shield and sandy and gravely glacial deposits (tills and fluvioglacial drift). In the rocks, the permafrost generally contains little ice (within its structure), so that its melting generally has a very limited impact. In the tills and fluvioglacial drift, the ice of the permafrost is predominantly interstitial ice, such that its melting usually causes little perturbation.

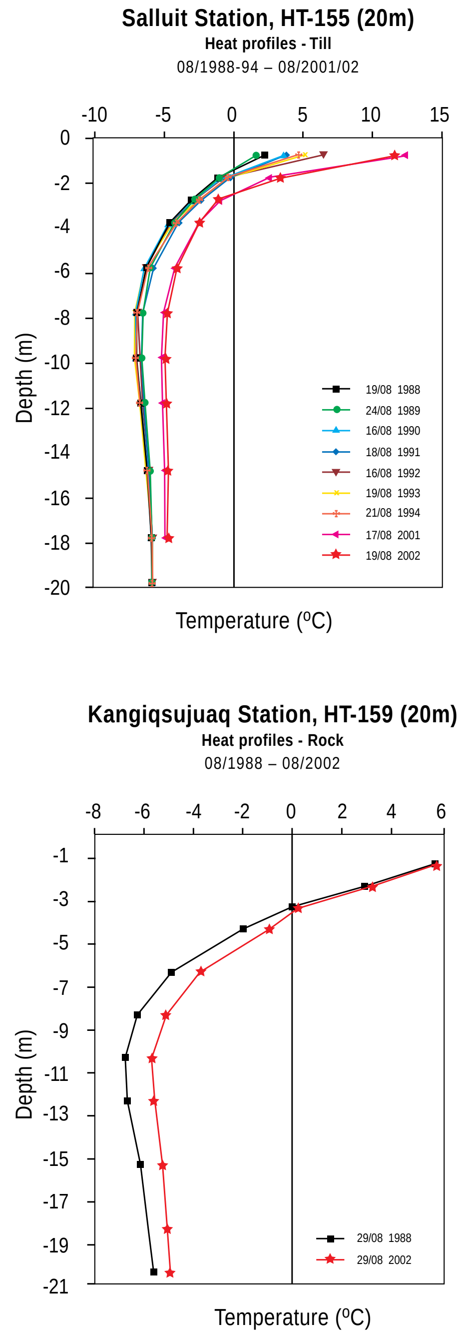
On the other hand, in the costal regions in which all the villages are located, the soils are clayey, silty and sandy, and their stratigraphic arrangement and sedimentological composition vary greatly from one place to the next. These fine-textured soils generally have a high concentration of ice, especially segregated ice.

Expected impacts

Warmer winter temperatures and the increased thickness of the snow cover (resulting from greater precipitation), as well as the rise in summer degree days, will raise the temperature of the permafrost. Over a short period (three to five years), and with a slight rise in temperatures (such as an annual mean increase of several tenths of a degree), surface factors will smooth the changes and slow the thawing a little. However, in the long term, or in the event of a faster rise in temperatures, the transfer of heat from the atmosphere to the soil can only result in a melting of the permafrost. In areas in which the permafrost is relatively thin and its temperature near 0° C, this thaw could be very rapid, being slowed only as the latent heat is absorbed by melting ice. Where it is thicker, the winter freeze will eventually no longer penetrate to the ceiling of the permafrost, and on slopes compaction of the soil and landslides may occur.

Figure 15

Soil temperature gradient at two arctic stations
(Allard *et al*, 2002)






Moreover, the approaches used thus far in the area of construction and on which the stability of the existing buildings depend will no longer be sufficient to ensure the permanence of the permafrost, creating risks to the current stock of infrastructure, residences, and other buildings. Furthermore, new construction and development will henceforth need to account for the warming of the climate and the inevitable degradation of the permafrost that will ensue.

The villages of Nunavik will not all be exposed to the same level of risk. Villages that are partly or totally built on clayey soils with a high ice content may be vulnerable to more severe damage and will require mitigating and adaptation measures in the next few years. Salluit presents the most difficult case in this regard. Other villages are located on terrain that may prove problematic. However, it should be borne in mind that in most cases these problems are linked to the presence of one or two sensitive soil zones within a given sector. Nonetheless, these sensitive sectors may require relatively expensive geophysical surveying and drilling activities to allow them to be identified and delimited.

The consequences for the villages are related to large buildings, such as schools, community centres, and other public structures. A significant impact has to do with residential construction rendered necessary by high population growth. In order to limit the cost of these interventions, better urban planning than that applied today needs to be developed and based on an adequate understanding of the local permafrost conditions. It may also be necessary to improve construction techniques for raft foundations and drainage systems.

It is also foreseeable that the landing strips serving three villages will require remedial work, and in one case major renovations, which may extend to redesigning their layout, along with periodic resurfacing. The other runways will need increased surveillance.

The expected lengthening of summers will result in a thickening of the active layer, causing melt water to be released at the end of the season and generating internal pressures that may create fissures in the active layer and retrogressive slipping. This degradation of the permafrost will have ecological impacts that have scarcely been documented to date: affecting the turbidity of waterways, creating numerous lakes, swelling marshlands, and changing vegetation—especially a transition from moss and lichen heath to scrubland. These processes are liable to affect the hydrological regime of many watersheds. In conjunction with the ecological changes affecting plants and animals, the degradation of the permafrost will in all likelihood contribute to a significant redesign of northern ecosystems.

Impacts on the population

These changes to the arctic environment will also have consequences for native populations living north of the 55th parallel. Thus, the displacement of communities brought on by damage to infrastructure resulting from the melting of permafrost could create psychosocial stresses. Issues related to nutrition attributable to ecosystem impacts could also come into play. However, climate warming may also result in a shift of certain populations of animals and plants toward the north, thus increasing the food diversity available to these populations. Warming could also extend the hunting and fishing seasons, which would increase the quantity of traditional foods available for consumption by native populations. However, modifications to the distribution and stability of the ice and in the composition of the snow, especially in the Arctic Region and northern zones, could lead to more deaths and injuries owing to accidents occurring during travel on the pack ice.

Adaptation strategies

In order to minimize the impacts of the expected changes to Québec's arctic climate, it would be necessary to conduct thorough studies throughout the north before initiating any construction projects—these should include temperature measurements and an evaluation of the changes that will occur as a result of climate change. Collecting a broad series of borehole samples (frozen core drilling) and temperature readings will be required for a proper understanding of the permafrost conditions. In natural zones, even inland, on tills and sandy deposits, surprising discoveries could be made: For example, there could be tills with a fine-grained soil matrix rich in ice, fissured or stratified rock containing ice, frozen organic soils, or zones in which seepage from the water table is frozen.

The measures and practices to be undertaken will focus on built-up areas and eventual large industrial projects. Impacts on the natural environment are difficult to identify with precision. They do not impose immediate costs, but the environmental changes they cause may eventually create indirect costs for construction of hydroelectricity generation stations. There again, gathering detailed information on the evolution of the conditions of the permafrost is important.

Finally, and more specifically, the expected costs to communities and their financial backers (for example, claims for moving buildings and homes as well as litigation) associated with adapting to a warming climate could be reduced by taking the following steps in areas covered by permafrost:

- Conduct a study of the condition of the permafrost in each community. For cases presenting no apparent problems, such a study could consist of a few hours of verification and questioning of the population. Salluit is already being studied. The methodology developed for this study could be applied to other communities.

- Maintain a climate and temperature monitoring network. A considerable part of this network is already in place following the construction of the airports between 1987 and 1992. Four sites remain to be equipped: Kuujjuaq, Kangirsuk, Ivujivik and Inukjuak. Repairs to the installations are required in several places.

- Analyses of the readings and time series of data in terms of climate scenarios, in the form of calculations or the application of a heat transfer model, will allow potential problems to be anticipated. These measurements and computations will allow local thresholds to be identified beyond which temperature changes will endanger the installations.

- Finally, construction standards adapted to northern climes in terms of the landscape, soils, and climate changes must be elaborated.

THE RESOURCES REGION

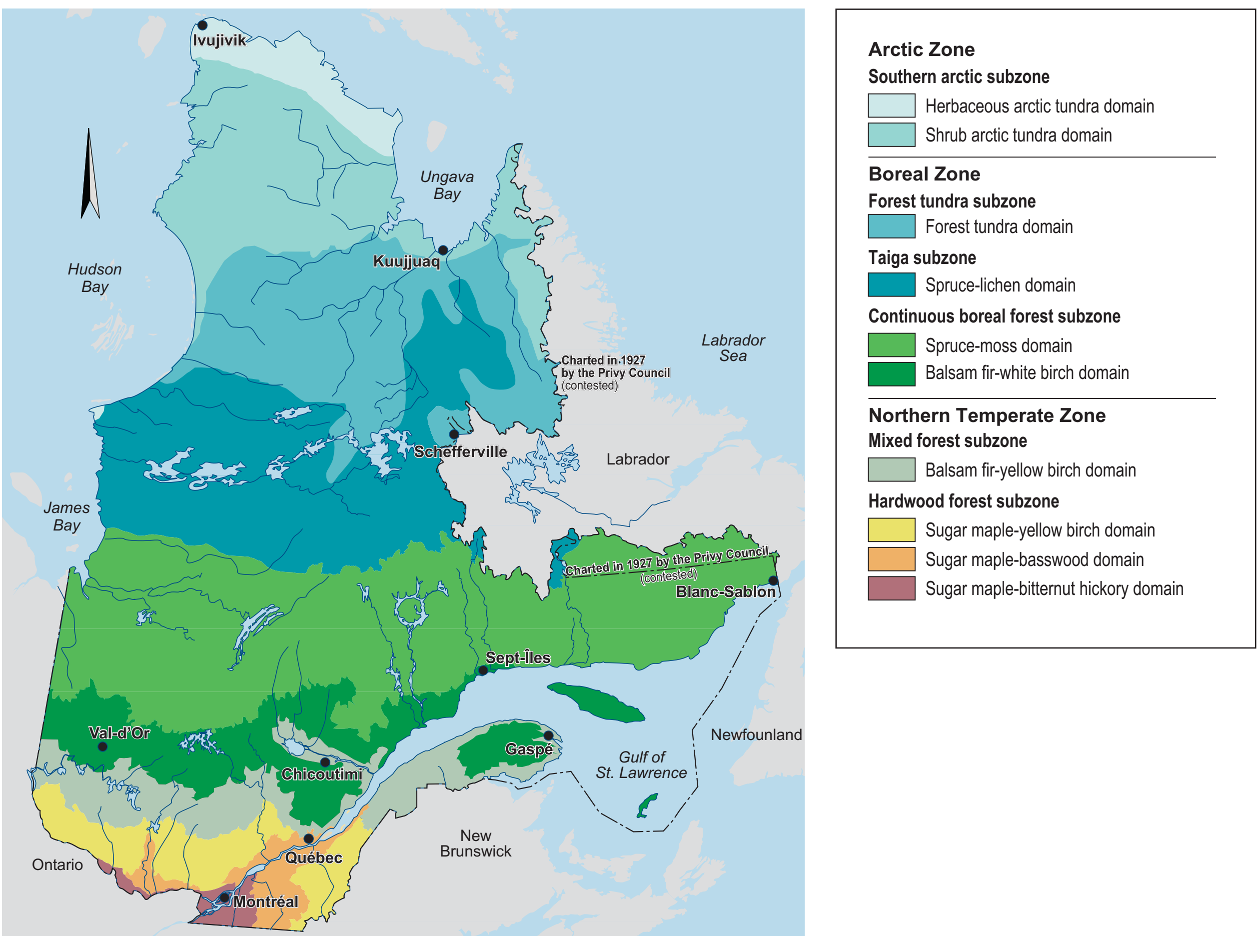
Further to the south, the Resources Region covers half of Québec's territory. Primarily located on the Laurentian Plateau, it consists mostly of coniferous forest, or taiga, and is home to over 500,000 inhabitants. The potential impact of climate change on the vast hydroelectric reserves and extensive forestry operations bears vital significance for all of Québec, and not least for the population of this region where the economy is intimately linked to resource exploitation.

FOREST

Forest covers around half of Québec's territory, or 757,000 km^2. The forested zone extends over seven degrees of latitude, and so it is not surprising that it comprises three very different broad bioclimatic zones, which are largely reflected in the diversity of the forests. From north to south, we have the boreal forest, the mixed forest, and the southern forest.

Figure 16

Forest zones
(Ministère des Ressources naturelles, de la Faune et des Parcs, 2003)



The taiga makes up 73.7 per cent of Québec's forests. It consists mainly of balsam fir, black spruce, white spruce, jack pine, and larch. The only deciduous trees growing here are the white birch, trembling aspen, and the balsam poplar. As to the mixed forest, it harbours both coniferous and deciduous trees. Finally, the southern forest is dominated by hardwoods. The most abundant are the sugar maple, the yellow birch, and the beech, but one also finds black cherry, basswood, three species of oak, three of ash, two of hickory, three other maple species, and two poplars. The southern forest also contains some softwood species, such as the white pine, red pine, hemlock, and cedar.

The forest underlies the economic activity of many communities, whether for the production of lumber, pulp and paper, or biomass. It provides a living environment for local populations and natives. It is host to a very large number of animal and plant species and makes an essential contribution to Quebeckers' lifestyle by providing a setting for outdoor recreational activities, such as hiking, hunting and fishing, camping, and vacationing.

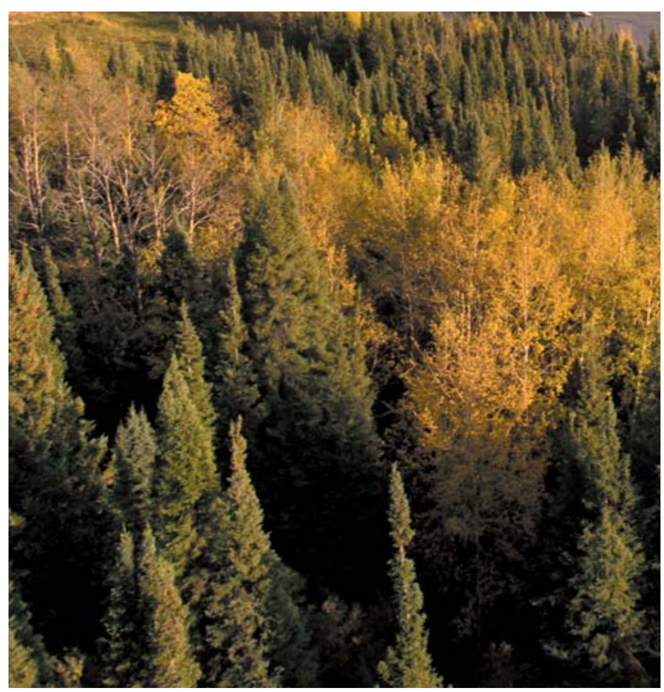
Expected impacts

In addition to defining the forest landscape, the climate has an impact on most of the metabolic processes of trees, such as growth and reproduction, and soil processes, such as mineralization. To varying degrees, it also plays a role in the frequency and intensity of forest fires, insect infestations, disease, and the occurrence of extreme weather events.

A warming of summer temperatures by 0.15° to 0.5° C per decade, accompanied by a moderate increase in precipitation in some regions, can be expected to affect the health and growth rates of trees. Several studies have shown that increased temperatures should have a positive impact on the growth (Courchesne, 2001; Brooks, 1998) and productivity of some species (Churkina and Running, 2000). Conversely, it has been established that colder and more humid conditions favour the growth of the black spruce (Brooks, 1998). Similarly, higher CO_2 concentrations could assist the growth of certain tree species by increasing the efficiency with which they use water, but the overall impact on Québec's species remains to be established. According to these authors, the expected effect of increased CO_2 varies between nil and very beneficial, depending on the species and the stage of development. Overall, increased CO_2 concentrations will favour, in decreasing order, annual herbaceous species, perennials, and broadleaf and coniferous trees—younger trees benefiting more than older ones (Korner, 1993). Conversely, the availability of water is a limiting factor in the productivity of several species. A study conducted in western Québec (Hofgaard, 1999) revealed that higher precipitation levels in June of the current and previous year had a positive effect on the growth of the black spruce.

In theory, in the medium to long term this should translate into a competitive edge for some species, while others will be negatively impacted by the combined effect of more precipitation and higher temperatures. Thus, overall, a shift of the temperate mixed forest into the range of the boreal forest, and of the boreal forest into the subarctic region, is to be expected (Rizzo and Wilken, 1992). Some of these changes may become apparent in the ecotones. The migration of species will be highly variable, and will run into significant obstacles, such as the composition of the soil and humidity conditions. We may be able to observe some of the first signs of this migration on the local scale—specifically, by cataloguing the species best adapted to the new climate conditions at the regeneration stage.

On the other hand, the aforementioned assumptions may prove utterly misguided when we account for the impact climate change may have on insects, disease, and forest fires. In particular, we may find an increase in the intensity of infestations in the case of some insects, such as the spruce budworm (Jardon *et al*., 1994). There is also some concern about the combined impact of changes to heat, precipitation, and CO_2 concentrations on the frequency and extent of forest fires (Flannigan *et al*., 2000). Depending on the period examined, not all studies conclude that there will be a higher fire risk, but increased dryness in conjunction with more frequent storms would normally be expected to result in a greater number of forest fires. Also, the condition of the vegetation after disease and other disturbances may affect their magnitude (Bergeron and Leduc, 1998). Conversely, according to specific Québec studies, the frequency of fires will be reduced in a warmer and more humid climate (Bergeron *et al*., 2001).



Climate models predict that the warming will be relatively more pronounced in winter than in summer, which will increase the damage to trees. Sustained cold temperatures in winter, combined with a snow cover and the absence of rain, is good for trees, in contrast to winters characterized by alternating periods of intense cold and thaws and the absence of snow on the ground—a situation that can arise anytime if precipitation often falls as rain, exposing young plants and roots to freezing temperatures. In particular, species that are sensitive to thaws, such as yellow birch (Zhu *et al*., 2002) and white birch (Cox and Malcolm, 1997), could show signs of decline. Finally, the warming of winter temperatures could favour the growth of some insect pests, while others may be at a disadvantage because of the decline in the snow cover.

Also, an increase in the frequency of extreme climate events could also disturb the growth of forests, as is witnessed by the significant impact of the 1998 ice storm, which particularly devastated the region of maple stands. Elsewhere in the world, one is reminded of the violent winds that swept over France and destroyed many mature forests. Extreme events (heat waves, droughts, winter thaws, and late freezes) may create more serious problems than those caused by a slight change in the mean temperature (Flannigan, 1998; Cox and Malcolm, 1997).

One forestry industry that is sensitive to climate change is maple syrup production. In fact, it relies on daytime thaws alternating with cold nights. Production in some regions would be drastically cut if successive day- and night-time temperatures remained above zero as of the beginning of the sugaring-off season. This problem has also been identified in New England as a potential fallout of climate change.

In summary, the impacts of climate change on tree growth, when all factors (especially the incidence on forest fires, insects, and disease) are accounted for, could be very substantial. The forestry industry is such a key part of Québec's economy that any impact of climate change on the forests would necessarily have considerable repercussions on Québec society. However, many factors need to be considered here, such as the impact on competing producers, technological change, and the evolution of the demand for products from the forest. Since the principal negative impacts are expected to take some time to materialize, the industry should take this opportunity to develop forest management and resource allocation strategies that will help it adjust to new situations.

Adaptation strategies

A wide variety of adaptation strategies are available, involving forest management practices that account both for increased precipitation and rising temperatures. The choice of species (Carter, 1996), favouring those species or genotypes most resistant to climate change, may be of paramount importance. The harvesting methods used may also have an effect on how the forest reacts to climate change, by benefiting the spread of species more adapted to this type of environment and altering the natural availability of seeds of species liable to migrate. Finally, adapting firefighting strategies to account for the desired goals is essential.

Strategies should be adopted to reflect the various environmental, social, and economic circumstances. For successful adaptation it is essential that the industry take into consideration the results of research efforts. It is indicated, in particular, to examine the impact of climate change on species with longer crop-rotation cycles and those more vulnerable to suffering the full effect of the changes.

Our grasp of the impact of climate change on forests is currently patchy and incomplete. Studies on some plants' reactions to environmental change have been conducted, but their response in the natural environment and under competitive pressures from other species remains to be seen.

Much is yet to be learned on species' migration. Indeed, it would be necessary to know the impact of climate change on every species at each stage of development (seedling, sapling, etc.), as a function of such parameters as temperature, the maximum rate of change, the threshold of tolerance, and the metabolic processes at stake (photosynthesis, dark respiration, sexual reproduction, competitive ability at the stage of regeneration, etc.). Furthermore, the contribution of Québec's forests to the carbon balance and to climate change, as a source of emissions and potentially as a carbon sink, should also be the subject of more detailed studies.

HYDROELECTRICITY GENERATION

Electricity generation occupies a key place in Québec's economy, making up nearly four per cent of gross domestic product, and accounting for between five and twelve per cent of total investment over the past decade. Also, this resource has allowed Québec to enjoy a low priced supply and has been a major contributor in attracting several large exporting industries, such as aluminium and pulp and paper.

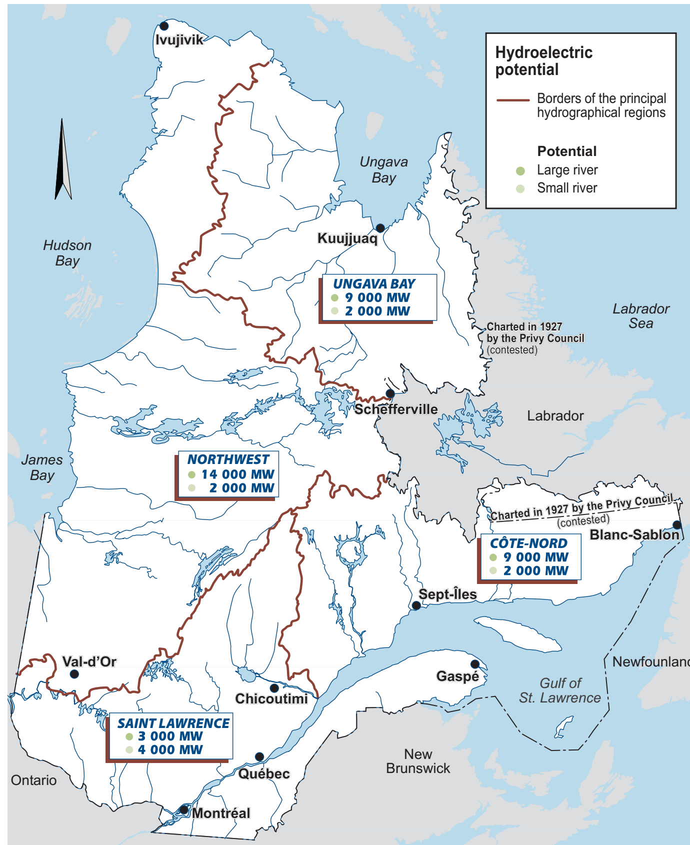
Québec has at its disposal an installed electricity capacity of over 40,000 megawatts (MW), which supplies more than 41 per cent[10] of its total energy requirements. Ninety-four per cent of electricity generation is from hydroelectricity stations. More that 80 per cent of installed hydroelectric capacity is located north of the 49th parallel, in the Resources Region. Over this vast territory, 95 per cent of installed capacity makes use of the storage potential of reservoirs that can hold one or several years supply, while in the south 95 per cent of capacity is comprised of run-of-river facilities. This particularity makes it important to distinguish between the impact of climate change on power plants with a reservoir and those that are run-of-river.

Clearly, it is important to determine the impacts of climate change on the currently installed generation capacity. It is also important to account for this when planning future installations, since the time-frame for the evolution of the climate corresponds entirely with the planning horizon for large hydroelectric stations. Québec still has a theoretical potential of 45,000 MW, much of which could be added to current production. This potential is divided between large rivers (with a potential of 100 MW and over), totalling about 35,000 MW, and small rivers (under 100 MW), which account for about 10,000 MW. Figure 17 presents the remaining hydroelectric potential that can theoretically be developed, by watershed.

The impact of climate change on the evolution of internal and external energy demand are dealt with in the section "Energy demand." However, it is worth bearing in mind that hydroelectricity presents enormous benefits compared to the use of hydrocarbons from the perspective of reducing greenhouse gas emissions. Hydroelectricity is thus an energy source that should be used and developed to its fullest potential. A discussion of internal demand scenarios and the business opportunities presented by foreign markets falls outside of the scope of this document. Nonetheless, it is self-evident that, in this context, any adaptation strategy should account for the level of the development of generation capacity and the expansion of internal and external markets.

Figure 17

Hydroelectric potential
(Ministère des Ressources naturelles, de la Faune et des Parcs, 2003)



Expected impacts

Global climate models predict that, by the end of the century, mean temperatures in northern Québec will increase by about 4° to 5° C in the winter and 2° to 3° C in the summer, thus causing the period of freezing to be shortened and the rate of evaporation and of evapotranspiration to increase during the period of free water. This increase in water loss to the atmosphere should, however, be compensated by a significant rise in precipitation: 10 to 25 per cent in winter and 5 to 10 per cent in summer. The hydrological balance derived from these global models thus points to greater inflows into the reservoirs of northern Québec.

10 In 2002, the share of electricity in total energy consumption excluding biomass was 41 per cent, and 37 per cent if biomass is accounted for.

These positive results must, however, be taken with a grain of salt. Global climate models are hard pressed to accurately capture climate conditions in northern Québec, surrounded as it is by water and subject to highly changeable circulation patterns. In addition, their spatial resolution of only 400 km does not allow the Great Lakes, Hudson Bay, Greenland, and other geographical features that may have highly differentiated impacts on the various regions of Québec to be adequately accounted for.

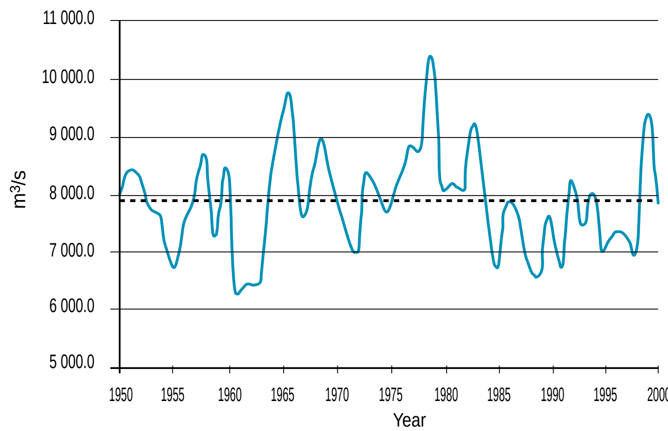
Figure 18 presents the mean annual natural inflow, in cubic metres per second, into the developed watersheds of the Resources Region for the years 1950–2000. We observe a great deal of fluctuation about the historic mean water supply attributable to variations in the climate. We also observe that the inflow in every year since 1985 was generally below the annual average. However, global climate models do not indicate a downward trend for that period. Rather, this recent downward trend seems to be correlated with some global climate indices, such as the North Atlantic Oscillation (NAO, discussed in greater detail hereafter) and other general circulation indices. These climate indices correspond to weather models that are, unfortunately, not yet well understood or simulated by global climate models.

It is likely that climate change will have an incidence on weather regimes. The increase in runoff predicted by global climate models is less than one standard error (1961–1990), and could thus be cancelled by the natural variability of weather regimes that remain imperfectly modelled and understood. These systems appear to affect the various regions of Québec differently, and are most notable in the north. Other types of variability caused by local factors in conjunction with global changes to weather regimes could increase water inflows in any given region. For example, a prolonged absence of ice on Hudson Bay would promote inflows in the northwestern part of Québec. Thus, it is important to make the serious effort required to better understand the factors that contribute to variations in runoff and to develop tools and models allowing for a finer spatial resolution of the various phenomena so as to forecast the climate of Québec's different regions over the upcoming decades.

As for southern Québec, it appears more certain that the increase in temperatures on the order of 2° to 3° C in summer and 3° to 4° C in winter will cause a significant increase in evaporation and evapotranspiration, with serious consequences for the availability of water in the Great Lakes watershed and in the region as a whole, and thus reducing the quantity of water available to drive the turbines of hydroelectric plants on the Saint-Lawrence. The expected increase in precipitation of 0 to 5 per cent in the summer and 10 to 20 per cent in the winter will be insufficient to compensate for these losses.

Figure 18

Annual mean inflow from developed drainage basins in the Resources Region (Hydro-Québec, 2003)



Seasonal changes

In the north, warmer winter temperatures will allow the annual reservoirs to be filled with liquid precipitation until later into the early winter, while the spring thaw may arrive sooner and be less voluminous. On an annual basis, the new climate regime will thus have a greater natural regulating effect and could force a review of reservoir management methods.

In the south, the regulating effect of increasing temperatures in winter and spring could also be beneficial, in light of the fact that the power plants in this region are run-of-river. Indeed, a later onset of winter and an earlier spring would allow these power plants to be used to greater capacity during a period in which generation is limited by the availability of liquid water and by constraints imposed by ice in the rivers. This shortening of the winter season should also allow better management of high waters, the volume of which will be reduced despite the slight increase in winter and spring precipitation. This will help to limit the unproductive release of excess water and spring floods affecting waterfront properties near hydroelectric facilities.

Increased temperatures in early winter should also have effects on the productivity of run-of-river stations. Indeed, for this type of station it is important to have an adequate ice build-up upstream from the hydraulic installations at the beginning of the winter. A smooth ice cover for the water to flow under improves the yield of the adjacent plant by reducing the effect of friction. This constraint sometimes means that the power plant must reduce generation for several days. However, if a freeze/thaw cycle causes the formation of the ice cover to be repeated, the generation of hydroelectricity could be impacted over a longer period of time. Moreover, more frequent alternation of freeze/thaw periods could, in some cases, create more problems with frazil ice and affect the management of the stations.

Increased extreme precipitation events

Though the level of uncertainty remains high, it seems that we can reasonably expect an increase in the frequency of extreme events. In northern Québec, extreme hydrological events could result in more frequent unproductive releases of excess water. Of course, the economic consequences of these releases are important, but they should not affect the integrity of the facilities or threaten surrounding populations. In the south of Québec, however, the greater population density along the shores and the presence of run-of-river stations mean that more care will be required.

Adaptation strategies

The great uncertainty regarding the long term supply of water in the Resources Region does not make a quick implementation of short- and medium-term adaptation measures practicable. For each of the hydroelectricity generation zones at issue, the first requirement is to work on improving climate scenarios so as to better understand the consequences for the hydrological regime.

Even if it should prove that, overall, inflows remain similar or increase slightly, it is likely that the distribution over space and time will be significantly affected. For regions that will benefit from greater inflows, it would be of interest to examine the possibility of adding capacity to existing stations. This consideration could also make development more attractive in some regions that are liable to see their hydraulic potential rise. On the other hand, a decline in inflows will make it necessary to plan for new generating facilities or to implement demand management measures.

Strategies for water storage and management for existing installations and for the construction of new facilities should account for the new climatic conditions. They should also account for the global and regional economic environment, and adjust to the evolution of target markets. As mentioned above, hydroelectricity is a high value source of energy for reducing emissions of greenhouse gasses locally and globally. The various scenarios that can be envisaged for using this resource will thus have a determinant impact. For example, a strategy designed to primarily meet heating needs will necessarily differ from one developed to accommodate air-conditioning requirements at home and abroad.

Extreme events

In the Resources Region, the holding capacity of the reservoirs and the spillways next to stations, in conjunction with management based on stringent safety standards, allow the consequences of extreme hydrological events to be minimized. In the south, where population densities near these installations are much higher, these preoccupations assume more importance. Clearly, the high safety standards by which hydroelectricity plants are managed in Québec will provide protection against this rare type of event. If, however, the frequency of intense storms—characterized by brief but torrential downpours—were to increase, that would doubtlessly constitute a reason to re-evaluate the management of water resources so as to maintain the level of safety of the affected facilities.

As to transmission networks, the experience acquired during the ice storm in southern Québec in 1998 has already provided the occasion for an examination of the criteria for designing a less vulnerable power grid.

New hydroelectric facilities

It is important to conduct a detailed analysis before adding new generation facilities in any region. Climate change is liable to increase or decrease the availability of water to these future power plants, whose useful life makes them vulnerable to these changes. The very design of these installations should account for the impending changes. If the annual volume of water inflows is likely to increase, the capacity of the generation equipment should be adjusted. With respect to storage capacity, a more regular annual hydrological regime could lead to a reduction in their dimensions.

The current state of knowledge

Clearly, the impact studies that need to be conducted before designing adaptation strategies in the area of hydroelectricity generation will benefit from an expansion of our knowledge in the various fields targeted over the course of the coming years. In light of this, several cooperative ventures have already been launched with the university community and very high-calibre scientific expertise is gradually being mobilized around the issue of climate change.

The quality of the forecasts of impacts on hydroelectric generation from eventual changes to the climate is intimately linked to the precision of the climate scenarios used. As we discussed above, it is essential to have access to high-resolution climate change scenarios, generated by dynamic or statistical models, so as to be able to form the most precise estimates possible of the effects of climate change at the level of the watershed. Thus, we must focus our efforts on developing these climate simulation tools (Yarnal *et al*., 2001).

Another interesting path to pursue consists of analysing the links between historical hydrological conditions and the broad patterns of atmospheric circulation. In this context, the North Atlantic Oscillation (NAO) merits a more detailed examination. The NAO is an atmospheric and oceanic phenomenon primarily affecting the North Atlantic. The NAO index is computed annually from the pressure difference between Lisbon (Portugal) and Reykjavik (Iceland) by taking this value with respect to the mean from January to March over several years. We speak of an oscillation because there is a to and fro, from north to south, between the arctic and Icelandic region and the subtropical belt near the Azores and the Iberian peninsula. Recent work has shown a link between the NAO and the thermal regime in the Great Lakes region and in the north-eastern United States and Canada (Wettstein and Mearns, 2002).

When the NAO index is positive, as has usually been the case since the beginning of the 1990s, northern Canada and Greenland tend to have winters that are rather cold and dry. Ouranos' observations on snowfall in the Resources Region for this period corroborate this hypothesis, according to which a positive NAO index translates into years in which natural water inflows are generally low (cf. Figure 17). It thus appears possible to establish a link between the NAO and the annual hydrological regime of these systems. It would now be of interest to study the effect of climate change on the NAO and possibly on other indices linked to general circulation patterns in the atmosphere.

The role of wetlands in the hydrological balance

In terms of the northern water systems, a substantial effort will be required to better understand the role played by wetlands. Though varying from one region to the next as a function of topography, bogs cover about 15 per cent of the total surface area of the boreal region—roughly the same percentage as that occupied by lakes. When other wetlands, such as riparian zones, are included, over 50 per cent of some regions is wetlands and aquatic ecosystems. Given the vast extent of all these wetlands in northern Québec, it is essential to understand their evolution in light of past and future climate changes (Payette and Rochefort, 2001).

Extension of climatological and hydrological series

Given the relative shortness of the period in which instrument readings have been taken of flow rates in the Resources Region, the extension of these series into the past using derived data (paleo-indicators) may allow us to better anticipate the impacts of climate change in the future. For example, tree-ring chronology allows us to reconstruct some historical climatic and hydrological parameters and better understand the climate-hydrological dynamics under various climate systems, some of which may be similar to those anticipated in a climate change context (Bégin, 2001).

THE MARITIME REGION

The coastline of Québec's Maritime Region is quite long, extending from the mouth of the Saint Lawrence estuary downstream of Québec city to the Îles de la Madeleine in the Gulf of Saint Lawrence. Several large population centres are found there. Indeed, for Gaspésie, the Îles de la Madeleine, the Bas-Saint-Laurent, and the Côte-Nord, all of life is intimately linked to the sea. This vast Maritime region, home to nearly 400,000 inhabitants, merits particular attention from the perspective of climate change, to the extent that it will directly and indirectly be affected by rising sea levels and by the intensification of storms that may, among other things, exacerbate problems of coastal erosion. Indeed, climate change is expected to translate into rising sea levels owing to the expansion of water as it warms and the melting of glaciers and the ice caps, and into an increase in violent climatic events.

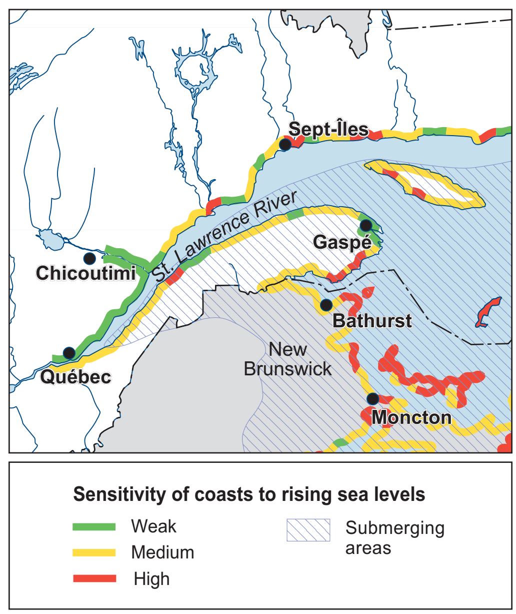
COASTAL EROSION

Coastal erosion is a natural phenomenon. It is the result of wave action, currents, ice, river flows, and human activity. The Côte-Nord, Gaspésie, and Îles de la Madeleine regions are particularly affected. Several municipalities are directly vulnerable, and potential damage to buildings and infrastructure may attain several hundred million dollars. In Figure 19, the sections of the Québec coast most sensitive to coastal erosion are indicated in red. The zones of medium vulnerability are in yellow. As we see in the figure, a large proportion of Québec's coast is vulnerable, especially that in the hatched section of the map, corresponding to isostatic submerging areas.

On the north shore, from Tadoussac to Blanc-Sablon (including the île d'Anticosti), over a 1,825 km stretch, 38 per cent of the shore is moderately sensitive to erosion and 28 per cent is very sensitive (Dubois, 1999). In the highly eroded zones, the rate of loss is one metre per year, and one can observe up to ten metres per year.

Figure 19

Zones sensitive to coastal erosion
(The Atlas of Canada, 2003)



In the Bas-Saint-Laurent and Gaspésie regions, nearly all coasts are moderately or highly sensitive to erosion. There are already 112 km of works protecting the coastline against erosion in Gaspésie between Sainte-Anne-des-Monts and Carleton. In addition to Route 132, which is protected over 62 km, some municipal roads and railway tracks are also exposed to erosion. The Ministère des Transports du Québec is currently examining what measures to take for 55 stretches of road in this sector.

Increasing coastal erosion will have significant impacts on the affected populations, especially in terms of municipal infrastructure and road maintenance costs, but also in damages to waterfront residential and commercial properties. For example, an evaluation of the impacts on Prince Edward Island puts the losses of property values at 10 per cent over 20 years and 50 per cent over 100 years. Increased risk to the safety of the inhabitants of these regions should also be foreseen.

Expected impacts

According to the IPCC, one of the main impacts of climate change over the coming years will be increased coastal erosion attributable to rising sea levels and stronger wave action and storms associated with cyclonic activity.

This reflects a global phenomenon in which 70 per cent of beaches, representing one third of the world's shorelines, are retreating (Bird, 1985). The rising sea will also submerge lowlands along the seaboard, such as baymouth bars and spits, and could gradually destroy coastal marshlands. Québec, which is already confronting considerable problems of coastal erosion, will be seriously affected by this phenomenon.

In addition, warming could result in shortening the period of ice cover, which protects the coasts during winter, and thus exacerbate the impact of winter storms on the littoral zone. The amplification of the freeze/thaw cycle, which contributes to the erosion of cliffs consisting of gravel or rocks, is a further factor. Thus, in the case of the gravely cliffs of the north shore, a sudden thaw in the middle of winter could provoke landslides and result in a rapid retreat of the coastline.

The rise in sea level corresponding to the temperature increases of the SRES scenario in Figure 7 would be on the order of 30 to 50 cm by the end of the current century. The frequency of winter storms appears to have been increasing in the past thirty years or so in the Northern Hemisphere, but neither the frequency nor the intensity of these storms or of cyclonic activity during the upcoming decades is known. Moreover, at the local level, rising sea levels will coincide with geophysical movements that will modify their impacts. In this context, Québec is facing two contrasting situations: isostatic emerging areas along most of the north shore of the Saint Lawrence River, and submerging areas in some zones in Gaspésie and the îles de la Madeleine.

Adaptation strategies

An analysis of all these phenomena is an essential prerequisite for any adaptation strategy. In light of this, a better understanding of the geomorphology of the coasts and littoral processes is necessary in order to establish an exact diagnosis and recommend adaptation strategies appropriate to each situation. These studies must subsequently be combined with analyses of the strength of winds, water levels, currents, the magnitude of wave action, the intensity of storms, and the periods of ice cover, in order to establish risk levels with greater precision.

In Québec, the issue of erosion has never been the subject of close scrutiny or specific preventive campaigns. Sea level data are numerous but incomplete, and to date have essentially been designed to meet the needs of shipping safety or to document port infrastructure improvement projects. The absence of an analysis of the recurrence of storms constitutes a major shortcoming for the design of protective works.

Moreover, phenomena related to the shortening of the period of ice cover, which has recently been observed, are little documented owing to its newness. Finally, cyclonic activity which generates powerful storms, has also been increasing in recent years and is of yet poorly documented. The only measurement instruments currently available in the Gulf and the Estuary of the Saint Lawrence are two tide gauges and a buoy.

Meteorological stations that measure the wind speed, water levels, currents, wave size, and other data should be set up in a sufficient number of strategic locations to cover all of the Estuary and Gulf. These data could then be inserted into climate simulation models to verify models that predict erosion induced by wave action.

Once risk levels have been established, available strategies include:

- Moving buildings and infrastructure back and letting nature model the shore freely. This strategy implies relocations that may prove costly.
- Protective works, such as riprap, breakwaters, and other similar structures. These solutions are often equally expensive, especially when maintenance costs and the harmful impacts on adjacent sectors are counted. Indeed, these protective works often shield an erosion zone to the detriment of bordering zones, which are deprived of the sedimentary influx required for their upkeep.
- Appropriate zoning and development that accounts or erosion—this option is founded on a thorough understanding of the environment and a reasonable appreciation of its vulnerabilities. Probably the least expensive in the long run, this approach is ongoing and must account for advances in our understanding as we re-evaluate the situation in light of the continuing erosion of the littoral zone.

Questions specific to the most sensitive coastal zones of Atlantic Canada, British Columbia, the Arctic, and Ontario were dealt with in the regional chapters of the Canada Country Study: Climate Impacts and Adaptation. More recently, a study (McCulloch, M. M. *et al*., 2002) was conducted on the economic consequences of increased flooding for the properties and urban infrastructure for the city of Charlottetown, where the sea level has risen 32 cm since 1911. This provides an excellent example of the type of work that will allow the impact of climate change to be better evaluated and to determine the best strategies to adopt. No equally thorough studies are available for Québec to date. However, a study of the vulnerabilities of the Côte-Nord region has been jointly undertaken by six Québec government departments, with this in mind, that should be available over the course of the next year.

THE SOUTHERN QUÉBEC REGION

Situated on the Saint Lawrence Lowlands and in the Appalachians, the Southern Quebec Region, which covers less than 10 per cent of the province's territory and is home to over 90 per cent of its population, extends over 500 km south of 50° N. In this region, with its high population density and diversified economic activity, agriculture, tourism, land and maritime transportation, energy demand, water management, health, human habitations and ecosystems are all domains that will be directly and indirectly affected by climate change.

AGRICULTURE

In this part of Québec, climate change is liable to mostly affect activities in the agricultural industry. Indeed, Southern Québec is the region in which the growing season is longest, and thus most propitious for agriculture. This advantage is magnified by the flat relief and fertile soils.

Climate change will have various direct and indirect effects on agricultural production, and may impact on both the quantity and the quality of produce. The impacts will vary considerably depending on the specific activity: grain crops, forage plants, fruit trees, horticulture, or animal husbandry. These changes may have consequences for the profitability of agriculture, depending on the adaptation strategies implemented.

Expected impacts

Direct effects

As described in Chapter 1, relative to the period 1960–1990, the average climate conditions predicted for 2080 to 2100 under the mean scenario covering Québec's agricultural land include a temperature rise of 2° to 3° C in summer and 3° to 4° C in winter, as well as a precipitation increase of less than 5 per cent in summer and 10 to 20 per cent in winter. These climate changes will probably result in a lengthening of the growing season for several crops, but also in more evapotranspiration from the soil. The main impacts could involve changes to the frequency of threshold or extreme events (for example, the date of the last freeze in the spring, or intense rainstorms) rather than in changes to a the climatic means.

The growing season, determined primarily by the frost-free period, proves to be a fundamental agro-climatic determinant of agricultural output. According to a modelling study (de Jong *et al*., 2001), with the atmosphere twice as rich in CO_2, the growing season for corn in the Saint-Hyacinthe region could be extended by nearly 20 days, while the potato season would be about 12 days longer in the Lac-Saint-Jean region. However, these studies do not foresee a significant lengthening of the growing season for wheat or barley. This is attributable to the fact that, despite an earlier seeding date, the harvest would simply be moved up by an equivalent time.

In Québec, we have already had the opportunity to observe how some crops at the northern limit of their range were able to benefit from a longer growing season during the relatively hot years 2001 and 2002. Notably, vineyards experienced a rise in the quantity and quality of grapes. On the other hand, heat waves can be harmful to the production and quality of several market crops, such as lettuce and cabbage.

The need for heat and cold conditions the growth and winter survival of perennials. In the case of forage plants, modelling studies have revealed that warmer autumns and a reduced snow cover could impair their winter survival, even if a longer growing season might yield more harvests (Bélanger *et al*., 2002a). However, under those same scenarios, fruit trees would probably benefit from better hardening-off conditions and sustain less damage from the cold (Bélanger *et al*., 2001). Conversely, we have noticed that the warm autumns of recent years may have the effect of diminishing the quality of apples by slowing their reddening.

Since these climate scenarios do not predict a significant increase in summer precipitations along with the higher temperatures, the water deficit (potential evapotranspiration minus seasonal precipitation) is expected to expand. Periods of water stress for corn and soybean could increase by about 20 days (de Jong *et al*., 2001). It has also been noted that, while they were generally good despite lengthy periods of drought, corn yields in 2001 and 2002 would have been disastrous had the rains been delayed by even a few days.

Finally, the atmospheric concentration of CO_2 has a direct impact on crop growth. Experiments have shown (Hunt, R. *et al*., 1991; Ziska *et al*., 2001; Sionit *et al*., 1984) that a higher concentration of CO_2 improves the efficiency of water use by plants and stimulates photosynthesis, as long as other factors (water and nutritional elements in the soil) are not limiting. Some crops, such as soybeans, react more strongly to CO_2 enrichment than do others, like corn, for instance.

Animals, especially those raised indoors (like pigs and poultry), will be exposed to heat stress more often in the summer. Their health and growth rates could be affected (Myer and Bucklin, 2002). Note, as an illustration, the heat wave in early July 2002, which killed at least 500,000 fowl in Québec. Even if poultry farmers had introduced new technologies to improve their ventilation systems, that would not have been adequate to keep the temperature from reaching nearly 35° C in some livestock buildings. On the other hand, milder winters could allow for better growth rates of beef cattle raised outdoors.

Indirect effects

Temperature and humidity play determinant roles in the geographical distribution of weeds, pathogens, and agricultural entomofauna. Under the new climatic conditions, we expect new species to arrive and changes in populations that threaten crops. A greater variability of temperatures and precipitation will have both positive and negative impacts on host/parasite interactions. Additional efforts will be required to ensure that systems for predicting disease and insect crop pests are effective under more variable climatic conditions.

If the survival of some insects will be abetted by milder winters (for example, aphids), the reduced protective snow cover will undoubtedly harm others (such as chrysomelids). Higher summer temperatures could increase the number of generations per year in the case of mites and the corn borer. Altered atmospheric conditions may also increase the risk of invasions by alien species. We point out that the hot summer of 2001 seems to have encouraged the proliferation of the usually uncommon army worm, causing damage to cereal and forage crops in southwestern Québec.

Crop weeds are often species that are able to adapt and disperse rapidly, suppressing them may thus become more difficult under climate conditions of greater variability. Increasing temperatures and a sporadic water supply may make some market crops more sensitive to physiological disorders, such as the tip burn associated with calcium deficiency in lettuce. Some parasitic diseases, such as those caused by bacteria, could benefit from higher temperatures and humidity levels.

Hotter and dryer seasons would impact on the persistence of pesticides in the soil. Furthermore, an increased frequency of torrential downpours may aggravate the loss of soil to erosion. These facts, combined with a greater need to irrigate some crops, could exacerbate pressures on water quality.

While climate plays a determinant role, directly and indirectly, in agricultural production, economic impacts are also very much influenced by prices. These prices are, in many cases, established by the interplay of global supply and demand, which are also highly dependent on climatic factors. In a word, the economic impact that climate change will have on the agro-processing industry will, to some extent, be a result of the changes to Québec's climate relative to those experienced elsewhere.

Adaptation strategies

Agricultural production is linked to local climate conditions and, as a consequence, when choosing the appropriate adaptation strategies producers must be able to reduce their risks and benefit from profit opportunities presented by climate change. Farming practices and financial strategies must, however, be adapted so as to confront the prospects of greater climatic variability.

In general, agricultural producers feel that have the technological tools they need to deal with climate change (Bryant *et al*., 2000), especially in terms of the choices of cultivars and crops. Indeed, the varieties of corn and soybean already used by our neighbours to the south are available to Québec producers now. According to some authors, introducing species such as timothy grass could alleviate the risk of winter losses of alfalfa (Bélanger *et al*., 2001). They also point out that in the case of species that take a long time to become established (such as fruit trees), it will be necessary to re-evaluate the geographical distribution of agro-climatic risks more frequently in order to adequately plan the introduction of other varieties or species. Finally, agricultural research centres should develop cultivars that are more tolerant to increased variability in temperature and humidity.

Input levels will also require adjustments: In dealing with plants, we often observe that under conditions of water stress, a better economic yield is obtained when a smaller dose of fertilizer is used than that generally recommended. Also, in response to an eventual evolution of crop predators, new crop protection products that are environmentally benign need to be developed. Owing to the greater potential for soil erosion, in some circumstances or locations, the use of green fertilizers that are spread after the harvest is even more desirable. A longer growing season may even facilitate their acceptance.

It would be necessary to account for the evolution of climate at the time of considering some long-term investments—notably, irrigation systems and the design of buildings for housing animals. New cooling systems for livestock buildings may need to be developed. Some dairy farmers are already applying a white ceramic paint to the roofs of their barns in order to reduce heating by the sun.

Various government policies and programs have been developed to assist in the management of agricultural risk. In light of the expected increase in risks, these programs may need to be reviewed more often. In the future, agricultural weather forecasts will be even more critical.

The impact of climate change on the agri-food system will mostly be felt locally, while the available knowledge will be on the global scale. Refining regional climate models will allow us to better target the negative impacts and the potential for new opportunities unique to each region. Biophysical research, which links climate models to agricultural output, provides elements for reflection on the future of the farming sector in an atmosphere containing greater concentrations of CO_2 However, these models will be hard pressed to capture all the complexity of the interrelationships between the climate, plants, animals, soils, disease, insects, and agricultural output.

While awaiting the development of climate models for Québec, it would be useful to examine in detail the vulnerability, risk exposure, and adaptability of the agri-food system in light of the vagaries of the current climate.

ECOSYSTEMS AND BIODIVERSITY

The conservation of ecosystems and biodiversity is one of the main concerns in the context of climate change.[11] Even more than human economies and environments which, thanks to technology, are in a position to adapt to all manner of change, natural environments are in danger of being overwhelmed by the speed and extent of the changes. In terms of measures covering the reduction of greenhouse gas emissions, as well as those affecting land use and forestry, the *United Nations Framework Convention on Climate Change* will have a direct impact on the conservation of biodiversity.[12]

Québec is home to at least 40,866 species of plants and animals. Québec's floral patrimony (algae, lichen, liverworts, mosses, horsetails, lycopods, ferns, conifers, and flowering plants) includes more than 7,000 species. In addition, there are over 2,500 species of fungi—counting only mushrooms.

As to wildlife, it includes a further 653 species: 199 species of fish, 21 species of amphibians, 16 species of reptiles, 326 species of birds, and 91 species of mammals. This diversity is augmented by many species of invertebrates. Insects alone account for over 25,000 species. This amazing diversity, while not comparable to that of more southerly countries, is explained by the huge variety of ecosystems and the immensity of the territory encompassing three climatic zones.

The arctic zone (about 15 per cent of the territory) presents a limited biological diversity, but the species living there are very hardy. They possess a particular significance because of their role in the lifestyle of native communities, to which hunting and fishing remain crucial.

Further south, species diversity in the vast boreal zone (over 70 per cent of the territory) is also relatively small. Here again, their importance is enhanced by the role they play in the lifestyle of native populations, especially the hunt for migratory birds and the harvest of several species of fish. In the mossy spruce stands south of the 52nd parallel, the fauna and flora are more diversified, and biological resources are used in a more sustained fashion.

Finally, in the southern reaches of the province, the northern temperate zone (about 10 per cent of the territory) presents a wide biological diversity. Over the course of centuries, this wealth has encouraged human settlement and the resulting creation of large agricultural and urban tracts. This is also the zone crossed by the Saint Lawrence River—the home to many aquatic species.

Expected impacts

The climate changes expected over the course of the next hundred years will have different impacts on ecosystems and biodiversity. While possessing an inherent ability to adapt to natural stresses, living organisms could be hard hit by the extent of the changes, especially in the most northerly areas.

If CO_2 concentrations double, several populations, or even species, of plants and animals may disappear because climate change overwhelms their ability to migrate and the loss or shrinkage of their habitat. The combination of higher temperatures and other environmental stresses, especially habitat loss, could easily break ecological links between interdependent species and cause a reorganization within biological communities. These new communities, though adapted to the changing climate, may be less diversified than those they replace (Root *et al.*, 2003).

In addition to forcing unprecedented migrations, the warming will likely also result in significant habitat loss. Over half of Québec's territory is at risk. It is impossible to predict whether the destroyed habitats will be replaced by new types of habitats that are equally diversified, or whether similar habitats may become established elsewhere. Finally, there will be a loss in the surface area of specific habitats within surviving habitats. In the most vulnerable arctic and mountainous habitats, up to 20 per cent of local species may disappear.

11 In this context, it is interesting to note that the *Convention on Biological Diversity* was signed at the same time as the *Climate Change Convention* at the Earth Summit in Rio de Janeiro, Brazil, in 1992.

12 According to the *Convention on Biological Diversity*, biological diversity is "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

Terrestrial environments

As to species of fauna, rising temperatures could cause heat stress during the summer in both the north and the south of Québec, as the intensity and length of heat waves increases. This may provide an incentive for some species to leave their preferred range, while other indigenous or exotic species might move in. For species that are able to migrate rapidly, a northward extension or displacement of their ranges may result. Some animal species might migrate faster than plants. However, for most animal species to successfully colonize new areas, they will require the presence of an appropriate flora and other constituents of a habitat suitable for their survival. While most species can gradually move into the fringes of their territory, few are hardy enough to rapidly occupy a vast range.

In their migration, species from the south encroach on more northerly zones. When the competition proves too stiff, some species or populations will be able to move even further north, while others will not. Thus, the range of white-tailed deer and moose can shift northward, while that of woodland caribou will shrink, specifically because of the absence or scarcity of the arboreal lichen on which they feed. Woodland caribou and moose will compete for that food. The moose's arrival will inevitably lead to an increase in wolf populations. The moose's principal natural predator, the wolf may also hunt the caribou in this newly occupied range.

Climate change will result in a shortening of the period of ice cover and a reduction in the extent of sea ice, which could prove detrimental to some animal species indigenous to the North and the Gulf of Saint Lawrence, such as polar bears, harp seals, and grey seals. These latter, which can be observed on the ice of the Gulf in the winter, produce fewer offspring in the absence of ice (Gagné, Jacques, 2000).

Liquid or freezing rains, occurring principally during periods of unseasonable warmth in the winter, could cause problems for riparian fauna and flora following high waters or floods. Some species may be unable to find sufficient sustenance if their food sources are covered by a layer of ice.

Despite the anticipated increase in precipitation, the snow ratio can be expected to decline in a context of climate change. While plants will be adversely affect by the loss of the protective layer of snow, some large animals may benefit from the reduced snow ratio. We know that, the thicker snow is on the ground, the less it is compact, and the longer it remains, the more it impairs the movement of white-tailed deer—causing increased mortality in their population.

Aquatic environments

Some of the most threatened animal species live in Québec: migratory birds that use coastal wetlands and arctic environments, amphibians and reptiles, and some species that make use of the arctic ice. Owing to falling water levels and the rise in water temperatures that may result, especially in the Saint Lawrence River, climate change may make aquatic ecosystems and wetlands particularly vulnerable.

As to wildlife habitat, we may see the loss of natural and improved habitats for a large number of species, several of which are threatened or endangered—redfin pickerel, map turtle, yellow rail, sedge wren, pigmy shrew (Beaulieu, H. and M. Huot, 1993)—and others with considerable economic value—yellow perch, Atlantic tomcod, American eel, waterfowl, northern pintail, blue-winged teal, and gallinule (Langlois, C. *et al*., 1992). Researchers have established a link between the flow rate and the temperature, on the one hand, and the abundance by age-class of lake sturgeon in the Rivière des Prairies, on the other hand. They have also drawn attention to the carp's sensitivity to heat during the spawning period (Mingelbier *et al*., 2001). Studies are ongoing to evaluate salmon's sensitivity to heat.

Climate change may disturb the synchronization between events that trigger some species' biological cycle and the climatic conditions that make the environment suitable for their survival. For example, the northern pike, which reproduces in floodplains, would be harmed by early thaws creating floodplains that are too cold to permit spawning.

As to the tributaries of the Saint Lawrence, variations in annual flow rates on the order of 10 per cent (falling within the limits of the current variability) should not create the same problems as those that may be experienced by the ecosystems and species associated with the Saint-Lawrence itself.

Climate change will cause a rise in the mean sea level, increasing the salinity of some sectors of the Saint Lawrence and the mouths of several of its tributaries, whose water is currently brackish or fresh. Aquatic fauna and flora, and that of wetlands, would be subject to various disruptions: threats to their food sources or survival, displacements of species and habitats, and the emergence of new parasites and diseases (Dumas, 1989; International Joint Commission, 1993).

The submerging of some parts of terrestrial ecosystems could also have an incidence on fauna and flora, as their habitats may end up under water. Under these conditions, coastal erosion, which would be exacerbated by more frequent sea storms in a context of a changing climate, would constitute an additional aggravating force for these ecosystems.

Furthermore, climate change could affect the thermal stratification of the waters of the Gulf of Saint Lawrence. When the intermediate layer of water (the coldest) cools, as has been happening since the 1980s, snow crab reproduction increases while the condition and fecundity of cod is adversely affected. As a first approximation, a warming of the waters of the Gulf thus appears harmful to the snow crab but beneficial to the cod. However, climate models do not yet allow us to predict the likely evolution of the thermal stratification of the Gulf in the coming decades.

Adaptation strategies

The many impacts of climate change on ecosystems and biological diversity on the regional, even local, scale are still relatively poorly understood and difficult to evaluate. Assorted interactions between elements of the climate and other factors, including the often highly disruptive role played by humans, exercise a profound influence on the evolution of ecosystems and on the development and distribution of species. Activities such as intensive commercial fisheries, dredging of the seaway, reforestation with a small number of species, and the expansion of cities and farms are only a few examples of the negative impact humans have on the natural environment. Corridors between natural habitats surrounded by developed areas could help species reach their intrinsic level of maximum migration and slow the disappearance of species (Pearce, F., 1998; Secretariat of the Convention on Biological Diversity, 2002; Environment Canada, 2002; Stachowicz, J. J. *et al*., 2002; Malcolm, J. R. and Markham, A., 2000; Ministère de l'Environnement, 2002b).

We may be concerned about the capacity to adapt to climate change of species or environments that are already stressed owing to human activity. Adaptation strategies will need to account for the increased stress caused by climate change. Among terrestrial ecosystems, it is within the agricultural milieu that areas having remained in their natural state, and the organisms that inhabit them, could be severely tried. The countryside and farming practices have undergone considerable modifications in recent decades, causing a loss of areas left untouched and of species. It will be difficult to distinguish between the effects of climate change and those of human intervention. Changing some agricultural practices to better adapt to climate change or to reduce greenhouse gas emissions could have repercussions on natural areas and their inhabitants, which will need to be evaluated.

In Québec, like elsewhere, a growing number of exotic species are occupying new ranges by using corridors linked to human activity. Whether intentionally imported or arriving as stowaways, the organisms that manage to survive in their new habitat sometimes create severe ecological and economic impacts, flourishing at the expense of some indigenous species—and sometimes even replacing them. A recent study (Stachowicz *et al*., 2002) of coastal marine species suggests that global warming helps invading exotics to become established in new ranges, and contributes to accelerating the homogenization the world's ecosystems. Measures aimed at controlling the introduction of new species will be crucial in this environment.

The Saint Lawrence is one of North America's largest rivers. Originating in the Great Lakes, it ends its course in a vast estuary over 65 km in width that empties into the Atlantic Ocean. Dotted with over 500 islands, it widens in places to form shallow lakes, spilling into aquatic beds and marshes and flooding riparian forests. As the drainage basin for nearly all watercourses in the inhabited parts of Québec, it has several dozen tributaries that double its flow between the Great Lakes and the estuary.

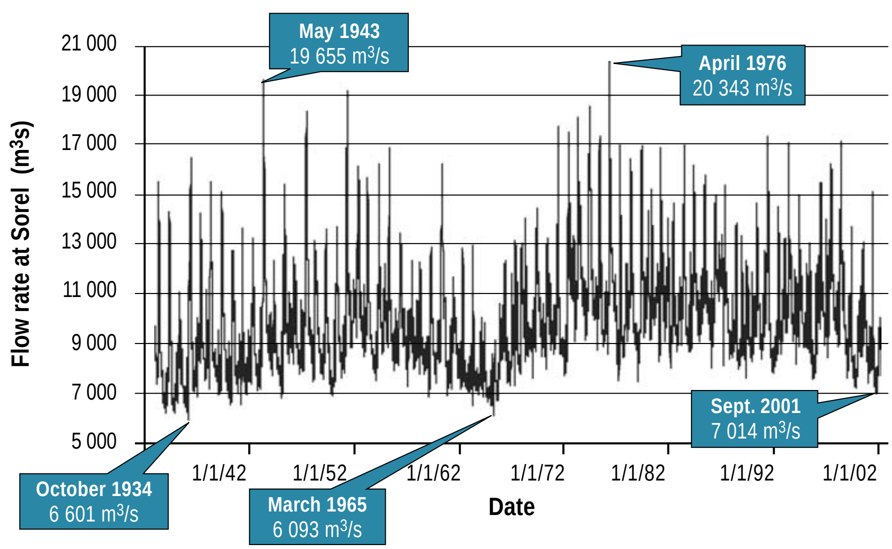
A veritable gash deep into the heartland of America, the Saint Lawrence River forms the border between the United States and Canada for about 200 km. It is one of the world's largest navigable waterways, and the pre-eminent river route of the North American continent. In Canada, its entire length has been developed for navigation—making up the Saint Lawrence Seaway that was inaugurated in 1959. Connecting the Atlantic Ocean to the vast Great Lakes Basin, the seaway creates a navigable 3,800 km route linking the main industrial centres of Canada and the United States, and even the western prairies.

Data from Saint Lawrence drainage basin hydrometric networks yield a portrait of the cyclical behaviour of the river's runoff. Figure 20 (Morin, J. *et al*., 2000) illustrates the evolution of the monthly flow at Sorel for the period 1932–2001. Examining this entire dataset reveals the tremendous variation in these flows—over 14,000 m^3/s, or between 6,000 and 20,000 m^3/s. Though very low, the readings from the summer of 2001 fall within the range of values measured over the century.

Referring back to the average scenario laid out in Chapter 1, in which the temperature rises by 2° to 3° C in summer and 3° to 4° C in winter and precipitation increases less than 5 per cent in summer and 10 to 20 per cent in winter, we could see a potential decline of 24 per cent in the mean outflow from Lake Ontario, owing to increased evaporation caused by the warmer temperatures. However, this assumption is uncertain and results vary between studies. Indeed, outflows from Lake Ontario could fall by about 24 per cent, or rise by about 8 per cent, over the next hundred years (Lofgren *et al*., 2002). Other results, obtained by applying general circulation models (Mortsch *et al*., 2000), suggest a decline in Lake Ontario's outflows that could reach 40 per cent, primarily because the warmer winter temperatures would dramatically reduce ice formation on the Great Lakes and lead to more evaporation.

Figure 20

Flow rate of the Saint Lawrence River at Sorel, December 1932–December 2001
(Morin, J. *et al*., 2000)



Principal inflows: the Ottawa River and the Great Lakes

The main tributaries of the Saint Lawrence River are two regulated basins: The Great Lakes and the Ottawa River. The volume of the former is greater, with an annual rate of flow that averages 7060 m^3/s and varies between 6000 and 9000 m^3/s, but the latter fluctuates more, with an outflow ranging between 1000 and 8000 m^3/s in the spring. In the absence of regulating structures, the variability of the Saint Lawrence and Ottawa Rivers would be even more pronounced.

In general, flow regulation reduces outflows in the spring and increases them in the autumn and winter. Average flows are reduced by at most about 2000 m^3/s in the spring and increased by 300 to 900 m^3/s between September and March. While the typical impact of flow control operations appears quite extensive, the actual leeway available for averting extreme events is in fact quite limited. For example, during extended periods of limited runoff, the level in the Great Lakes falls so low that it becomes very difficult to meet the downstream water requirements without exacerbating an already tenuous situation upstream. Similar considerations come into play with respect to flood prevention during periods of high flows.

High and low flows

Examination of the flow rates measured since the beginning of the 1960s reveals that the mean annual rate for the Saint Lawrence River at the level of Sorel is about 9,500 m^3/s, with seasonal fluctuations falling between the threshold values of 20,300 m^3/s and 6090 m^3/s. In a climate change scenario under which the mean flow rate falls by about 24 per cent, we would expect a mean annual rate of a little over 7,000 m^3/s. A decline of this magnitude could cause the level of the Saint Lawrence to fall by nearly one metre (Morin, J. *et al*., 2000).

Expected impacts

Climate change and the resulting fall in water levels in the Saint Lawrence River will have a variety of impacts affecting both the timing and the extent of high waters, desiccating aquatic zones and flood plains, reducing water supplies to some municipalities, and disrupting commercial and pleasure boating on the river.

The hydrological cycle

In southern Québec, higher winter temperatures and more precipitation in the watersheds of the tributaries of the Saint Lawrence could result in earlier springtime high waters with greater flow rates. Thus, the spring thaw in the Ottawa River could cause flooding problems for the Montréal archipelago. During the summer, increased evapotranspiration in watersheds with heavy forest cover could further reduce declining flows. In the Great Lakes, warmer temperatures could lead to more evaporation, a phenomenon that could possibly be accentuated by reduced ice cover in winter.

On the tributaries of the Saint Lawrence River, higher winter temperatures could increase the frequency with which ice jams form and break up. The specific features of some rivers, such as the Châteauguay, make them particularly prone to this type of event—implying that they can be expected to occur with greater frequency.

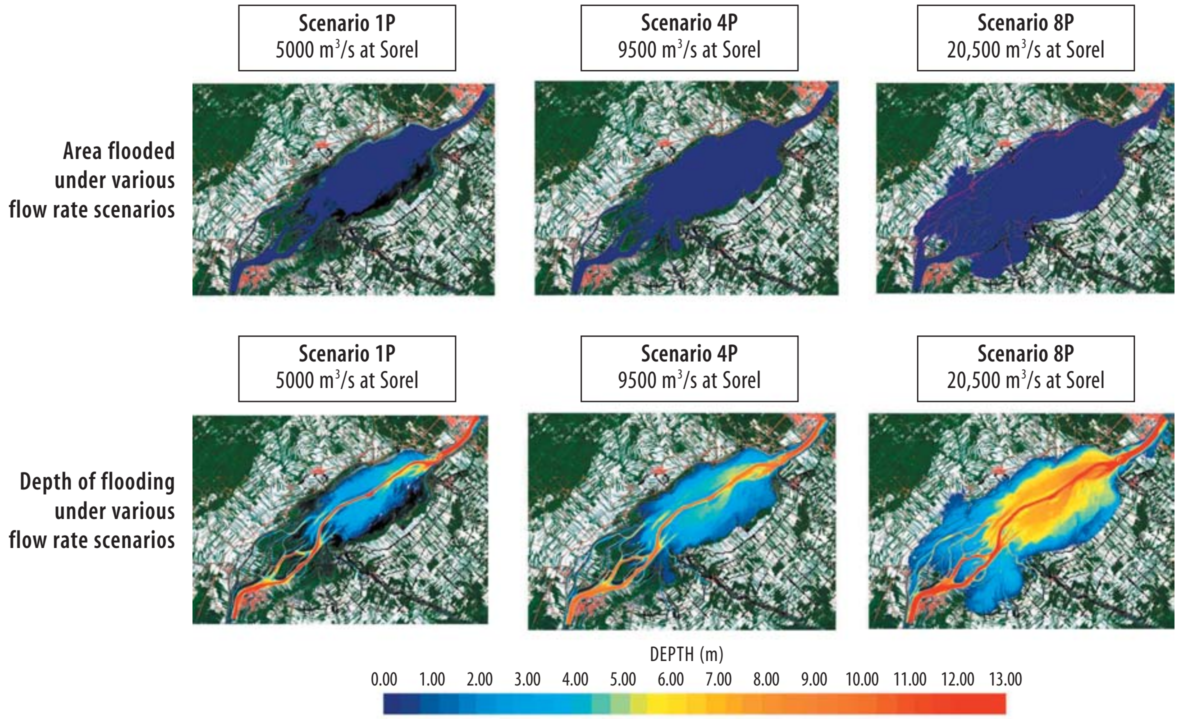
Drought, flooding, erosion, and biodiversity

Under a scenario in which the flow of the Saint Lawrence River declines, large areas that are currently aquatic beds could become floodplains, covered by water only during the spring thaw or following prolonged heavy rains in the Great Lakes basin. To the extent that sound land management plans are implemented, there will be less danger that urban or semi-urban developments will find themselves located in flood zones.

Figure 21 shows the area of Lake Saint-Pierre's floodplain for flow rates equal to 5000 m^3/s, 9500 m^3/s, and 20,500 m^3/s, along with the associated depths. On average, lower levels can be expected to result in less erosion of the banks than current levels. Conversely, coastal platforms located on the edges of shipping channels will be subject to a greater rate of vertical erosion, increasing the level of sedimentation. We can also expect that a fall in the mean level of the Saint Lawrence River will cause the configuration of some river deltas to change, such as the Yamaska and Saint-François, both of which flow into Lake Saint-Pierre.

Figure 21

Area of the floodplain and water depths for three flow levels of the Saint Lawrence River (Morin, J. *et al*., 2000)



In terms of the environment, there is good reason to worry about the impact of a fall in the water level on the sensitive and rich ecosystems bordering the river and located in flood zones. The low levels observed in recent years have resulted in a proliferation of opportunistic terrestrial plants in the dry zones of the Saint Lawrence floodplain. With time, these plants will impoverish the biological diversity of riverside ecosystems, since they are of no use to the existing fauna: fish, ducks, amphibians, and reptiles (Garneau, 2000). Moreover, we may observe changes to emergent and submerged vegetation and an increased vulnerability of the riverbank to colonization by aggressive or undesirable exotic plant species (Hudon, 1997; Lehoux, 1996). Lake Saint-Pierre, a World Biosphere Reserve, is particularly vulnerable to this. Improved marshland, which is a vital contributor to fish productivity, could be affected by the reduced water levels in spring (Mingelbier *et al*., 2000). It should also be borne in mind that commercial and sports fishing is an important activity on several reaches of the Saint Lawrence River. Any potential decline in the system's productivity could imperil the resource and the uses to which it is put.

Drinking water supply

The issue of drinking water supply is more thoroughly covered in the section on "Water management." However, one must take into consideration that water issues could affect some municipalities whose intakes are insufficiently deep in the Saint Lawrence.

We need also to mention that in the summers of 2001 and 2002, municipalities that draw their drinking water from the Mille-Îles River were alarmed by a decline in water quality attributable to very low flow rates and the resulting lessening in the dilution of the pollution load. This river presents a special case owing to the peculiarities of its topography. Its source is Lake Deux Montagnes, which also empties into the Saint Lawrence River and the Rivière des Prairies. Since the river bottom of the Mille-Îles River is higher than that of the other outlets, its inflow is the first to be reduced, so that its flow rate is cut more than that of the Saint Lawrence River. It proved necessary to increase the flow of the Ottawa River to improve the water quality in this outlet of Lake Deux Montagnes. Consequently, a hydroelectricity plant was forced to operate under conditions that were somewhat less than optimal.

A rise in water temperatures may further exacerbate the deterioration of the water quality. These types of problems will impact especially those municipalities whose water intakes are located within a plume of waste water discharges, such as municipal and industrial sewage outlets.

Pleasure boating

A fall in water levels in the Saint Lawrence River may potentially affect access to marinas as well as the types of boats that can approach and dock at them, owing to shallower channels and basins. A loss of clientele can be expected, depending on the types of pleasure boats moored at the different marinas.

Shipping

In economic terms, the greatest impact of climate change will be on shipping. Indeed, a fall in the level of Saint Lawrence River and a reduced usable depth of shipping channels will affect access to the river's ports and traffic on the seaway overall. The reference chart data used for navigation may need to be revised downward. Some commercial vessels will need to reduce their tonnage, causing economic losses to the shipowners. Uncertainty concerning the underkeel clearance in the seaway may undermine the competitiveness of the port of Montréal compared to other ports on the eastern seaboard of North America.

Adaptation strategies

Floods, droughts, and biodiversity

With regards to floods, the 20- and 100-year levels—and the legal ramifications their definitions have in practice—need to be re-examined in light of the new data, in order to account for generally lower flow rates but also for the possibility of greater variability, especially in the spring. Zoning maps for shores and floodplains requiring revised regulation will also be needed to limit negative economic fallout.

In order to prevent deterioration of the water quality and maintain other uses, such as navigation, regulating structures may be called into service more often to increase flow rates from the Great Lakes or major tributaries, such as the Ottawa River, during periods of low flow. In that eventuality, compromises between hydroelectricity generation and other uses will need to be worked out.

Adaptation strategies and mitigating measures for habitats and faunal and floral resources will also require substantial efforts that are difficult to quantify. A possible approach would be to adjust water regulation to protect the spawning grounds of certain fish species. On the regulatory front, there may be a need to review the regulations governing fishing, such as the length of the season, the allowed species, and the size of the catch, before losses become irreversible. Also, the possibility of establishing protected areas and parks should be explored.

Potential mitigation measures include controlling invading species of plants and animals so that quality vegetation habitats will be able to migrate nearer the riverbed. The creation of new marshes lying lower than existing ones would ensure a minimum of success for fish spawning in the early spring. Finally, movable barriers could also be set to maintain the water level above a minimum level in some sensitive sectors.

Drinking water supply

As to the supply of water to municipalities relying on the Mille-Îles River, several solutions have been proposed, including lowering the river's source at Lake Deux Montagnes. Elsewhere, simply moving water intakes should settle problems caused by the lower flow. Finally, problems arising from a deterioration in the quality of the raw water may necessitate a change in the parameters of water treatment or the introduction of different technologies. The scope for protecting water quality through regulating flows remains limited, particularly during lengthy periods of limited runoff.

Shipping

A decline in the average water level of the Saint Lawrence River will make it necessary to implement various adaptation measures in the Montréal–Trois-Rivières corridor, involving federal and provincial bodies as well as shippers and other private organizations whose activities are closely tied to the river.

In order to alleviate uncertainty concerning the depth of the navigation channel, more efforts could be invested in monitoring and forecasting water levels all along the Saint Lawrence. The reference chart data used for navigation might also require a review, allowing marine charts to be redrawn to reflect the new configuration of port facilities and the navigation channel. In addition, and in keeping with precedent, the International Joint Committee for the Great Lakes could adjust the outflow from Lake Ontario in response to the needs of commercial shipping, providing the required additional centimetres on a case-by-case basis.

The available means of adapting to reduced depths include diminishing tonnage, increasing the use of boats with a shallower draught, and decreasing the speed of ships to minimize squat. Moreover, to increase the available depth of the shipping channel and ensure the prescribed underkeel clearance, renovating infrastructures, reconfiguring port facilities, and over-dredging some sections of the channel will need to be considered.

The extent of our knowledge

In terms of hydrology, the Saint Lawrence watershed is covered by several networks that together monitor the evolution of inflows into the river on an hourly basis. Hydrological models, coupled with general atmospheric circulation models and, in some cases, regional models, are applied to several watersheds (such as those of the Great Lakes and the Châteauguay and Ottawa Rivers). However, the river's entire drainage basin is not covered, so the reaction of its tributaries to climate change scenarios cannot currently be forecast. Historical flow-rate time series remain the basic tool available to researchers for estimating future inflows, but their usefulness is limited because their statistical characteristics will be altered by climate change.

Water quality surveillance stations on the principal tributaries provide monthly parameter readings and a water quality index covering the bacteriological and physiochemical aspects (Simard, 2002).

Analysis of the impacts of water level changes on the Saint Lawrence River system, as a function of water inflows, began around 1995 in the framework of the Saint Lawrence River Action Plan. A physical characterization of the river would appear to be an essential step in studying the impacts of flow and level changes. Modelling of the hydrodynamics, water quality, erosion, and sediment transportation under different flow conditions is ongoing for the whole river. It will lay the groundwork for studying impacts on the overall ecosystem. Several stretches of the river, and several essential aspects (such as the distribution of the volume of water), remain to be dealt with.

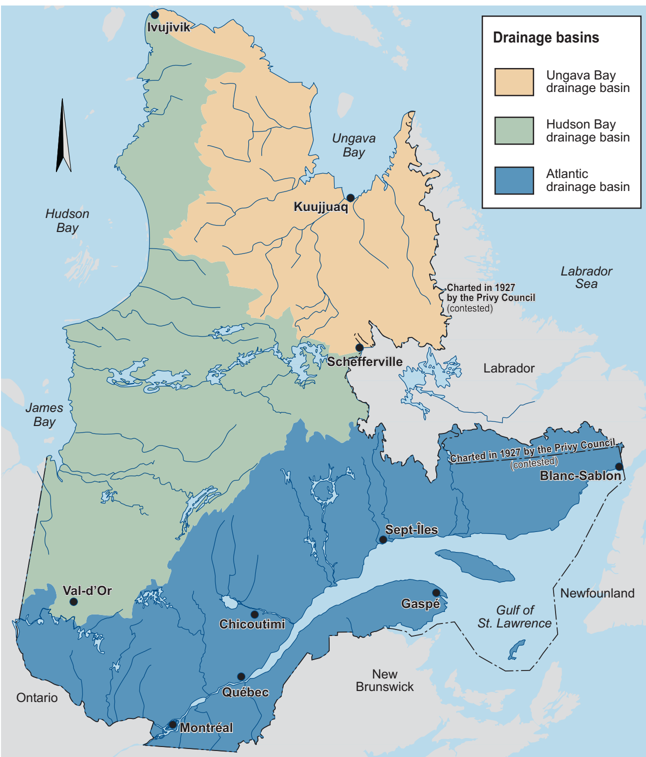
Work conducted in the framework of the International Joint Commission's study plan aims to redefine management plans for the Great Lakes–Saint Lawrence River system—a forecasting model for this system's reaction will be set up. However, this will need to be improved and up-dated as knowledge is accumulated.

These efforts, especially as they focus on impacts on living species, are embryonic and must be complemented by an analysis and quantification of impacts on primary productivity and the relationships between trophic levels. It also appears essential to look at the interactions between endangered species and those introduced into the milieu (plants, mussels, fish, etc.), and to monitor the evolution of the system by corroborating the acquired information and the established models.

Québec's water resources (Figure 22) amount to an annual average of 990 km^3—three per cent of the planet's renewable water supply—flowing in more than 4500 rivers that empty into the oceans and Hudson Bay, along with approximately 2000 km^3 of groundwater, of which about 10 per cent is located in the heavily populated region (MENV, 2002a, 1999). One third of Québec's territory lies in the Saint Lawrence River drainage basin. This river alone contains about 40 per cent of the renewable water and supplies 80 per cent of the population (Delisle, 1998).

Figure 22

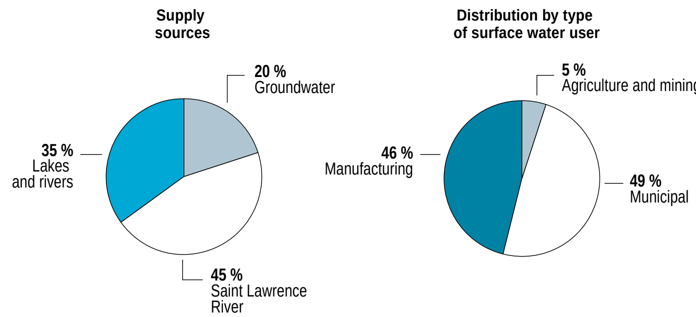
Québec's hydrographic regions (Atlas Picard, 1994)



As we see in Figure 23, the supply of water to Québec's population and economy, nearly 4.6 km^3, is derived from the Saint Lawrence (about 45 per cent), lakes and other rivers (35 per cent), and groundwater (20 per cent) (Government of Québec, 1997; MENV, 2002, 1999). In addition to providing drinking water, water from aquifers, rivers, and lakes serves in various uses as major instruments of economic and regional development for Québec. These uses can be grouped into two categories: those involving withdrawal (supplies to industry, municipalities, pisciculture, agriculture and mining, and thermoelectricity generation) and in situ uses (hydroelectricity generation, shipping, recreation, fishing, wastewater disposal).

Figure 23

Québec's water supply: sources and users (MENV, 2002, 1999; Government of Québec, 1997)



Water quality upstream of the Saint Lawrence River's main sub-watersheds, and in underground aquifers, is good (Government of Québec, 1997), but some issues arise in the context of wastewater and drinking water management in the vicinity of large urban and industrial centres, as well as in agricultural areas (Simard, 2002). Over the years, Québec has adopted pollution abatement programs so as to ensure the integrity of the receiving water bodies (Painchaud *et al.*, 2002) and regulations on the quality of drinking water to protect public health. Nonetheless, Québec society is still wrestling with the issue of how to reconcile various private and public uses of water in a framework of sustainable development and in light of a changing climate.

Expected impacts

Water management strategies depend first and foremost on the demand for, and supply of, water to satisfy the various uses, as well as the laws and regulations in effect. Thus, the impacts of climate change on water supply and treatment systems are a function of their nature and scope, the vulnerability of water resources and infrastructures, the evolution of demand, and the extent to which organizations and firms can be sensitized to changing their management practices in a new climate reality (Natural Resources Canada, 2002).

Drinking water

Over the course of the past decade, accidental breaks in water infrastructure, leaks from water mains, sporadic surges in demand, and low rainfall have resulted in bans on watering lawns, washing vehicles, and filling swimming pools, while point-specific or diffuse contamination of sources of drinking water have forced authorities to issue advisories to boil water or even refrain from drinking it in several localities (Rousseau *et al*., 2003). Recently, in the wake of extremely low water levels, Québec City and the town of Rosemère reached critical thresholds in the supply of surface water. Climate change is liable to exacerbate these issues.

Indeed, the anticipated combined changes to temperature and precipitation levels under the 2 x CO_2 scenario will, in all likelihood, cause the flows of the principal tributaries of the Saint Lawrence River to decrease during the period from July to October and to increase between November and March (Environment Canada, 1999 a, b; Bruce *et al*., 2000; MENV, 2000). The reduced summer flow could thus increase the frequency with which municipalities that draw surface water from these tributaries encounter problems. As to groundwater, the level of some aquifers may fall, or they may even dry up.

Average flows in the Saint Lawrence River at Montréal might diminish by 24 to 40 per cent, compared with their mean levels during the 1900–1990 period (Lofgren *et al*., 2002; Mortsch *et al*., 2000; Moulton and Cuthbert, 2000). However, since the volume of water in the river will remain substantial, this change should not create hardship for the municipalities that draw their water from it, except perhaps to force them to lower their intakes. This potential fall in the flow could also shift the salt front (Bourgault, 2001) upstream from 10 or 20 km off of the easternmost point of the Île d'Orléans. However, except in a situation of critically low water levels, which would advance this front a further 30 km, this should not compromise the water supply to Sainte-Foy and Lévis (Villeneuve *et al*., 2001).

Wastewater

Seasonal ebbs and flows in the volume of water and in spring runoff caused by changing rainfall patterns will have direct consequences for the transportation, residence time, and dilution of pollutants, as well as for the temperature and, by extension, the quality of the water. The anticipated changes to the Saint Lawrence River's hydraulic regime could displace the plumes of effluents and waste, leading to a widening or lengthening of the contaminated area in the receiving waterway. A water intake that was initially outside of a plume could find itself inside of one, resulting in a significant change in the quality of the raw water.

As to urban drainage, climate change may translate into an increase in the frequency of extreme precipitation events, which can, if rainwater management is inadequate, cause storm drains to back up and result in floods and untreated sewage overflowing into the receiving milieu. In fact, the capacity of existing infrastructure was determined on the basis of historical data available at the time of its construction, so it will not necessarily be able to handle the significant increase in rainfall that may occur.

Conflicts over use

The IPCC Working Group on Impacts, Adaptation and Vulnerability mentioned in its last report (IPCC, 2001b) that the impacts of climate change on the Saint Lawrence River could create a substantial divergence between supply and demand, resulting in supply problems. Thus, lower flow rates and warmer temperatures, in particular during the summer, could give rise to, or exacerbate, situations of conflict over use in several regions of Québec, especially in places where the supply comes from surface waters in lakes and rivers other than the Saint Lawrence River. Indeed, higher temperatures might increase urban populations' water requirements for domestic and recreational purposes, while agriculture, benefiting from the warmer weather, could also have greater irrigation needs. Also, greater water demand for industrial processes to satisfy burgeoning market demand linked to demographic growth could enter into competition with uses that do not require withdrawal, such as run-of-river hydroelectric generation, recreational activities, support for aquatic ecosystems, or the dilution of industrial and municipal effluents. In the Saint Lawrence River, these conflicts over use could be more focussed on the choice between commercial navigation and the provision of water in the summer.

Floods and overflows

One expected aspect of climate change is an increase in the frequency of heavy precipitation. These events could result in more frequent floods and overflows into flood zones. The costs ensuing from such events could be considerable. Similarly, increased turbidity crests and microbiological indicators for raw water (Rose, J. B. *et al*., 2000) will have considerable impacts on aquatic ecosystems (IPCC, 2001b) and on the quality of raw and treated water.

Adaptation strategies

Serious analysis of various adaptation strategies to climate change is just beginning in Québec, but we can already see that emphasis must be placed on implementing incentive measures to facilitate demand management and reconciliation of water uses. These strategies should focus on five primary issues:

- the sensitivity of the water resource,
- the needs of the main users,
- the state and capacity of the supply infrastructure,
- the vulnerability of the resource-infrastructure complex,
- adapting to climate change.

Drinking water

Confronted with the expected impacts on the supply of the drinking water resource, the first adaptation strategy should probably consist of improving demand management and thus reducing total consumption. Indeed, Québec's per capita consumption of drinking water is 794 litres per day, which is above the Canadian average of 600 litres per day (Delisle, 1998). Per capita residential consumption, for its part, is between 350 and 400 litres per day in Québec, representing about double the corresponding value for France (150 litres per day per person) and England (200 litres per day per person).

As regards to water intakes, if the Saint Lawrence River system falls to the anticipated levels several of them may need to be relocated. We can also envisage that the bodies that manage the water regulation facilities in the Great Lakes–Saint Lawrence system will need to re-examine their operating rules. As to municipalities that are supplied by groundwater, it may be necessary to dig deeper wells or to assume the costs of obtaining a surface water supply from farther away or of lesser quality. If the deterioration in quality is sufficiently acute, the effectiveness of wastewater treatment processes may need to be reviewed.

Wastewater

In matters of urban drainage, it will be necessary to review the design criteria for infrastructure. However, since it will not be feasible to rebuild all these networks from the ground up, innovative rainwater management methods based on new intensity-duration-frequency curves will be required along with the construction of high-capacity storage facilities to avoid floods and overflows. Given a framework in which meteorological data is constantly evolving, it will be necessary to re-examine design flows in light of environmental effluent goals so as to keep the standards for the discharge of waste-water treatment plants up-to-date.

Reconciling uses

Establishing watershed-based management structures (BAPE, 2000; Rousseau *et al*., 2000) could play a key role in reconciling water uses. To illustrate, in some drainage basins in southern Québec (such as the Ottawa River) drinking water and recreational needs of downstream communities are considered and integrated into the planning of hydroelectricity generation. This way of operating reminds us that water management requires that all users and most sectors of the economy adjust their processes to promote sustainable development. In light of this, it should be emphasized that Québec's new national water policy is committed to the progressive implementation of integrated watershed management (MENV, 2002).

Evaluation framework

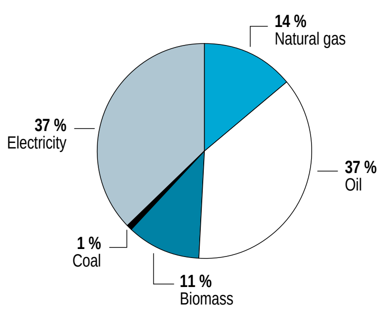
Impact analyses and the elaboration of strategies for adapting to climate change require climate and hydrological data that are more detailed and on a much finer scale than those currently provided by coupled general circulation models (CGCMs). In this regard, in the coming years we will be able to use results for Québec of climate simulations from the Canadian Regional Climate Model (CRCM, v3.6; Laprise *et al*., 2003; Frigon *et al*., 2002; Caya and Laprise, 1999). These results, generated in the framework of Ouranos' regional climate modelling project, could be used as a framework for hydrological, hydraulic, limnological, and hydrogeological modeling. In the meanwhile, it is possible to determine the future sensitivity of water supply systems by using scenarios derived using disaggregation techniques on data derived from general circulation climate models, currently under development at Ouranos. These techniques will allow the construction of scenarios of precipitation changes including, for examples, extremes and variability while quantifying the associated uncertainty. One can also make use of "spatial parallelism," in which regions are identified whose current climate is analogous to the expected future climate in the region under study. Combining these two approaches allows us to obtain a better sample of the plausible scenarios and their potential impacts. Finally, it would be necessary to have access to credible scenarios for the socio-economic development of the main regions of southern Québec.

Owing to its industrial structure, climate, the extent of its territory and, to some extent, the North American lifestyle of its population, the Québec economy is very energy intensive. In 2000, the industrial sector alone accounted for 40 per cent of energy demand, transportation a further 27 per cent, and the commercial, institutional, and residential sectors used the remaining 33 per cent.

Québec has the advantage of being able to draw over 37 per cent of its energy requirements from electricity that is, for the most part, generated from hydraulic resources—a renewable and pollution-free source. This partially explains Québec's excellent performance, on the Canadian and North-American scale, in matters of greenhouse gas emissions. In 2000, Québec's emissions amounted to 12.3 tonnes per capita, compared with 23.5 tonnes for Canada and 24.8 tonnes for the United States. As for natural gas and oil, they respectively made up 14 and 37 per cent of energy used in 2000, with biomass and other non-conventional energies providing the remainder. In total, Québec's energy demand approached 1700 PJ (petajoules) in 2000, and is expected to grow by nearly 0.9 per cent annually until 2021, or about 15 PJ per year. As to electricity demand, which reached nearly 180 TWh (terawatt hours) in 2000, it is expected to rise by over 46 TWh between the present and 2026.

Figure 24

Québec's energy balance sheet
(Ministère des Ressources naturelles, 2001)



Increasing temperatures will have two direct and opposite effects on energy demand, depending on the season: reduced heating needs in winter and increased air conditioning needs in summer. The relationship between temperature, heating, and air conditioning in the residential sector is well known, and has been the subject of numerous studies over the course of recent decades, notably in the context of energy efficiency studies and analyses of demand forecasts (Ministère des ressources naturelles, 2001).[13] However, less is known about heating and, in particular, air conditioning requirements in the commercial and institutional sectors.

Heating needs are essentially proportional to the number of degree-days.[14] Thus, a 10 per cent decline in the number of degree-days entails a 10 per cent fall in heating requirements. However, energy demand will not decrease by 10 per cent, but rather by 12 per cent, owing to the heat emitted by residential electrical appliances[15] (free heat). Air conditioning requirements are also a function of degree-days, but the relationship is less direct, since not all households and firms use it during hot weather, nor do they all seek to maintain the same temperature or comfort level. Also, the penetration rate of air conditioners[16] is expected to increase in step with household wealth and the age of the population. Similarly, the energy intensity of each unit will vary with its characteristics and the temperature to which it is set.

According to the MÉDÉE model (Ministère des ressources naturelles, 2001), if the expectations described in Chapter 1 concerning higher summer and winter temperatures in Québec over the next 100 years materialize, residential heating needs will fall by 15 per cent and air conditioning needs will increase nearly four-fold (see Figure 25). Since air conditioning constitutes a much smaller share of Québec's energy use than heating, the 5.6 PJ increase in air conditioning will be more than offset by the 31.9 PJ decline in heating, resulting in a fall in energy consumption of over 26.3 PJ.

13 The Ministère des ressources naturelles du Québec periodically publishes analyses of the evolution of medium-and long-term energy demand.

14 Heating degree-days measure the difference between the mean temperature for a given day and a reference temperature—expressing domestic heating needs. The reference temperature used is 18° C. Air conditioning degree-days are identical to heating degree-days, except that they measure domestic air conditioning requirements during the hot summer months. In general, air conditioning needs are proportional to the positive divergence from the 18° C threshold.

15 Range, dryer, dishwasher, and light bulb.

16 Heating degree-days for Montréal are provided as a reference. However, decreases and increases in demand were individually computed for each region.

Figure 25

Impact of higher temperatures on Québec's energy demand for residential buildings
(Ministère des Ressources naturelles, 2003)

Year	Heating degree-days in Montreal[17]	Difference from 2001 (%)	Heating demand (PJ)	Difference from 2001 (%)	Air conditioning degree-days	Difference from 2001 (%)	Air conditioning demand (PJ)	Difference from 2001 (%)	Net difference (PJ)
2001	4 575		209.05		237		1.94		
2020	4 456	- 2.60	202.50	- 3.13	268	13.08	2.61	34.53	- 5.88
2050	4 280	- 6.45	192.86	- 7.74	317	33.76	3.97	105.15	- 14.15
2080	4 108	- 10.21	183.39	- 12.27	370	56.12	5.88	203.67	- 21.72
2100	3 994	- 12.70	177.16	- 15.25	409	72.57	7.51	288.04	- 26.31

In 2001, the demand for heating and air conditioning in the commercial and institutional sectors were 121.1 PJ and 9.2 PJ, respectively. Air conditioning's share is greater in these sectors than in the residential sector. By 2100, climate change is expected to result in a 12.70 per cent decline in degree-days in the winter, yielding energy savings of about 13 per cent (or 15.7 PJ), since there is less free heat in these sectors. Rather than quadruple, like in the residential sector, air conditioning requirements are projected to double in the commercial and institutional sectors, representing a 9.2 PJ rise. The net outcome under these assumptions is a 6.5 PJ fall in energy demand.

Ultimately, higher temperatures, under the average scenario of Figure 8, are expected to reduce overall heating and air conditioning related energy demand across all sectors by 32 PJ, or to 9.4 per cent of 2001 levels. Since heating is the principal component, the peak period load (the most costly to meet) on Québec's electricity grid and natural gas network will end up falling more. Overall, it could be a matter of annual savings that grow to reach several hundred million dollars.

Conversely, we foresee that, in the markets south of Québec, reduced heating requirements will be more than offset by increased air conditioning needs in summer. According to a study for the New York metropolitan region (Center for International Earth Science Information Network, 2000)—conducted with models assuming a constant humidity level—heating demand will fall by 20 to 40 per cent, while air conditioning will increase 45 to 135 per cent, A higher level of humidity will have the effect of increasing the elasticity between the demand for air conditioning and the temperature. Since air conditioning is essentially electric, summer peak demand will increase progressively and substantially (between 7 and 17 per cent) over the course of the upcoming decades, thus rendering the generation, transmission, and distribution of electricity more vulnerable.

Adaptation strategies

Turning down the heater does not, in and of itself, require any particular adaptation. Conversely, the increased use of air conditioning could be mitigated by some simple steps to reduce the flow of heat into residences, such as planting trees and installing blinds, as is done in tropical countries. The application of more reflective external coatings could also help. These simple solutions could contribute to reducing the use of air conditioning and also increase comfort levels in residences that have none. Also, the use of energy efficient cooling systems, such as fans and evaporative cooling, reduces the reliance on more energy intensive systems, by either delaying their use or eliminating the need for them. Since the lifespan of residences often exceeds 50 years, it would be wise to design them with an eye to the expected impact of climate change and, if necessary, the eventual installation of the most efficient air conditioning systems available.

Energy demand is one area in which the state of our knowledge is actually quite advanced and in which the models are by and large satisfactory, owing to considerable concern about energy security. However, it could still be quite useful to better understand the reaction of power grids to a higher frequency of extreme climate events, and to study the consequences of various alternative climate scenarios.

17 Heating degree-days for Montréal are provided as a reference. However, decreases and increases in demand were individually computed for each region.

As to our neighbours to the south, using the generation capacity of networks further north presents an interesting avenue for potentially satisfying their increased energy requirements in the summer—to the extent that the appropriate electricity transmission grids can be set up. Indeed, hydroelectricity produces far fewer greenhouse gas emissions, and thus possesses an enormous advantage over the fossil fuels that are widely used in the energy systems bordering on Québec. Thus, while globally reducing GHG emissions, this altered environment opens up the possibility of developing new external markets for hydroelectricity.

A discussion of how to satisfy Québec's energy needs with different forms of energy exceeds the scope of this document. Nonetheless, any adaptation strategy designed to globally optimize reducing GHGs while developing economic opportunities in internal and external markets will have consequences for the relative use of different forms of energy. For example, we could envisage a scenario in which more natural gas is used for heating in Québec, freeing up more electricity for export and entailing a decrease in GHG emissions stemming from the use of coal to generate electricity elsewhere in North America.

TRANSPORTATION

The transportation sector plays a vital role in Québec's economic activity, as well as in individuals' lives. Indeed, transportation is an important element of competitiveness in Québec's access to outside markets. Domestically, transportation is essential for most commercial activities, work, and recreation. In this sector, climate, in both its mean and extreme values, exercises a non-negligible influence on land, maritime, and air transportation. One need only consider the extent of disruptions to air and land transportation caused by blizzards. This influence varies by region and by the nature of the transportation infrastructure. Our understanding of the concrete and quantifiable ways in which climate change will affect transportation activities and infrastructures in Québec is, however, little developed. To date, only a few studies have examined potential impacts. Concerns about the impact of climate change pertain to infrastructure in the first instance, then to the conditions under which transportation will need to operate.

Expected impacts

The warming of the climate will cause a rise in sea levels, a change in precipitation patterns, and higher temperatures that will be accompanied, owing to milder winters, by an increased frequency of freeze/thaw alternations and freezing rain. Observations that have been made so far suggest that the impacts may vary considerably between transportation modes (road, maritime, rail, and air) and regions. Furthermore, climate events, either individually or jointly, can influence the frequency of natural phenomena—such as mudslides, avalanches, rockslides, floods, high tides, and storms of varying intensity—which can in turn have a severe impact on the efficiency and lifespan of transportation infrastructures in all regions of Quebec (Environment Canada, 1997c).

Thus, it is foreseeable that, in Québec, the integrity of transportation corridors located in zones that are already sensitive to inclement weather, or that are subject to a potentially non-negligible risk, will be negatively affected by climate change. In particular, road transportation infrastructures in metropolitan and urban environments are vulnerable and could sustain considerable material damage. The floods in the Saguenay (1996) and the major ice storm in southwestern Québec (1998) provide striking illustrations of the damage that can be incurred by transportation infrastructure during this type of event. Moreover, during the ice storm, bridges and other structures were particularly difficult to de-ice, endangering the security of motorists. Also, several roads and one highway were closed.

The section titled "Coastal erosion" covers the issue of potential damages to the road network in coastal regions—these are caused by several factors working in conjunction, including the rise in the sea level and the amplification of wave action and storms associated with cyclonic activity. According to the medium scenario of the IPCC, sea levels will rise more than 30 cm over the century. Furthermore, the most recent results from general atmospheric circulation models for Canada indicate that by the year 2045 the Gulf of Saint Lawrence will be ice-free in winter. This will increase the frequency of unusually high waves. All of these phenomena will contribute to erosion of the shores and increase damage to road infrastructure located on or near the coast (Forbes, D.L. *et al*., 2002). Port facilities could also be affected.

For example, we observe that the main road along the coast of the Gaspé Peninsula (highway 132) is increasingly threatened by the retreating shoreline in several locations. Interventions to create bulwarks are costly. The frequency with which protective interventions are required is constantly growing. Most of the damages to protective works along the main road occur during violent storms, which are as sudden as they are unpredictable. Thus, we anticipate that climate change may amplify these phenomena, which will be compounded by other significant factors attributable to activities occurring far from the shore, such as river regulation, deforestation, agricultural drainage, and farming (Morneau, F. *et al*., 2001).

In Québec's north, several "all season" roads will be vulnerable, since they were constructed in areas of permafrost (Environment Canada, 1997c). In a few villages in Nunavik, some elements of the airport facilities are already showing accelerated signs of degradation caused by the thawing permafrost (see the section on "Québec's Arctic Region").

Maintenance of the transportation routes, or winter viability

In terms of the costs of maintaining transportation routes in the winter, several studies present generally positive forecasts of the direct impacts of the expected changes. Indeed, according to the predictions of climate models, winters will be shorter and milder—contributing to reduced expenditures on road maintenance. The Ministère des transports du Québec's annual snow removal budget, for the roads under its jurisdiction, is approximately $180 million. Warming of the climate could result in a considerable reduction in these costs. Here again, however, scientific data in support of that assertion tend to be scanty and not specific to the regions of Québec.

However, winter maintenance costs attributable to more frequent incidents of freezing rain could increase, since they would be more expensive and difficult to manage. The appearance of this new precipitation regime will increase the level of tension within maintenance crews. Furthermore, more salt will be used on the roads, with negative impacts such as corroding structures. Also, road surfaces will sustain greater damage, owing to the increased frequency of the freeze/thaw alternation as temperatures tend to hover around the freezing point.

Scientific data in this area are generally rare and not specific to Québec's regions. Furthermore, the available observations suggest that the impacts will vary considerably by region.

Shipping

One of the major transportation-related problems caused by climate change is the anticipated decline of the water level in the Saint Lawrence River (see the section "The Saint Lawrence River"). In the absence of appropriate adaptation strategies, this decline in water levels could have serious economic impacts. For example, as the underkeel clearance declines in some places, lower water levels will make it necessary to reduce tonnages in the short term, and so increase the number of ships if an equivalent quantity of freight is to be transported. A reduction in tonnage, which has sporadically occurred in recent years, implies less competitive maritime transportation. Conversely, the potential extension of the shipping season in ice free water could result in less damage caused by ice to ships and a reduced use of icebreakers by the Coast Guard.

Impacts on the use of transportation modes

The IPCC report mentions that an increase in summer precipitations could result in an increase in traffic accidents and injuries. Even if less abundant on average, precipitation causes more accidents in a dryer environment than in a generally more humid climate. Extreme heat waves could also cause asphalt and concrete road surfaces to deteriorate and warp railway tracks. Motor vehicles will also be more vulnerable to overheating. Conversely, according to Adams (1997), mechanical breakdowns and the real costs of operating vehicles will be considerably reduced during cold temperatures.

Adaptation strategies

The transportation sector should start taking into account data on climate change as soon as possible. To do this, information on the expected impacts should be gathered so as to better define the direction and planning of adaptation activities as well as strategies for improving safety. Also, this sector will have to quickly adapt to the evolving levels and forms of precipitation and changes in the levels of Québec's water bodies.

As for coastal erosion, coordinated land and transportation infrastructure management strategies need to be developed. Depending on the particularities of each region and the evolution of the issues, various strategies—protection, relocation, or zoning—could be implemented. In a framework of integrated planning, they should also aim to minimize environmental impacts. An intervention strategy focussed on safeguarding the equilibrium of littoral dynamics should also consider the preoccupations of the local population.

Concerning the far-reaching impacts of a decline in the mean level of the Saint Lawrence River, several adaptation measures are conceivable downstream in the Montréal–Trois-Rivières corridor. These measures involve federal and provincial government bodies, as well as shipping lines and other private organizations whose activities are closely linked to the Saint Lawrence River (see the section "The Saint Lawrence River").

In order to keep the shipping community well informed on the anticipated depths of the navigation channel, efforts to monitor and forecast levels could be increased all along the Saint Lawrence River. The International Joint Commission could also intervene, adjusting the outflow from Lake Ontario to meet the needs of commercial shipping by supplying some centimetres as required. The reference chart data used for navigation might also require a downward adjustment, and marine charts updated to integrate the new configuration of port facilities and the navigation channel.

The available means of adapting to reduced depths include diminishing tonnage, increasing the use of ships with a shallower draught, and decreasing speeds to minimize squat. Moreover, to increase the available depth of the shipping channel and ensure the prescribed underkeel clearance, renovating infrastructures, reconfiguring port facilities, and over-dredging some sections of the shipping channel will need to be considered. It is necessary to implement management practices that can guarantee the sustainable development of a strategic, competitive port system. centred on high quality infrastructures suitable for cabotage and intermodal freight transfer.

Knowledge of the real and quantitative impacts of climate change are quite rare. To better comprehend the impact of climate change, it is necessary to access climate data specific to each region of Québec, in particular in terms of winter road serviceability and maintenance and transportation safety.

Five areas of research are priorities in terms of the transportation sector:

- determine the vulnerabilities of transportation activities by identifying the known and expected impacts of climate change through the acquisition and inventorying of the relevant data and parameters;
- evaluate how increased coastal erosion caused by rising sea levels in conjunction with more numerous and extreme meteorological events will affect transportation networks so as to identify the required measures;
- identify the new geomorphological conditions that will arise as the permafrost thaws, so as to determine their impacts on road, maritime, and airport facilities in northern Québec;
- evaluate the requirements for ensuring the future of shipping on the Saint Lawrence River and of its infrastructures through a better understanding of expected fluctuations in the water levels;
- determine what adjustments will be needed to practices that depend on winter variability as a function of the new conditions resulting from changes to the precipitation regime and freeze/thaw cycles.

One of the greatest concerns to the population at large arising from climate change is its impact on health and mortality. This may also be one domain in which a better understanding of the upcoming changes could contribute to implementing adaptation measures allowing a significant reduction of the expected impacts (World Health Organization, 2000, 2001, 2003).

Expected impacts

In terms of human health, the impacts of climate change will vary from one region of Québec to the next. Higher temperatures and more frequent extreme events, along with indirect impacts created by the increased presence of pathogenic agents, will all have an affect on Quebeckers' health.

Climate warming will have both positive and negative repercussions. Thus, milder winters may have a beneficial impact: reducing morbidity and mortality caused by the cold. This would lower the incidence of cardiovascular diseases and deaths. On the other hand, hotter summers with longer heat waves, especially in the south, may increase mortality rates for respiratory and cardiovascular ailments, though a progressive acclimatization would significantly reduce the initial impact. For example, the 1995 heat wave in Chicago resulted in 85 per cent more deaths than occurred during the previous summer. The considerable rise in death rates in Europe during the heat wave in the summer of 2003 should also be noted.

Across the province, there could be an increase in infectious diseases, stress, the level of social and psychological tensions, and risks to workplace health. The elderly and children will be the most vulnerable (Institut national de la santé publique du Québec (INSPQ), 2003), along with those suffering from respiratory and cardiovascular problems, workers (both out- and indoor), and disadvantaged urban populations, such as lower income and homeless people. In particular, those with no air conditioning will be the most threatened: In Montréal, the rate of penetration of air-conditioning in residences is only 20 per cent, compared with 60 per cent in Toronto.

More specifically, in the south climate warming may cause an increase in air pollution (contaminants, pollens, and spores) and probably in the frequency and intensity of smog alerts.[18] An upsurge of respiratory illnesses (asthma and hay fever) and cardiovascular diseases constitute the most likely negative impacts on health. Several studies conducted in Montréal have shown significant increases in deaths attributed to respiratory illnesses (on the order of seven per cent), as a function of levels of ozone and fine particulates during several of the episodes examined (Goldberg, 2001). Emergency room visits for respiratory ailments may also increase dramatically (by about 20 per cent), particularly involving the elderly (Delfino, 1997). There could also be an incidence on skin cancer related to exposure to ultraviolet radiation, and even premature deaths. While we assume that all Quebeckers will be affected, individuals with respiratory and cardiovascular ailments, as well as neurological problems, will be the most vulnerable.

In all of Québec's regions, the frequency and intensity of extreme events are expected to increase (for example, floods and severe storms), but the zone south of the 55th parallel is the most vulnerable. These events will cause more deaths and injuries, as occurred during the ice storm. They will also create more stress for a certain proportion of the population—studies have shown that, following an exceptional climate event (such as a flood or hurricane), between 20 and 30 per cent of the affected adults show signs of suffering from post-traumatic stress disorder, as measured two years after the event (Maltais, 2001). Extreme events exacerbate psychological and social tensions, also affecting the workplace. While the whole population may be affected, impacts will be greatest in high-risk zones in which these climate events are most likely to occur, such as flood plains, coastal areas, or regions susceptible to freezing rain.

Changes to the geographical distribution of mosquitoes, ticks, and other potential vectors for communicable diseases will be mostly felt in the south of Québec. This could result in a greater likelihood of the emergence of new sources of morbidity brought on by bacteria, viruses, and other vector-borne pathogenic agents. While this will be relevant to everyone, the most vulnerable will be agricultural and forestry workers, individuals suffering from chronic diseases or whose immune system has been compromised, and the elderly.

Higher temperatures, in conjunction with lower water levels, will provide a favourable environment for the development of infectious agents associated with drinking water, swimming, and foodstuffs, altering the local ecology in all regions of Québec. This will lead to significant changes in the incidence of ailments caused by enteropathogenic bacteria and parasites—food poisoning, diarrhea, and other existing infectious diseases—and new infectious diseases could also appear. While no one is immune in this scenario, rural populations will tend to be most at risk, owing to the absence of water treatment outside urban zones and the greater proximity of animals.

18 Heat promotes the formation of photochemical smog from the reaction of nitrogen oxides with volatile organic compounds.

Adaptation strategies

In the industrialized world we tend to gloss over the level of risk and the need to act immediately, secure in our belief that climate problems are only of concern to developing countries. However, everyone on this planet will be affected by changes to the climate—only their magnitude and the tools available to manage them will differ from one region to the next. The preferred measures for reducing the medical impacts of climate change draw on traditional public health strategies, such as increasing monitoring, sensitizing the public and administrators, adapting infrastructures to the new environment, and training interveners.

Thus, the establishment of a real-time monitoring system for some emerging infectious diseases that could be linked to climate change (such as the West Nile Virus) is an excellent example of the first of these measures. A more vigorous epidemiological monitoring of water quality will also be necessary, since heat promotes the growth of pathogenic agents. This measure would complete an update of drinking water regulations and wastewater control. According to the World Health Organization (WHO), monitoring and surveillance are the most basic forms of adaptation. Identifying and developing indicators appears to be a desirable course of action for tracking the impacts of climate change on the environment and human health in a given territory. This, in turn, provides the basic conditions under which a monitoring program can be put into place.

Sensitization of the public also plays a major role. Indeed, air conditioning and maintaining hydration are the best solutions to rising temperatures and longer heat waves. In this context, let us recall that the air conditioning penetration rate is much lower in Montréal than in Toronto. Since acclimatization is vital, changing lifestyle habits during these periods can also have an impact on the repercussions of heat waves. The establishment of a monitoring/alert system for oppressive heat could also be promoted as a complementary strategy. These measures could be complemented by case-by-case interventions, especially in limiting the use of motor vehicles to control smog, as is done in Ontario.

Other steps to improve infrastructures should also be taken by government authorities, ranging from equipping chronic care hospitals with air conditioning to improving municipal and individual water treatment and filtration systems.

Training health care and emergency response staff is also vital. In particular, attention must be paid to the continuing education of clinicians in the area of emerging diseases and emergency preparedness, as well as better preparation of public health units for handling and tracking exceptional climate events, including teams that ensure epidemiological surveillance.

Adaptation strategies must be proactive, rather than reactive: Natural disasters, like the Saguenay flood in 1996 and the ice storm in 1998, provide irrefutable proof that an ounce of prevention is worth a pound of cure. Up-to-date municipal emergency procedures, as well as the identification of vulnerable populations, are essential and must be part of the adaptation strategies.

The current state of knowledge

All of the authors of the principal studies on this subject agree on one point: The available information on the sensitivity of human health to the anticipated vagaries of the weather and climate change is very limited. This gap exists in both scientific and traditional, or folkloric, knowledge, which is required in some regions to complete the picture.

The quality of data on the environment and health must be improved. To alleviate the deficiencies of scientific understanding of the environment and health in some regions, in particular where the population is thinly spread, specialists having received the appropriate training should make observations and conduct consultations locally. [19]

It would be desirable to conduct impact-specific studies for the territory of Québec that resemble those currently examining the issues of drinking water in Nunavik and contaminants, pollens and spores in southern Québec. In all such endeavours, it will be necessary to account for all impacts on the human elements of ecosystems, such as human health, lifestyle, infrastructure, and socio-economic elements. In this regard, a multidisciplinary approach is also called for to unite the efforts of specialists from various domains: environmental science, biomedicine, and social and behavioural studies—especially with regard to impacts of climate change.

Several authors (Last *et al.*, 2001; Smith *et al.*, 2001) suggest establishing risk levels specific to each population group (elderly, children, natives, homeless, etc.) that account for where they live. To establish the appropriate level of risk, several factors need to be identified: population density, level of social, economic, and technological development of the group under study, overall state of health, local environment, quality and availability of healthcare, health network, and level of preparation for emergencies.

19 A team constituted by the Public Health Research Unit of the Centre hospitalier universitaire de Québec (CHUQ) and the l'Institut national de santé publique du Québec (INSPQ) is currently working on developing this kind of data gathering network for Nunavik and Labrador (Northern Ecosystem Initiative, 2003).

Many studies only discuss the negative impacts of climate change, omitting the positive aspects. While it may contribute to the appearance of a vector-borne pathogen in a given region, a warmer climate can also extend the growing season for some crops, thus contributing to increased wealth and food security in the same region. Finally, few studies have touched on psychological and social impacts.[20]

Internationally, the sharing of knowledge and research results is particularly important. On this matter, the healthcare sector is already well organized in Canada (C-CIARN Health Node), as well as internationally (CHUQ participation in the WHO collaborative programme).

TOURISM

Tourism is one of the largest sectors of economic activity liable to be directly affected by climate change, whether negatively or positively. Tourism generates more output than many other industries, and it creates many jobs. Climate is very often one of the primary natural resources on which tourism is based, whether directly (sunshine, balmy weather, snow and ice), or indirectly (landscapes and plant life), especially in terms of outdoor recreational activities. It determines the duration and the nature of the activities, be it snow and cold for skiing and snowmobiling, water for swimming and other nautical activities, or the colour of the foliage for autumnal hikes in the forest. Finally, climate also has an impact on the condition of wild game and fish for hunting and fishing.

Expected impacts

According to one study, a 1° C rise in temperature would increase tourism revenues by four per cent in Canada, while a cooling of the same magnitude would only have a marginal impact in the winter (Wilton and Wirjanto, 1998).

However, such broad generalizations can be misleading, since a variety of factors come into play. Thus, the weight of each tourist activity within the whole package affects overall seasonal sensitivity, while the response of each activity to the temperature varies by season. While some activities, such as cultural tourism, are little (or less) subject to the vagaries of the climate, others, such as outdoor activities and sports, are much more so. Consequently, for each outdoor recreational activity specific to each season, there will be different thresholds that must be analysed separately. Finally, even if climate change were beneficial for tourism, other associated phenomena, such as coastal erosion or water shortages in lakes and rivers (Wall, 1998b), could negatively affect the industry.

At first sight, however, substantial losses are a real possibility in the case of skiing. Thus, the warming associated with a doubling of GHG concentrations is expected to cause a notable shortening of the season, especially in the spring (Wall, 1998a). Studies in the lower Laurentians suggest that the ski season will be cut by 34 to 49 per cent (McBoyle and Wall, 1992) and even between 42 and 87 per cent (Lamothe and Périard, 1987). A subsequent study of this industry in Ontario yielded less draconian results, with an estimated reduction ranging from 21 to 34 per cent depending on the climate model used (Scott *et al*., 2002). Investments in snowmaking equipment have substantially reduced the vulnerability of ski resorts to the whims of the climate. It is even possible that some ski resorts will benefit from the difficulties climate change creates for others that are further south or at lower elevations. Conversely, other activities, such as snowmobiling and cross-country skiing, which do not have access to the same resources, could be more severely affected by the shortening of the season—possibly by as much as 50 per cent in some regions. Also, ice fishing is highly vulnerable to climate warming, and increased risks to those who practise it are foreseeable.

As to summer activities, negative impacts could specifically result from more precipitation or a greater number of days of extreme heat. Similarly, maintaining golf courses could prove more costly if the increased evapotranspiration caused by warmer temperatures dries out the ground, especially in the summer months. Swimming may also be affected by a deterioration of the water quality. Fishing of several species that are sensitive to small variations in temperature could also be seriously disrupted, particularly in terms of their reproduction.

20 A first workshop on behavioural modifications attributable to climate change was held in Québec City in August of 2002 (Gosselin, 2002).

Adaptation strategies

Ski resorts already possess the means to adapt that will help them address moderate changes to the climate like those expected over the coming decades. Here again, depending on each activity's unique thresholds of tolerance to various climate parameters, adaptation strategies may vary widely. For example, in the case of downhill skiing, snowmaking equipment is only effective to the extent that temperatures remain at acceptable levels. Conversely, there is no apparent solution for snowmobiling and cross-country skiing. Solutions will probably be found in the development of a wider range of leisure activities adapted to the changing climate, responding to both consumers' needs and the requirements imposed by sustainable economic development.

Another approach consists of developing alternate vocations for these sites, reflecting their climate conditions. For example, cross-country skiing and snowmobiling could be emphasized in regions that are less sensitive to the warming trend, while technological adaptation could be encouraged for downhill skiing.

As to summertime recreational activities, several means are available to mitigate the negative effects of warming. These vary from sowing plant cover on the banks of watercourses frequented by sports anglers to increased monitoring of water quality in areas reserved for swimming. Adaptation strategies should also include the provision of equipment capable of meeting increased demand, which could result from climate warming, or extended operating hours.

More comprehensive studies that detail the expected impacts and potential adaptation strategies are required. Indeed, there are relatively few studies available on the impacts of climate change on tourism—the existing research and documentation deals mostly with the sustainable development of tourism related activities, the evolution of the market for tourism and recreational activities, territory-based marketing, and the construction of tourist areas. As to these impacts, while there are several broad-based studies on economic impacts by region, they are few in number, probably because of their cost, and they do not usually deal with the phenomenon of climate change. In the case of ski resorts, in particular, climate scenarios on a finer scale would be required since impacts can vary considerably depending on the region and the elevation.

Despite the fact that significant progress has been made in understanding the difficulties that agriculture and forestry will face adapting to climate change, the same cannot be said for tourism and recreational activities. Adaptation requires a deep understanding of the actors—the promoters and managers of the activities and infrastructures of tourism and recreation—in order to know how much relative weight to give to climate change for each scenario, tolerance thresholds by activity, and various spontaneous or planned adaptation possibilities. As to consumers, or the users of tourism infrastructures, it would be wise to identify their reactions to different climate thresholds for each activity and the appeal each one holds relative to the others under the new climate conditions.

Extreme climate events are becoming more and more of a concern around the world. Statistics on losses, both economic and in terms of human lives, are staggering. It would be good to know whether the rising loses in recent years are attributable to an increase in the number of extreme events, or only to society's greater vulnerability to them. Indeed, the very definition of an extreme event is at issue. Should they only include events that fall into the five, or even one, per cent tails of the distribution for a given aspect of climate (such as temperature or precipitation), or should any event having extreme consequences on the financial or human level be counted? Are the extremes a matter of distribution, or intensity? Also, events that are not extreme in terms of meteorological statistics may well be seen as such from the financial or human perspective given the right confluence of socio-economic factors.

Our vulnerability to extreme events is increasing because of population growth, urbanization, and our greater dependence on communications, transportation, and energy transmission infrastructures, and also because of the ageing of these networks.

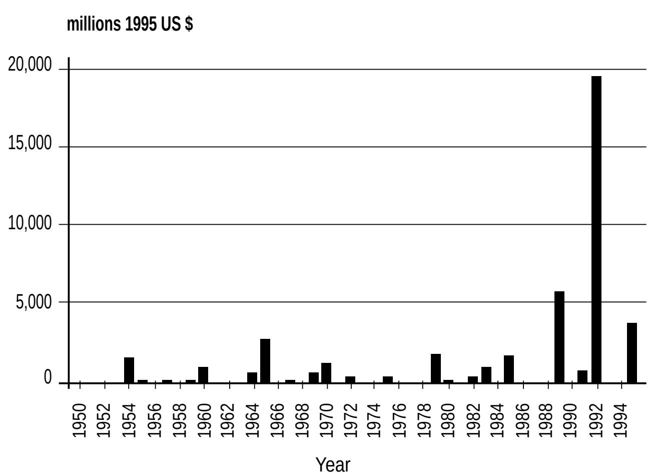
In the case of Canada, as for most other developed economies, the losses will be mostly financial. Thus, the drought of 2001–2002, the most costly climate event to date, was evaluated at five billion dollars. Québec has experienced two other costly events: the ice storm of 1998 ($4.2 billion) and the Saguenay flood of 1996 ($1 billion). Furthermore, the ice storm caused the deaths of 25 people and left 3 million without electricity or heat for several days or, in some cases, several weeks.

Another example of this phenomena are the losses related to hurricanes in United States, where they are the most expensive extreme events. Figure 26***a*** shows the history of insured financial losses attributable to hurricanes in the United States from 1950 to 1995, in 1995 U.S. dollars (Pielke and Landsea, 1998). The growth rate appears to suggest that in recent decades hurricanes have become more frequent and disastrous than they used to be, causing several billion dollars worth of destruction In fact, the frequency of hurricanes actually seems to be diminishing in recent years. This growth trend in costs should not, then, be attributed to a rise in the frequency or violence of hurricanes, but rather to society's increasing vulnerability to them.

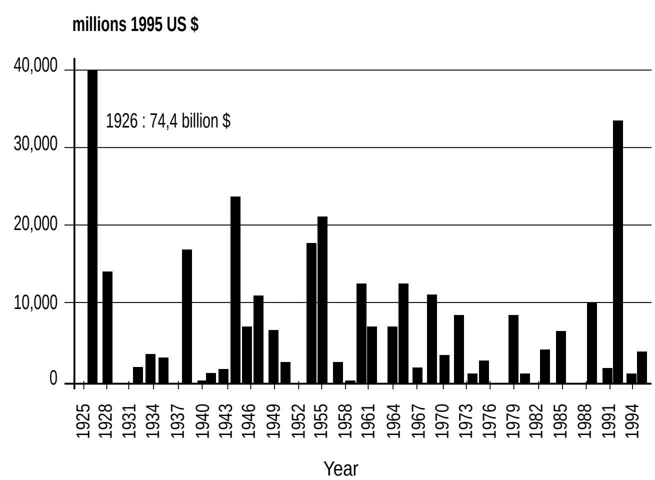
Figure 26***b*** presents losses from 1925 to 1995, normalized over this period. This normalization is based on the assumption that losses are proportional to three factors: inflation, population, and wealth. Normalization proceeds by evaluating losses associated with each hurricane as if it had occurred in 1995. The normalized data reveal that losses equivalent to several billion dollars can be traced back several decades—not just to the recent past. According to this data, there were seven years during the 1940s and 1960s during which losses would have exceeded 10 billion dollars, compared with only one during the 1970s and 1980s. The researchers conclude that "The data further refute recent claims that the rapid increase in non-normalized damages are due to climatic changes. When inflation, wealth, and population changes are taken into account, instead of increases, normalized damages actually decreased in the 1970s and 1980s." This brings us back to the concept of society's vulnerability, which we will pick up on further down when discussing extreme climate events.

Figure 26

a) **Annual hurricane damage (United States) 1900–1995** (Pielke et Landsea, 1998)



b) **Annual hurricane damage (United States) 1925–1995 Normalized to 1995 values** (Pielke et Landsea, 1998)



The greater vulnerability is real and based on facts, while the higher frequency of extreme events caused by climate change is less well established. Any analysis of the impact of extremes on society must account for these two factors. Indeed, it remains a challenge to establish the relative weight of these two factors in the near future in terms of the impact extreme events may have on the economies of Québec and the eastern seaboard of North America.

For example, the annals of Jean-François Gaultier, a king's physician in New France in the 18th century, mention that an ice storm on December 22 and 23, 1748, coated the roofs and walls of the houses of Québec City with eight centimetres of ice. The impact of such an ice storm on an industrialized city in the 20th century would have been much more dramatic, owing to the growing vulnerability of modern societies to the vagaries of climate. To illustrate, the ice storm that struck Montréal in January 1998 was the second most costly natural disaster in Canada. Thus, we see that society's vulnerability to extreme climate events is an essential component of the study of these events.

Expected impacts

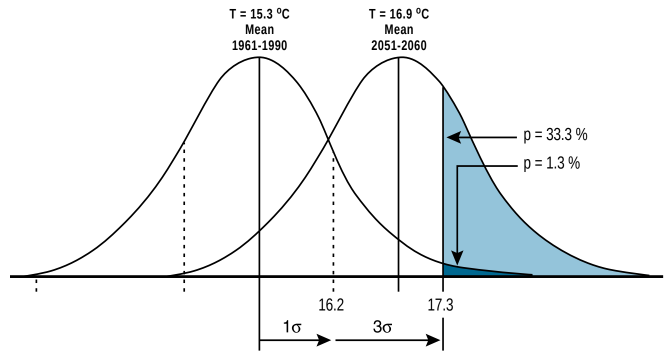
Even in the absence of human-activity induced climate warming, the level of vulnerability to extreme events would remain a vital question. However, this phenomenon adds a new variable to the study of the impacts extreme climate events have on society.

Various studies have dealt with variability in temperatures and precipitation and emphasized extreme climate events, using continent-wide instrumental data from the last one hundred years. One of these (Karl *et al*., 1995), using data from hundreds of stations in the United States, China, the ex-Soviet Union, and Australia, covers the period 1911–1994. It appears that the intra-seasonal variability of temperatures over a period of less than 30 days generally fell in the Northern Hemisphere over this period, with a statistically significantly decline in the case of the United States. Furthermore, the proportion of daily precipitations in the United States occurring during extreme events (>20 mm/day) increased substantially, while the proportion of mild (1–5 mm/day) and moderate (5–10 mm/day) events fell. This works out to an average of one additional extreme precipitation event every two years.

For several climate variables, including temperature, the distribution of frequencies approaches the normal, or Gaussian, curve. Climate change could thus alter the mean and the variance. For example, a change to the mean implies higher maximum temperatures, but not necessarily a change in variability (see Figure 27). On the other hand, a change to the variability with the mean constant would cause more frequent extremes of cold and heat, and also increase the value of these extremes. A higher mean and greater variability is also possible, which would result in more frequent heat waves and fewer spells of intense cold. Often it is difficult to determine whether changes are caused by a modification to the mean or the variability. As to meteorological variables whose frequency does not resemble the normal, or Gaussian, distribution, the situation is even more complex.

Figure 27

Impacts of climate change on the frequency of extreme climate events (Environnement Canada)



The extremes of a meteorological variable are found in the part of the distribution called the tail (see Figure 27). The impact of changes to the frequency of extremes can be surprisingly far-reaching for apparently small deviations from the mean. In other words. the tail of the distribution can change disproportionately subsequent to a small change in the mean. Now, it is frequently changes to the extremes, and not the means, that most affect ecosystems and human habitats.

Climate models provide us with an idea of the changes to the frequency of extreme events that higher temperatures will cause. For example, with twice the concentration of CO_2, extreme precipitations will increase over most of the globe (Zwiers and Kharin, 1998). To date, analysis of data on extreme precipitations in Canada since 1990 have not shown a net rise in their frequency (Zhang *et al*., 2001). For example, time series on the mean number of intense spring rains for four regions of Canada (West, Centre-South, Centre-North, and East) are characterized by a strong inter-decade variability. Conversely, there is a statistically significant upward trend in eastern Canada (including Québec). It is possible that the climatic warming trend witnessed in Canada during the 20th century was only a foretaste of the atmosphere's response to global warming, and that the changes to extreme events have not yet become apparent. More detailed work is absolutely essential for determining the nature of extreme events in a world with a warmer climate.

Adaptation strategies

Several adaptation strategies are available to society to confront extreme climate events. In each case, a better evaluation of the risks constitutes a vital element of the strategy.

The first type of strategy involves land management: It is frequently less expensive to simply refrain from building on land that is subject to flooding, erosion, and violent winds than it is to build structures that are resistant to these weather hazards. A large share of the increased damages suffered in recent years is attributable to the use of land that is less suitable to development, in particular in floodplains or on the shores of watercourses and the ocean.

The second type of strategy consists of redefining construction standards for buildings and infrastructures, in terms of their capacity to resist wind and precipitation in the form of rain, snow, or freezing rain, for example. The extreme climate events of recent years have already impelled government authorities and industrial associations to review their standards in light of a greater probability of such events. Protective works could also be constructed, in particular with regard to coastal erosion. In some cases, large projects, such as the Red River Floodway in Manitoba, could also play a part in shielding the greatest areas of vulnerability. While this approach requires supplementary funding, it is generally less expensive than compensating the damages.

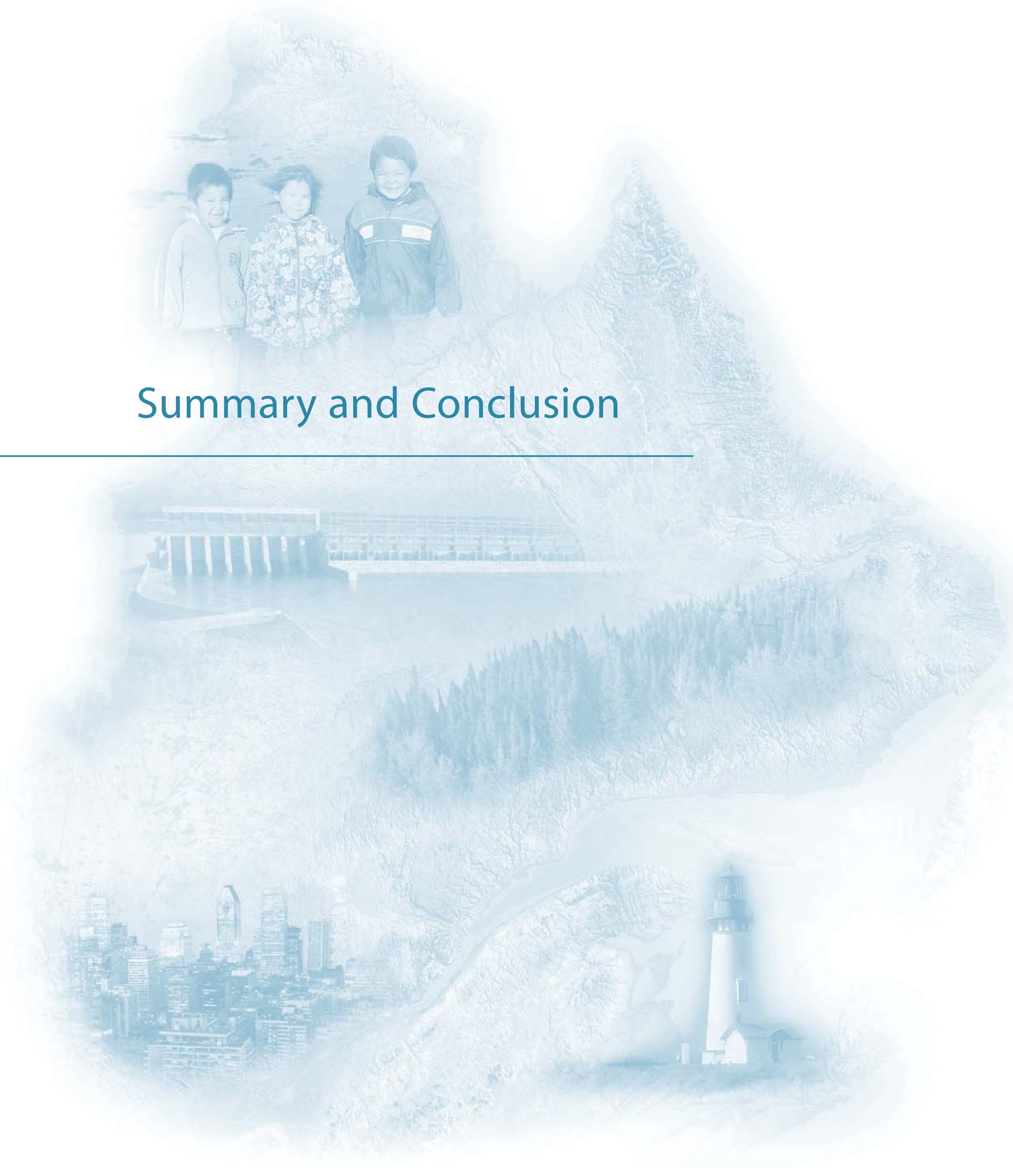
Finally, improved weather forecasting, allowing extreme weather alerts (hurricanes, floods, and tornadoes) to be issued earlier, and updated emergency response plans are also effective means for reducing the costs of these events, in both financial and human terms.

However, since it will never be possible to prepare for every eventuality, instruments of financial compensation and insurance will continue to play an important role. At present, governments provide the bulk of compensation for natural disasters. If these were to increase substantially, other financing mechanisms might be envisaged. For the financial industry to be able to fully play its role, while still ensuring its viability, it would be necessary to establish more precise evaluations of climate risks and obtain a better appreciation of the costs associated with extreme events. More generally, an increase in these risks might also lead the industry to develop new products in the form of insurance derivatives based on climate indicators.

Characterization of extreme events relies on the availability of long series of historical data that, by definition, are rare. The longer the series, the more confident we can be that a given extreme climate event is abnormal. Instrumental data for North America with a broad spatial coverage is available for about 100 years. Further back, the data is more sporadic, both in terms of space and time. Data from this earlier time includes personal records kept by individuals and derived data, such as that obtained from dendrochronology (examining tree growth-rings).

In addition to being rare, extreme events—and their impacts—are often very localized. Thus, it is necessary to have available data with a high spatial resolution to characterize them. For example, the 1996 floods in the Saguenay resulted from high levels of precipitation in an area covering 5,000 km^2, or less than one square in the modelling grid of general atmospheric models. These models are entirely appropriate for simulating the overall behaviour of the climate system, but they are inadequate for establishing the small-scale characteristics of several extreme events. Thus, it is vital to establish the relationships between extreme regional events and broad circulatory flows in the atmosphere, so as to be able to derive the characteristics of small-scale extreme events from broad atmospheric currents.

Summary and Conclusion



The magnitude and speed with which the climate has warmed over the course of the past century are unprecedented in human history. In particular, the climate of the Northern Hemisphere has warmed by nearly 0.6° C, on average, since the beginning of the 20th century, and the decade of the 1990s was the hottest ever. Unlike some other warming phases that have occurred in the past, this one is observable across the entire planet.

As the Intergovernmental Panel on Climate Change (IPCC) has stated, this rise in temperatures is essentially attributable to the increased greenhouse effect caused by an accumulation of concentrations of greenhouse gasses (GHGs) in the atmosphere since the beginning of the industrial revolution. Since 1750, the concentration of CO_2 has risen by 30 per cent, reaching 367 ppm in 2000. Seventy-five per cent of this growth in emissions is attributable to the use of fossil fuels (coal, oil, and natural gas), while the remainder comes from changes to land use patterns, for example deforestation. Concentrations of several other GHGs, some of which did not even exist before industrialization, are also increasing.

RISING EMISSIONS

CO_2 emissions will continue to rise over the course of upcoming decades, according to a relatively broad range of scenarios. Though we may reasonably hope for a certain degree of stabilization of emissions from the industrialized world in the long term, owing to a levelling of populations and evolving technologies, it is important to bear in mind that rising GHG emissions in developing economies, especially the Asia/Pacific countries, will be increasingly prominent in the global balance. Now, over the coming decades, these countries, with their substantial demographic weight, are clearly to experience a lot of catching up in terms of living standards, and can thus be expected to substantially increase their GHG emissions. Under the various IPCC scenarios, CO_2 concentrations will rise from 367 ppm in 2000 to a level ranging from 540 to 970 ppm in 2100—between two and three and a half times their concentration during the pre-industrial reference period (280 ppm).

Current projections of global energy consumption suggest that, over the next 25 years, greenhouse gas emissions will increase by two per cent annually. This is consistent with scenarios in which CO_2 concentrations will be equal to four times the reference concentration (4 x CO_2) by the end of this century or the beginning of the next. Moreover, in most of the scenarios elaborated by the IPCC, CO_2 concentrations would not be stabilized and would continue to rise during the next century. Stabilizing concentrations at a constant level is made more difficult by the fact that oceanic and terrestrial systems require hundreds of years to take up CO_2 levels exceeding their equilibrium absorption capacity.

Concentrations of three to four times the reference level are likely to drive climate changes that are difficult to predict and highly nonlinear, and that pose a danger of tipping our planet's climate into a system creating enormous, or simply unacceptable, adaptation costs and difficulties. It is vital that mitigation measures be taken to avoid reaching these concentrations. The goal should thus be to try to stabilize CO_2 concentrations at approximately twice the reference levels (2 x CO_2). This would require successive commitments equivalent to over ten times the goals of the Kyoto Protocol, which only provides for a reduction of emissions of at most five per cent from industrialized economies and those in transition.

Consequently, one needs to accept the fact that it is virtually inevitable that we will have to adapt to a new planetary climate under the effect of greenhouse gas concentrations, which will have at least doubled relative to pre-industrial levels.

AN INEVITABLE INCREASE IN TEMPERATURES

Under the various scenarios, global temperatures will rise by an average of 1.5° to 6° C over the course of the century. In northern latitudes, the increase could be about 40 per cent higher than the average. Furthermore, in the medium and higher latitudes of the north, precipitations are is expected to increase over the course of the second half of the 21st century. These changes will probably be accompanied by greater variations across time and regions. In other words, the gradual changes envisaged on the global scale are liable to be sudden and chaotic on the regional scale.

As to Québec, various climate models predict that, under a mid-range scenario, by the end of the century, summer temperatures will rise 2° to 3° C in the south (below 50° N), while precipitation will increase between 0 and 5 per cent. In the north (above 50° N), the same rise in temperatures will cause precipitations to increase by 5 to 10 per cent. Winter temperatures will rise more, by about 3° to 4° C in the south, accompanied by a substantial jump in precipitation of 10 to 20 per cent, while in the north temperature increases of 4° to 5° C will be associated with 10 to 25 per cent more precipitation, falling in the form of either rain or snow.

However, we should recall here that the spatial resolution of global climate models is approximately 400 km. Consequently, these models can only indicate trends for a region the size of Québec. Only the use of a regional model with greater spatial resolution could, for example, identify the local impacts of the proximity of large water bodies and mountains on large-scale atmospheric circulations, such as the jet stream and the trajectory of storms and anticyclones. In addition to having available a climate model with greater resolution, it would also be necessary to account for increased evaporation associated with warmer temperatures to evaluate the impact on various sectors of activity, such as the forests, agriculture, or hydroelectricity generation.

THE IMPACTS BY REGION

To better measure the impact of climate change, it appears necessary to consider all the affected sectors as well as expected developments in the human and natural environment. Indeed, only a global approach will allow the multiplicity of phenomena to be placed in context and the combined impact to be understood. It is also useful to integrate the analysis by using shared assumptions on the evolution of the principal climate parameters. Such an approach would allow cumulative and crossover effects between sectors to be accounted for.

Covering about 1,700,000 km^2, Québec is immense. From south to north, Québec stretches over about 2000 km, and from east to west, about 1500 km. Consequently, changes to the climate will be quite different in the various parts of the territory. Information on the topography and geological formations, on the climate and vegetation zones, and on the population, the economy, and employment leads us to consider the issue of climate change in Québec from the perspective of four distinct regions: Québec's Arctic Region, Resources Region, Maritime Region, and Southern Region. In each of these regions the impact of climate change is liable to be felt differently, owing in part to variations in its extent, but also to the distinct manner in which the natural and human environment will react to it.

Québec's Arctic Region

Québec's Arctic Region will probably experience the greatest changes in terms of the climate and alterations to the environment, especially with the expected melting of a large proportion of the permafrost. Even though the affected population is small, constraints particular to this area, notably its remoteness, geographic dispersal, and climate will render the adaptation process more complex.

The thawing of the permafrost

In this region, it is the thawing of the permafrost that is of greatest concern. In areas in which the permafrost is relatively thin and its temperature near 0° C, this thaw could be very rapid, being slowed only as the latent heat is absorbed by melting ice. In some cases, the stability of existing constructions cannot be ensured, creating risks for residences, buildings, and infrastructure. Compaction and landslides could result on slopes, endangering nearby dwellings. Villages that are partly or totally built on clayey soils with a high ice content may be vulnerable to severe damage and require mitigating and adaptation measures, which may include more or less sweeping relocations, in the next few years. Furthermore, new construction and development will henceforth need to account for the warming of the climate and the inevitable degradation of the permafrost that will ensue. These changes to the arctic environment will also have consequences for ecosystems, and thus indirectly affect native populations subsisting on hunting and fishing. The changing period of snow cover will disrupt access to the land and alter the duration of hunting and fishing seasons, as well as their yields.

The Resources Region

Further south, in the Resources Region of the Laurentian Plateau, blanketed by coniferous forests, the potential impact of climate change on large reservoirs and extensive forestry operations is at issue. These resources are of great importance to both Québec as a whole and to the inhabitants of this region. The vastness of this territory makes it necessary to account for climate phenomena unique to each sub-region or watershed.

Forests

Several studies have revealed that an increase in temperatures and CO_2 concentrations could have a positive impact on the growth and productivity of various species of tree. On the other hand, climate change could also favour the growth of noxious insect populations, diseases, and an upsurge in extreme climate events, such as freezing rain, storm gales, and drought. Similarly, depending on the period examined, not all studies conclude that there will be a higher fire risk, but increased dryness in conjunction with more storms would normally be expected to result in a greater frequency of forest fires. The forestry industry is such a key part of Québec's economy that any impact of climate change on the forests would necessarily have far-reaching repercussions for Québec society.

Unfortunately, our grasp of the impact of climate change on forests is currently patchwork and incomplete. Studies on some plants' reactions to environmental change have been conducted, but their response in their actual environment and under competitive pressures from other species remains to be seen.

Hydroelectricity generation

Québec has, at its disposal, an installed electricity generation capacity of over 40,000 megawatts (MW) that supplies more than 41 per cent of its total energy requirements. Over 80 per cent is from hydroelectricity plants located north of the 49th parallel in the Resources Region. Québec has a remaining theoretical potential of 45,000 MW, much of which could be added to current generation.

From the perspective of both economics and Quebeckers' energy security, it is clearly important to determine the impact of climate change on the currently installed generation capacity. It is also important to account for this when planning future installations, since the time constants of the evolution of the climate correspond closely with the planning horizon for large hydroelectric stations. Moreover, since hydroelectricity presents enormous benefits compared to the use of hydrocarbons from the perspective of reducing greenhouse gas emissions, there should be an added incentive to develop its full potential in the upcoming decades.

Currently available climate scenarios suggest that, despite higher temperatures, the hydrological balance would actually leave more water in the reservoirs of northern Québec. Nonetheless, it must be borne in mind that the global climate models currently used for these evaluations are hard pressed to accurately capture climate conditions in northern Québec, surrounded as it is by water and subject to changeable weather patterns—such as the North Atlantic Oscillation (NAO)—which global models have difficulty accounting for. For example, a prolonged absence of ice on Hudson Bay is expected to promote inflows into the northwestern part of Québec. Moreover, the NAO weather regime that has been dominating northern winters for a number of years now is detrimental to spring inflows, which are essential for runoff. Thus, it is vital to dedicate substantial efforts to developing tools and models that will yield a better understanding of these various phenomena and that have a finer spatial resolution so as to better anticipate the climate of the upcoming decades for the different regions of Québec.

The Maritime Region

As to the Maritime Region, rising sea levels, the shortening of the freeze-up season, and the possibility of more intense storms could exacerbate the problem of coastal erosion.

Coastal erosion

Developing adequate strategies for adapting to these new conditions, whether in terms of zoning, relocation, or protection of the shores, requires having reliable data on hand concerning geological conditions, sea levels, and wind patterns. Sea level data are numerous but incomplete, since to date they have essentially been collected to meet the needs of shipping safety or to document port infrastructure improvement projects. In Québec, the issue of erosion has never been the subject of close scrutiny or specific measurement campaigns. The absence of an analysis of the recurrence of storms is a major shortcoming for the design of protective works, which various Québec government departments are now attempting to compensate through new programs and measures.

Like the population, the transportation axes and economy of this region are highly concentrated on the rim of the Saint Lawrence Estuary and Gulf, and the impact could be severe. The fact that the population generally wishes to live near the shoreline exacerbates this problem. Increasing coastal erosion will have significant impacts, especially in terms of municipal infrastructure and road maintenance costs, but also in damages to waterfront residential and commercial properties.

Québec's Southern Region

Québec's Southern Region, located in the lowlands of the Saint Lawrence and the Appalachians and home to the bulk of the population and economic activity, will be affected in various ways. Agriculture, tourism, land and maritime transportation, energy demand, water management, health, human habitats, and ecosystems are all aspects that will be directly and indirectly affected in this region.

Ecosystems and biodiversity

The conservation of ecosystems and biodiversity is one of the main concerns in the context of climate change. Even more than human economies and environments which, thanks to technology, are in a position to adapt to all manner of change, natural environments are in danger of being overwhelmed by the speed and extent of the changes. Some of the most threatened animal species live in Québec: migratory birds that use coastal wetlands and arctic environments, amphibians and reptiles, and some species that make use of the arctic ice. The rapid warming of the arctic presents a unique challenge to the terrestrial and aquatic fauna of this region. In addition, aquatic ecosystems and wetlands bordering lakes and rivers are liable to be particularly threatened, owing to the falling levels and rising temperatures of the water that may result. Finally, higher average sea levels will increase the salinity of some sections of the Saint Lawrence River and the mouths of several of its tributaries, in which the water is currently brackish or fresh, and thus disrupt aquatic fauna and flora and the wetlands of the Maritime Region.

The Southern Region, characterized by great biological diversity, is in danger of being particularly affected. Crossed by the Saint Lawrence River, its landmarks include Saint-Pierre Lake, a World Biosphere Reserve and home to several of the most endangered aquatic species. In this region, in particular, higher temperatures and other environmental stresses attributable to widespread and predominant human activity, along with a decline in the size of habitats, could lead to the disappearance of several animal and plant species as climate change overwhelms their ability to migrate. It is impossible to predict whether the destroyed habitats will be replaced by new types of habitats that are equally diversified, or whether similar habitats may become established elsewhere.

Agriculture, land and maritime transportation, and tourism

Some industries, such as agriculture, transportation, and tourism, will need to re-examine how they do business so as to reduce costs caused by climate change and to take advantage of opportunities that may arise.

As to agriculture, impacts will vary considerably depending on the specific activity: grain crops, forage plants, fruit trees, horticulture, or animal husbandry. These changes may have consequences for the profitability of agriculture, depending on the adaptation strategies implemented. Water availability will be one of the main problems climate change poses for this industry. Indeed, it appears that the proper choice of crops will allow agriculture to adapt to warming quite effectively if it can count on good irrigation.

Temperature and humidity play determinant roles in the geographical distribution of weeds, pathogens, and agricultural entomofauna. Under the new climatic conditions, we expect the arrival of new species and changes in populations that threaten crops. A greater variability of temperatures and precipitation will have both positive and negative impacts on host/parasite interactions. Additional efforts will be required to ensure that systems for predicting disease and insect crop pests are effective under more variable climatic conditions. More than in any other sector, agriculture will need to adapt: from changing farmers' ways of doing business to adjusting insurance programs to deal with greater climate uncertainty.

In transportation, the main challenges are: –to determine the measures required to ensure the integrity of transportation infrastructures in light of greater coastal erosion caused by rising sea levels and an increase in the number and intensity of extreme meteorological events; –to evaluate the requirements for ensuring the future of shipping on the Saint Lawrence River and its infrastructures through a better understanding of expected fluctuations in water levels; –to identify what adjustments will be needed to practices that depend on winter variability as a function of the new conditions resulting from changes to the precipitation regime and freeze/thaw cycles; –and to measure the impacts on the road, maritime, and airport facilities in northern Québec attributable to the new geomorphological conditions that will arise as the permafrost thaws.

Tourism is one of the largest sectors of economic activity liable to be affected by climate change, both negatively and positively. Climate is very often one of the primary natural resources on which tourism is based, whether directly (sunshine, balmy weather, snow and ice), or indirectly (landscapes and plant life). For instance, in light of rising temperatures, ski resorts may need to make additional investments to maximize their snow cover. Other winter activities in southern Québec, such as cross-country skiing and snowmobiling, could face growing problems. On the other hand, some other recreational activities could be well served by the warming trend, including nautical activities, golf, other outdoor sports, and even strolling through the woods, benefiting the entirety of Québec's tourism industry.

Human health and energy demand

In terms of human health, hotter summers with longer heat waves and a deterioration in air quality, especially in the south, could increase mortality rates and respiratory and cardiovascular ailments, though a progressive acclimatization would significantly reduce the initial impact. There could be an increase in infectious diseases, stress, the level of social and psychological tensions, and risks to workplace health. The elderly and children will be the most vulnerable, along with those suffering from respiratory and cardiovascular problems, workers (both out- and indoor), and disadvantaged urban populations, such as lower income and homeless people. Recent events in Europe have demonstrated the extreme vulnerability of some populations to a dramatic and sustained rise in temperatures.

The preferred measures for reducing the medical impacts of climate change all draw on recognized public health strategies, such as increased monitoring, sensitization of the public and administrators, adapting infrastructures (water treatment facilities, public and private buildings) to the new environment, training interveners, and conducting research in the field. Since acclimatization is vital, changing lifestyles and working habits (especially in the case of physical labour) during these periods can also have an impact on the repercussions of heat waves. The establishment of a monitoring/alert system for oppressive heat would be a complementary means to be promoted, as would a significant bolstering of a surveillance system for acute illnesses that are connected to extreme events and zoonotic diseases. Finally, air conditioning and maintaining hydration are the best means of coping on the short term with rising temperatures and longer heat waves. In this context, it should be borne in mind that the air conditioning penetration rate is much lower in Montréal than in Toronto.

As to energy demand, heating needs are expected to decrease in the residential, as well as in the commercial and institutional, sectors, while air conditioning requirements will rise. Nonetheless, since energy consumption for heating requirements in Québec far exceeds that for air conditioning, climate change should translate into a reduction in overall demand and an even greater decline in the peak load, the most costly to meet. Altogether, it could be a matter of incremental annual savings reaching several hundred million dollars. Conversely, we foresee that, in the markets neighbouring Québec to the south, reduced heating requirements will be more than compensated by increased air conditioning needs in summer, leading to an expansion of export markets.

Water management

The combined changes to temperatures and precipitation levels will, in all likelihood, reduce flows in the main tributaries of the Saint Lawrence River during the period from July to September, possibly creating difficulties for municipalities that draw their water supply from them and forcing them to adapt their supply system. Seasonal ebbs and flows in the volume of water and in spring runoff caused by changing rainfall patterns will have direct consequences for the transportation, residence time, and dilution of pollutants, as well as on the temperature and, by extension, the quality of the water.

In the case of urban drainage, climate change may translate into an increase in the frequency of extreme precipitation events, which can, if rainwater management is inadequate, cause storm drains to backup and result in floods and untreated overflow into the receiving milieu.

Finally, low flow rates and warmer temperatures, in particular during the summer, could create or exacerbate conflicts over use in several regions of Québec, especially in places where the supply comes from surface waters in lakes and rivers that flow into the Saint Lawrence River. Higher temperatures could result in increased water requirements among urban populations for domestic and recreational purposes, while agriculture, benefiting from the warmer weather, could also have greater irrigation needs. As to the river, choices may become necessary between the needs of shipping, which requires higher water levels in the fall, and municipalities, whose water needs are greater in the summer.

Extreme climate events and natural variability

While there is a great deal of confidence surrounding the foreseeable increase in extreme weather events in the context of climate change, existing climate models do not allow us to precisely predict the magnitude of the increase in these types of events, nor their distribution. Furthermore, recent experience has demonstrated that even medium intensity climate events, let alone high intensity events, have major, and rising, economic consequences. This phenomenon is largely attributable to the growing wealth of our societies. The increasing vulnerability of our societies, springing from the high level of technological dependence that characterizes them, is also an aggravating factor.

THE NECESSARY ADAPTATION

A review of the anticipated impacts and possible solutions reveals that, in most cases, targeted interventions can substantially reduce negative impacts and in some cases even allow considerable benefits to be realized. The implementation of adaptation strategies, which may take the form of better identification of high risk zones, a review of design standards for buildings and equipment, or preventive investments in new production capacity or service infrastructures, may allow the negative effects to be substantially reduced. At the same time, since Québec is a northern region, a moderate warming of the climate would most likely benefit some sectors of the economy especially vis-à-vis external markets. However, this would require identifying the positive impacts and implementing measures to capitalize on these changes.

The design of such measures requires a detailed analysis that is often not possible at this stage of events. In many areas, a high level of uncertainty persists in terms of the magnitude of the impacts, their exact nature, and the speed with which they will materialize. It is important to establish the relationship with historical statistics, bearing in mind that past climate variations cannot guarantee the future and do not necessarily permit a correct estimation of risk levels. In particular, in the case of extreme climate events, it would be unwise to wait until the signal becomes statistically significant before undertaking any actions. Essentially, it is a matter of adopting a risk management approach in an uncertain world.

One aspect that is frequently pointed out is the shortage of precise information available to researchers on both the impact of climate change and on relatively long-term variations. We have data on temperature variations and precipitation for the last century, but the existing historical series are often incomplete and primarily cover locations in the southern part of Québec, while data gathering networks were largely neglected further north.

To evaluate regional impacts, we need forecasts of temperature changes, precipitation levels, and hydrological balances with a sufficiently detailed spatial resolution—the forecasting ability of global climate models is relatively weak at the watershed, ecozone, and urban and rural region level. The identification of adaptation measures, be they irrigation, sowing alternate crops, hydroelectricity power stations, or dredging the Saint Lawrence Seaway, requires this type of forecast with a high level of confidence. In the short term, the best strategy thus seems to be to better identify the vulnerabilities and risks while investing in a climate science that can generate more precise and applicable scenarios on the regional scale.

A GLOBAL SOLUTION

The potential impacts are substantial, and in some cases can already be evaluated. The best approach to dealing with climate change is to reduce greenhouse gas emissions as fast as possible, so as to minimize the expected impacts. That being said, some of these changes have already become unavoidable, to the extent that increased concentrations are already an established fact and reducing emissions to a level allowing concentrations to stabilize will take a long time. It is to be hoped that international cooperation, in conjunction with technological change, will allow changes to be limited to acceptable levels.

Adaptation to climate change will thus be necessary—a phase that is both inevitable and complementary to action targeted at reducing GHGs. To this end, an in-depth analysis undertaken soon would constitute the first step in any true adaptation strategy targeted at minimizing costs or capitalizing on opportunities. This analysis must simultaneously address the evolution of climate data and their relationship to biophysical impacts. In addition, it will be necessary to obtain forecasting scenarios that correspond, over time and space, to any potential sectorial impacts having been identified. While general climate models can be useful for initial evaluations, they are inadequate for establishing precise regional impact assessments. Only regional models with a finer resolution, which are still in the development and testing phase, are liable to yield the relevant answers. While awaiting these models, the identification of vulnerabilities constitutes a first phase of the analysis.

Analysing the biophysical and economic impacts would form the second step of the adaptation strategy. Often changes to the climate can exacerbate a pre-existing or emerging issue. For example, many elements outside of climate change are responsible for threats to biodiversity, while the rising damages associated with coastal erosion are more a function of the growing value of waterfront developments than of climate change itself.

However, this analysis cannot be conducted in isolation, and requires the participation of the largest possible number of stakeholders. This participation is necessary so that the analysis addresses the true issues and identifies the correct indicators of vulnerability. A close collaboration between analysts and the socio-economic actors will also guarantee the implementation of the identified adaptation measures. If the mobilization of specialists is necessary to tackle society's priority issues, it must also involve decision makers.

Adapting to climate change entails a spectrum of solutions that depend upon the time-horizon. They involve sensitizing the affected populations to new ways of behaving, developing adapted products as well as modifying the design criteria for equipment, and defining new policies, programs, and regulations. Often adaptation to climate change can be integrated into measures developed for other purposes and combined with sound risk management practices. Finally, it must be noted that a good part of adaptation is spontaneous, and needs only to be facilitated or guided.

THE OURANOS CONSORTIUM

These factors, considered in their entirety, led to the establishment of Ouranos, a consortium for research into regional climatology and adaptation to climate change. Ouranos is structured as a unique partnership focussed on delivering results in fourteen broad programs that essentially address the issues described in this document. In addition to its own staff, Ouranos has teamed up professionals from many organizations: eight Government of Québec departments, Environment Canada's meteorological service, Hydro-Québec, UQAM, INRS, Université Laval, and McGill University. Many other bodies (universities, foundations, and subsidizing agencies) are involved and contribute to specific projects. Ouranos' activities allow the efforts of over 250 researchers and specialists from several dozen organizations to be combined, and to ensure the cohesiveness of their labours in light of the real needs of decision makers. Nearly one hundred of these researchers and specialists work out of Ouranos' offices in downtown Montréal, near UQAM, McGill University, Hydro-Québec, and several other stakeholders.

Ouranos' mission is to promote the acquisition of expertise that will advance the understanding of regional climate change and of its environmental, social, and economic impacts. The mandate of Ouranos consists of providing precise, forward-looking, and reliable information on the changing climate, and the adaptations this makes necessary, to those whose job is to anticipate and prevent. To this end, it develops and adapts the tools necessary for providing decision makers with detailed climate change scenarios on a regional scale and evaluates expected sectorial impacts in order to optimize adaptation strategies.

One of the first tasks that fell to Ouranos was to construct banks of historical climate data from various sources, so as to have available consistent data on different climate and hydrological variables over the longest possible time and on the relevant spatial scale. This demanding work is indispensable if Ouranos' researchers are to effectively conduct their studies. Ouranos' role is also to supply access to climate and hydrometric databases (basic and derived data and metadata).

Ouranos is also responsible for developing detailed medium- and long-term scenarios for the evolution of the Québec climate. Two complementary approaches are used to produce results at a spatial and temporal scale useful for evaluating impacts on a given region or issue based on low resolution climate models. An initial method relies on using the Canadian Regional Climate Model (CRCM) to translate the results from global climate models to a finer scale. This approach is very promising, but also very demanding in terms of specialized personnel, computing power, and computer storage. Ouranos has a supercomputer that will allow the generation of a first series of simulations, on a scale of 45 km, for all of North America as of 2004. Later, climate change projections for several scenarios of increased concentrations of greenhouse gasses and several versions of global models, which will be fed into the regional model, will be generated to better characterize the uncertainty inherent in these projections. Simultaneously, Ouranos is pursuing work perfecting this regional model , including, among other things, coupling it with models of inland seas and including a multilevel surface scheme and improvements of hydrological flows. The second method for scaling down the output of large scale forecasting models to the regional level relies on statistical methods that establish a link between the results of climate models and historical data for the specific region. This statistical scaling approach can use global models or, if a finer resolution is desired, regional models.

Many projects are currently ongoing on the prioritary subjects and areas described in this document. Given the importance of hydroelectric resources to Québec, Ouranos is paying particular attention to the physical processes that condition the hydrological regime of northern watersheds as a function of precipitation, temperatures, and some climatic phenomena, such as the weather regime. Validation of the CRCM on the basis of historical data for some drainage basins will yield projections of hydrological conditions over the next decades. Other projects address the evolution of the melting of permafrost in the villages of northern Québec, an analysis of the progression of coastal erosion in light of storms and rising sea levels, adaptation strategies for the Saint Lawrence Seaway, and water management systems for municipalities and the agricultural sector. Still other studies bear on the expected impacts of climate change on ecosystems, wind speeds, disruptions to forests, tourism and health.

Ouranos' various activities should thus yield a picture, both global and precise, of the expected impacts of climate change on Québec over the course of the upcoming decades, as a function of various scenarios. This portrait is essential for guiding decision makers in their interventions and investments, so as to better adapt and thus reduce the costs associated with these changes and, in several instances, even benefit from them.

GLOSSARY

Acclimatization:	The process by which a species adapts to a new climate.
Active layer:	The topmost layer of soil that is subject to freeze/thaw alternations and lies above the permafrost.
Albedo:	A measure of the light reflected by an object. Bright objects have a high albedo, and dark objects a low albedo.
Annual storage:	An increase in water reserves during one year.
Baymouth bar:	A small port in the lee of an exposed sand bar.
Birthrate:	The ratio of annual births within a group to the childbearing population of that group.
Blight control:	The set of all practices used to safeguard the health of plants.
Chrysomelid:	Leaf beetle.
Climate forcing:	A disturbance to the earth's energy balance.
Climate regime:	The set of climate variations as a function of the weather.
Corn heat unit:	An indexing system based on the total accumulation of heat during the corn growing season, computed from daily minimum and maximum temperatures.
Cultivar:	A variety of a plant species having characteristics making it useful for agriculture, forestry, or horticulture.
Deforestation:	Changing land allocation from forest to some other use (e.g. agriculture, urbanization).
Dendrochronology:	A method for dating past events or climate changes by studying tree growth-rings.
Ecotone:	A zone of transition between two ecosystems.
Elasticity:	The sensitivity, or reaction intensity, of one value with respect to another. The relationship of the growth ratios of two variables (in percentages): an elasticity equal to 1 means that the value of the first increases in the same proportion as that of the second. E.g. the increase in energy demand for heating and the drop in temperature.
Entomofauna:	Community of arthropods (noxious and beneficial insects, spiders, and mites) in a given environment.
Evaporation (rate of):	The quantity of water transformed into vapour from liquid water bodies.
Evapotranspiration (rate of):	The quantity of water evaporated from the soil and plant transpiration.
Extreme event:	An event that is rare according to the statistics on its occurrence in a given area. While the definition of the term "rare" varies considerably, a meteorological event should normally be at least in the 10, or 90, percentile tail of the distribution. By definition, the notion of an extreme event varies by location.
Fecundity (rate of):	The ratio of live births to the total number of women, or marriages, during a given period, usually one year.

Forage plant:	Any plant serving as livestock feed.
Frazil ice:	Ice crystals or fragments carried by the current and floating on the surface of a watercourse: a film of ice that is starting to solidify.
Green manure:	A crop that is grown for purposes of being ploughed into the soil to protect it from erosion and increase its fertility.
Growing season:	The period during which temperatures, humidity, and luminosity are adequate for growth of a given crop. It varies between species and cultivars.
Hardening off:	A natural adaptation mechanism of perennials, especially with regard to the cold.
Hardwood:	Various species of tree having leaves and whose wood is relatively hard.
Heating degree-days:	A measure of the difference between the mean temperature for a given day and a reference temperature—expressing domestic heating needs.
Hydrological forcing:	A disturbance to the hydrological regime caused by climate change.
Hydrological system:	A drainage basin whose flow is regulated by civil engineering works (dams, plants, or other).
Hydrological:	Concerning the study of water (cycle, balance, regime, condition, event).
Hydrometric network	The set of all hydrological stations and observation posts located within a given zone (drainage basin, administrative region) allowing the study of hydrological regimes.
Isostatic:	Characterizes the rising and falling of the earth's crust in response to changes in its mass, resulting from events such as the formation or thawing of glaciers, the formation of mountains, or erosion and sedimentation.
Limnological:	Related to the study of the biological and physical characteristics of lakes.
Livestock growth rate:	The relative growth rate of an animal, measured as its weight gain during a specific period.
Marine spit:	An elongated littoral formation created by the accumulation of loose materials (sand or pebbles) advancing into the ocean in an arrowhead shape that is pointed only at one end.
Morbidity (rate of):	The ratio of sick individuals to a specific population.
Mortality (rate of):	The ratio of deaths to a specific population.
Multiyear storage:	An increase in water reserves over several years.
Nunavik:	The part of Québec's territory that lies north of the 55th parallel.
Perennial:	A plant that resumes growth from a persisting part each year.
Periphyton:	Aquatic organisms (bacteria and algae) living on the surfaces of underwater plants.
Permafrost:	All soil or rocks whose temperature remains below 0° C for at least two consecutive years.

Photosynthesis:	The metabolic process of plants that uses chlorophyll and sunlight.
Plant protection:	The protection of plants against pests, disease, and weeds.
Probable maximum flood:	The most severe flooding that is likely to occur at a given point on a watercourse, assuming a confluence of the worst meteorological and hydrological conditions.
Radiative climate forcing:	A change to the radiation balance cause by a substance, such as a gas, or a modified albedo.
Raft foundation:	Coating or platform, generally in the arctic, comprised of granular material that covers the soil and serves as a foundation for buildings.
Regulating effect:	A reduction in the gaps between minima, maxima, and the mean, especially in terms of water flows.
Regulation:	The action of managing a watercourse by reducing the differences between periods of high and low water.
Retrogressive slipping:	Slipping of the soil induced by a thaw causing a rigid cliff face to disintegrate in layers and giving rise to slides of debris comprised of sediments and meltwater.
Runoff:	The natural inflow of water during a given period, generally one year.
Run-of-river plant:	Electricity generating plant that is driven directly by a watercourse with little or no artificially retained water. Its output thus varies with the level of flow.
Sapling:	A generic term for a young tree that is larger than a seedling but smaller than an adult tree: stem.
Segregated ice:	Ice formed by the migration of water in the soil to the frozen layer where it freezes into discrete lenses.
Smog:	This word is a contraction of smoke and fog. This pollution is spread through the atmosphere by aerosols, occurring in part naturally and in part from human activity.
Softwood:	A class of trees producing resin and cones (conifers) and whose leaves are needles. Also refers to the wood of these trees.
Spruce forest:	A forest containing mostly spruce trees.
Squat:	A reduction in water pressure under a vessel's hull as a function of its speed, causing it to settle deeper than its static mean draught.
Taiga:	A single-species coniferous forest, comprised of over 80 per cent spruce.
Thermal power plant:	A plant that generates electricity from thermal energy. This type of plant includes, in particular, traditional thermal plants, nuclear plants, diesel electric and gas turbine plants.
Timber:	Wood after an initial transformation.
Trophic:	Concerning the different levels of the food chain.
Troposphere:	The part of the atmosphere lying between the earth and the stratosphere.

Tundra:	A northern territory characterized by the absence of trees and the presence of shrubs, lichen, and moss.
Water deficiency:	The cumulative difference between potential evapotranspiration and precipitation during some period in which the latter is below the former.
Water stress:	The stress caused to plants or animals by water deficiency.
Zoonosis	A disease typically found in animals, but which may be transmitted to humans.

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