CHAPTER 5
Quebec

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KEY FINDINGS

Climate change will have many environmental, public health and socioeconomic impacts. In Quebec, these impacts will differ depending on the particular sensitivities of each region. The extent and costs of climate change impacts will likely increase over time. Key findings include the following:

The extent and magnitude of climate change impacts depend largely on changes in demographic, socioeconomic and environmental conditions. Apart from climate change per se, an analysis of anticipated impacts must also include an analysis of the factors that will affect the vulnerability of each subregion. Accordingly, the following points should be considered:

- From 1960 to 2003, temperatures in southern Quebec increased by between 0.5°C and 1.2°C in the southwestern and south-central areas, and by less than 0.5°C in the southeastern part. In northern Quebec, a gradual cooling has been replaced by a sudden warming of about 2°C since 1993.
- Despite uncertainties, the use of increasingly high-performance climate models makes it possible to produce detailed climate scenarios for several parameters and several regions, all of which point to major changes in climate trends.
- In Quebec, there is a slowing of population growth and an increasingly aging population, except among First Nations and Inuit communities. There has been a population shift from urban centres mainly to the outer edges of developed areas and suburban belts in southern Quebec, resulting in urban sprawl onto high-potential agricultural land.
- Although the general state of public health is improving, the future trend is uncertain due to several factors, including the fact that high-risk populations are becoming increasingly vulnerable.
- Quebec's growing economy is now based primarily on the tertiary (service) sector and is largely integrated into the North American and world economies. In contrast, infrastructure is aging and is largely exposed to the vagaries of the weather. In addition, many communities outside large urban centres are dependent on natural resources and are therefore also highly vulnerable to the vagaries of the weather.

The largest climate changes in absolute terms are anticipated to occur in the northern subregion. They will exacerbate the problems already being experienced in this region with respect to communities' high level of exposure to natural disasters and their dependence on critical infrastructure, access to resources and traditional ways of life that are closely related to the existing natural environment. Terrestrial and aquatic ecosystems have begun to change, specifically in terms of their structure, due to permafrost degradation, the formation of thermokarst lakes and ponds, the expansion of shrub communities and wildlife population displacements.

Climate change will result in alterations to the natural environment with potentially significant implicationsin areas where natural resource development is central to the economy. The landscape, hydrology and geomorphology of streams, the distribution of plant and animal life, and regional biodiversity could all undergo significant changes, particularly in areas already subject to a high level of human pressure. In contrast, this could have a certain beneficial effect, due to an anticipated increase in productivity in certain sectors, such as hydroelectricity and forestry. Nevertheless, these scenarios remain tinged with uncertainty for several reasons: lack of data, conflicting historical trends, poorly understood processes, uncertainties related to the tools used, and North American market effects.

In the maritime subregion, where the coast is highly exposed to the hydrosphere, there will likely be increased shoreline erosion along the Gulf of St. Lawrence and the St. Lawrence River estuary, the area where most of the subregion's socioeconomic activity is currently concentrated. The combination of sea-level rise, the gradual disappearance of surface ice, the geology of certain coastlines and possibly changing storm patterns all appear to result in an increase in the natural process of erosion, causing adverse effects on the built environment, tourist attractions and the quality of life for many communities in this subregion, which depends heavily on waterways for access.

In the south subregion, an increase in the frequency, intensity or duration of extreme weather events is believed to pose increased risks for the aging built environment, vulnerable populations and communities living in areas exposed to natural hazards. Historical meteorological events have shown the high degree of dependency of urban and rural communities on water, energy supply and transportation infrastructure, all of which are exposed to the vagaries of the weather. Milder winters and hotter, more humid summers would lead to increased evaporation of natural waters; this could exacerbate water-use conflicts and lead to further degradation and loss of wetlands that rely on flooding. Climate change also poses significant risks to a number of threatened species already subject to various other stresses; these species have a low migration capacity and their habitat has become degraded. However, in this subregion, climate change could also result in energy savings (reduced demand) and development opportunities (increased plant productivity), resulting in annual gains of several hundred million dollars.

Adaptation to climate change offers many possible solutions to significantly reduce its adverse impacts. Human societies have always demonstrated an ability to adapt to climate variability and seem once again capable of overcoming the obstacles to climate change adaptation, which is based on the following elements: identifying and understanding the priority issues; collecting and disseminating information and data needed by the stakeholders involved in climate change adaptation; developing and applying the optimal techniques and technologies; amending or adapting policies, standards and organizational structures; and considering emerging uncertainties when making decisions. Quebec has a high degree of adaptive capacity, due specifically to its increasingly diversified knowledge economy. As for the natural environment, it adapts spontaneously and autonomously, and human systems may be able to assist with its adaptation. Although adaptation appears to be increasingly inevitable, little is generally known about its costs and limitations, particularly in the long term. Climate change adaptation measures should therefore be accompanied by reductions in greenhouse gas emissions in order to tackle the source of the problem and to minimize the 'nasty' surprises that the weather may hold in store for the future.

1 INTRODUCTION

The objective of this chapter is to update existing assessments (Bergeron et al., 1997; Ouranos, 2004; Lemmen and Warren, 2004) on sensitivity, impacts and adaptation to climate change; this summary of information concerning Quebec should thus contribute to a better understanding of the phenomenon and lead to the discovery of solution pathways.

Figure 1 presents the problem of impacts and shows how atmospheric conditions can directly or indirectly affect natural and human systems, either subtly or suddenly. All climate change impacts can be grouped into three elements that will react and adapt to the new situations (*see* United States Global Change Research Program, 2000). These three 'key elements' are population (human beings), the natural and built environment (their surroundings) and socioeconomic activity (the human dynamic), all of which can sustain direct impacts from changes in mean temperatures, variability and climate extremes, so long as they are exposed and sensitive to them. Moreover, any impact on one element can have repercussions on the other two as a result of indirect impacts; these are generally more difficult to quantify and are responsible for the complexity of overall impacts. For example, consider the effect of extreme precipitation events becoming more abundant: they directly influence the hydrosphere and frequency of sewer overflows and have an indirect influence on the frequency of residential flooding, as well as on public health, utility interruptions and the state of the economy, and thus lead to many other cascading effects. Given the scope of the problem, the Quebec chapter restricts itself to presenting a summary of the most important anticipated issues, based on available documentation.

Figure 1 raises one of the great challenges of this kind of synthesis, which is to choose an approach that makes the classifying and grouping of the many issues possible while dealing with cumulative and cross issues.

Following the 'Introduction', in which general information and concepts are presented, Section 2 briefly describes the current characteristics and evolution of the three 'key elements' under the influence of climate change. Section 3 constitutes the core of this update and outlines the current state of knowledge regarding the four subregions of Quebec and the three key elements. Finally, Section 4 presents a synthesis and recommendations to guide the development of the science of climate change, which includes research on climate, improvement of knowledge on expected impacts and the evolution of everything related to adaptation, an emerging theme of recent years. This science of climate change will become increasingly necessary for effective decision-making.

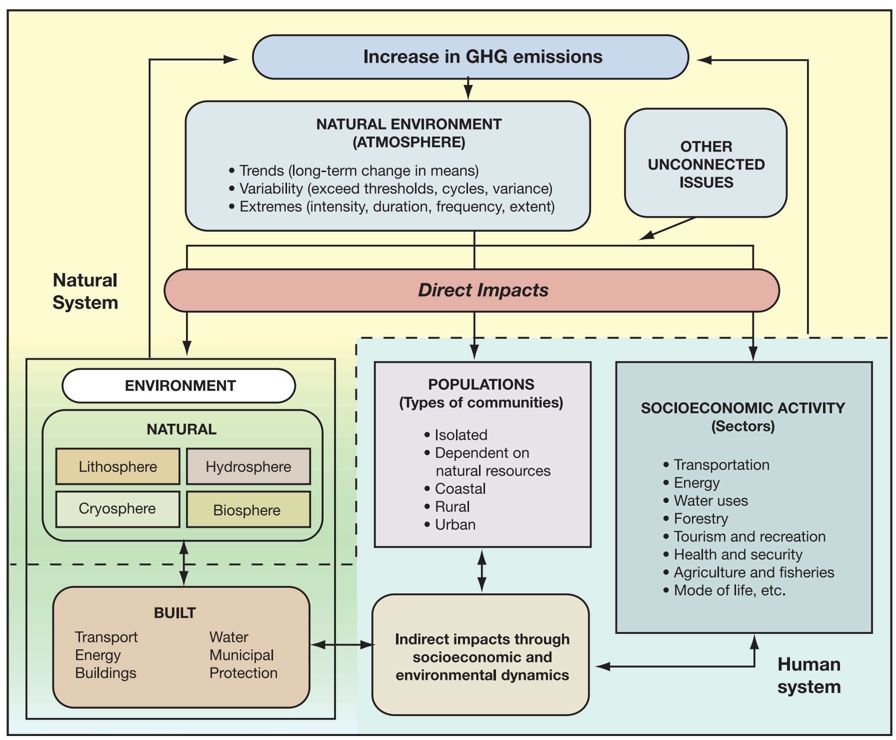

FIGURE 1: Direct and indirect impacts of climate, its variability and its extremes on the three key elements (the environment [natural or built], the population and socioeconomic activity), illustrating the significant influence and complexity of climate impacts. Other issues, such as technological development, societal choices, infrastructure aging and demographic changes, occur in parallel and interact with these climate changes. It should be noted that, in this document, the natural environment refers to the five climate subsystems defined by Peixoto and Oort (1992), in which the atmosphere is the initiator of the climate change that causes these impacts.

2 A CHANGING QUEBEC

With or without climate change, Quebec has never ceased changing over time. Its population, natural and built environment, and socioeconomic activity have transformed over recent centuries, and more particularly in recent decades. Since the nature and magnitude of climate change impacts will depend as much on features of these three key elements, as on climate change itself, it is important to summarize these characteristics, as well as those linked to climate. Before dealing with specific and regional issues related to the impacts of climate change, this section presents the broad features and likely picture of changes in Quebec for the coming decades.

2.1. POPULATION

With a population of 7.5 million (2005), Quebec is the second most populous province in Canada. A large part of its population (82%) is concentrated in the south and along the St. Lawrence River, while the remainder is scattered in other regions where the economy relies more heavily on natural resource development. Quebec is urbanized, with 75% of its population living in 73 cities of more than 10 000 inhabitants — including 54% in the nine cities with more than 100 000 inhabitants, namely Montréal, Québec, Lévis, Gatineau, Sherbrooke, Laval, Longueuil, Saguenay and Trois-Rivières — and its economy is diversified. The rural area (80% of inhabited territory) represents 1.6 million people (22% of the population) living in nearly 1000 villages. Finally, the total Aboriginal population of close to 83 000 consists of 73 000 First Nations people and 10 000 Inuit (Secrétariat aux affaires autochtones, 2006).

In the coming decades, Quebec's population will stabilize in numbers of inhabitants and will show changes in regional composition and age groups. According to the Institut de la statistique du Québec (ISQ), the population will increase to nearly 8 million in 2026 and 7.8 million in 2051 depending on the reference scenario (*see* Figure 2; Institut de la statistique du Québec, 2003). The uncertainty of this forecast is related mainly to assumptions regarding trends in net immigration and fertility that frame the weak and strong scenarios of the ISQ.

Moreover, 12 of Quebec's 17 administrative regions would experience a population decline by 2026. This decline would be even more pronounced in the long term, ranging from –16% to –32%. At the same time, the population of the Montréal region would increase by nearly 450 000 persons (+13%), who will settle primarily in the north and south belts, thus contributing to the trend towards urban sprawl. The Outaouais region would also experience strong growth, with an increase of 13% by 2041. Nunavik would see its population (10 000 in 2001) increase by 28% (13 000) by 2021, mostly due to special features inherent to this area (*see* Section 3.1). The current population is young (in 2004, 56% were under 25 years old) and lives in 14 villages located along the coasts of Hudson Bay, Hudson Strait and Ungava Bay (Institut de la statistique du Québec, 2004). Its growth is already creating strong demand for housing (*see* Section 3.1).

Given these projections, variations in population by age group will be even more pronounced than expected variations in total population in the regions (Figure 3). In fact, because of the ratio between the number of persons older than 65 and those who are younger, demography in Quebec will be completely transformed. In 2051, the number of persons aged 65 and over will exceed 2 million and, in 2026, their demographic weight may exceed 20% in all regions except northern Quebec. In 1996, the Mauricie region, with the greatest number of elderly, had fewer than 15% of persons aged 65 and more. By 2026, only one crescent-shaped area centred on the Montréal region (from the Outaouais to central Quebec) would be showing significant demographic change. As a result, a growing proportion of the population will swell those age brackets often associated with groups currently vulnerable to climate change. These changes will have impacts on the vulnerability of Quebec society, particularly on the financial resources available for health services, which are increasingly in demand (Godbout et al., 2007).

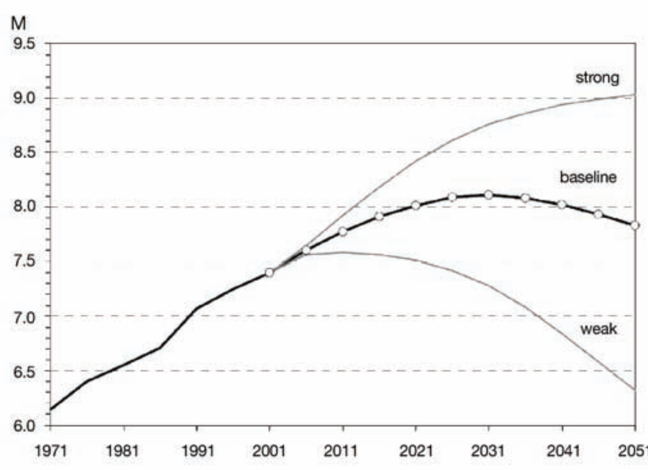

FIGURE 2: Scenarios for total population change in Quebec until 2051 (Institut de la statistique du Québec, 2003).

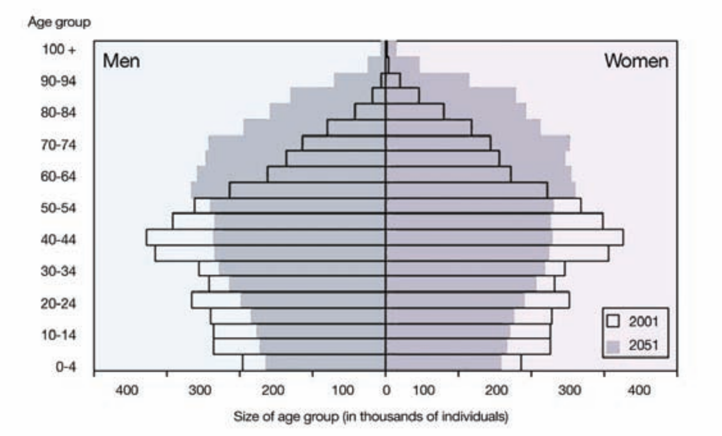

FIGURE 3: Age pyramid of the Quebec population, 2001 to 2051, reference scenario A (Institut de la statistique du Québec, 2003).

The state of health of the Quebec population is changing positively and is well documented for the different administrative regions of the province (Institut national de santé publique du Québec, 2006). Although most socioeconomic and health indicators show a gradual and steady improvement in health, an earlier report identified certain behaviour, perceptions and indicators conducive to a potential increase in vulnerable populations (sedentary behaviour, excess weight, elderly persons living alone; Institut national de santé publique du Québec, 2006). Since then, these trends have not generally been confirmed except in the case of already vulnerable populations, which have seen their vulnerability increase.

Given the slow rate of change in the demographic trends, projections show an aging population, slower growth of urban populations and depopulation of remote regions. Consequently, demographic changes and the state of health will contribute equally to increasing or decreasing the vulnerability of populations to climate change.

2.2. SOCIOECONOMIC ACTIVITY

2.2.1. Economy

Canada's largest province in terms of area, Quebec had a gross domestic product (GDP) of more than $274 billion in 2005 (Statistics Canada, 2007b). Its diversified economy, which is largely export oriented, provides Quebecers with a high standard of living and gives them considerable financial means to address the potential impacts of climate change (*see* Chapter 2, Section 2.3).

Long known for its natural resources, Quebec has seen a profound transformation of its economy in recent decades. It now has a service sector (tertiary sector) in which commercial and financial activities, health and education services, recreation and public administration account for nearly 70% of GDP compared to 30% for goods-producing primary and secondary sectors (Statistics Canada, 2007b). All indications are that this trend towards a service economy will continue, especially in light of continued growth in the information, leisure and tourism industries, and in the health services sector.

Although dominant at the beginning of the twentieth century, the primary sector, including activities such as agriculture, forestry and hunting and fishing, represented only 2.3% of GDP in 2005. In the manufacturing secondary sector, many industries are based on resource transformation, including agri-food and wood processing. The latter industry accounts for nearly 3% of GDP and a sizable share of Quebec exports. In addition, electricity production in Quebec, of which 96% is water-generated, accounts for 4% of GDP and should grow somewhat during the next decade. The same applies to wind power, an industry now flourishing in response to Quebec's new energy policy. Its installed capacity should grow from 100 to 4000 MW by 2015 (Ministère des Ressources naturelles et de la Faune du Québec, 2006a).

The Quebec economy is also characterized by profound differences between its regions. Although manufacturing and service activities play a significant role in providing work and employment in an economically highly diversified southern Quebec, a significant share of direct employment (12% to 20%) in certain other regions is provided by agriculture, forestry, hydroelectricity production and the mining and resource transformation industries. Several hundred communities depend directly on existing natural resources.

This portrait of the Quebec economy should change greatly in coming decades. Based on current demographic and labour productivity trends (+1.6% according to Lafrance and Desjarlais, 2006), Quebec will experience sustained economic growth and double its production in 50 years (Ministère des Finances du Québec, 2005). Households and individuals will see their incomes rise substantially, giving them greater means to satisfy their needs. A rise in education levels and urbanization is also expected (Institut de la statistique du Québec, 2003). In the different administrative regions, demographic change would create important differences in overall and per capita economic growth, compounded by the effects of the different growth rates of the resource industries relative to those of the other economic sectors.

Finally, the production of goods and services will be influenced by changes in trade (new trade agreements, economic development of emerging countries), in technology (demand, production methods or processes) or in the availability and cost of supplies. Although the evolution of certain sectors is easy to project for the first decades, it is less so for the next 50 or 100 years, particularly for industries such as pulp and paper, wood processing and agri-food, which are all subject to rapid socioeconomic changes.

Demographic and sociocultural changes will also have notable impacts on the demand for goods and services, such as an aging population's greater need for health services or that of retirees for recreation, accompanied by the development of technological means to satisfy them. In short, the socioeconomic context will also be quite different from that of the present day and increased links with international markets will result in complex changes (*see* Chapter 9) to the socioeconomic system's sensitivity to impacts occurring in Quebec and elsewhere.

2.2.2. Social change

The evolution of human systems is closely tied to numerous social aspects, ranging from individual perceptions to public policy and social capital (Adger, 2003), along with leadership (Bacal, 2006) and changing values. Beyond the more easily measurable physical and economic impacts, the magnitude of various impacts of climate change will be influenced by changes in perceptions and social values, both of which are difficult to evaluate. Decision-making designed to cope with the impacts of climate change will be particularly influenced by socioeconomic growth, rising education levels, increased sensitivity to environmental protection, communications and the complexities of environmental issues (Bryant et al., 2007). For example, the concerns of Quebecers for environmental quality prompted governments to strengthen the baselines for animal waste management (National Water Research Institute, 2004) and abandon other major projects such as the Suroît thermal power station, and even to enact new legislation for the conservation of water resources (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2002). Scientific research on certain extreme climate events, as well as their media coverage, probably had varied social consequences that were significant yet sometimes difficult to measure. Similar realities and perceptions had previously resulted in Quebec displaying an interest in climate change, starting back in November 1992 when it supported the principles and objective of the United Nations Framework Convention on Climate Change. Since then, Quebec has taken different steps, including the publication of its 2006 to 2012 climate change action plan (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2006) and the adoption of sustainable development regulations, that highlight how it supports a concept that was still relatively unknown scarcely 20 years ago.

On another level, a significant proportion of the population lives in precarious socioeconomic conditions related to employment, demographics and immigration, reduced buying power and the challenge of acquiring a higher education level (Institut national de la statistique du Québec, 2001). This part of the population is concentrated in the large cities and poses particular challenges. For other groups, such as the Inuit of Nunavik and the First Nations communities of other regions, their particular socioeconomic situation will increase or decrease their vulnerability to various aspects of climate change.

Nevertheless, there is every reason to believe that public interest in environmental issues, such as climate change, will increase despite the need to deal with many other rapid transformations, including greater international competition, demographics and technological advances, as well as in issues related to social, educational and individual and collective well-being.

2.3. ENVIRONMENT

2.3.1. Built environment

The built environment has grown rapidly in Quebec since the start of the twentieth century, as a result of urbanization, increased wealth, technological development, population growth and sprawl, and the growing interdependence and complexity of socioeconomic activity. The built environment, usually exposed to the climate, is vulnerable to climate events exceeding an established cost/risk threshold. Assuming a stationary climate, structural engineers incorporate climate data from past decades into infrastructure design intended to meet future needs. Naturally, any change to this stationary climate will affect performance, useful life and safety. Whether the impacts are direct or indirect, a climate event can cause destruction, failure, loss of performance or create an external hazard for all exposed infrastructure.

The grouping by type of infrastructure and buildings that constitute the built environment (Figure 1) is drawn from the *Loi sur les ingénieurs du Québec* (Quebec Engineers Act; Ordre des ingénieurs du Québec, 2006). Transportation infrastructure makes socioeconomic activity possible in many regions (isolated, coastal, urban, rural) using a variety of transportation modes (land [road, rail], maritime, air). Infrastructure related to water resources, such as dams (5144 in Quebec, including 333 large dams, according to the National Water Research Institute, 2004), canals and ports uses the hydrosphere. Infrastructure associated with energy and geology is related primarily to the use or conservation of landscapes. Municipal infrastructure deals with water distribution and treatment, surface water management and waste disposal. Buildings represent by far the largest infrastructure group and shelter people. Protection infrastructure, often described as critical, guarantees the safety of the public, of socioeconomic activity and of the natural and built environment. Well known examples include flood protection structures around the city of Winnipeg and New Orleans, as well as coastal riprap and breakwaters in eastern Quebec. Finally, the natural environment can be developed or modified to maintain or upgrade both it and the built environment (slope under a road or artificial shore).

Built environement, particularly municipal infrastructure, is aging overall and many structures have already exceeded their useful life span (Infrastructure Canada, 2004; Villeneuve et al., 1998; 2004). There is an important need now, and in years to come, for new infrastructure, but more so for refurbishing existing infrastructure, and the massive investments expected and planned for the next decades are already being sought (Statistics Canada, 2006). Due to their unique nature, the northern villages in Nunavik have received sizable investments over the past thirty years or so to acquire municipal, school and business infrastructure, as well as a transportation infrastructure. These villages are not connected to each other or to southern Quebec by a road network and therefore rely on supplies being delivered by boat or plane, the latter for the most part using airports with runways that are unpaved or built on permafrost.

Although the built environment will continue to grow, the trends with regard to aging infrastructure, public investments, demographics and urbanization, as well as the increasing density of southern Quebec, suggest that attention will have to be paid to the refurbishment and replacement of existing infrastructure to meet the needs of an aging population whose activities and socioeconomic interests are different from those associated with the twentieth century. These trends suggest that it will be essential to integrate, where relevant, new climate data or new approaches to future design and refurbishment when considering the future vulnerability of the built environment in Quebec.

2.3.2. Natural environment

Quebec covers an area of 1 667 441 km^2 and is made up of the Canadian Shield (hills, vast forests and many lakes), the clay plain of the St. Lawrence Lowlands and part of the Appalachians. The many cycles of glacial advance and retreat left the land with little relief, rarely exceeding 900 m in altitude. The northernmost part of the province is characterized by tundra vegetation, soil underlain by more or less continuous permafrost and a harsh climate with strong winds in which adapted plants and wildlife have become established. Farther south, the forest cover (757,900 km^2) is dominated by dense boreal forest (73.7%) that shelters considerable wildlife and a great variety of birds. The mixed wood forest, a combination of hardwoods and conifers, covers the St. Lawrence Lowlands and contains a great diversity of plant and animal species. Moreover, with its thousands of lakes and rivers, it is estimated that Quebec holds 3% of the planet's renewable water. Finally, 10% of groundwater underlies inhabited areas and one-third of Quebec is within the St. Lawrence watershed, which supplies 80% of the population (Ministère des Ressources naturelles du Québec, 2006; Le Québec géographique, 2006). Furthermore, Quebec's basic economic and societal needs for a growing quantity (in absolute value but not in percentage of GDP) of products and services is gradually being met by increasing development of natural resources.

With respect to the atmosphere, many climate characteristics, such as mean annual temperature and total annual precipitation (Figure 4), have contributed to shaping the cryosphere, hydrosphere, biosphere and lithosphere of Quebec over many centuries. The largely spontaneous nature of adaptation processes, in natural systems suggests a higher potential for significant direct and indirect impacts following any change in atmospheric conditions. This contrasts with populations and their socioeconomic activities, which are generally less exposed and have a variety of means for anticipating and adapting to climate change, thus creating a situation potentially conducive to more indirect, more complex impacts.

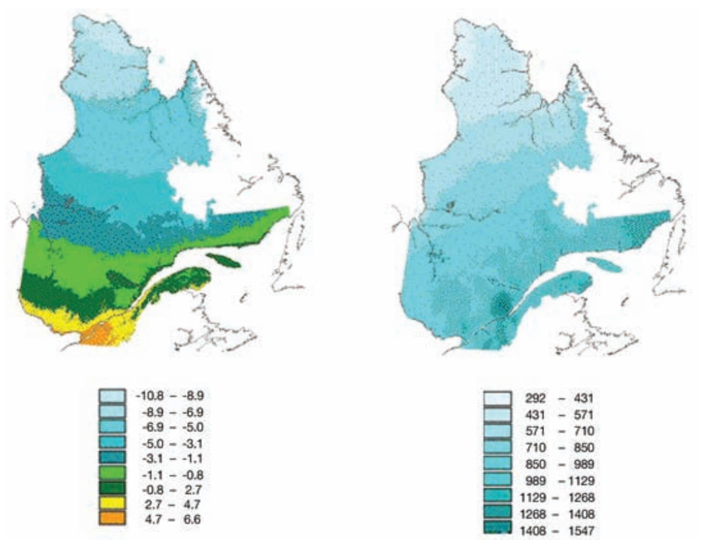

FIGURE 4: Mean annual temperatures (°C, right) and precipitation (mm, left) in Quebec between 1966 and 1996 (Ouranos, 2004).

Human activity has contributed to transforming landscapes, vegetation and wildlife, mainly through population growth and natural resource development. Despite an increasingly service-oriented economy and greater importance placed on the natural environment, human activity will induce further changes, including those related to changing climate. Some conclusions on climate trends and projections for Quebec are discussed in the following section, with detailed discussions of these points found in other documents (Ouranos, 2007).

2.3.3. Climate

In addition to the three key elements (population, natural and built environment, socioeconomic activity), regional and local climate changes will strongly influence the nature and magnitude of impacts and adaptation, responses.

Historic climate trends

Barrow et al. (2004) and Gachon et al. (2005) noted statistically significant rises over many decades in annual temperature, total annual precipitation and number of days of rainfall, but shrinking ice cover.

In recent studies, Yagouti et al. (2006, in press) observed significant warming in several parts of southern Quebec between 1960 and 2003. A marked increase in mean annual temperatures of between 0.5°C and 1.2°C was observed in southwestern and south-central Quebec. This warming trend shows a decreasing west-to-east gradient and, in southeastern Quebec, an insignificant increase of less than 0.5°C occurred over the same period. Most stations recorded that warming occurred more rapidly starting in the second half of the 1990s and was more pronounced at night than during the day, primarily in summer. The most significant warming occurred in winter and summer. For example, in summer, minimal temperature increases in south-central and southwestern Quebec ranged from 0.4 to 2.2°C, whereas the majority of stations in southeastern Quebec recorded no significant trend (Figure 5). Finally, the increase in winter and summer temperatures resulted in a distinct change in several climate indicators, such as growing degree-days, heating degree-days and length of the frost-free season. Readers interested in a more detailed analysis of the evolution of temperatures and the associated climate indicators are referred to the study by Yagouti et al. (2006).

Analysis of homogeneous data retrieved from several stations suggests that the climate in northern Quebec warmed faster than in any other part of the province during the twentieth century. For example, at Inukjuak, where the longest series of climate data has been collected, the trend in the mean annual temperature shows an increase of 2.9°C from 1922 to 2004. However, all northern stations (Figure 6), including Inukjuak, exhibit a flat or even slightly downward trend between 1950 and the early 1990s, followed by an increase of at least 1°C over the 1961 to 1990 normals. As an example of this increase's impact, the temperature of the surface permafrost warmed by nearly 1°C over 10 years at many locations in northern Quebec (Allard et al., 2004).

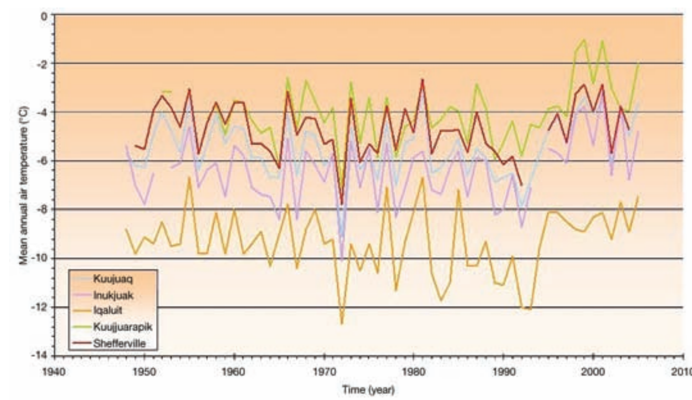

FIGURE 6: Trends in mean annual temperatures for five inhomogeneous stations in northern Quebec (M. Allard, pers. comm., 2006).

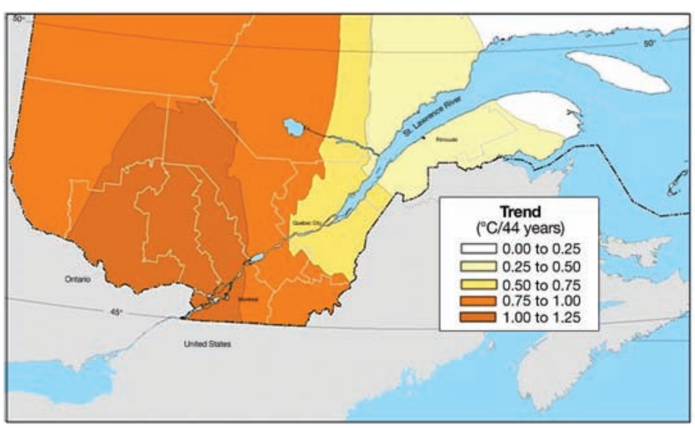

FIGURE 5: Interpolation of trends in mean annual temperature in Quebec between 1960 and 2003. The trends shown here are consistent with analyses done on a continental scale. The large water bodies to the east would explain the east-west difference (Yagouti et al., 2006).

Other climate studies not specific to Quebec (Intergovernmental Panel on Climate Change, 2007) suggest potential climate trends within the province, including:

- increased cloud cover (Milewska, 2004);
- a decrease in mean sea level pressure gradients between northern and southeastern Canada (Gillett et al., 2003; Wijngaard et al., 2003);
- a recent increase in intense cyclones (McCabe et al., 2001; Lambert, 2004);
- a 181 km northward displacement of the average trajectory of winter depressions in the North Atlantic (Wang et al., 2006);
- an increase in fall precipitation (Stone et al., 2000), although interdecadal variability seems to dominate at the global scale (Zhang et al., 2001);
- less availability of water between 1950 and 2002, mainly in central Quebec (Dai et al., 2004; Ouranos, 2004; Déry and Wood, 2005); and
- a number of modifications to the cryosphere, specifically early spring disappearance of snow and ice between 1966 and 1995 (Groisman et al., 2003; Duguay et al., 2006).

Several studies link these observations to indices such as the North Atlantic Oscillation (NAO), particularly for the cold season (Voituriez, 2003), even in the case of temperatures (Wettstein and Mearns, 2002). Higuchi et al. (2000) suggested that the persistence of a positive NAO and El Niño conditions in the Pacific Ocean favour freezing-rain storms in southeastern Canada. An exhaustive description of these studies is, however, beyond the scope of this chapter.

Projected climate scenarios

Following the recommendations in Chapter 2, the seasonal temperature and precipitation changes projected by six global climate models (GCMs) using different scenarios for greenhouse gas emissions are presented for four subregions (Figure 7). Mean changes projected for three decades, centred on the decades 2020, 2050 and 2080, are presented and interpreted in relation to 1961 to 1990 climate normals (Environment Canada, 1993). The four scatterplots (Figures 8 to 11) and related summary tables (Tables 1 to 4) summarize the most recent seasonal projections (for interpretations, *see* Barrow, 2004; Ouranos, 2004; Chaumont, 2005; Chaumont and Chartier, 2005). The regional climate models (RCMs), which simulate dynamics and physics with greater refinement, produce results on spatial and temporal scales of interest for assessing regional impacts (Ouranos, 2004). Increasingly, the results of RCMs, including the Canadian model (CRCM), make it possible to develop more refined projections of climate change (Plummer et al., 2006), hence the inclusion of CRCM results in the scatterplots (*see* Figures 8 to 11).

Overall, mean temperatures would increase for the three climate decades, especially in the cold season. Total seasonal precipitation would also increase, especially in winter and spring. In the southern and maritime subregions, changes in total summer and autumn precipitation remain undetermined, with as many scenarios indicating decreases as increases, and some decreases being as much as 25%. The projected changes generally diverge from natural climate variability simulated by the CGCM3 starting in the 2020s for temperature and much later for precipitation, sometime in the 2050s or even later in the 2080s.

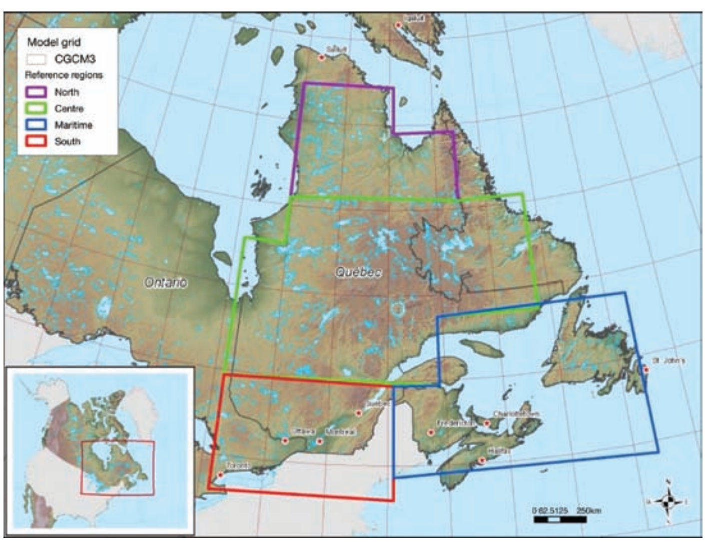

FIGURE 7: The four subregions chosen to establish equally probable scenarios expressed in the form of scatterplots (temperature/precipitation). The grid of the Canadian Global Coupled Model (CGCM3) was added to illustrate the typical spatial resolution of Global Circulation Models (GCMs).

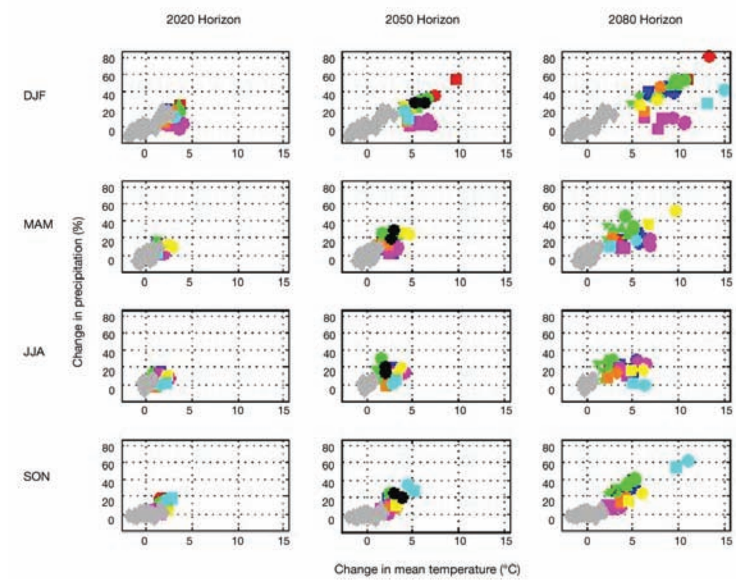

FIGURE 8: Scatterplots of changes in temperature/precipitation for the north subregion by season and by future climate period, compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s. For legend, *see* Figure 11.

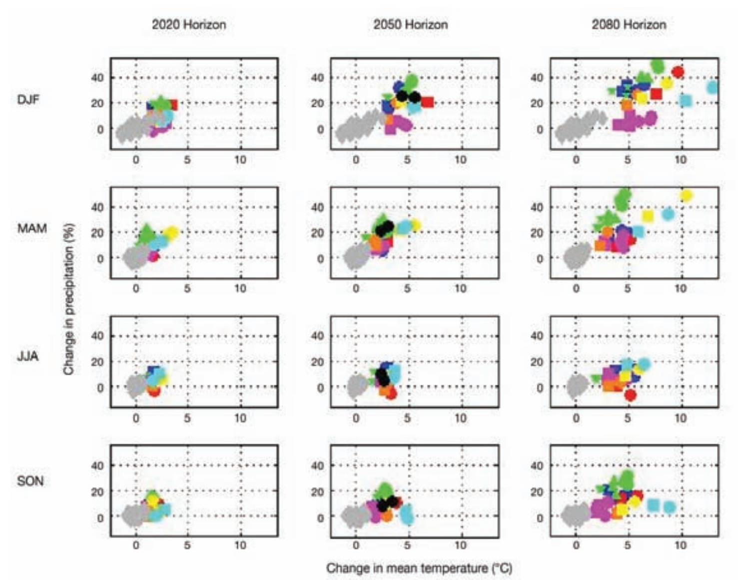

FIGURE 9: Scatterplots of changes in temperatures/precipitation for the central subregion by season and by future climate period compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s. For legend, *see* Figure 11.

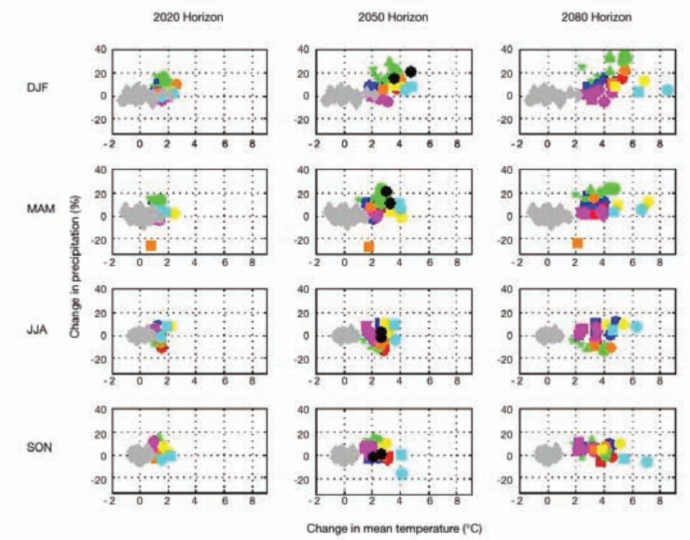

FIGURE 10: Scatterplots of changes in temperatures/precipitation for the maritime subregion by season and by future climate period compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s. For legend, *see* Figure 11.

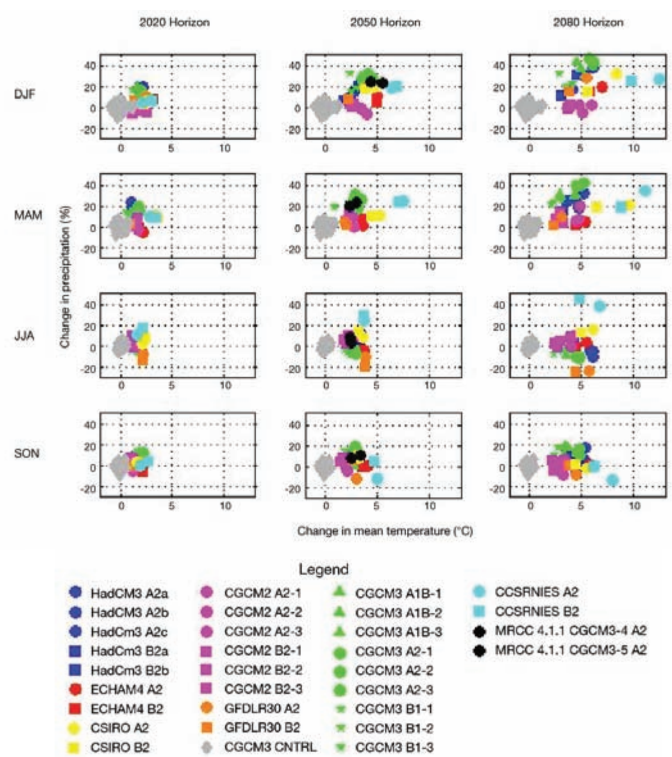

FIGURE 11: Scatterplots of changes in temperature/precipitation for the south subregion of Quebec by season and by future climate period compared to 1961 to 1990 climate normals. The values come from several GCMs (colour) for different scenarios of GHG emissions (shape). The grey diamonds indicate natural variability of the climate over 1000 years of the CGCM3 control simulation. Each diamond represents an average of 30 years. The changes simulated by CRCM 4.1.1 deal only with the 2050s.

TABLE 1: Climate normals and synthesis of scatterplot for the north subregion.

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-21 to 25°C	+2,5 to +3,5°C	+4 to +7°C	+6 to +12,5°C
	Precipitation	60 to 180 mm	+1 to +18%	+2 to +32%	+5 to +53%
Spring	Temperature	-7 to -17°C	+0,5 to +2°C	+1,5 to +3.5°C	+2,5 to +7°C
	Precipitation	75 to 125 mm	+1 to +12%	+4 to +26%	+8 to +35%
Summer	Temperature	6 to 10°C	+1 to +2,5°C	+1,5 to +4°C	+2 to +6°C
	Precipitation	150 to 230 mm	+1 to +12%	+3 to +19%	+5 to +28%
Fall	Temperature	1 to 4°C	+1,5 to +2,5°C	+2 to +3,5°C	+2,5 to +6°C
	Precipitation	150 to 240 mm	+2 to +16%	+5 to +24%	+9 to +42%

TABLE 2: Climate normals and synthesis of scatterplot for the central subregion.

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-11 to -21°C	+1,5 to +3°C	+3 to +5,5°C	+4,5 to +9,5°C
	Precipitation	130 to 325 mm	+1 to +18%	+4 to +32%	+6 to +47%
Spring	Temperature	3 to -7°C	+0,5 to +2°C	+1,5 to +4,5°C	+2,5 to +8,5°C
	Precipitation	125 to 300 mm	+1 to +19%	+6 to +25%	+8 to +45%
Summer	Temperature	10 to 17°C	+1 to +2°C	+2 to +3,5°C	+2,5 to +5,5°C
	Precipitation	230 to 310 mm	0 to +8%	-2 to +13%	0 to +13%
Fall	Temperature	-1 to 6°C	+1 to +2°C	+1,5 to +4°C	+2,5 to +5.5°C
	Precipitation	215 to 300 mm	0 to +13%	0 to +20%	+2 to +26%

TABLE 3: Climate normals and synthesis of scatterplot for the maritime subregion.

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-10 to -13°C	+1 to +2°C	+2 to +4°C	+3 to +6°C
	Precipitation	295 to 400 mm	-2 to +12%	–1 to +21%	+1 to +32%
Spring	Temperature	–1 to –3°C	+1 to +2°C	+1,5 to +3,5°C	+2,5 to +5°C
	Precipitation	250 to 325 mm	-3 to +13%	-2 to +16%	+1 to +23%
Summer	Temperature	13 to 17°C	+1 to +1,5°C	+1,5 to +3°C	+2,5 to +5°C
	Precipitation	250 to 350 mm	-6 to +7%	-10 to +9%	-11 to +9%
Fall	Temperature	3 to 6°C	+1 to +1,5°C	+1,5 to +3°C	+2 to +5°C
	Precipitation	275 to 350 mm	+2 to +11%	-3 to +11%	-3 to +11%

TABLE 4: Climate normals and synthesis of scatterplot for the south subregion.

Season		1980s climate	Delta 2020s	Delta 2050s	Delta 2080s
Winter	Temperature	-7,5 to -11°C	+1 to +2,5°C	+2 to +5°C	+3,5 to +8°C
	Precipitation	270 to 330 mm	-5 to +19%	0 to +32%	+1 to +43%
Spring	Temperature	3,5 to 6°C	+1 to +3°C	+2 to +5°C	+2,5 to +8°C
	Precipitation	240 to 280 mm	-1 to +19%	+2 to +25%	+4 to +39%
Summer	Temperature	18 to 20°C	+1 to +2°C	+2,5 to +4°C	+2,5 to +6°C
	Precipitation	280 to 350 mm	-5 to +10%	-7 to +13%	-11 to +15%
Fall	Temperature	6,5 to 9°C	+1 to +2,5°C	+2 to +4°C	+2,5 to +5,5°C
	Precipitation	270 to 330 mm	-1 to +10%	-8 to +16%	-7 to +18%

3 SENSITIVITIES, IMPACTS AND ADAPTATION

The key concepts presented in Chapter 2 provide the foundation for understanding the following description of the sensitivities, vulnerabilities, opportunities, anticipated impacts and possible adaptation strategies, both spontaneous and planned, for Quebec.

The approach used here is not only regional in focus (north, central, maritime and south subregions), but also sectoral and cross-sectoral (*see* Section 3.5), in order to integrate issues not addressed in the sections dealing with the subregions. As indicated in the Ouranos (2004) report, the boundaries of these four subregions must not be perceived as administrative boundaries, but rather as gradual transition between zones that share similar characteristics.

Figure 12, which should be referred to constantly throughout this section, synthesizes several key characteristics pertaining to Quebec, which can be summarized as follows:

- **the north subregion** (*see* Section 3.1) is characterized by the presence of a few isolated communities experiencing significant socioeconomic and demographic changes.
- **the central subregion** (*see* Section 3.2) is characterized by extensive natural resources that are important for the local and overall Quebec economy.
- **the maritime subregion** (*see* Section 3.3) is characterized by development along coastal areas.
- **the south subregion** (*see* Section 3.4) is the locus of steady urbanization and contains the majority of the population, economic activity and infrastructure, all of which create growing pressure on the natural environment.

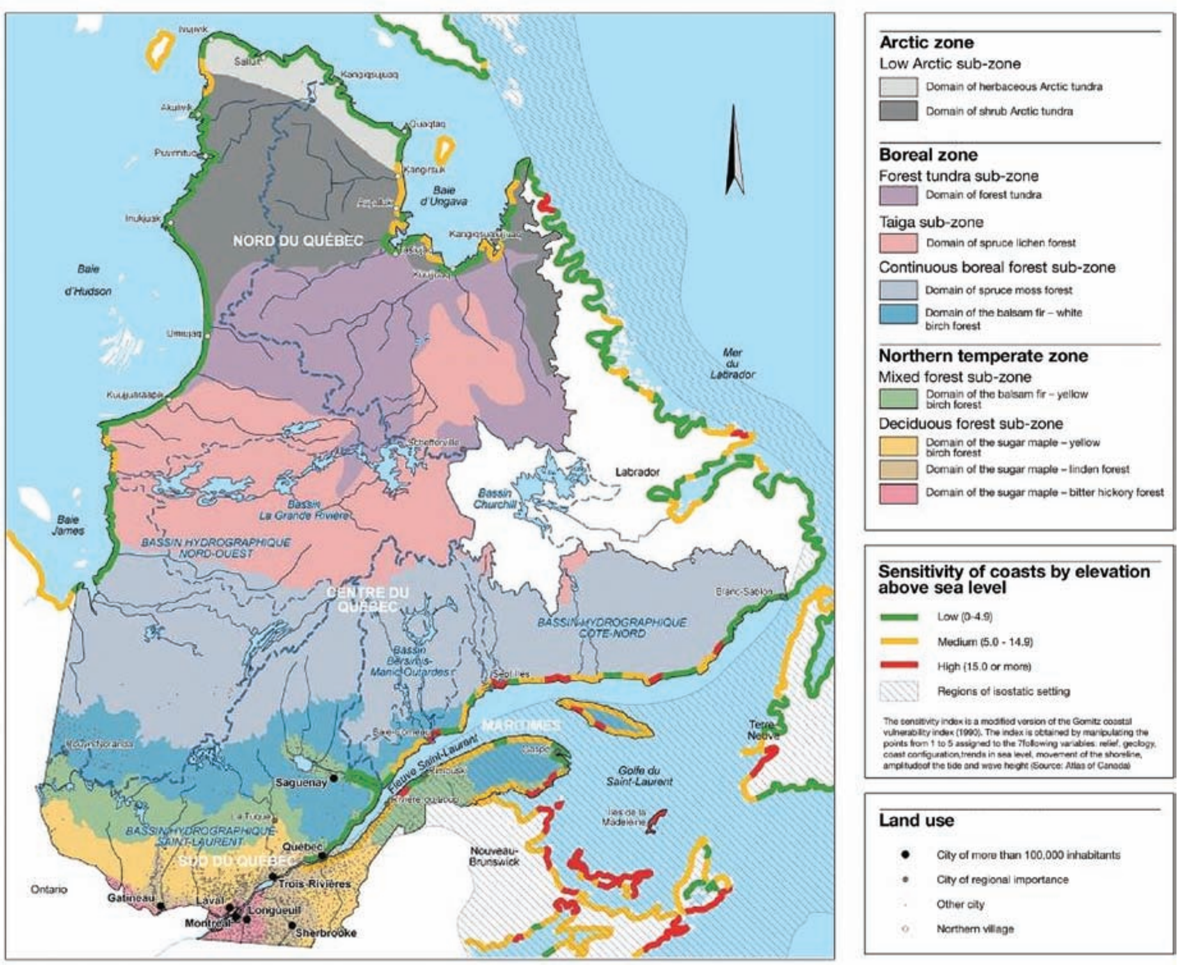

FIGURE 12: The four subregions and a variety of characteristics that help determine sensitivity to climate change.

3.1. NORTH SUBREGION

Nunavik differs from other Quebec regions due to its sparse plant and animal life, a long cold season and a landscape dominated by snow and ice. The way of life of its mainly Inuit population is closely tied to the environment. The Inuit live in 14 villages (Figure 12) where infrastructure is concentrated. Their society is coping with important generational changes and undergoing rapid demographic growth and a transformation of socioeconomic activity formerly based on traditional ways of life. Despite these profound changes, certain activities (food supply, fur sales on international markets) still account for an important share of the local economy. Figure 8 and Table 1 suggest that Nunavik will experience, along with many other diverse changes, the greatest climate change in Quebec in absolute value, mainly due to the climate feedback effect of snow and ice and the presence of Hudson Bay to the west. The results and conclusions of initiatives such as the Arctic Climate Impact Assessment (Arctic Climate Impact Assessment, 2004), ArcticNet (2006), the Canadian Climate Impacts and Adaptation Research Network (Canadian Climate Impacts and Adaptation Research Network, 2006) and the Ouranos projects, apply to this region north of the 55th parallel known as 'Arctic Quebec'.

Changes to the natural environment

Along with recent climate change, the temperature of the permafrost rose an average of 1 to 1.5°C to a depth reaching 20 m at some study sites in Nunavik between 1990 and 2002, accompanied by a noticeable deepening of the active layer, the surface layer that thaws in summer (Allard et al., 2002a). The Inuit report significant environmental changes and even experienced hunters say they have difficulty predicting weather, snow and sea conditions in their travels by snowmobile or canoe (Tremblay et al., 2006). Traditional Inuit knowledge seems less reliable and many accidents, sometimes involving experienced individuals, are reported (Nickels et al., 2005).

Heat transfer in the soil following climate warming will inevitably cause partial or total thawing of the permafrost, depending on the real extent of warming during the twenty-first century (Lawrence and Slater, 2005). Consequently, ecosystems will be greatly disturbed by permafrost degradation, which is already causing subsidence of the land and creating and expanding small thermokarst lakes (Seguin and Allard, 1984). Drainage networks on sensitive soils are likely to be modified by the drying and the extension of peat bogs and wetlands (depending on local topography and soil texture), as well as by gullying and rill erosion (Payette et al., 2004). Stimulated by milder summers and greater snow cover protection on the tundra in winter, the expansion of shrub populations would transform ecosystems significantly, increasing their primary productivity, which should have repercussions on the animal kingdom. The distribution of animal species is bound to move northward in keeping with these changes. It remains to be determined how this will affect the behaviour of such migratory populations as caribou herds, Arctic char, geese and ducks, seals and whales. Ecosystems that adapt spontaneously are discussed at the provincial scale in Section 3.5.

To the extent that precipitation, evapotranspiration and subsurface flow are affected, the hydrological regime of the rivers will change and water temperatures will rise. Sediment inflow may result from permafrost degradation, although its scope remains to be assessed. All these changes will have a significant effect on regional aquatic wildlife.

Sensitive infrastructure

The risk posed by permafrost degradation varies from community to community depending on geomorphology (rock outcrops, granular or clayey soils containing ice, instability factor when thawing). From the tree line to the shores of Hudson Strait, the climatic gradient is such that the discontinuous permafrost, having temperatures near the freezing point, becomes colder as one moves farther north. Consequently, a fairly uniform regional warming would act first on the southern fringes of the permafrost and then gradually on more northerly areas. Up to now, municipal planning has taken into account the nature of the terrain in each community as much as possible. Moreover, most institutional buildings, such as schools and hospitals, and most houses are built on piles or trestles, which allow air circulation and keep the soil at or near air temperature (Fortier and Allard, 2003a, b).

However, important buildings and infrastructure (airports, roads) are partially or totally built on sensitive terrain. In areas where the soil consists of unconsolidated deposits containing ice, permafrost thawing causes soil subsidence and buckling that can damage infrastructure. This is the case for airport infrastructure in 13 of the 14 villages. There is concern for the safety and integrity of these airports (Grondin and Guimond, 2005), which fall under the responsibility of the Quebec Ministère des Transports (MTQ). In fact, permafrost thawing has already caused subsidence, cracks and signs of deterioration on several airport runways and on roads connecting them to the villages (Beaulac and Doré, 2005). Existing maintenance measures have so far been enough to ensure safety. However, the frequency and rising cost of repairs, observed damage and increased maintenance activity have prompted the MTQ and Ouranos to draw up a research program to characterize the permafrost beneath and at the edge of infrastructure (thermal profile, subsidence, climate conditions) to assess the behaviour of this infrastructure since its construction, to predict its evolution and, finally, to develop adaptation measures (Beaulac and Doré, 2005; Ministère des Transports du Québec, 2006a).

Local transportation and access to resources

In Nunavik, the hunters and gatherers travel mainly by boat in summer and snowmobile in winter. The types of roads used (waterways and ice roads) are important for food supply (hunting, fishing, berry picking, egg gathering), moving goods and people between communities, and accessing sites for traditional pursuits, such as trapping, gathering or family and social activities. Travel and access to resources are critical both to acquire food and to preserve the social cohesion essential to maintaining a culture already weakened by other stresses (Lafortune et al., 2005). Climate impacts (difficult weather forecasting, late freeze-up and early melting of the ice) make travel more risky, and thus affect socioeconomic and cultural aspects as much as the transfer of traditional knowledge, and have repercussions on individual and collective identity in this changing society (Tremblay et al., 2006).

Growing economic activity

Resource development is growing in Nunavik. Mining activity is increasing rapidly as the area becomes more accessible and with the help of international metals markets. Climate change offers new development opportunities, such as the reduced cost of ore shipping made possible by waterways that remain ice-free for longer periods (Beaulieu and Allard, 2003). On the other hand, this new access will put additional pressure on species that depend on the ice cover, and on populations that depend on these species for their subsistence. Moreover, climate change makes it uncertain whether toxic mine tailings will freeze during mine operation and after the deposits have been depleted. The effect of this uncertainty on future production is higher-than-expected cost estimates during and after mine operation to prevent any contamination of the natural environment by the seepage or flow of toxic material.

If harnessing the rivers of Ungava Bay to generate electricity were ever to become acceptable from a business and social viewpoint, the promoter would have to manage uncertainties related to the hydrological regime due to a climate that is changed but probably more beneficial because of the expected increase in precipitation. In addition, the high wind potential of the subregion (Environment Canada, 2007a) would promote the development of wind energy as a complement to electricity production by diesel power stations in several communities, thereby achieving diversity of supply while reducing dependence on costly fossil fuels, which are transported by boat. Even by contributing in a small way to reducing GHG emissions, wind production would present a strong political argument, since the Inuit would help to reduce GHG emissions by greatly reducing their use of fossil fuels.

Adaptation strategies

Recent knowledge regarding permafrost located beneath infrastructure and the application of civil engineering practices and solutions will help manage the impacts of climate change on airports, roads and buildings (Allard et al., 2002b). To strengthen and maintain the integrity of infrastructure built on permafrost, various solutions are being tested or have already shown their effectiveness. For example, heat penetration into backfill can be countered by air convection and the use of insulation techniques and reflective surfaces; otherwise, the heat can be extracted from backfill using drains. Installing geotextiles, or even strengthening and raising infrastructure at risk, can also help diminish vulnerability (Beaulac and Doré, 2005).

Large-scale mapping of permafrost conditions in each village is a tool to improve municipal planning aimed at adaptation to climate change in the long term. In any event, building standards and decision-making must henceforth take climate change into account (Allard et al., 2004) to prevent an increase in vulnerability.

Access to the land for traditional pursuits receives special attention from local authorities such as the Kativik Regional Government in terms of ensuring safety along land routes (ice roads) or on navigable waterways (Bégin, 2006). In collaboration with local communities, a study is underway to determine how to better anticipate and better adapt to the new winter ice and snow conditions by relying on a network of northern weather stations (Lafortune et al., 2005). The small number of weather stations and the poor quality of chronological data series currently make it difficult to validate the models used, but this difficulty should be reduced with the establishment of new weather stations by Environment Canada.

At a workshop on the status of regional projects, held in Montréal on October 6, 2005, education and the development of awareness and information tools were identified as important ways to reduce the vulnerability of infrastructure to climate change. Officials from the Kativik Regional Government also emphasized the need to improve weather data and the ability to predict extreme events, such as blizzards, storms, gales, sudden thaws and fog. Concerns raised by the Inuit included their need for a better analysis of the impact of climate change on ecosystems and wildlife. Current studies focus on defining adaptation methods that resolve built environment or municipal planning problems. To a lesser extent, they also seek to better understand the most important changes affecting resources and the traditional pursuits of hunting, fishing and gathering.

In summary, strong regional population growth, the resulting urban development, and changes in access to resources and the traditional pursuits of hunting, fishing and gathering are responsible for bringing on difficult and multifaceted socioeconomic change. Accelerated thawing of the permafrost and pronounced climate change are raising the stakes and increasing the pace of change.

CASE STUDY 1

From impact to adaptation: case study of Salluit

To lessen the impact of accelerated permafrost degradation at Salluit and reduce the consequences on infrastructure, the Centre d'études nordiques (Nordic Studies Centre) and Ouranos are developing a geological and geothermal model that integrates all factors that could affect soil stability. The part of the study already completed provides maps (Figure 13) on which information layers identify sensitive soils and make it possible to optimize land-use planning that takes the impact of climate change into consideration (Allard et al., 2004). In communities as a whole, current planning practices, including urban drainage maintenance, snow removal methods, layout of new streets and design of foundations, should be revised to limit the impact of climate change on the land. Certain recent decisions should perhaps be reviewed, one example being the paving of streets, which can increase heat transfer into the permafrost and therefore constitutes a maladaptation. Various civil engineering–related adaptation methods, such as convection in backfill, heat drains and reflective surfaces, will be tested in Salluit as part of a project to assess their cost effectiveness given conditions prevailing in the study areas (Doré and Beaulac, 2005).

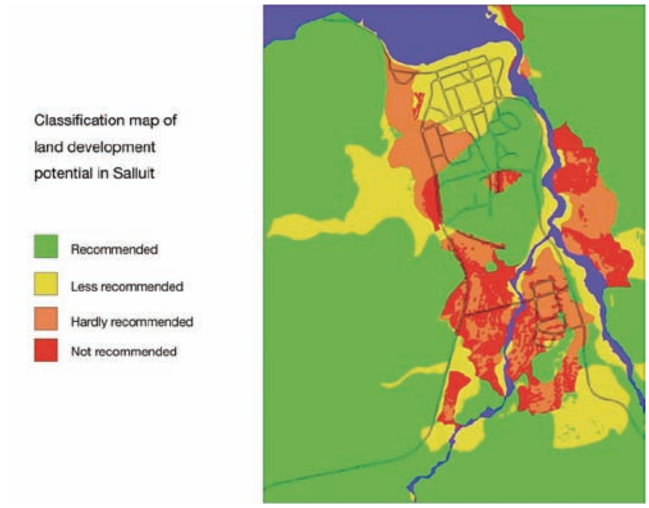

FIGURE 13: Sample map of Salluit in Nunavik, Quebec, showing vulnerability of the land with regard to infrastructure construction (Solomon-Côté, 2004).

3.2. CENTRAL SUBREGION

The environment in the central subregion is characterized by boreal forest and numerous lakes, rivers and reservoirs (Figure 12). Whereas the cold season is dominant in the north subregion and the warm season is dominant in the south subregion, the two seasons are closer in length in the central subregion. Snowfall is generally much more abundant in the east due to numerous winter storms arriving from the east coast of the United States. Population density is low and declining, and local economies often depend on a single industry, yet primary sector economic activity from natural resource (water and forest) exploitation stimulates the strength of Quebec's economy as a whole. Ouranos (2004) calls this subregion a 'resource region' and, for this reason, the sensitivity of forests and water resources to climate change is addressed here.

3.2.1. Forests

Since the last glaciation, Quebec forests have evolved under a harsh climate combined with dynamic natural disturbances, which have led to the formation, from south to north, of large forest ecozones of maple, balsam fir and spruce. Significant climate warming over the last century has already resulted in a change in equilibrium between the climate and forest composition (Forget and Drever, 2003). Anticipated warming will further accelerate the rupture of this equilibrium and result in changes in the composition and productivity of forest stands. The dynamics of natural disturbances (fire and insects) and the frequency of extreme weather events (droughts and freezing rain) are also bound to change.

Growth and productivity

A rise in temperature can act directly on physiology and metabolism and can also lengthen the growing season. Signs of a lengthening of the growing season are already visible. Bernier and Houle (2006) estimated that the budbreak date of the sugar maple has occurred earlier by several days in the past 100 years, and Colombo (1998) reported similar results for the white spruce. In Alberta, the blossoming date of the aspen poplar has advanced by 26 days in the past 100 years (Beaubien and Freeland, 2000). In Europe, the growing season of several plant species has lengthened by 11 days since just 1960 (Menzel and Fabian, 1999).

The preliminary results of growth prediction models based on a 2 x CO_2 scenario suggest an increase in net primary productivity for forests in eastern Canada, while forests in the west would be affected in the opposite manner (Price and Scott, 2006). However, most models are based on climate-growth relations of diverse species and do not consider factors that are potentially negative for productivity. The rather positive picture in Quebec must be considered as an optimistic scenario from which potential losses must be subtracted. For example, the emergence of exotic species or more frequent drought conditions could cancel out any gains (Kirschbaum, 2000; Johnston and Williamson, 2005).

A rise in atmospheric concentration of CO_2 would have a fertilizing effect on forests, leading to an increase in net primary productivity (Ainsworth and Long, 2005: Price and Scott, 2006). Greater productivity has already been observed in the upper and middle latitudes between 1980 and 1999 (Nemani et al., 2003), for black spruce at the northern limit of its distribution range since the 1970s (Gamache and Payette, 2004) and for poplar, whose average biomass increased by up to 33% (Gielen and Ceulemans, 2001). However, some studies suggest that the gains would be either cancelled by an acclimatization to the new CO_2 levels after a few years (Gitay et al., 2001) or limited by nutrients (Drake et al., 1997) and other factors (Kirschbaum, 2000; Johnston and Williamson, 2005).

Migration

Analyses of various biotic communities based on a 2 x CO_2 scenario suggest significant movements from geographic areas in both latitude and altitude, as was observed in the Rockies in response to the 1.5°C increase in mean temperature during the past 100 years (Luckman and Kavanagh, 2000). The migration should nevertheless take several centuries, since the dispersal capacity remains limited. For example, the anticipated rise in annual mean temperature of 3.2°C by 2050 for the central subregion (*see* Table 2) would cause climate zones to move 515 km northward at the rate of 10 km/year for forests — a speed clearly higher than the fastest observed migration speed of trees (500 m/year). The migration would probably not take place by groups of species, since dispersal speeds and physiological responses vary by species, as much for black spruce and jack pine (Brooks et al., 1998) as for mixed forest (Goldblum and Rigg, 2005). Finally, soil fertility would limit the movement of trees, since the nutrient requirements of the forest vary by stands (maple > balsam fir > spruce forest; Houle, pers. comm., 2006).

Disturbances

Natural disturbances play an important role in shaping the forest landscape. They affect ecosystem composition, structure and processes. These disturbances include insect epidemics, forest fires, disease and extreme weather conditions such as drought, ice storms and violent winds. A change in climate conditions will influence the severity, frequency and extent of these disturbances.

The short life cycle and ease of movement of insects would allow them to become established at higher latitudes with the help of milder winters, although the reduction in snow cover thickness could shrink the distribution range of certain species (Ayres and Lombardero, 2000). However, it is difficult to predict the reaction of a given insect due to differences between species with respect to seasonality, thermal reactions, mobility and host plants (Logan et al., 2003). Based on landscape-level models, Régnière et al. (2006) suggested that the range of the spruce budworm (*Choristoneura fumiferana* [Clem.]) would increase significantly, and Quebec would experience a southward extension of the gypsy moth (*Lymantria dispar* [L.]), a spread of the mountain pine beetle (*Dendroctonus ponderosae* [Hopk]) from west to east in the boreal forest, and the establishment of the Asian long-horned beetle (*Anoplophora glabripennis* [Motchulsky]) on maples, elms and poplars (Cavey et al., 1998; Peterson and Scachetti-Pereira, 2004). In addition, trade globalization and reduced merchandise transit times favour the introduction and establishment of new exotic species (Ayres and Lombardero, 2000).

There is some uncertainty regarding the future frequency of forest fires. Although most climate models predict an increase in fires for the northern hemisphere due to the lengthening of the growing season and the increased occurrence of lightning (Wotton and Flannigan, 1993), the situation could be more variable in Quebec because of more abundant rainfall (Flannigan et al., 2001). Thus, fire frequency could increase in the west and north, diminish in the east and remain constant in the centre (Bergeron et al., 2004). Under a 3 x CO_2 scenario, Flannigan et al. (2005) estimated that the burned area would increase by 74% to 118%. The differences between these studies arise from the lower reliability of regional predictions related to large ecozones and the fact that potential interactions with other disturbances (insect epidemics) are not considered. Considerable uncertainty also remains with respect to the frequency, scope and intensity of extreme events (violent winds, hurricanes, ice storms) affecting deciduous forests (Cohen and Miller, 2001; Hooper et al., 2001).

A reduction in the duration of winter has direct and immediate impacts on forestry activity and its planning, specifically a reduced period of site access (winter roads) and a marked change in the seasonality of employment. This type of direct impact is of interest to forestry companies because reduced thickness, discontinuity or early melting of the snow cover have become preoccupying issues where forests in the south subregion are concerned. The ground exposed to ambient air is subject to freezing, causing significant damage to tree roots and affecting growth (Boutin and Robitaille, 1995).

Adaptation strategies

There are various aspects to adaptation mechanisms. For example, adaptation to the anticipated effects of climate change can be considered from an operational standpoint or a strategic planning perspective. They could range from very concrete strategies regarding the condition of forest roads and modifications to machinery, particularly in areas dependent on winter operations, to more global considerations, such as taking the anticipated effects of climate change into account when undertaking forest management strategic planning. By integrating climate scenarios and knowledge on the fertility and characteristics of forest soils at the planning stage, forest management could promote adaptation to climate change.

A number of adaptation options appear to be feasible, such as the use of reforestation with seedlings that are more adapted to the new climate conditions, even though only 15% of harvested areas are currently reforested. However, this solution would require the availability of accurate regional climate predictions.

In the case of forest fires, there already exists a set of adaptation measures, including increased surveillance, an effective warning system and an improvement in salvage cutting (Wotton et al., 2003). If the number of forest fires were to increase significantly, it is possible that these adaptations would not be enough to reduce the impact of climate change on the fire regime.

Because of the large area covered by forests in Quebec, adaptation measures on a large scale are difficult to apply. In addition, uncertainty surrounding the potential impacts of climate change on the forest in general, and more specifically at the regional scale, limit the implementation of specific measures in the short term.

In summary, climate change will increase the growing period and the northward migration of vegetation zones. The frequency and intensity of natural disturbances, such as the spread of pathogens and insect pests, would increase along with extreme climate conditions. Given the importance of the forest industry in Quebec, adaptation strategies aimed at reducing these impacts are few in number and would be implemented on a case-by-case basis, based on the biophysical and socioeconomic characteristics of the subregions.

3.2.2. Hydroelectricity production

The energy sector holds a predominant place in the Quebec economy. Electricity comes mainly from hydroelectric generating stations (96%), a few thermal generating stations (oil, natural gas or biomass) and one nuclear plant, Gentilly-2. Some 80% of the installed capacity of 42 950 megawatts (Ministère des Richesses naturelles et de la Faune du Québec, 2006c) is located north of the 49th parallel and three large hydroelectric complexes (Bersimis–Manic-Outardes, La Grande and Churchill Falls) draw upon vast reservoirs (Institut national de recherche sur les eaux, 2004) to satisfy the bulk of Quebec demand. In the north, storage power stations represent 95% of installed capacity, whereas run-of-river power stations account for 95% of installed capacity in the south. For this reason, the anticipated impacts of climate change on these two types of power stations are considered separately. It is also important to clarify that changes in the hydrological regime depend both on changes in precipitation and variations in temperature. The latter are likely to affect evapotranspiration in watersheds and therefore have a significant impact on the hydrological cycle (Guillemette et al., 1999; Allen and Ingram, 2002).

In the northern part of the central subregion, all climate models forecast warmer temperatures and more abundant precipitation. The following considerations were drawn up according to regional climate scenarios, but they must be treated with caution given the level of uncertainty.

A modified thermal regime would result in reduced precipitation in solid form and snow cover. It would also cause an increase in evapotranspiration rates during the open water period, which would nevertheless be offset by an important increase in general precipitation, resulting in higher reservoir levels.

The anticipated hydrograph (Figure 14) was produced by feeding a hydrological model with observed climate data that were altered based on the differences in temperature and precipitation, as suggested by different climate scenarios generated by global climate models. It can be deduced from this figure that future natural inflow would be more sustained in winter (from November to April), that the spring flood would occur two to three weeks earlier, that the flood volume would probably be reduced and that summer inflow would probably be less important due to a significant increase in evapotranspiration. Adjustments in annual reservoir management practices must be expected, since reservoirs would be fed later in early winter by more precipitation in liquid form, while floods would occur earlier and be less significant. The new climate would have a

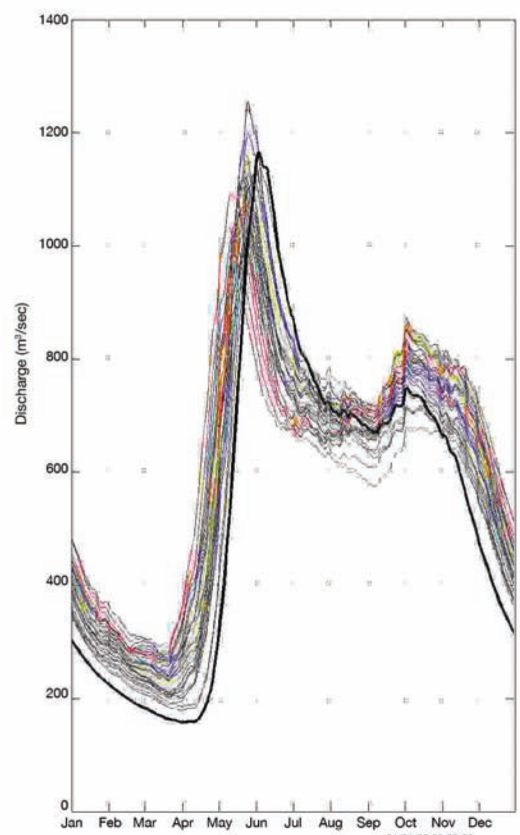

FIGURE 14: Average annual hydrographs simulated using climate observations (thick line: 1960-2002) and climate projections from 9 models running several different emission scenarios (thin lines: 2041-2070) for a northern Quebec watershed (Ouranos, 2007).

greater natural regulating effect on an annual basis, a conclusion consistent with those reached by Slivitzky et al. (2004) using the first versions of the CRCM.

Since the historic annual inflow series (Figure 15) shows no statistical change in average, cycle or trend, it was agreed by Hydro-Québec for purposes of planning future production equipment that the mean value of inflow over the historical period would be observed over the coming years. However, available climate scenarios show a rising trend in mean annual inflow values over a 50-year period, together with larger year-to-year variations for the subregion, thereby casting doubt on the assumption of a stationary climate.

Furthermore, the periods during which temperatures fluctuate around 0°C would occur more frequently. These are periods of the year when reservoirs are filled to a high level. Indeed, high heating demand in winter requires reservoirs to be full at the start of winter to ensure sustained electricity production throughout the cold season. It is precisely at this time of the year that temperatures fluctuating around 0°C would either limit inflow (precipitation in the form of snow), or increase it if the precipitation was in liquid form and flowed on ground that was frozen or covered with a thin layer of snow. These particular conditions would require a change in current reservoir filling strategies to limit the risk of non-productive spillovers and their considerable financial consequences (Forget, 2007). However, if these rainfall events were to occur during mild spells later in the winter, when the snow cover is thicker, the rain would be absorbed by the snow and the impact on flow would be limited, all the more since reservoir levels would be somewhat lower due to intensive electricity production at that time of the year.

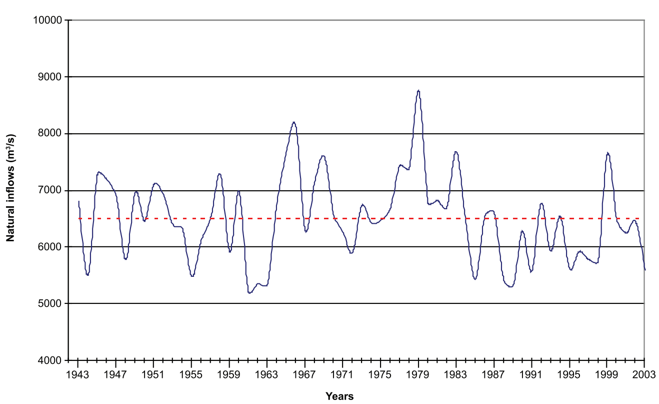

FIGURE 15: Distribution of mean annual inflow in watersheds developed for hydroelectricity production north of the 49th parallel, compared to the mean value (red dotted line) of inflows (Ouranos, 2004).

Despite the low certainty level, the frequency of extreme events associated with the water cycle is expected to increase. A higher frequency of intense storms, which produce heavy precipitation over a short period of time, would require that special attention be paid to affected facilities and more frequent non-productive spillovers. Aside from the economic consequences of such situations, at least the security of structures and populations would not be threatened. In contrast, greater vigilance must be shown in southern Quebec, where a dense population lives in proximity to dams and run-of-river generating stations. This requires better knowledge regarding the frequency and magnitude of possible extreme events to guide design work for new facilities, as existing facilities were designed to meet safety criteria related to past extreme events.

Adaptation strategies

In Quebec, lack of knowledge of future hydrological events is an issue of concern for water resource managers, and the related economic stakes are high (Hydro-Québec, 2006). However, different adaptation strategy elements can be considered that cover a wider range of scenarios with respect to an increase or a reduction of natural inflows. The high level of uncertainty associated with long-term forecasts of natural inflows in northern Quebec makes it impossible to decide which adaptation measures should be implemented right away. Considering that Hydro-Québec possesses significant financial and technical capacity to deal with any challenge, the choice of proper strategies depends on improved climate scenarios and a better understanding of their impact on the hydrological regime. In addition, given the extent of wetlands in northern Quebec (15% of the boreal area consists of peat bogs), a better understanding of their role in the hydrological balance seems to be required (Payette and Rochefort, 2001).

Quebec has considerable remaining potential for hydroelectric development, but the impact of climate change on future water availability should be considered when selecting regions suitable for hydroelectric development, just as it must be considered in developing design criteria for the facilities. For example, a more regular annual water regime would allow a smaller reservoir storage capacity, while a greater year-to-year variability would justify the need for larger reservoirs in order to counteract the impact of water deficits spread over several years. Solutions aimed at reducing risks related to uncertain hydrological conditions include diversification of electricity production sources and the gradual integration of wind energy production into the transmission network, even though little is known about wind in a climate change context. As for electrical transmission facilities, design criteria were revised after the 1998 ice storm to make the transmission network (conductors and towers) less vulnerable to severe weather (Hydro-Québec, 2006).

3.3. MARITIME SUBREGION

The maritime subregion includes the St. Lawrence River estuary and part of the Gulf of St. Lawrence, including the Côte-Nord, Bas-Saint-Laurent, Gaspésie, Îles-de-la-Madeleine and Île d'Anticosti. The population of this subregion declined from 430 000 in 1971 to 395 000 in 2004, and from 7.1% to 5.3% of Quebec's total population (Statistics Canada, 2005). More than a third of inhabitants are estimated to live less than 500 m from the banks of the St. Lawrence River, and more than 90% less than 5 km away. Communities in the maritime subregion are generally dependent on the coastal area for their social and economic well-being and security, whereas inland communities belong more to the central subregion. The main industries (tourism, fishing, pulp and paper, forestry, aluminum smelting and mining, as well as maritime transport) depend on critical infrastructure often situated in the coastal zone (provincial Highways 132, 138 and 199, as well as the ports) and on the resources found in this zone (beaches, lagoons, tidal marshes). A sizeable proportion of this infrastructure is affected by climatic and hydrodynamic processes that influence shoreline dynamics. As for population centres, most coastal villages were built on friable, weakly consolidated deposits bordering the shores. The value of the built heritage being threatened by erosion within thirty years is significant; on the Côte-Nord alone, east of Tadoussac, over 50% of the buildings in communities along the river, and their population of close to 100 000, are located less than 500 m from the shoreline (Dubois et al., 2006).

The geology of the maritime subregion is marked by the presence of a high proportion of friable, unconsolidated deposits easily subject to erosion under the action of low- to medium-energy hydrodynamic processes. For example, the Côte-Nord is covered mainly by postglacial clayey silt overlain by delta sand, all of which rests unconformably on Precambrian granite formations of the Canadian Shield (Comité d'experts de l'érosion des berges de la Côte-Nord, 2006). These unconsolidated deposits, up to about 100 m thick, extend into the gulf and form estuary deltas, terraces and beaches. In Gaspésie and Îles-de-la-Madeleine, rocky Appalachian formations are composed of sandstone and weakly consolidated clayey shale that erodes easily under the action of freezing, thawing, rain and hydrodynamic processes that attack the foot of slopes, causing regular slumping and landslides. Fluvial and marine erosion of these friable rocks loosens the sand and gravel that form the numerous beaches and sand spits dotted with lagoons or tidal bays. In the St. Lawrence River estuary, large tidal marshes shelter or serve as migratory halts for numerous wildlife species. In some cases, such as the snow goose, the bulk of the world population gathers in this area on its twice-yearly migrations.

Vulnerability of coastal zones

Coastal zones are generally vulnerable to climate change, and the shores of the Gulf of St. Lawrence are no exception. One of the main causes of growing vulnerability is the rise in sea level. This results in increased erosion rates, flood risks and saltwater intrusion into groundwater, or at least into municipal water intakes (Villeneuve et al., 2001), posing a threat to populations living near the high water mark (Neumann, 2000; Intergovernmental Panel on Climate Change, 2001; Zhang et al., 2004). Although some studies (Mörner, 2003) have questioned whether sea levels are actually rising, most models and studies anticipate a rise of 18 to 59 cm during the twenty-first century (Intergovernmental Panel on Climate Change, 2007). The rate of sea level rise varies depending not only on the rate of glacier and ice cap melting and the warming of ocean waters (warmer water expands), but also on the locally measured rate of vertical movement of the Earth's crust (isostatic rebound) and on factors that alter mean sea level (density of seawater, local gravimetric constant and mean atmospheric pressure).

In the Gulf of St. Lawrence, McCullogh et al. (2002) reviewed historical rates of change in mean sea level at Charlottetown (Prince Edward Island), showing that the mean level rose by about 2.0 to about 3.2 mm/year between 1911 and 2000. The northern part of the gulf is rebounding at a rate that tends to cancel the effect of rising sea levels. A recent study of historical rates of sea level variation in the gulf (Xu et al., 2006) emphasized the complexity of trends observed in this subregion. Nevertheless, it also highlighted a large increase in the frequency of storm surges in the Québec City region and the southern gulf region during the twentieth century. This trend is confirmed by an analysis of surges for the gulf as a whole, using a numerical model (Daigle et al., 2005). Based on a mean rise in sea level of 20 cm in 2050, Lefaivre (2005) estimated that net sea-level rise will be 14 cm in Québec City and Rimouski by 2050. Even if this change in mean sea level seems of little importance, the study by Xu et al. (2006) indicated that it could shorten the recurrence times for storm surges at Rimouski by a factor of more than three.

Several other climate factors can affect shore erosion, including a reduction of the freeze-up period and duration of sea ice cover (Bernatchez and Leblanc, 2000), as well as rises in the number of cyclones (Forbes et al., 2004) and the frequency of freeze-thaw cycles. Ice can help reduce bank erosion by attenuating waves and forming a protective screen that stabilizes beaches and slopes. The first attempts to model waves using a coupled climate-atmosphere model on a regional scale (Saucier et al., 2004) forecast a 60% reduction in the duration of sea ice by 2050 and its total disappearance before the end of the twenty-first century. The beaches would then be exposed to winter storms in addition to autumn storms. The data collected by the expert committee on shore erosion of the Côte-Nord (Dubois et al., 2006) show that erosion rates have increased greatly over the last ten years, a period during which the ice cover in the gulf, especially along the Côte-Nord, was much thinner than average (Environment Canada, 2007b).

Cyclones affect bank erosion in two ways. First, the intensity and frequency of storms can vary depending on climate conditions and change the number of storm surges caused by the reverse-barometer effect and the wind on certain coasts. Next, the organization of cyclone systems (source and path of depressions) modifies the waves (height, frequency, direction) in the gulf, which affects the long-shore current and sediment balance of the beaches. In many cases, these modifications can take the form of a rise or a lowering of beaches, resulting in an increase or decrease of slope protection against erosion due to storm surges and waves. Daigle et al. (2005) found considerable variations in temperature and precipitation extremes between 1941 and 2000 in the gulf. Diaconesco et al. (2007) showed that the wind regime changed during this period. These studies suggest that the changes affecting extreme conditions also result in a reorganization of sediment transport, which would partly explain fluctuations in erosion rates of banks observed in several regions of the gulf.

The clayey slopes of the Côte-Nord and the friable sandstone cliffs of the Îles-de-la-Madeleine and Baie-des-Chaleurs are sensitive to frost weathering. An increase in the number of winter mild spells would lead to increased erosion of these cliffs (Bernatchez and Dubois, 2004). Other climate-related factors can also indirectly affect bank erosion. The increase in winter mild spells and the reduced quantity of snow spread out the period of spring floods and reduce their intensity. The reduction of floods favours the retention of sea front sand in coastal estuaries and deltas, and thus modifies the sediment balance of adjacent beaches. The absence of ice and snow also affects the wind balance and the formation of beach dunes. All these factors can contribute to shifting the equilibrium of sand inputs, resulting in modifications to the erosion rate (Dubois, 1999).

Climate change impacts and human activity

Although coastal erosion is a natural process, the vulnerability of coastal communities has increased in recent decades and should increase even more in the future due to imminent climate change (Morneau et al., 2001). However, certain factors that explain the increased vulnerability of communities are of human origin. Morneau et al. (2001) noted an increase in construction along shorelines since 1970, resulting from the growing tourism-related attraction to coastal areas and the availability of methods to protect banks.

Bank protection methods have enabled public authorities to safeguard infrastructure and residential or industrial zones in coastal areas. However, the technologies used to preserve banks, which consist mainly of linear protection by riprap and the erection of vertical walls (concrete, sheet pile, rocks and timber cribs), result in poor adaptation and, as such, are causing significant residual environmental impacts. One of the largest impacts is a deficit in granular materials, such as sand, in zones protected by a structure. On the Côte-Nord, nearly 40% of active slopes are being protected from erosion by riprap at the foot of the slope (Morneau et al., 2001). The cumulative effect of this protection is to reduce by half the inflow of sand resulting from erosion of the slope, which causes the sinking of beaches and increased erosion of unprotected slopes.

Human activity can also influence the natural processes that act on bank erosion. Examples of activities and structures that can alter sediment dynamics and affect bank erosion include modifications to the water regime due to river diversions and the presence of hydroelectric facilities, deforestation of banks, destruction of dune vegetation by all-terrain vehicle traffic, coastal infrastructure (jetties, wharves, artificial channels) and municipal storm sewers.

In coastal zones of the gulf, the economic, social and environmental stakes of climate change are high (Forbes, 1997). Climate change will greatly increase the vulnerability of populations in this subregion for several reasons. First, these populations are already displaying socioeconomic vulnerability, evidenced by data on population, employment, economic growth and other indicators of economic and social stability. The partial collapse of the fishing and forest industries has already hit this subregion hard. In this context, the future impacts of climate change will likely be negative and could vary depending on the capacity for preventive adaptation of the populations involved. The trends observed are consistent with conclusions reached in the chapter on Atlantic Canada (*see* Chapter 4) and closely tied to impacts on the marine ecosystem (discussed later). Moreover, coastal communities are already affected by coastal erosion (Canadian Climate Impacts and Adaptation Research Network, 2003: Dolan and Walker, 2003), a subject regularly covered by local media. The cost of erosion and damage to coastal infrastructure has been rising for several years, and is projected to continue rising quickly if nothing is done to correct the situation.

In addition, climate change affects several hydrodynamic variables that can combine to cause a significant rise in erosion rates, threatening the integrity of coastal infrastructure. Much of this infrastructure, especially roads, is of critical importance to the entire population of affected regions. Moreover, trends observed for several years indicate that residents and local decision-makers are reacting to the increasingly frequent and acute problems posed by bank erosion and extreme events by spontaneously applying improvised solutions (often in emergency situations) that are inappropriate and poorly adapted to long-term impacts. The challenge is to reverse this trend and have residents and decision-makers adopt a preventive approach by selecting adaptation strategies and methods that minimize undesirable impacts on the environment or avoid exacerbating the problem in the long-term (Klein et al., 2001; Bruce, 2003; Parlee, 2004).

CASE STUDY 2

Towards integrated management of coastal zones

The complexity of human interactions, combined with that of the causality chain that connects climate to bank erosion, requires a multidisciplinary and comprehensive approach to deal with this problem. Studies were begun in 1998 by the Quebec government and in 2002 by Ouranos, to assess the magnitude of the coastal erosion problem and evaluate the potential impacts resulting from climate change (*see* Figure 16). The studies in progress include three elements: 1) an historical tracking of the evolution of banks in the Gulf of St. Lawrence; 2) a detailed analysis using numerical modelling at the regional scale of climate and hydrodynamics of the gulf, which will make it possible to better evaluate the future climatic situation; and 3) an integrated manage-ment framework for coastal zones that involves local and regional communities and decision-makers supported by scientists.

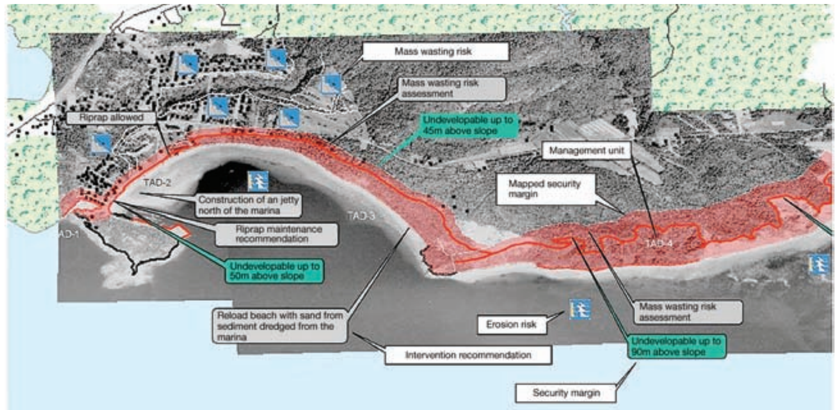

FIGURE 16: Zoning map of erosion risk for the Côte-Nord (*from* Dubois et al., 2006).

A comprehensive review of policies and associated regulations will also be required (municipal zoning, planning diagram, critical infrastructure management, public security policies, methods of protection and regulation). The adaptation choices will then be made by committees elected by an assembly of coastal community representatives.

The adaptation tools currently being developed include numerical models that integrate data on marine currents, ice, waves and water levels, and systems that monitor and analyze erosion scenarios. They could also include maps showing changes in the coastline over 30 years based on erosion scenarios that take into account available data, Internet communications and exchange tools, and updated documents on bank protection methods and their impacts and effectiveness. For example, Figure 16 was used in the adoption of regulation dealing with interim control of coastal management.

An important aspect of adaptation is the development of local and regional expertise among decision-makers and front-line stakeholders in management of the coastal zone (National Institute of Coastal and Marine Management of the Netherlands, 2004). Projects underway on the impact of, and adaptations to, climate change in the coastal area of the Gulf of St. Lawrence rely on committees made up of decision-makers and stakeholders to build a regional node of persons possessing the latest scientific and technical knowledge regarding the factors that control bank erosion and coastal dynamics in their region. Completed in 2008, this project shows the importance of a balanced approach between knowledge stemming from climate science and that stemming from the assessment of on-site vulnerabilities, processes and implications, and seeks to integrate stakeholders and actors involved in the problem into the understanding and search for optimal adaptation options.

3.4. SOUTH SUBREGION

The vast majority of Quebec's population lives in the southern part of the province (Figure 17), where most of the economic activity is concentrated. The impacts of climate change here could be numerous, varied and sometimes complex, given the interrelations between infrastructure and socioeconomic activities. The rural regions have a fragile primary manufacturing economy that can be directly affected by climate, whereas the urban regions rely on a tertiary economy on which climate can act indirectly (e.g. infrastructure failure during the 1998 ice storm crisis).

FIGURE 17: The south subregion presents a variety of issues. The rural landscape is characterized by a built or managed natural environment (agriculture, silviculture, residential) in which watersheds can play a unifying management role. The growing urban areas are dominated by a large quantity and variety of infrastructure related to the needs of a growing and aging population (Ouranos, 2004).

3.4.1. Energy

Quebec's economy is associated with high energy consumption because of its industrial base, climate, size and way of life. In 2002, the industrial sector accounted for 39% of energy demand, while transportation totalled nearly 25% and the commercial, institutional and residential sectors consumed 37% (Ministère des Ressources naturelles et de la Faune du Québec, 2004).

More than 38% of Quebec's energy needs are provided by electricity, of which 96% is water-generated. Demand reached 41.5 million oil-equivalent tonnes in 2002, an increase of 6% over 2001 (Ministère des Ressources naturelles et de la Faune du Québec, 2004).

The impact of global warming on energy demand would be lower heating needs in winter and higher 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 analyses in recent decades (Lafrance and Desjarlais, 2006). However, knowledge of heating and air-conditioning needs in the commercial and institutional sector is more limited.

Residential heating needs in 2050 should decrease by 21% (Sottile, 2006) and air-conditioning needs should increase by 12% (Table 5), resulting in a net reduction (8.8%) in energy needs (Lafrance and Desjarlais, 2006) and considerable savings (Table 6).

In 2001, the share of commercial and industrial air conditioning was higher than the residential sector. In 2050, energy demand should fall in winter by 14.3% and air-conditioning needs in the commercial and industrial sectors should rise by 3%, for a net decline of 5 to 11% in total demand.

According to the reference scenario, energy demand (heating and air conditioning) in all sectors would decline by 2 to 3% in 2050. The increased annual savings would amount to several hundred million dollars. For southern Quebec, peak summer demand for air conditioning (between 7 and 17%) would rise, emphasizing the vulnerability of electricity production, transmission and distribution networks, as illustrated by the power failure that occurred throughout eastern North America (except Quebec) in 2003.

TABLE 5: Impacts (%) of climate change on heating and air conditioning in the residential sector (Lafrance et Desjarlais, 2006).

	Impact (%) on the total			Impact (%) on electricity demand		
	Heating	Air conditioning	Net	Heating	Air conditioning	Net
Scenario						
2030						
Optimistic	-7.5	3.4	-4.0	-5.8	4.3	-1.5
Median	-11.0	4.4	-6.7	-8.6	5.5	-3.1
Pessimistic	-15.7	6.4	-9.2	-12.1	8.1	-4.0
2050						
Optimistic	-10.5	5.5	-5.1	-8.5	6.6	-1.9
Median	-15.2	8.3	-6.9	-12.3	10.0	-2.3
Pessimistic	-21.1	12.3	-8.8	-17.1	14.8	-2.3

TABLE 6: Savings achieved in all sectors (residential, commercial, industrial) by demographic, economic and climate scenarios, in millions of 2003 dollars without tax. Note: For the definition of scenarios used in the table, *see* Lafrance and Desjarlais, 2006.

Baseline scenario		Optimistic	Median	Pessimistic
Residential	2030	-197	-329	-453
	2050	-229	-313	-397
Commercial	2030	-77	-139	-206
	2050	-104	-166	-259
Industrial	2030	-56	-83	-118
	2050	-82	-117	-163
Total	2030	-330	-552	-776
	2050	-415	-596	-820

Adaptation strategies

Planting trees and the use of shutters, more reflective surface coverings, green roofs and low-energy cooling systems (fans and evaporation air-conditioning systems) would lessen the rise in air-conditioning needs and increase the comfort level of residences without air conditioning. Since houses last more than 50 years, their design must be adapted to include the installation of efficient air-conditioning systems (Lafrance and Desjarlais, 2006). It would be useful to have a better understanding of the impact of more frequent extreme climate events on power grid behaviour and to study the impacts of diverse alternate climate scenarios (Lafrance and Desjarlais, 2006).

With Quebec's electricity transmission networks also supplying the United States, hydroelectricity production presents an opportunity for new market development, while reducing emissions from local thermal generating stations (Lafrance and Desjarlais, 2006).

3.4.2. Agriculture

Agricultural activity is concentrated primarily in the south subregion, an area favourable for agriculture due to its climate and fertile land. In response to various socioeconomic factors, the area under cultivation declined from 2.5 million ha in 1941 to 1.8 million ha in 2001 (Statistics Canada, 2002). Agricultural activity will continue to change due to a variety of factors, including climate change, that can result in both business opportunities and income loss, in both the quantity and quality of agricultural production and in the use of inputs (water, fertilizer, herbicides and pesticides).

Present agro-climate situation

The length of the growing season is a fundamental agro-climate factor that determines crop choice and yields. According to Yagouti et al. (in press), growing degree days increased by 4 to 20% between 1960 and 2003 in the western and central parts of southern Quebec, making the season more favourable for most crops.

Past year-to-year climate variability makes it possible to assess the current sensitivity of agriculture to climate conditions. Over the 1967 to 2001 period, the greatest reduction in corn yield took place in 2000 (Figure 18), a year marked by excessive moisture and insufficient sunshine to promote growth (Environment Canada, 2002). Consequently, crop insurance compensation for corn reached a record level of $97 million in 2000, compared to $191 000 in 1999 (La Financière agricole du Québec, 2006). During this period, regional differences were also evident in the impact of climate variability because of different biophysical environments — soil type, topography and temperature (Bryant et al., 2005).

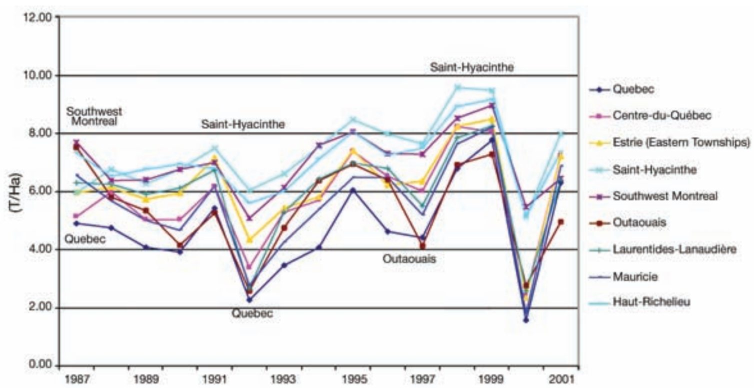

FIGURE 18: Changes in grain-corn yields as reported by farmers in their compensation claims, 1987 to 2001, in different agricultural regions of Quebec (Bryant et al., 2007).

Climate change impacts on Quebec agriculture

A considerable increase in thermal indices and growing season length for corn, soybeans, spring cereals and forage plants is predicted in the coming years (Bootsma et al., 2004, 2005a, b). On the other hand, barley would be less favoured by these changes. In addition, there is a greater probability of water stress during the growing season since, on average, possible increases in precipitation cannot offset the increased evaporation rates that accompany higher temperatures. Since the efficiency of water use by plants increases under an atmosphere enriched in CO_2 (Bunce, 2004), it remains difficult to assess the combined impacts of these different factors on crop productivity.

Excess water is also devastating to agriculture. Along with the question of water inputs, consideration must be given to changes in the intensity and the rain/snow ratio of precipitation (Nearing et al., 2004), since these factors influence runoff, soil erosion and water quality. The adaptation choices of farm producers can increase these anticipated risks when they expand surface areas by adopting crop management practices that leave soil exposed to erosion, or else mitigate the risks by improving soil conservation practices or water resources management practices (Madramootoo et al., 2001).

Horticultural production is particularly sensitive to water and thermal stress. These conditions also affect livestock production. The loss of at least 500 000 poultry in July 2002, despite the use of modern ventilation systems, shows the gravity of heat waves.

Climate conditions outside the growing season will also have impacts on agriculture. According to Rochette et al. (2004), there would be less risk of damage to fruit trees from the first autumn cold, but a higher probability of damage due to hardening losses. For forage plants, a reduction in snow cover and increase in winter rains would increase winter mortality risk despite autumn conditions more favourable to hardening (Bélanger et al., 2002). Less severe winter conditions would result in greater weight gain for beef cattle raised outdoors and reduce heating requirements for poultry and hog barns.

Changes in pathogen, weed and insect populations are inevitable. However, most studies lack an assessment of the magnitude of these impacts. Scherm (2004) explained this as being due to the sometimes large differences between climate scenarios, the existence of non-linear responses of biological systems to environmental parameters and the unpredictable capacity of organisms to adapt genetically to the new environmental conditions.

Not only are there many complex interactions between climate factors, but the role of decision-makers (producers, consultants and other stakeholders) is crucial. For these reasons, preparing an integrated picture of impacts and the potential adaptation of farming to climate change requires that the decision-making context of producers be taken into account (Wall et al., 2004). The European ACCELERATES project (Assessing Climate Change Effects on Land Use and Ecosystems; Rounsevell et al., 2006) attempts to integrate diverse biophysical and socioeconomic models in order to assess the future sensitivity of European agroecosystems. Rounsevell et al. (2006) noted that the most important impacts are related to economic rather than climate scenarios, and that the inherent variability of results prevents drawing clear conclusions as to the future of agriculture. The challenge for agriculture is to properly define the questions and pertinent applications of climate scenarios based on its own strengths and weaknesses, and to appropriately integrate its own relevant socioeconomic dimensions into these scenarios.

Adaptation strategies

At the farm enterprise level

Producers feel they possess the tools and methods to adapt the management of their farms to climate change, at least in the medium term (André and Bryant, 2001; Bryant et al., 2007). As for livestock production, recommendations exist to help producers care for livestock during hot spells in order to reduce their stress (Blanchard and Pouliot, 2003). They focus on the density of livestock indoors and their feeding, as well as on ventilation and misting of buildings. Outdoor livestock production would benefit from more shelters and drinking troughs.

With respect to crops, planting and harvest dates will be adapted to changes in the growing season. Producers will also be able to choose varieties currently used in more southerly regions. Although crop diversification is often considered as a risk management strategy related to climate change, Bradshaw et al. (2004) concluded that, despite the regional diversification of agriculture on the Canadian Prairies observed since 1994, the farms themselves have become more specialized.

Different agricultural practices, such as the establishment of riparian strips, management of field residues and fertilizer application timing and methods, have been developed to protect environmental quality. They could be re-assessed and strengthened if meteorological events such as precipitation and drought become more intense. Besides, a longer growing season would promote the establishment of cover crops that protect the soil against erosion and leaching of nutrients after harvest of the main crop.

At the institutional level

Many programs and regulations establish standards for farm practices. It should be noted that the rules concerning the capacity of manure storage facilities and the deadline dates for seeding, crop harvests and manure spreading are all connected to anticipated climate conditions. When these standards are revised, it would be timely to consider the changing climate and encouraging producers to adapt their practices accordingly.

With the support of government resources, certain losses related to problematic climate conditions can be prevented or reduced. The Plant Protection Warning Network (Réseau d'avertissements phytosanitaires) provides producers with information on the presence and evolution of crop pests and the most appropriate response strategies based on forecasts made by mathematical models using climate data. Bourgeois et al. (2004) emphasized that climate evolution will make it necessary to revise these models to take into account non-linear responses to higher temperatures.

The same applies to the water issue, which requires planning and co-ordination of adapted activities at the regional level. Several micro-irrigation projects are already proceeding in horticultural crop fields. This method allows for more effective use of water and represents a gain for the environment.

3.4.3. Water management

Surface water

Surface waters represent about 80% of the water volume used in Quebec (Mailhot et al., 2004; Rousseau et al., 2004). Although this resource is abundant in Quebec, the impact that climate change will have on it must be taken seriously (Rousseau et al., 2003; Nantel et al., 2005). There are two aspects to consider: 1) the impact on available quantity and raw water quality (Hatfield and Prueger, 2004; Booty et al., 2005); and 2) the impacts on land uses or users (Lauzon and Bourque, 2004; Lemmen and Warren, 2004). For example, the impacts on water availability will be linked to changes in the frequency and magnitude of low flows and droughts (Institut national de recherche sur les eaux, 2004), whereas the vulnerability of drinking water supply systems will depend on the magnitude of those changes (qualitative and quantitative), but especially on the capacity of infrastructure and organizations to cope with the changes, an area about which few evaluations have been done to date.

In addition to supply, the various uses of water are viewed as economic and regional development tools. In both rural and urban areas of the south subregion, there are major and numerous different water uses, including removals for various purposes (bottled water, industrial, municipal, aquaculture, agriculture and mining) and on-site use (hydroelectric production, river transportation, recreation, fisheries and wastewater evacuation; Vescovi, 2003; Ouranos, 2004). Given both the demographic and socioeconomic trends presented above and the fact that 65% of the population of Quebec already live in urban watersheds and 32% live in moderately urban watersheds (Statistics Canada, 2005), the pressure on watersheds in southern Quebec will result in increased vulnerability. Added to this is the possibility suggested by Table 4, and presented in recent studies (Turcotte et al., 2005; Rousseau et al., 2007), that climate change leads to summers characterized by higher temperatures but without sufficient additional precipitation to offset the increased evaporation rates, thus leading to hydroclimatic changes that are likely to exacerbate use conflicts. These conflicts have already generated interest among several groups, resulting in the adoption of a new water policy (Government of Quebec, 2002), which is a tool that can assist in reducing vulnerabilities.

As for hydroelectric production, even though the expected impact of climate change — especially a late start to freeze-up and an early spring — tends to favour production, the constraints associated with ice cover upstream from power stations would be emphasized. In fact, a recurring formation of ice cover in the same winter would affect the performance of power stations over a long period. Also, the more frequent alternation of freeze-thaw periods could cause problems of frazil ice and more frequent ice jams, and reduce the output of these power stations accordingly, while posing other risks. Beltaos and Prowse (2002) suggested that an increase in frequency of winter mild spells tends to increase the risk of ice jams in other regions of the country.

St. Lawrence River

A synthesis of the state of knowledge specific to this major river, which drains southern Quebec and central North America, is provided in a study by Ouranos (2004) entitled *S'adapter aux changements climatiques* (Adapting to Climate Change). In another study, Croley (2003) used the output of four global climate models to estimate that outflow from Lake Ontario to the St. Lawrence River would be reduced by 4 to 24% annually. Using a similar method, Fagherazzi et al. (2005) concluded that there would be a slight reduction in flow of between 1 and 8% from the Ottawa River, the main tributary of the St. Lawrence. Combining these two results, Lefaivre (2005) concluded that water levels on the St. Lawrence would be reduced in the Montréal area by a maximum of 0.2 to 1.2 m, depending on the scenario. This would considerably reduce the area of open water in the river, particularly in Lake Saint-Pierre, which is shallow. A cascade of effects could occur along the entire length of the river that are similar to those identified above but potentially of a different magnitude, given the size of the area affected.

In this context, the Comité de concertation navigation du Plan d'action Saint-Laurent (Navigation Committee of the St. Lawrence Action Plan) examined adaptation options that would make it possible to maintain maritime and harbour activities at their current level (D'Arcy et al., 2005). The study explored various adaptation options and found that, if water level reductions are small, improving long-term predictions would make it possible to optimize the safety margins established by overseas shipping companies, thereby reducing their vulnerability. If the reductions are more significant, adaptations of an organizational nature, such as the restructuring of maritime transport and its infrastructure, or of a technological nature, such as the adaptation of vessels to reduce the draught required, appear to be theoretically feasible. However, these could prove difficult to apply in a context of increased commercial activity and given the major investments required for such a reorganization ($260 million to $1 billion). Finally, adaptations of the physical environment (dredging, regulation structures) can reduce the vulnerability of shipping, but would cause significant environmental impacts. The effects and costs associated with compensation measures would be difficult to assess precisely.

A number of initiatives that illustrate the efforts being made by various authorities to minimize the risks and conflicts that could be caused by a significant decline in water levels merit discussion. Several years ago, the International Joint Commission (IJC) initiated an extensive study to evaluate various flow regulation plans. Several of the management plans tested included flow analysis under climate change conditions (International Joint Commission, 2006), and the options that were proposed could help with adaptation. This evaluation even addressed items such as the advantages of wetlands relative to the economic advantages and losses of regulation plans. Furthermore, in December 2005, the governments of Quebec, Ontario and the eight American Great Lakes states signed the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement, which regulates removals of water from the entire watershed in all sectors and prohibits out-of-basin removals. The agreement makes explicit reference to climate change and the precautionary principle (Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement, 2005).

Groundwater

This resource provides 20% of all drinking water in Quebec. Rivard et al. (2003) observed that the annual groundwater recharge seems to have remained stable or declined slightly in recent decades in Quebec and the Maritimes, while precipitation and temperatures have tended to increase. Significant declines in groundwater availability would have major impacts, especially in rural areas where a large proportion of the population (26% in Chaudière-Appalaches versus 10% for Quebec as a whole) is supplied by groundwater from individual wells (Régie régionale de la santé et des services sociaux de Chaudière-Appalaches, 2001). Their vulnerability is all the greater given that knowledge of groundwater in Canada remains incomplete. In Quebec, the mapping of the aquifer of the Châteauguay River basin (Côté et al., 2006) is a step in the right direction. Moreover, several research projects in this same basin, started in 2006 and supported by Ouranos and the National Science and Engineering Reseach Council (NSERC), are seeking to improve knowledge of systems that integrate both surface water and groundwater using coupled modelling. This knowledge will contribute to the study of the vulnerability of these aquifers on a local scale.

Management Plans for Southern Watersheds: the Case of the Upper Saint-François River Watershed

To assess the capacity of existing management plans for southern watersheds to adapt to anticipated hydroclimate impacts, a pilot project was conducted in the Upper Saint-François River basin, located in the south-central part of Quebec (Turcotte et al., 2005; Fortin et al., 2007). On the one hand, the approach was based on climate change scenarios (Chaumont and Chartier, 2005) and hydrological modelling on a day-by-day basis to assess the impact on basin hydrology. On the other, it was based on a model simulating the daily application of management plans for the Saint-François and Aylmer reservoirs.

The results are similar to those obtained for the Châteauguay River watershed (*see* Case study 3): the impacts on the intensity of spring (earlier and generally smaller), summer and fall peak flows, on winter flows, on the magnitude of low waters (sustained

CASE STUDY 3

Flooding in the Châteauguay River Watershed

The example of the Châteauguay River watershed is used to illustrate the problem of floods, particularly spring floods, in a climate change context. As demonstrated by several authors, flooding caused by high waters in spring remains one of the most damaging extreme hydroclimatic events (Ashmore and Church, 2001; Brissette et al., 2003; Ouranos, 2004) to which Quebec is continually attempting to adapt (Ministère de la Sécurité publique du Québec, 1996). To analyze the potential impact on water resources, Caron (2005) and Mareuil (2005) led a modelling exercise on this watershed based on the development of a stochastic climate generator, including monthly temperature and precipitation anomalies taken from three general circulation models: CGCM2, HadCM3 and ECHAM4.

The 2050s scenarios taken from the ECHAM4 model indicate a statistically significant reduction in spring floods for return periods of 2 to 500 years. The HadCM3 and CGCM2 models show similar results (but not statistically significant), namely a reduction in floods for short return periods and an increase for longer return periods. For the summer period, HadCM3 shows a slight (but not statistically significant) increase in flood intensity for all return periods. The ECHAM4 and CGCM2 models show a statistically significant reduction of 8 to 10% in flood intensity.

Another hydrological simulation was conducted on the Rivière des Anglais, a tributary of the Châteauguay River (Figure 19). The Hydrotel and HASMI models, using six future climate scenarios (the models ECHAM4, HadCM3 and CSIRO, to which were applied GHG emission scenarios A2 and, B2), show earlier peak floods, moving up from late April in the 1961 to 1990 period to early March in the 2050s. There would also seem to be a change in flood volume: HadCM3 projects a rise in spring flood volume, whereas ECHAM4 shows a major decline in flood volume. The CSIRO model presents results falling between those of the two other models. These discrepancies are explained by differences in the projected temperature and precipitation change shown by these climate models. Finally, the example seems to indicate a decline in low water flow caused by a rise in evapotranspiration volume, despite a projected rise in precipitation (Pugin et al., 2006).

Notwithstanding this observation, assessments on Norton Creek, a sub-basin of the Rivière des Anglais, of water content in upper soil layers using a balance model show an increase in irrigation water needs of agricultural land caused by the rise in evapotranspiration of plants resulting from higher temperatures. By taking into account certain environmental constraints related to removal of water from waterways, and despite the relative scattering of results from the different climate scenarios used, the study concludes that, to maintain the proportion of future needs for irrigation water that is currently being provided by surface water will require a more concerted approach to planning, based on integrated watershed-scale management of this resource (Pugin et al., 2006).

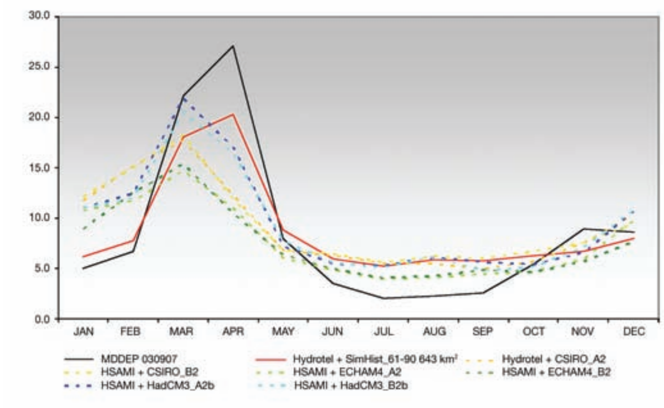

FIGURE 19: Mean annual hydrographs simulated by the Hydrotel and HSAMI hydrological models at the outlet of the Rivière des Anglais. The simulations correspond to the 1961 to 1990 reference period and the 2050 decade, covering 2040 to 2069 (Chaumont et Chartier, 2005).

Finally, Leclerc et al. (2005) indicated that floods caused by ice jams at Châteauguay itself result mainly from the behaviour of the hydrological basin and the presence of ice accumulating on the river. As for floods in open water, they would be the result of fluctuating St. Lawrence River water levels, causing the recurring floods experienced by this municipality. So, for southern Quebec in general and the Châteauguay River watershed in particular, the expected impact of climate change takes the form of earlier and more intense spring floods. Indirectly, variations in the water levels of the St. Lawrence and Ottawa rivers and summer floods in open water can be expected.

winter low waters and weaker summer low flows) and on the intensity of annual increases in volume vary depending on the general circulation model and GHG emissions scenario used (Figure 20). In the approach dealing with the analysis of management plans, the modelling exercise shows that climate change, as simulated by the ECHAM4 and CSIRO models, would result in a modification of current arrangements for the different uses of water from the reservoirs (Figure 21). No major adaptation would be required if the climate changes as simulated by HadCM3. In the first two cases, necessary adaptation measures would include filling the reservoir earlier and raising minimum levels.

Adaptation measures

Depending on the nature of the problem, many adaptation measures are considered, such as the rehabilitation or relocation of certain water intakes, more effective water treatment, reduced water volume loss in the system and increased reserve capacity. They target both infrastructure and management methods (a water-saving program).

Preliminary studies on flood management, such as those undertaken to solve problems related to meeting future needs for irrigation and drinking water, as well as those of ecosystems, must be addressed using an approach that favours planning based on integrated watershed-scale management of water. Large urban

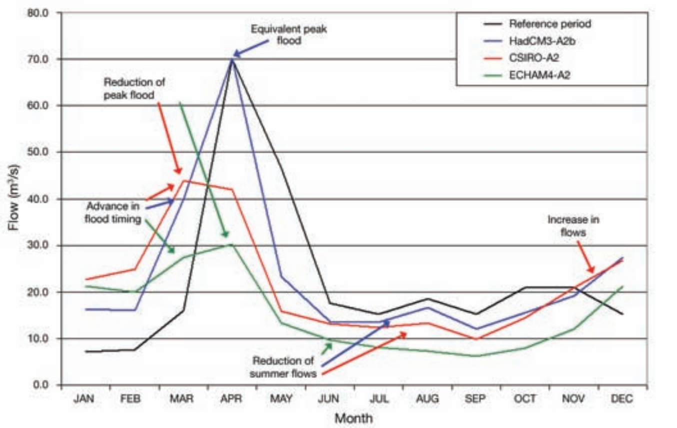

FIGURE 20: Monthly inflow into Lake Saint-François (Turcotte et al., 2005).

centres that depend on surface water seem vulnerable to change in levels of the St. Lawrence River. On the other hand, rural areas that can count on sufficiently abundant groundwater are less vulnerable in quantitative terms. Aside from quantity, the question of water contamination could be a problem, as indicated in Section 3.5.1. In general, the adaptation challenge for small municipalities with limited means is greater than for large population centres. Here again, adaptation solutions ideally involve global and integrated management adapted to the water cycle of southern watersheds as well as the Great Lakes and St. Lawrence system. They must be developed in a sustainable regional planning context that takes socioeconomic and environmental realities into account.

As for water management infrastructure, drainage systems were dimensioned using statistical recurrence criteria produced from available historical analyses of precipitation at a given site (Mailhot and Duchesne, 2005). The anticipated change in recurrence of heavy rainfall events should result in an increase in system overflows, backups and even flooding. Mailhot et al. (2007) stressed that, under the current conditions of aging infrastructure, the impact of a probable increase in intensity and probability of heavy rainfall events (Intergovernmental Panel on Climate Change, 2007) would be lessened if 1) design criteria for infrastructure and buildings were reveiwed; 2) new ways of using statistics on intense precipitation when dimensioning (Duchesne et al., 2005) were found; and, above all, 3) source control was improved through optimal city planning and maximized infiltration, especially in situations where existing infrastructure and buildings will still be in service for several decades.

Finally, adaptation strategies, which should include more robust management plans than those currently in place, will be defined with a view to improve risk management for each climate scenario, since it seems difficult at present to find a single strategy for all scenarios. The results show (Turcotte et al., 2005) that the current consensus on dam management plans must be discussed by community stakeholders even though an adaptation solution for all climate scenarios studied has yet to be defined. A preventive approach would minimize risks. More refined climate scenarios that better represent the future climate based on more advanced methods of scaling would reduce uncertainties. It would thus be possible to better prepare the community for possible changes in management rules and so ease its adaptation to the coming reality. To make consensus adoption of an adaptation strategy easier, it would be advisable to better integrate each step of the modelling (to properly understand the system studied) within the framework of integrated and participative watershed-based management. Besides, in the area of water management, just as watershed-based management has come to be recognized as one of the best climate change adaptation planning approaches, it is becoming increasingly apparent that climate change perspectives must also be integrated into watershed-based management planning. These two components naturally and mutually make a whole.

	Current management plan				Adapted management ECHAM4 A2			Adapted management CSIRO A2		
	Reference period	ECHAM4 A2	CSIRO A2	HadCM3 A2b	ECHAM4 A2	CSIRO A2	HadCM3 A2b	ECHAM4 A2	CSIRO A2	HadCM3 A2b
Rupture risk	0	0	0	0	0	0	0	0	0	0
Reservoir damage (upstream)	14	0	8	12	8	39	82	0	8	29
Tourism	481	2634	1137	480	461	192	61	2028	481	213
Water supply	0	310	15	0	0	0	0	272	0	0
Damage to Lake Louise (downstream)	16	4	17	13	4	16	29	2	12	12
Energy production	596	364	523	579	345	482	498	369	526	567

Current compromise

Adaptation unnecessary or negligible

Minimum level increased

Earlier fill period

Positive impact

Negative impact

Earlier fill period

FIGURE 21: Simulations to 2050 of the current management plan for the Saint-François and Aylmer reservoirs under climate change conditions, using ECHAM4 A2 and HadCM3-A2b models and scenarios. The figures in the table correspond to the number of days over a 30-year period (1961–1990) on which the limits set out in the management plan (for specific uses) were not met. These limits are reservoir water levels and/or river flows (Fortin et al., 2007).

3.4.4. Tourism and recreation

Tourism, through its contribution to gross domestic product and employment, is one of the important economic activities potentially affected by climate change. Climate is the primary element affecting sports and outdoor activities, either directly (sun, fine weather, snow and ice), or indirectly (scenery and plants). It determines the nature and duration of activities involving snow and cold (skiing, snowmobiling), water (swimming, nautical activities) or autumn colours (hiking), and influences living conditions for fish and game (fishing, hunting). It can even influence the number and duration of cultural outings.

Anticipated impacts

According to Wilton and Wirjanto (1998), a 1°C rise in summer temperature would increase Canadian tourism receipts by 4%, whereas a decrease of 1°C would have only a marginal impact in winter. The sensitivity of tourism and recreation activities to temperature varies depending on the season and includes different thresholds. Other phenomena also come into play, such as coastal erosion, water deficits in lakes and rivers, or water supply deficits (Wall, 1998).

According to Singh et al. (2006) and Scott et al. (2006), the Quebec ski industry must expect and adapt to more difficult climate conditions in the coming decades. The southern regions (Montréal, Eastern Townships) should see an increase in mild and rainy conditions during the ski season that will shorten its length. Certain profitable periods (Christmas, Easter, school break) would be affected. However, warming (less cold and wind) would increase the number of skiable days and use of trails, especially in January and February. The cost of artificial snow-making, despite the fact that the equipment is already installed, may rise, affecting profitability and making availability of the required water a critical issue. A higher extraction volume combined with a possible drop in water levels would trigger or amplify usage conflicts (Singh et al., 2006). The importance that customers give to natural snow and the skiing quality it provides should be an advantage for Quebec because of its latitude, particularly for those ski centres whose customers come from outside the area and whose advertising campaigns have been adapted. The urban perception (rain in the city means it is snowing in the countryside) can also have consequences on business traffic. Depending on the climate model used, a study of the Ontario ski industry (Scott et al., 2002) projected a reduction in snow cover of 21 to 34%, resulting in some activities losing their popularity (snowmobile, cross-country skiing) as the season becomes shorter by up to 50%. Ice fishing is highly vulnerable to temperature warming, as safety risks for fishermen increase. Finally, events such as winter festivals would also be affected.

The golf season should be extended by two to three weeks (Singh et al., 2006), mainly through an earlier start to the season, although 75% of play occurs between July and September. There should be an increase in the number of unfavourable days because of more frequent heat waves and, possibly, summer precipitation. Greater irrigation needs due to warmer temperatures would likely become a problem and a source of usage conflicts, given lower water levels and stricter withdrawal regulations, all of which represent the sector's main challenge. Current grass varieties would deteriorate more rapidly during summer and winter mild spells, as future climate conditions encourage bacteria and other pathogens. The quality of drainage on golf courses would also be affected by the intensity and recurrence of precipitation, and it would cost more to maintain the grounds if increased evapotranspiration dried out the course. These new climate constraints would be of major concern for operators already facing keen and recent competition and needing to meet mandatory environmental standards related to the regulated use of maintenance products (Singh et al., 2006).

With regard to other summer activities, despite the lack of studies on the subject, an increase in such summer tourist activities as hiking, park use, water recreation and boating, can be assumed (Jones and Scott, 2005). Several tourist regions with a more temperate climate would benefit from temperature warming, and Quebec would be privileged compared to more southerly regions, helping its overall tourist balance despite having to contend with socioeconomic factors that could limit revenue dedicated to tourism and recreation. The negative impacts would stem from increased precipitation, heat waves and deteriorating water quality, due specifically to the spread of cyanobacteria and other harmful species (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2005a). Fishing would be disturbed, since fish are sensitive to small variations in temperature.

Adaptation strategies

Faced with greater market competition, constant infrastructure renewal and cost increases (artificial snow-making, electricity, property taxes), many ski hill operators believe that better understanding of future climate phenomena, which leads to better planning of investments and satisfaction of increasingly demanding and selective customers, is the best adaptation strategy. While benefiting from steady technical progress, the ski industry shows a capacity to adapt to new consumption habits, growing competition and new social phenomena, such as excessive and rapid consumption, changes in the family situation and instant access to weather forecasts, which will play an increasingly dominant role. In the case of ski centres, diversification would be one way to adapt to climate impacts and variability, and could be seen as a useful adaptation pathway when dealing with more significant changes (Singh et al., 2006).

Adaptation strategies for the golf industry deal mainly with water management, both natural inputs and land drainage. Grass quality, a major customer requirement, must be monitored to avoid increased withering. Extending the season would generate additional income if the benefits reflect on other services such as food and lodging. However, climate change does not seem to be the priority of this sector, since golf course maintenance costs are mainly related to labour and plant health products (Singh et al., 2006).

As for other summer activities, impacts on sport fishing could be mitigated by planting a vegetation cover on banks, and water quality should be more closely monitored at sites reserved for swimming.

Developing appropriate adaptation strategies requires that stakeholders in these sectors be well informed to better grasp the significance of climate change scenarios, threshold levels for activities and the various possibilities for spontaneous or planned adaptation (Singh et al., 2006). As for consumers or users of tourism infrastructure, it would be advisable to clarify their reactions to different climate thresholds for each activity and the comparative attraction of these activities under the new climate conditions.

3.4.5. Transportation

The Quebec road network is influenced by a harsh climate, the size of the province, the population distribution and heavy traffic in large population centres (Ministère des Transports du Québec, 2006b). This particular situation increases the sensitivity of infrastructure (*see* Section 3.5.3) and transportation activity to climate change.

Winter maintenance

Winter driving on Quebec roads is a challenge, mainly due to difficult and changing conditions. Winter storms are predicted to be less frequent but more intense (Cohen and Miller, 2001). This should increase the complexity of managing winter road maintenance, which covers all measures taken by various parties to combat or adapt to the deterioration of driving conditions in winter. On the other hand, a winter maintenance decision support system (named DVH-6024), using information obtained from stations equipped with weather and road sensors, was set up by the MTQ in 1999 (Tanguay and Roussel, 2000). The development and application of road weather technologies continues, particularly in the case of fixed and mobile instrumentation deployed across the province.

Road surface

In the south subregion, temperatures can change by up to 25°C in a few hours. For more than four months, the ground freezes to depths of 1.2 to 3 m, and precipitation can reach 1000 mm a year (Ministère des Transports du Québec, 2006c). In spring, after resisting deformation due to deep frost, the road must once again be able to support heavy loads while pavement strength is reduced by 40% (Frigon, 2003). Scenarios derived from climate models suggest an increased incidence of mild spells (Government of Quebec, 2006c). Since freeze-thaw cycles and the presence of increased water on the road exacerbate surface deterioration, the new climate conditions will have an impact on pavement conditions and, consequently, on maintenance costs. The rapid evolution of methods and knowledge concerning road surface design and the emergence of new technologies and products have led the MTQ to adapt diverse technologies to the Quebec situation and to design and fine-tune new pavement assessment equipment. These activities, conducted in collaboration with the university community, have been the subject of meetings and technical exchanges, as well as joint research projects with several countries, including France (Doré and Savard, 2006) and the United States.

3.4.6. Context specific to the south subregion

A high level of socioeconomic activity is concentrated in southern Quebec, which places significant stress on the environment and inevitably complicates the analysis of vulnerabilities and the prediction of climate change impacts on both the natural and human systems. In fact, the complicating factors are similar to those of other highly developed, densely populated regions:

- a high and growing population density
- growth of the built environment serving a heavily service-oriented economy
- ubiquity of institutions with important investment and regulatory capacities
- change in public perceptions with respect to activities less and less directly related to climate conditions and ability to choose from among a wide range of historical choices when making land-use decisions
- pressures brought on by urbanization of watersheds that were previously largely agricultural or forested.

This dynamic is also influenced by global socioeconomic issues and associated climate impacts that are likely to have repercussions in the south subregion (*see* Chapter 9). In this context, and as illustrated in Sections 3.4.1 to 3.4.5, the available studies are essentially sectoral, except when dealing with water management, in which case the studies start quantifying and integrating the impacts of different users on the management rules.

The weather event that best illustrates the vulnerabilities associated with a high degree of infrastructure interdependence is the ice storm of January 1998. In that event, the impacts hit several sectors simultaneously, generating a complex series of effects that, when combined, led to the failure of socioeconomic activities and to outcomes whose cost has been estimated at several billion dollars (Ministère de la Sécurité publique du Québec, 1999). Since all infrastructure or societal choices are actually socioeconomic compromises between what is considered acceptable costs and desired benefits, climate change could affect this ratio. These compromises, once considered acceptable, could be revisited on the basis of past or anticipated extreme weather events. However, while quantitative climate studies on the links between climate change and extreme weather events are emerging (Tebaldi et al., 2006), they rarely allow an assessment of impacts at the infrastructure, building or community scale. An increase in heavy precipitation simulated by one version of the CRCM for the south subregion would affect the urban area, overloading municipal infrastructure and triggering flash floods in rural watersheds (Mailhot et al., 2007). Various tools (Secretan et al., 2006), policies (Government of Quebec, 2006c) and land uses (Mailhot et al., 2007) would help reduce the vulnerability.

Little is known about links between the regional climate and the geology of the south subregion, but most of inhabited Quebec lies on clay soil subject to landslides (*see* Case Study 4). This area is characterized by significant urban sprawl, and any increase in the number of landslides would have significant consequences for the security of people and property. As mentioned in Chapter 2, lack of knowledge about a potential problem can significantly affect the adaptive capacity of a system.

3.5 OTHER INTEGRATED ISSUES AT THE PROVINCIAL SCALE

This section will present the key issues for the four subregions, followed by a discussion of other sensitivities and impacts at the provincial level. Although this discussion cannot be exhaustive, given the potential scope of the problem and the limited number

CASE STUDY 4

Landslides in Quebec

Hundreds of landslides occur every year in Quebec, most of them in clay soils (Figure 22) in areas experiencing significant population growth, as discussed in Section 2. Water infiltration into the ground following the spring snow melt or during rainfall events is one of the two major causes of landslides, others being the gradual erosion of stream banks or destabilizing human activity. Extreme weather events often take the form of heavy rainfall that frequently causes major floods. This is shown by the many landslides that occur in spring or during exceptional events — such as the torrential rains of July 1996 in Saguenay–Lac-Saint-Jean, when more than 1000 landslides occurred in less than 36 hours (Ministère des Transports du Québec, 2000).

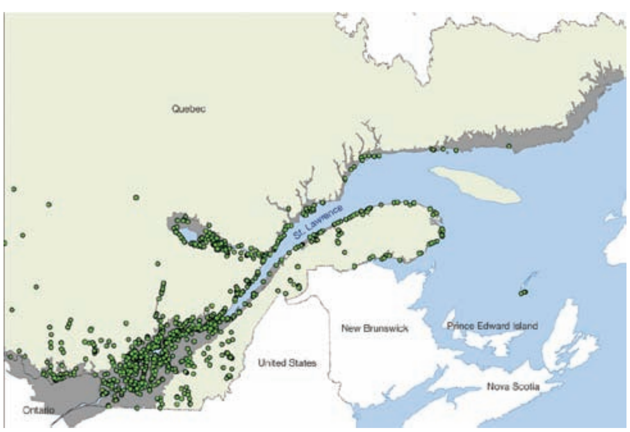

FIGURE 22: Inventory of requests to respond to landslides in Quebec between 1972 and 2005. The grey zone shows the limits of the postglacial marine transgression that left clay deposits (map provided by the Ministère des Transports du Québec, pers. comm., 2006).

Although the link between these events and climate change does not seem obvious, it appears that the increase in this phenomenon in a region experiencing significant urban sprawl can generally be linked to an increase in extreme precipitation events. Nevertheless, the Saguenay flood improved understanding of the phenomenon through mapping of certain regions at risk, thus adding to the historic efforts initiated by the 1971 landslide at Saint-Jean-Vianney (Figure 23) to assess vulnerabilities and promote a safer use of the territory.

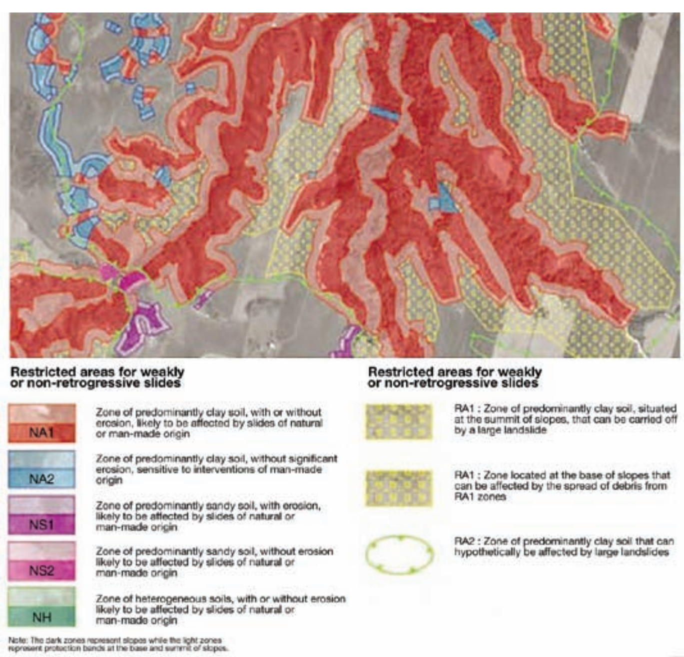

FIGURE 23: Sample map showing areas at risk from landslides for a locality of Saguenay–Lac-Saint-Jean (Government of Quebec, 2005).

of pertinent studies on the subject, the objective is to obtain a clearer overall picture of the situation and to examine certain specific issues that have not previously been discussed. The discussion is based on the three key elements identified in Figure 1.

Although it is valid for all of Quebec, the present section is particularly pertinent for the socioeconomically dominant south subregion that will see climate change combined with interrelated environmental and socioeconomic changes that have already been underway for several decades. The vulnerability of this subregion, and Quebec as a whole, will be influenced by climate changes, weather events, information distribution, international negotiations, public perceptions, the market economy and the public policies of different levels of governments.

3.5.1. Sensitivity and adaptation of populations

Climate change presents a challenge for human health. Its impact is either direct (e.g. death due to heat stroke), or indirect (e.g. outbreak of pathogenic insects). On the other hand, populations show different degrees of vulnerability to climate change, which complicates the introduction of adaptation measures to limit anticipated impacts.

Impacts and sensitivities

Impact of mean warming on mortality

In Quebec, the anticipated rise in mean temperatures may lead to an increase in annual mortality rates (Figure 24). The study by Doyon et al. (2006) predicted a rise in summer mortality (all non-injury causes) on the order of 2% for 2020 and 10% for 2080, according to the A2 scenario (Intergovernmental Panel on Climate Change, 2001a); this increase is not entirely offset by lower winter mortality. Hence, the rise in the annual mortality rate would be about 0.5% for the 2020 period and 3% for 2080, a conclusion similar to that reached for many cities in the United States by Kalkstein and Green (1997), who estimated the number of deaths on hot days to be three times higher than on cold days. Keatinge et al. (2000) predicted a net annual drop in mortality in the United Kingdom due to decreased mortality during winter, which does not seem to be the case in Quebec. However, these simulations do not consider population aging — which can substantially increase mortality rates — nor do they consider physiological and environmental adaptation measures or those related to housing — which can reduce mortality by the same amount. In Québec, there will be more and more people aged 65 and over. Their proportion rose from 9.7 to 12% between 1986 and 2001, and should reach around 24% in 2025 (Institut de la statistique du Québec, 2000). What’s more, the study by Doyon et al. (2006) confirmed that the group aged 65 and over is historically much more vulnerable to climate warming than the group aged 15 to 65.

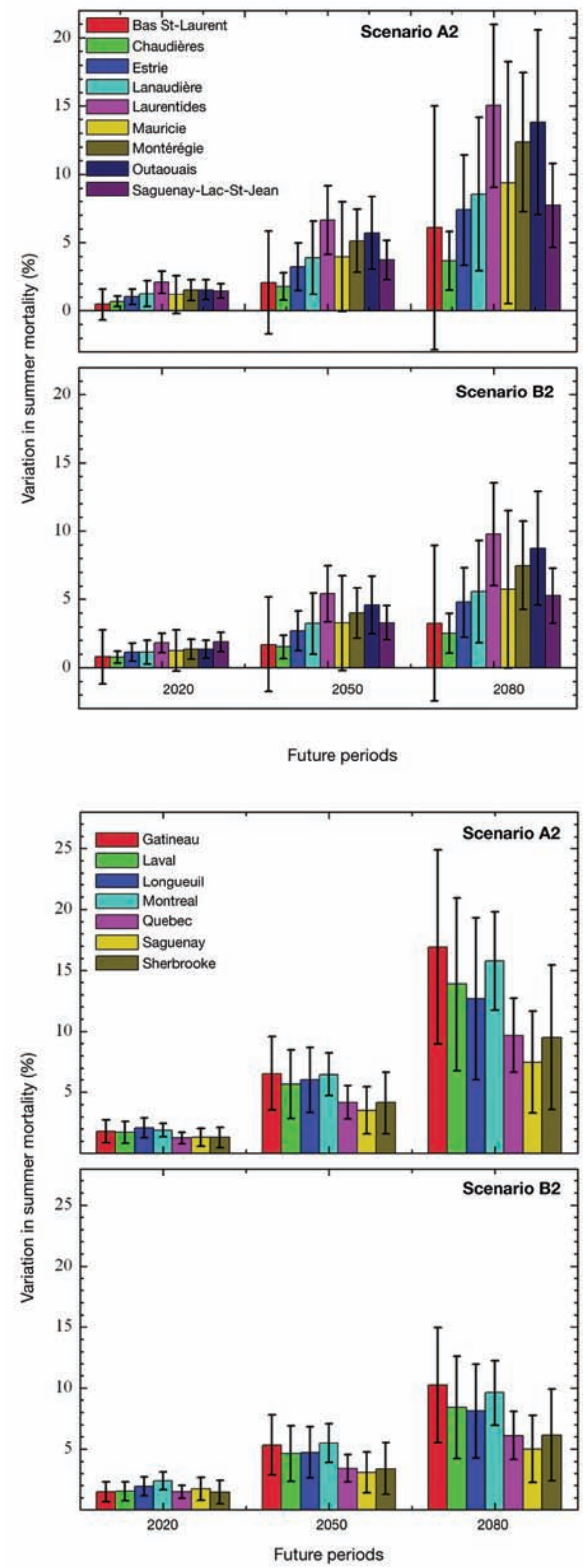

FIGURE 24: Variation in summer mortality in Quebec (cities and regions) according to various scenarios (Doyon et al., 2006).

The direct health effects of violent rain and floods include injury, heart problems and death by drowning. The indirect effects take the form of infectious diseases, such as conjunctivitis and dermatitis, caused by contaminants present in the flood waters and gastroenteritis due to microbiological contamination of drinking water sources. Respiratory problems linked to mildew are also listed. Victims and aid workers would suffer post–traumatic stress that could lead to depression, anxiety, psychosocial troubles and even suicide (World Health Organization, 2005).

The direct health effects of winter storms include injury, chilblain, hypothermia and sometimes death, with 100 Canadians dying every year (Institute for Catastrophic Loss Reduction, 2005).

In 2004, lightning was responsible for about 12% of forest fires (Organisation de patrouilles de la Société de protection des forêts contre le feu, 2006). In addition to their considerable economic impact on the forest industry, forest fires emit chemical compounds into the atmosphere (e.g. particles, nitrogen oxides, carbon monoxide, organic compounds). In humans, these emissions can cause irritation of respiratory pathways, worsening of chronic diseases and poisoning due to smoke inhalation. Acute syndromes may also occur in firefighters and forestry workers exposed to smoke for long periods (Dost, 1991). The indirect effects on health are post–traumatic stress, possibly leading to suicide (World health Organization, 2005), particularly in the case of a significant economic loss (e.g. residential fire or plant fire with job losses). However, the current scenarios associated with the boreal forest do not predict significant changes in precipitation or forest fires in Quebec, but uncertainty remains (Ouranos, 2004).

In January 1998, freezing rain fell on Quebec for five consecutive days, leaving more than 3 million people without electricity, some for as long as 40 days. This event was responsible for 21 deaths and 200 cases of carbon monoxide poisoning (Roy, 1998), mainly in the Montérégie and on the Island of Montréal (Tremblay et al., 1998). Laplante et al. (2004) conducted a study on 224 women who were pregnant at the time or became pregnant in the three months following the storm. 'Objective' stress factors (number of days without electricity) and 'subjective' reactions (post–traumatic stress syndrome) were assessed. The results show a connection between major prenatal stress in the mother and elevated perinatal mortality, differences in psychomotor development in children aged 2 to 5.5 years and behavioural problems in children from 4 to 5.5 years old.

In the north, recent climate trends may be related to the avalanche at Kangiqsualujjuaq in 1999, where 9 people died and 25 were injured (Public Security Canada, 2006). Other, less tragic incidents occurred in other villages during the same time. In Salluit (Hudson Strait), a landslide occurred in 1998 following failure of the active soil layer. In Tasiujaq (Ungava Bay), permafrost thawing was in part responsible for subsidence of a building and deformation of the airport runway (Allard et al., 2002). In addition to putting lives in danger, these events cause considerable insecurity among residents who depend on air transport for food supplies and medical evacuations to hospitals.

Impact of heat waves and of the urban heat island effect on health

Higher temperatures, a daily Humidex that has been rising during the past four decades in Montréal and Québec City, and more frequent and intense heat waves represent important risks for human health (Environment Canada, 2004a, b). Adding to these events is the urban heat island effect, produced by asphalt surfaces and infrastructure materials that absorb heat and raise the ambient air temperature by 0.5°C to 5.6°C in urban settings (Oke, 1982).

The heat can cause discomfort ranging from weakness to consciousness disorders, as well as fainting and heat stroke that can cause death (Besancenot, 2004). Indirectly, heat can also exacerbate such chronic diseases as diabetes, respiratory insufficiency and kidney failure. Sunshine also contributes to the formation of ground-level ozone in urban areas, a gas harmful to human health. Ground-level ozone can irritate the eyes and respiratory pathways, reduce respiratory function, exacerbate respiratory or heart disease, and even cause premature death (Health Canada, 2004).

Southern populations are more sensitive to an increased frequency of oppressive heat episodes, whereas people in the north suffer more from the rise in temperature, since they are not acclimatized (Health Canada, 2005). Several scientific studies (Commission de la santé et de la sécurité du travail, 2004; Direction de la santé publique de Montréal, 2004) referred to people with higher vulnerability based on environmental characteristics (e.g. housing, work, access to cool places) or personal characteristics (e.g. diseases, disabilities, age). The study by Bélanger et al. (2006) shed new light on the vulnerability of certain groups to heat. It highlighted certain known factors and documented new relationships that can exacerbate the impact of heat waves, including 1) elderly persons living alone; 2) economic precariousness; 3) limited mobility; 4) chronic neurological problems (epilepsy, multiple sclerosis); 5) social support; 6) type of housing (including certain types of residential buildings); and 7) access to recreational activity during heat waves (such as bathing areas).

The relationship between multiple-storey residential buildings and higher mortality during heat waves has been established by several researchers (Klinenberg, 2002; Dixsaut, 2005), and public perceptions throughout Quebec have also recognized this vulnerability (Bélanger et al., 2006).

A tracking study conducted in the Eastern Townships on the use of prescription drugs during intense heat episodes showed the importance of the warnings issued by pharmacists (Albert et al., 2006). A significant percentage (30.2%) of people aged 65 and older take a type of prescription medication whose absorption can be affected by dehydration, or that can impede caloric loss and kidney function. Nearly 5% of elderly persons had three or more prescriptions for drugs of this type to be taken simultaneously.

Effects of air pollution on health

The World Health Organization recently presented the hypothesis that a warmer and more humid climate would increase the atmospheric concentration of certain pollens and thereby provoke an outbreak of allergic disorders such as allergic rhinitis and asthma (McMichael et al., 2003). Allergic rhinitis is a serious public health problem in industrialized countries, altering the quality of life of affected populations and causing absenteeism and loss of productivity at work. The costs related to hospitalization, drugs and medical consultations are also significant (Breton et al., 2006; Garneau et al., 2006). In the Québec City and Montréal regions, a rise in both pollen concentrations and frequency of medical consultations for rhinitis was noted between 1994 and 2002. Allergic rhinitis due to pollen and other allergens, or resulting from a non-specific cause, ranks 5th (9.4%) among declared health problems (Institut de la statistique du Québec, 2000). This prevalence seems to have increased by 6% since 1987 (Garneau et al., 2006), but many external factors could also contribute to it apart from climate.

According to Garneau et al. (2006), allergic rhinitis affects mainly the 15 to 24 age group (14.6% of the Quebec population) and the 25 to 44 age group (13.6%). Medical consultations for the 1994 to 2002 period were more frequent among women than men. However, for the 0 to 14 age group, they were higher for males. These results are consistent with those of studies by Banken and Comtois (1990) and Goulet et al. (1996) that reported a maximum incidence of allergic rhinitis among those 0 to 24 years of age.

The use of fossil energy produces not only a significant amount of CO_2 emissions but also of precursors to ground-level ozone and fine particulate matter. Climate change would increase temperature extremes, resulting in a rise in the frequency and duration of heat waves and smog (House and Brovkin, 2005; World Health Organization, 2005). In Quebec, low-altitude ozone levels have been rising constantly during the past 15 years on a seasonal mean basis (Environment Canada, 2005), although the number of acute episodes varies greatly from one year to another. With greenhouse gas increasing by 6% from 2001 to 2003 (Institut national de santé publique du Québec, 2006), this risk remains significant and growing, to varying degrees, for most of the south subregion.

Effects of climate change on the quantity and quality of water resources

In the south subregion, if the projected effects of climate change result in lower stream levels and flows, a change in precipitation (*see* Section 3.4.3) and a rise in salinity levels of the St. Lawrence River (Bourgault, 2001), this would be a serious concern since more than 70% of the public takes its drinking water from surface water (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2004a). The risks of microbial, chemical and natural biotoxin contamination are also higher. Moreover, water shortages, linked to reduced capacity of aqueducts, present a higher risk in case of fire, with injury, death and considerable psychological impact for families whose personal property is destroyed (Enright, 2001).

Water-borne diseases can appear if pathogenic micro-organisms migrate to groundwater or surface water sources used for water supply (Canadian Council of Ministers of the Environment, 2005a, b). Phosphorus, sunshine and temperature are the key factors responsible for blue-green algae blooms (Agence de développement de réseaux locaux de services de santé et de services sociaux, 2003). In Quebec, this phenomenon has already affected about 84 lakes and streams between 1999 and 2003 (Institut national de santé publique du Québec, 2006) and has led to prohibitions on water consumption and bathing, but without any human illness being reported so far. Cyanotoxins, produced by cyanobacteria, can cause skin irritation and serious liver or nerve damage, through both skin contact and water ingestion (American Water Works Association, 1999; Agriculture and Agri-Food Canada, 2003). Young children, the elderly and persons with chronic diseases are more at risk of developing severe symptoms resulting from water contamination. Persons practicing water activities are particularly vulnerable to contamination by natural biotoxins (Agence de développement de réseaux locaux de services de santé et de services sociaux, 2003; Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2005b). The general public would be affected by water shortages at the physical and psychological levels; families already in precarious situations would experience more insecurity with respect to food supply by having to buy their water (Direction de la santé publique de la Montérégie, 2004).

Water-borne diseases (transmitted through protozoa, bacteria or viruses) are common in Nunavik and, from 1990 to 2002, certain of these diseases (e.g. giardiasis, salmonellosis) were found in proportionately higher numbers there than elsewhere in Quebec, while the number of other types of infectious diseases was lower

(Furgal et al., 2002). Climate change can affect water supply (individual or community systems), degrade the permafrost and contribute to saltwater intrusion in aquifers, thereby exacerbating a situation that is already cause for concern. For many villages, burying garbage in the permafrost would pollute groundwater, streams and adjacent lands (Furgal and Seguin, 2005). In Nunavik, one person in five is under five years of age — a group at risk for gastroenteric diseases because of the weakness of children's immune system (Martin et al., 2005b). The feared changes highlight the urgent need to improve environmental monitoring and health surveillance systems for quick detection and treatment of health problems related to water quality (Owens et al., 2006). A pilot project related to this is currently underway in Ungava Bay within the framework of the ArcticNet Network of Centres of Excellence (Gosselin, 2006).

In 2004, QANUIPPITAA, the health survey among the Inuit of Nunavik (Régie régionale de la santé et des services sociaux Nunavik, 2004), conducted in all villages of the subregion, prompted the development of new strategies. During the visit of the Amundsen, an icebreaker for scientific research, 232 homes and 19 raw water supply sites were visited as part of an ArcticNet project (Martin et al., 2005c) associated with the health survey. This survey provided both an understanding of drinking water consumption habits of residents and an overall picture of bacteria levels in the water consumed. It will be used to develop important environmental and health databases for the north subregion, which can then be used for climate-based tracking.

A similar survey was conducted among the Cree population of Mistissini (Nituuchischaayihtitaau Aschii, 2005). It will contribute to the creation of a valuable database on changes in water quality during the next seven years in First Nations communities of the north subregion.

Impacts of climate change on the emergence and intensification of zoonotic and vector-borne diseases

Climate change would modify the distribution range of parasites and diseases transmitted by animals, insects and ticks, resulting in a rise in existing infectious diseases and the appearance of new infectious diseases in Quebec.

Zoonotic diseases include the hantavirus pulmonary syndrome (HPS), for which certain rodents are the vectors. A warmer climate would result in the propagation of rodents into new areas. Many indigenous rodents carry this disease: a first case was reported in Quebec in 2005 (Direction de la santé publique, 2005). Rabies is another disease that can be transmitted to humans through bites or scratches received from infected animals. Climate change would give rise to changes in habitat and length of hibernation and breeding conditions of vector animals, leading to the northward spread of diseases (Ontario Forest Research Institute, 2003).

Quebec presently has few mosquito species that are vectors of viral diseases transmissible to humans. However, a few species present in the south subregion are vectors for the West Nile virus, St. Louis encephalitis, La Crosse encephalitis and eastern equine encephalitis (Institut de santé publique du Québec, 2003a, b). Encouraged by milder winters and longer summers, the mosquitoes live longer and the season during which the St. Louis encephalitis virus can be transmitted is extended. La Crosse encephalitis is endemic to the United States, and the Snowshoe Hare variety of this virus is present in Quebec, as is the eastern equine encephalitis virus, with no cases reported so far (Institut de santé publique du Québec, 2005a, b). However, it can be reintroduced every year by migrating birds (Ontario Forest Research Institute, 2003).

Lyme disease, an emerging zoonotic disease in Canada, can be transmitted by bacteria to humans through bites from infected ticks. According to Université de Montréal researchers, the ticks responsible for the spread of Lyme disease will spread to several parts of eastern Canada, including Quebec, within 10 to 20 years, as the climate warms (Ogden, Faculté de médecine vétérinaire, Université de Montréal, pers. comm. 2005).

Several zoonotic diseases already exist in Arctic animal species, such as tularemia in hares, muskrats and beavers; rabies in foxes (Dietrich, 1981); brucellosis in ungulates, foxes and bears; and echinococosis in canine species (Chin, 2000). The Inuit present high levels of many parasitic zoonotic diseases, particularly toxoplasmosis (Tanner et al., 1987), and climate change is likely to increase the incidence of transmission, either through eating flesh or by water-borne contamination. From 21 to 56% of Inuit households already report a certain level of insecurity with respect to food (Statistics Canada, 2001). The QANUIPPITAA survey will update this data at the beginning of 2008.

Other effects on the north subregion

For millennia, the Inuit have practiced subsistence hunting and fishing. Although they have access to food imported from the south, they continue to feed themselves in traditional ways and derive much more beneficial health effects from 'country foods' than from imported products (Ministère de la Santé et des Services sociaux du Québec and Institut national de santé publique du Québec, 2004). However, should the animals be sick, harbour parasites, suffer from an increase in biting insects, experience famine, change or loss of habitat, the Inuit would then be exposed to a double change because their resources would be transformed or moved, which might, in turn, affect their quality. Their intake of highly nutritious animal protein would be reduced, a matter of some concern, since demographic growth and the maintenance of their hunting and fishing skills are in decline (Furgal et al., 2002). This change is also a concern for public health officials because the replacement of traditional foods with imported foods that are higher in sugar and carbohydrates would lead to cardiovascular problems, diabetes, vitamin deficiencies, anemia, dental problems and obesity, as well as lower resistance to infections. The Inuit already present much higher mortality or morbidity rates than elsewhere in Quebec, mainly in relation to food (Institut national de santé publique du Québec, 2006) and reduced life expectancy due in large part to death by injury, cancer and, to a lesser extent, cardiovascular disease.

The direct and indirect impacts of climate conditions on the natural and built environment would probably increase risks to health, security and well-being of these isolated populations. For example, the considerable increase in quantity and intensity of precipitation would cause more landslides or avalanches. Following the Kangiqsualujjuaq avalanche in 1999 (9 dead and 25 injured), a thorough risk assessment was conducted in all villages and critical infrastructure was moved, particularly the diesel power stations and fuel tanks (Schweizer and Jamieson, 2003).

Adaptation strategies

Mortality and morbidity

The modelling of the relationship between mortality and mean temperature conducted for most regions of Quebec (Doyon et al., 2006) would be complete if the morbidity-climate connections were quantified and variations in hospitalization or emergency consultation rates were examined. Specific response thresholds for regions and cities could be established and modified from time to time, depending on changes in the temperature as well as death and disease. This work is planned in the framework of an Ouranos program, while some cities have already begun to adapt (Kosatsky et al., 2005a, b).

Extreme climate events

Quebec has good mechanisms for reacting to emergencies, and most existing adaptation initiatives consist of surveillance and monitoring activities, training and education, and changes to regulations and policies. In surveillance and monitoring, however, several observers (Giguère and Gosselin, 2006a) believe it is necessary to extend and strengthen the role of geographic information systems (GIS) and new technologies in the management of flood risks. Different Quebec government departments (Public Security, Health and Social Services), Public Safety Canada and organizations such as the Red Cross make guides available to the public on measures to take during different types of extreme events. The creation of Ouranos and its health section (in collaboration with Health Canada, the Ministère de la Santé et des Services sociaux du Québec and the Institut national de santé publique du Québec) fits with Quebec's strategy on adaptation to climate change (Ministère de la Sécurité publique du Québec, 2003a, b; Institut national de santé publique du Québec, 2005a, b). Management by watershed, now being developed, will provide for an ecosystem approach to water management that includes public health officials (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2004a).

On the other hand, it would be desirable to develop and encourage a number of other initiatives for adapting to extreme climate events (Giguère and Gosselin, 2006a), in particular:

- enhanced preventive planning associated with extreme climate events;
- the modelling and communication of risks tied to different types of extreme climate events, in the short, medium and long terms, in order to develop adequate initiatives; and
- research on the impact of extreme climate events on health in the short and long terms, as well as improvement of emergency health measures.

The Ministère de la Santé et des Services sociaux (Gouvernement du Québec, 2006a) announced its intention to establish, by 2011, a system for surveillance and epidemiological tracking of the consequences of extreme climate events.

Air pollution

According to Garneau et al. (2006), critical pollen thresholds must be determined and warning notices issued when the thresholds are exceeded. Control methods should also continue against *Ambrosia* spp., the pollen associated with the largest percentage of allergy symptoms, and the main parties should be made to strengthen their responses. The Quebec Ragweed Board (Table québécoise sur l'herbe à poux) was set up in 1999 for this purpose and continues to support the actions in the field of municipal, private and non-government partners to control this risk (Agence de la Santé et des Services sociaux de la Montérégie, 2007). Different public health notices aimed at reducing urban sprawl and automobile traffic have been issued in recent years (Direction de santé publique de Quebec, 2004; King et al., 2005), but with no measurable impact to date. The Info-smog program is now available for all of southern Quebec, all year long (Ministère de la Santé et des Services sociaux, 2006b), but its impact on behaviour seems minor up to now (Bélanger et al., 2006; Tardif et al., 2006).

Adaptation strategies related to preserving air quality generally focus on promoting the purchase of smaller, more fuel efficient vehicles, travel by bicycle or on foot, or the promotion of public transit, for which the Government of Quebec (Gouvernement du Québec 2006b) is encouraging an annual increase in ridership of 8% by 2012.

Quantity and quality of water resources

In the context of climate change, several major adaptation initiatives related to the quantity and quality of Quebec water resources are already established, or will be by 2007 (Giguère and

Gosselin, 2006c). Programs to monitor surface water quality will contribute to safe aquatic activities, but only at some sites. The Règlement sur la qualité de l'eau potable (Regulation Respecting the Quality of Drinking Water) requires that employees who supervise and control drinking water quality or are responsible for maintaining wastewater treatment plants be adequately trained. Research and development programs on methods for treating drinking water have been underway for several years in many Quebec universities. The new Quebec regulation (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2005b) on water quality prescribes strict surveillance using standards that are among the highest in North America. However, it provides no standard for cyanotoxins, toxic to humans, which may spread at a faster pace under warmer climate conditions. Research is also underway on the links between climate, health and water quality. According to Charron et al. (2005), water- or food-borne diseases represent the most important health problem of the planet. The Centre for Infectious Disease Prevention and Control of the Public Health Agency of Canada, in collaboration with the Institut de santé publique du Québec, is currently conducting a study on health-related aspects (ecosystems, population, society, individual) in order to define the vulnerability of Canadians to water- and food-borne diseases arising from climate change, including those in rural Quebec. The Quebec government's 2006 to 2012 Action Plan (Gouvernement du Québec, 2006a) calls for an improvement in methods for detecting epidemics and infectious disease based on climate variables.

Zoonotic and vector-borne diseases

In Quebec, most initiatives related to climate change adaptation seem to focus on zoonotic and vector-borne diseases, although risks seem low here compared to other socioeconomic sectors. The Institut de santé publique du Québec co-ordinates activities on early detection, real-time monitoring (Figure 25) and research on the West Nile virus (Bouden et al., 2005; Gosselin et al., 2005a; Institut de santé publique du Québec, 2005a, b). The Quebec government makes information documents available to the public on zoonotic and vector-borne diseases, as well as on ways to protect oneself. The Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, 2006) has invested large amounts of funding into research to better monitor and combat these diseases.

In addition, some experts (Giguère and Gosselin, 2006b) have suggested developing and implementing initiatives such as integrating climate change impact indicators into the monitoring of zoonotic and vector-borne diseases; and intensifying research on methods to control these diseases.

Heat waves and urban heat island effect

In 2006, seven out of eight regions had an emergency response plan for a heat wave, as required by the Ministère de la Santé et des Services sociaux (Ministère de la Santé et des Services sociaux, 2006a). These emergency plans, involving early warning systems and mobilization, are based on a threshold established by an analysis of health and weather data collected over the past 20 years. Some include monitoring of deaths in a crisis situation. The Direction de la santé publique de Montréal has developed expertise in this field since 2004, but the emergency plans have not yet been tested in an actual situation of a prolonged heat wave, although a simulation exercise was carried out for the Island of Montréal (Health Canada, 2005), leading to some improvements in the emergency plans. Other simulation exercises also revealed several shortcomings (Health Canada, 2004). Other initiatives dealing with the risk of oppressive heat were implemented to inform the public and the most vulnerable groups (Ministère de la Santé et des Services sociaux, 2006c), specifically the elderly and their attendants as well as certain groups of workers. A similar approach was undertaken with health establishments, agencies (e.g. Commission de la santé et de la sécurité au travail, Réseau public québécois de la santé au travail) and organizations (e.g. medical clinics, pharmacies, Association des locataires des habitations à loyer modique). Initiatives aimed at workers were developed, particularly in the Chaudière-Appalaches region and mainly related to the dissemination of information. In addition, research projects on heat waves and urban heat island effects (UHIE) are presently planned or have been undertaken by Ouranos (2006).

According to Bélanger et al. (2006), adaptation strategies related to heat waves should be geared to monitoring, research, information dissemination and assistance programs. Research

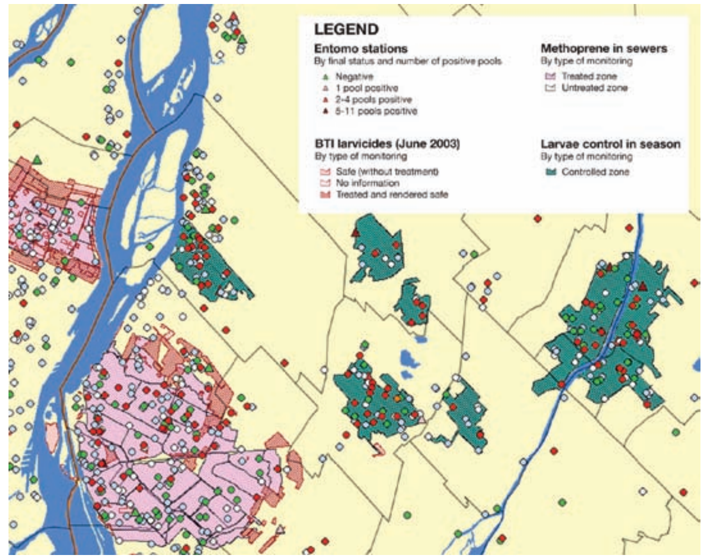

FIGURE 25: Example of thematic map from the real-time monitoring system of the Institut national de santé publique du Québec (Système intégré des données de vigie sanitaire – Virus du Nil occidental or SIDVS-VNO). It shows different preventive insecticide treatments (darkened zones) against larvae of the vector mosquito for the West Nile virus on the south shore of Montréal, in 2003 (*see* Gosselin et al., 2005).

would determine what services vulnerable people need to ensure their security during these heat episodes. The key findings should be conveyed to community organizations and front-line workers assigned to civil security.

The study by Vescovi et al. (2005) made it possible to map zones presenting risks for climate warming. An Internet atlas project dealing with certain public health vulnerabilities is being developed on a Quebec-wide scale (Gosselin, 2005) and in more detail for the Island of Montréal (Kosatsky et al., 2005b).

To combat the UHIE, the use of green roofs or roofs built with high-albedo materials is attracting growing interest, as is the use and availability of public transit in certain regions (Ducas, 2004; Ville de Montréal, 2005). Certain regional public health administrations are starting to promote these approaches in urban settings.

However, certain supplementary initiatives could be implemented (Giguère and Gosselin, 2006d), such as:

- training health professionals;
- establishing pilot projects for mass education on the subject of personal protection in case of heat waves and to help combat the UHIE; and
- adding economic incentives that encourage initiatives to mitigate the phenomenon of intense heat.

The Quebec government's 2006 to 2012 action plan calls for promoting islands of coolness and training personnel in practices adapted to climate change over the next few years, under the supervision of the Ministère de la Santé et des Services sociaux.

Ultraviolet rays (UV)

In Quebec, climate change would lengthen the warm season, prompting people to spend more time outdoors and thus be increasingly exposed to ultraviolet (UV) rays (Hill et al., 1992; Diffey, 2004), an impact quantitatively more significant than that arising from the thinning of the ozone layer. The health consequences of overexposure to UV (skin cancer, cataracts, immunosuppressive effect reducing vaccine effectiveness, epidemic development) would increase (World Health Organization, 2003). However, at the Quebec scale as opposed to the Canadian scale, protection against UV rays is not yet properly taken into account (Institut de recherche en santé du Canada, 2002), despite the 80 000 new cases of skin cancer diagnosed each year in Canada. It is the most common form of cancer in the country (National Cancer Institute of Canada, 2005). Environment Canada issues a UV index that is widely available to the public, and there is a National Sun Safety Committee (Canadian Strategy for Cancer Control, 2001).

Adaptation, whether through education or behaviour modification, nevertheless seems a cost-effective measure. In Australia, protecton against the effects of UV rays costs an average of US$0.08 per capita, whereas cancer treatment costs reach US$5.70 per capita (Organisation mondiale de la santé, 2003). The effect of climate change on this factor is not yet known (Institut de recherche en santé du Canada, 2002), but preventive measures aimed at creating shade for protection from the sun could prove useful (Government of Quebec, 2006a).

3.5.2. Sensitivity and adaptation of socioeconomic activity

The sensitivity of the Quebec economy to climate change shows significant differences in the quantification of impacts, associated degree of certainty and difficulty in specifying a monetary value. Impacts on the economy can be grouped into several categories:

- The first category includes impacts on infrastructure and buildings. This can mean loss of infrastructure or buildings, maintenance work, greater protection, relocation, reconstruction or redevelopment. In this regard, the Arctic region and the maritime coastline are particularly vulnerable (permafrost thawing, coastal erosion, change in precipitation).
- The second category covers impacts on economic activity that would change productivity or demand and prices. Long-term economic vulnerability depends on the importance of the sectors affected (positively or negatively) by temperature and precipitation changes. Given the importance of natural resources in its economy (Figure 26), Quebec is more sensitive than some other developed regions of the world where economy is less linked to climate. Indeed, the forest industry, agriculture and hunting and fishing represent 2% of the province's economy ($3.8 billion), and precipitation-dependent hydroelectricity production represented $7.8 billion in 2001. Transformation industries (agri-food,

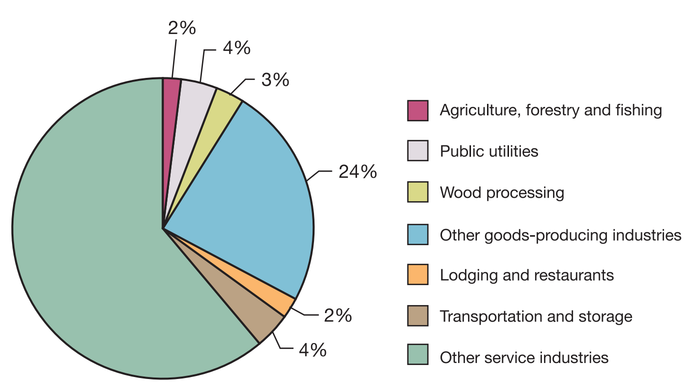

FIGURE 26: Breakdown of Quebec GDP by types of economic sector affected by climate (Ministère des Transports du Québec, 2006c).

lumber, pulp and paper, metal fabrication) would be affected in terms of availability and cost of raw materials. In addition to resource-based industries, the services sector — such as tourism (restaurants and accommodation, or $4 billion and many jobs) — would likely be affected, either positively or negatively, depending on its adaptation to the changing conditions. Health and medical services would have greater needs faced with the new risks. Other sectors (highway and marine transportation, financial services and insurance) will have to adjust to greater uncertainty and higher claims. In short, a significant share of the Quebec economy would be directly or indirectly affected.

- The third category includes impacts on the security, health and well-being of populations, as well as ecosystems, following a change in both mean and extreme values of climate. However, and despite the major role they play in the economy, it is difficult to quantify the real value of these variables other than with indirect measurements.
- Finally, extreme climate events, such as flooding, ice storms, tornadoes and heat waves, represent a set of impacts on the economy that warrant being grouped, as they vary in their duration and magnitude. They affect public security, the integrity of natural ecosystems, the conduct of economic activity and numerous buildings and infrastructure, resulting in high costs (in the billions of dollars) but limited in time.

The south subregion has a diversified economy in which manufacturing and services occupy a large proportion of work production and employment. The resource and rural regions are much more dependent on just one or two activities, including logging, tourism, hunting and fishing, or agriculture. The distribution of climate change impacts would not be uniform across Quebec, and the very survival of certain communities would depend on their capacity to adapt efficiently to the new climate. Climate change is only one aspect of a world in constant evolution. Indeed, Quebec will experience sustained economic growth, doubling its production over 50 years, according to one extrapolation of current trends. Business and technological changes will affect this evolution, making it difficult to forecast the impact of climate change (Ministère des Finances du Québec, 2005).

With respect to the little-studied social dimension, it is likely that the adaptation of Quebec society will require an increased awareness of the phenomenon, such that 1) it would mean relying on an education system systematically embedded in communications aimed at young people (and their parents) on the issue of climate change; 2) this would positively influence the economic and political system, as adaptation measures require action from the public sector; and 3) the media would have an expanded role related to awareness. Media coverage would probably increase with the rising number of victims of climate change. This situation already exists and is expected to grow in importance.

3.5.3. Sensitivity and adaptation of the natural and built environments

Natural environment and ecosystems

Each ecosystem has its own biodiversity that maintains itself dynamically over time, in line with the evolution of environmental parameters (Di Castri and Younes, 1990). Biodiversity takes three forms — genetic diversity, species diversity and diversity of ecosystems (Di Castri and Younes, 1996). A population is a group of individuals of the same species that tries to maintain its numbers from generation to generation. It is the unit on which adaptation pressures are exerted. With each new generation, the individuals must adapt to a set of ecological factors and beget fertile descendants to maintain the species. Ecosystems offer a multitude of goods and services essential to human survival, as shown by certain aboriginal or rural communities that are particularly dependent on these resources (Intergovernmental Panel on Climate Change, 2002).

Climate is the principal factor acting on vegetation structure and productivity and on the global distribution of animal and plant species (Intergovernmental Panel on Climate Change, 2002). Climate change expected for Quebec will probably have locally observable effects on sensitive populations and ecosystems. For certain species, climate change will result in reduced numbers or the disappearance of populations. For others, it will be an opportunity to multiply numbers and extend their distribution range. Climate change will modify the ecological conditions specific to known ecosystems, and even landscapes in the medium and long term (McCarty, 2001; Root and Schneider, 2002; Scott et al., 2002; Walther et al., 2002). These transformations are not deterministic. Living creatures are subject to multiple pressures and climate change is but one part of the equation.

Different issues

The majority of threatened or vulnerable species and ecosystems live in the south subregion (Institut québécois d'aménagement de la forêt feuillue, 2003) and will be affected by the rise in mean temperature and change in the frequency of floods and winter mild spells (Kling et al., 2003). The impact of climate change on the Great Lakes will indirectly alter flooding and mean flows and water levels of the St. Lawrence River; the resulting geomorphological adjustment will affect numerous plant and animal species, some related to wetlands, which already feel the impact of human activity (Mortsch et al., 2000; Morin et al., 2005). The change of St. Lawrence River flows and base levels implies a morphological readjustment of tributary mouths, resulting in the incision and destabilization of beds and banks. Structures on two deltas of Lake Saint-Pierre show the result of the rapid adjustment processes accompanied by a progradation of these features into the river (Boyer et al., 2004).

Plant and animal species in the central subregion have a high resiliency and the communities are ecologically young, arising from the postglacial retreat that ended less than 10 000 years ago. These species, well-adapted to significant annual climate variations and recurring catastrophes and forming large populations distributed over an immense area, will be affected mainly in transition zones (mountainous and riparian areas).

In the maritime subregion, coastal and estuary ecosystems are most at risk from greater erosion, resulting in reduced reproduction and feeding areas for many resident or migratory species (Harvell et al., 2002; Jackson and Mandrak, 2002; Kennedy et al., 2002).

The north subregion will possibly be most affected by the scope of climate change (Flanagan et al., 2003). Ecological changes will occur to the detriment of species adapted to extreme Arctic conditions (Rizzo and Wilken, 1992; Payette et al., 2001). The northward expansion of species typical to the boreal forest will be initiated by existing trees, which produce viable seeds more easily. A certain adaptation of black spruce (*Picea mariana*) has already been noted (Gamache and Payette, 2004, 2005). However, the migration speed of isotherms will be much faster than that of plants.

River systems and lakes everywhere are particularly sensitive, given their compartmentalization with respect to the migration of fish species (Hauer et al., 1997). Phenological changes in species are also conceivable, as well as an extension of species range limited by mean or minimum temperatures (Edwards and Richardson, 2004).

Sensitivity of species

Living organisms react directly to ecological factors and survive based on their tolerance. Hence, the number of individuals in an ecosystem population is an indicator of their adaptation (Dajoz, 2000) — the higher their tolerance, the better their adaptation, as was shown for fish by Albanese et al. (2004).

An invasive species quickly expands its range in a new ecosystem, either because it is no longer limited by a previously active ecological factor or because it benefits from new conditions created by a disturbance influencing the dominant species of the environment (Bagon et al., 1996).

Phenology is the study of climate-based variations in the periodic phenomena of the plant and animal life cycle, such as dates of migration, triggering of reproductive behaviour, moult, flowering or foliage drop (Budyko, 1974). Several phenological changes have been observed in the twentieth century and this trend will accelerate (Intergovernmental Panel on Climate Change, 2002), triggered by temperature, precipitation, photoperiod or a combination of events. Visser and Both (2005) showed that most species are unable to co-ordinate changes in their phenology optimally with changes in their diet. For example, the migration date triggered by a specific photoperiod will not change with a rise in temperature, but instead based on the behaviour of prey. This absence of co-ordination risks reducing the number of migrating predators (Jones et al., 2003; Strode, 2003).

In the south subregion, species dependent on the flood regime of the St. Lawrence River, including the northern pike (*Esox lucius*) and perch (*Perca flavescens*), will be affected (Casselman, 2002; Chu et al., 2005; Brodeur et al., 2006). The approach combining multivariate habitat models with 2-D physical modelling (Morin et al., 2003; Mingelbier et al., 2004, 2005) makes it possible to measure the impact of climate change on habitat areas available to several fish species during critical periods of their life cycle. Water temperature, current speed and water level are key variables for understanding how climate change will affect fish. Already, data indicate a warming of water in certain areas (Hudon, 2004), and the atypical temperatures of summer 2001 produced a massive mortality of carp in the fluvial St. Lawrence River and its tributaries (Mingelbier et al., 2001, Monette et al., 2006). Changes in spring floods will result in a decline in breeding in both marshland birds and waterfowl of the St. Lawrence plain, which include several species at risk (Giguère et al., 2005; Lehoux et al., 2005; Desgranges et al., 2006). In the river flood plain, the muskrat is particularly sensitive to winter fluctuations in water level, and changes will profoundly affect it (Ouellet et al., 2005).

In the Arctic region, the polar bear (*Ursus maritimus*) is dependent on sea ice, while the Arctic fox (*Alopex lagopus*) has to contend with an extension in the range of the red fox (*Vulpes vulpes*), which lives off the same food resources (Hersteinsson and MacDonald, 1992; Stirling, 1999; Walther, 2002; Derocher et al., 2004).

Sensitivity of ecosystems

Aquatic ecosystems seem most sensitive to climate change since their biotic communities have difficulty moving from one watershed to another (Hauer et al., 1997). Species such as the Atlantic salmon (*Salmo salar*) will be disturbed by rising water temperatures that will reach the upper limits of their survival range (Swansberg and El-Jabi, 2001). The new temperature conditions will favour species more tolerant of high temperatures (Figure 27).

Populations of cold-water fish in the south subregion will be affected by rapid eutrophication and the arrival of sudden, potentially more frequent floods that will result in erosion of the watershed and sediment transport into lakes, a trend already reinforced by human activity such as agriculture, urbanization and logging (Shuter et al., 1998).

Increasing southern lake temperatures will lengthen thermal stratification periods, resulting in anoxic conditions in the hypolimnion during part of the year. Lake trout (*Salvelinus namaycus*) are sensitive to these two latter stresses (Hesslein et al., 2001). Changes in the flow of the St. Lawrence River will also modify the spatio-temporal distribution of water masses and the typical physical and chemical properties (Frenette et al., 2003, 2006). These changes may affect the nutritive quality of algae (Huggins et al., 2004) and their community structure. The shallower depths should result in more light near the bottom, leading to an increase in the quantity of submerged plants and changes in the properties of dissolved organic matter and particles in the water (Martin et al., 2005a).

Wetlands in all subregions are sensitive to climate change due to the greater variation in annual or inter-annual flood and low water levels associated with violent precipitation or droughts. Turgeon et al. (2005) showed that there exist fundamental links between hydrology and the spatial distribution of major classes of wetlands. Many wildlife species using wetlands will be disturbed, an important issue for the St. Lawrence ecosystem and the marshes of Lake Saint-Pierre (Hudon et al., 2005). Other pressures will also be exerted here, including agriculture and industrial and urban development (Bernier et al., 1998; Robichaud and Drolet, 1998; Jean et al., 2002; Ouranos, 2004), resulting in a fragmentation of habitats (Root and Schneider, 2002).

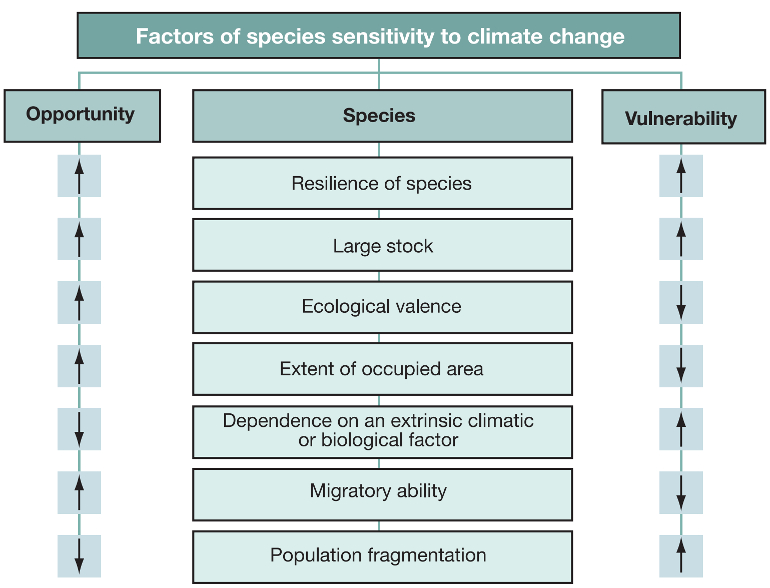

FIGURE 27: Factors of species sensitivity to climate change. Climate change should not result in the disappearance of many species in Quebec, but rather in changes to distribution ranges. However, certain populations will probably disappear in the most sensitive ecosystems because of the appearance of new limiting factors (Root and Schneider, 2002) or a combination of man-made factors degrading their environment.

The forest ecosystems of the central subregion should not experience major changes in their species composition. On the other hand, forest fire frequency and human activity can encourage certain plant associations locally by hastening the process of making forested land available (Gagnon, 1998; Payette, 1999; Coté and Gagnon, 2002; Jasinski and Payette, 2005).

Adaptation strategies

Several actions could be taken to adapt to climate change and reduce the impact on biodiversity:

- **Ecosystem resilience:** Increasing connectivity and reducing fragmentation between ecosystems seem to be effective pathways for maintaining genetic heterogeneity.
- **Monitoring sensitive species:** Quebec's biodiversity strategy encouraged each department to establish an action plan and present regular progress reports to the Ministère du Développement durable, de l'Environnement et des Parcs du Québec (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2004b). However, as noted by Gérardin et al. (2002), information on plants and wildlife is incomplete, particularly on the subject of unforested areas (e.g. unproductive forest land, wetlands, subarctic and alpine plants), which can undermine the government authorities' capacity to monitor species sensitive to climate change.
- **Strategy for protected areas:** Protected areas, in which some or all human activities are prohibited, serve to ensure the preservation of natural areas or ecosystems that are representative or rare (Figure 28). In contrast to the past, the current approach (Protected Areas Strategy) to selecting new protected areas underlies "a holistic approach of the territory, where the ecosystem is considered as a spatial entity and where the concept of coarse filter appears" (Gérardin et al., 2002, [translation]). However, this method, which places a predominant value on the physical elements of the ecosystem — climate, geology, topography, hydrology, soils — risks weakening the future network of protected areas and its role in protecting species and ecosystems, since the climate and hydrology are destined to change in the medium term. At the national level, Parks Canada developed a strategy that considers climate change in its approach to biodiversity management in existing parks (Wrona et al., 2005). At the municipal and private levels, such mechanisms do not seem to exist. Protected areas could usefully be considered as control areas for natural regions and their evolution, and their management could take future climate change into account. Therefore, in promoting adaptation, it would be advisable to:
    - complete the network of protected areas as soon as possible in order to conserve areas representative of each natural region; and
    - promote the scientific management of protected areas using inventory, research and monitoring programs to

track changes in species and ecosystems under climate change conditions, while maintaining comparison points with adjacent areas.

- **Change of harvest rules for live resources:** Changes observed in the numbers of certain animals sought by sport and commercial hunters and fishermen will require closer monitoring to avoid additional pressures on fragile species or to slow the expansion of certain species into areas where they were historically absent, thus putting previously resident species in danger.
- **Integration of climate change in land management:** Génot and Barbault (2005) presented a strategy that describes in detail the issue of preserving biodiversity in a context of climate change. It calls for extending responsibility for monitoring and managing biodiversity to land managers, who could then better understand the issue and better adapt their practices to promote the adaptation of species to the new conditions.

Conclusion: Quebec's changing natural environment

The importance of climate to living organisms needs no further demonstration. Climate change will not result in direct and continuous changes in the composition of ecosystems and the range of species. Instead, its effects will combine with other factors to cause environmental degradation at the local and regional scales. Adapting to climate change will require efforts to reduce the stress imposed on ecosystems. Above all, it will be necessary to develop knowledge about, and monitor, species and ecosystems that are most likely to be vulnerable, in order to adjust management methods to this new reality.

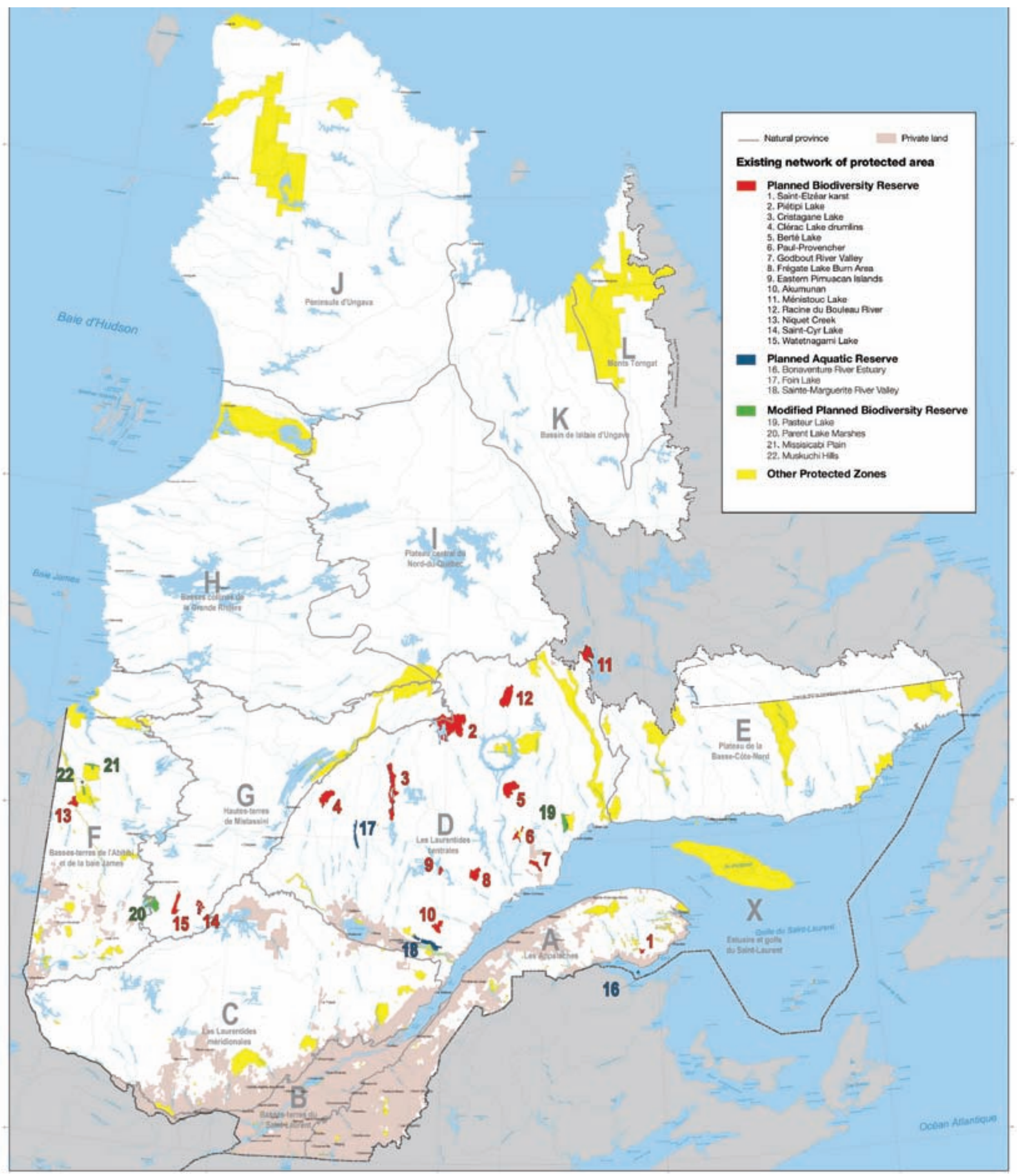

FIGURE 28: Protected areas under different jurisdictions of Quebec. Protected areas in Quebec fall under federal, provincial and municipal jurisdiction, and some protected areas are private. Quebec's conservation policy aims to create a network of protected areas covering 8% of its territory (Ministère du Développement durable, de l'Environnement et des Parcs du Québec, pers. comm., 2005).

Built environment

The preceding sections dealt with several aspects of the vulnerability of climate-sensitive infrastructure and buildings. The evidence is clear that the vast majority of infrastructure sensitive to climate and built in the last century was designed using statistics on past climate and risks, considered at the time to be representative of future climate conditions. This criterion is questioned throughout this document, raising questions about the security and performance of this infrastructure, particularly in the long term. Fortunately, users and engineers are increasingly aware of this problem (Engineering Institute of Canada, 2006) and adaptive capacity seems to be growing (Infrastructure Canada, 2006). Nevertheless, there will continue to be considerable need for new infrastructure related to socioeconomic development as well as for the refurbishment of a variety of aging infrastructure (Statistics Canada, 2006).

In the long term, the direct and gradual impacts of climate change (*see* Figure 1) will result in faster wear or loss of performance of different types of infrastructure and buildings. An increase in freeze-thaw cycles tends to accelerate degradation of infrastructure that receives large quantities of abrasives. Road surfaces would buckle more under higher summer temperatures, while poorly adapted buildings would make indoor temperatures risky for vulnerable people. In Quebec, building damage has sometimes been observed when clay soils dry out (Canada Mortgage and Housing Corporation, 1996) following hot and dry summers. In addition, any change in the frequency, duration, intensity and even range of extreme weather events would have significant impact on the vulnerability of the built environment, particularly as such events, depending on the type, have a tendency to involve the hydrosphere (e.g. floods), cryosphere (e.g. ice jam) or lithosphere (e.g. landslide). In fact, there is no shortage of examples in Quebec where low-probability climate events presenting a risk actually happened, affecting the built environment as well as socioeconomic activity, populations and even the natural environment. For example, failing infrastructure contributed significantly to the socioeconomic and environmental impacts of the Saguenay flood in 1996 (Ministère de la Sécurité publique du Québec, 1996). Damage to the built environment can be caused by a multitude of other failures related to destructive waves, storm surges or tides following the passage of storms (*see* Section 3.3); landslides caused by heavy saturation or destabilization of the soil (Lebuis et al., 1983); avalanches (Public Security Canada, 2006); excessive precipitation in solid form (Ministère de la Sécurité publique du Québec, 1999); or even forest fires.

Adaptation of infrastructure and buildings

Such events, as well as those expected in the future, tend to prompt officials to review their operating methods in order to reduce vulnerability (*see* Table 7). These officials have thus started to:

- revise design criteria and technologies used;
- establish improved emergency measures;
- set up communications networks, while ensuring information circulation and knowledge transfer;
- re-examine land-use planning policies and regulations; and
- develop preventive warning systems.

Despite this experience and learning, planned adaptation to minimize the impact of climate change remains rare. Although studies on this subject are few, it would be beneficial to consider various available climate scenarios when designing infrastructure, since infrastructure, once built, has little adaptability and often has a long life cycle. This was done for Confederation Bridge (Canadian Environmental Assessment Agency, 2000). As for highways, which have a shorter life, it is easier to introduce lower cost adaptation solutions as and when they are repaired. For critical infrastructure related to essential services (energy, water, food, health services), it is essential to minimize its vulnerability and introduce mitigating measures in case of failure. This latter consideration may be difficult to achieve at reasonable cost for remote regions.

In fact, adaptation measures can be implemented or introduced at different stages in the life cycle of infrastructure (Figure 29). An analysis of climate risks would support the decision to build or restore critical infrastructure far from a coastal site. It would promote the use of better adapted construction materials, suggest a revision of building criteria and refocus maintenance programs on anticipated problems. These are the types of decisions currently made by engineers to resolve or minimize a problem.

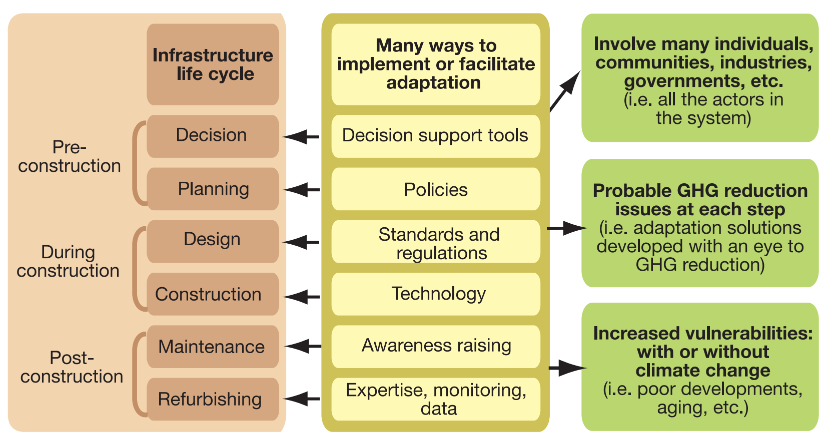

FIGURE 29: Various types of adaptation solutions related to infrastructure life cycle. A detailed analysis of acceptable risk compared to cost-benefits would make it possible to develop a strategy designed to minimize risk and maximize performance; it could also make it possible to implement other strategies meant to reduce GHG emissions responsible for climate change (Gosselin et al., 2005).

TABLE 7: Examples of applied or experimental decisions (grouped by type) promoting adaptation to climate change for various communities and sectors (developed for this study). The numbers match references given on pages 217-218.

	Develop and understand Acquire information and develop expertise	Communicate and raise awareness Increase awareness and modify behaviour	Respond and legislate Amend laws, regulations and standards	Apply new or existing technologies Use techniques, products and materials	Apply/recommend guidelines or ways of doing things Adjust practices and policies
COMMUNITIES					
Isolated	Map sensitive zones for the development of infrastructure (1)	Disseminate information on transportation system conditions (2)	Establish land-use planning standards based on sensitive zones (2-3)	Apply techniques to reduce permafrost thawing (4)	Produce a best practices guide for building on permafrost (46)
Dependent on natural resources	Identify the best sources of seeds/genotypes (6)	Inform communities on fire risks using the forest fire-weather index (7)	Regulate fishing (opening and closing dates, places, etc.) (8)	Manage fishing by habitat to ensure the viability of resources (8)	Establish a program for economic diversification of communities at risk (9)
Coastal	Creation of an integrated scientific project acting in coordination with other participating agencies to meet needs of coastal regions (10)	Hold a simulation exercise to help prepare citizens, municipalities, governments and other actors (11)	Regulate construction in flood-prone areas, zoning and temporary control regulations (12)	Monitor protection structures (13)	Establish integrated management of coastal areas (14)
Rural	Learn about varieties used farther to the south (analogs) and adapted to the region (5)	Increase public awareness about saving water during droughts (16)	Establish a program of income stabilization, private insurance and incentives to take climate change into consideration (17)	Extend drip irrigation and the combined technologies of surface drainage and flow (18)	Install effective ventilation systems or sprinklers to cool livestock (19)
Urban	Identify lands favourable to allergens and map sources of allergenic emissions (20)	Give information on municipal emergency measures (21-22)	Regulate resistance standards in construction (23) and the Building Code concerning energy (24)	Extend the use of reflective surfaces and coverings (roofs, facade paints, etc.) (25)	Set up local heat-health-heat wave systems (26)
SECTORS					
Health	Analyze the link between morbidity-mortality and climate (27-28)	Increase public awareness about smog and heat waves and give advice (29)	Take preventive measures to limit polluting emissions (at the start of the anticyclone) (30)	Launch campaigns to pull up ragweed and plant competing species (20)	Use green roofs or high-albedo materials (12-25). Establish care guides adapted for home care clienteles during extreme events
Infrastructure	Analyze aerial photos of the coastline over time and calculate the erosion rate (12)	Set up forecast and early warning systems systems and public education systems (23)	Provincial Civil Protection Act adopted in 2001 following the ice storm crisis of 1998 (31)	Design more resistant buildings (12) or better adapted to the new means (32)	Add 1 m to the Confederation Bridge due to the anticipated rise in sea level (38)
Primary sector of the economy	Develop biological methods to control propagation (6)	Increase awareness about harvest and field management adapted to present and anticipated climate conditions (15)	Amend the Forest Act to remove the outdated concept of sustained volume yield (34)	Use species and varieties adapted to different climate conditions (10)	Anticipate by building up one's own financial reserve (35)
Tertiary sector of the economy	Economic assessment tools (39-36)	Diversify recreational tourism choices to minimize climate risk (37)	Insure against losses due to bad weather and climate by-products (22)	Establish emergency, response and evacuation plans (15)	Raise the design criteria for bridges and culverts by 10% (civil engineering, MTQ) (38)
Water	Update the IDF curves (40,41)	Communicate practices to manage rainwater recovery (24)	Implement international agreement on the Great Lakes basin water resources (48)	Rehabilitate degraded resources (22)	Test and review management rules based on various possible climate scenarios (42)
Ecosystems	Map ecological niches and assess the changes (43)	Symposium at popular science events (44)	Maintain representative regional plants and wildlife (protected areas) (45)	Restore and preserve wetlands (46)	Protection of species and habitats (47)

The impact of changing climate-related risks to the built environment requires that 1) better climate scenarios and better impact scenarios be developed (for both the natural and built environment); 2) climate uncertainty be considered in risk analysis at the infrastructure design stage; and 3) new risk tolerance thresholds be integrated, subject to change depending on the needs.

Adaptation under a stationary climate is a known field of expertise sprinkled with success stories, but adaptation under a new, highly variable and uncertain climate is a recent field of expertise for which success stories are yet to come, though likely achievable. Moreover, pertinent adaptation solutions for municipal engineers (e.g. surface retention pond for urban drainage) can become major problems for other factors affected by climate change (e.g. increased breeding of mosquitoes, which can spread the West Nile virus).

4 SUMMARY AND CONCLUSION

The influence of weather conditions and climate is vast. Impacts that are generally poorly documented appear gradually and subtly at the pace of changing mean values or variability statistics. Until now, these changes have generally followed global trends anticipated by the Intergovernmental Panel on Climate Change and presented in their assessment reports. The impacts of extreme events are remarkable because of their scale, suddenness and spectacular nature, but it is difficult to tie them directly and exclusively to climate change because they are, by definition, rare events. Globally, the scope of climate change, including some extreme events for which an increase in frequency, intensity and duration is predicted, is expected to have an increasingly significant and perceptible impact on the public, the natural and built environment, and socioeconomic activity. Given the anticipated scope of climate change, natural and human system reaction (adaptation) will be able to adjust and even transform impacts that are sometimes negative, other times positive. Despite the many remaining uncertainties and the complexity of direct and indirect impacts occurring in parallel with other changes that affect vulnerability, the following qualitative observations emerge from this summary:

- For the public, the impact of climate change — particularly indirect impacts through reactions of the natural and built environment — would result in heightened risk to health, security and well-being. The application of adaptation measures, mainly preventive and prioritized for populations now or soon to be at risk, would minimize the scope of negative impacts, including oppressive heat, increased pollution, poorer water quality, exposure to ultraviolet rays, zoonotic diseases and events causing injury and death. These measures include actions to alter risk-creating behaviour, assist vulnerable groups and strive to reduce climatic risk in land-use planning.
- In the natural environment, the lithosphere, hydrosphere, cryosphere and biosphere would experience gradual transformations corresponding to long-term trends, with occasionally more perceptible displays related to changes in the frequency, intensity and duration of extreme or threshold events. Landscapes would, of course, be reshaped under the influence of climate change, as would the hydrology and geomorphology of streams and the distribution and relative abundance of plants and wildlife. Various regional impacts would trigger spontaneous and complex adaptation reactions. Of more serious concern than the northward movement of ecosystems, many threatened species and rare ecosystems would be at risk of disappearing, particularly in areas of intense human activity, but the effects of these changes would be positive or negative depending on the subregion, uses or interests, and according to perceptions. With respect to forest resources, it is difficult to predict the changes that will occur, given that both positive (e.g. CO_2 level and higher temperatures, longer growing season) and negative impacts (e.g.insects and pathogens, extreme weather events) are anticipated.
- The built environment does not adapt spontaneously. For example, engineering practices that have been based on the assumption that climate has been historically stable should be revised in light of new and changing climate data. Although changes in means can result in accelerated wear or loss of performance of infrastructure, several types of infrastructure are known to be particularly sensitive to increases in the frequency of extreme events. Adaptation strategies applied on a priority basis to critical infrastructure or infrastructure with favourable cost-benefit analyses (costs of adaptation solutions versus life cycle of infrastructure) would make it possible to limit the magnitude of anticipated impacts. In a context of widespread aging of infrastructure contributing to a potential

rise of vulnerability in Quebec, it will be crucial to invest in the refurbishment or replacement of infrastructure and in new projects in order to reduce climate risks in a preventive way, rather than react after events with significant direct and indirect impacts.

- Of all the anticipated impacts, those that affect socioeconomic activity remain the most difficult to identify. In fact, they depend on still poorly quantified biophysical impacts and complex reactions, such as market mechanisms, perceptions and technological development. Certain activities would benefit from gradual changes of low amplitude, whereas others would be disadvantaged by more dramatic, unpredicted changes or, also, by an increase in the number of extreme weather events. The economic impacts are starting to be estimated, but social impacts in the medium and long terms are more speculative, if not unknown. Although many economic gains and economic development opportunities worth an estimated several hundred million dollars per year could stem from climate change in Quebec, feared economic losses and risks are much more difficult to estimate and go far beyond uniquely economic consequences. Nevertheless, the socioeconomic capacity of Quebec to adapt to climate change, especially gradual change, is high relative to less robust and less diversified economies. The challenge lies in structuring efforts to identify the challenges and implement sustainable solutions in a complex sociopolitical system. The capacity to manage the change — like the opportunities to be seized — will tend to lessen the magnitude of impacts.
- The north subregion should undergo the most significant climate change in absolute terms. It will contribute to the complexity of the issues the subregion is currently facing, which are associated, among other things, with the high exposure of communities to natural risks, to their dependence on critical infrastructure, their access to resources and their traditional way of life, which is closely related to maintaining the current natural environment. It will therefore be necessary to manage the impacts of permafrost thawing, changes in the snow and ice regime, and the transformation of the biosphere, particularly the increased risks to species that are dependent on sea ice, at the same time as high population growth, the many issues related to development, and major socioeconomic changes. Development opportunities associated with navigation, energy production and the mining sector in warmer winter conditions, and diversification of plant and animal life, are possible. Although efforts are being made to minimize the costs of impacts and adaptation, the issues are associated primarily with security, health and well-being of the vulnerable populations due to their isolation. Climate change should be considered in environmental impact studies pertaining to new development projects.
- The vast, resource-filled central subregion could see its environment transformed and its economic sectors increase their productivity (e.g. hydroelectricity production due to higher annual inflows and forest productivity due to faster growth resulting from warmer climatic conditions). However, this scenario remains uncertain for several reasons, including limited historical observations and inconsistent recent trends, lack of understanding of the phenology of species and regional hydrology, assessment tools under development, higher risk related to poorly understood extreme weather events, uncertainty of climate scenarios and, finally, the impacts on the price of resources on continental markets. In addition, given the limited literature available on this sparsely populated subregion, it is likely that many environmental and social impacts that may be considered undesirable are completely unknown at this time.
- The maritime subregion is strongly exposed to climate vagaries and the hydrosphere. Its communities are coastal and partially isolated, and present a marked socioeconomic vulnerability emphasized over the last decade by the collapse of the fishing and forest industries. Moreover, already-occurring coastal erosion will accelerate, increasing the vulnerability of infrastructure, the built environment, or even tourist attractions. Integrated management, including good planning and sustained and early development, appears to be the best adaptation strategy for limiting impacts. One of the great challenges in the coming decades is, beyond question, impact management and prevention in regions of growing risk.
- The south subregion could profit from greater crop productivity if problems of water availability and climate variability are limited. In addition, one effect of an increase in temperature will be a reduction in annual energy consumption. In contrast, whether in rural or urban areas, the built environment will not be optimized as a function of the anticipated climate. Therefore, this subregion, which is characterized by a growing population and increasing population density, the complex interdependence of infrastructure, a shift of its economy towards the service sector associated with changes in international markets, a changing social fabric and a population that is increasingly desensitized to climate conditions, brings together numerous factors that can generate many complex and sometimes costly impacts, related especially to an increase in the frequency, intensity or duration of extreme weather events. The anticipated changes in the water cycle and impacts on water's many uses would help keep sustainability of the resource and public security from floods on the agenda. Finally, an array of indirect impacts often poorly documented and combining with events not connected to climate change, will affect regional biodiversity and public health, security and well-being, the price of seasonal goods and services, immigration, tourism and recreation. Risks should be reduced by applying solutions as diverse as integrating the idea of adaptation to climate change into legislation, building standards and organizational policies, and making efforts to enhance public awareness of climate change. Although planning that integrates the anticipation of impacts can contribute to

adaptation, a variety of information, tools and policies will also make society more resilient to climate change.

Clearly, adaptation solutions add to the efforts made to reduce greenhouse gas emissions in the context of the challenges posed by climate change. For hundreds of years, human systems have tended to react to the impacts of the natural variability of the climate system in such a way as to reduce their exposure to climate and increase their adaptive capacity and resilience. With respect to initiatives designed to address future climate unknowns, Table 7 briefly presents a variety of adaptation strategies that already exist or are under study, applied and applicable both to communities and to socioeconomic activities. The table illustrates that human systems will adapt in different ways to minimize or address adverse impacts, or to optimize development opportunities. The table shows that adaptation involves many actors (individuals, communities, industries, provincial, federal and international authorities), that response time varies in length (short-term decision and long-term planning) and that the strategies target different obstacles to adaptation. These strategies can be grouped into five categories:

- **develop and understand** refers to information acquisition;
- **communicate and increase awareness** is related to aspects affecting awareness and behaviour modification;
- **respond and legislate** refers to amendments to laws, regulations and standards;
- **apply new or existing technology** refers to the use of techniques, products and materials;
- **apply and recommend guidelines or ways of doing things** gives examples of adjustments to internal practices and policies.

The table therefore gives a brief portrait of what could become more general in future.

The challenges that Quebec must meet, along with all inhabitants of the planet, are immense and coloured with uncertainty. As set out in Chapter 10, there are many requirements for meeting the challenge of climate change. They include 1) more relevant and higher-quality data for understanding; 2) better monitoring and warning systems for preparing; 3) greater interaction between scientists and political and operational players in the field of adaptation to maximize technology transfer; 4) leadership and open-mindedness of all society to identify and prioritize the right problems and know how to question oneself at the right time and in the right way; and 5) growing multidisciplinarity and interdisciplinarity while pursuing research in various specialized climate-science related fields, other biophysical sciences, economics, social sciences and health sciences.

Finally, the perceptions and behaviours, the processes and factors leading to decision-making, and the goals and convictions of individuals and communities appear fundamental to the adaptation of human systems because it is humans who will, in the end, make the right or wrong decisions influencing the future.

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