CLIMATE CHANGE IN SOUTHERN QUÉBEC

Drinking water supply and public health: climate projections for precipitation and runoff in southern Québec

Summary

BACKGROUND

This study, conducted as part of the Ouranos Consortium's Health Program, and coordinated by the Institut national de santé publique du Québec (INSPQ), comes under the “Water Quality” component of the program; it was funded by the Ouranos Consortium and the ministère de la Santé et des Services sociaux du Québec.

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Québec

INTRODUCTION, HISTORICAL OVERVIEW AND BASIC CONCEPTS

One of the projected consequences of climate change (CC) is an increase in weather events or situations which until now have been rare, such as heavy precipitation or extended periods of drought. In this context, major infrastructure is likely to be affected by changes in the water regime, including the drinking water supply. Climatic variables that may affect volumes available for drinking water in a context of CC include rainfall and temperature. In the event of a significant change in rainfall resulting in a climate that is drier or more conducive to periods of drought, for example, drinking water production and distribution systems will be subject to unusual or exceptional constraints which they were not designed to handle. In addition, increased rainfall could affect the quality of raw water in the sites from which it is taken, raising the possibility of outbreaks of waterborne diseases.

These considerations show the importance of establishing and analyzing the current climate projections for southern Québec, if only on a preliminary basis, to see whether further analysis of the possible impact on drinking water supply systems should be carried out. In this context, a series of climatic projections of variables that are likely to affect the volume and quality of available water was produced. Two variables were seen as climatic indicators of trends in water availability: monthly precipitation and monthly runoff over the surface of the soil.

Drinking water supply in Québec

Québec has 3% of the planet's renewable fresh water resources and only 0.1% of the world's population. About 44% of Québec's municipal systems are supplied from surface water (lakes and rivers) and these serve more than 5.3 million people or over 70% of the population of Québec. Despite the abundance of fresh water in Québec, where only 0.5% of the volume of water available in the territory is taken (compared to 11% in OECD countries), some parts of the province could face drinking water shortages during low-flow periods. The climatic changes anticipated over the coming decades could exacerbate some of these situations, which are already critical in some localities.

Drinking water supply and climate change

The overall increase in the average temperature will affect the hydrologic cycle. Climate experts agree that changes in this cycle will result in an increased frequency and amplitude of extreme events, such as flash floods, tornadoes, hurricanes and droughts. The magnitude of these phenomena has not yet been quantified, but the observation of precipitation during the twentieth century already shows a change in the spatial and temporal distribution of rainfall. This means that climate change could cause an increase or a reduction in average rainfall, with increased periods of heavy rain and/or prolonged drought.

Most models point to significant changes in precipitation in the high latitudes of the northern hemisphere in the coming decades, which would result in reduced flows in summer and increased flows in winter. A decrease in soil moisture in areas in the interior of North America (not including Québec) and an associated risk of drought is also expected. Over the past 30 to 50 years, the average flow of rivers has decreased in several regions of Canada, especially in the south, particularly in August and September. It is anticipated that this trend will continue as a result of climate change. Some studies also predict an increase in runoff from the main tributaries of the Saint Lawrence during the winter months (November to March) due to an increase in precipitation in the form of rain rather than snow, and a decrease in runoff during the summer months (July to October) because of reduced rainfall. Between 50° and 70° north latitude (and thus north of the densely populated areas in Québec), trends in annual precipitation are rising, and no definite conclusions can be drawn regarding the trend between 40° and 50° degrees north latitude (the region that includes southern Québec).

The first action to be undertaken in order to adapt to a possible decline in water resources is certainly to strengthen the management of drinking water to reduce demand or, at the very least, curb its growth. Programs to raise awareness among citizens and restrict the use of drinking water for certain purposes (e.g. watering lawns) during periods of high demand and/or low flow are important measures that can help achieve this goal. Also, better maintenance of drinking water supply and distribution systems (e.g. detection and proactive sealing of leaks) can significantly reduce the volume of water to be produced by municipalities.

Climate modeling

Climate models (GCM for "Global Circulation Model") are capable of simulating the many ocean-atmosphere-land interactions as well as the physical and chemical processes involved in the "mechanics" of the earth's climate. Based on a mathematical description of the physical laws that govern the climate, astronomical parameters (e.g. solar radiation), geographical parameters (e.g. land cover) and a description of the chemical composition of the atmosphere, these models simulate a number of climatic variables such as temperature, humidity, precipitation, etc. over long periods, for the entire planet. They are thus able to simulate likely climatic changes in a context of increased greenhouse gases (GHGs). However, their spatial resolution is quite coarse – in the order of several thousand square kilometres – areas known as "grid-boxes". The simulated values are therefore averages or accumulations for the grid-boxes and the models are not able to reproduce phenomena on a more local scale. Moreover, GCMs are not designed to forecast the weather at a particular time and place, but rather to estimate long-term statistical trends for climatic variables. These highly complex "climate simulators" exist in many forms, and many research teams in various countries have developed their own models. These models are referred to as "global" as opposed to the "regional" models that divide the territory into smaller areas (for example, the Canadian Regional Climate Model uses 45 km x 45 km grid-boxes). The climate projections developed as part of this study use simulation results from global models.

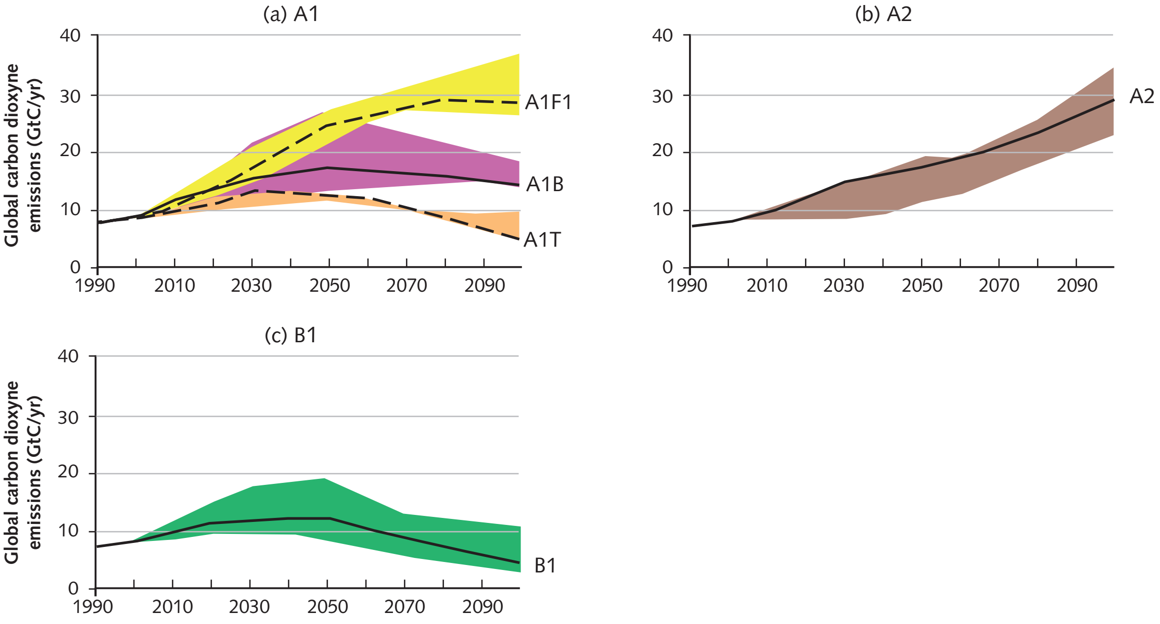
Several sources of uncertainty must be considered when the results of global climate simulation models are analyzed or used for climate projections. However, it is now recognized that the main source of uncertainty in climate projections comes from the models themselves. Indeed, each model uses its own particular representation of climate processes, which means that from a set of identical data each model will simulate different climate changes. In some cases, these differences may be major (for example, one model may predict an increase in precipitation while another may predict a decline in the same region). This variability between models can be taken into account by considering the overall results from several models (this is called a multi-model approach).

The use of the multi-model approach is, in fact, increasingly widespread in CC impact studies. It is often used because it allows a more reliable and more robust estimation of climate variables. By comparing the results of several models we can also assess the "consistency" of trends for various indices/climate variables in the different regions of the planet that have been studied. The multi-model approach was used in this study.

Three broad families of GHG emissions scenarios (referred to as "storylines") have been proposed, each based on a number of assumptions concerning future demographic, social, economic, technological and environmental developments. The simulations used in this study are based on emission scenarios called A1B, A2 and B1 (figure 1). The A1 storyline, to which the A1B scenario belongs, assumes that there will be rapid economic growth, that the world's population will grow until the middle of this century and then decline, and that new, much more energy efficient technologies will be brought on line. The A2 scenario assumes a heterogeneous world in which the world's population will continue to increase until 2100; there will be a significant regional component to economic development, and new technologies will not penetrate evenly throughout the world. This would result in a very significant growth in greenhouse gas emissions. The B1 scenario assumes that the world's population will grow until mid-century, and then decline. Economic changes, although rapid, will favour an information and services based economy. The emphasis is on finding sustainable, global solutions to economic, social and environmental problems. The profile of GHG emissions will grow until the middle of this century, followed by a marked decline until the year 2100. These scenarios can be classified according to how optimistic they are about future GHG trends: scenario B1 can be described as optimistic, scenario A2 as pessimistic, and scenario A1B is between the other two.

FIGURE 1

Total CO_2 emissions (gigatonnes per year) for the period from 1990 to 2100, for the three storylines[1]



The continuous lines correspond to representative scenarios from each storyline, i.e. scenarios (a) A1 (b) A2 and (c) B1. The bands of colours correspond to the intervals within which all the scenarios belonging to each storyline are confined.

METHODOLOGY

Future changes in monthly precipitation were established following an analysis of simulations from 23 global climate models. In total, 51 simulations were available for scenario AB1, 36 for scenario A2 and 42 for scenario B1. For runoff, the corresponding values were 54, 37 and 46 simulations. The simulations for the various GHG emission scenarios were first compiled and analyzed for each model (before applying the multi-model approach) to see whether this would result in more or less marked trends for the climate variables. The period from 1900 to 2100 was defined as a common period of analysis. All grid-boxes covering Canada and the northern United States were analyzed. The multi-model approach was subsequently used to combine results from the various simulations obtained by each model.

The trends (precipitation and runoff) were classified according to whether a statistically significant trend (95%) had been detected or not. Three classes of trends were identified: '+' if a positive trend was detected; '0' if no significant trend was detected and '–' if a negative trend was observed. The results for a given grid-box of the reference grid were analyzed by estimating the number of simulations (for a given model where applicable) with a positive trend, a negative trend or no trend. Equal weight was given to results from each model (this is a simple multi-model approach).

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[1] Figure taken from: IPCC (2000). *Emission scenarios. Summary for policymakers. Special report of Intergovernmental Panel on Climate Change Working Group III*. IPCC, Geneva, Switzerland, 21 p.

RESULTS

Climate projections for monthly precipitation

Overall trends for Canada[2] (figure 2) are summarized as follows:

- the multi-model approach consistently indicates an upward trend in monthly precipitation for the northern part of the territory studied (including northwestern Canada and Alaska and to a lesser extent, northern Québec); this trend clearly dominates during the winter months (November, December, January and February) and it tends to decrease from north to south;
- significant downward trends in rainfall are detected only for the northwestern United States and to a lesser extent for southwestern Canada, and fade as we head east. This downward trend in rainfall dominates slightly during the summer months (June, July and August) for southwestern Canada and the northwestern United States;
- an increased probability of observing upward trends in precipitation is observed in the area between 45° and 55° degrees north latitude as we move from west to east, reaching their maximum in the regions of southern Québec and southeastern Ontario. An increase in precipitation seems to be higher for January, February, March, April and November and December, while for other months, the models point to stable levels of precipitation.

A sample result is shown in figure 2 for scenario A2 (April to June).

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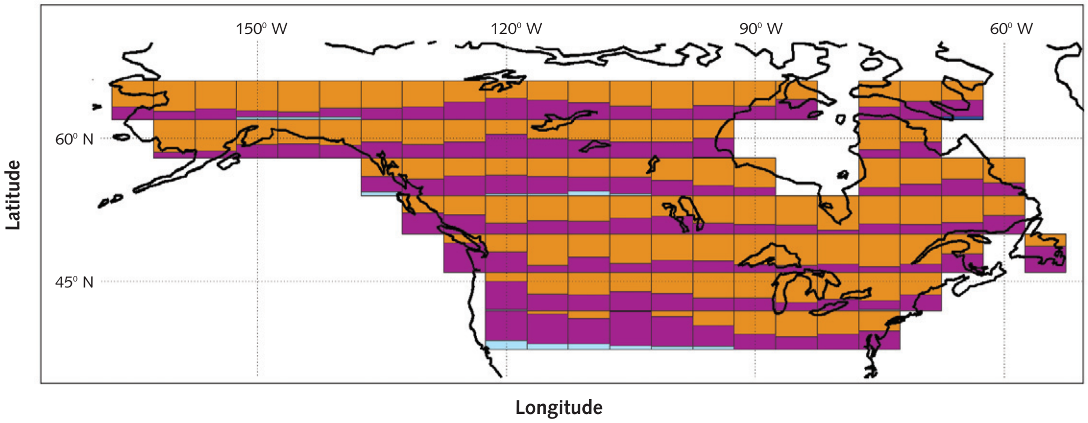
[2] The full report presents the results for all of Canada with figures and maps. In this summary, the overall trends are presented briefly in writing, focusing specifically on southern Québec.

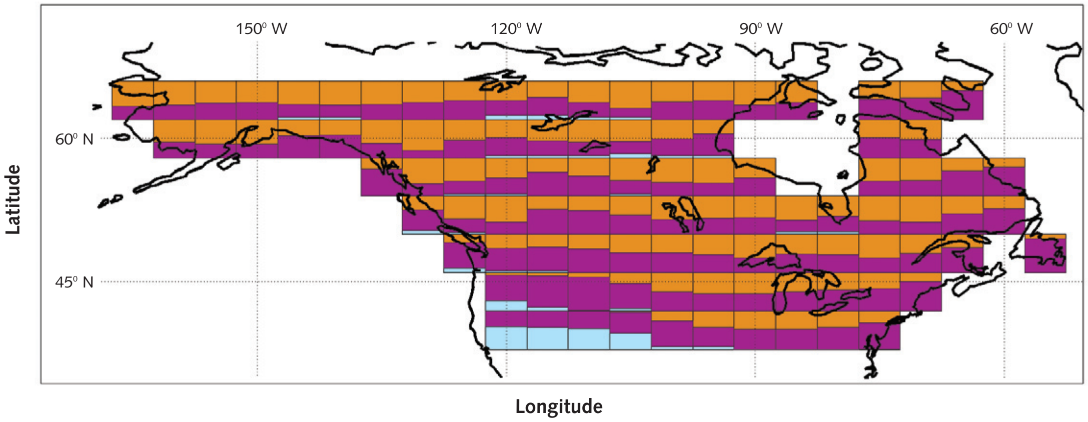
FIGURE 2

Probability of positive trend (orange), negative trend (blue) or no trend (purple) for monthly precipitation (April, May and June) over the period 1900-2100 for the A2 GHG scenario (the fraction of the grid-box of a particular colour corresponds to the probability of having the corresponding trend)

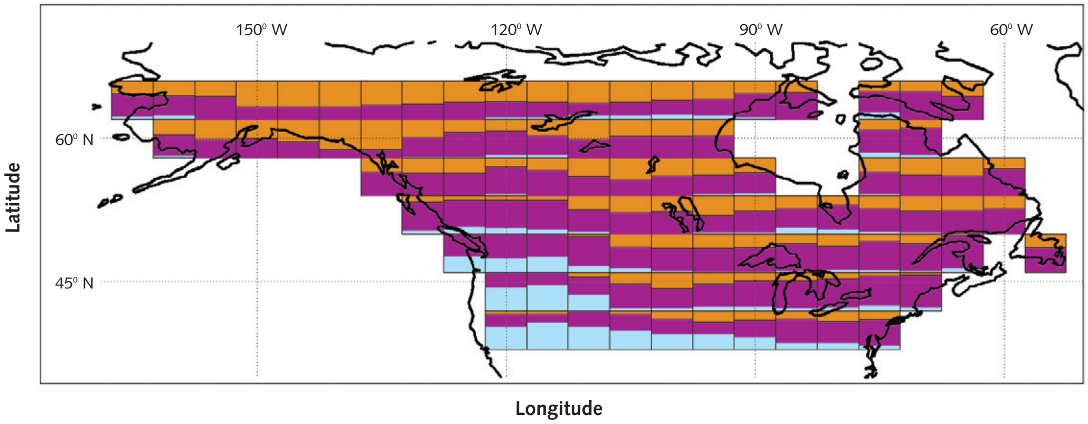
April



May



June



More specifically, for Québec, the grid-boxes covering the southern part of Québec were examined (figure 3). The results for these grid-boxes, four in number, were first analyzed according to changes to the year 2100.

FIGURE 3

Grid-boxes considered for the southern Québec analysis

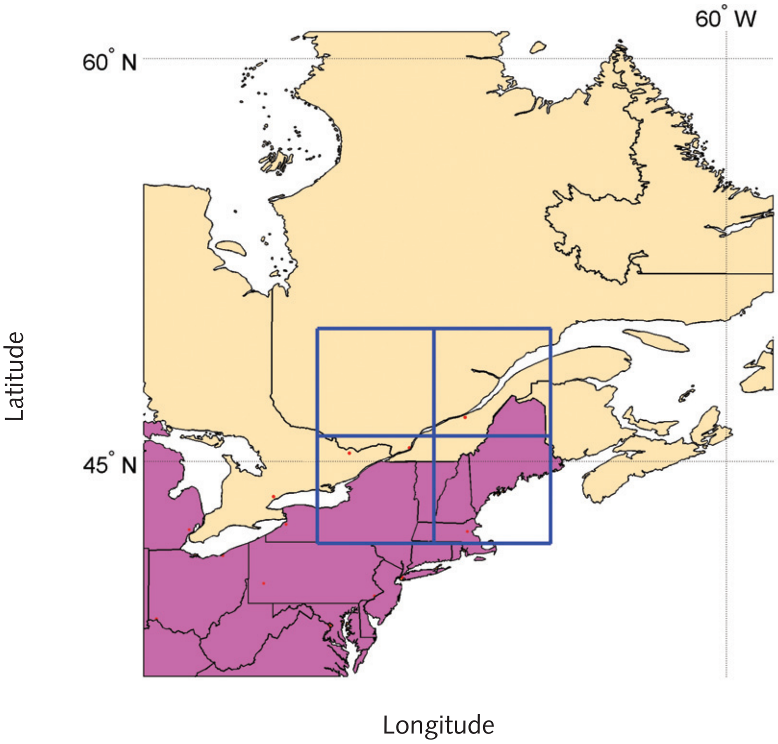
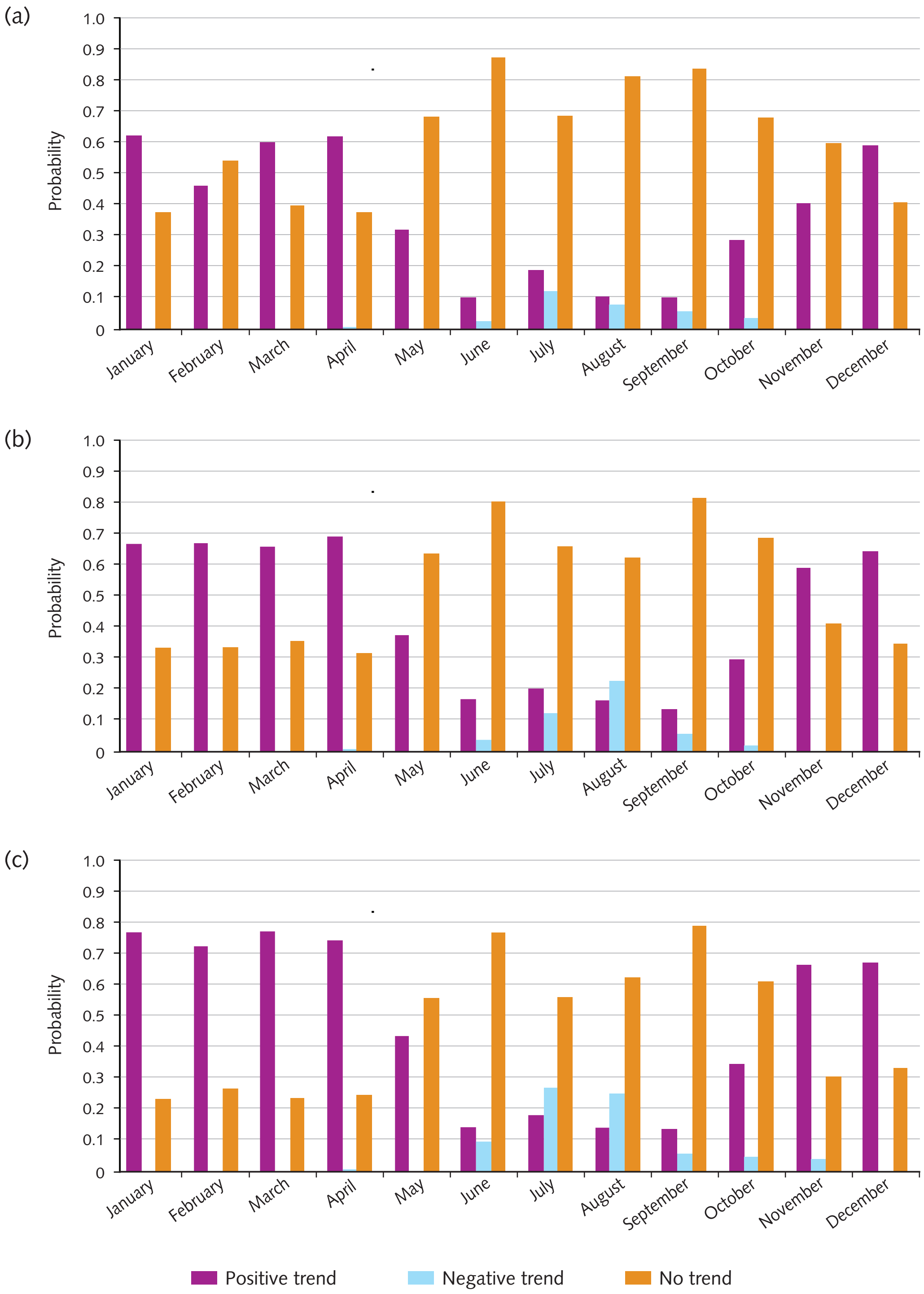


Figure 4 shows the average probability of obtaining a positive trend, negative trend or no trend on these grid-boxes, for each of the three GHG scenarios considered in the analysis. These three graphs suggest a clear dominance of the likelihood of upward trends in monthly rainfall (purple bars) for the months of January, March, April and December, particularly for scenarios A1B and A2. Moreover, the probability of not observing the trend (orange bars) dominates for other months except February and November, for which the probability of not observing a significant trend dominates scenario B1, while the probability of an upward trend dominates the other two scenarios. It is interesting to note that non-zero probabilities of a downward trend (blue bars) are shown for the months from June through October, but they are significantly lower than the probability of not observing the trend, and are more pronounced for the A2 scenario.

FIGURE 4

Probabilities of positive, negative or no significant trends in precipitation on the grid-boxes in southern Québec for scenarios (a) B1 (b) A1B (c) A2



According to the results of this analysis, the most likely climate scenario for the region of southern Québec during the period from 1900 to 2100 is an upward trend in rainfall for January to April, then November and December, with no significant trend for the other months of the year. Furthermore, the mean changes projected for the period from 1900 to 2100 decline as we go from scenario A2 to A1B to B1.

Climate projections for monthly runoff

An analysis based solely on monthly precipitation data cannot predict the combined effects that temperature increases and changes in precipitation may have on the earth's water system. Since the development of a hydrological model would have been far beyond the scope of this study, it was decided to consider another variable simulated by global models, i.e. runoff[3]. The main purpose of the analysis of monthly runoff is to verify whether the answers provided by the various models have a certain level of consistency and whether the answers are themselves consistent with the results previously obtained for monthly precipitation. Indeed, since the overall monthly precipitation throughout the area will increase or remain the same, it is logical to assume that, for areas where precipitation will remain the same, the volumes of water available for runoff could decrease following a rise in global temperatures (increased evaporation/evapotranspiration). Conversely, if rainfall increases, the combined effect of increases in temperature and precipitation may in part offset one another. Obviously, several local considerations may also come into play. The method of analysis used for runoff is identical to that already used to analyze monthly precipitation.

Overall runoff trends for Canada[4] can be summarized as follows:

- simulated trends are surprisingly consistent from one model to another for October, November, December, January, February and March. A clear upward trend in runoff begins in the fall, reaches its maximum extent in December and January, and then tapers off in the spring;
- in contrast to this positive trend, an area showing a negative trend emerges in southern Canada. This area reaches its maximum extent and amplitude in June, particularly in Québec and on the west coast;
- there is no dominant trend in central Canada and the United States for the months from May to September.

More specifically, for Québec, the grid-boxes covering the southern part of the province were studied (figure 3). Figure 5 shows the average probability of obtaining a positive trend, negative trend or no trend on these grid-boxes (up to 2100) for each of the three GHG scenarios considered. Two points emerge when we look at these graphs. The first is that the projected upward trend largely dominates for December, January, February and March, for all GHG scenarios, while for those same months, the downward projection would be very unlikely. The second finding is that the dominant trend for the months from March to November is much less pronounced and that the probability of downward trends or no trends are often comparable. An upward projection for the same months appears highly unlikely.

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[3] Runoff refers to what happens to water after it reaches the ground. Water from precipitation may run along the surface of the soil, seep into the soil and down to the water table (groundwater), evaporate as it is warmed by the sun during the day or be captured and used by plants or evaporate through them (evapotranspiration).

[4] The full report presents the results for all of Canada, with figures and maps. In this summary, the overall trends are summarized in written form, focusing specifically on southern Québec.

FIGURE 5

Probabilities of positive, negative or no significant trends for runoff on the grid-boxes in southern Québec for scenarios (a) B1 (b) A1B (c) A2 (up to 2100)

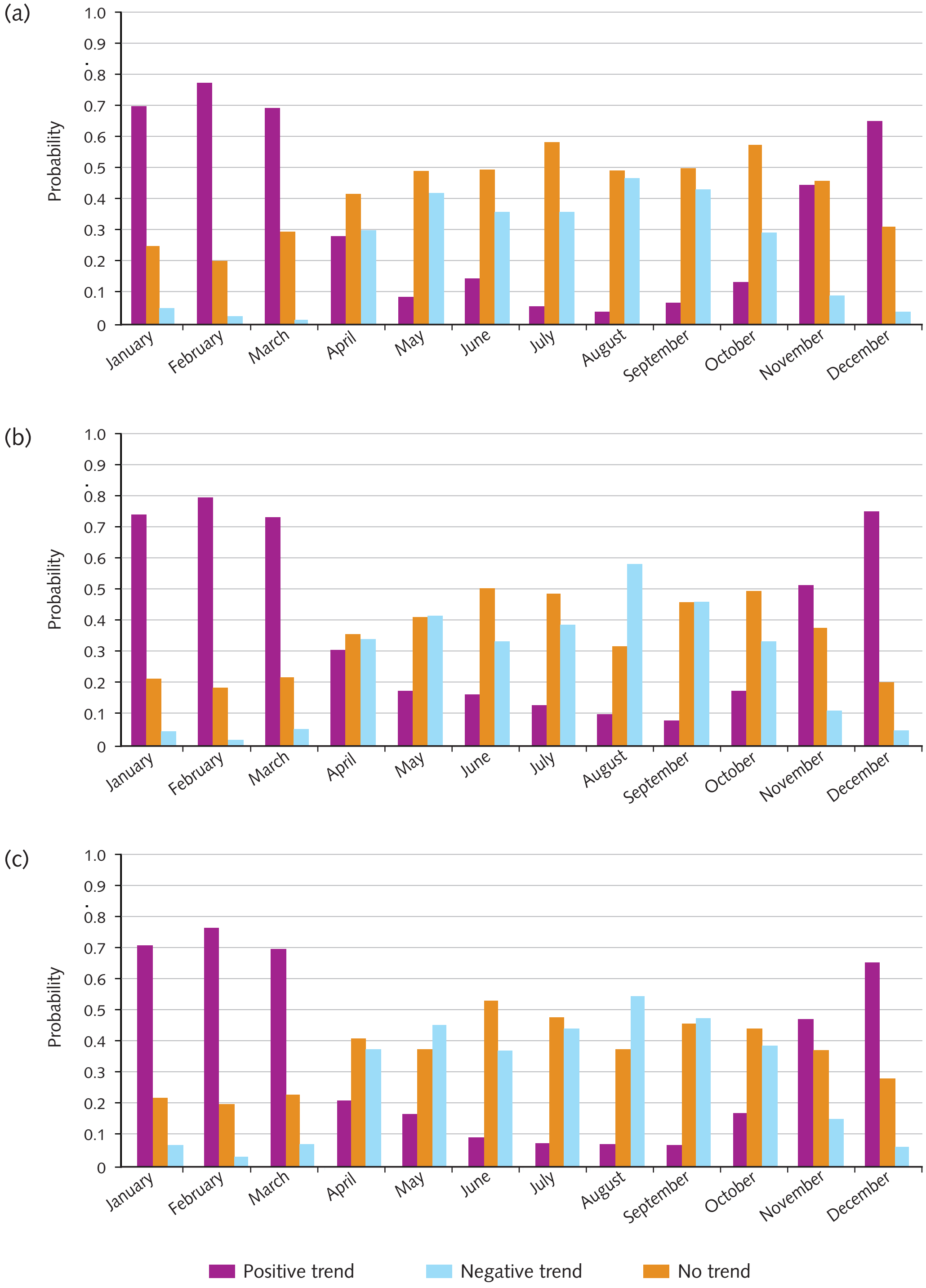

Table 1 includes the values of average variations (percentages) in runoff for the months from April to October for the grid-boxes in southern Québec up to 2050 and up to 2100 for the most likely trends (the other months not shown on the table all show fairly significant relative increases). For April, June, July and October, the most likely projection is no trend; reported variations are zero for all three GHG scenarios. It should be noted however that the projection with a downward trend is also very likely for these months (figure 5). For May, August and September, declines of about 13% to 27% are estimated. These declines become larger as we consider the GHG scenarios in the order B1 ➝ A1B ➝ A2.

TABLE 1

Relative average variations by percent (%) for April to October in monthly runoff for the grid-boxes covering southern Québec to 2050 and to 2100 for the most likely monthly trend (zero corresponds to cases in which the most likely scenario indicates no significant trend)

	B1		A1B		A2	
Month	Horizon 2050	Horizon 2100	Horizon 2050	Horizon 2100	Horizon 2050	Horizon 2100
April	0	0	0	0	0	0
May	0	0	-10	-13	-12	-16
June	0	0	0	0	0	0
July	0	0	0	0	0	0
August	0	0	-17	-23	-20	-27
September	0	0	-12	-16	-15	-20
October	0	0	0	0	0	0

CONCLUSION

The purpose of this study was to analyze climate projections for some variables that are likely to change the volume and quality of surface water. Two variables were analyzed: monthly precipitation and runoff, two key components that will determine the future development of the hydrological conditions of surface water. The results of simulations from 23 climate models (GCMs) were used. Three GHG emission scenarios were considered (A2, A1B and B1) and the analysis covered the period from 1900 to 2100. Results from several different models were combined in order to determine the consistency between the projections from these models.

An analysis of trends for monthly precipitation shows that: 1) the vast majority of the territory of northern Canada is highly likely to see an increase in rainfall from January to April and from September to December (this upward trend will affect all of Québec); 2) an area on the west coast of Canada may suffer decreases in rainfall between May and August. More specifically, for the grid-boxes covering southern Québec, the most likely trend for January, February, March, April, November and December is an increase (except in the B1 scenario for February and November, which would not see any significant trend). The other months would see no change in their precipitation.

The results for monthly runoff are similar and show that: 1) the dominant probability is for increased runoff over a large part of the territory, but more specifically the northern part, from January to March (and to a lesser extent April), then from October to December; 2) the probability of detecting downward trends becomes greater on the west coast of Canada and in southern Québec from April to July, then decreases from August to October. For the grid-boxes covering southern Québec, the most likely projection supports a scenario of increased runoff in January, February, March and December for all GHG scenarios. In the most likely projection, there is no significant trend in April, June, July and October, while the monthly runoff declines in May, August and September. However, it is very important to mention that for the months from April to October, no clear trend dominates and that, considering the uncertainties regarding these projections, any one of these projections could turn out to be correct.

A comparison of the results for monthly precipitation and runoff shows that globally, the two sets of results are consistent. In the winter months, the marked upward trends toward heavy precipitation generally correspond to a situation of increasing runoff, which is also consistent between models. The combined effects of precipitation and evaporation also clearly favour a net increase, resulting in greater runoff. By contrast, the models tend to suggest that precipitation will remain the same in summer. Considering projected temperature increases and consequent increases in the rate of evaporation, this stable regime may result in a negative water balance for these months, leading to a tendency toward lower runoff. The consistency in the results for rainfall and runoff is important, given the rudimentary nature of the representation of the hydrological cycle in global climate models. In the case of a decline in average precipitation, there is an increased probability of months of low rainfall and, consequently, a higher likelihood that we will have to face critical situations with regard to the drinking water supply. However, a more sophisticated analysis is needed.

The results of this study suggest two things with regard to the availability and quality of surface waters in a CC context. First, it is very likely that the availability of surface water will not be affected during the winter, spring and autumn months, considering the projected increases in precipitation. In this case, even if there is no need for concern about the volumes of water available, it is possible that the quality of surface water will be altered. However, it is difficult to be specific about the extent of these changes beyond the general findings mentioned in the literature (higher water temperatures, a possible increase in the frequency of overflows in combined sewer systems, greater volumes of runoff and polluting load, and a possible increase in the negative effects on the environments receiving stormwater). The impact could be greater in urban streams into which the water from combined sewer systems and stormwater is discharged. Increased precipitation will certainly change the geomorphology of streams in rural areas and increase the non-point loadings in agricultural areas. Moreover, in summer, there is liable to be a decrease in runoff, with the result that supply systems will be exposed to unprecedented low flows and a likely deterioration of raw water quality.

The main effects of CC on public health generally reported in the literature relate more specifically to a possible increase in waterborne infectious diseases[5] in a future context of more abundant and more intense precipitation, more frequent floods, more severe droughts, and higher temperatures. A number of studies suggest a relationship between the emergence of episodes of waterborne infections and extreme weather events. In addition, retrospectively, an association between a rise in temperature and waterborne bacterial or parasitic infections has been demonstrated. However, it is still difficult to determine with accuracy the impact of a climatic change, such as the occurrence of extreme rainfall, on the frequency and extent of outbreaks of infections. An increase in rainfall does seem to be conducive to outbreaks of waterborne diseases in the future climate. But it must not be forgotten that climatic conditions are only one of the factors involved in the sequence of situations that could lead to outbreaks of waterborne diseases.

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[5] Viral gastroenteritis (such as the types caused by enterovirus, adenovirus or Norovirus), bacterial gastroenteritis (including types caused by *Campylobacter, Escherichia coli* or *Salmonella*) and parasitic gastroenteritis (*Cryptosporidium* and *Giardia*) are examples of potentially waterborne infectious diseases (several of these micro-organisms can also be transmitted through food or liquids other than tap water - fruit juice or milk, for example).

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