Hydroclimatic Atlas of Southern Québec

The Impact of Climate Change on High, Low and Mean Flow Regimes for the 2050 horizon

2015

Québec

Information

Centre d'expertise hydrique du Québec
Ministère du Développement durable, de l'Environnement
et de la Lutte contre les changements climatiques
675 Boulevard René-Lévesque Est, Québec (Québec) G1R 5V7
Louis-Alexandre-Taschereau Wing, 4th floor, Box 28
Telephone: 418-521-3993
Fax: 418-643-6900
Email: cehq@mddelcc.gouv.qc.ca
Web site: www.cehq.gouv.qc.ca

Recommended bibliographical notice

Hydroclimatic Atlas of Southern Québec. The Impact of Climate Change on High, Low and Mean Flow Regimes for the 2050 horizon. Québec, Centre d'expertise hydrique du Québec (CEHQ), 2015, 81 pp.

Cover photo

Grégory Reuchet

Legal deposit

Bibliothèque et Archives nationales du Québec, 2015
ISBN: 978-2-550-73925-8 (paper)
ISBN: 978-2-550-73926-5 (PDF)

Production team

Simon Lachance-Cloutier, Eng., M. Sc.
Philippe Noël, Eng., M. Sc.
Simon Ricard, Eng., M. Sc.
Richard Turcotte, Eng., Ph. D.

Collaboration

Marco Braun, Ph. D., Ouranos
Blaise Gauvin St-Denis, M. Sc., Ouranos
Yves Rochon, M. Sc.
Jean-François Cyr, Eng., M. Sc.
Frédéric Côté
Éric Levasseur
Stéphanie Beauregard

Scientific committee

François Brissette, Ph. D., Eng., professor, École de technologie supérieure
Diane Chaumont, M. Sc., Climate scenarios and services group leader, Ouranos Consortium
Alain Maillot, Ph. D., professor, Institut national de la recherche scientifique – Centre Eau, Terre et Environnement
Alain N. Rousseau, Ph. D., Eng., professor, Institut national de la recherche scientifique, Centre Eau, Terre et Environnement
René Roy, Ph. D., Scientific Program Director, Ouranos Consortium

Communications and design

Anne-Sophie Cauchon
Caroline Châteauvert
Sophie-Anne Tremblay

Proofreading and translation

Carole Pâquet
Jacinthe Morency
Studio 9

A word from the Assistant Deputy Minister

Water is a resource of inestimable riches that must be protected, all the more so in today's context, where climate change has affected and will continue to impact the quantity and quality of available water and its usage. Produced under the 2013-2020 Climate Change Action Plan, the 2015 edition of the *Hydroclimatic Atlas of Southern Québec* provides a clear and accessible picture of the potential impact of climate change on water resources for the 2050 horizon.

I want to thank everyone from the Centre d'expertise hydrique du Québec who contributed to the 2015 update of the *Hydroclimatic Atlas of Southern Québec*, for their hard work and their expertise. The Atlas now includes the Gaspésie, Côte-Nord and part of the James Bay regions and fully covers the integrated water resource management zones as defined by the Ministère in 2009. It is also one of the first publications to incorporate the latest Coupled Model Intercomparison Project Phase 5 (CMIP5) generation of climate simulations produced for the Intergovernmental Panel on Climate Change (IPCC) and made available in Québec through the work of the Ouranos Consortium.

Since the spring of 2014, a scientific committee has guided the development and improvement of modeling practices needed for producing the hydrological projections on which information shown in this publication is founded. Even if the main messages remain unchanged from the first edition of the *Atlas*, we now possess more detailed nuances as to signal quantification and location.

Within Québec, as is the case in many other jurisdictions around the world, climate change raises the question of society's capacity to face up to a growing number of problems that are related to water management. This new edition of the *Atlas* provides the various actors involved in water management in Québec with credible hydroclimatic projections that can improve their ability to guide, plan and implement measures for adapting to climate change. Working together, we can identify the optimal measures to put in place in order to enhance our resilience to climate change and ensure a better future for ourselves and for our children.

Jacques Dupont
Assistant Deputy Minister, Water and Environmental Expertise and Assessment
June 2015

Executive Summary

Québec possesses significant water resources from which depend various ecosystems and which are impacted by human activity. This dependency requires appropriate management of the resource in order to adequately respond to issues that are associated with water shortages and surpluses. During low flow periods, the insufficiency of the resource compromises a variety of uses such as drinking water supply, energy production and navigation. Contrariwise, the overabundance of water during episodic high flow can cause flooding and erosion. Additional challenges stem from the close relationship between available quantities of water and the diversity of issues that are associated with water quality. There is no doubt that climate change will have an impact on the southern Québec water regime and magnify water management challenges. Numerical simulations using modeling tools created through international and local efforts can help by enabling quantitative impact assessments to be made.

The main trends forecast for southern Québec for the 2050 horizon are as follows:

Trends for the 2050 horizon	Confidence level
Spring high flow will come earlier.	High
Spring high flow volume will be lower in southernmost Québec.	Moderate
The spring high flow peak will be lower in southernmost Québec.	Moderate
The summer and autumn high flow peak will be higher throughout large areas of southern Québec.	Moderate
Summer low flow will be more severe and last longer.	High
Winter low flow will be less severe.	High
Winter low flow will be less severe.	High
Summer mean flow will be lower.	High
Annual mean flow will be higher in the north of southern Québec and lower to the south.	Moderate

Glossary

Climate modeling	
Climate members	Group of climate simulations produced using a single climate model and RCP and whose initial conditions varied slightly.
Climate model	Numeric representation of the climate system based on atmospheric and ocean process modeling.
Climate scenario	Post-processed climate simulation.
Climate simulation	Climate model run for selected parameters and initial conditions.
CMIP5	Coupled Model Intercomparison Project Phase 5. The most recent group of climate simulations prepared for the Working Group on Coupled Modelling (WGCM) that support the 5th Intergovernmental Panel on Climate Change (IPCC) report. CMIP5 was achieved using various climate models and for different Representative Concentrating Pathways (RCP).
Post-processing	Procedure that aims at correcting or compensating for deviations between climate simulations and reference observations.
RCP	Representative Concentration Pathways. Replaces greenhouse gas scenarios in climate simulations prepared for the CMIP5 Special Report on Emissions Scenarios.

Hydrology	
High flow	Period of high flow.
Hydrological model	Numeric representation of hydrological processes.
Hydrological projection	Simulated flows corresponding to climate conditions defined by a given climate scenario.
Low flow	Period of low flow.
Mean flow	Average value of flow over a long period of time (month, season, year).
Peak flow	Maximum flow value observed during a high flow period.
Recurrence	Long-term average for the statistical return of a given hydrological event.
Southern Québec	Refers to the 726,000 km^2 area of southern hydrological Québec that covers the watersheds of the tributaries of the St. Lawrence River, the Ottawa River and the rivière Saguenay, as well as the Gaspésie, Côte-Nord and a portion of the Abitibi-James Bay regions.
Volume	Quantity of water carried by a watercourse in a given period of time.
Watershed	Geographic unit representing the drainage area of a given point called outlet.

Analysis of change	
2050 horizon	Period running from 2041 to 2070.
Amplitude	Median value of estimated changes.
Change	Relative deviation between an estimated hydrological indicator for a reference period and a future period.
Confidence level	Assessment of the value of a given piece of information, based on expert opinion.
Direction of change	Proportion of hydrological projections anticipating an increase or decrease of a given indicator.
Dispersion	For a given value of amplitude, an interval that includes half of the estimated change values.
Hydrological indicator	Mathematical expression quantifying a component of the water regime.
Reference observation	Value of a hydrological indicator calculated from measured flow for a given reference period.

Table of contents

Photo: Mario Bolduc

Context

The *Hydroclimatic Atlas* presents a synthesis of the state of knowledge describing the expected impact of climate change on the southern Québec water regime. This publication is first and foremost intended for hydric resource professionals, to support planning and implementing adaptation to climate change. The information presented in the *Atlas* is based on hydrological projections produced in accordance with modeling practices that are widely recognized by the scientific community. Analysis of a change signal is made on the basis of a hydrological indicator–a mathematical expression that quantifies a component of the water regime.

The 2015 edition of the *Atlas* is the first in a series of updates that incorporate the most recent advances of research into hydroclimatic modeling. The point of departure of this process was the launch of the first edition of the *Atlas* in March 2013. Since the spring of 2014, a scientific committee has guided the development and improvement of the modeling practices required to produce the *Atlas*. In the coming years, the Centre d'expertise hydrique du Québec will continue its exploratory and update efforts in order to broaden and strengthen the scope of its water regime impact analyses.

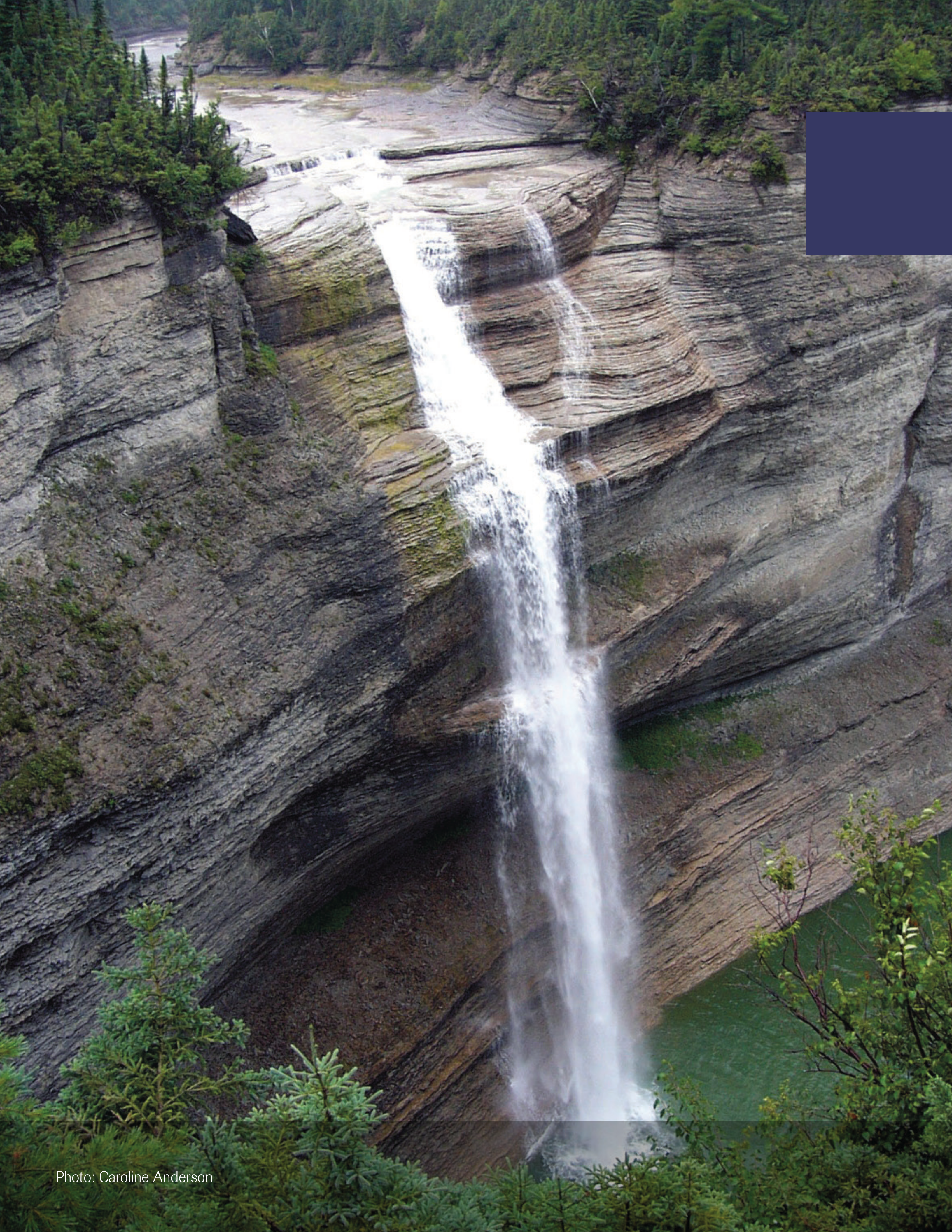


Photo: Caroline Anderson

New features

The 2015 edition of the *Atlas* includes two main new features. The first relates to territorial expansion and modeling capacity. The modeling platform now includes the Gaspésie and Côte-Nord regions, as well as a portion of the James Bay region. The modeled area thus corresponds to the integrated water resource management area as defined in 2009 by the Ministère du Développement durable, de l'Environnement et de la Lutte contre les Changements Climatiques[1]. The capability of the hydrological modeling platform to simulate low flow has also been improved.

The second new feature is the use of CMIP5 (Coupled Model Intercomparison Project Phase 5) climate simulations adopted by the Intergovernmental Panel on Climate Change (IPCC). The future evolution of greenhouse gases (GHG) is henceforth looked at from the angle of Representative Concentration Pathways (RCP). Two such pathways were used to produce the 2015 *Atlas*: RCP4.5 and RCP8.5. RCP4.5 is deemed an "optimistic" scenario associated with emission capping measures that will make it possible to limit concentration pathways caused by climate change to approximately twice their current levels for the 2100 horizon. RCP8.5 can be described as a "pessimistic" scenario that is yet both plausible and representative of the invariability of current behaviour in terms of greenhouse gas emissions. It hypothesizes that concentration pathway values will be approximately four times what they are today for the 2100 horizon. For each hydrological indicator, the amplitude of change is presented separately for RCP4.5 and RCP8.5. The reader will note that both pathways induce similar impacts on the water regime for the 2050 horizon. This is an expression of the ineluctable nature of expected impacts for the 2050 horizon, independent of GHG abatement efforts. The differences between the RCP4.5 and RCP8.5 scenarios become more significant as we approach 2100.

1 [Online] [http://www.mddelcc.gouv.qc.ca/eau/bassinversant/gire-bassins-versants.htm].

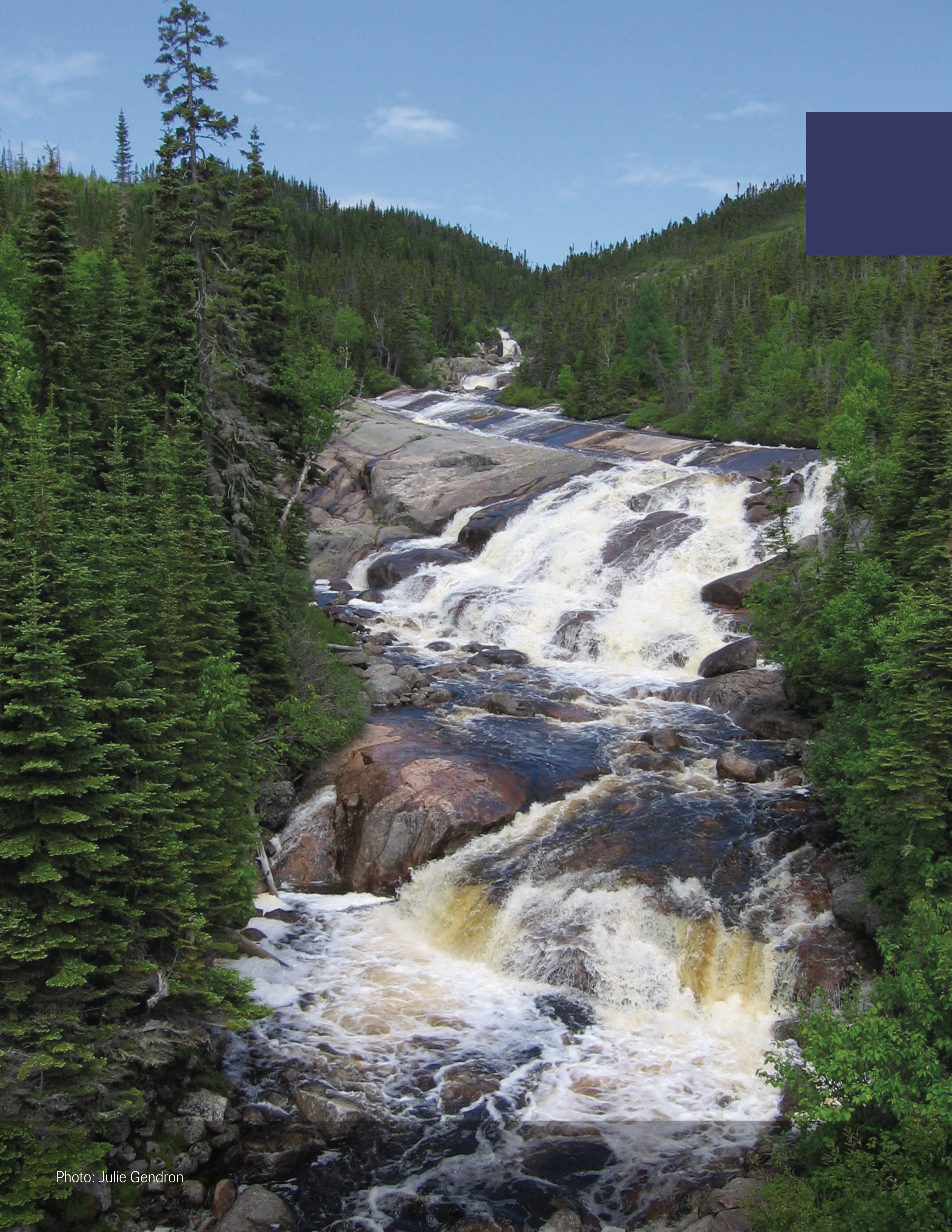


Photo: Julie Gendron

Usage and limitations

The information presented in the *Atlas* is meant to support hydric resource adaptation measures. The main findings are essentially the same as those presented in the 2013 edition of the *Atlas*, which remains scientifically valid and complementary to the 2015 update. However, the abovementioned new features make it possible to fine-tune the findings and achieve a higher confidence level for the various signals of hydrological change.

Utilisation of the information contained in the *Atlas* is conditional on appropriate interpretation of the following methodological limitations:

- The hydrological projections are located at a selection of hydrometric stations in southern Québec.
- The hydrological projections are limited to the natural regime of surface watercourse flow and should not be generalised to watersheds of less than 500 km^2 or greater than 20 000 km^2 in area.
- The hydrological projections do not take account of the local effects of dam operations on change signals.
- The climatic projections exclude so-called “marginal” scenarios and are limited to a sub-set of simulations based on CMIP5.

Depending on the degree of complexity of a given problem, precise assessment of the impact of climate change may require detailed analyses that go beyond the framework of this work. Nevertheless, any actor in the field of water will find herein, basic information enabling the start of a reflective process on adapting to climate change. Readers seeking a deeper understanding are invited to take note of the information shown in the “Methodology” section of this work. The *Plateforme de modélisation hydrologique du Québec méridional* (CEHQ, 2014) technical report describes the modeling practices used to produce the *Atlas* in greater detail.


Photo: Elaine Lacroix

Hydrological projections

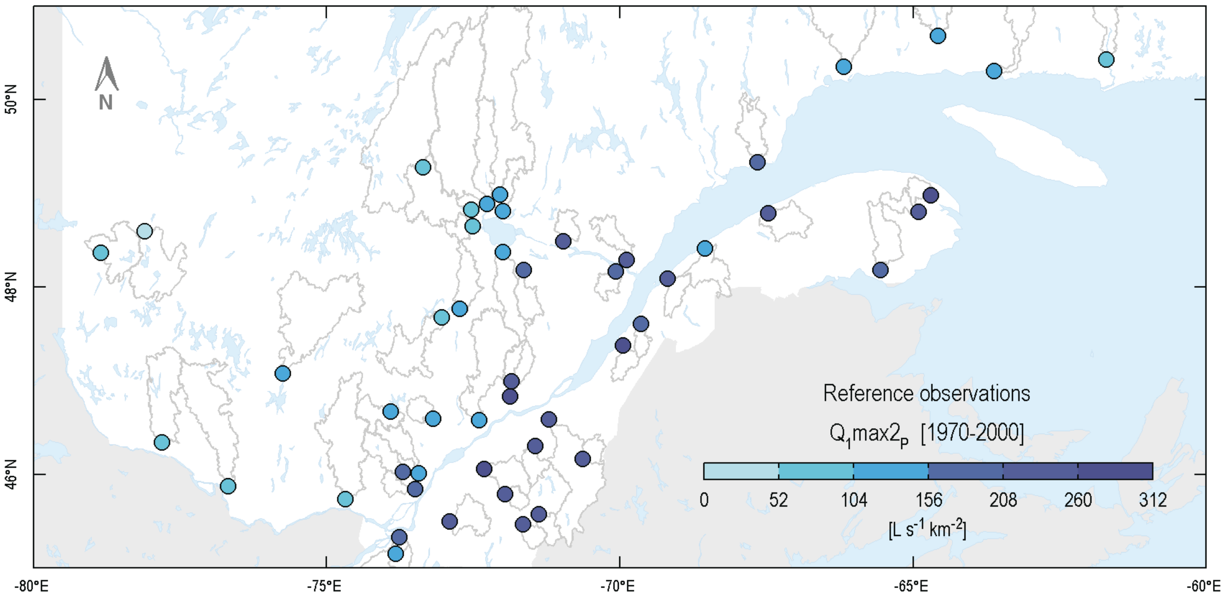
Table 1: Hydrological indicators*

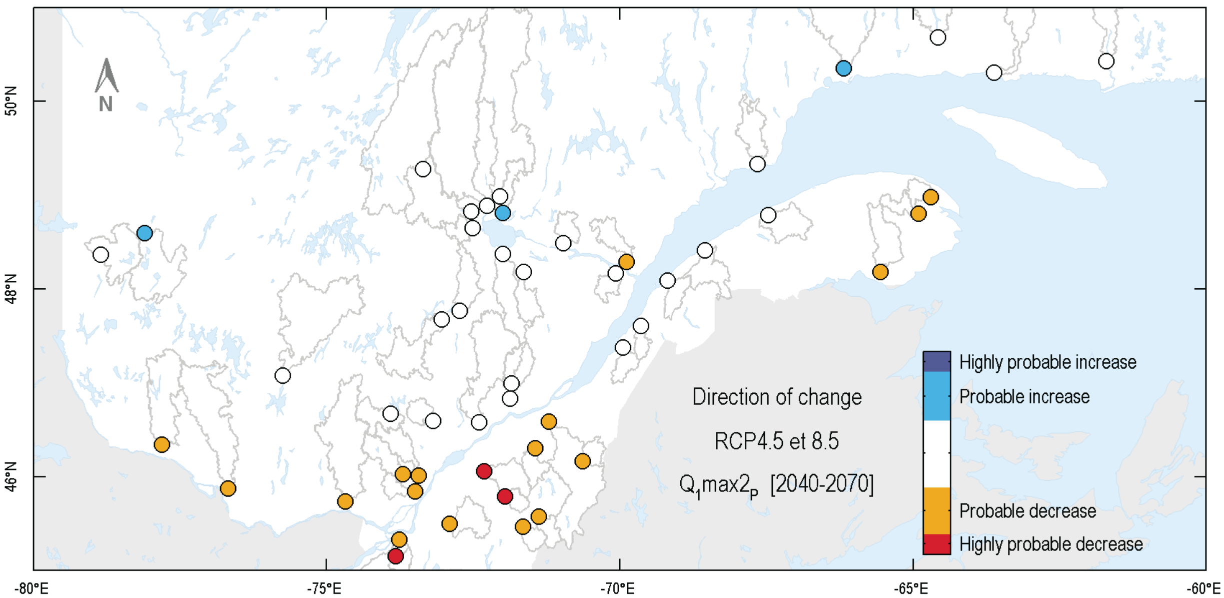
Hydrological phenomenon	Question	Indicator	Description	Pages
Spring high flow	For the 2050 horizon, will the spring high flow peak be greater?	Q_1max2_P	Annual maximum [max] of the daily [Q_1] spring flow [P] with a 2-year [2] return period	8-9
		Q_1max20_P	Annual maximum [max] of the daily [Q_1] spring flow [P] with a 20-year [20] return period	10-11
	For the 2050 horizon, will spring high flow volume be greater?	$Q_{14}max2_P$	Annual maximum [max] of the 14-day [Q_{14}] spring flow [P] with a 2-year [2] return period	12-13
		$Q_{14}max20_P$	Annual maximum [max] of the 14-day [Q_{14}] spring flow [P] with a 20-year [20] return period	14-15
	For the 2050 horizon, will spring high flow come earlier?	$J[Q_1max_P]$	Average day of occurrence [J] of the annual maximum [max] daily [Q_1] spring flow [P]	16-17
Summer and autumn high flow	For the 2050 horizon, will the summer and autumn high flow peak be greater?	Q_1max2_{EA}	Annual maximum [max] of the daily [Q_1] summer and autumn flow [EA] with a 2-year [2] return period	18-19
		Q_1max20_{EA}	Annual maximum [max] of the daily [Q_1] summer and autumn flow [EA] with a 20-year return period	20-21
Winter low flow	For the 2050 horizon, will winter low flow be more severe?	Q_7min2_H	Annual minimum [min] of the 7-day [Q_7] winter flow [H] with a 2-year [2] return period	22-23
		Q_7min10_H	Annual minimum [min] of the 7-day [Q_7] winter flow [H] with a 10-year [10] return period	24-25
		$Q_{30}min5_H$	Annual minimum [min] of the 30-day [Q_{30}] winter flow [H] with a 5-year [5] return period	26-27
Summer low flow	For the 2050 horizon, will summer low flow be more severe?	Q_7min2_E	Annual minimum [min] of the 7-day [Q_7] summer flow [E] with a 2-year [2] return period	28-29
		Q_7min10_E	Annual minimum [min] of the 7-day [Q_7] summer flow [E] with a 10-year [10] return period	30-31
		$Q_{30}min5_E$	Annual minimum [min] of the 30-day [Q_{30}] summer flow [E] with a 5-year [5] return period	32-33
Mean flow regime	For the 2050 horizon, will the mean flow regime change?	Qmoy	Annual mean flow [Qmoy]	34-35
		$Qmoy_{HP}$	Winter/spring [HP] mean flow [Qmoy]	36-37
		$Qmoy_{EA}$	Summer/autumn [EA] mean flow [Qmoy]	38-39
		$Qmoy_{1-12}$	Monthly [1-12] mean flow [Qmoy]	40-63

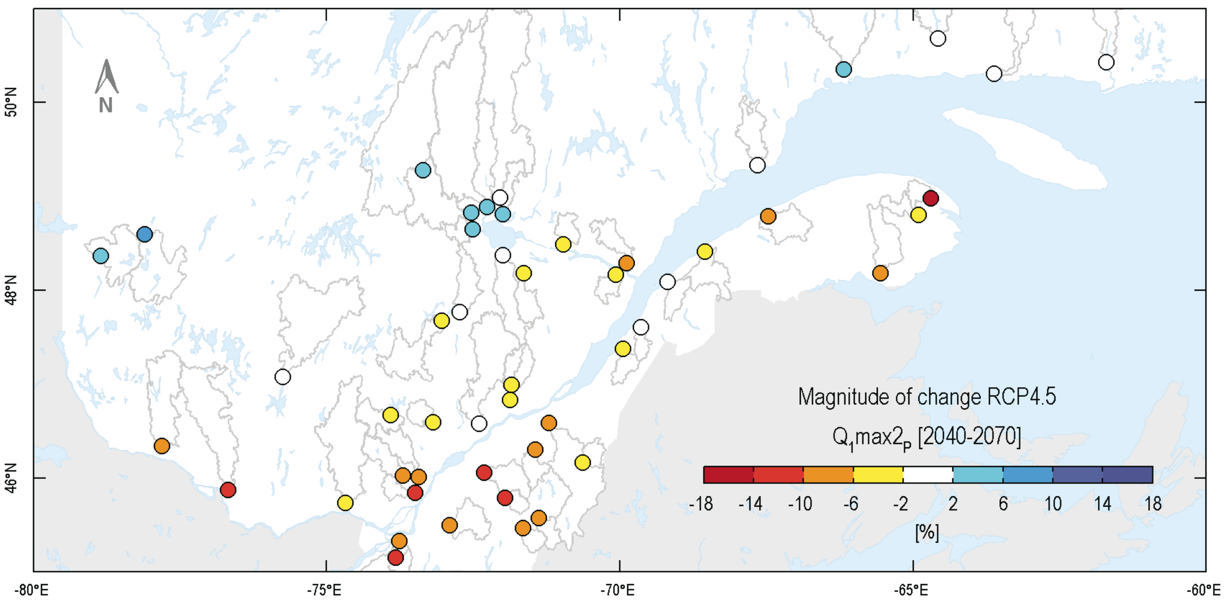
* Readers unfamiliar with the notions related to hydrological indicators (direction, magnitude and dispersion) are invited to read the "Change signals" section on pages 74 and 75.

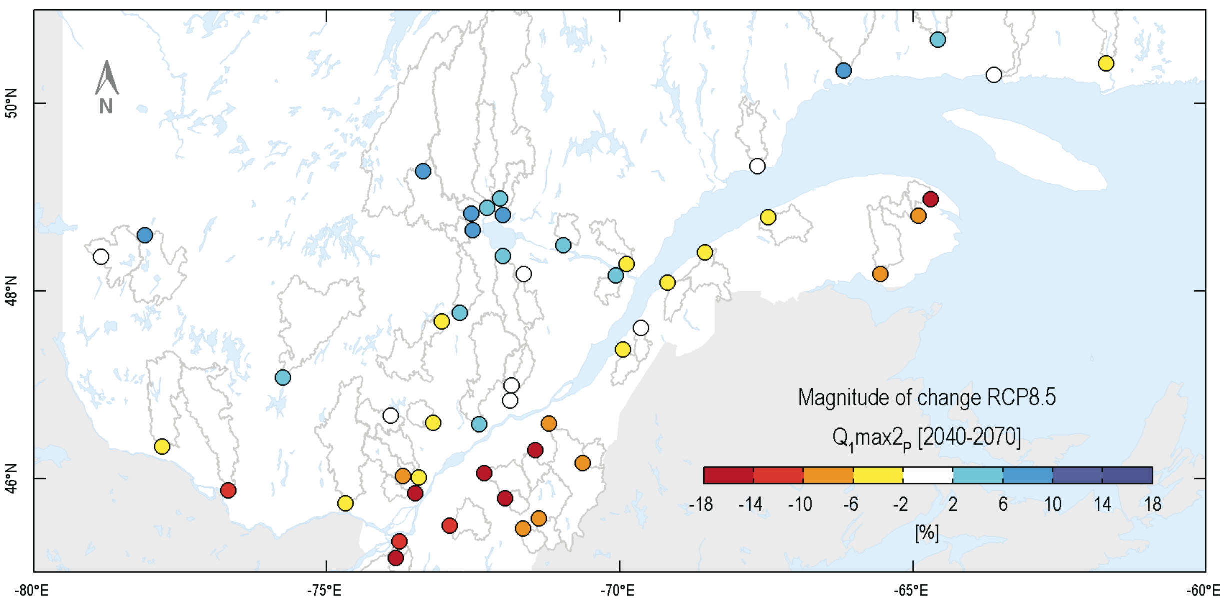
Spring high flow peak

Daily flow, 2-year return period





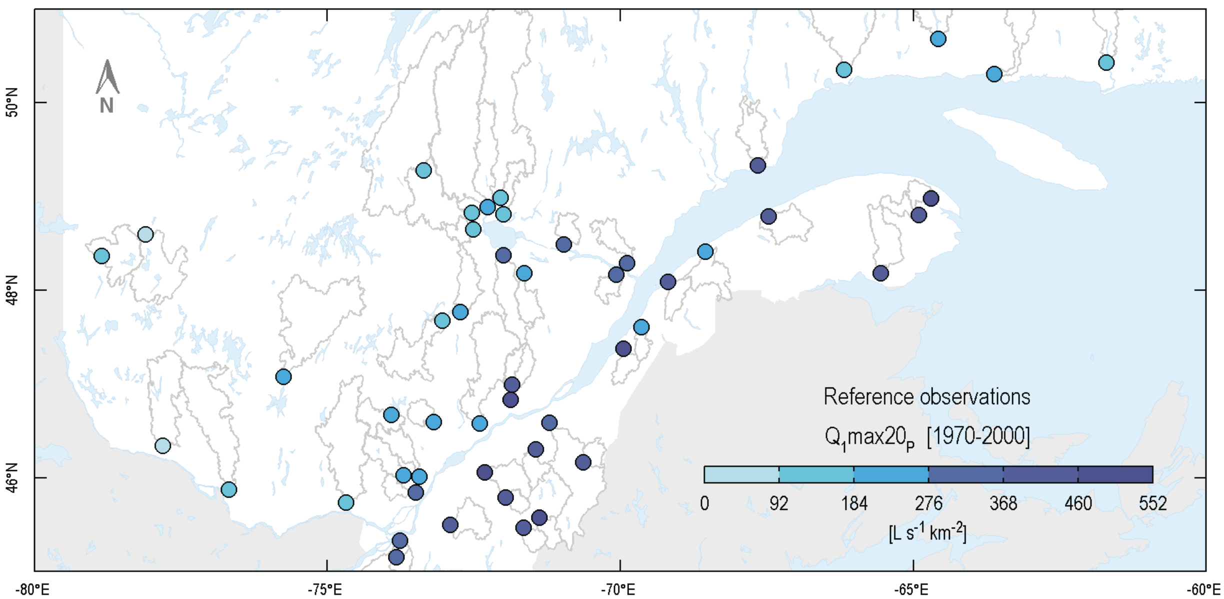


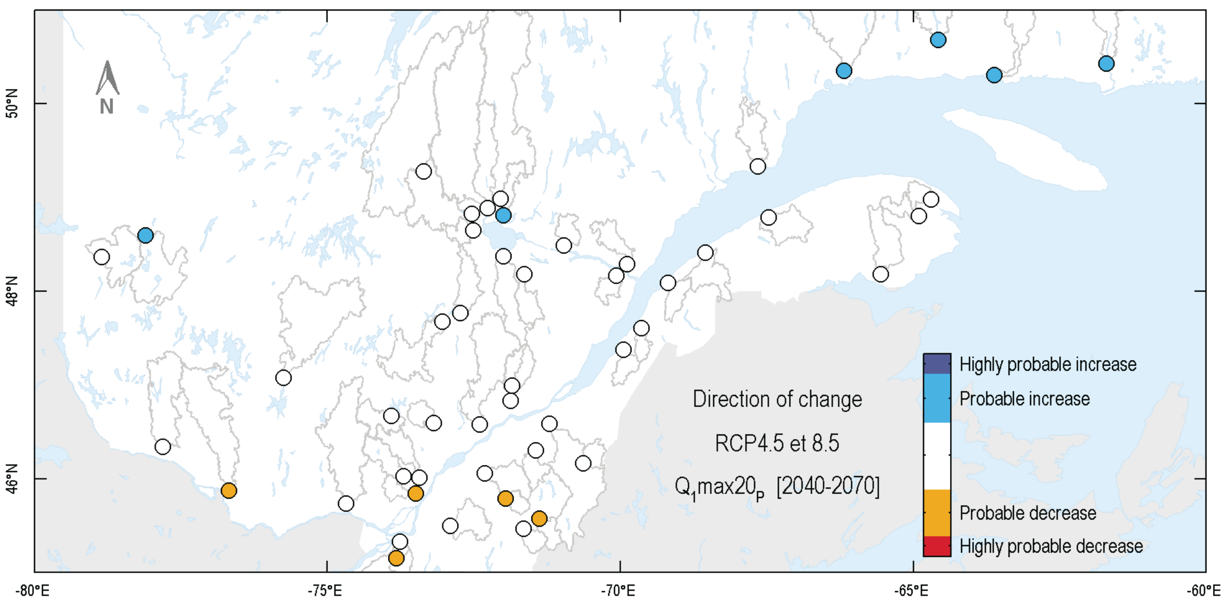


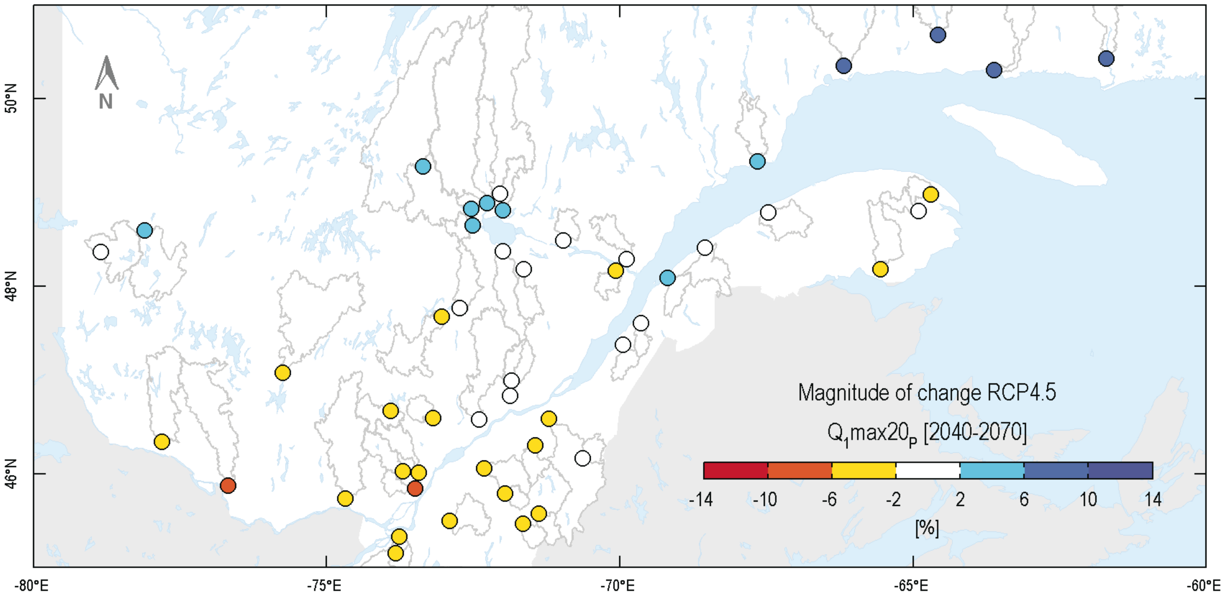
The Q_1max2_P hydrological indicator corresponds to the annual maximum of the daily spring flow with a 2-year return period. For the 2050 horizon, projections describe a probable to highly probable Q_1max2_P decrease in southern Québec and in the Gaspésie region in the order of -5% to -15% (RCP4.5) and that could reach -20% (RCP8.5). Projections describe a Q_1max2_P probable increase in some areas to the north of the Outaouais region, in the Saguenay region and on the Côte-Nord in the order of +5% to +10%. Dispersion is estimated at ±7%. The confidence level is moderate for direction of change and limited for magnitude and dispersion.

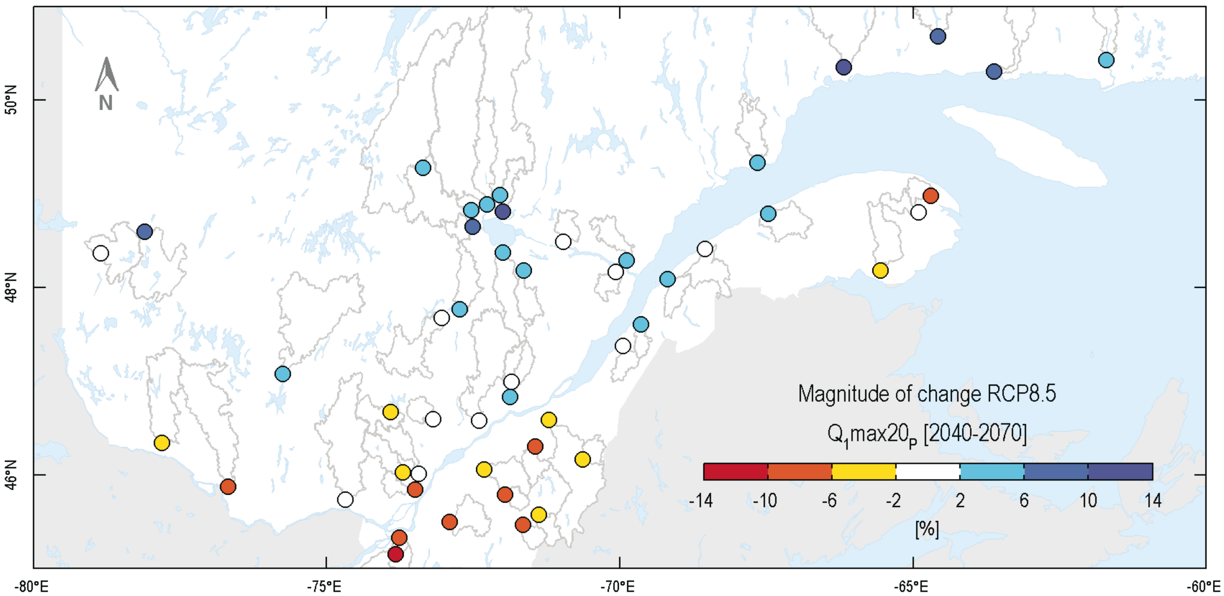
Spring high flow peak

Daily flow, 20-year return period





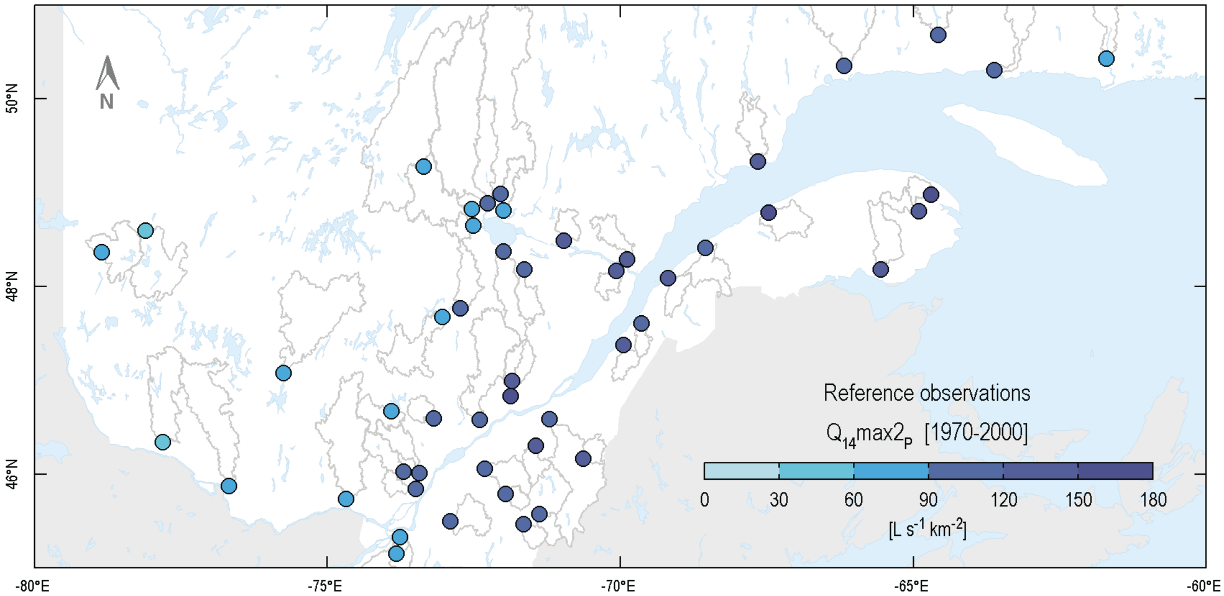


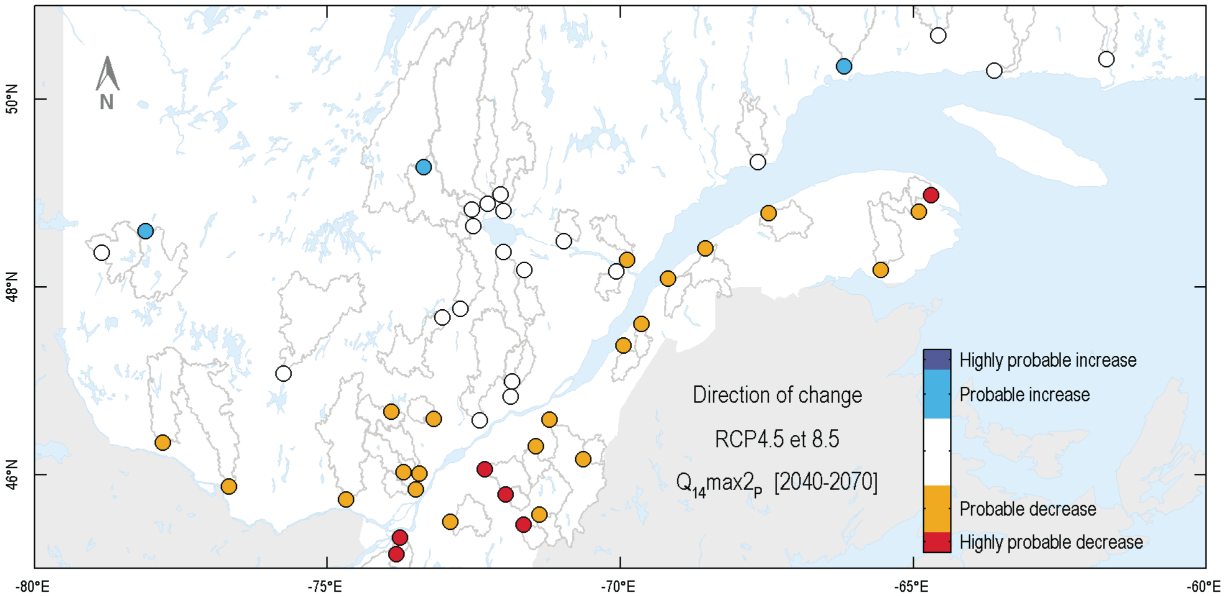


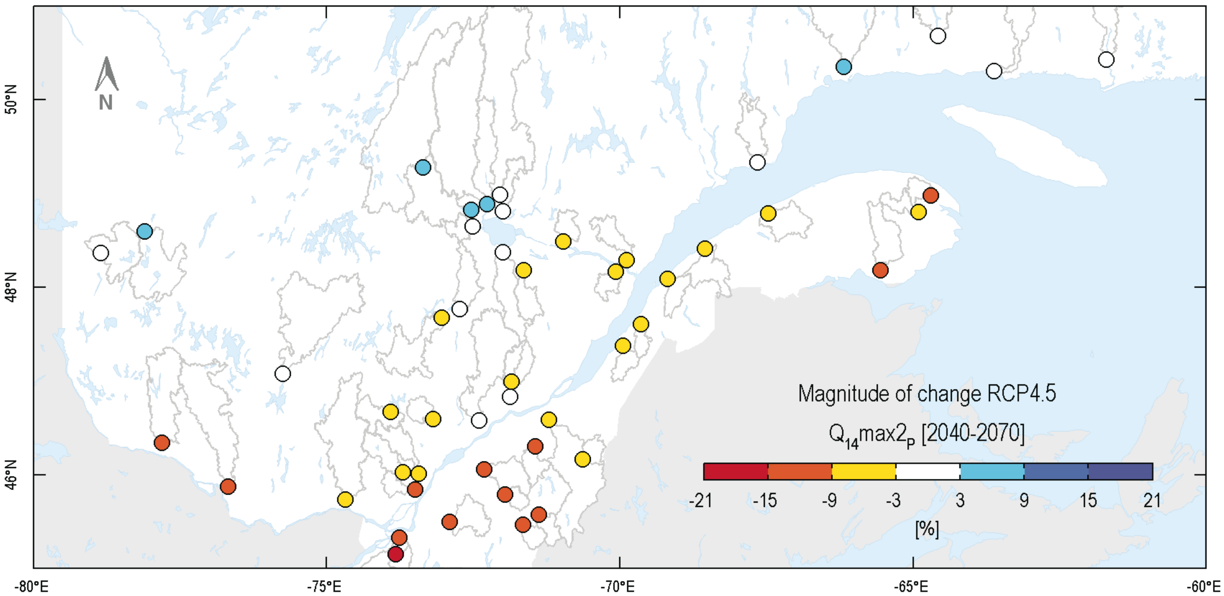
The Q_1max20_P hydrological indicator corresponds to the annual maximum of the daily spring flow with a 20-year return period. For the 2050 horizon, projections describe a probable decrease in Q_1max20_P in the far south of southern Québec in the order of -5% (RCP4.5) and that could reach -15% (RCP8.5). Projections describe a probable increase in Q_1max20_P at several sites to the north of the Outaouais region, in the Saguenay and on the Côte-Nord in the order of +10% to +15%. Dispersion is estimated at ±9%. The confidence level is moderate for the direction of change and limited for magnitude and dispersion.

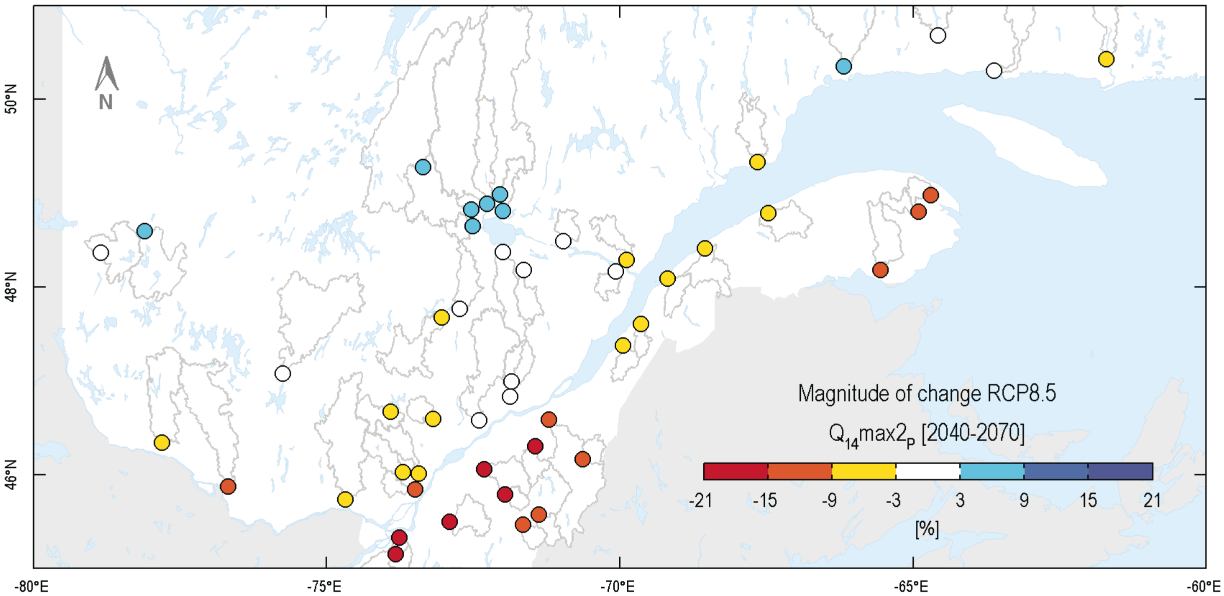
Spring high flow volume

14-day flow, 2-year return period





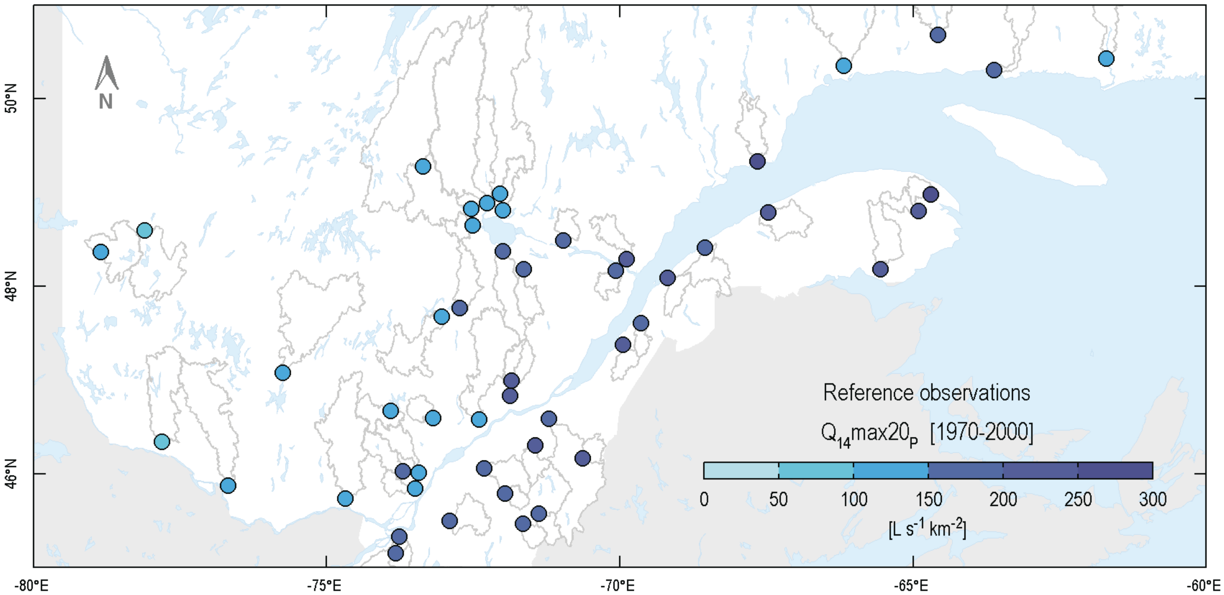


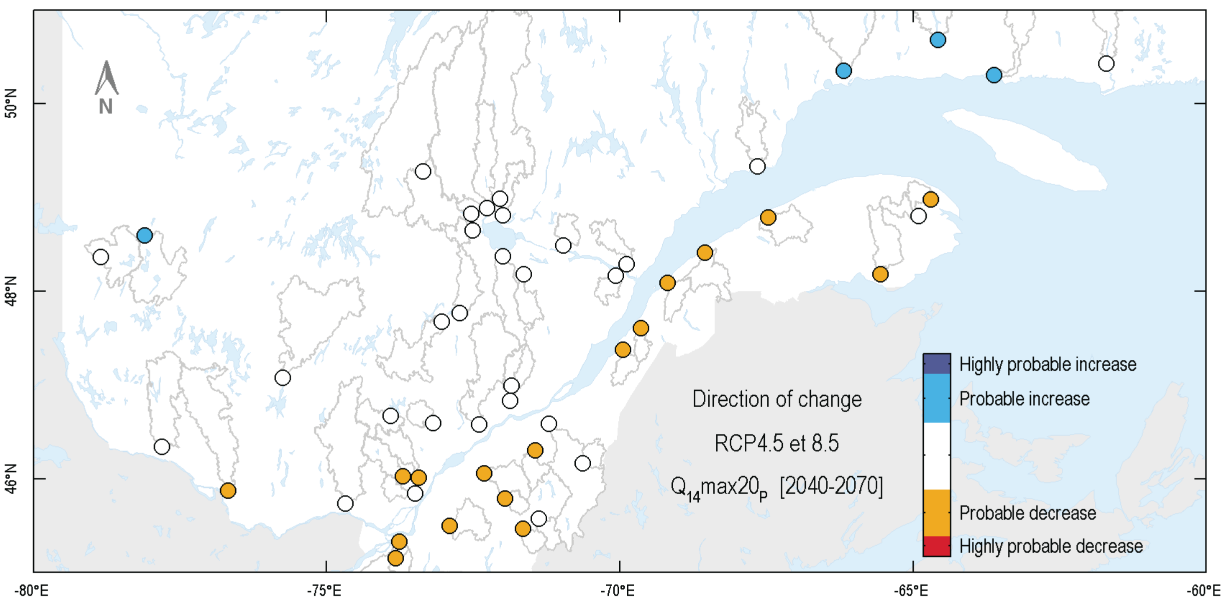


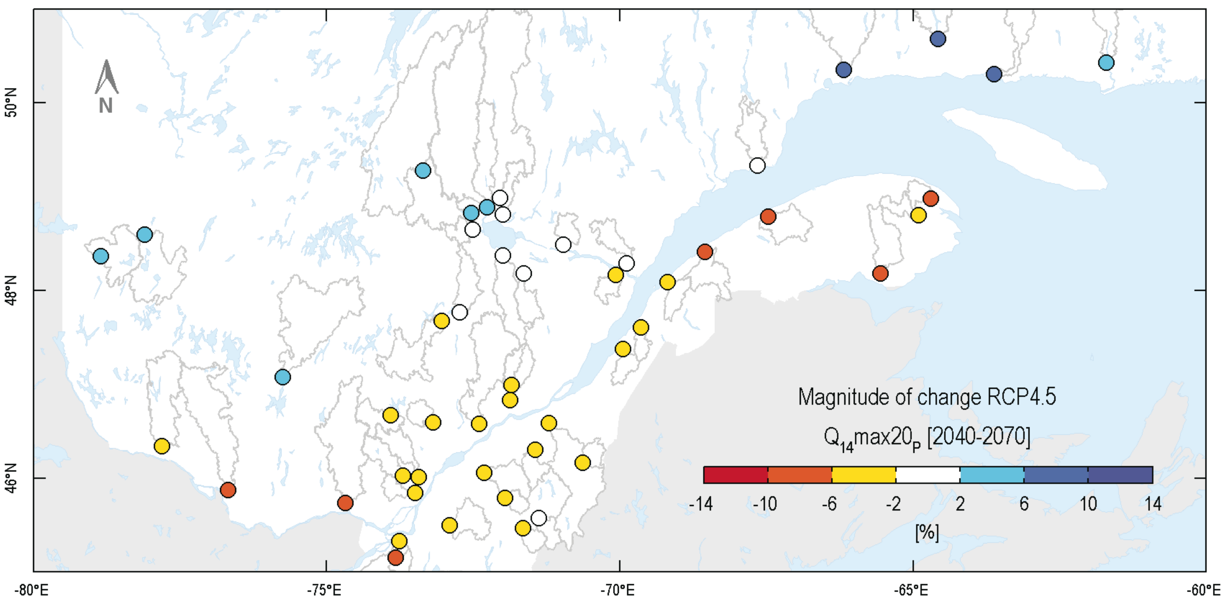
The $Q_{14}max2_P$ hydrological indicator provides an indication of annual maximum of the 14-day spring flow with a 2-year return period. For the 2050 horizon, projections describe a probable to highly probable decrease in $Q_{14}max2_P$ in southernmost Québec and in the Gaspésie region in the order of -5% to -15% (RCP4.5) and that could reach -20% (RCP8.5). Projections describe a probable increase in $Q_{14}max2_P$ at several sites to the north of the Outaouais region, in the Saguenay and on the Côte-Nord in the order of +5% to +10%. Dispersion is estimated at ±7%. The confidence level is moderate for the direction of change and limited for magnitude and dispersion.

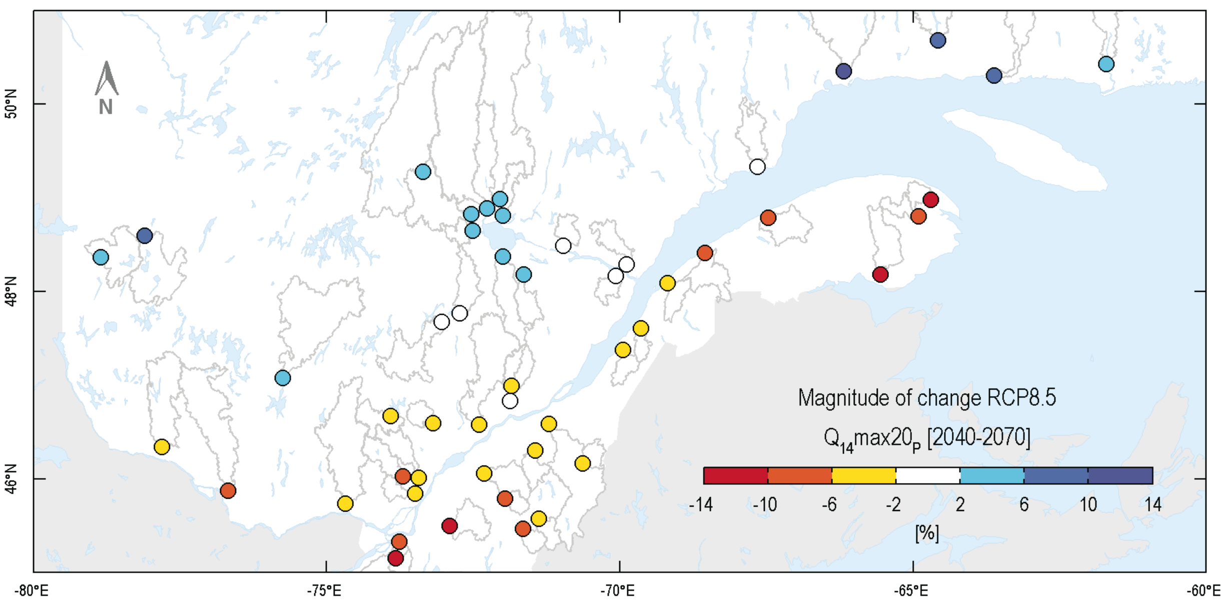
Spring high flow volume

14-day flow, 20-year return period



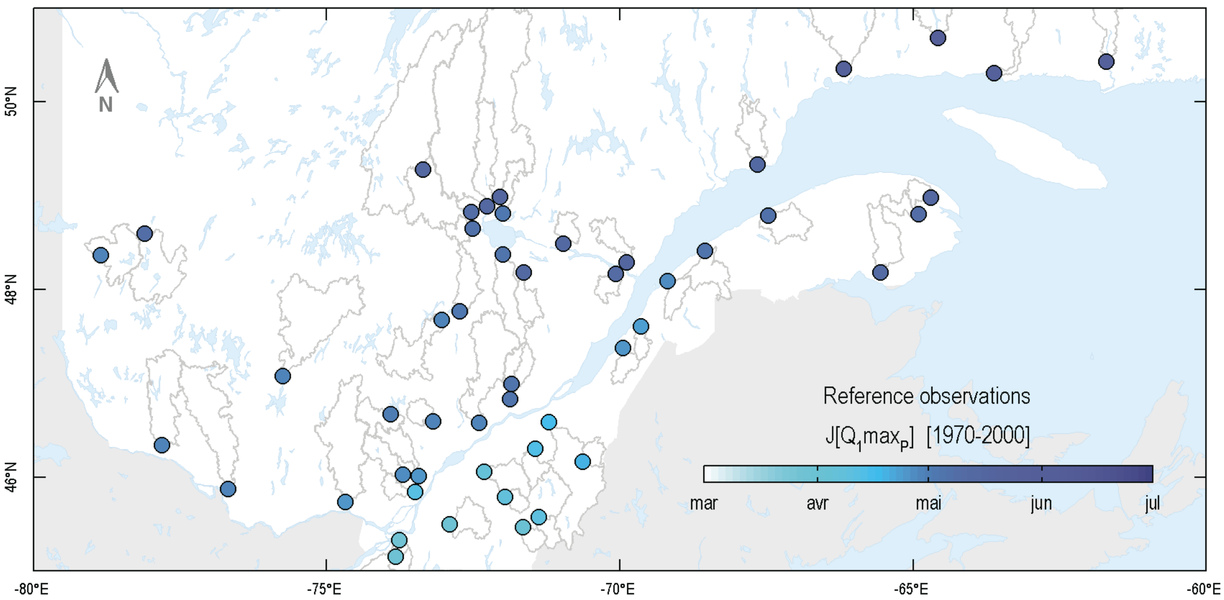


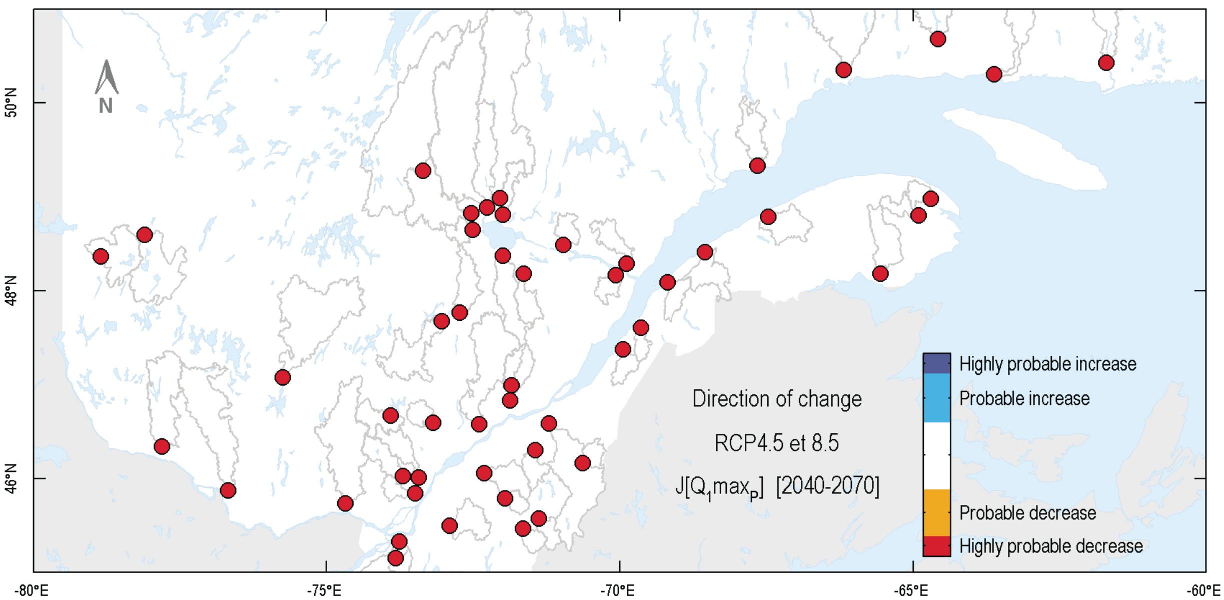


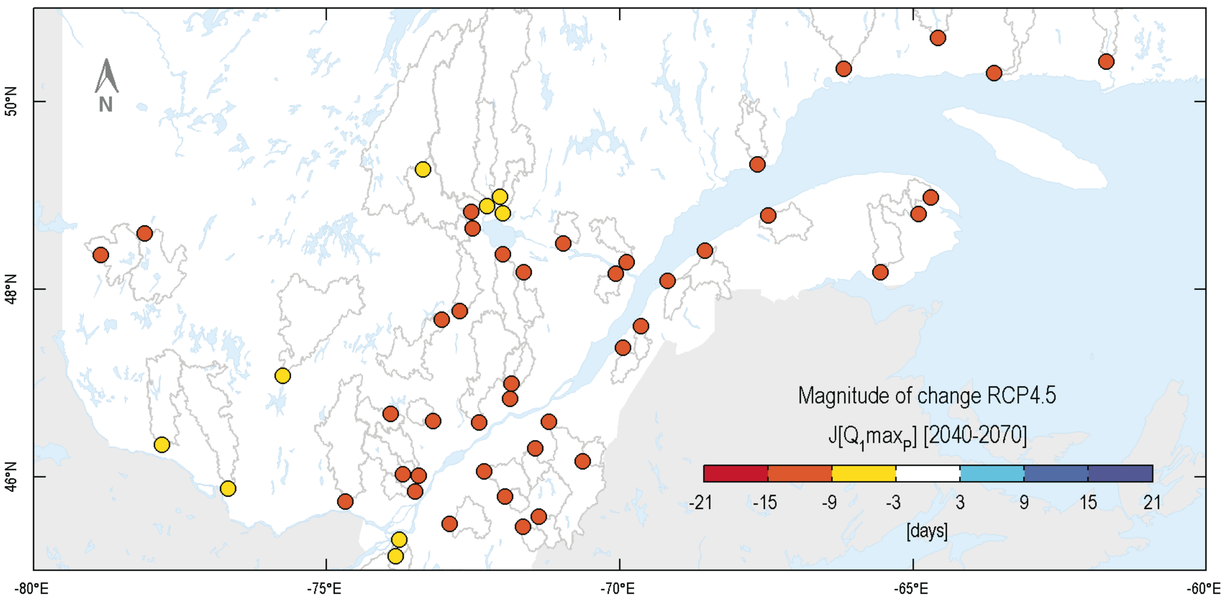


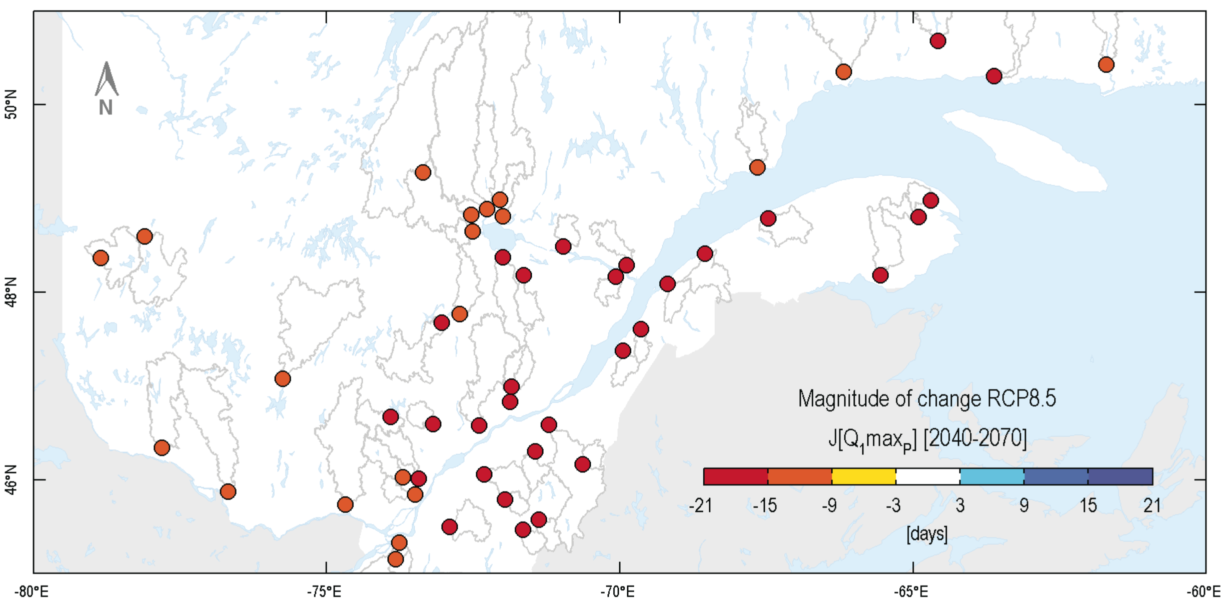
The $Q_{14}max20_P$ hydrological indicator provides an indication of the annual maximum 14-day spring flow with a 20-year return period. For the 2050 horizon, projections describe a probable decrease in $Q_{14}max20_P$ in the south of the province and in the Gaspésie region in the order of -5% to -10% (RCP4.5) and that could reach -15% (RCP8.5). Projections describe a probable increase in $Q_{14}max20_P$ in the order of + 8% at several sites to the north of the Outaouais region and on the Côte-Nord. Dispersion is estimated à ±10%. The confidence level is moderate for the direction of change and limited for magnitude and dispersion.

Spring high flow occurrence





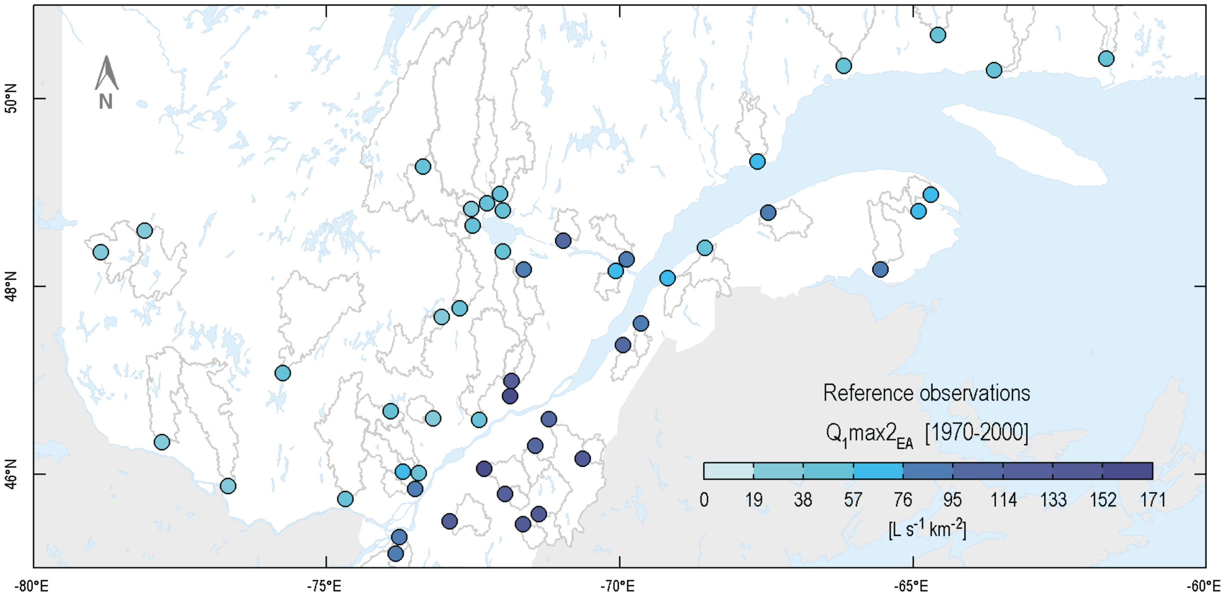


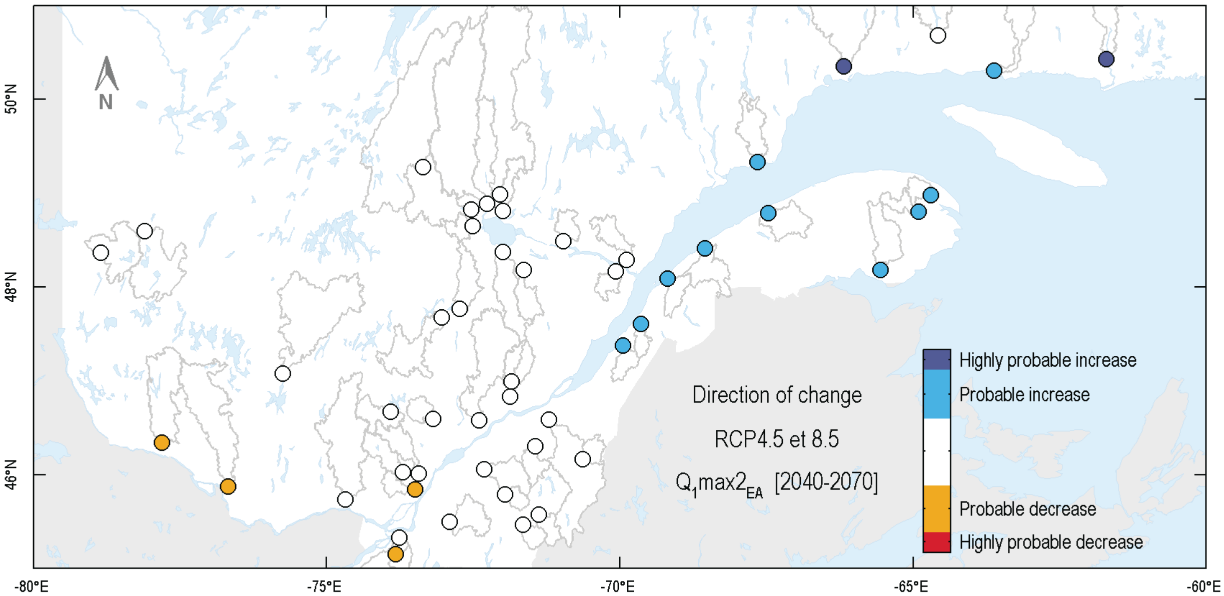


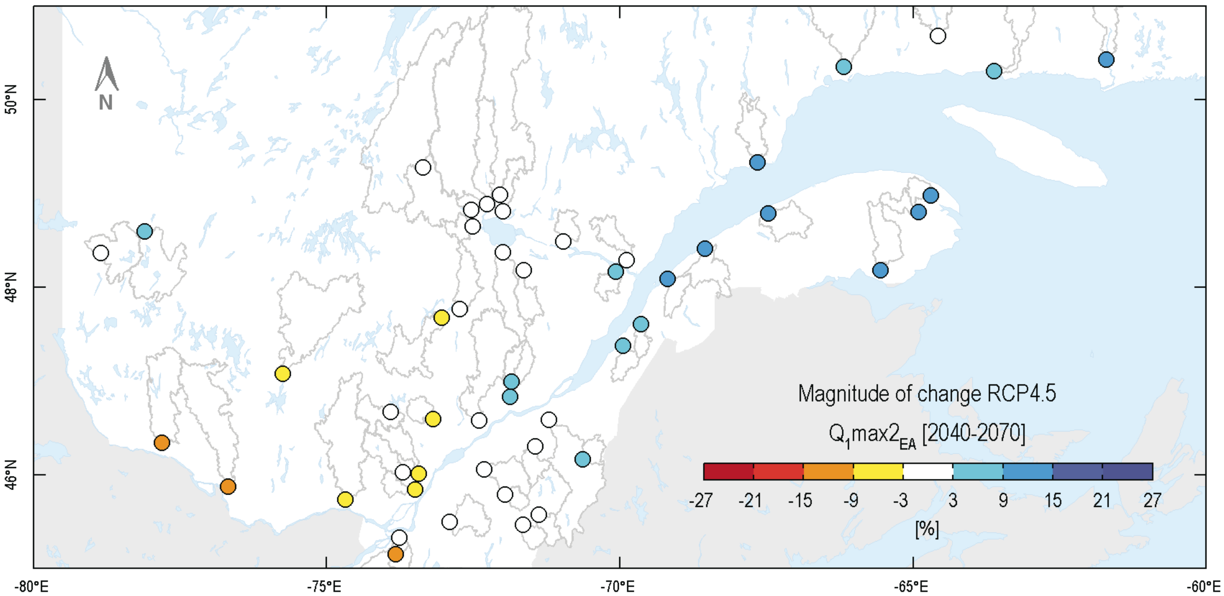
The $J[Q_1max_P]$ hydrological indicator corresponds to the average day of the year when spring high flow peaks. For the 2050 horizon, projections describe a highly probable earlier $J[Q_1max_P]$ throughout southern Québec in the order of -15 days (RCP4.5) to -20 days (RCP8.5). Dispersion is estimated at ±4 days. The confidence level is very high for the direction of change and high for magnitude and dispersion.

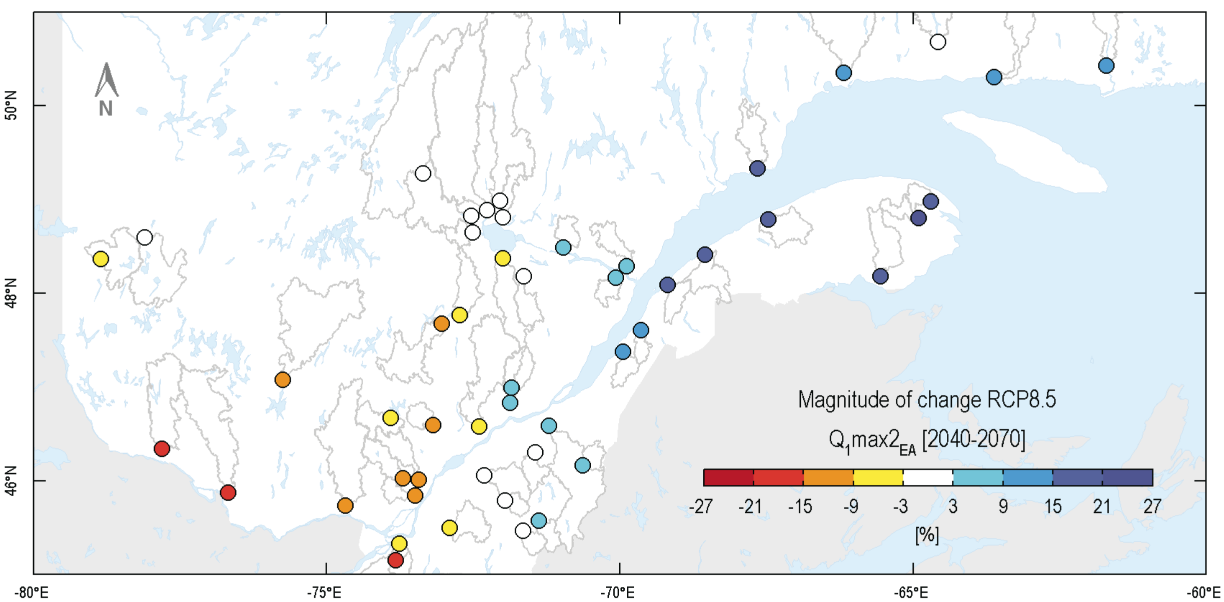
Summer and autumn high flow peak

Daily flow, 2-year return period





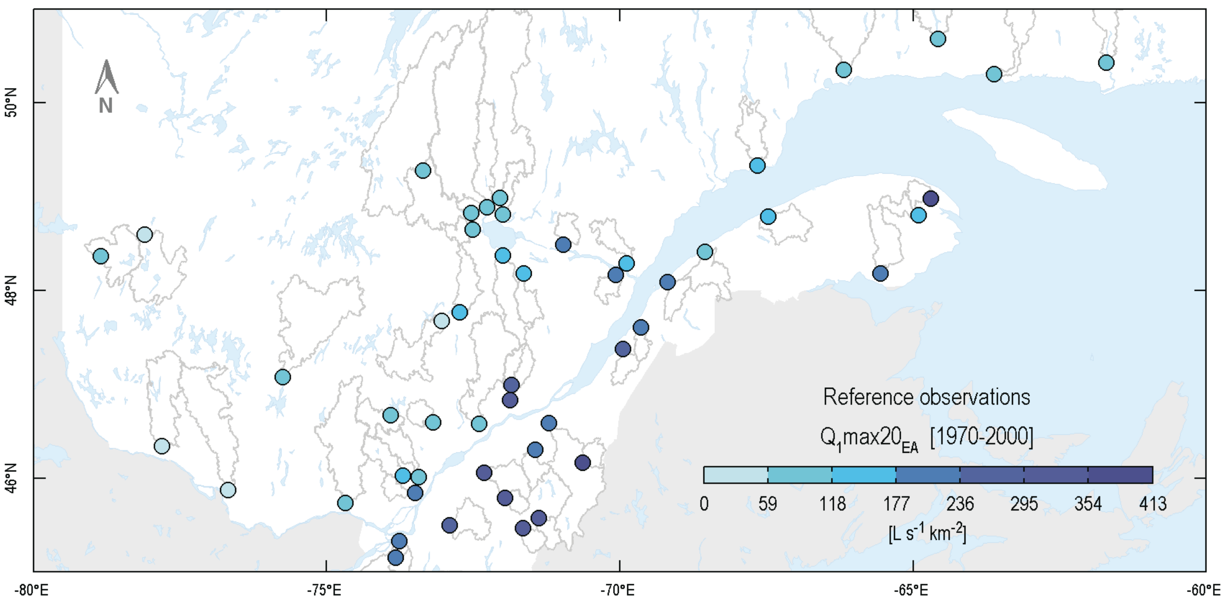


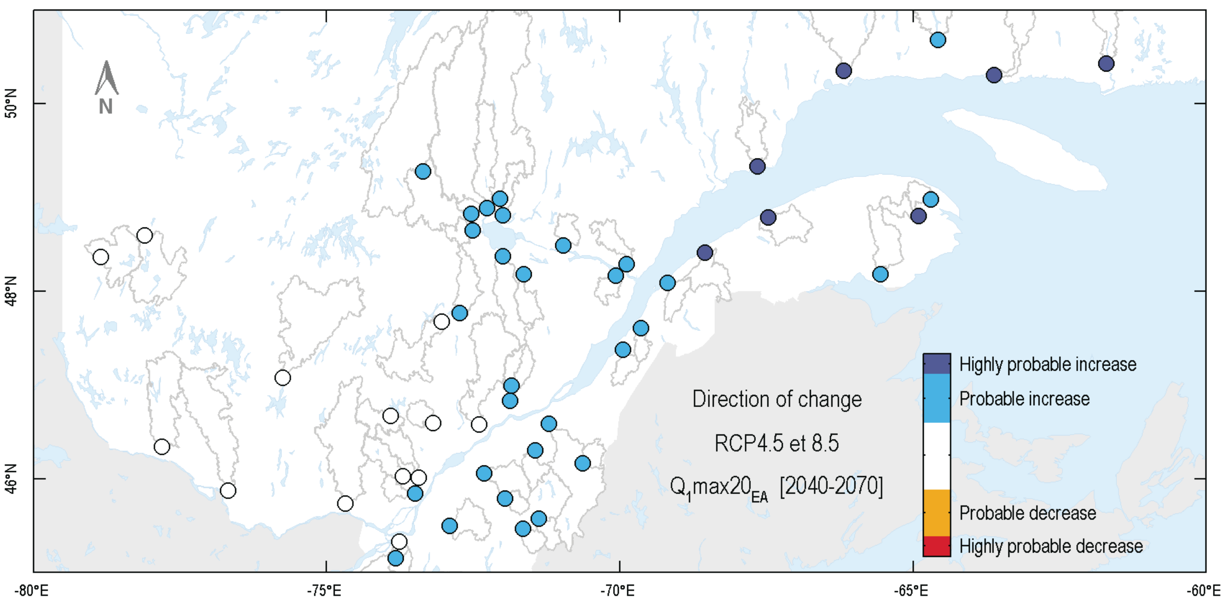


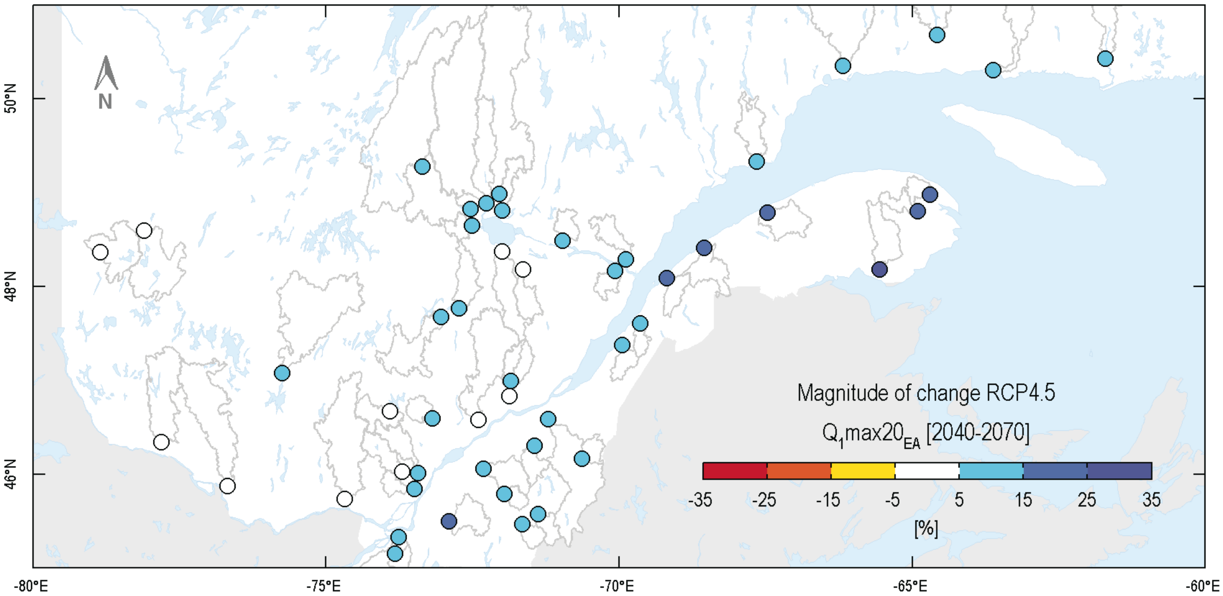
The Q_1max2_{EA} hydrological indicator corresponds to the annual maximum of the daily summer and autumn flow with a 2-year return period. For the 2050 horizon, projections describe a probable to highly probable increase in Q_1max2_{EA} in the Gaspésie and Côte-Nord regions in the order of +10% to +15% (RCP4.5) and that could reach +20% (RCP8.5). Projections describe a probable decrease in Q_1max2_{EA} at several sites in the extreme south of southern Québec in the order of -10% to -20%. Dispersion is estimated à ±11%. The confidence level is moderate for the direction of change and limited for magnitude and dispersion.

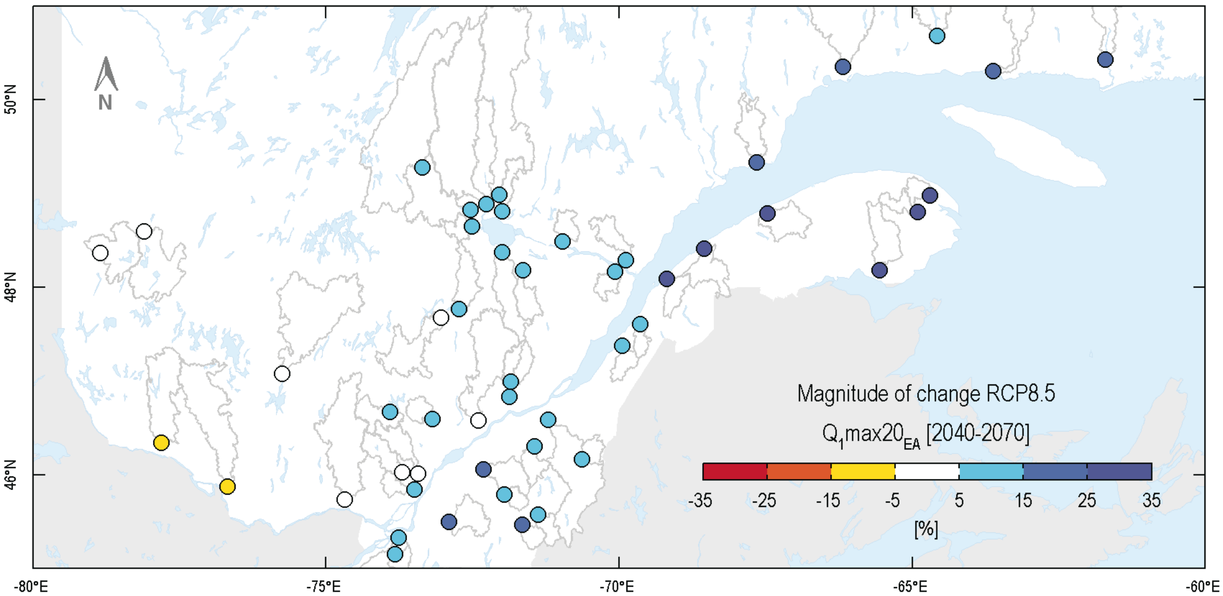
Summer and autumn high flow peak

Daily flow, 20-year return period





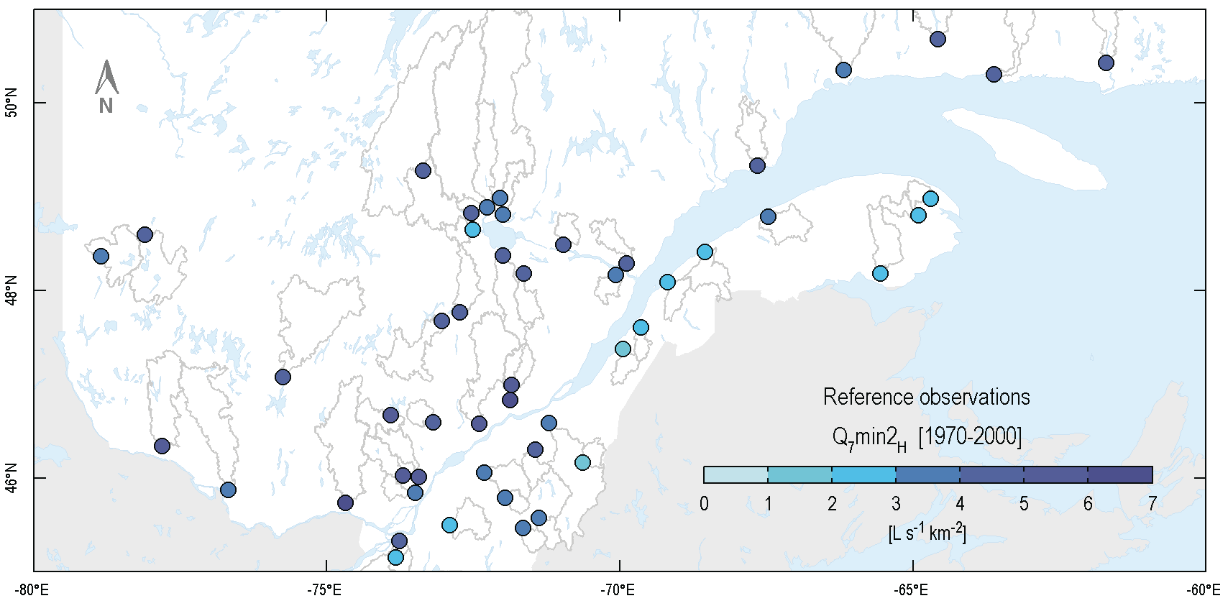


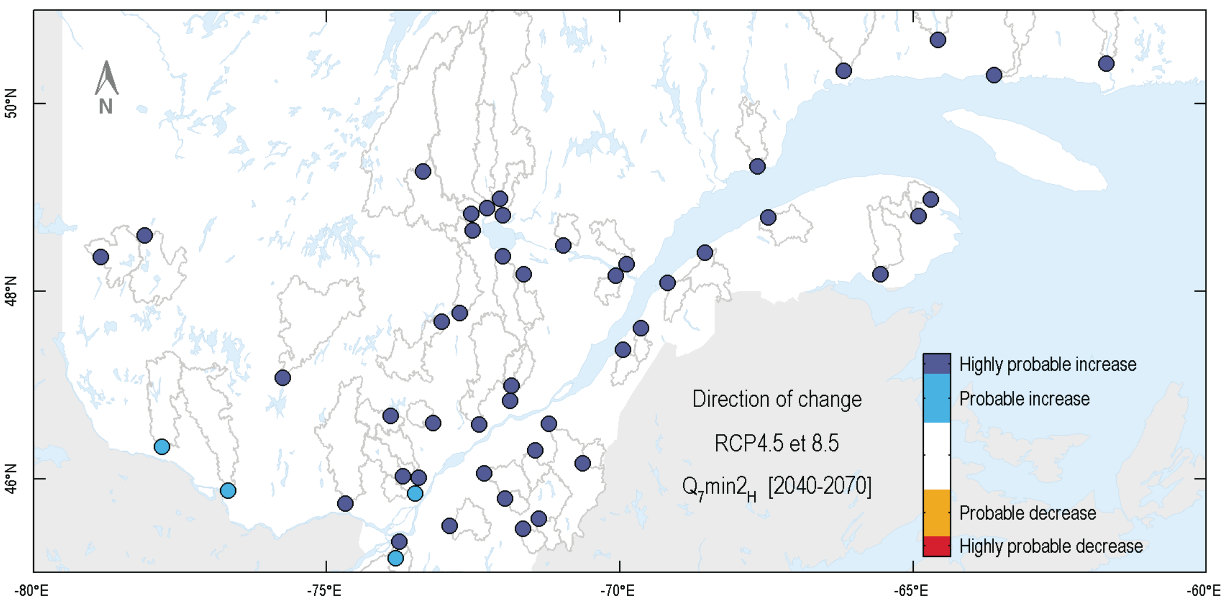


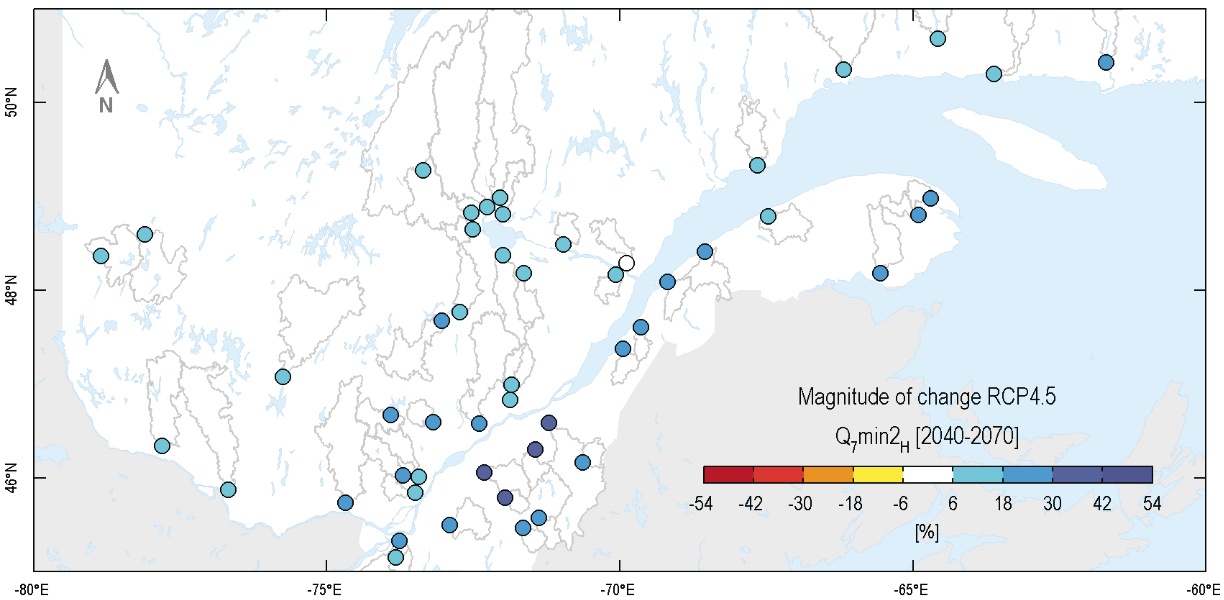
The Q_1max20_{EA} hydrological indicator corresponds to the annual maximum of the daily summer and autumn flow with a 20-year return period. For the 2050 horizon, projections describe a probable to highly probable increase in Q_1max20_{EA} over a large portion of eastern southern Québec in the order of +10% to +20% (RCP4.5) and that could reach +40% (RCP8.5). Dispersion is estimated at ±11%. The confidence level is moderate for the direction of change and limited for magnitude and dispersion.

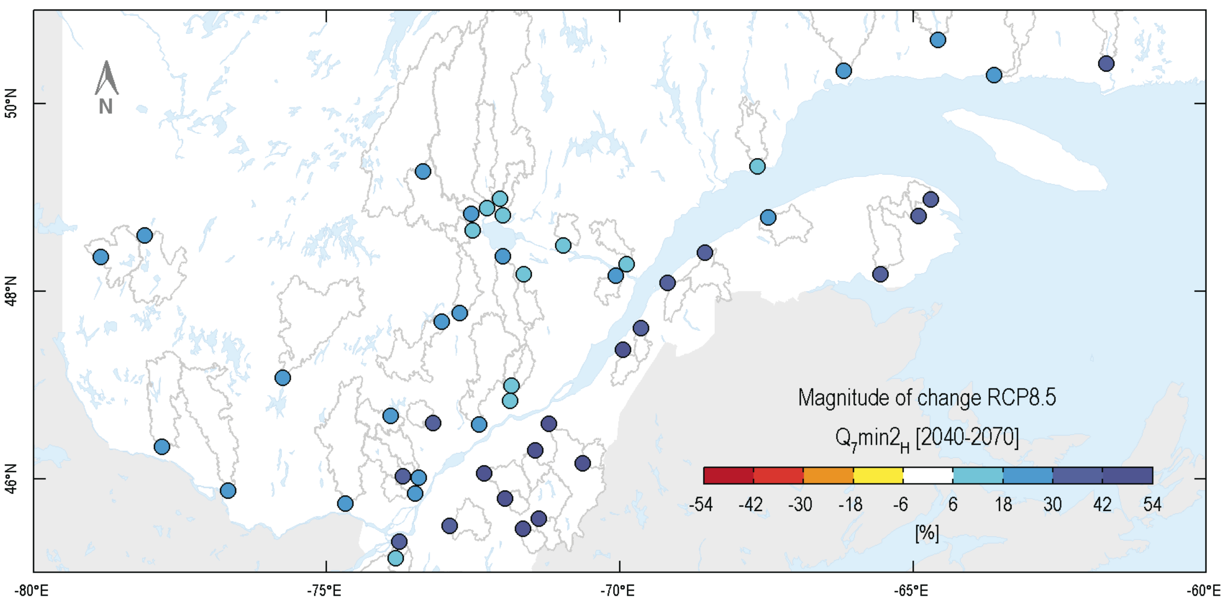
Winter low flow

7-day average flow, 2-year return period





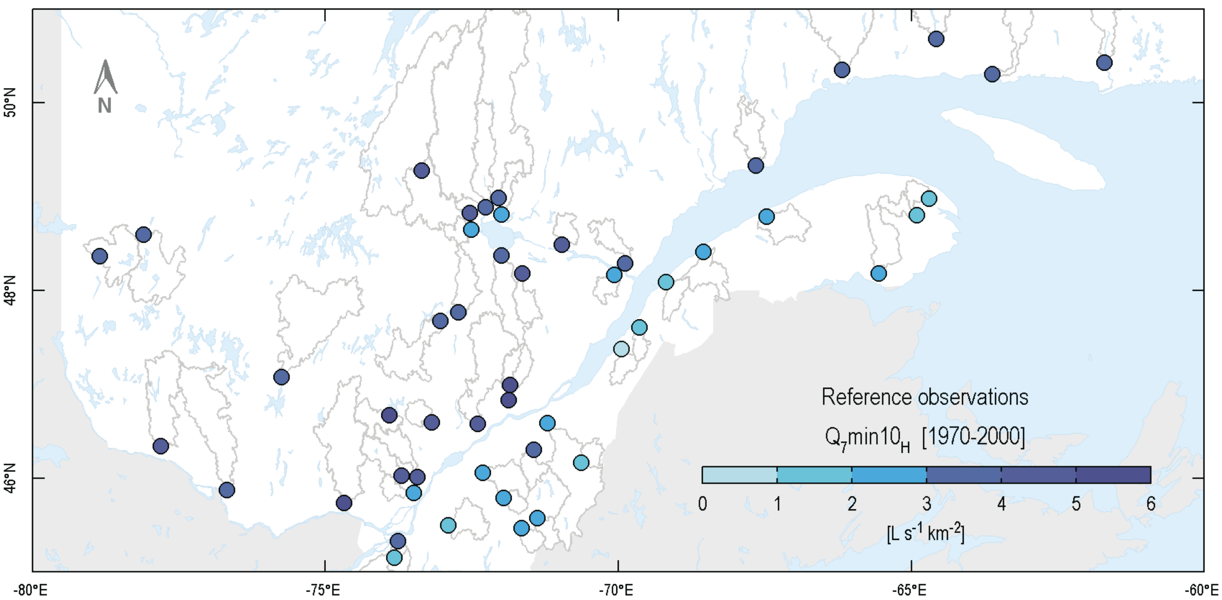


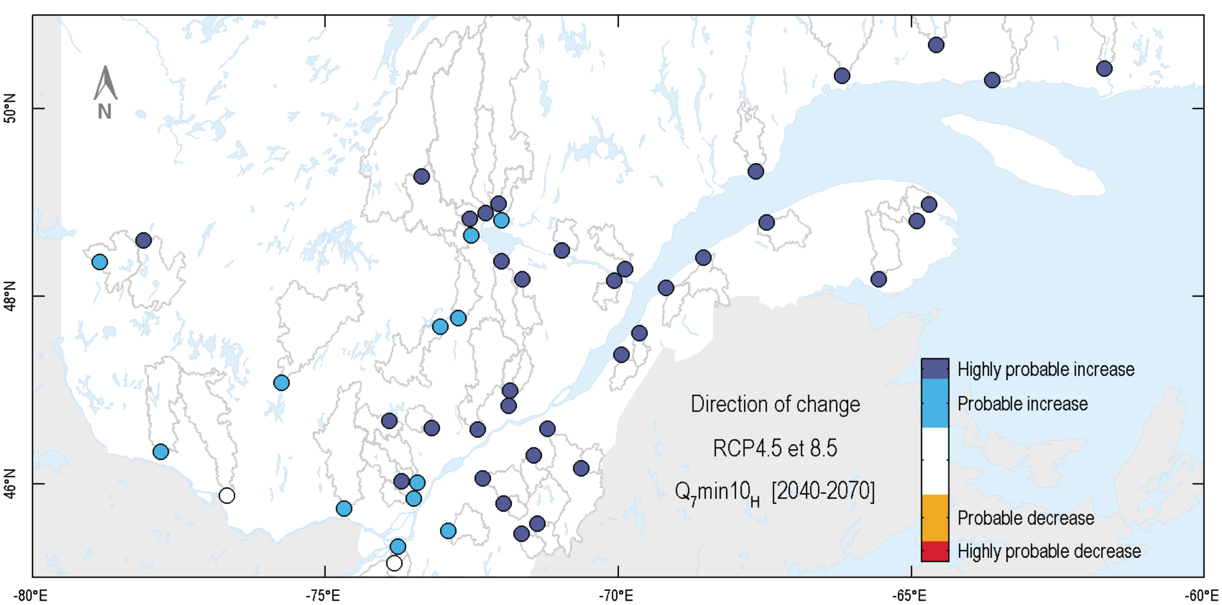


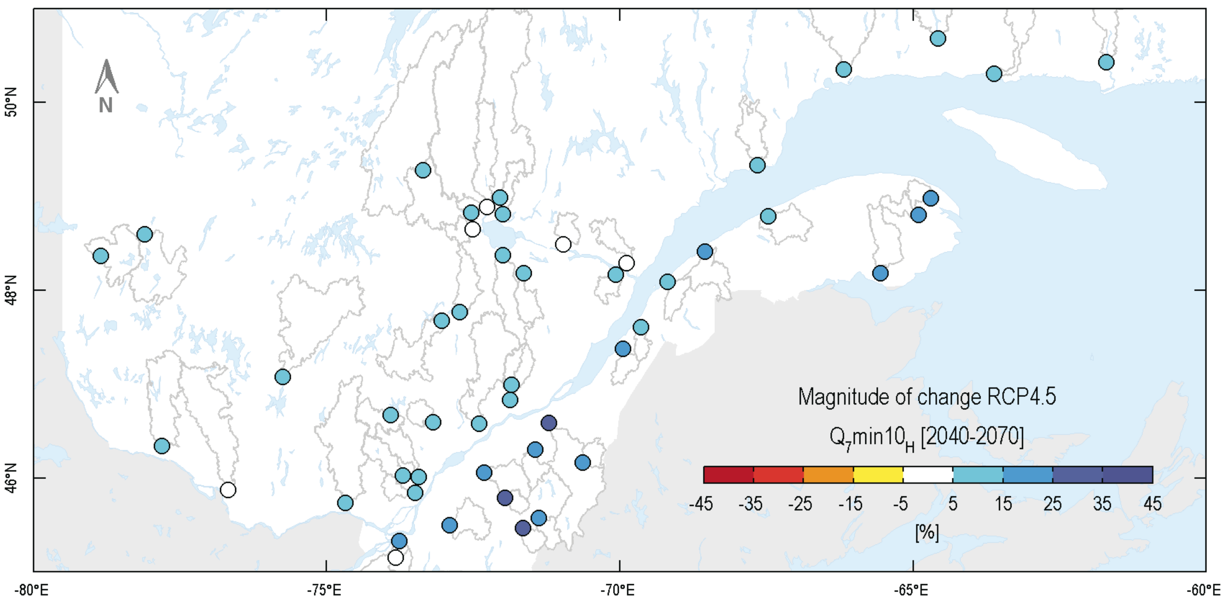
The Q_7min2_H hydrological indicator corresponds to the annual minimum of the 7 consecutive-day average winter flow with a 2-year return period. For the 2050 horizon, projections describe a highly probable increase in Q_7min2_H over a large portion of southern Québec in the order of +10% to +40% (RCP4.5) and that could reach +50% (RCP8.5). The increases are slightly greater south of the St. Lawrence River. Dispersion is estimated at ±8%. The confidence level is high for the direction of change and limited for magnitude and dispersion.

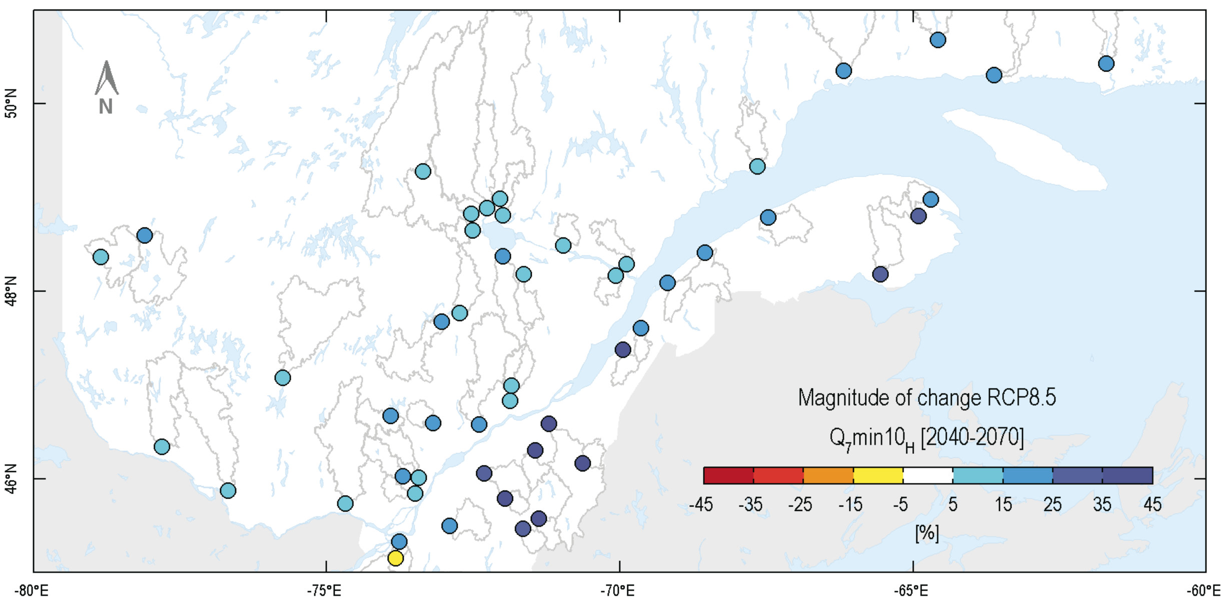
Winter low flow

7-day average flow, 10-year return period





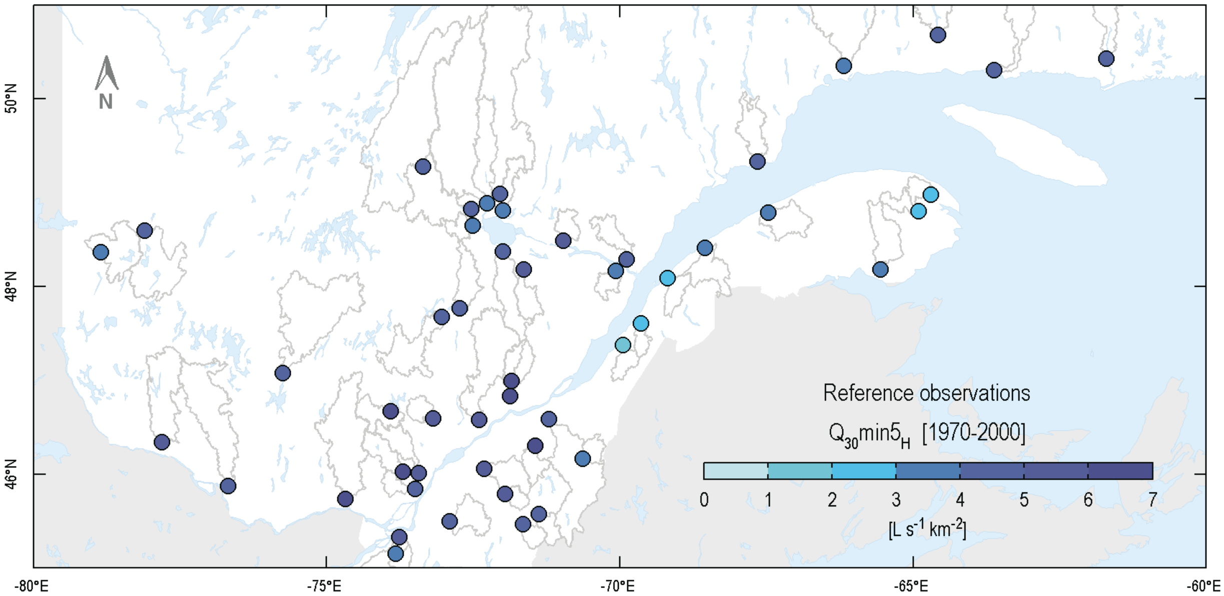


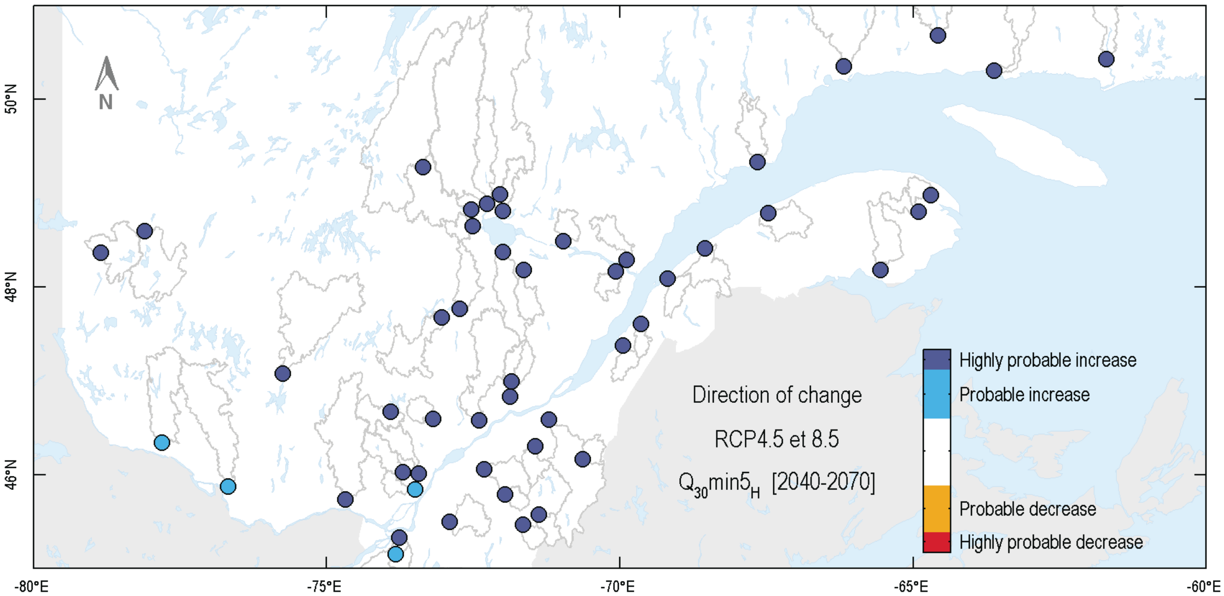


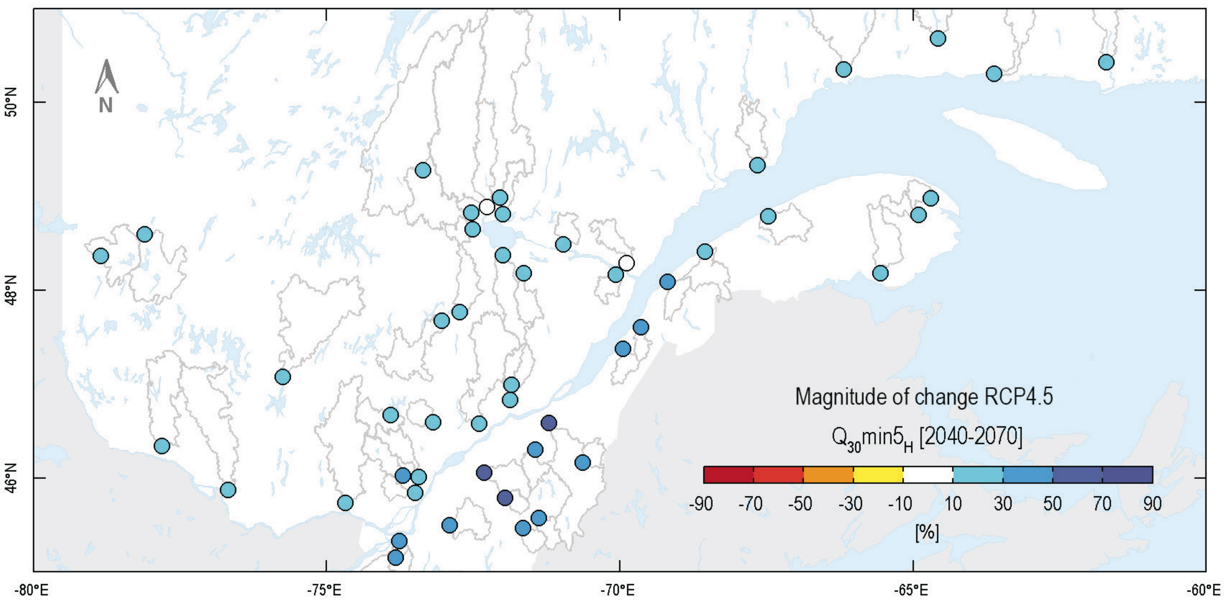
The Q_7min10_H hydrological indicator corresponds to the annual minimum of the 7 consecutive-day average winter flow with a 10-year return period. For the 2050 horizon, the projections describe a probable to highly probable increase in Q_7min10_H over a large portion of southern Québec in the order of +10% to +35% (RCP4.5) and that could reach +40% (RCP8.5). The increases are slightly greater to the south of the St. Lawrence River. Dispersion is estimated at ±8%. The confidence level is high for the direction of change and limited for magnitude and dispersion.

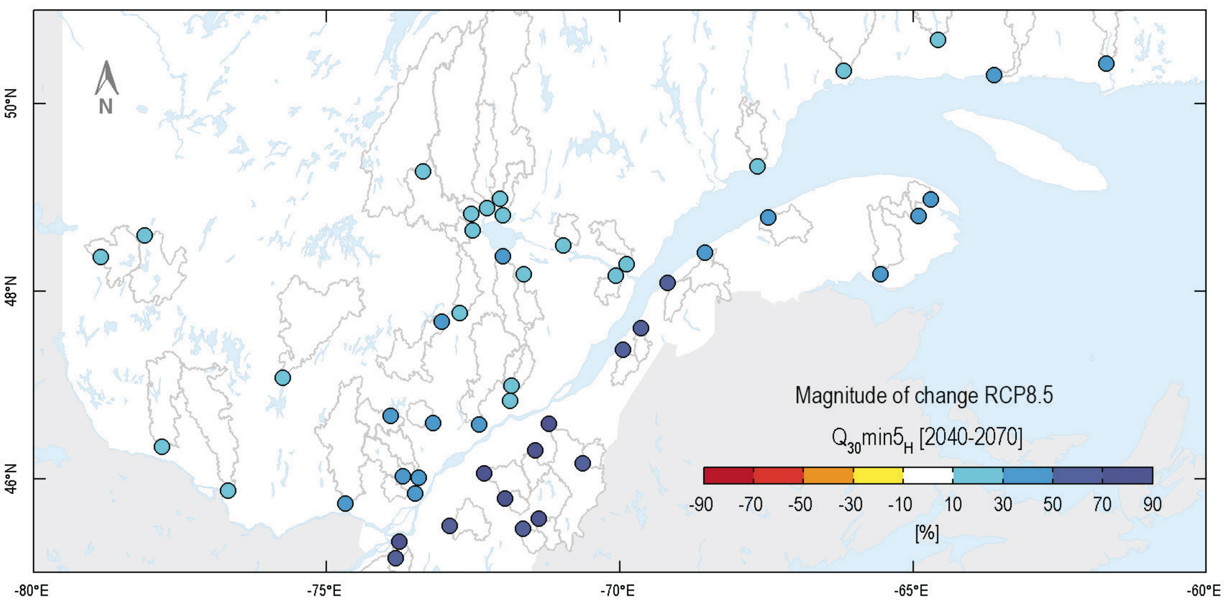
Winter low flow

30-day average flow, 5-year return period





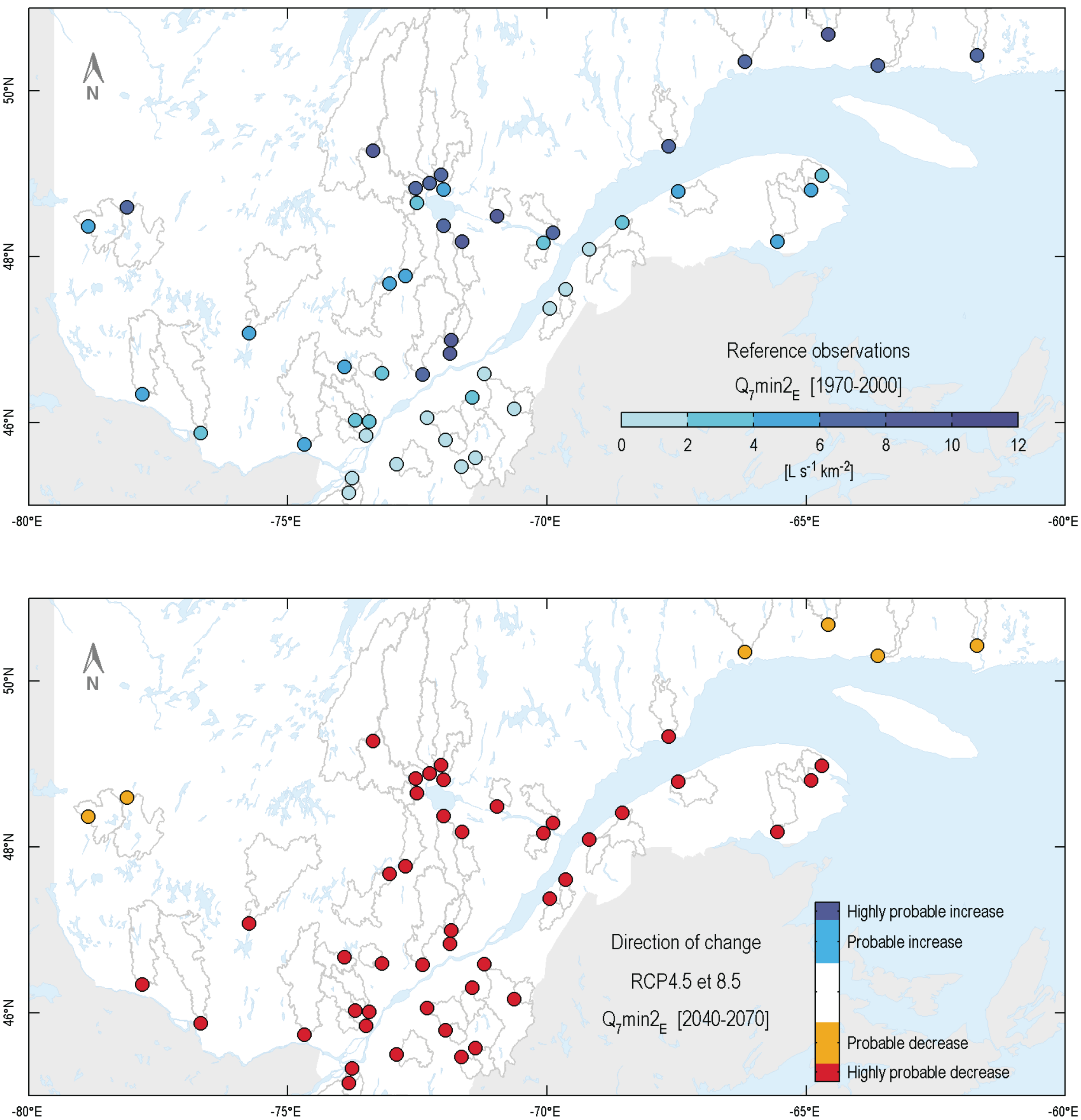


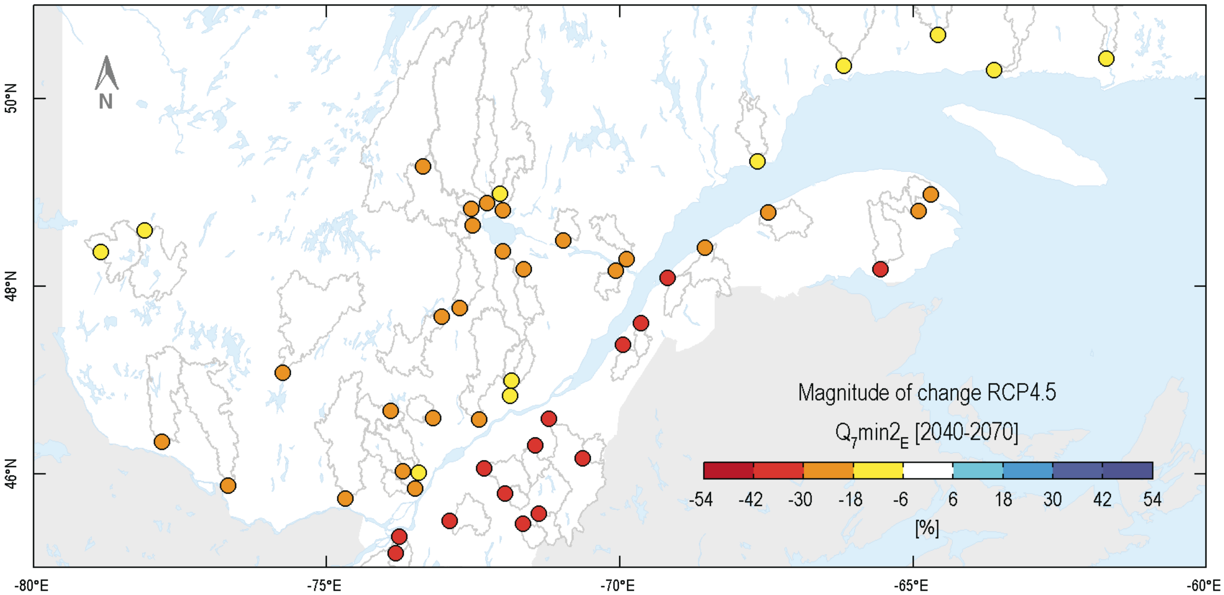


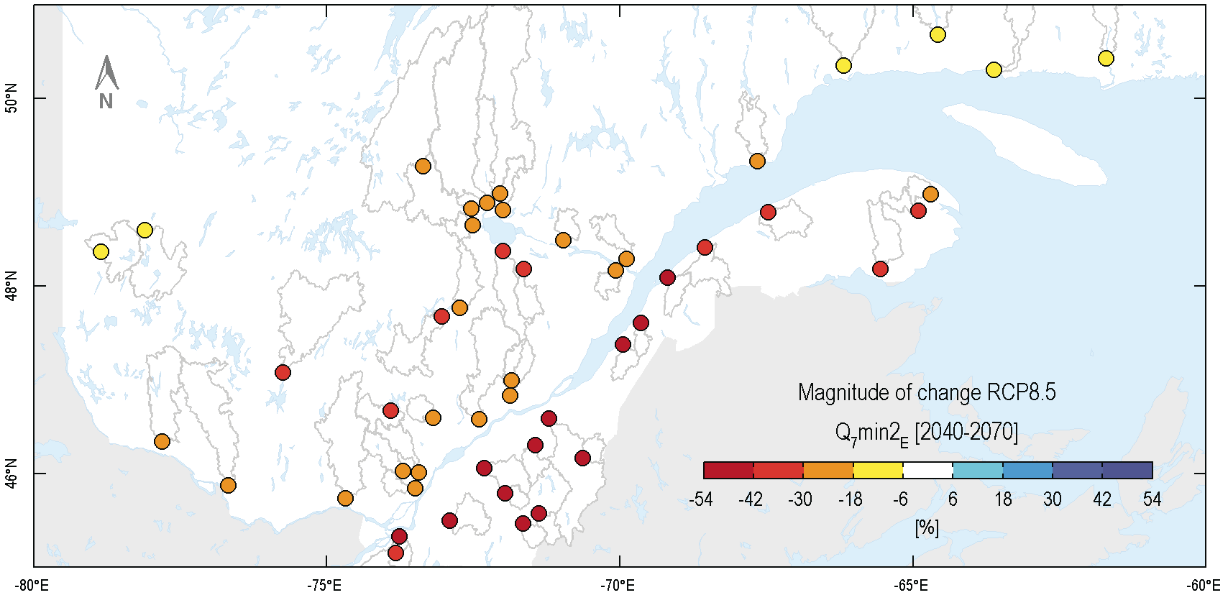
The $Q_{30}min5_H$ hydrological indicator corresponds to the annual minimum of the 30 consecutive-day average winter flow with a 5-year return period. For the 2050 horizon, the projections describe a highly probable increase in $Q_{30}min5_H$ on a large portion of southern Québec in the order of +20% to +50% (RCP4.5) and that could reach +80% (RCP8.5). The increases are slightly greater to the south of the St. Lawrence River. Dispersion is estimated at ±11%. The confidence level is high for the direction of change and limited for magnitude and dispersion.

Summer low flow

7-day average flow, 2-year return period



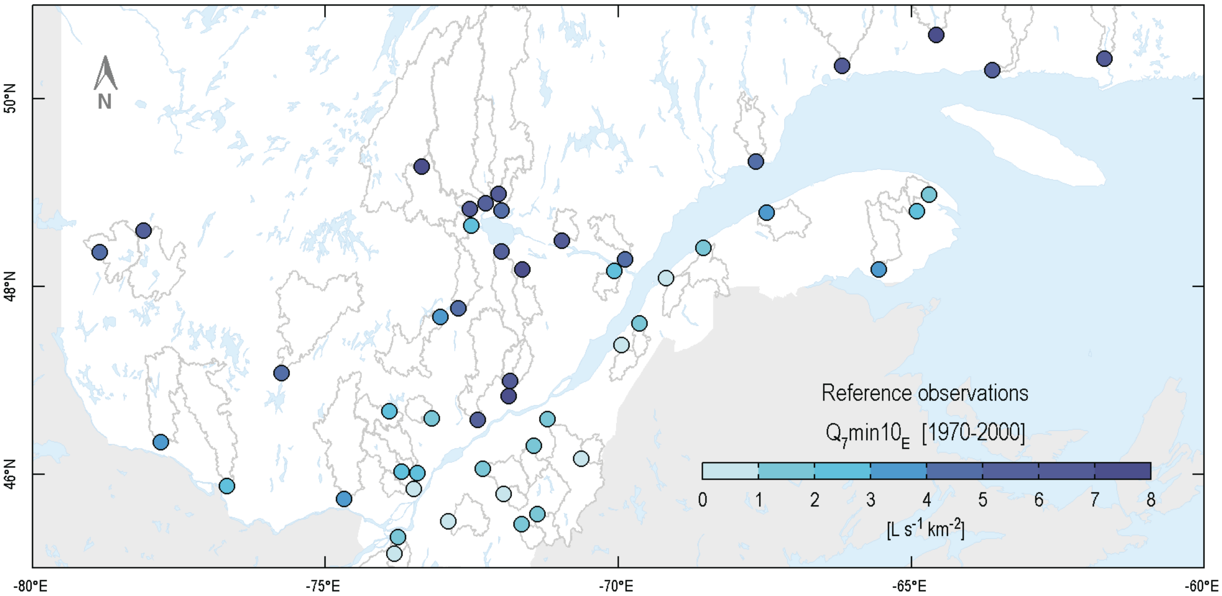


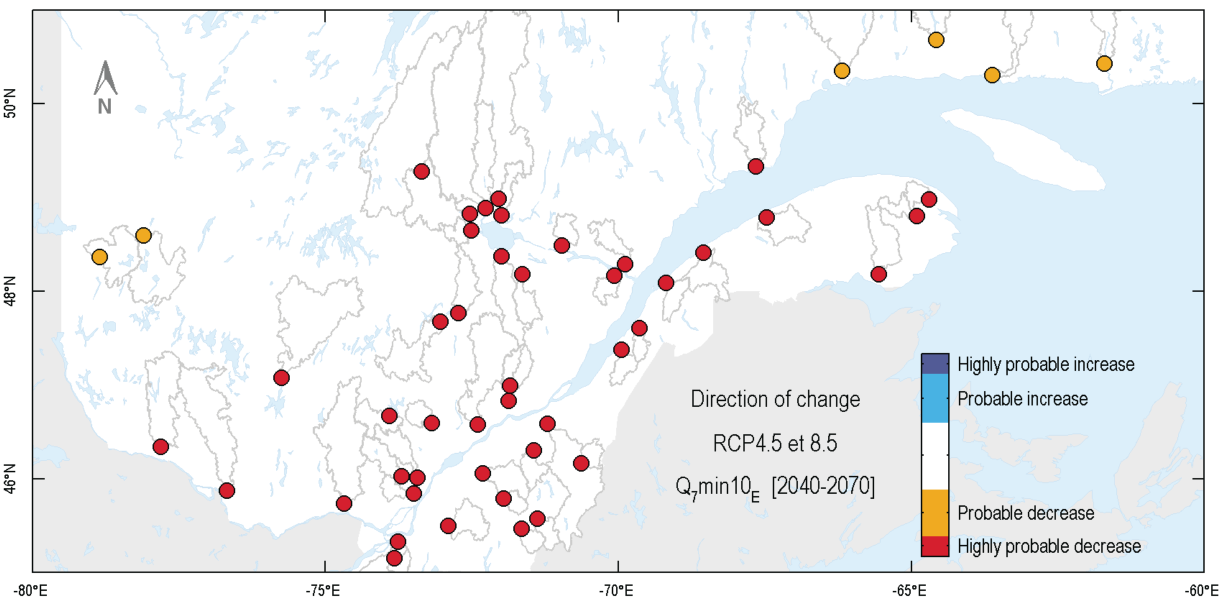


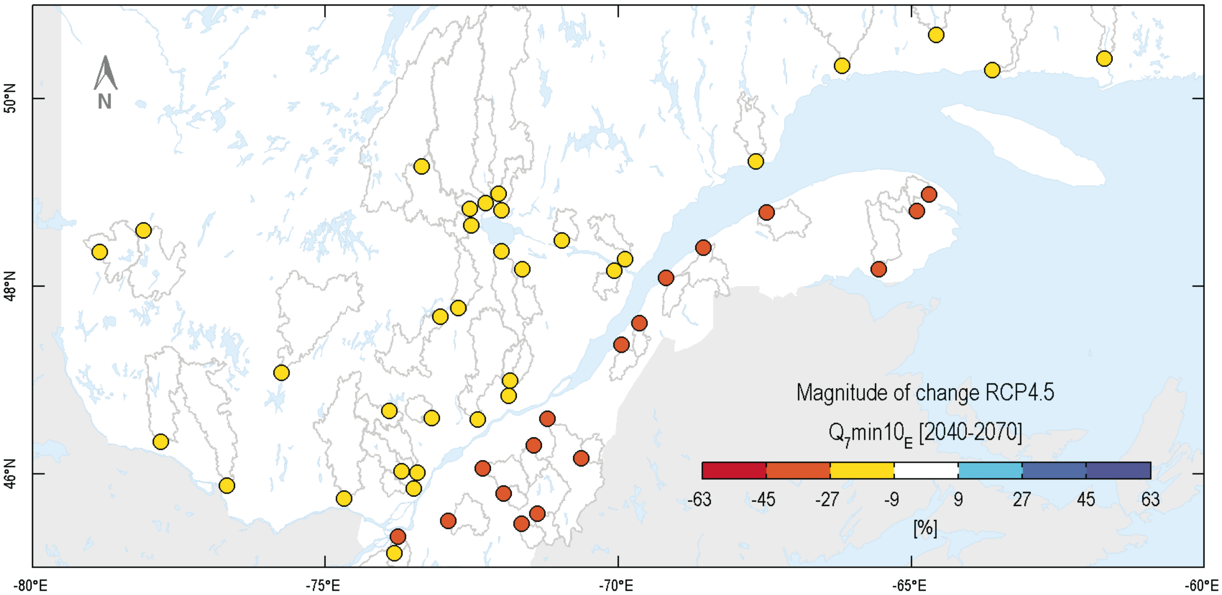
The Q_7min2_E hydrological indicator corresponds to the annual minimum of the 7 consecutive-day average summer flow with a 2-year return period. For the 2050 horizon, the projections describe a highly probable decrease in Q_7min2_E throughout southern Québec in the order of -10% to -40% (RCP4.5) and that could reach -50% (RCP8.5). The decreases will be slightly greater to the south of the St. Lawrence River. Dispersion is estimated à ±8%. The confidence level is high for the direction of change and limited for magnitude and dispersion.

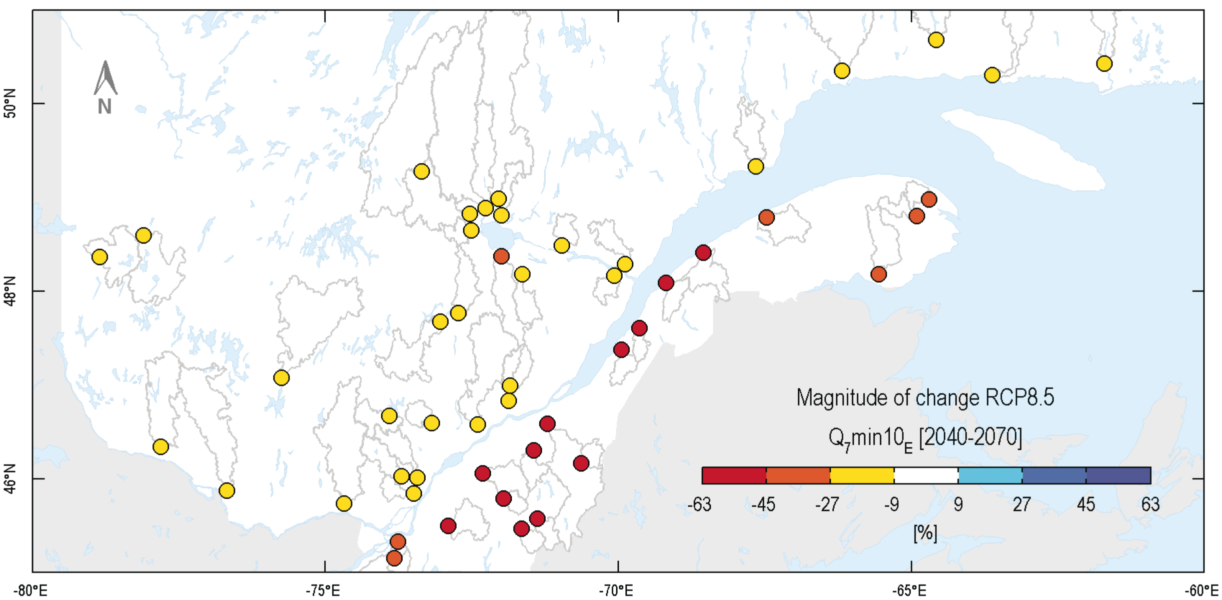
Summer low flow

7-day average flow, 10-year return period





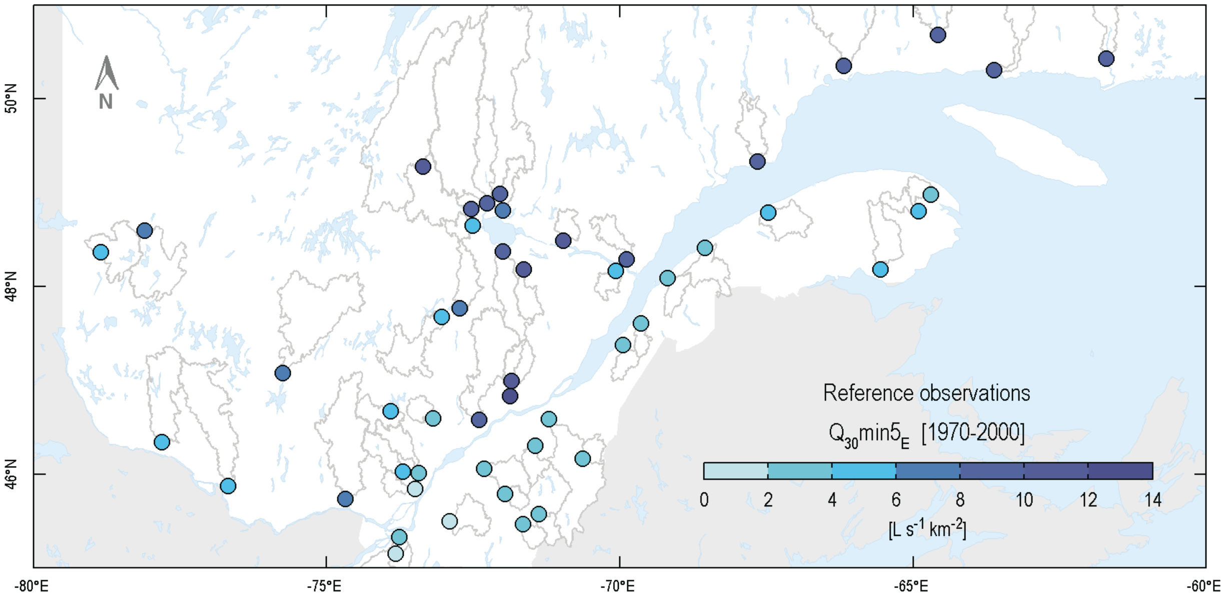


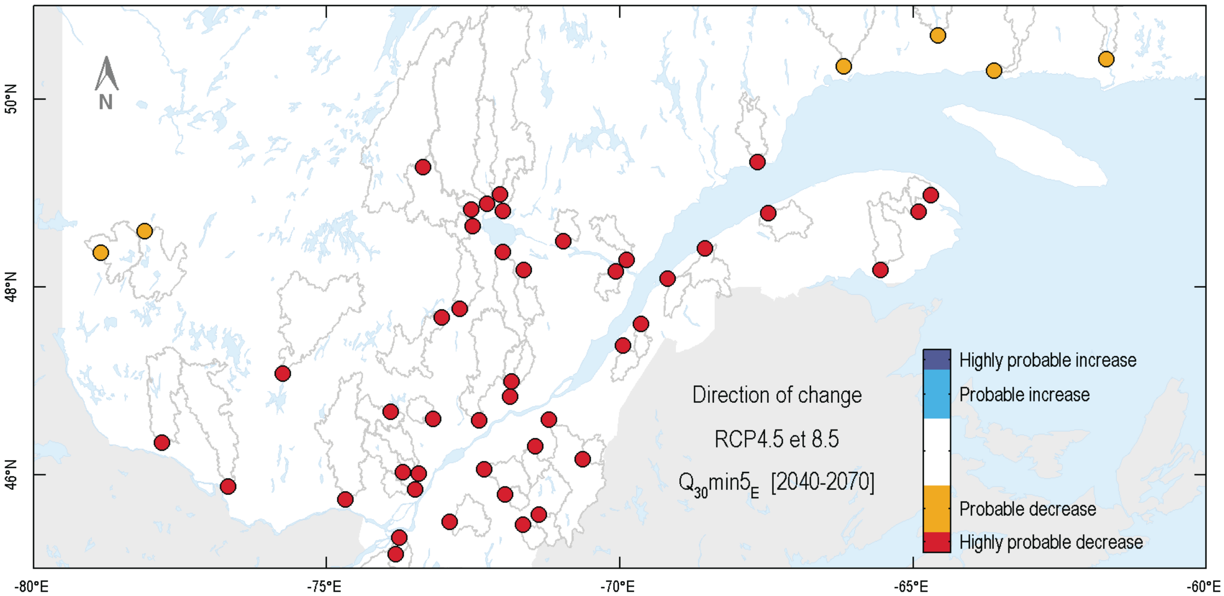


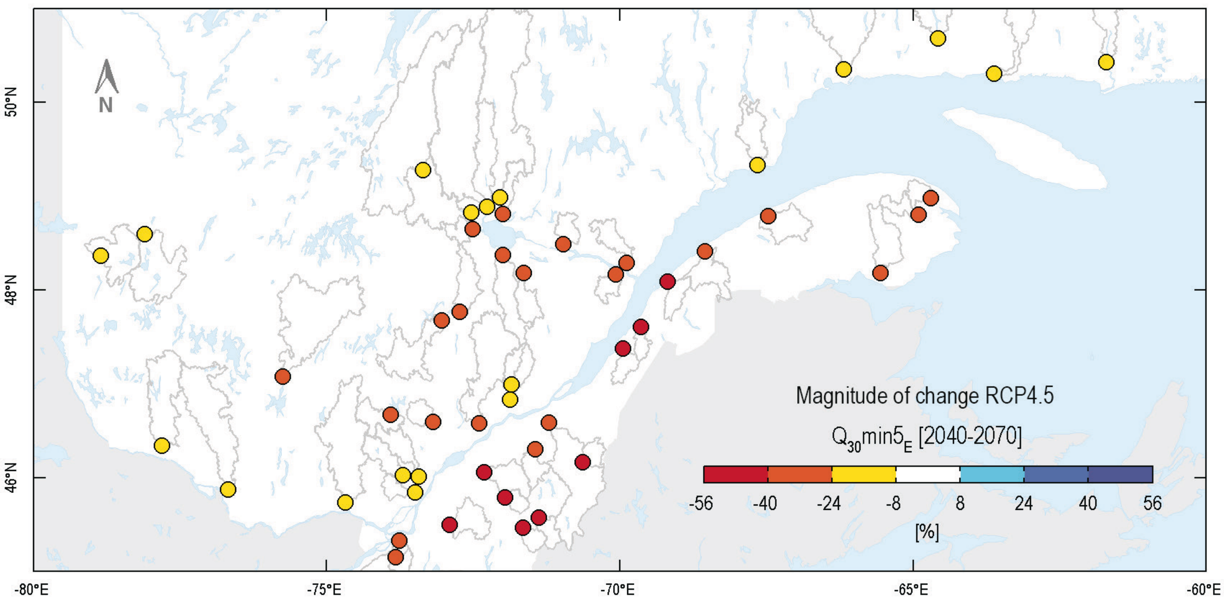
The Q_7min10_E hydrological indicator corresponds to the annual minimum of the 7 consecutive-day average summer flow with a 10-year return period. For the 2050 horizon, the projections describe a highly probable decrease in Q_7min10_E throughout southern Québec in the order of -10% to -45% (RCP4.5) and that could reach -60% (RCP8.5). The decreases are greater to the south of the St. Lawrence River. Dispersion is estimated à ± 8%. The confidence level is high for the direction of change and limited for magnitude and dispersion.

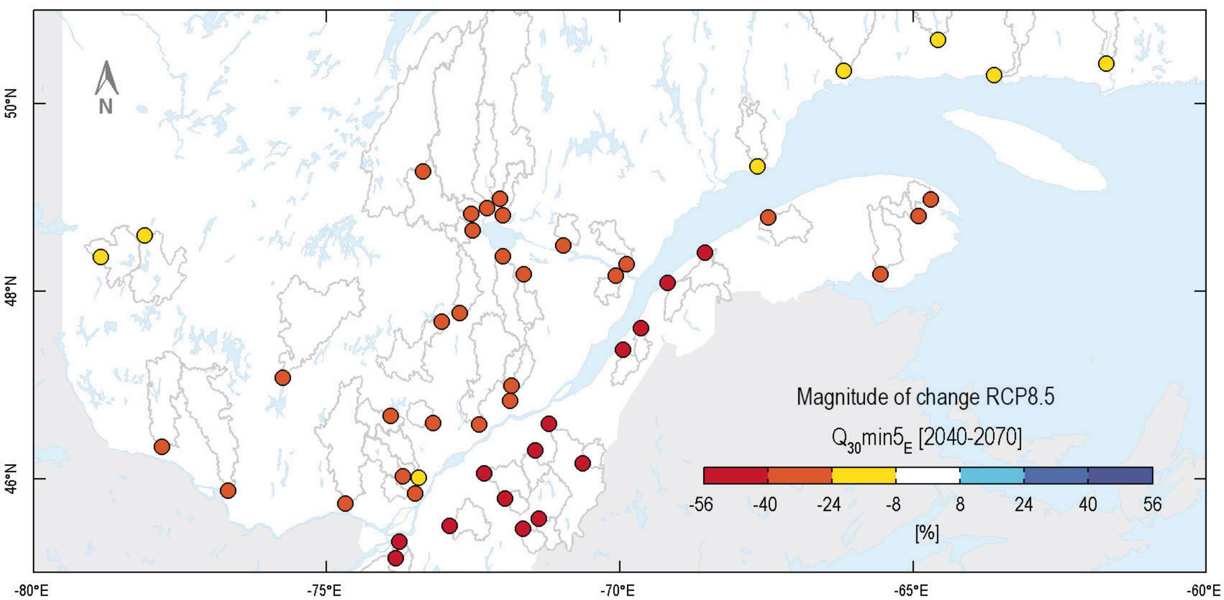
Summer low flow

30-day average flow, 5-year return period





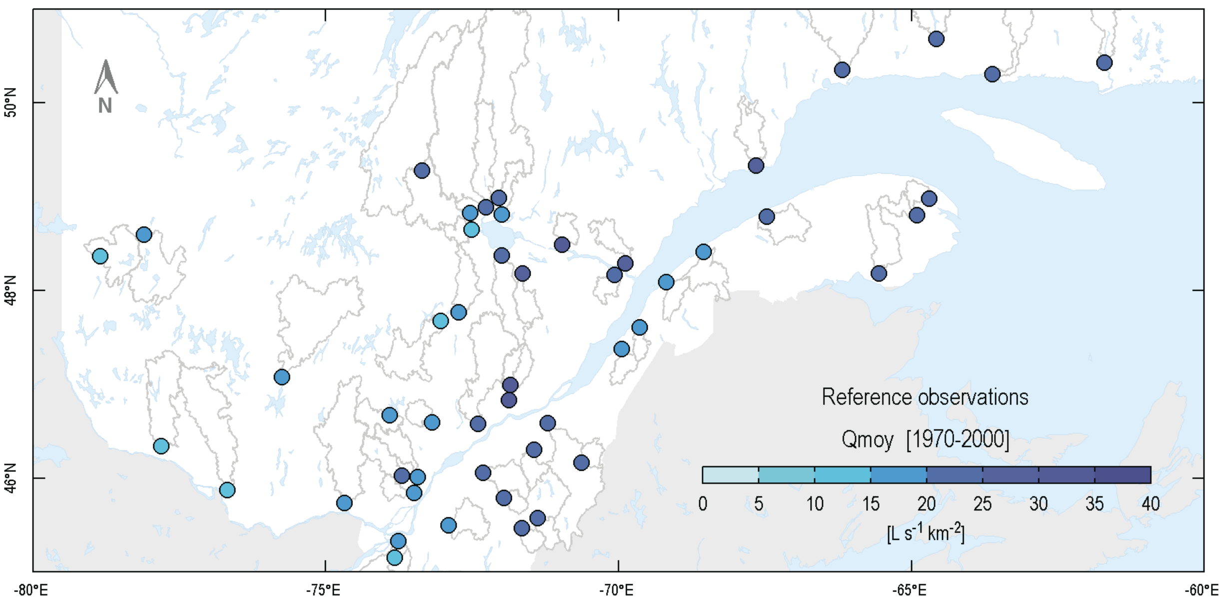


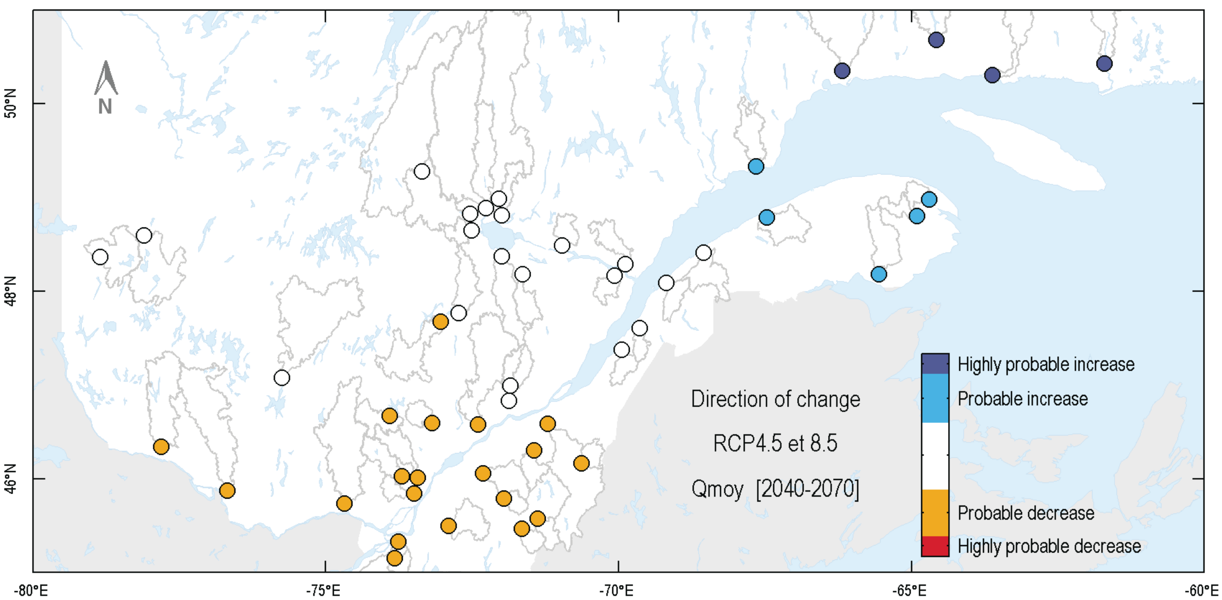


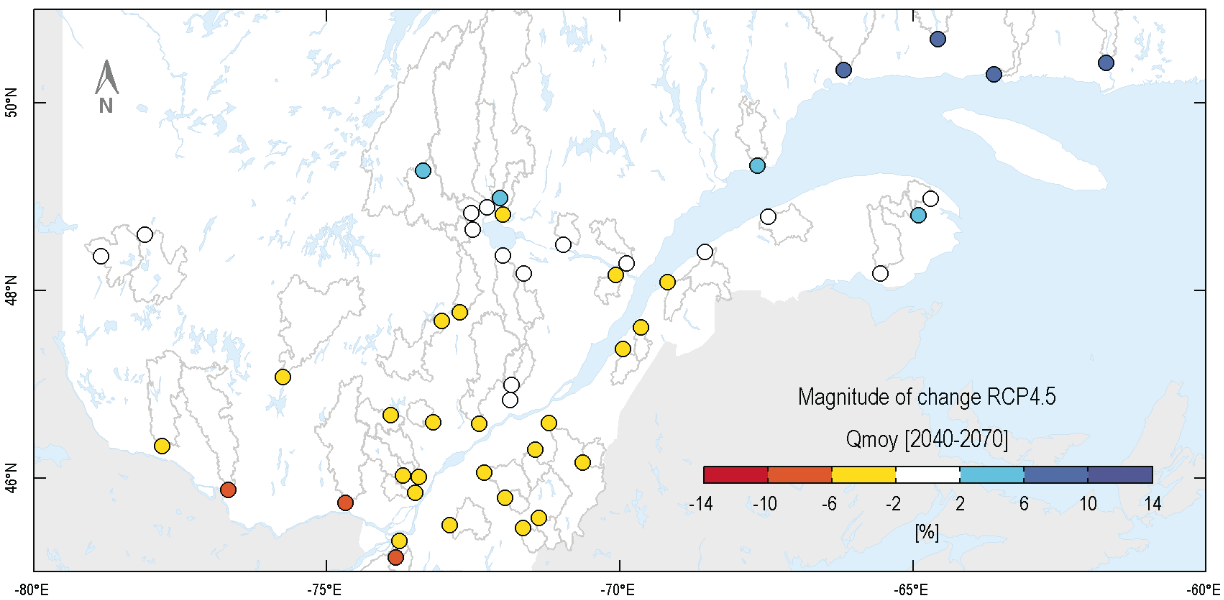
The $Q_{30}min5_E$ hydrological indicator corresponds to the annual minimum of the 30 consecutive-day average summer flow with a 5-year return period. For the 2050 horizon, the projections describe a highly probable decrease in $Q_{30}min5_E$ throughout southern Québec in the order of -10% to -45% (RCP4.5) and that could reach -50% (RCP8.5). The decreases are slightly greater to the south of the St. Lawrence River. Dispersion is estimated at ±9%. The confidence level is high for the direction of change and limited for magnitude and dispersion.

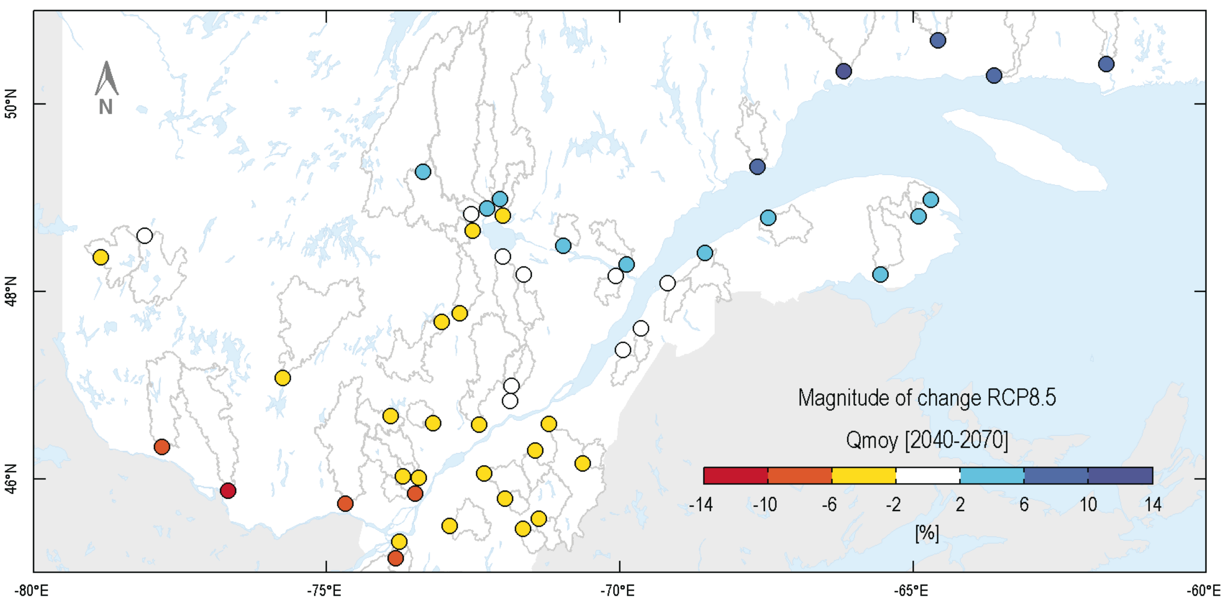
Annual mean flow

Average annual flow





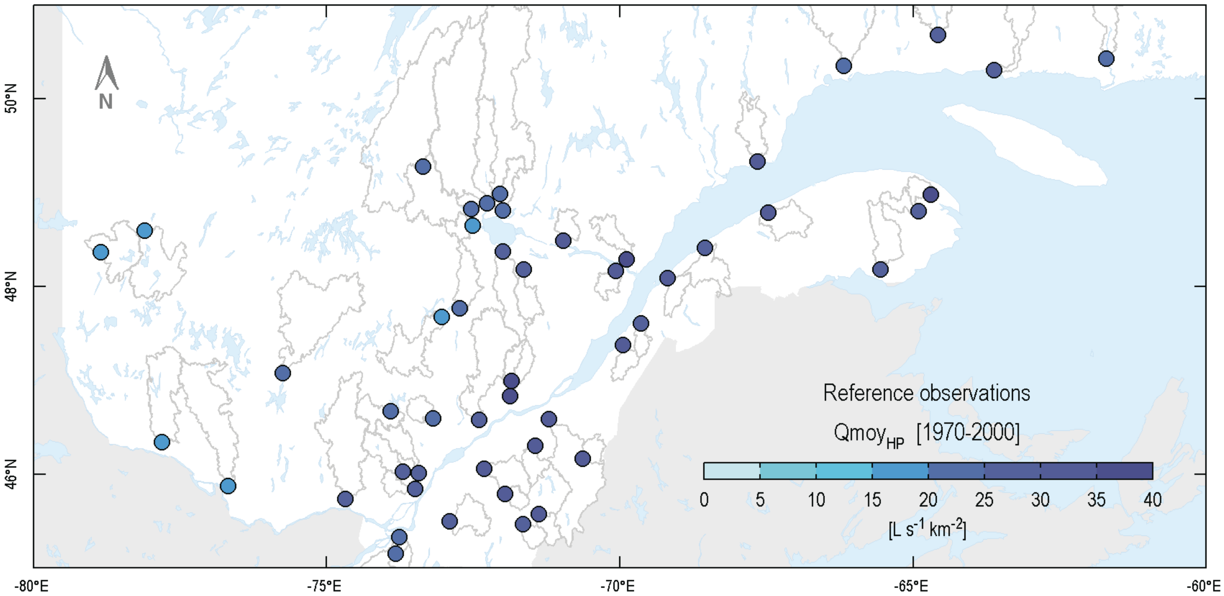


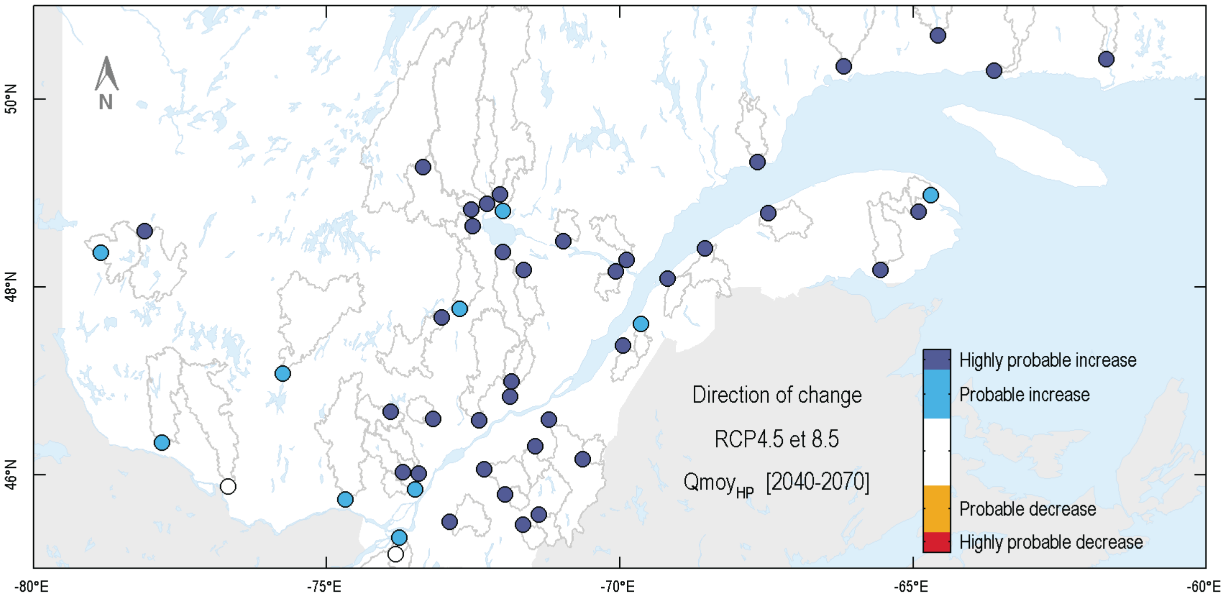


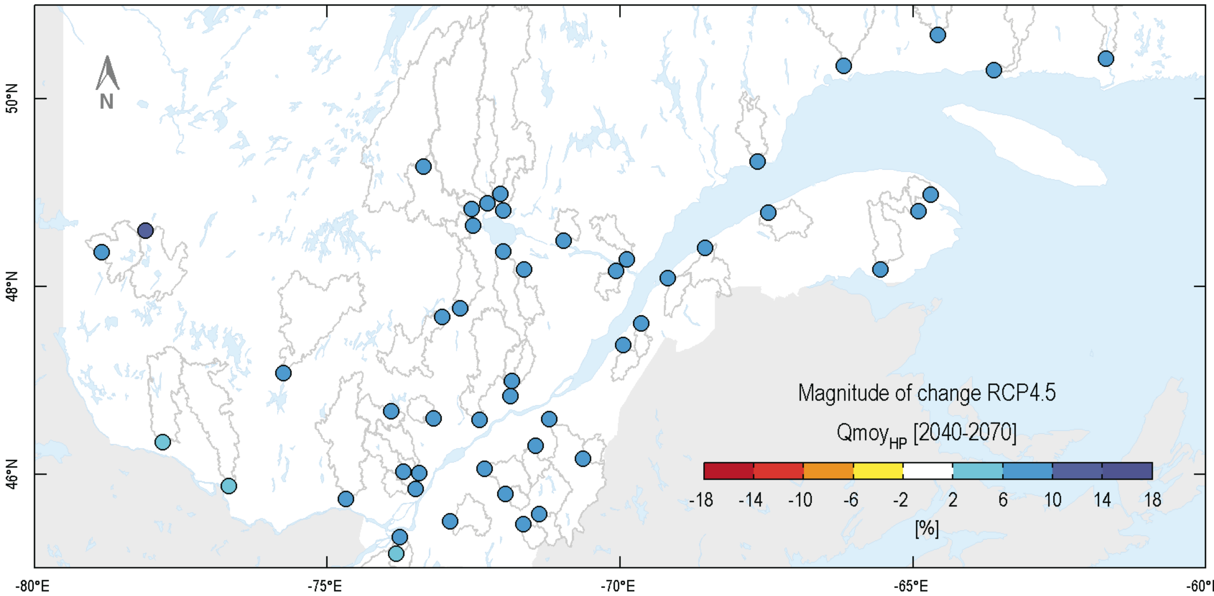
The Qmoy hydrological indicator corresponds to average annual flow. For the 2050 horizon, projections describe a probable decrease in Qmoy in southernmost Québec in the order of -2% to -8% (RCP4.5) and that could reach -12% (RCP8.5). Projections describe a probable to highly probable increase in Qmoy for eastern southern Québec in the order of +2% to +8% (RCP4.5) and that could reach +10% (RCP8.5). Dispersion is estimated at an average of ±6%. The confidence level is moderate for the direction, magnitude and dispersion of change.

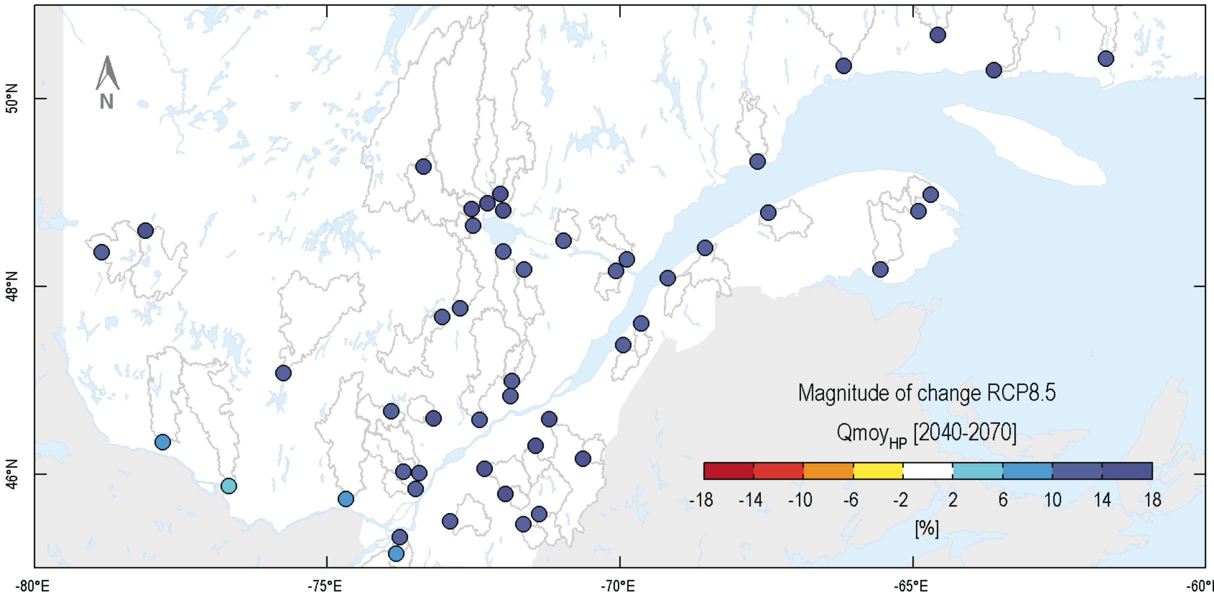
Winter/spring mean flow

Average seasonal flow





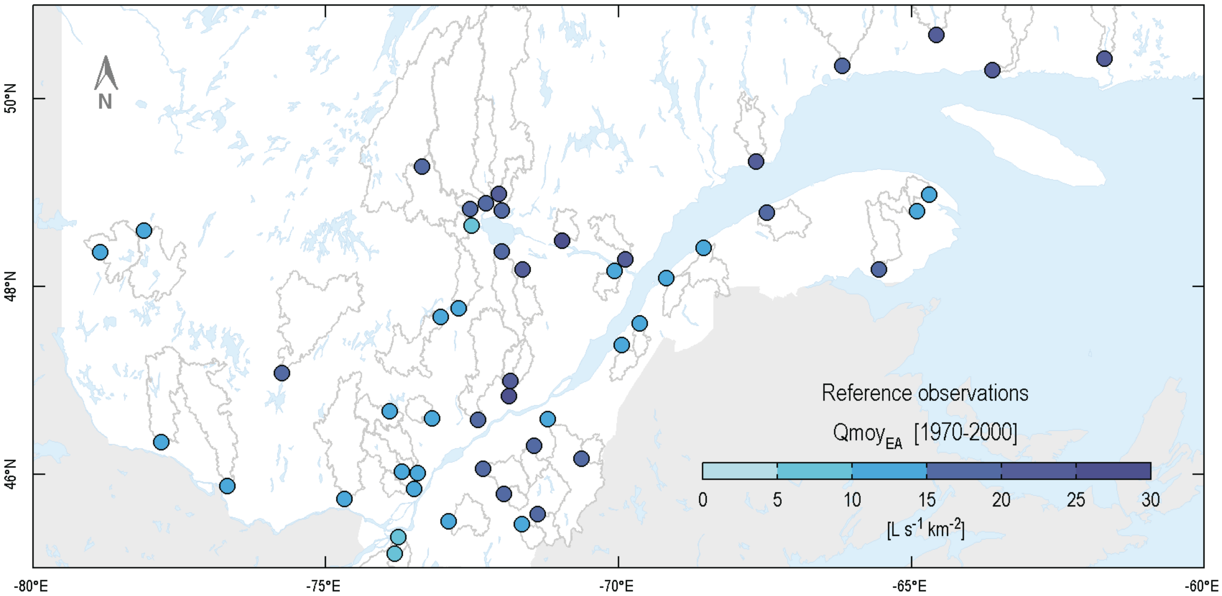


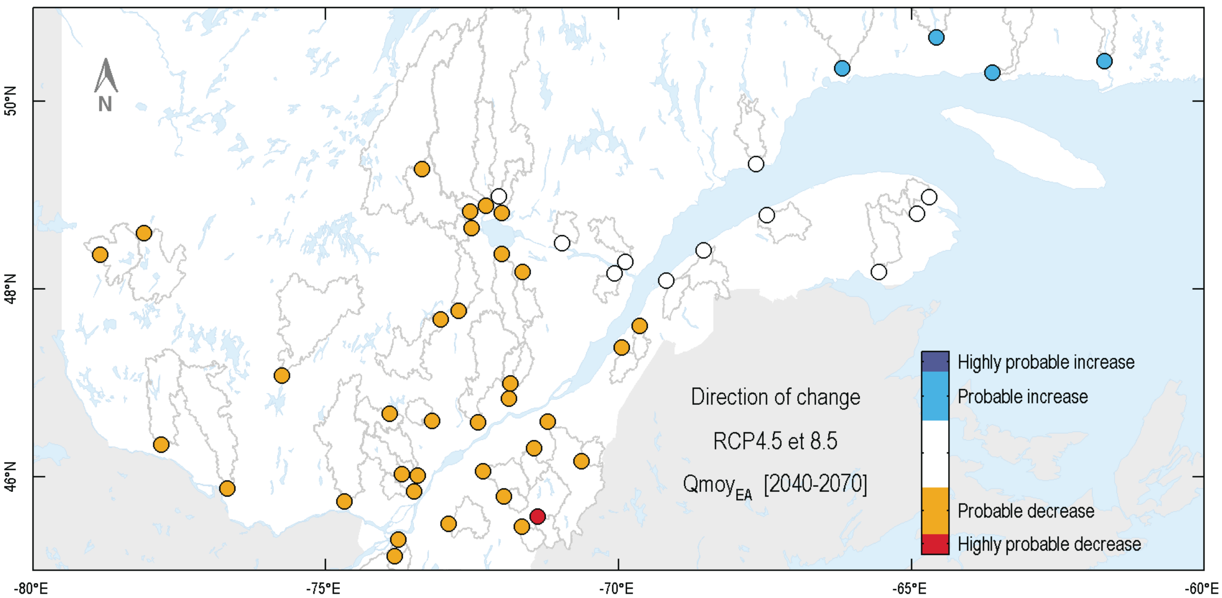


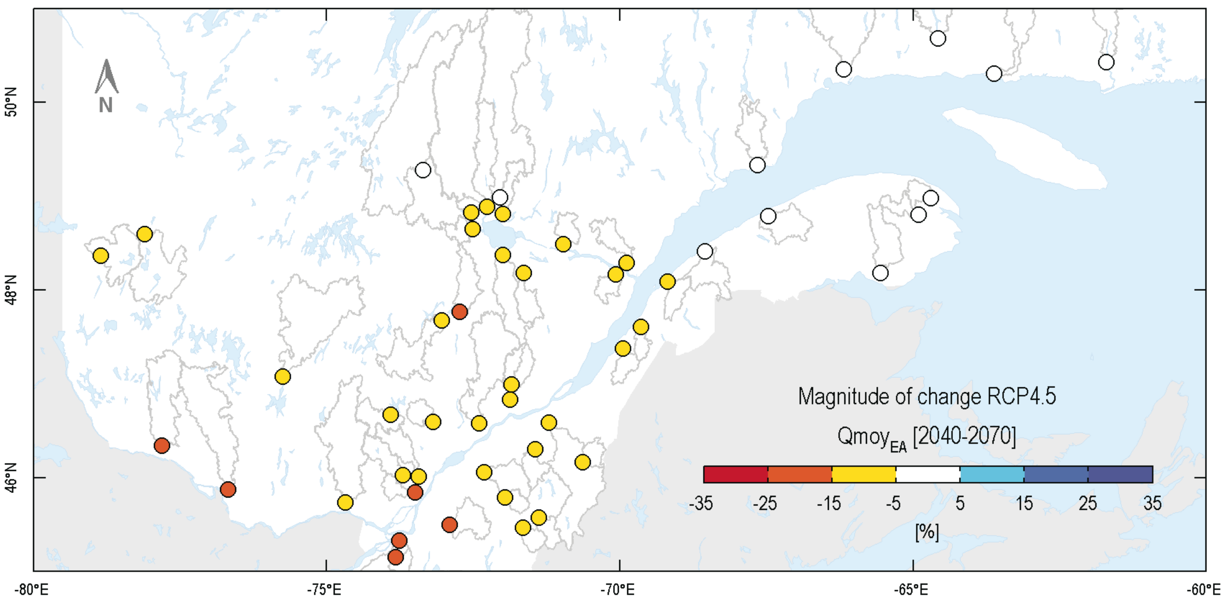
The $Qmoy_{HP}$ hydrological indicator corresponds to average winter/spring flow. For the 2050 horizon, projections describe a probable to highly probable increase in $Qmoy_{HP}$ over a large portion of southern Québec in the order of +5% to +10% (RCP4.5) and that could reach +15% (RCP8.5). Dispersion is estimated at an average of ±5%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

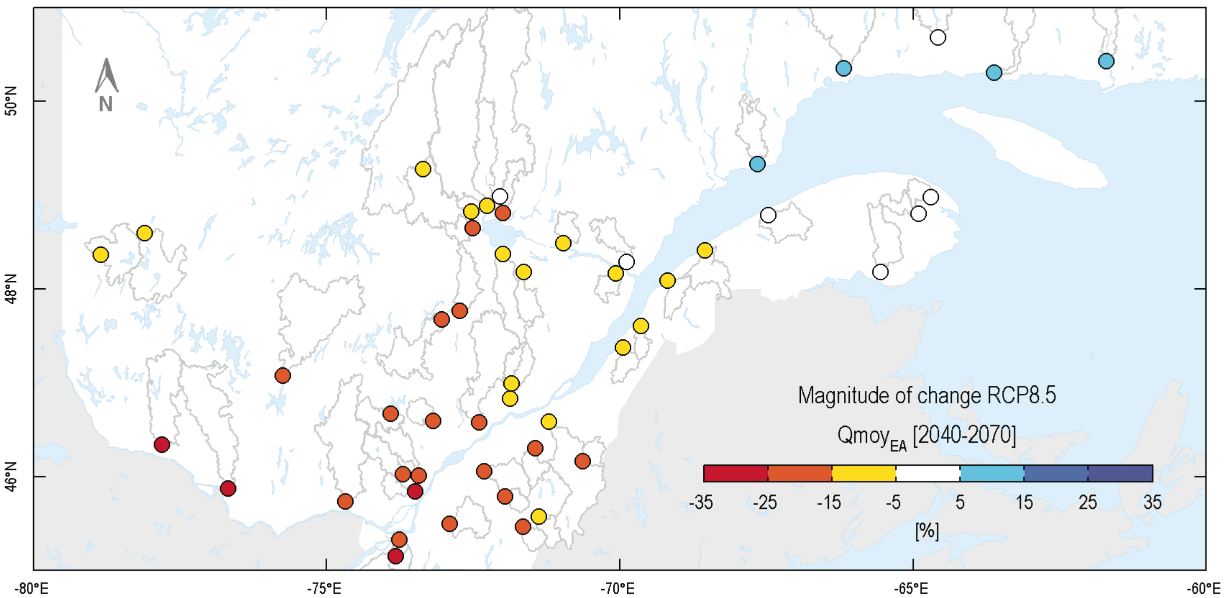
Summer and autumn mean flow

Average seasonal flow





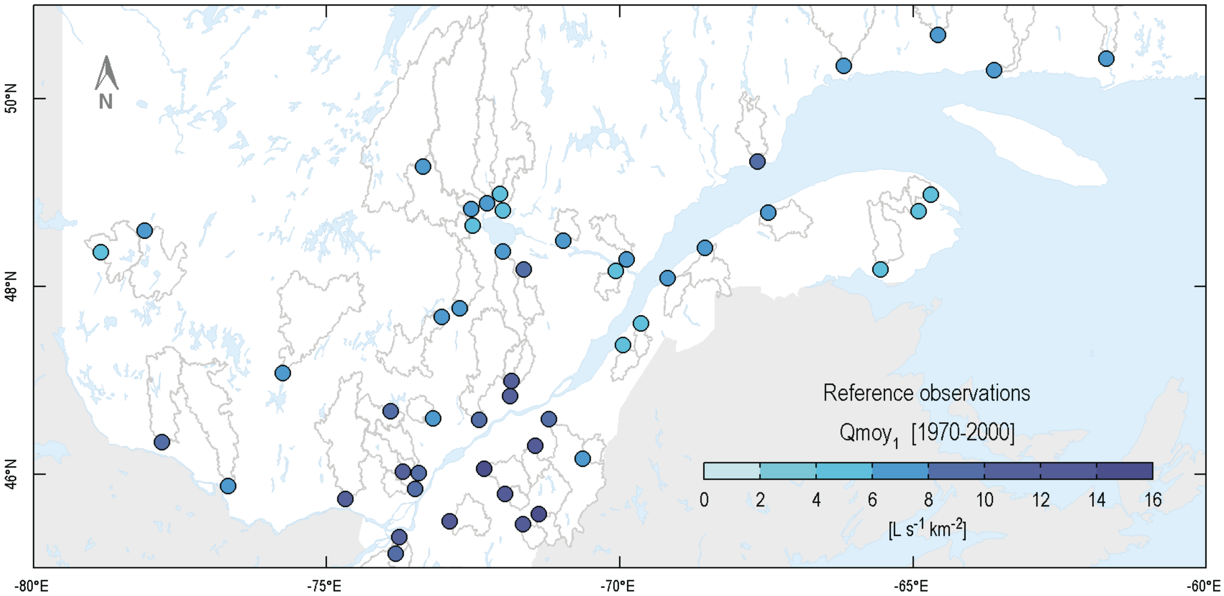


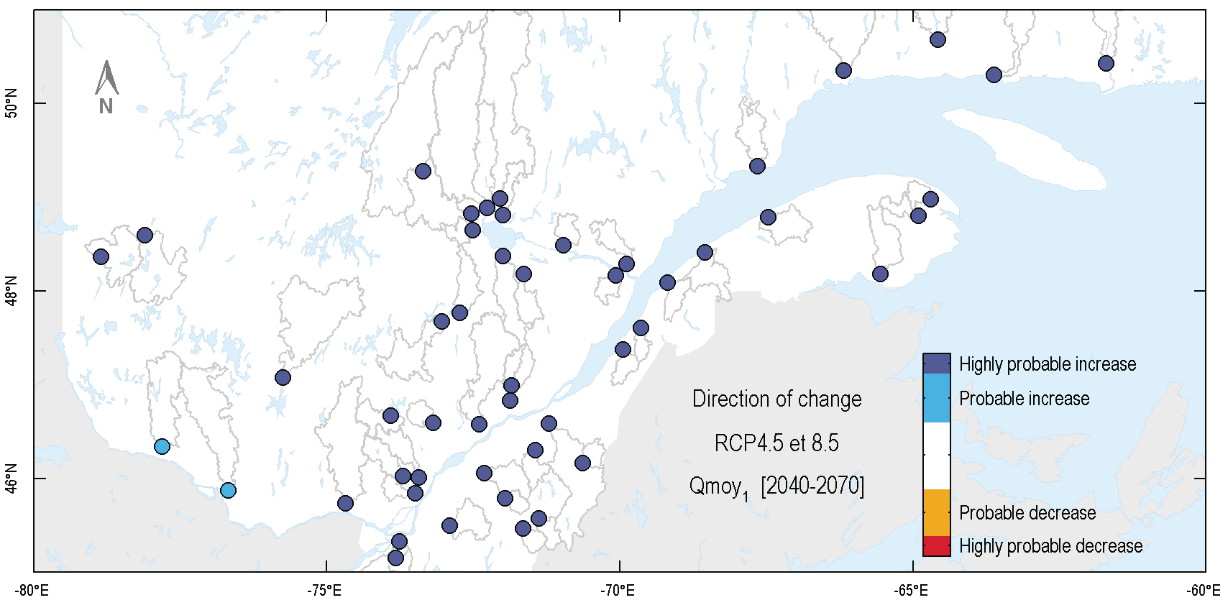


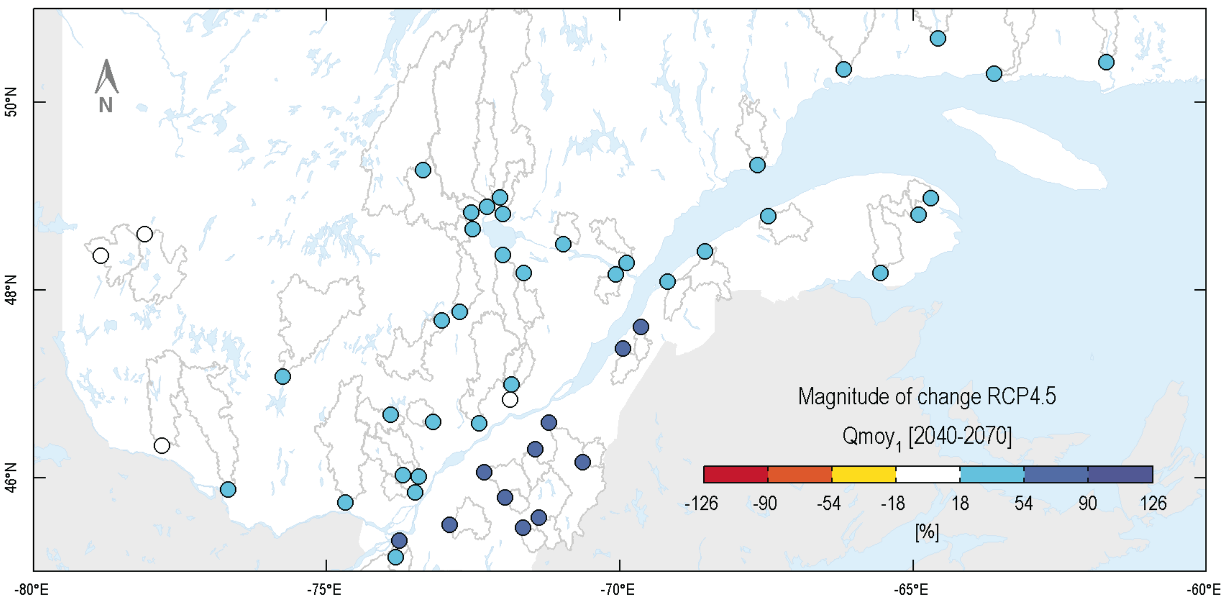
The Qmoy$_{EA}$ hydrological indicator corresponds to average summer/autumn flow. For the 2050 horizon, the projections describe a probable decrease in Qmoy$_{EA}$ over a large portion of southern Québec in the order of -5% to -20% (RCP4.5) and that could reach -30% (RCP8.5). The projections describe a probable increase in Qmoy$_{EA}$ in the Côte-Nord region in the order of +5% to +10%. Dispersion is estimated at an average of ± 10%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

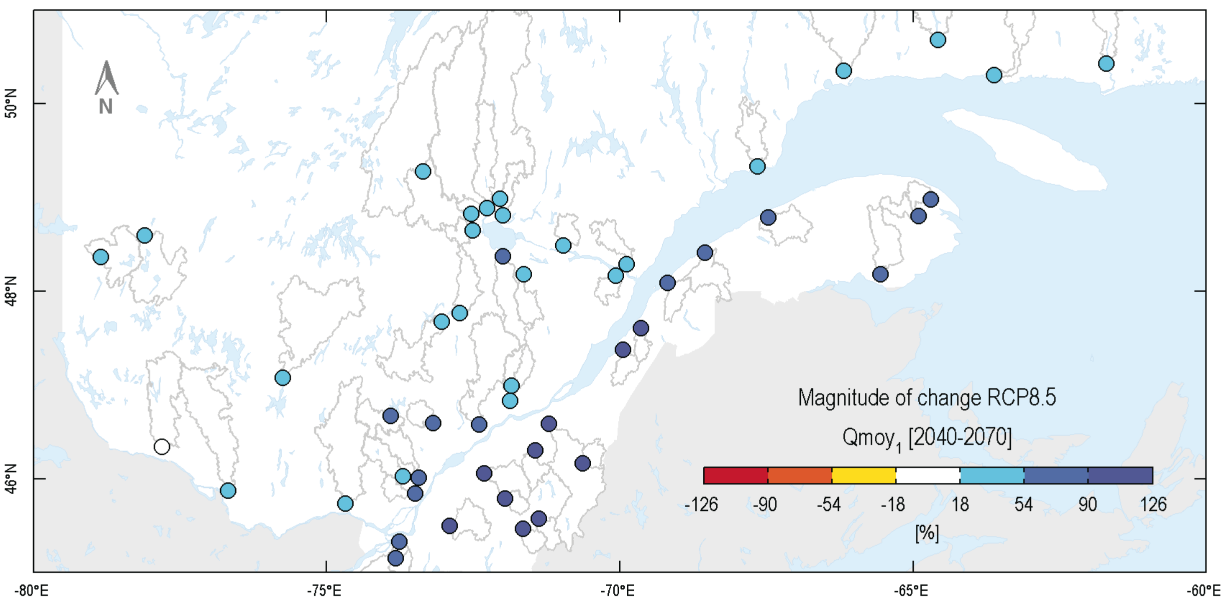
January mean flow

Average monthly flow





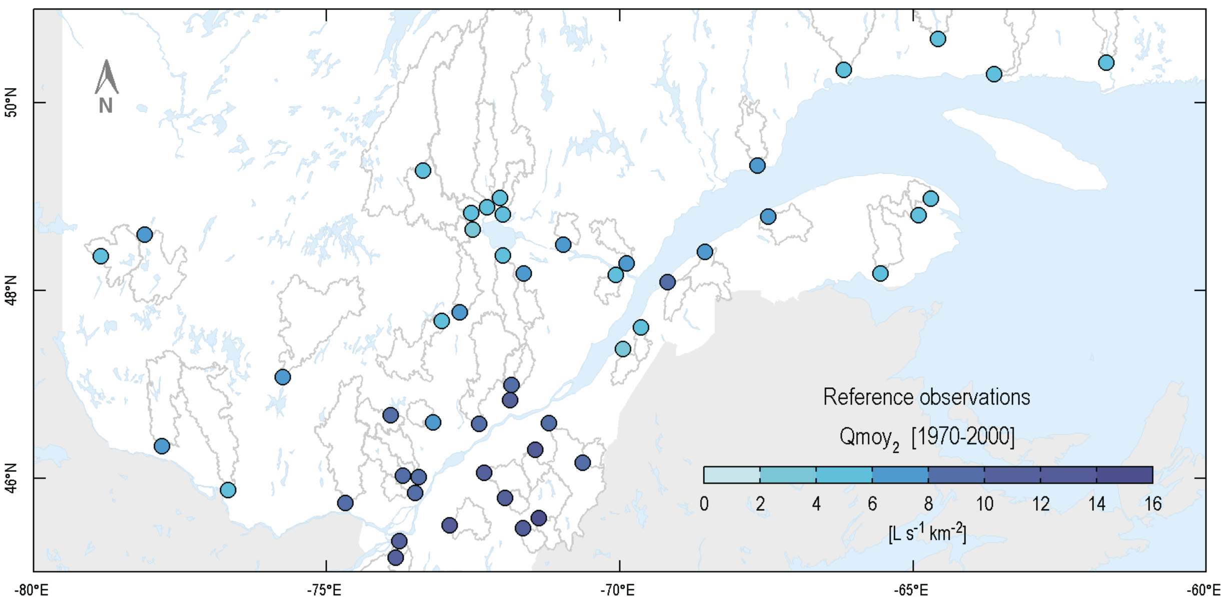


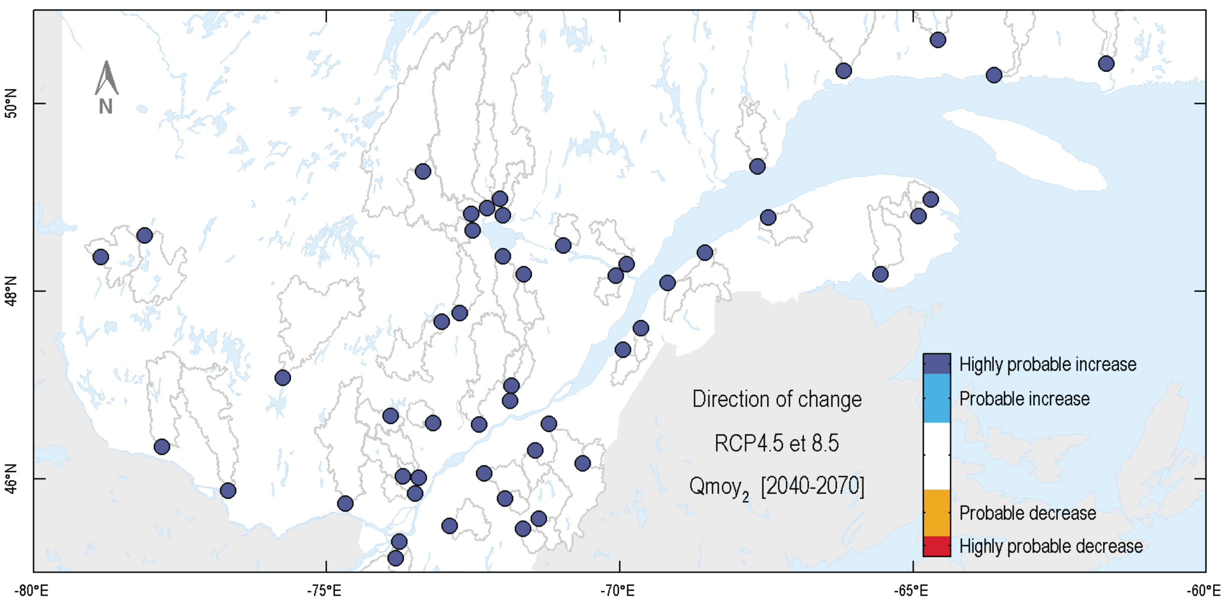


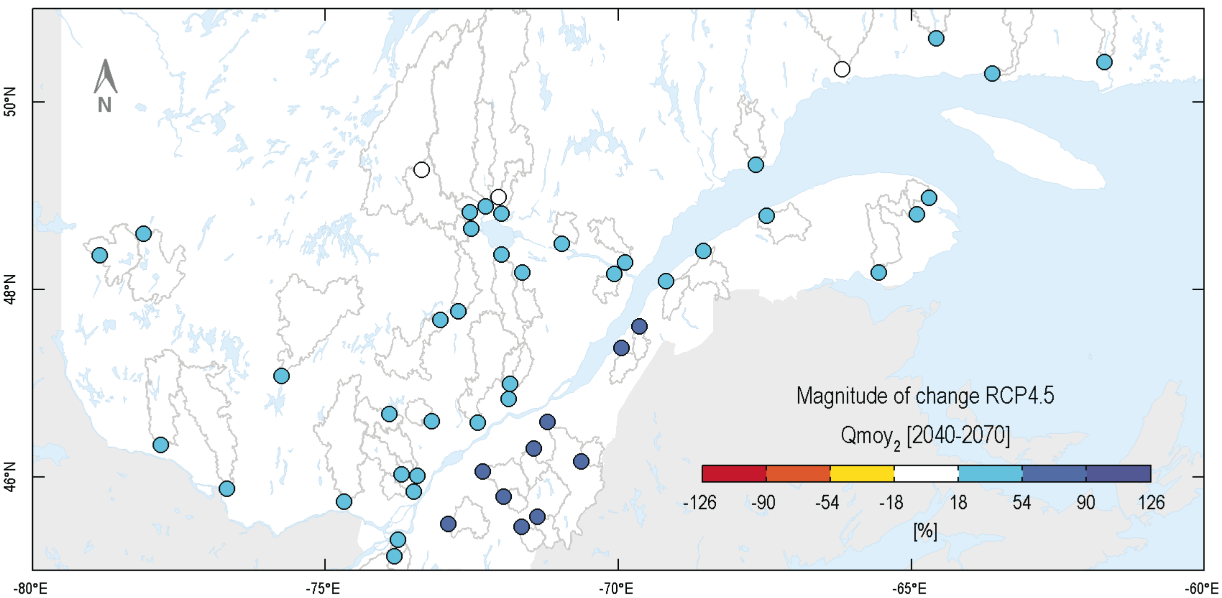
The $Qmoy_1$ hydrological indicator corresponds to average flow in January. For the 2050 horizon, projections describe a highly probable increase in $Qmoy_1$ throughout southern Québec in the order of +20% to +90% (RCP4.5) and that could reach +120% (RCP8.5). The increase in $Qmoy_1$ would be greater south of the St. Lawrence River. Dispersion is estimated at an average of ±16%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

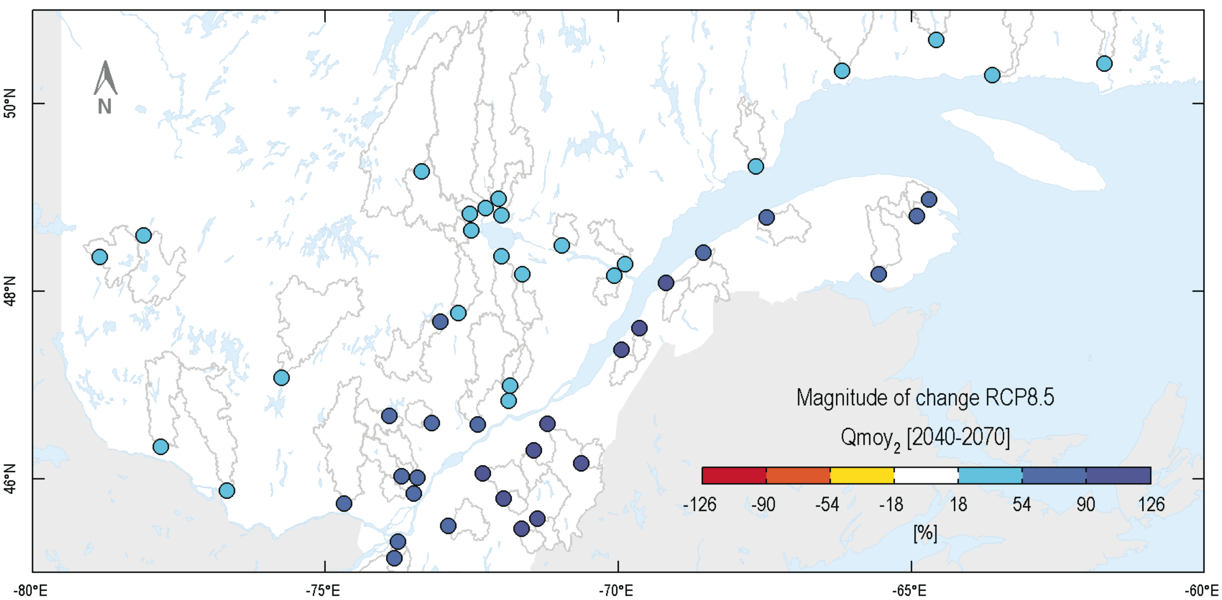
February mean flow

Average monthly flow





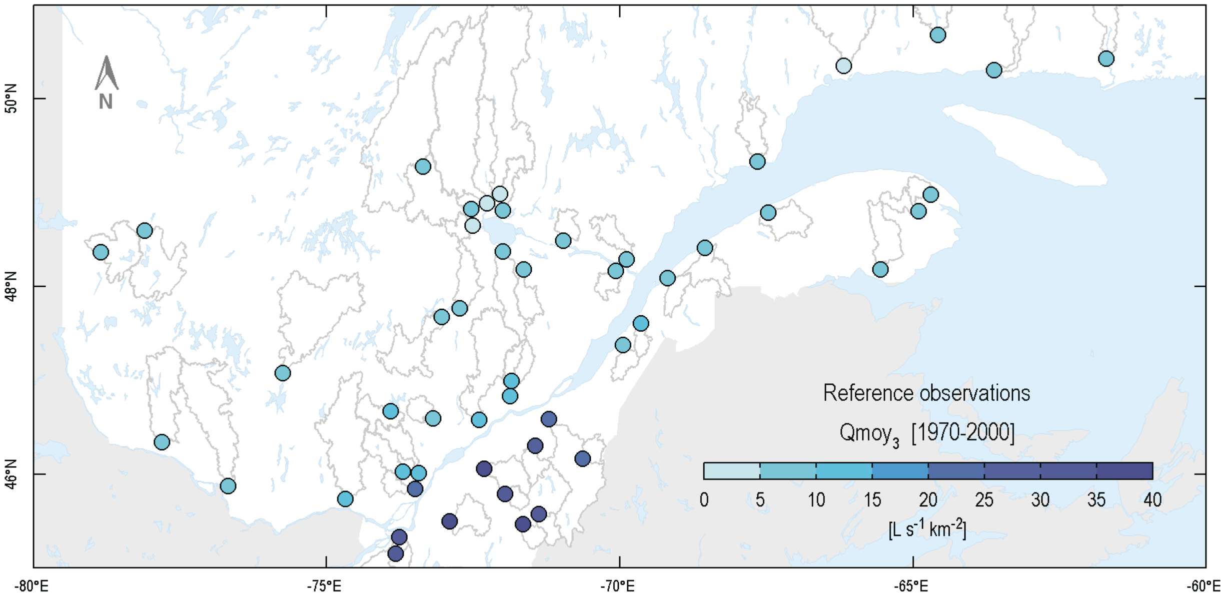


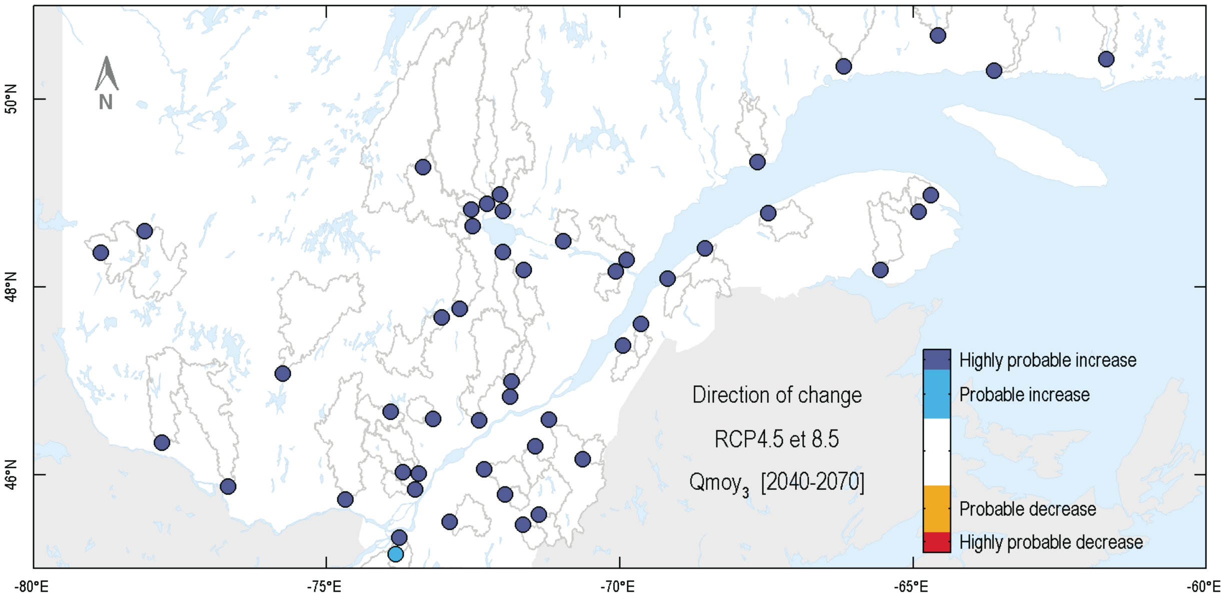


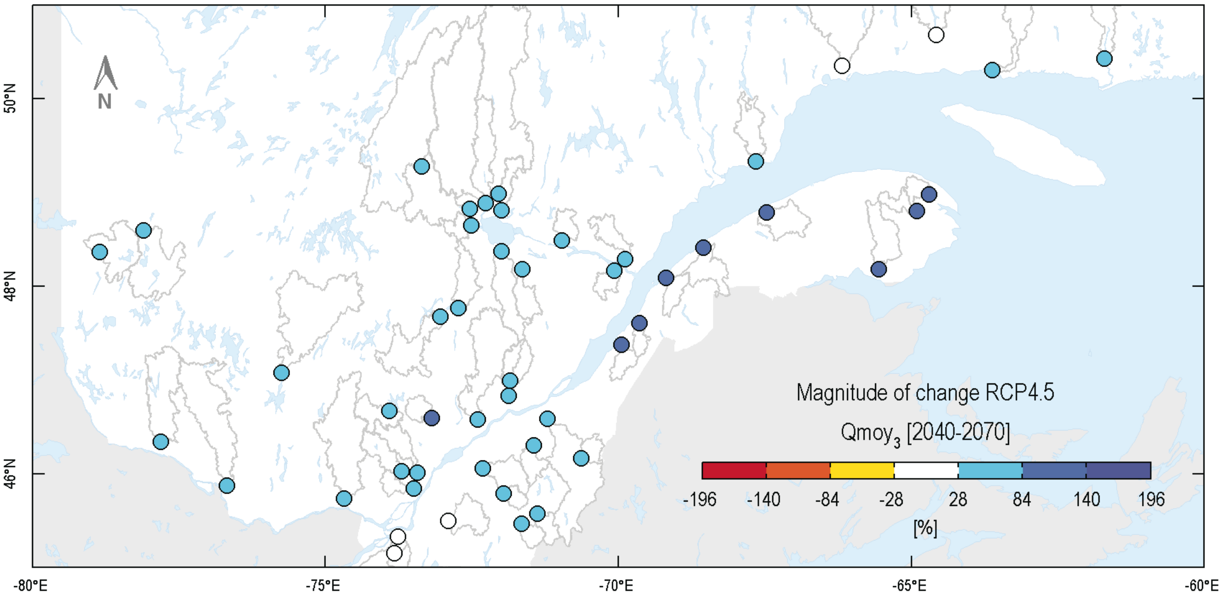
The Qmoy$_2$ hydrological indicator corresponds to average flow in February. For the 2050 horizon, projections describe a highly probable increase in Qmoy$_2$ throughout southern Québec in the order of +20% to +90% (RCP4.5) and that could reach +120% (RCP8.5). The increase in Qmoy$_2$ would be greater south of the St. Lawrence River. Dispersion is estimated at an average of ±17%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

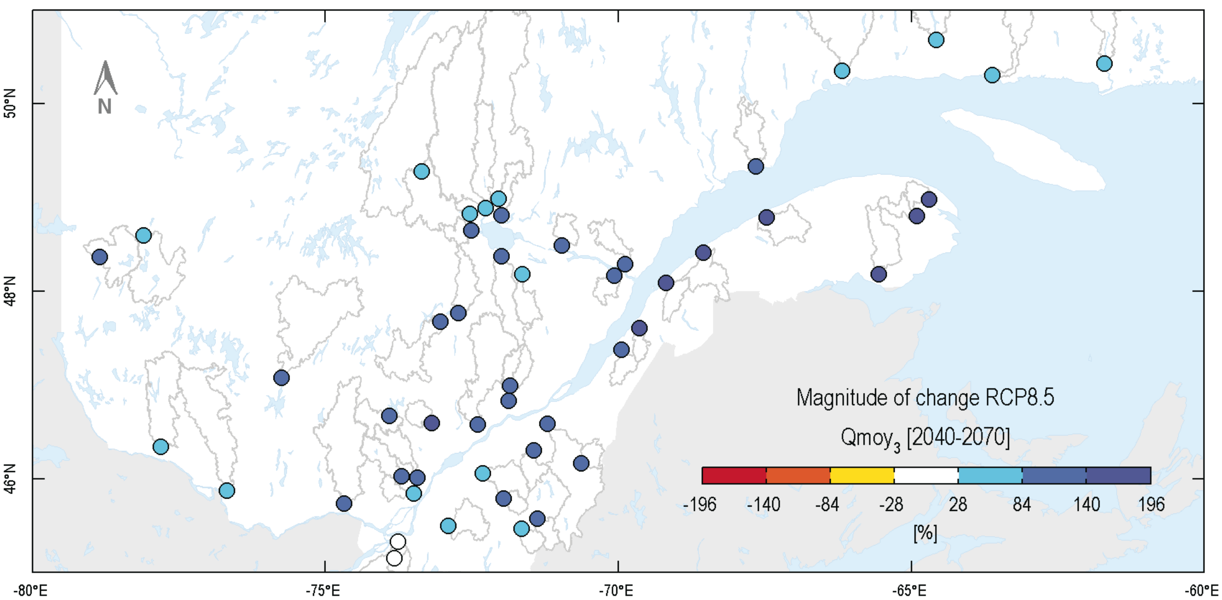
March mean flow

Average monthly flow





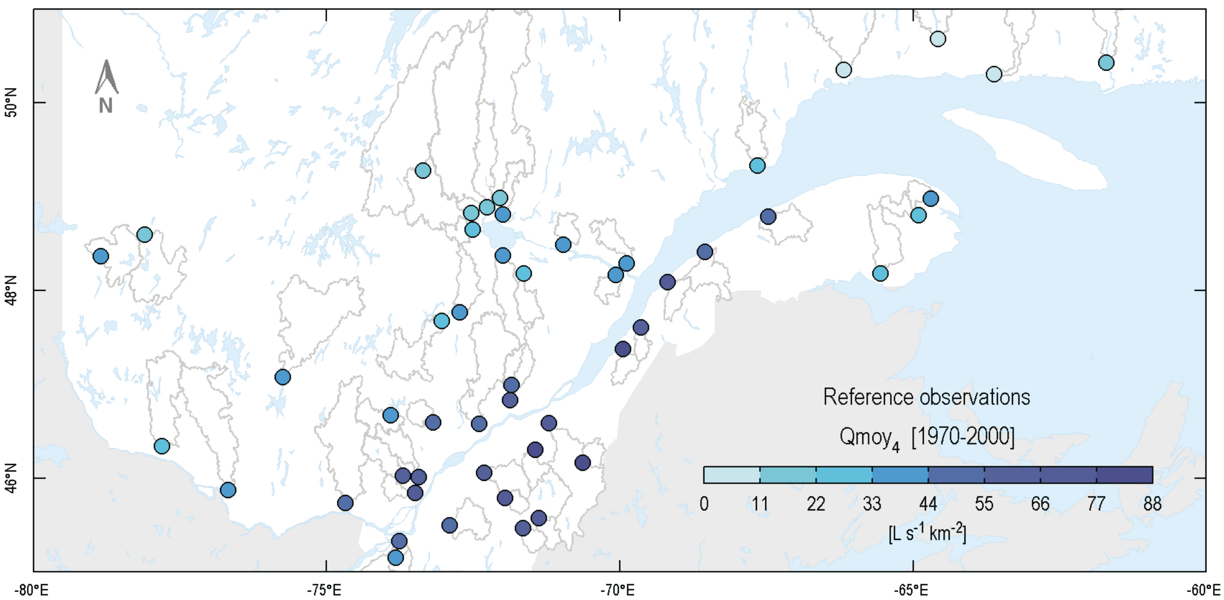


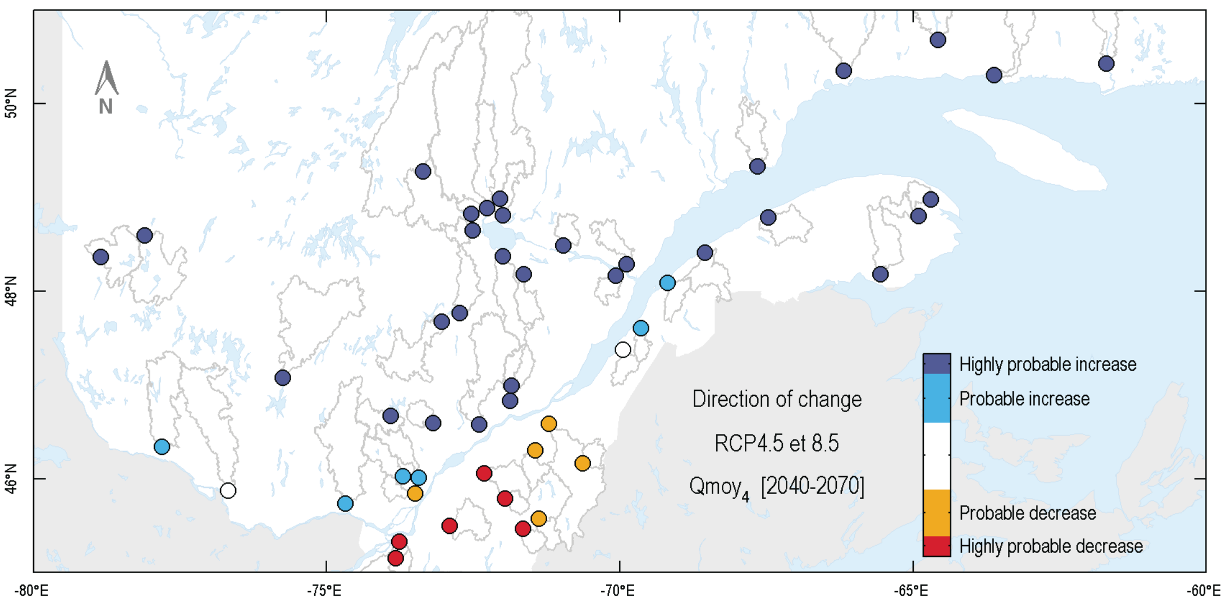


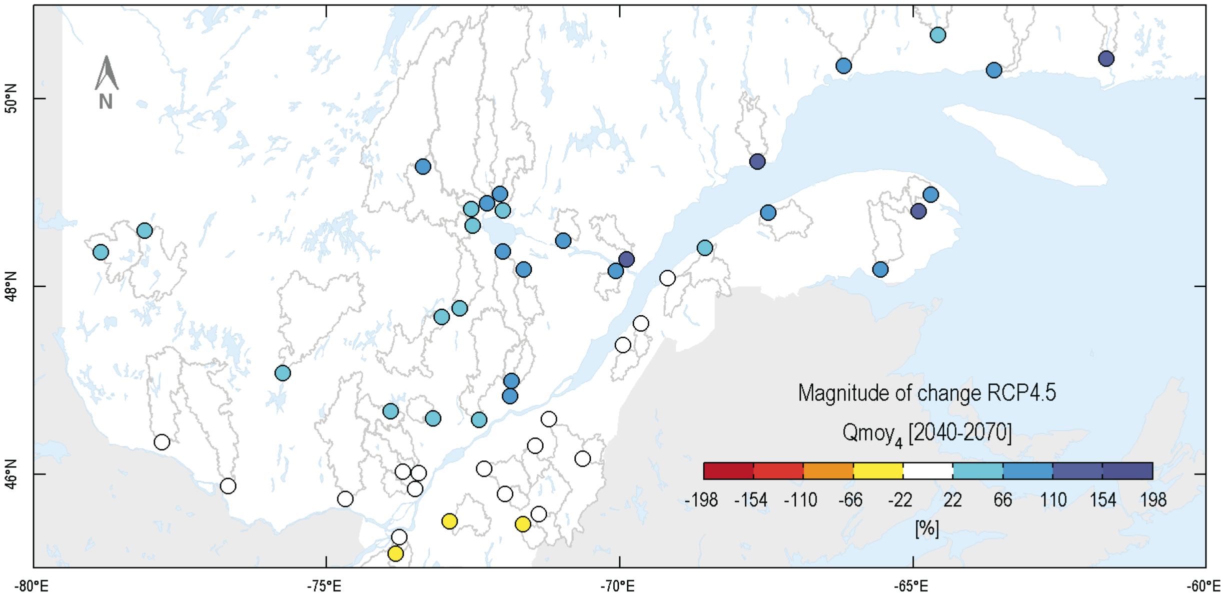
The $Qmoy_3$ hydrological indicator corresponds to average flow in March. For the 2050 horizon, projections describe a highly probable increase in $Qmoy_3$ throughout southern Québec in the order of +20% to +150% (RCP4.5) and that could reach +200% (RCP8.5). The highest increase in $Qmoy_3$ would be in the Gaspésie region. Dispersion varies by region and is estimated at an average of ± 34%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

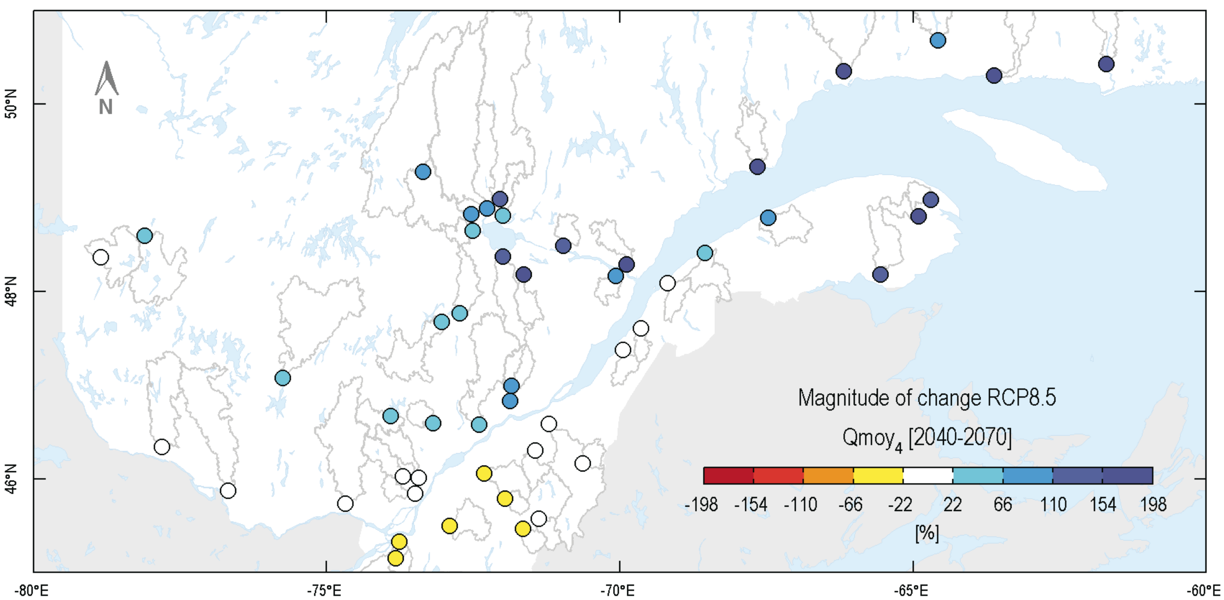
April mean flow

Average monthly flow





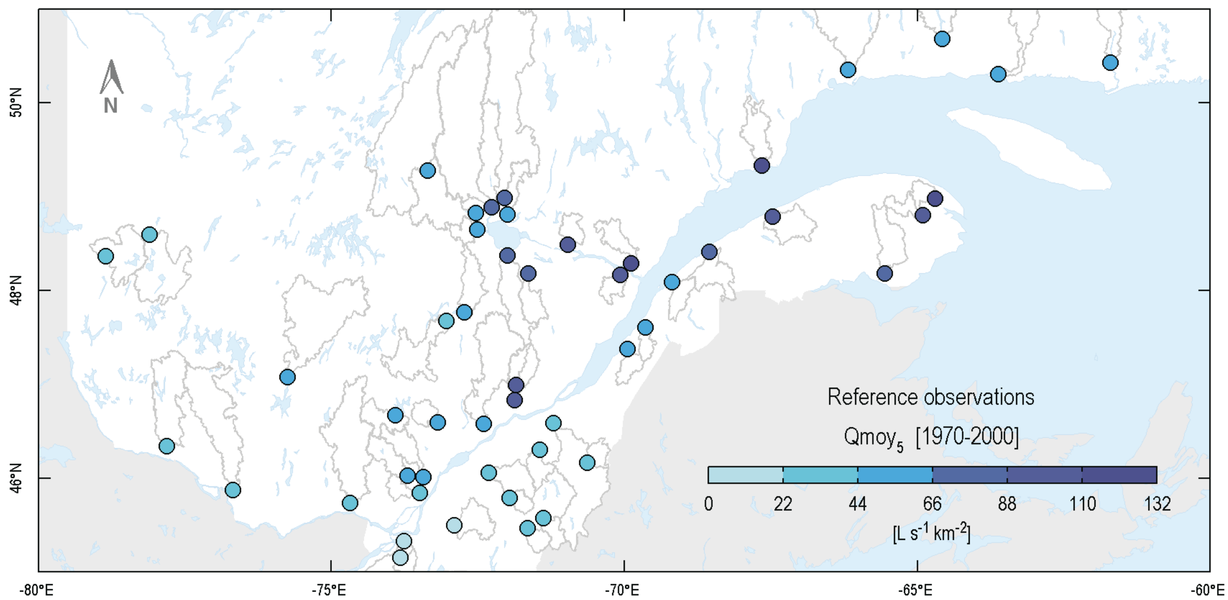


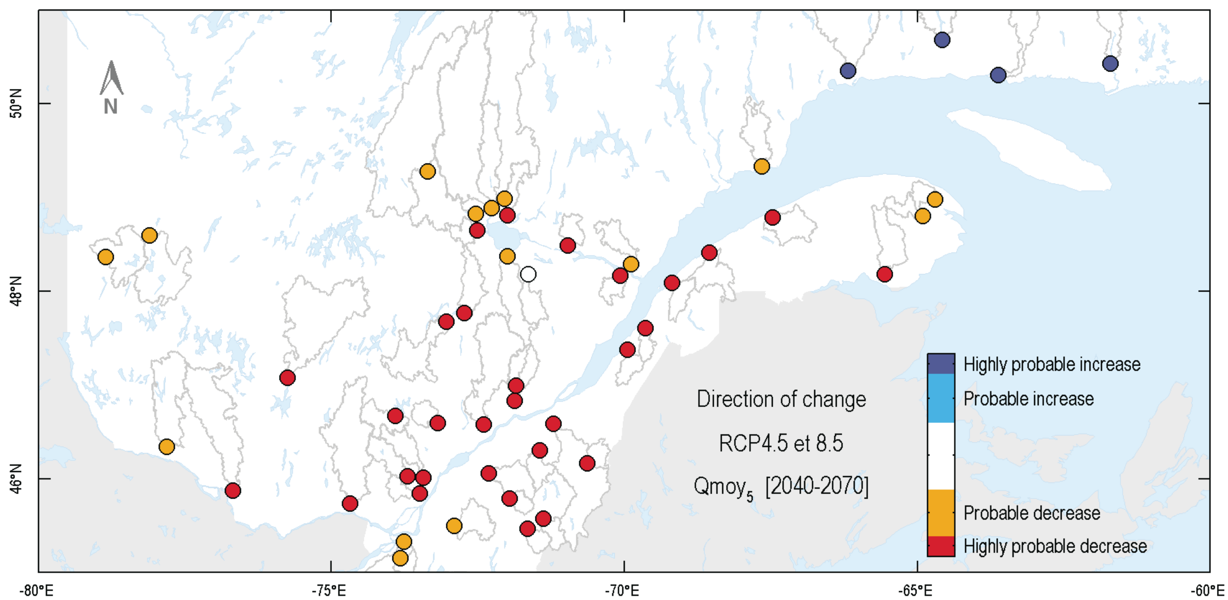


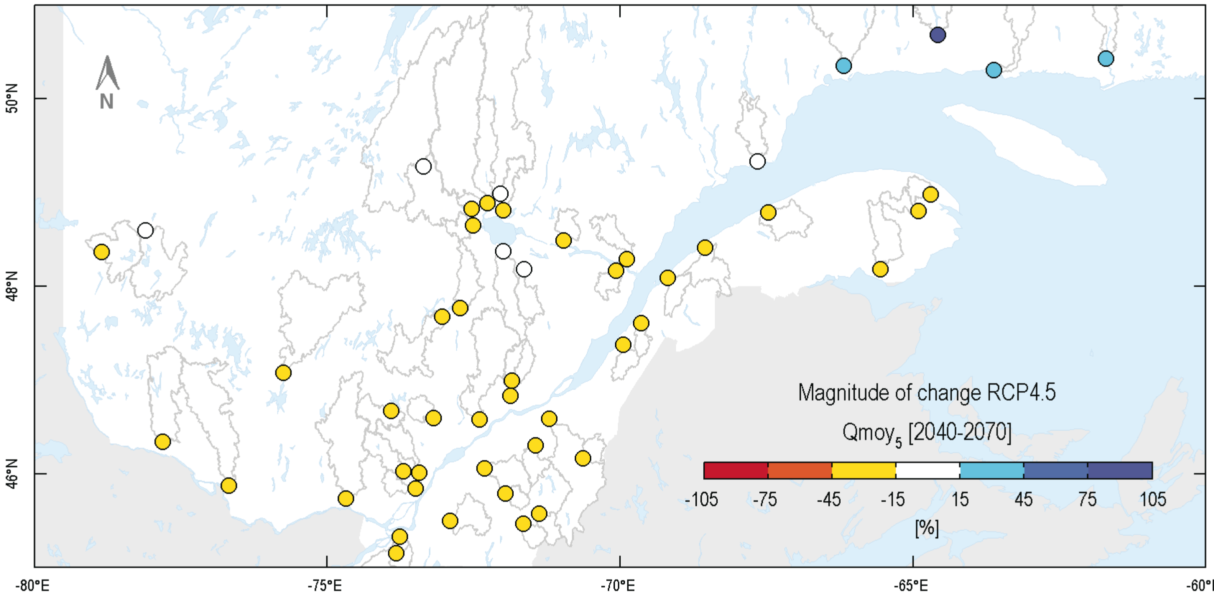
The $Qmoy_4$ hydrological indicator corresponds to average flow in April. For the 2050 horizon, projections describe a probable to highly probably decrease in $Qmoy_4$ in the far southern reaches of southern Québec in the order of -20% to -40% (RCP4.5) and that could reach -60% (RCP8.5). Projections describe a highly probable increase in $Qmoy_4$ north of the St. Lawrence River and in the Gaspésie region in the order of +20% to +150% (RCP4.5) and that could reach +200% (RCP8.5). Dispersion varies by region and is estimated at an average of ± 22%. The confidence level is moderate for the direction, magnitude and dispersion of change.

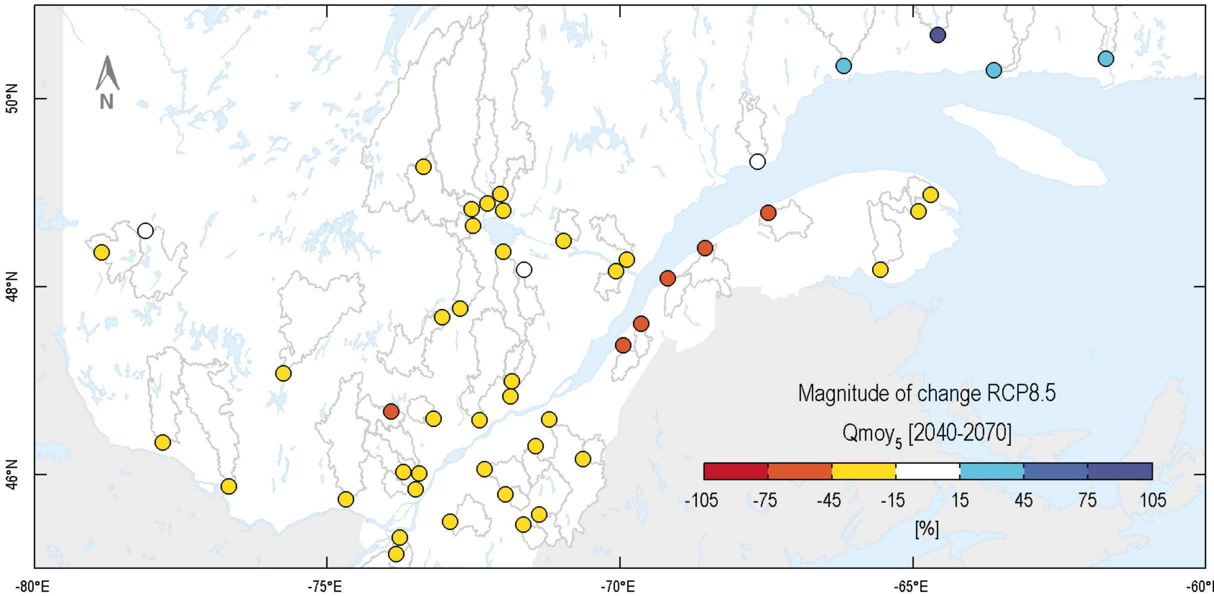
May mean flow

Average monthly flow





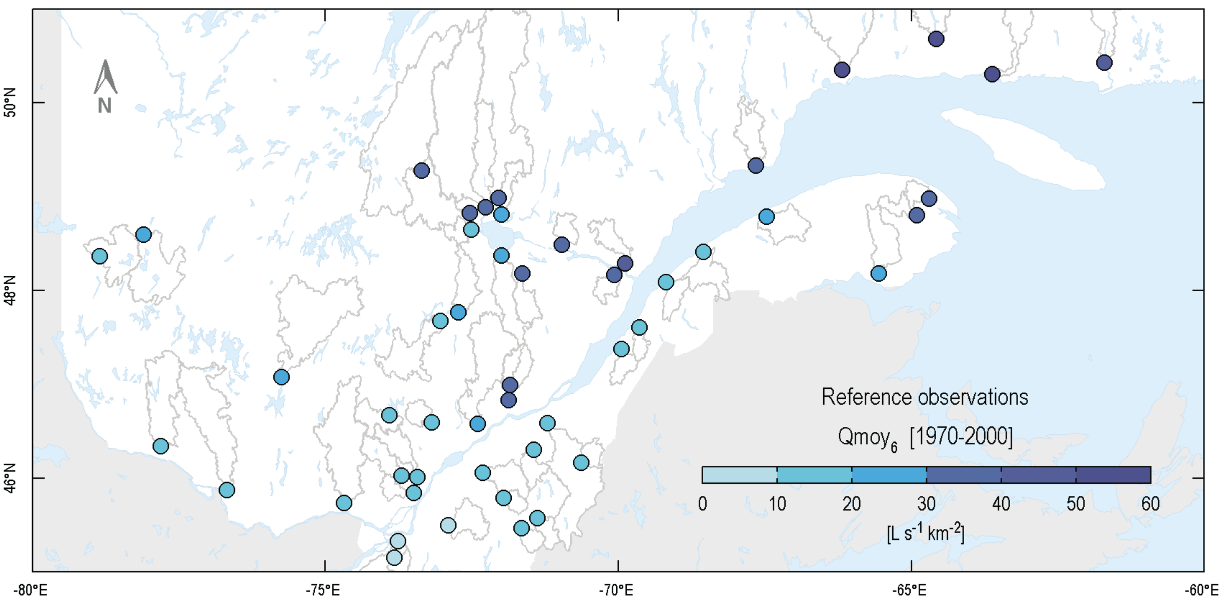


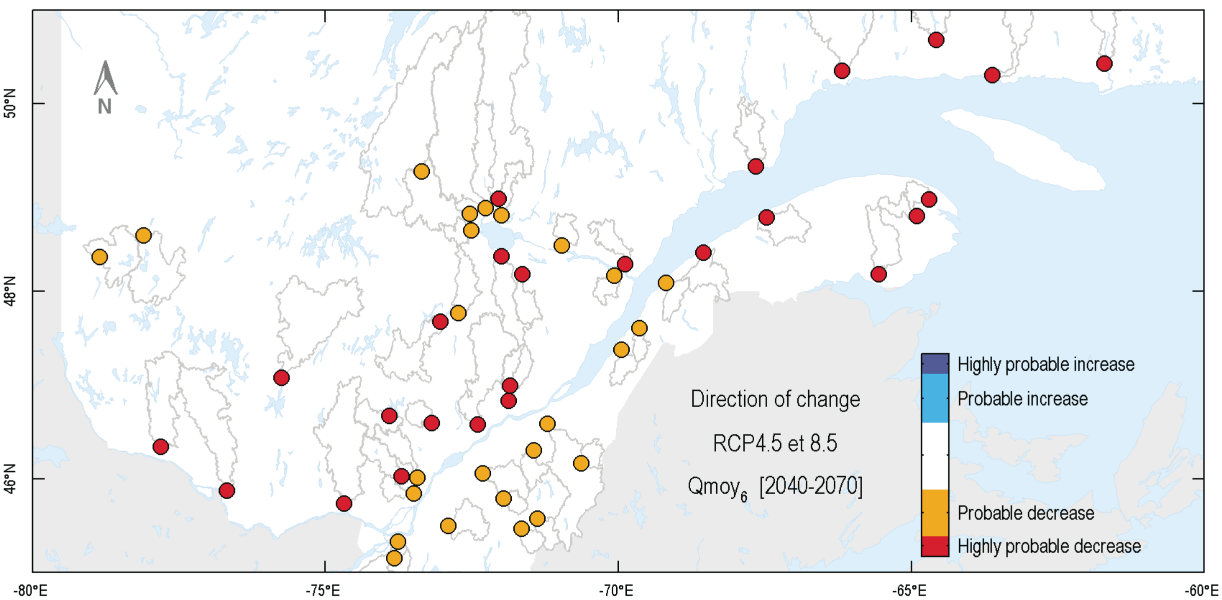


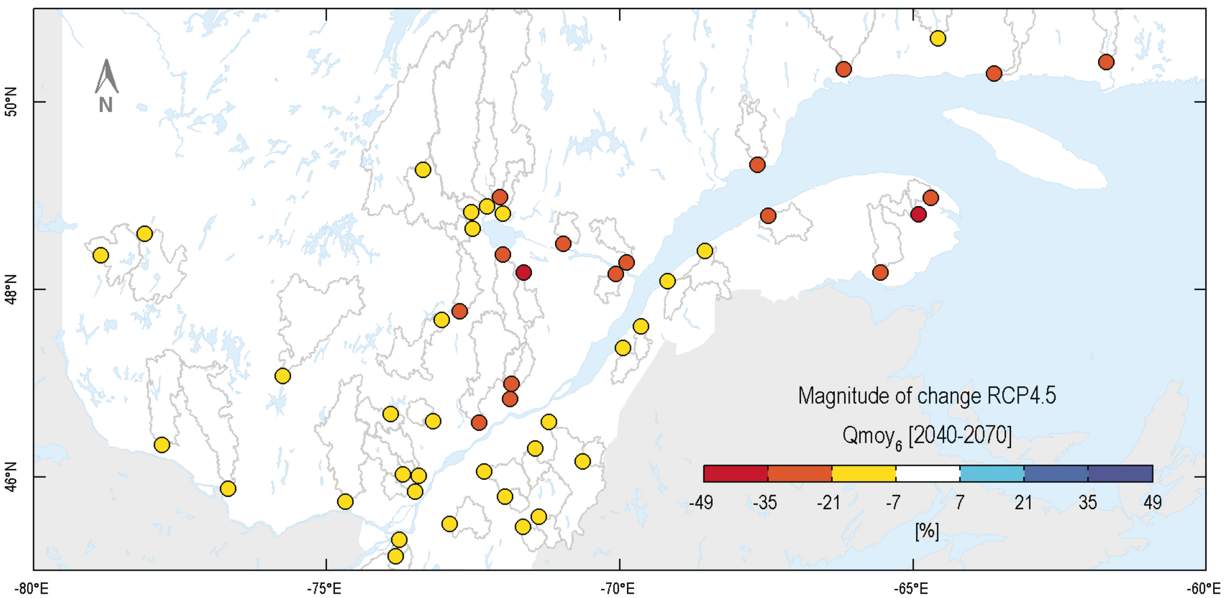
The $Qmoy_5$ hydrological indicator corresponds to average flow in May. For the 2050 horizon, projections describe a probable to highly probably decrease in $Qmoy_5$ on a large portion of southern Québec in the order of -15% to -45% (RCP4.5) and that could reach -60% (RCP8.5). Projections describe a highly probable increase in $Qmoy_5$ in the Côte-Nord region in the order of +15% to 50% (RCP4.5 and 8.5). Dispersion varies by region and is estimated at an average of ±12%. The confidence level is moderate for the direction, magnitude and dispersion of change.

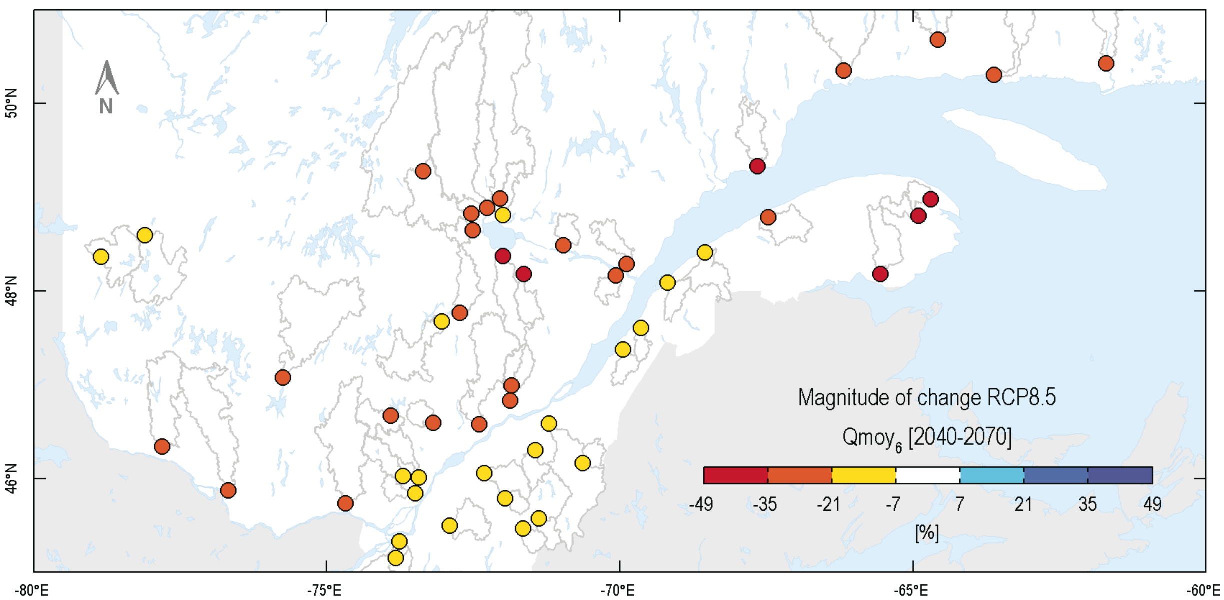
June mean flow

Average monthly flow





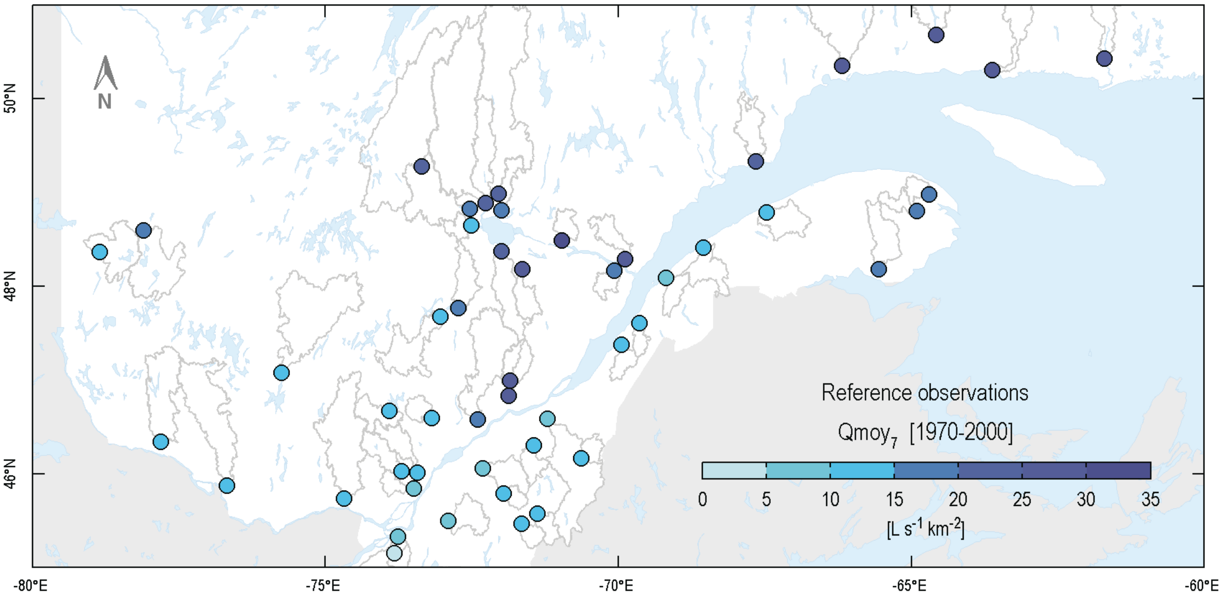


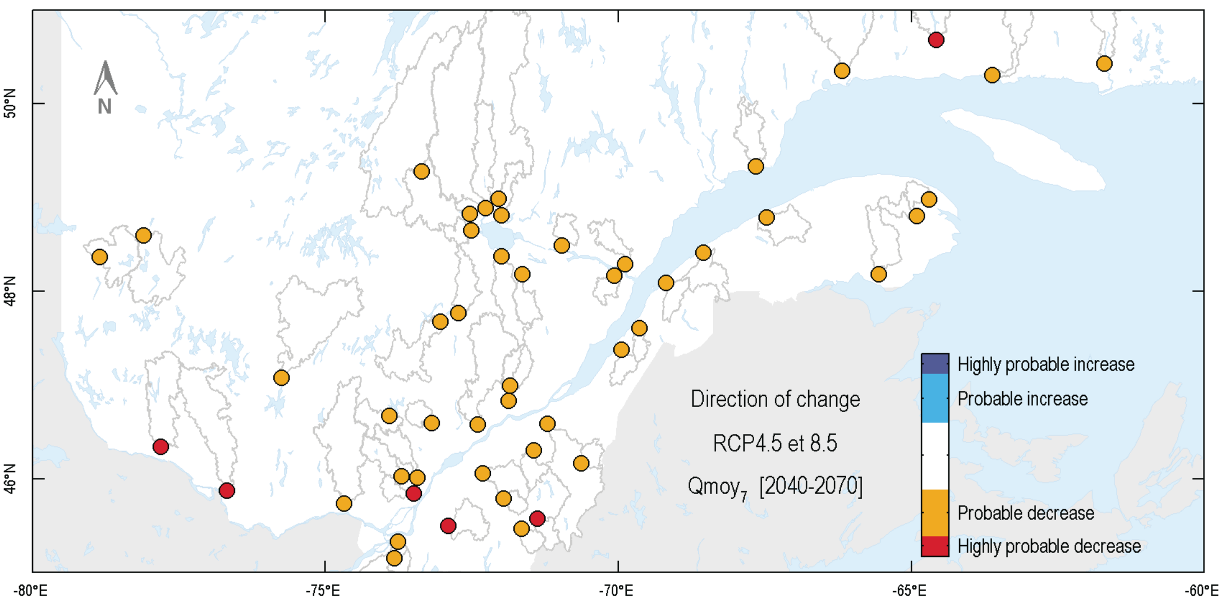


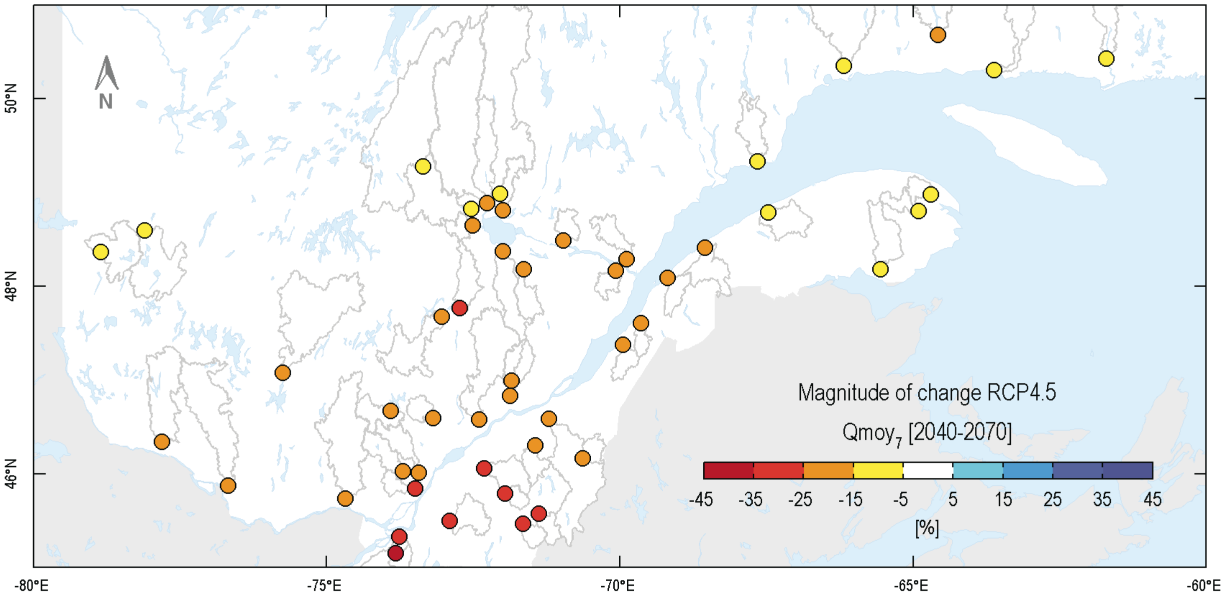
The Qmoy$_6$ hydrological indicator corresponds to average flow in June. For the 2050 horizon, projections describe a probable to highly probably decrease in Qmoy$_6$ throughout southern Québec in the order of -10% to -35% (RCP4.5) and that could reach -45% (RCP8.5). Dispersion varies by region and is estimated at an average of ±11%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

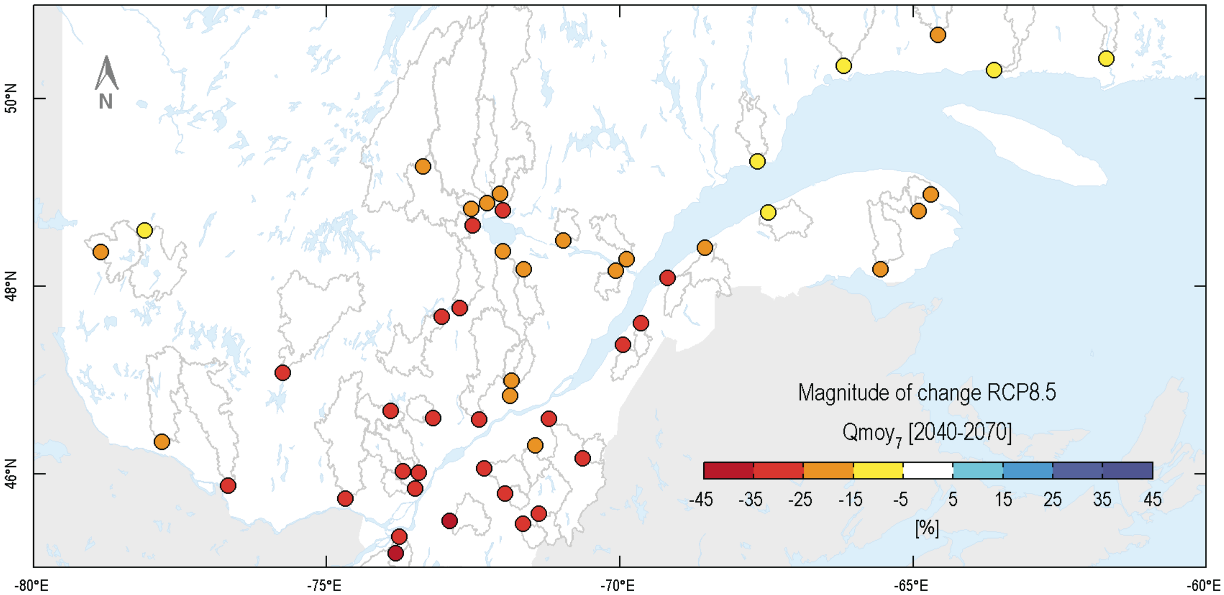
July mean flow

Average monthly flow





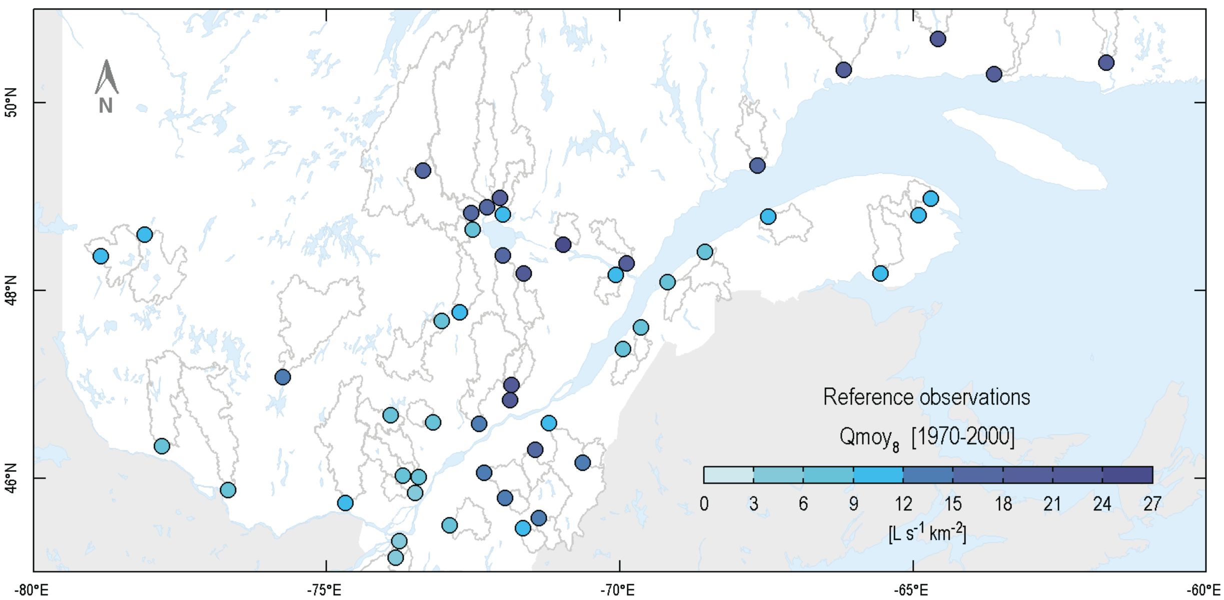


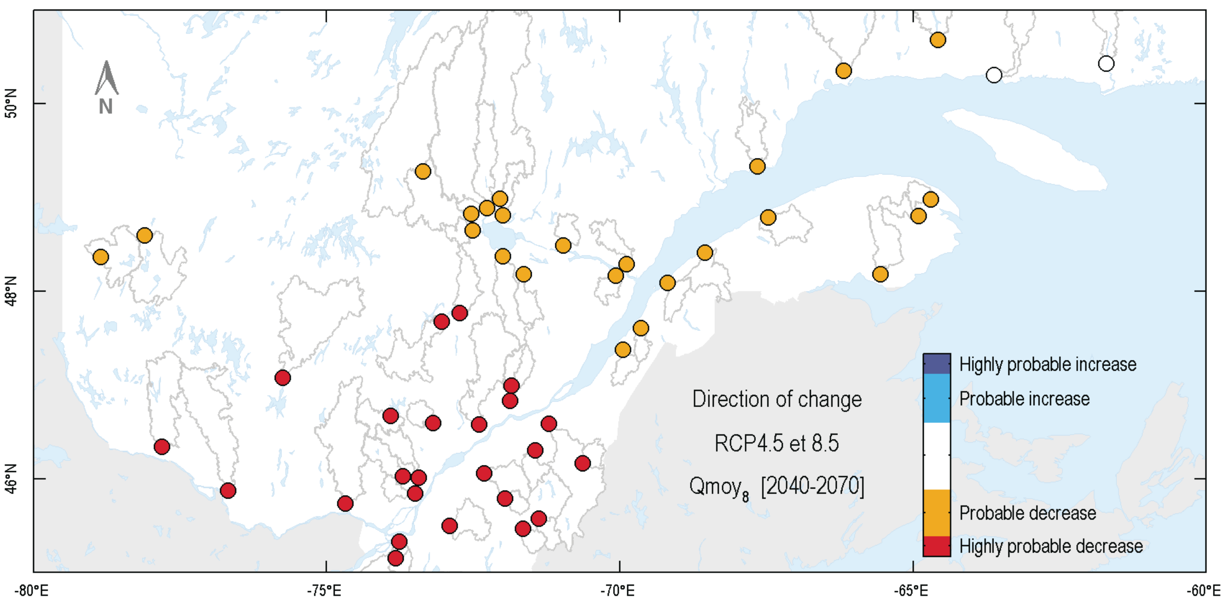


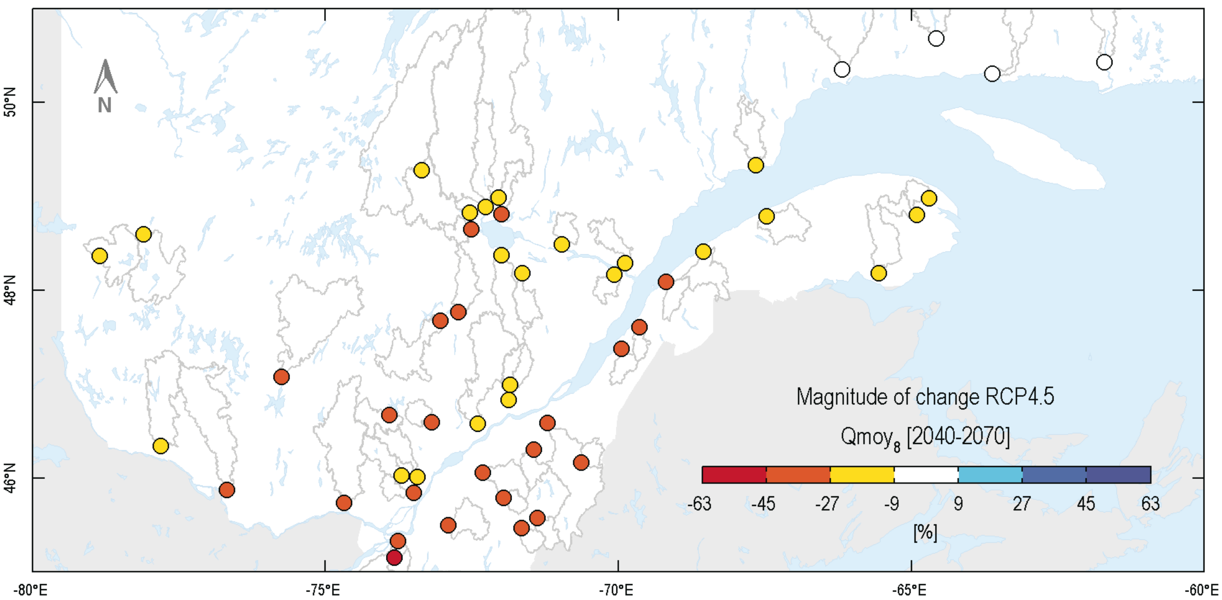
The Qmoy$_7$ hydrological indicator corresponds to average flow in July. For the 2050 horizon, projections describe a probable to highly probable decrease in Qmoy$_7$ throughout southern Québec in the order of -10% to -20% (RCP4.5) and that could reach -35% in the southernmost reaches of southern Québec (RCP8.5). Dispersion is estimated at ±12%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

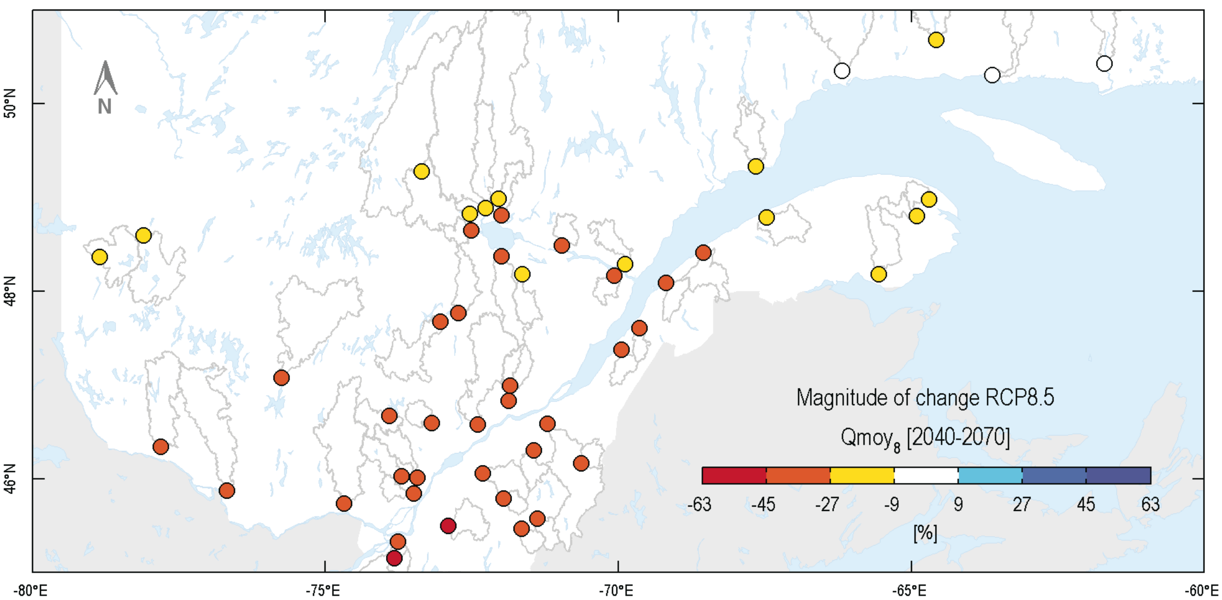
August mean flow

Average monthly flow





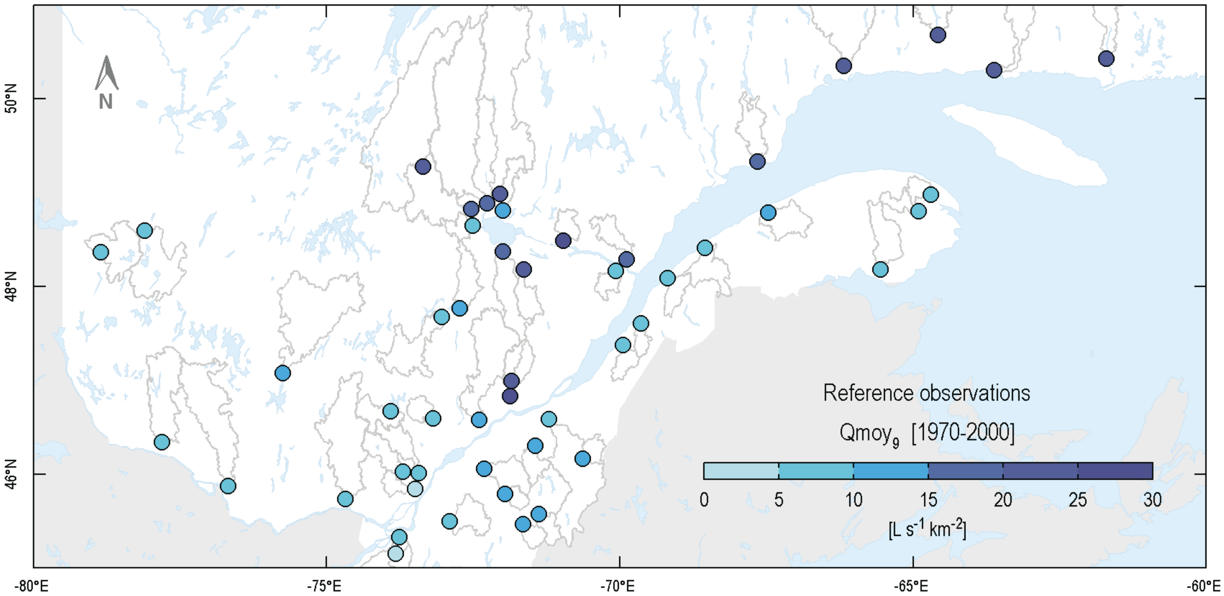


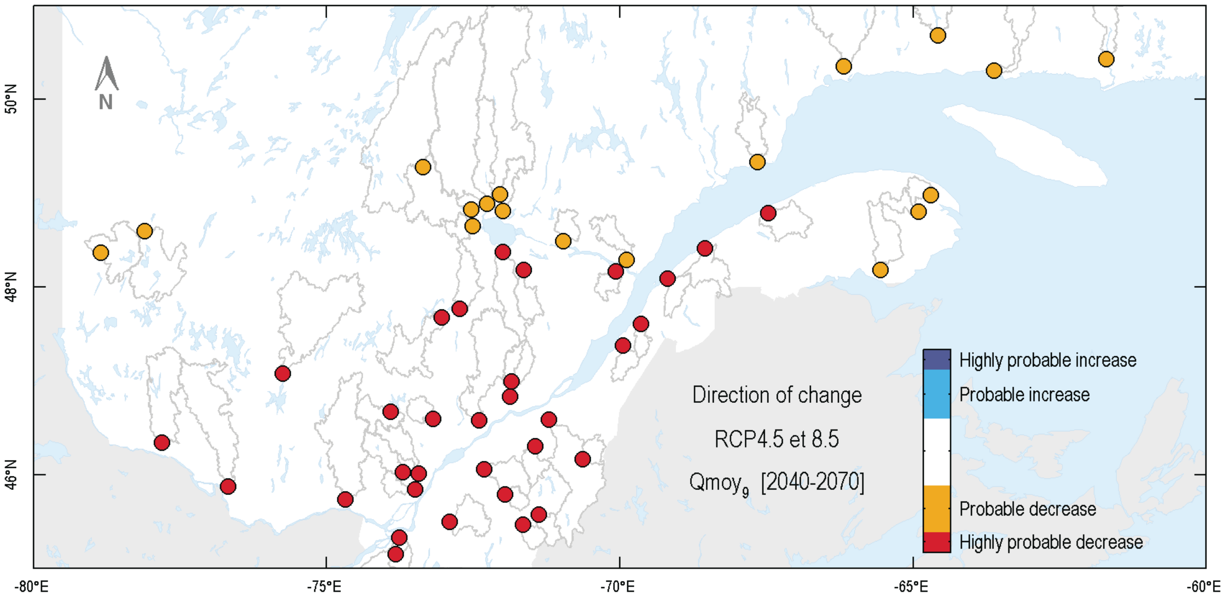


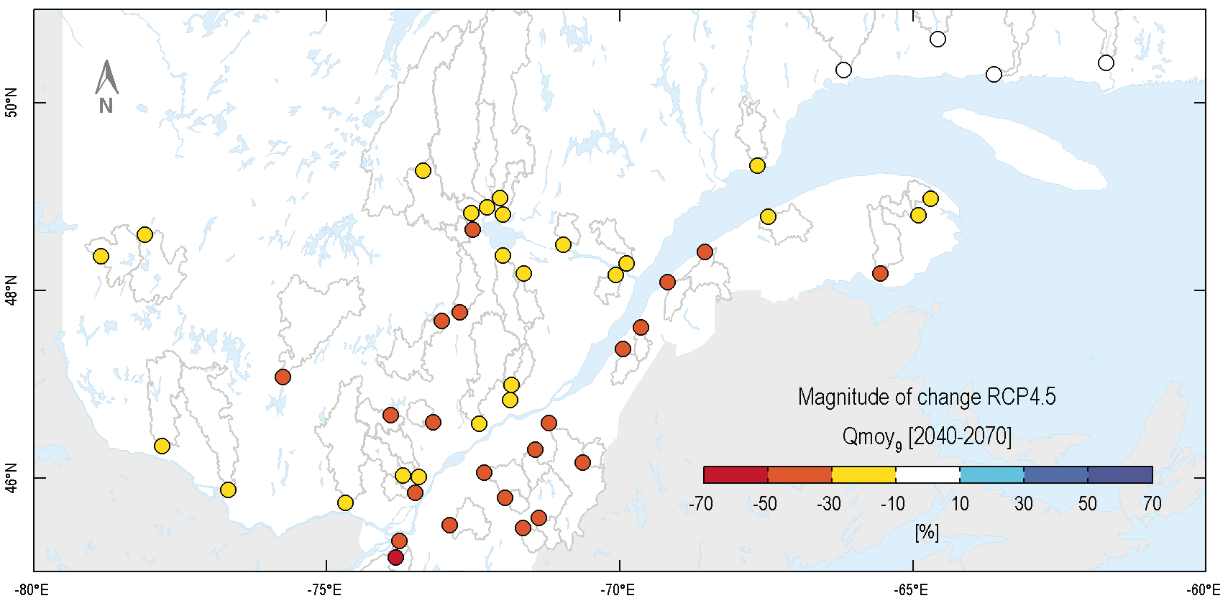
The Qmoy$_8$ hydrological indicator corresponds to average flow in August. For the 2050 horizon, projections describe a probable to highly probable decrease in Qmoy$_8$ over a large portion of southern Québec in the order of -15% to -30% (RCP4.5) and that could reach -50% in the southernmost reaches (RCP8.5). Dispersion is estimated at ±11%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

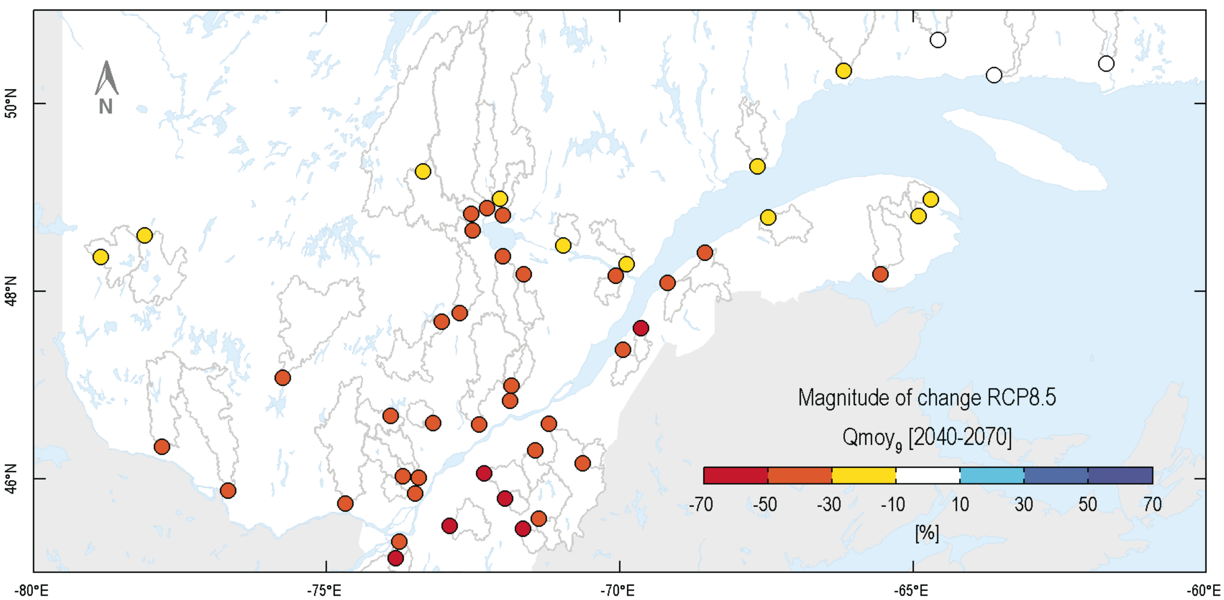
September mean flow

Average monthly flow





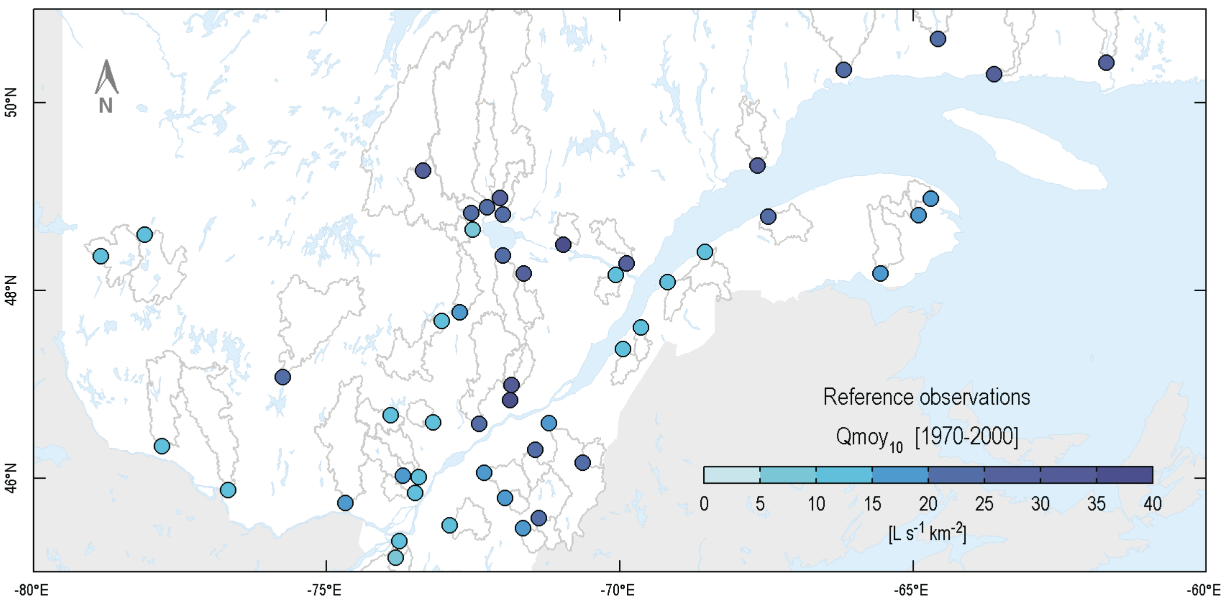


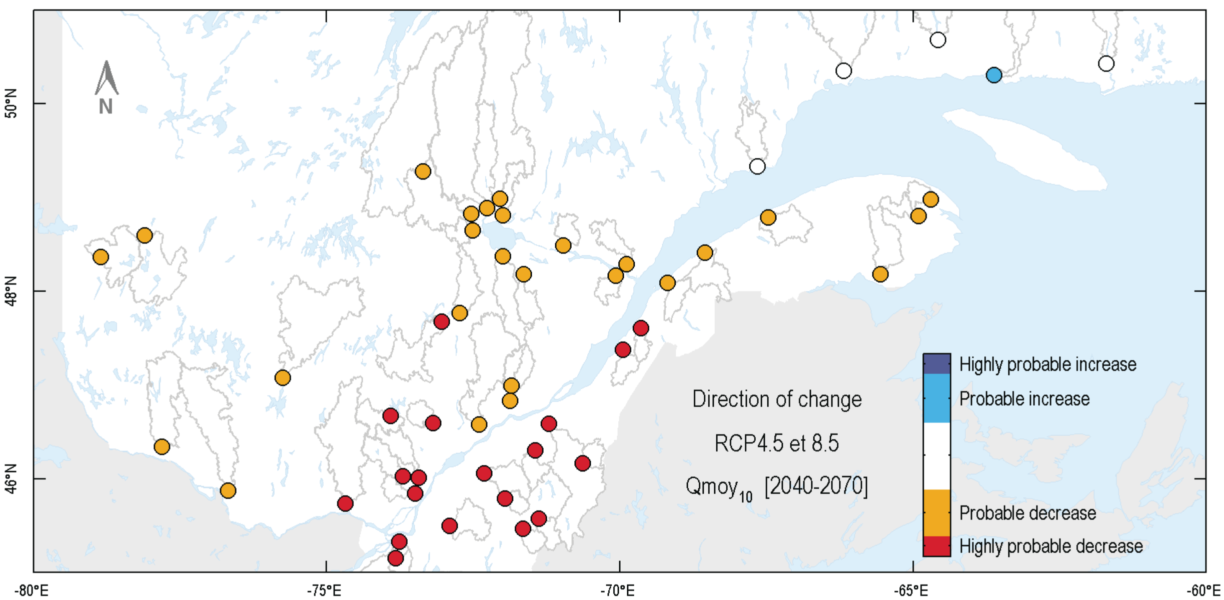


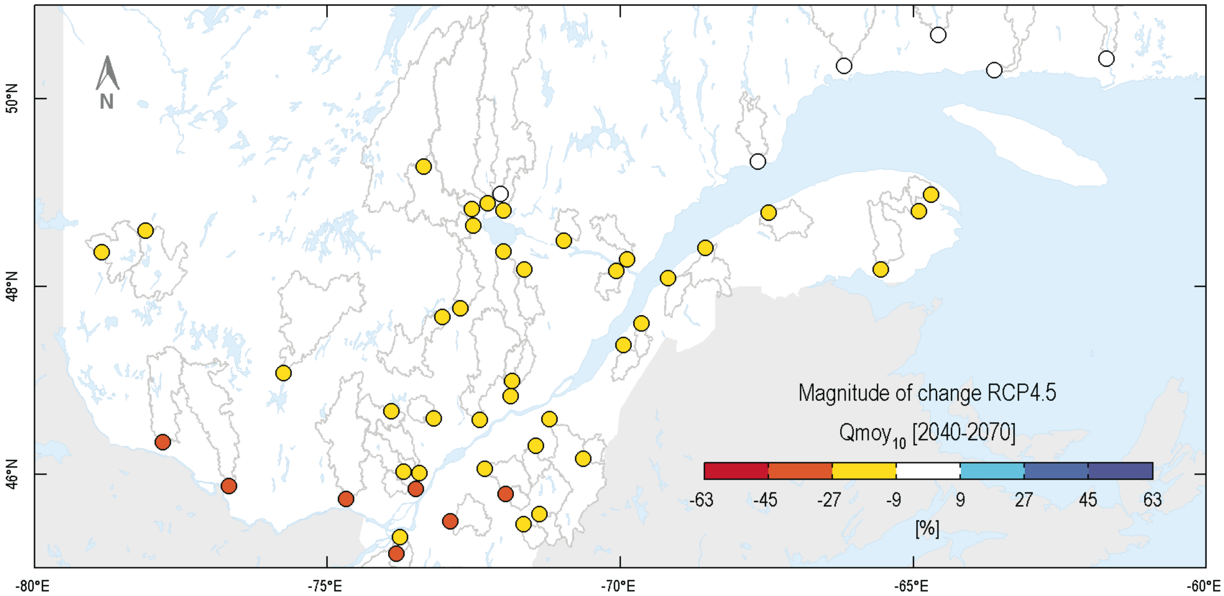
The Qmoy$_9$ hydrological indicator corresponds to average flow in September. For the 2050 horizon, projections describe a probable to highly probable decrease in Qmoy$_9$ over a large portion of southern Québec in the order of -20% to -40% (RCP4.5) and that could reach -60% in the southernmost reaches (RCP8.5). Dispersion is estimated at ±12%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

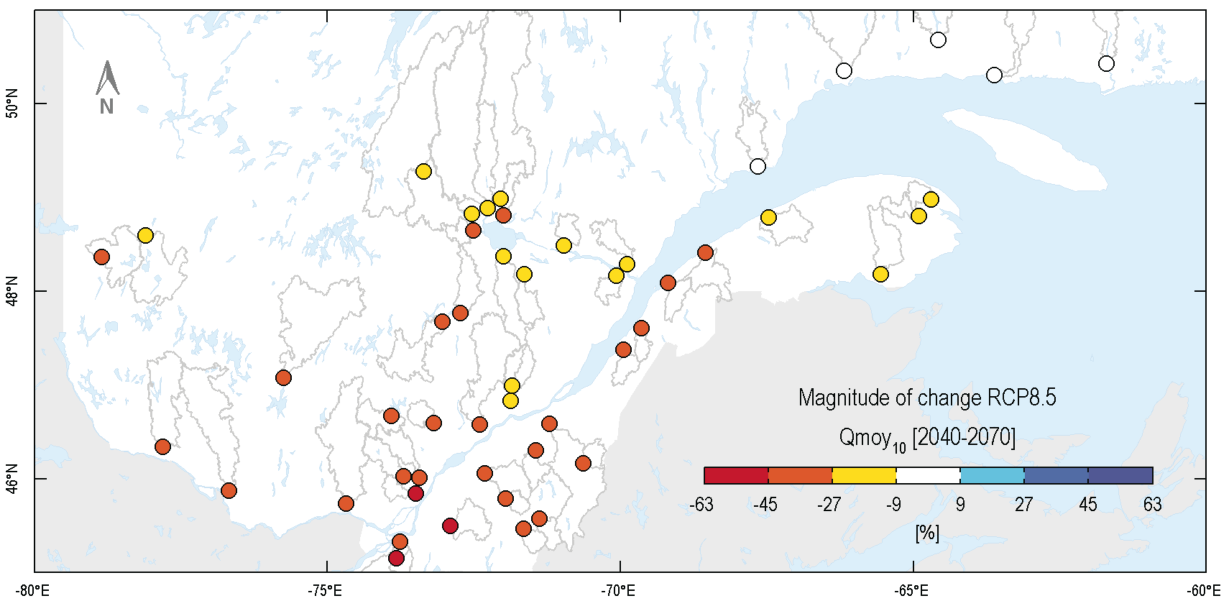
October mean flow

Average monthly flow





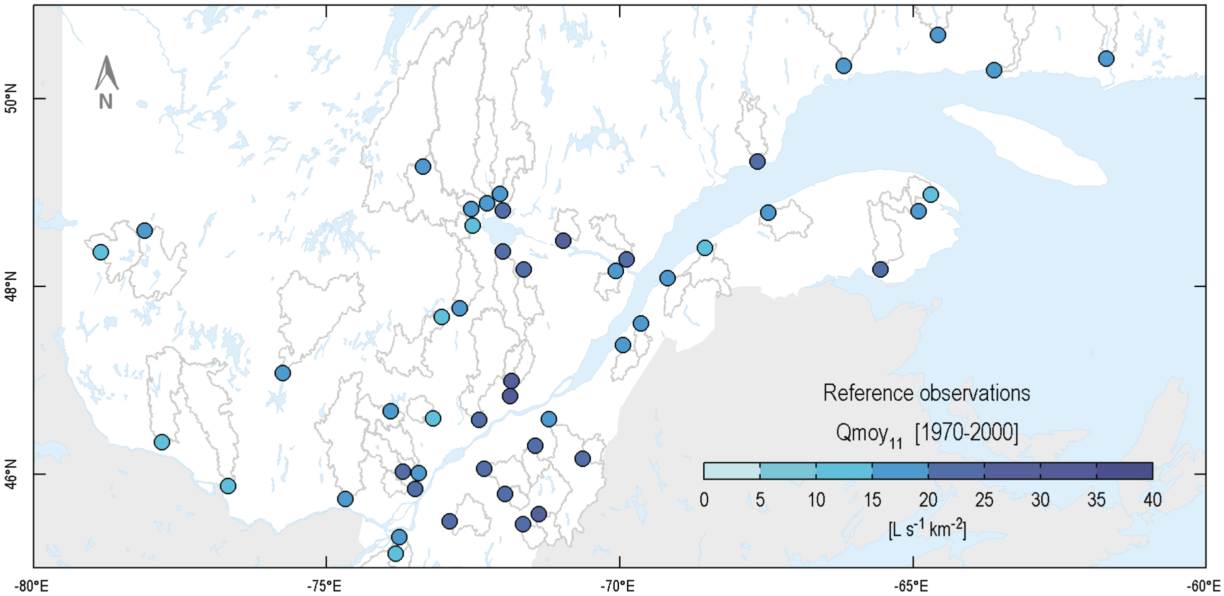


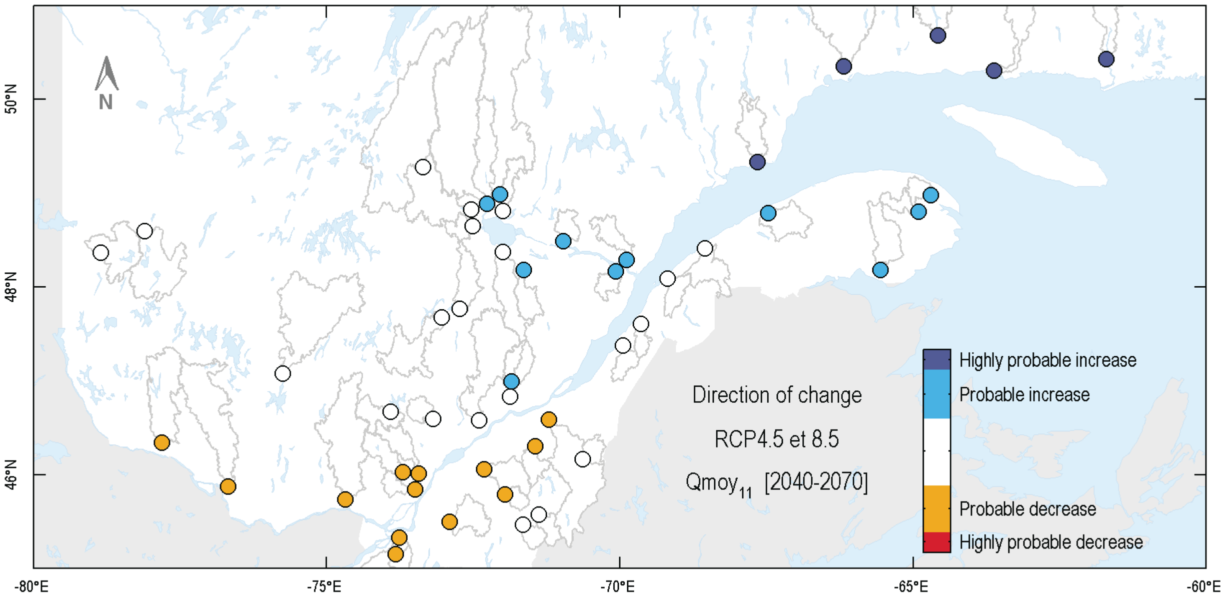


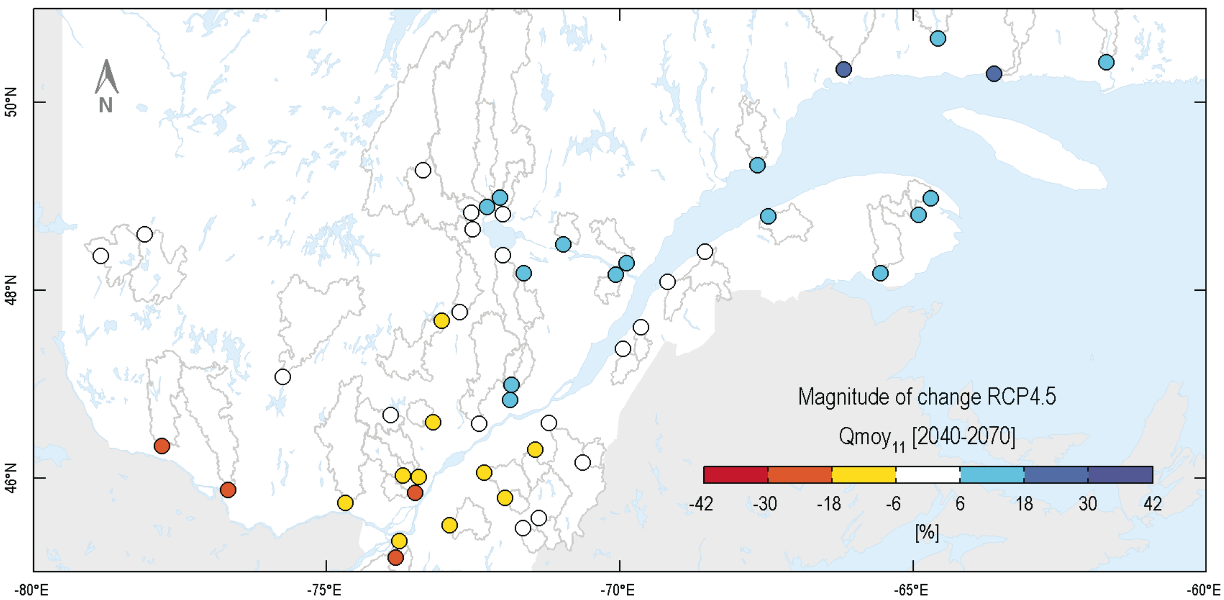
The Qmoy$_{10}$ hydrological indicator corresponds to average flow in October. For the 2050 horizon, projections describe a probable to highly probable decrease in Qmoy$_{10}$ over a large portion of southern Québec in the order of -20% (RCP4.5) and that could reach -50% in the southernmost reaches (RCP8.5). Dispersion is estimated at ±12%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

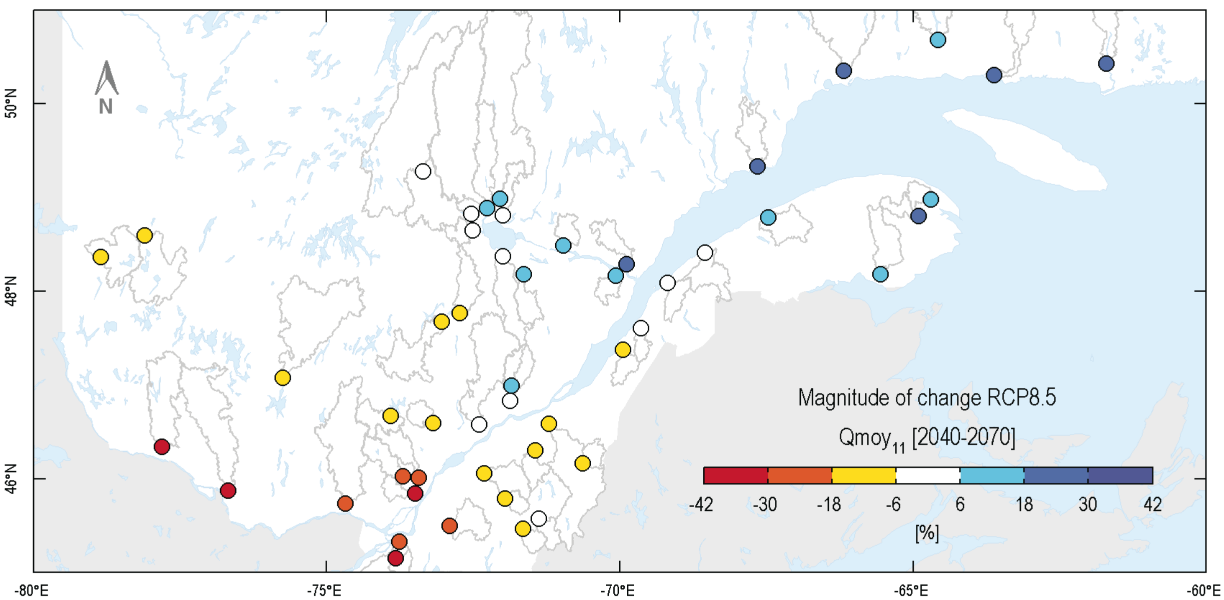
November mean flow

Average monthly flow





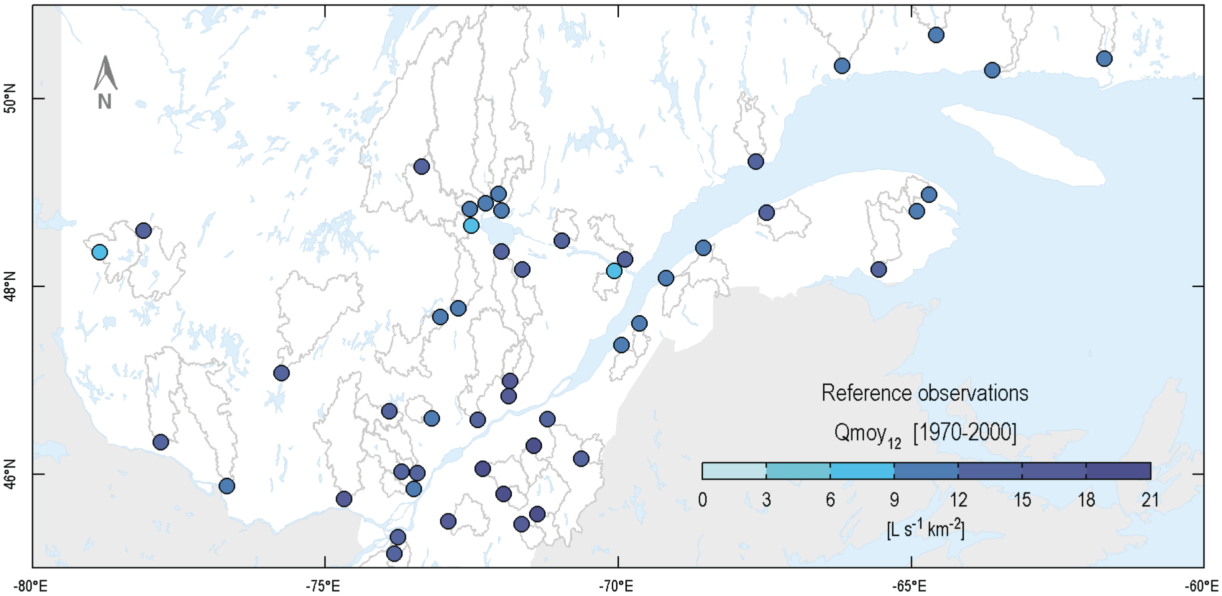


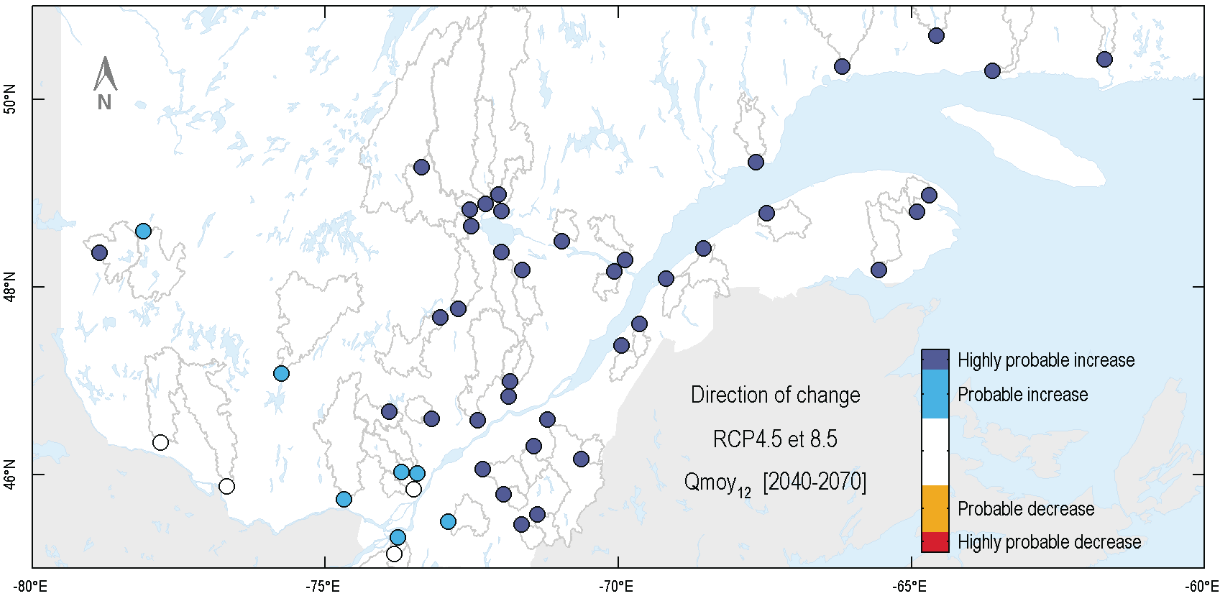


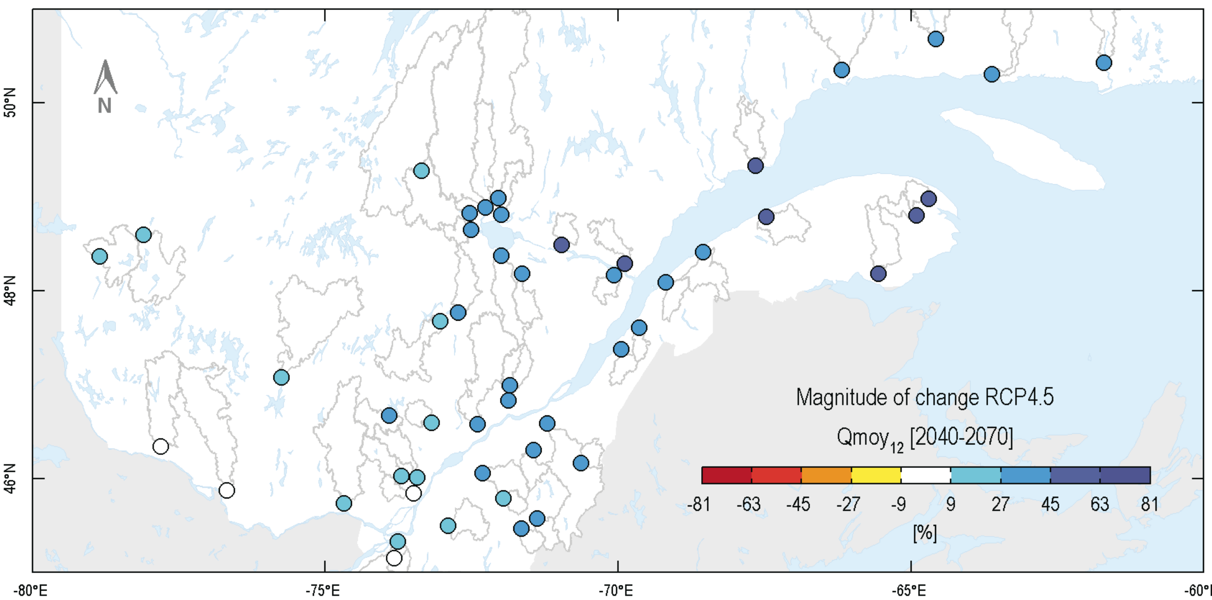
The Qmoy$_{11}$ hydrological indicator corresponds to average flow in November. For the 2050 horizon, projections describe a probable decrease in Qmoy$_{11}$ in southernmost Québec in the order of -15% to -25% (RCP4.5) and that could reach -35% (RCP8.5). Projections describe a probable to highly probable increase in Qmoy$_{11}$ in the eastern part of southern Québec in the order of +15% (RCP4.5) and that could reach +30% in the Côte-Nord region (RCP8.5). Dispersion is estimated at ±12%. The confidence level is moderate for the direction, magnitude and dispersion of change.

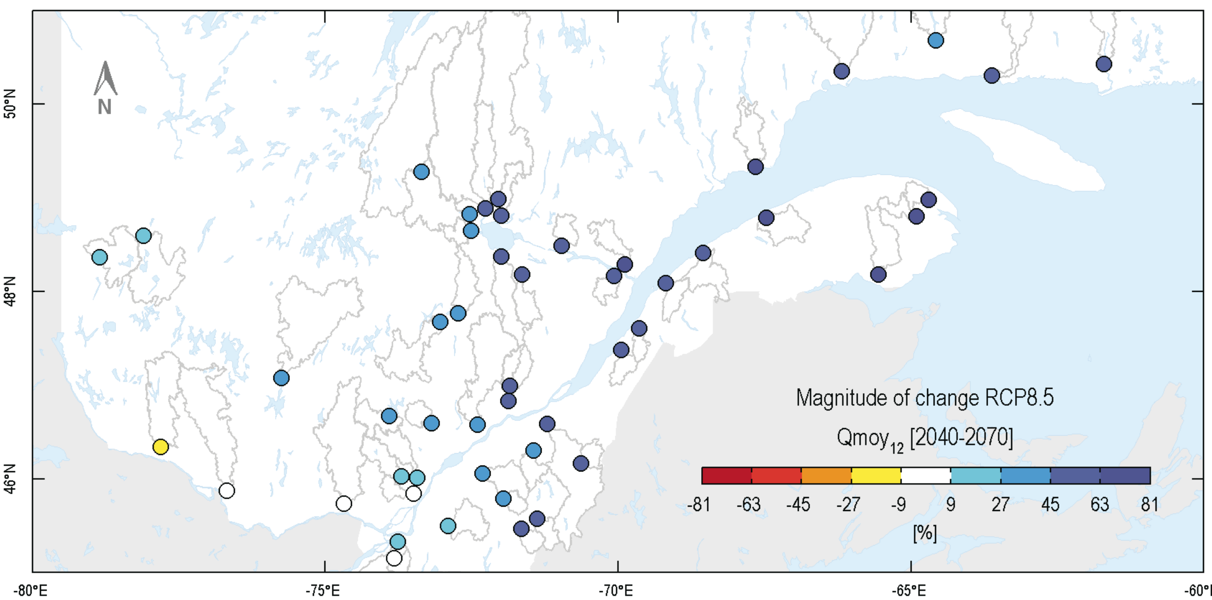
December mean flow

Average monthly flow









The $Qmoy_{12}$ hydrological indicator corresponds to average flow in December. For the 2050 horizon, projections describe a probable to highly probable increase in $Qmoy_{12}$ over a large portion of southern Québec in the order of +25% to +50% (RCP4.5) and that could reach +75% in the eastern part of southern Québec (RCP8.5). Dispersion is estimated at ±15%. The confidence level is high for the direction of change and moderate for magnitude and dispersion.

Photo: Sylvie Laurence

Methodology

Climate modeling

Climate models are numerical representations of interaction and feedback between the atmosphere, oceans, bodies of fresh water, the cryosphere, emerged land and the biosphere. In general, the so-called global climate models offer a rough spatial resolution using a vertical column grid built on a spherical base scaled to planetary dimensions (Figure 1). Climate models play an important role in analysing climate change by enabling the simulation of the impact of greenhouse gas increases on the climate. Such models simulate meteorological variables over lengthy continuous periods of time (temperature, precipitation, atmospheric pressure, humidity, sunshine, etc.). Climate changes are identified by comparing the statistical properties of these variables over distinct and sufficiently lengthy time periods–generally 30 years. For example, from 2041 to 2070, the average temperature in January would increase by 2 degrees Celsius compared to the 1970 to 2000 time span.

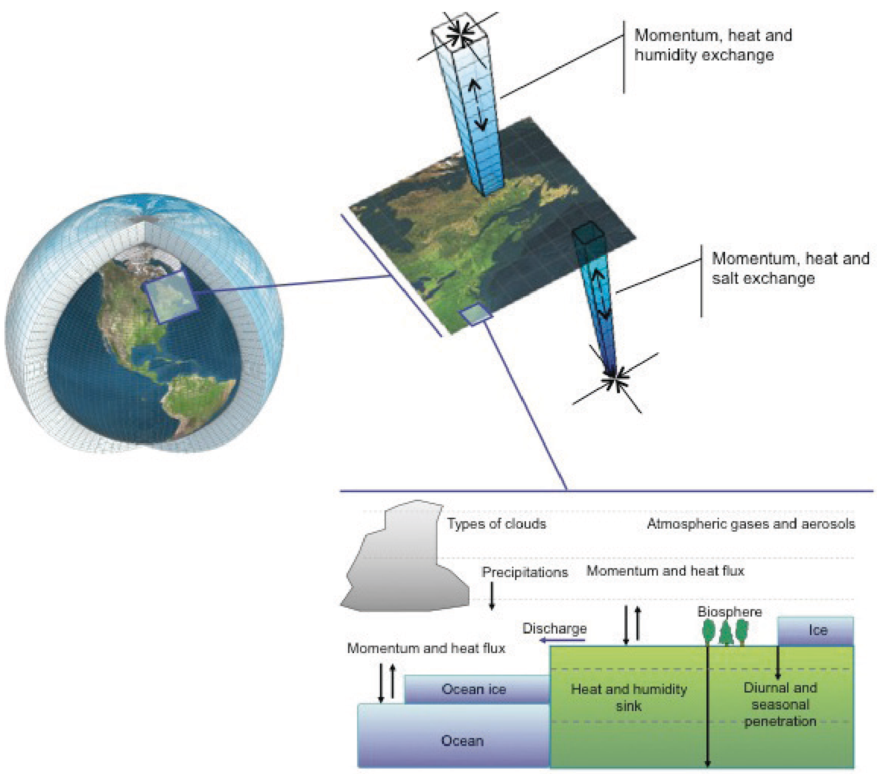


Figure 1: Schematisation of a global climate model

Source: CEHQ, adapted by [Online] [http://www.ipcc-data.org/guidelines/pages/gcm_guide.html]

The study of climate is different from meteorology, the latter being a science whose goal is to predict atmospheric conditions over a short time span (from several hours to 10 days). When using climate models, various sources of uncertainty need to be considered, the first and so-called implacable of which stems from the chaotic and random nature of atmospheric phenomena. Quantitative estimates of this uncertainty can be obtained by the production of climate members or simulations produced from a single climate model and a single RCP based on slightly differing initial conditions. A second source of uncertainty is bound to a future pathway of GHG emissions that will depend on human choices and policies, all of which are difficult to predict. In the end, the uncertainty stems from the fact that climate models are approximations of reality that imperfectly represent atmospheric and oceanic processes. These latter two types of uncertainty can be evaluated by using climate sets composed of a number of different models and RCPs.

Photo: Guy Brochu

Climate simulations

The 98 climate simulations used to produce the 2015 *Hydroclimatic Atlas* were derived from the Coupled Model Intercomparison Project - Phase 5 (CMIP5 – Taylor et al., 2012). These simulations were run using 3rd-generation Earth system models that incorporate a more complex representation of carbon cycle and cloud formation processes.

The potential evolution of greenhouse gas concentrations is represented by four Representative Concentration Pathways (RCP) (Van Vuuren et al., 2011). These pathways (Figure 2) were selected by the Intergovernmental Panel on Climate Change (IPCC) for its 5th Assessment Report, which was published in 2014. They lead to possible scenarios of the evolution of radiative forcing that represent the disequilibrium of energy between solar radiation that heats Earth and infrared radiation that escapes from the atmosphere. RCP8.5, for example, hypothesizes a radiative forcing of approximately 8.5 W/m^2 in 2100. Table 2 presents simulations derived from CMIP5 that were used to produce the 2015 *Hydroclimatic Atlas*. Simulations derived from RCP2.6 and RCP6.0 pathways (15 and 9 simulations respectively) were not selected due to their insufficient numbers. RCP2.6 is also deemed less realistic than the others and corresponds to an evolution of warming that is limited to less than 2°C. Available simulations for RCP4.5 and RCP8.5 respectively number 51 and 47. RCP4.5 is generally considered to be an optimistic scenario, while RCP8.5 is seen as a more pessimistic one.

The information contained in CMIP5 simulations corresponds to the dominant climate change current as established by the IPCC, and excludes outlier scenarios that involve feedback from anthropic GHG emissions such as a sudden and substantial melting of the Greenland Glacier. Finally, the CMIP5 simulations exclude natural events such as unusual volcanic eruptions that may temporarily alter climate projections.

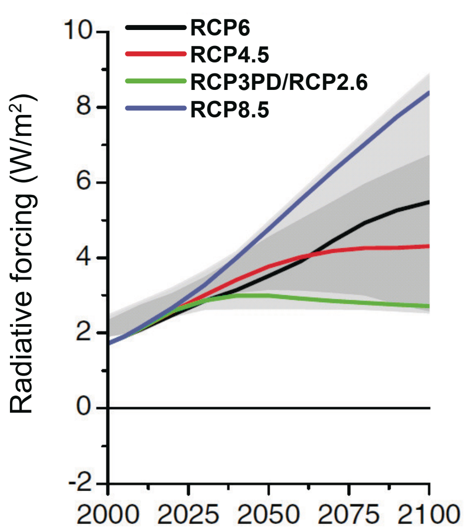


Figure 2: Radiative forcing related to Representative Concentration Pathways (RCP)

Source : [Online] [http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html].

Table 2: Climate simulations of CMIP5

Model	Institution	RCP4.5*	RCP8.5*
ACCESS1.0	CSIRO (Commonwealth Scientific and Industrial Research Organisation) and BOM (Bureau of Meteorology), Australia	1	1
ACCESS1.3		1	1
BCC-CSM1.1(m)	Beijing Climate Center, China Meteorological Administration, China	1	1
BCC-CSM1.1		1	1
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, China	1	1
CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada	5	4
CMCC-CESM	Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy	0	1
CMCC-CM		1	1
CMCC-CMS		1	1
CNRM-CM5	Centre National de Recherches Météorologiques/Centre Européen de Recherche et Formation Avancées en Calcul Scientifique, France	1	1
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation, in cooperation with the Queensland Climate Change Centre of Excellence, Australia	10	10
FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University, China	1	1
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, United States	3	1
GFDL-ESM2G		1	1
GFDL-ESM2M		1	1
GISS-E2-H	NASA Goddard Institute for Space Studies, United States	1	0
GISS-E2-R		1	0
IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France	4	4
IPSL-CM5A-MR		1	1
IPSL-CM5B-LR		1	1
INM-CM4	Institute for Numerical Mathematics, Russia	1	1
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology, Japan	3	3
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo) and National Institute for Environmental Studies, Japan	1	1
MIROC-ESM		1	1
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M), Germany	3	3
MPI-ESM-MR		3	1
MRI-CGCM3	Meteorological Research Institute, Japan	1	1
MRI-ESM1		0	1
NorESM1-M	Norwegian Climate Centre, Norway	1	1
	Total	**51**	**47**

* Number of climate members per simulation.

Post-processing

Variables simulated by climate models usually include statistical bias that may be manifested in excessively cold average temperatures or an excessive number of days of rain. In producing the 2015 *Hydroclimatic Atlas*, bias was corrected using two post-processing methods diagrammed in Figure 3: Quantile mapping, Figure 3a; and Delta quantile mapping, Figure 3b. Both methods are based on Mpelasoka and Chiew (2009). The purpose of quantile mapping is to correct the bias of simulated variables by comparing them to an observed climate reference state. Corrective factors are then produced for various quantiles and applied to the simulated variables. Delta quantile mapping evaluates the differences within the statistical properties of a single climate simulation by respectively isolating the reference and future periods. Delta factors are calculated for various quantiles and applied to the observations of the reference state in order to apply perturbation factors to the observed data set that reproduces the changes forecast by the climate simulation. The Natural Resources Canada data base (Hutchinson et al., 2009 and Hopkinson et al., 2011) spatially scaled up to CMIP5 global climate model sets was used as an observed climate reference state for post-processing climate simulations. A post-processed climate simulation is known as a climate scenario.

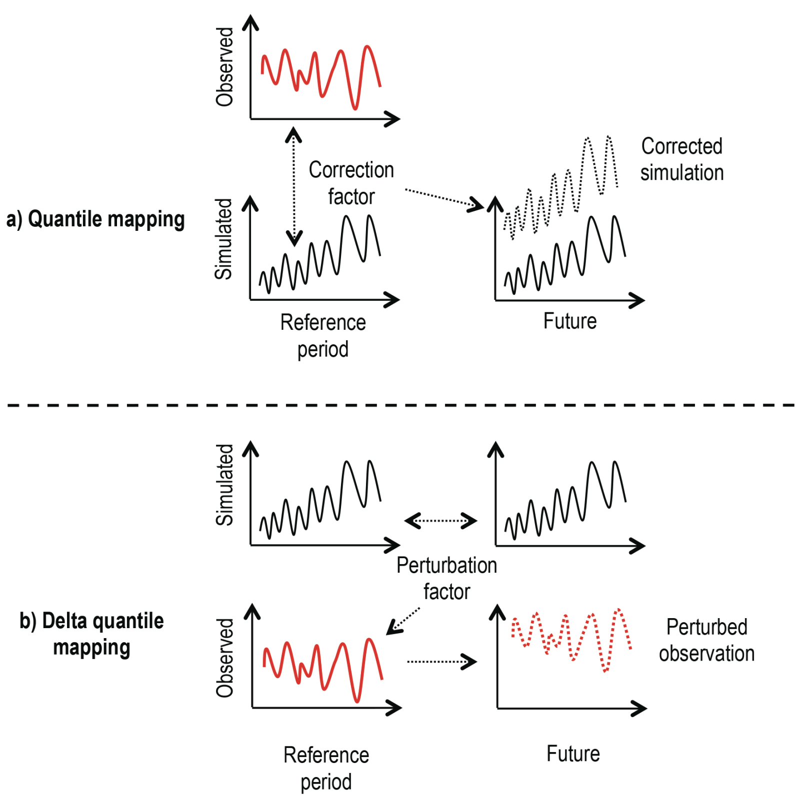


Figure 3: Diagram of post-processing methods used: (a) Quantile mapping; (b) Delta quantile mapping.

Hydrological modeling

The goal of hydrological modeling is to simulate river flow by reproducing the main components of the water cycle through a numerical representation of the hydrological processes that occur at the watershed level. In order to produce the 2015 *Hydroclimatic Atlas*, a large-scale modeling platform (CEHQ, 2014) was put in place using the Hydrotel hydrological model (Fortin et al., 2001). The platform simulated the following processes at the watershed level, starting with observed precipitation and temperature values: evapotranspiration, snowpack accumulation and melt, surface and subsurface runoff, river discharge. The platform was calibrated for 50 gauged watersheds (Table 3) using a global calibration approach (Ricard et al., 2012). These particular watersheds are associated with uninfluenced discharge from watercourses, meaning that they are not impacted by the operation of upstream dams. They are all located within southern hydrological Québec, an area of some 726,000 km^2 that covers the watersheds of the St. Lawrence and Ottawa River tributaries, as well as the rivière Saguenay and the Gaspésie, Côte-Nord and part of the Abitibi-James Bay regions (Figure 4). The modeling excluded the upstream (Ontario) portion of the St. Lawrence River basin but did include the portions of the Ottawa River and the rivière Richelieu not located within Québec.

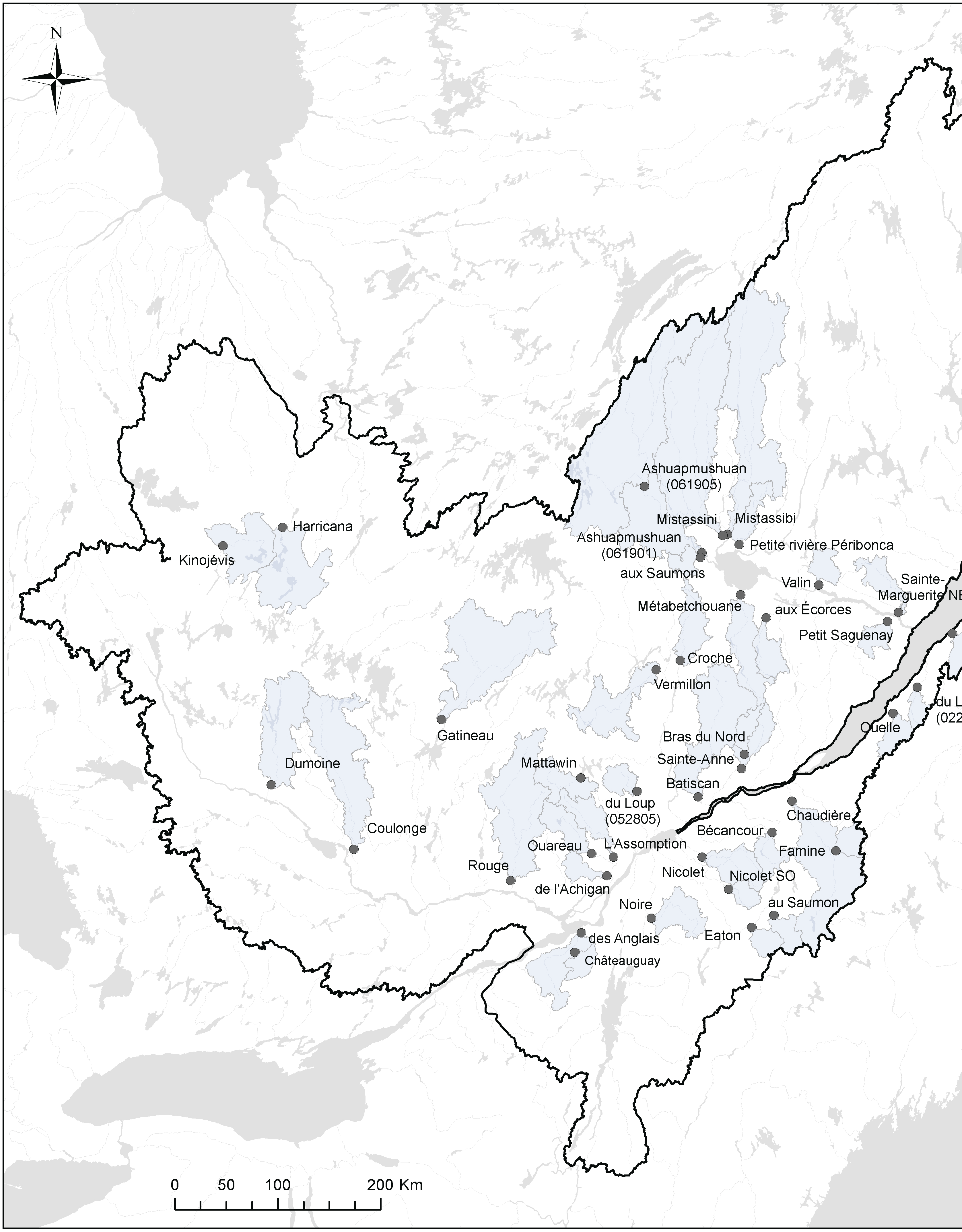
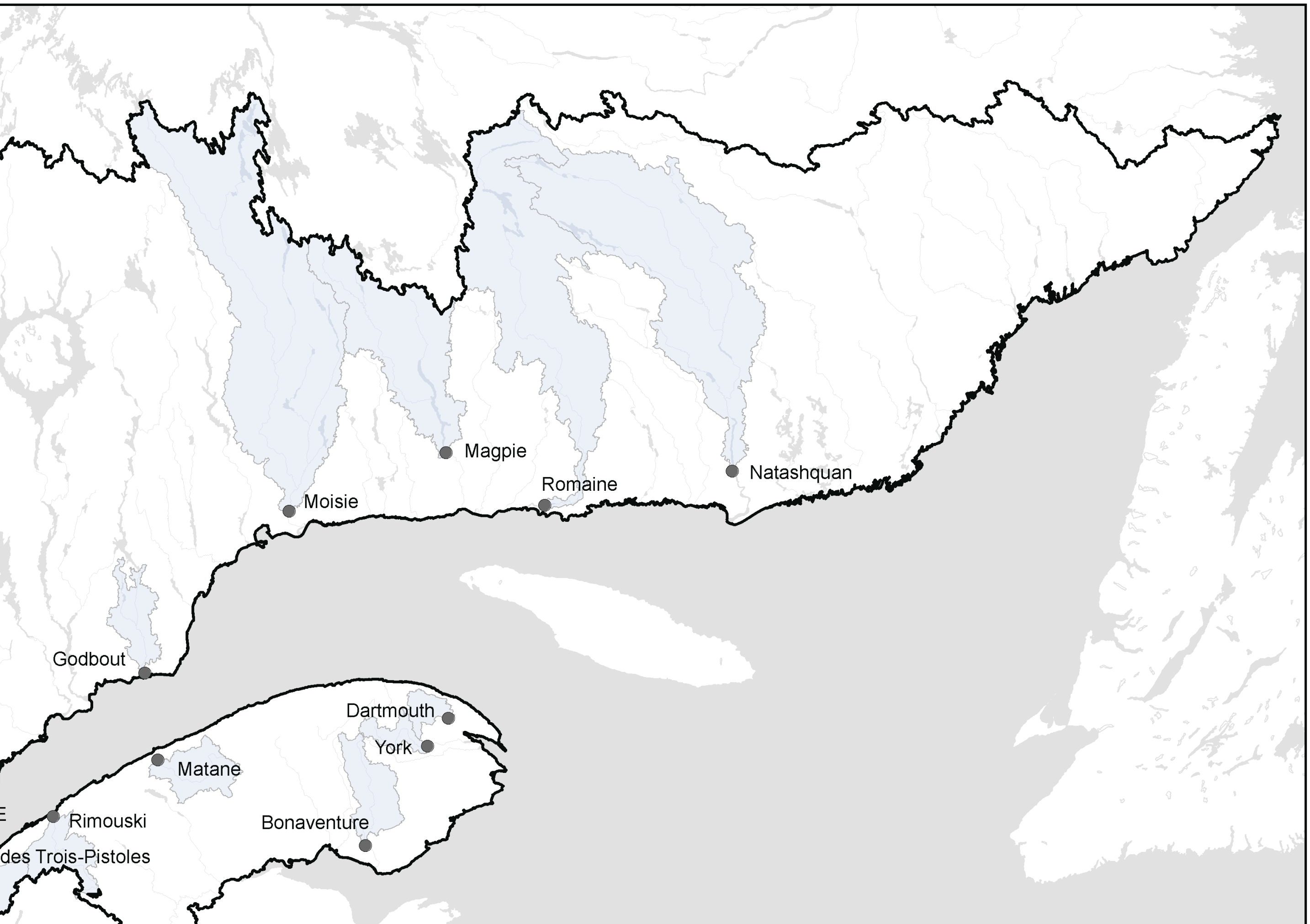


Figure 4: Southern hydrological Québec



Station	Name	Area (km²)	Station	Name	Area (km²)
061901	Ashuapmushuan	15348	043012	Kinojévis	2586
061905	Ashuapmushuan	11202	052219	L'Assomption	1285
030282	Au Saumon	736	061502	Métabetchouane	2198
061020	Aux écorces	1107	073503	Magpie	7100
061909	Aux Saumons	584	021601	Matane	1636
024003	Bécancour	916	050119	Mattawin	1384
050304	Batiscan	4459	062101	Mistassibi	8681
010802	Bonaventure	1894	062102	Mistassini	9523
050409	Bras du Nord	642	072301	Moisie	18754
030905	Châteauguay	2513	074903	Natashquan	15229
023402	Chaudière	5828	030103	Nicolet	1548
041301	Coulonge	5159	030101	Nicolet Sud-Ouest	549
050135	Croche	1552	030304	Noire	1505
020602	Dartmouth	627	052212	Ouareau	1262
052233	De l'Achigan	633	022704	Ouelle	776
030907	Des Anglais	645	060101	Petit Saguenay	696
022301	Des Trois-Pistoles	926	061801	Petite rivière Péribonca	1005
022507	Du Loup	512	022003	Rimouski	1587
052805	Du Loup	761	073801	Romaine	12925
041902	Dumoine	3736	040204	Rouge	5470
030234	Eaton	648	050408	Sainte-Anne	1540
023422	Famine	695	062802	Sainte-Marguerite NE	1097
040830	Gatineau	6797	062701	Valin	761
071401	Godbout	1573	050144	Vermillon	2653
080101	Harricana	3678	020404	York	664

Change signals

The hydrological projections were produced by piloting the modeling platform with CMIP5-derived climate scenarios. Analysis of the change signal proceeded on the basis of a hydrological indicator, which is a mathematical expression that quantifies a given hydrological characteristic of interest. For each hydrological projection, indicators were respectively numerically evaluated for a reference period (1971-2000) and a future period (2041-2070). The difference (Δ) between the two values corresponds to a relative change in the indicator between the historical climate reference and the future climate. A distribution of change values can be produced for any given set of hydrological projections. In the 2015 *Hydroclimatic Atlas*, the change values stemming from the various members of a single climate model set were averaged in order to avoid overrepresentation of the model within the set of change values (Knutti, 2010).

Indicator-associated change signals are presented using three main descriptors (Figure 5). These are the direction of change, which corresponds to the proportion (P) of hydrological projections that anticipate an increase ($\Delta > 0$) or decrease ($\Delta < 0$). in the indicator. The magnitude of change corresponds to the median value (Δ_{50}) of the set of change values. The dispersion of the signal around the magnitude is evaluated by the interquartile envelope (Δ_{75} - Δ_{25}), which includes half of the probable values that surround the median value (Δ_{50}).

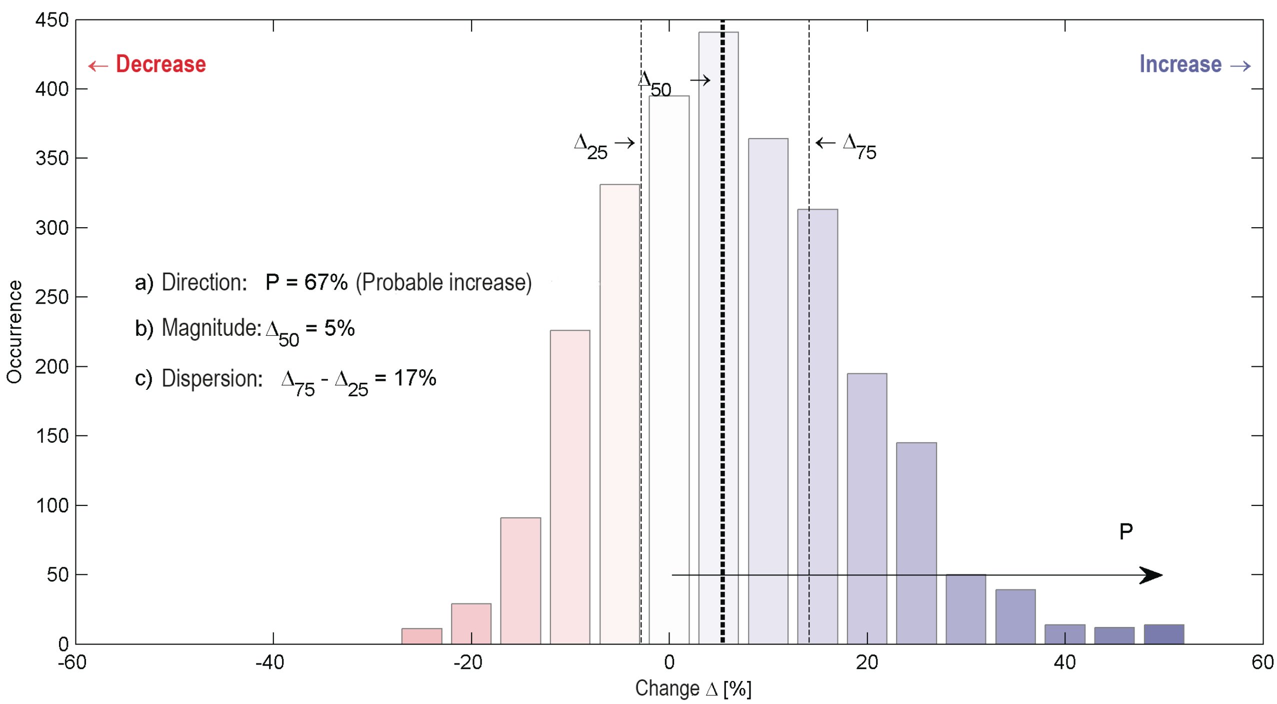


Figure 5: Hydrological change signals

The direction and magnitude of change are shown in the 2015 *Hydroclimatic Atlas* in map form for each indicator. Directions incorporate RCP4.5 and RCP8.5 values without distinguishing between the two and are qualified on the basis of consensus among the hydrological projections presented in Table 3. However, magnitude is presented separately for scenarios RCP4.5 and RCP8.5. Dispersion is shown in the descriptive text of the direction and magnitude maps and corresponds to the average dispersion values measured on all sites for a given hydrological indicator.

Table 3: Terms used to describe direction of changes

Direction	Consensus of hydrological projections
Highly probable increase	More than 90% of hydrological scenarios indicate an increase
Probable increase	From 66% to 90% of hydrological scenarios indicate an increase
	From 33% to 66% of hydrological scenarios indicate an increase or decrease
Probable decrease	From 66% to 90% of hydrological scenarios indicate a decrease
Highly probable decrease	More than 90% of hydrological scenarios indicate a decrease

Photo: Guy Brochu

Confidence level

Complementary to the notion of uncertainty, confidence level is acknowledged in the scientific literature (cf., Beven et al., 2014; Refsgaard et al., 2014). The assessment of confidence levels is an addition to the 2015 edition of the *Hydroclimatic Atlas*. The explicit assessment of the value of information shown enables users to adapt and use it appropriately for their own purposes.

Confidence levels shown in the *Atlas* are first and foremost based on expert opinion, which in turn relies on the capacity of the hydroclimatic modeling chain to adequately reproduce observed flows and their variability. The confidence level is not defined in absolute terms, but rather by comparing hydrological indicators. For any given indicator, the confidence level is generally higher for the direction of change than for scope and dispersion. As such, high, moderate or limited confidence levels may be allocated to the direction, scope and dispersion of changes.

Generally speaking, the confidence level is higher for indicators associated with large-scale spatial hydroclimatic processes over lengthy time periods–for example, processes related to snowpack melting and synoptic precipitation. Contrariwise, the confidence level is lower for heterogeneous processes over short periods of time, such as convective precipitation and summer and autumn high flow in small watersheds.

Photo: Caroline Anderson

Bibliographical references

Beven, K., R. Lamb, D. Leedal and N. Hunter, 2014. "Communicating uncertainty in flood inundation mapping: a case study." *International Journal of River Basin Management*, pp. 1-11.

Centre d'expertise hydrique du Québec (CEHQ), 2013. *Atlas hydroclimatique du Québec méridional – Impact des changements climatiques sur les régimes de crue, d'étiage et d'hydraulicité à l'horizon 2050*. Québec, 2013, 51 pp.

Centre d'expertise hydrique du Québec (CEHQ), 2014. *Plateforme de modélisation hydrologique du Québec méridional*. Québec, 20 p. et annexes. Rapport technique.

Fortin, J. P., R. Turcotte, S. Massicotte, R. Moussa et J. Fitzback, 2001. "A Distributed Watershed Model Compatible with Remote Sensing and GIS Data. Part 1: Description of the Model", *Journal of Hydrologic Engineering* – ASCE, vol. 6, #2, pp. 91-99.

Intergovernmental Panel on Climate Change (IPCC), 2014. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Hopkinson, R. F., D.W. McKenney, E. J.Milewska, M. F. Hutchinson, P. Papadopol and L. A. Vincent, 2011. "Impact of Aligning Climatological Day on Gridding Daily Maximum-Minimum Temperature and Precipitation over Canada." *Journal of Applied Meteorology and Climatology*, #50, pp. 1654-1665.

Hutchinson, M. F., D. W. McKenney, K. Lawrence, J. H. Pedlar, R. F. Hopkinson, E. Milewska and P. Papadopol, 2009. "Development and testing of Canada-Wide Interpolated Spatial Models of Daily Minimum-Maximum Temperature and Precipitation for 1961-2003." *American Meteorological Society* (April), pp. 725-741.

Knutti, R., G. Abramowitz, M. Collins, V. Eyring, P. J. Gleckler, B. Hewitson, and L. Mearns, 2010. "Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections," in T. Stocker et al. (ed.), *Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Assessing and Combining Multi Model Climate Projections*. Université de Berne, Switzerland.

Mpelasoka, F.S. and F. H. S. Chiew, 2009. "Influence of Rainfall Scenario Construction Methods on Runoff Projections." *Journal of Hydrometeorology*, #10, pp. 1168-1183.

Refsgaard, J. C., H. Madsen, V. Andréassian, K. Arnbjerg-Nielsen, T. A. Davidson, M. Drews, D. P. Hamilton, E. Jeppesen, E. Kjellström, J. E. Olesen, T. O. Sonnenborg, D. Trolle, P. Willems and J. H. Christensen, 2014. "A Framework for Testing the Ability of Models to Project Climate Change and its Impacts." *Climatic Change*, 122(1-2), pp. 271-282.

Ricard, S., R. Bourdillon, D. Roussel and R. Turcotte, 2013. "Global Calibration of Distributed Hydrological Models for Largescale Applications." *Journal of Hydrologic Engineering*, 18(6), pp. 719-721.

Taylor, K. E., R. J. Stouffer and G.A. Meehl, 2012. "An overview of CMIP5 and the Experiment Design." *Bulletin of the American Meteorological Society*, 93(4), pp. 485-498.

Van Vuuren, D. P.,J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G. C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Mausi, M. Meinshausen, N. Nakicenovic, S. Smith and S. K. Rose, 2011. "The Representative Concentration Pathways: An Overview." *Climatic Change*, 109(1-2), pp. 5-31.

Photo: Gaston Lyrette

Acknowledgements

Our thanks go to the World Climate Research Programme's Working Group on Coupled Modelling for its CMIP initiative and to the modeling teams (see list in Table 2, page 68) for their production and distribution of climate simulations. The U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison supports CMIP coordination and the development of computer infrastructures in collaboration with the Global Organization for Earth System Science Portals.

We also thank the member organisations of cQ2 (Ouranos, Hydro-Québec and Rio Tinto Alcan) as well as the Institut national de la recherche scientifique's Centre Eau Terre Environnement, the École de technologie supérieure and Université Laval. We thank the University of Munich and the Bavarian Environmental Agency for their involvement in QBic3 (Quebec-Bavaria International Collaboration on Climate Change) and their scientific and technical contributions.

Finally, we thank the members of the scientific committee for their enlightened comments on the identification of good modeling practices that led to the production of the *Atlas*. We underline the crucial nature of data banks of climate observations and flow in Québec rivers, without which this work would have been impossible to achieve.

In particular, our thanks go to Marco Braun, Étienne Foulon, Blaise Gauvin St-Denis, David Huard, Martin-Pierre Lavigne, Dominic Roussel and Stéphane Savary.

The costs of producing the *Atlas* were paid by the Green Fund as part of the implementation of the Government of Québec's 2013-2020 Climate Change Action Plan.

We dedicate this work to the memory of Jacques Lacasse.

Centre d'expertise hydrique

Québec

OURANOS

7456-15-05