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The United Nations World Water Assessment Programme

Scientific Paper

A Multi Model Experiment to Assess and Cope with Climate Change Impacts on the Châteauguay Watershed in Southern Québec

Luc Vescovi, Diane Chaumont, Ralf Ludwig, Marco Braun, Inga May, Wolfram Mauser, Jean-François Cyr, Richard Turcotte and Louis-Guillaume Fortin

Ouranos Consortium

United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

The United Nations World Water Development Report 3
Water in a Changing World

Coordinated by the World Water Assessment Programme, the *United Nations World Water Development Report 3: Water in a Changing World* is a joint effort of the 26 United Nations agencies and entities that make up UN-Water, working in partnership with governments, international organizations, non-governmental organizations and other stakeholders.

The United Nations' flagship report on water, the WWDR offers a comprehensive review of the state of the world's freshwater resources and provides decision-makers with the tools to implement sustainable use of our water. The WWDR3 represents a mechanism for monitoring changes in the resource and its management and tracking progress towards achieving international development targets. Published every three years since 2003, it offers best practices as well as in-depth theoretical analyses to help stimulate ideas and actions for better stewardship in the water sector.

Water in a Changing World has benefitted from the involvement of a Technical Advisory Committee composed of members from academia, research institutions, non-governmental organizations, and public and professional organizations. To strengthen the scientific basis and potential for implementation of its recommendations, interdisciplinary expert groups were also created for a number of topics, including 'Indicators, Monitoring and Databases', 'Business, Trade, Finance and Involvement of the Private Sector', 'Policy Relevance', 'Scenarios', 'Climate Change and Water', 'Legal Issues' and 'Storage'. An accompanying case studies volume, Facing the Challenges, examines the state of water resources and national mechanisms for coping with change in 23 countries and numerous small island developing states.

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Sectors and topics to which water is cross-cutting or important will be covered in this series of side publications. Some examples of subjects discussed in this collection of reports include climate change, security, biodiversity, poverty alleviation and land use.

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A Multi-Model Experiment to assess and cope with Climate Change impacts on the Châteauguay watershed in southern Québec

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Abstract

This paper discusses how participatory hydro-climatological modelling can be used to assess specific water issues on the Châteauguay watershed in southern Québec. It looks at different model responses regarding water budget dynamics, with a focus on summer water shortages and irrigation needs. It aims to stimulate water authorities' and managers' thoughts about climate-change adaptive planning options. The methodologies developed involve the use of a regional climate model providing climate information subsequently incorporated as forcing input (a) to two hydrological models (Hydrotel and Promet) and (b) to the FAO irrigation model.

Results show that in climate-change scenarios for a 2050 time horizon, summer flows are projected to decrease while irrigation needs appear to increase considerably. The lesson learned from this modelling exercise reinforces the principle of forward-thinking, adaptive watershed-management strategies (regarding, in this case, water volume management for irrigation purposes). This exercise also shows that before proposing any adaptive solution, the issue needs to be assessed scientifically (in terms of water budget as well as in the socioeconomic domain) to evaluate the uncertainties of climate-change impact analysis, with respect to the multi-usage and integrated watershed management contexts of southern Québec.

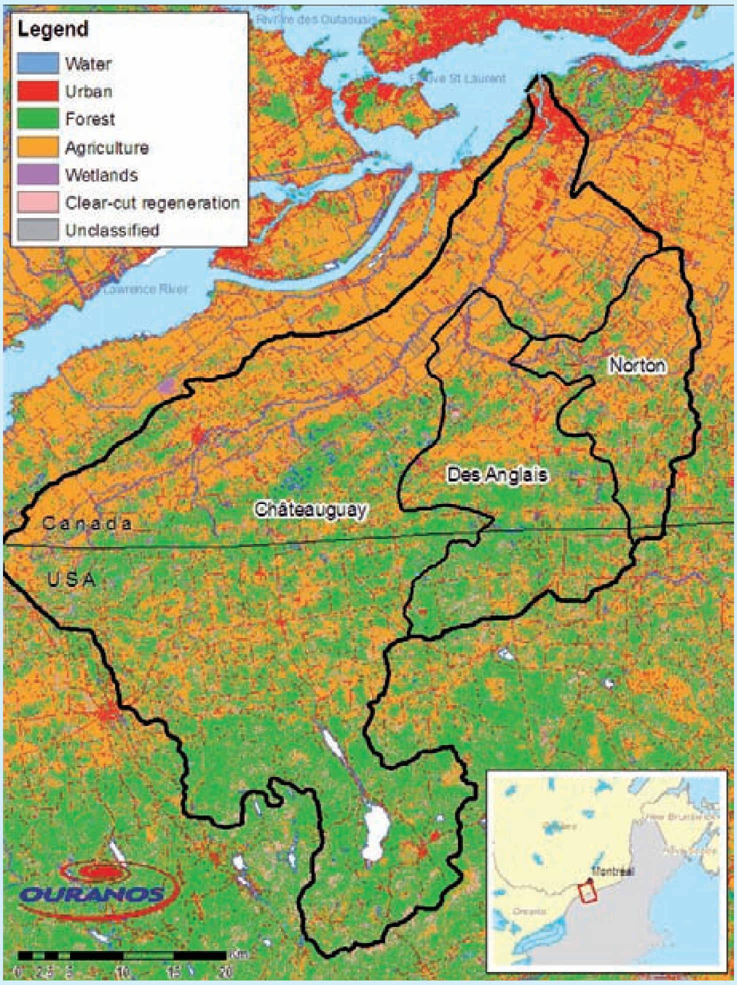
Climate-change context

Climate change is in progress and affects many economic, social and ecological developments. In Southern Québec, Yagouti et al. (2008) show that the surface air temperature has increased during the period 1960–2005 and that this warming is significantly evident in the western, southern and central parts of the province. In the summer, significant increasing temperature trends are found and precipitation indices indicate decreasing trends. Climate-change scenarios produced at Ouranos show that in the future, summer temperature will increase while no significant change is obtained for precipitation amount. This could lead to pronounced alterations in the seasonal water budget, putting increasing pressure on summer water availability and usage. Thus, reliable assessment of the potential climate-change impacts is necessary on a regional level. Suitable adaptation strategies must be developed in order to minimize adverse effects and to optimize possible benefits on water management issues. These adaptation schemes may profit largely from the careful integration of scientific model results into the decision processes of policy-making entities on different levels (Brugnach et al., 2007). This is not an easy task due to the manifold perspectives and interests in these issues. This paper discusses management issues arising from increasing agricultural water requirements under stressed water conditions, with the aim of optimizing possible benefits.

Site area description and water management context

Located south-west of Montreal (Canada), the Châteauguay River watershed extends on both sides of the Québec-New York State border. Figure 1 shows the main land use characteristics of the watershed, which encompasses approximately 2,540 km², with some 55 % of the catchment area in Canada and the remaining 45 % in the USA. From the mountainous regions of the Adirondacks, the Châteauguay River heads north covering, in Québec, the Saint-Lawrence Lowlands pedological province, before entering the Saint Lawrence River at the city of Châteauguay. The watershed is mainly occupied by forest and agriculture, which cover 38% and 34% respectively. The forest is mainly located on the US side. In Québec, the region is relatively densely populated with approximately 100,000 habitants and nearly 60% of the territory is covered by agricultural uses. In terms of cultivated areas, corn and soya bean occupy half the surface area.

Figure 1 **Châteauguay River Watershed**

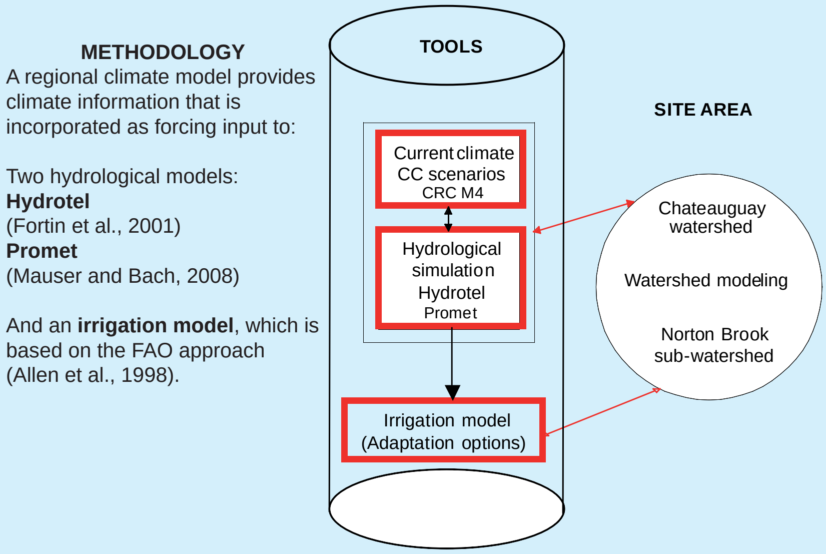


More specifically, the study deals with the Norton Brook sub-watershed, itself a sub-basin of the des Anglais River watershed (a tributary of the Châteauguay River). In the Norton River sub-watershed, vegetable farming occupies a major part of the cultivated areas, making this region the major vegetable producer in Québec.

The consequent application of significant amounts of chemical fertilizer constitutes a major concern in terms of water quality. In addition, vegetable farming is also a very important irrigation water user, and thus also comprises a quantitative water management issue. According to the Québec Ministry of Agriculture, Fisheries and Food (MAPAQ), 75% of the total water intake for irrigation on the Norton sub-watershed is provided by groundwater and the rest is provided by surface water, taken from the Norton Brook and its small tributaries. Most of the surface water supply is withdrawn by setting up local dams on many of these small watercourses in order to create small water ponds dedicated to irrigation purposes. All these small structures are currently managed on an individual and local basis, ruling out any overall watershed-based vision.

In terms of water management, the option of irrigating cultivated lands with high-quality groundwater gives rise to much controversy. However, using surface water taken directly from the watercourse or from small dams or ponds along the rivers also has its disadvantages. Indeed, on the one hand, using surface water that has been significantly impaired by agricultural nonpoint source (NPS) pollution can be very troublesome for crops, and on the other hand, direct surface water intake could impact the river's entire ecosystem – particularly during the extreme low ow conditions of the summer months . Thus, what is required is integrated and tailored water management that respects all users, from the vegetable farmers to the ecosystem. This has to be studied carefully taking into consideration that anthropogenic climate change might exacerbate water-use issues. In fact, a preliminary study on the Norton Brook watershed, using climate prediction from GCM runs forecast that under climate-change scenarios for 2050, summer low ows will decrease while irrigation needs will increase dramatically (Pugin et al., 2005). Based on the hypothesis that a constant rate of 25% of irrigation water would continue to be taken from surface water, a preliminary quantitative impact assessment allows us to conclude

Figure 2 **Schematization of the methodology used to assess potential climate-change impacts on the Châteauguay and Norton Brook watersheds**



Note: Regions are official UN regions. Source: International Institute for Applied Systems Analysis.

that, under such expected future climate conditions, the current way of providing and managing water for irrigation purposes from the Norton Brook could no longer respect current minimum ecological flow requirements. Therefore, forward-thinking, adaptive water-management strategies must focus on respecting multiple uses.

Scope of the study

The scope of this study is to investigate how hydro-climatological modelling can be used to assess specific water issues in the Châteauguay watershed in southern Québec. Thus, it aims to look at different model responses regarding summer water shortages and irrigation needs. The results will inform and inspire the views of water authorities (e.g. Centre d'expertise Hydrique du Québec [CEHQ] in its execution of the watershed's Hydrotel simulation) and provide a tool to facilitate provincial managers' reflections about climate-change adaptive planning options in a context of conflicting water use management. In this regard, it follows the notions of adaptive management (Pahl-Wostl, 2007) and a 'participatory modelling' approach (Olsson and Andersson, 2007), and intends to demonstrate how hydro-climatological modelling supports, builds and enhances water managers' knowledge as they examine climate-change adaptation options. The study is a bilateral Québec-Bavaria collaboration, set up between the Department of Geography at the Ludwig Maximilian University of Munich (LMU) and the Ouranos consortium in Montreal. It sets out to pinpoint existing limitations and highlight the research that's still needed in the field of integrated climate-change sciences. The lessons learned from this multi-model experiment on the Châteauguay River Watershed are addressed in more detail in Vescovi et al. (2008).

Methodology

As illustrated in Figure 2 above, the methods and procedures developed in this study involve the use of a regional climate model providing climate information that is subsequently incorporated as forcing input to three different computational tools. The first two are hydrological models of differing complexities: Hydrotel (Fortin et al., 2001) and Promet (Mauser and Bach, 2008) and the third is, an irrigation model based on the FAO computational approach (Allen et al., 1998). To cover the Châteauguay River basin region, ten grid cells of the Canadian Regional Climate Model (CRCM) (45km) grid were selected. The CRCM (version 4.1.1, CRCM4) driven by the Canadian Global Circulation Model version 3 (CGCM3) (following IPCC 'SRES A2' scenarios) was used. Regarding the temporal structure of input data, the information for Hydrotel and the irrigation model is provided on a daily basis. For Promet (a process-based uncalibrated environmental model), data were provided at a higher time scale resolution.

Results

Hydrological modelling

Hydrological modelling results calculated by the different models used within the experiment (CRCM, Hydrotel, and Promet) are represented in Figures 3 to 6. Each figure illustrates the spatially explicit patterns of water balance terms in the Châteauguay as obtained by (a) the CRCM version 4 model (coarse 45km resolution), (b) the Hydrotel model (using relatively homogenous hydrological units/sub-basins, with a mean RHHU value of 2.5 km^2) and finally, (c) the Promet model working on an isotropic grid at a higher resolution of 100m. Thus a strong gradient of spatial resolution is inherent in the model comparisons. In this modelling framework, different levels of

Figure 3 **Evapotranspiration for the reference period (1961–1990)**

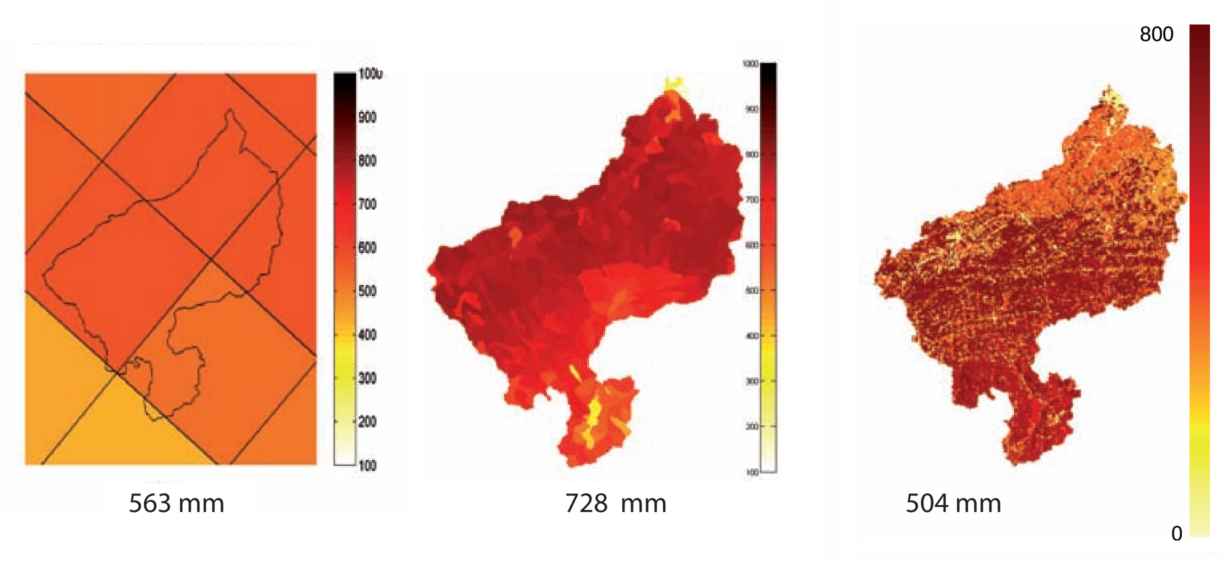
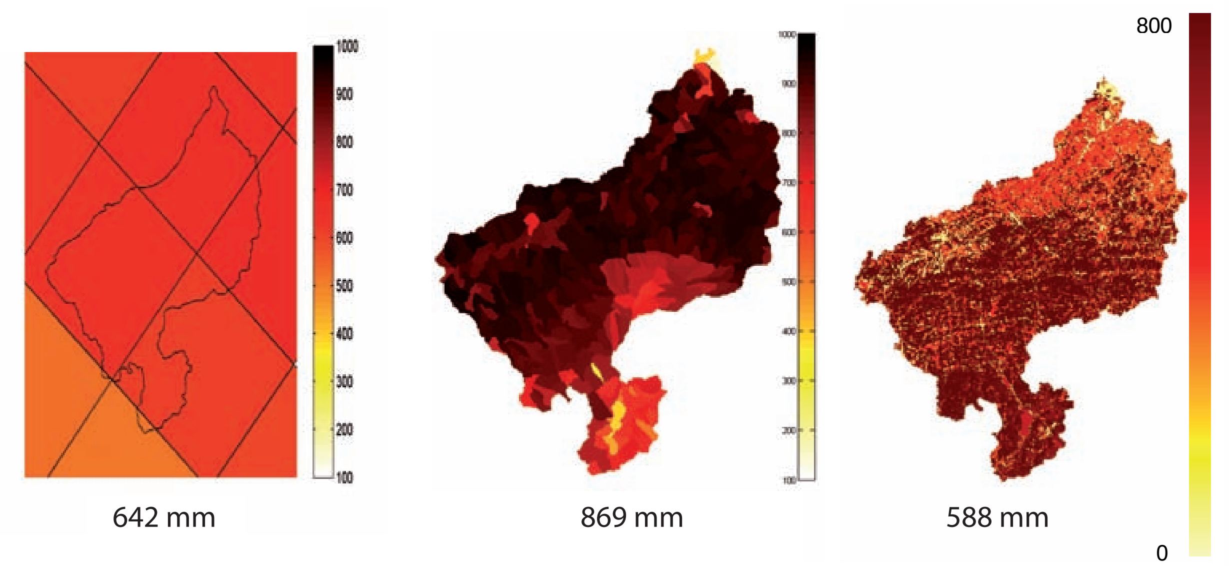


Figure 4 **Evapotranspiration for the future period (2041–2070)**



model complexity are introduced. Hydrotel, being the least complex model in terms of process descriptions, has long been successfully applied in operational water balance and flood forecasting in Québec.

Strong quantitative deviations in the results are apparent. These may be traced back to the use of different process descriptions and the discrepancies in spatial and temporal scale. However, all the models show that in a climate-change context for the time horizon 2050 of these models in southern Québec watersheds, evapotranspiration increases (Figure 3 and Figure 4) and runoff decreases (Figure 5 and Figure 6). Thus an intensification of water stress conditions can be expected in terms of both frequency and duration.

Irrigation needs modelling

The next step of this modelling exercise looks at the possibility of using Hydrotel within a modelling chain to assess a socioeconomic-sensitive issue in southern Québec related to summer water shortages and irrigation needs.

Irrigation needs under current conditions and expected changes by 2050 were assessed using Hargreaves' equation (FAO, 1998). Regarding the assessment of irrigation needs under current climate conditions, Figure 7 shows the underestimation made when using CRCM4 data (under current conditions forced by CGCM3) as input data compared with what is obtained by using meteorologically

Figure 5 **Runoff for the reference period (1961–1990)**

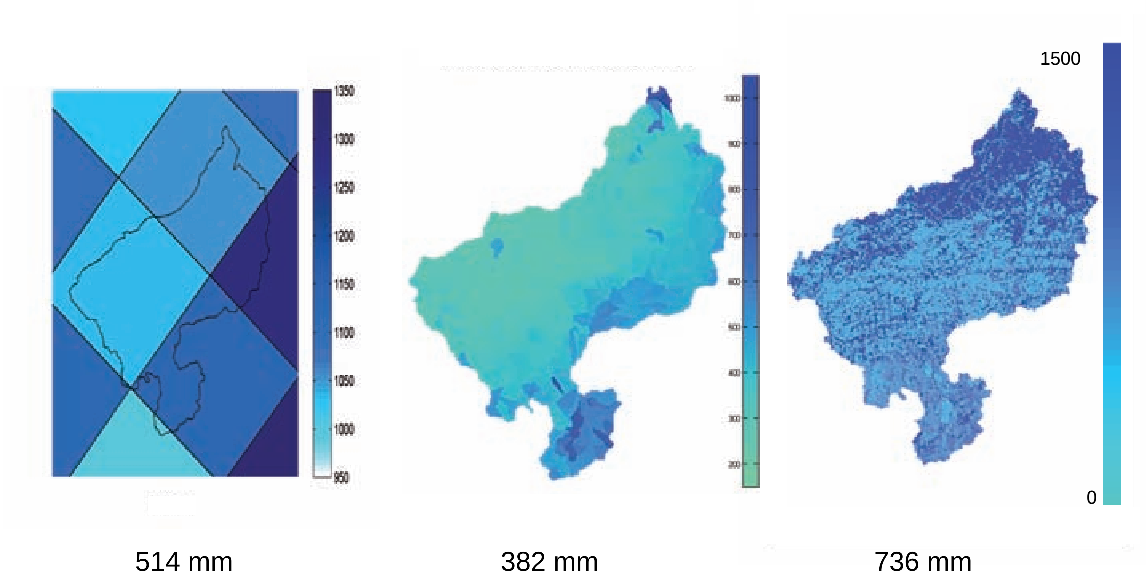
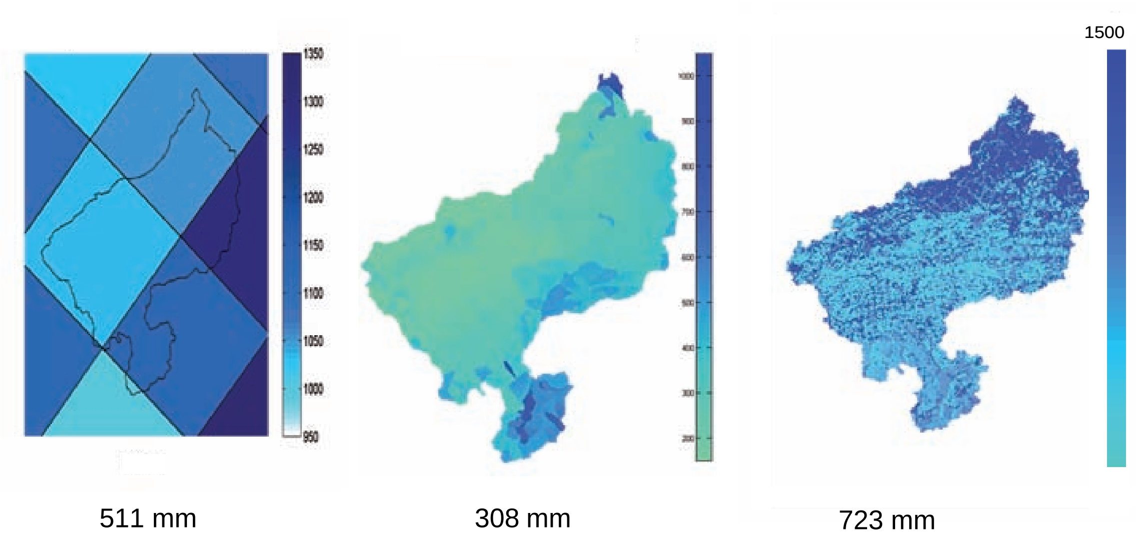


Figure 6 **Runoff for the Future period (2041–2070)**



observed data. The assessment of changes in irrigation needs due to climate change simulations using current and future data provided by CRCM4 forced by CGCM3. As illustrated Figure 8, the exercise showed that irrigation needs are expected to increase by about 30%, which imposes a need to adapt current water-management strategies.

Discussion and conclusion

This paper presents research developed during a two year pilot collaboration between Ouranos and LMU. Applied integrated watershed research in an anthropogenic climate-change context was performed to improve the scientific knowledge for evaluating innovative watershed-adaptation strategies in Bavaria and Québec.

It discusses a multi-model, hydro-climatological experiment performed using CRCM4, Promet, Hydrotel and the FAO irrigation model on the Québec Châteauguay River basin. This methodology appears to be very useful within a watershed management context for adaptation to climate change and especially for water quantity and irrigation issues. The main conclusion of this modelling exercise is that in an anthropogenic climate-change context for the time horizon 2050 in southern Québec watersheds, evapotranspiration increases and runoff decreases, enhancing water stress conditions. Irrigation needs are expected to increase dramatically by approximately 30% for the 2050 time horizon, while low flow conditions in watercourses are expected to become more severe. These conclusions not only confirm those obtained in earlier studies, they stress the intensity of the results and thus bring to light the need for a new, integrated water management approach to be implemented at the watershed scale. Such an approach should take into account the seasonality of the hydrological flow regime and the corresponding ecological requirements, in combination with the seasonal variations and distribution of water uses in the watershed

However, the modelling exercise also highlights several unanswered questions concerning the level of complexity required in a model in order for it to be used as a reliable management tool. One question concerns the fundamental issue of hydrological calculations performed by supplying climate-change-scenario data to a hydrological model that is calibrated to current climate conditions (Hydrotel). In that sense, a more complex, process-based hydrological model that performs well without any calibration might be more scientifically suitable for climate-change predictions. On the other hand, the study shows us that the best 'operational' tool is not necessarily the most complex, but the one that can work with available data sets and is designed for use by local water agencies and stakeholders, who then can easily 'translate' these modelling results into management recommendations.

This study presents and proposes a 'participatory modelling' approach based on water sciences to build and enhance our knowledge and to set milestones for water managers as they examine climate-change adaptation options. In this regard, the approach is one of adaptive management, where learning to manage a system also involves learning new scientific methods and practical tools for assessment and action-implementation. As illustrated by Figure 9, dealing with climate-change issues and thus working with climate scenarios (from climate models) adds another level of complexity and uncertainty.

These issues need to be clearly understood by stakeholders. In the course of this pilot project, the prioritization of case studies was discussed among watershed stakeholders (CEHQ, MAPAQ, and the local watershed agency). Enabling water authorities and water researchers to set up a platform to work with climate-change modelling tools and to deal with an uncertain future is an important achievement of this multi-model experiment.

This pilot project should be continued. Further investigations testing more complex models are needed to reinforce our knowledge-base and increase our capacity to examine complex water budgets and uses. For example, complex models such as Promet are powerful tools in addressing specific issues in biophysical water-related processes, but to put them into operational use in Québec's water resources management requires further investigation and more data. Further research must narrow the margins

Figure 7 **Irrigation needs (using Hargreaves' equation FAO, 1998) simulated for the reference period (1961–1990)**

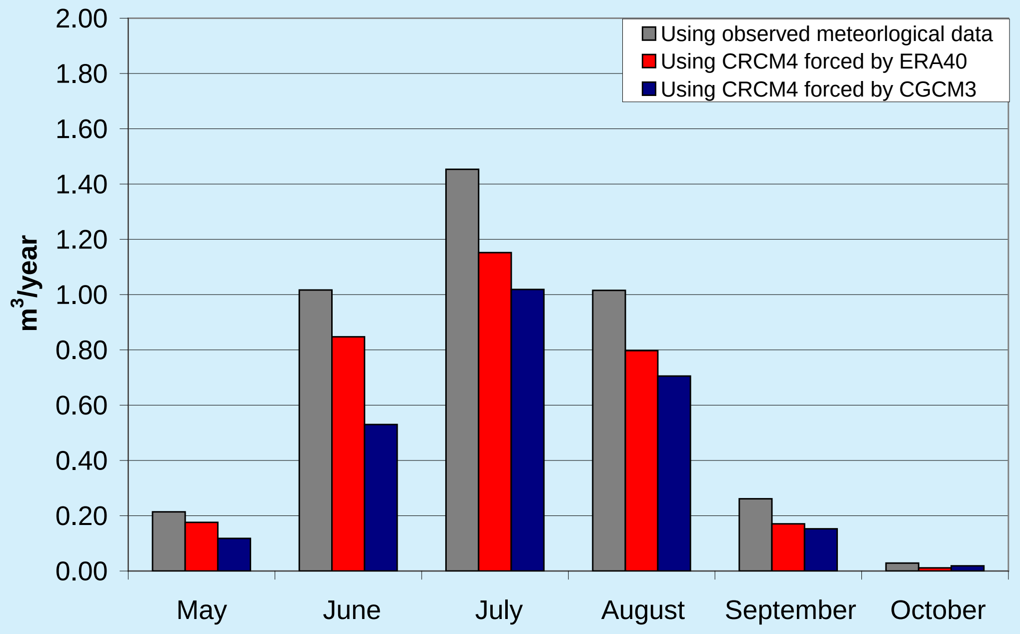


Figure 8 **Changes in irrigation needs (using Hargreaves' equation FAO, 1998) between the reference period (1996–1990) and the future period (2041–2070)**

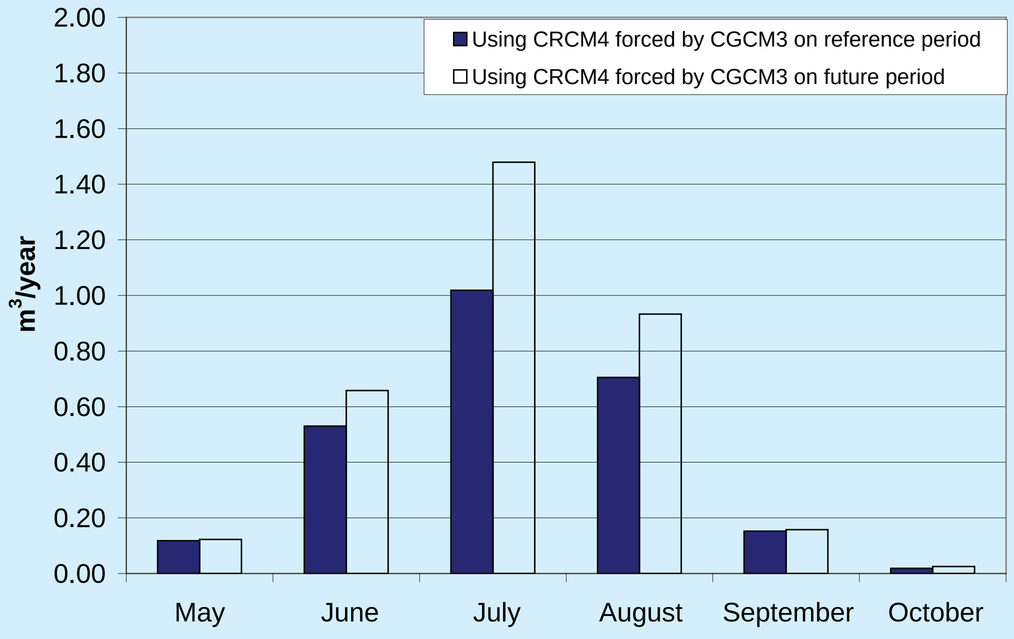
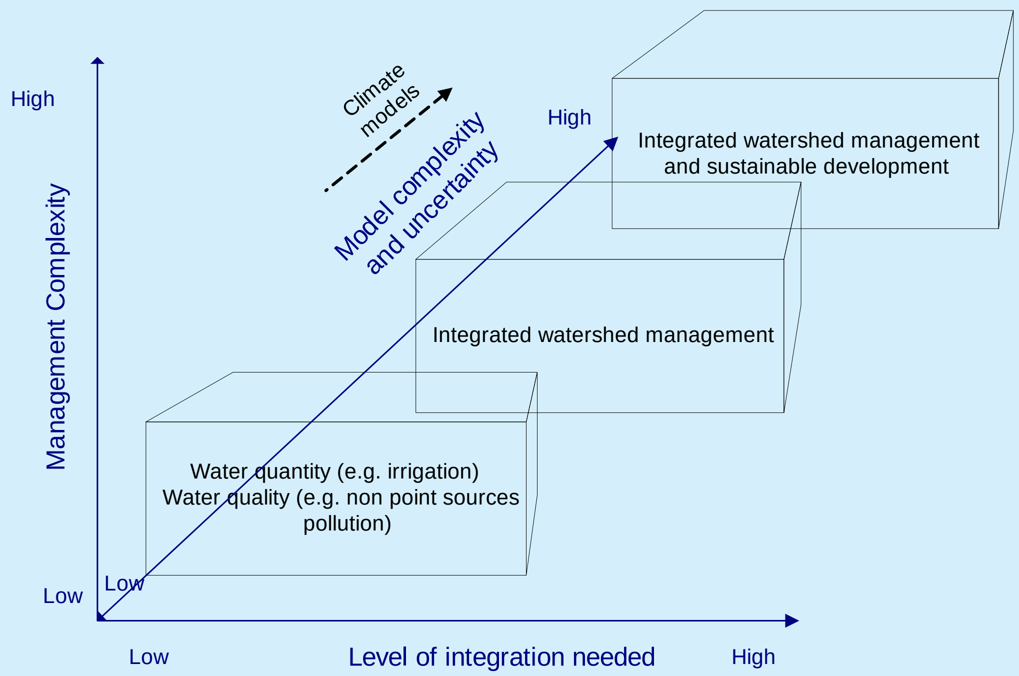


Figure 9 **Schematization of the level of integration of water issues needed for multi-usage watershed management vs the level of model complexity required (inspired by Gangbazo, 2004 and Schulze, 2007)**



of uncertainty in climate-change impact studies in order to develop sound and reliable adaptation strategies. The required level of model complexity must be identified and multiple scenarios used to tackle specific climate-change issues and address adaptation strategies within an integrated watershed management plan and framework.

Lesson learned

The main lesson learned from this modelling exercise reinforces the principle of forward-thinking, adaptive watershed-management strategies (in this case, irrigation) and also shows that before proposing any adaptive solution, the issue needs to be assessed scientifically (in terms of water budget) as well as socioeconomically. Only then can the multi-usage and integrated watershed management contexts in southern Quebec be fully addressed. Indeed, by providing the spatial, temporal and institutional framework that is needed to not only analyse the changing situation but also to incorporate gained knowledge in management-level policies, enhancing integrated watershed water management is an undoubtedly pragmatic way to plan water management adaptation strategies to cope with anthropogenic climate-change uncertainties. Moreover, this requires working and interacting closely with all stakeholders to concretely implant management strategies in a watershed.

In a multi-usage watershed, considering that climate change has manifold impacts and affects multiple sectors, we learned that developing adaptation strategies for specific issues needs to take into consideration the problems of conflicting uses (e.g. drinking water as well as agricultural, industrial, and recreational uses). Furthermore, from a management perspective, implementing pragmatic adaptation strategies requires the examination of specific case studies. Figure 9 illustrates the need to consider simple water issues in a complex, climate-change context, then, step-by-step, to try to reach higher levels of integration. Indeed, as a first step, this study investigates irrigation needs under climate change separately from other water uses. When considering the complexity of a fully watershed-based integrated study, it is perhaps wise to remember that such a segmented approach should, in most cases, be considered as a preliminary step, especially in the context of the additional layer of complexity that a climate-change impact analysis would add.

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World Water Assessment Programme side publications, March 2009

During the consultation process for the third edition of the World Water Development Report, a general consensus emerged as to the need to make the forthcoming report more concise, while highlighting major future challenges associated with water availability in terms of quantity and quality.

This series of side publications has been developed to ensure that all issues and debates that might not benefit from sufficient coverage within the report would find space for publication.

The 17 side publications released on the occasion of the World Water Forum in Istanbul in March, 2009, in conjunction with *World Water Development Report 3: Water in a Changing World*, represent the first of what will become an ongoing series of scientific papers, insight reports and dialogue papers that will continue to provide more in-depth or focused information on water–related topics and issues.

Insights

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Institutional Capacity Development in Transboundary Water Management
by Ruth Vollmer, Reza Ardakanian, Matt Hare, Jan Leentvaar, Charlotte van der Schaaf and Lars Wirkus for UNW-DPC

Global Trends in Water-Related Disasters: An Insight for Policymakers
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by Enrique Bello, Jorge Rucks and Cletus Springer for the Department of Sustainable Development, Organization of American States

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Scientific Papers

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A Multi-Model Experiment to Assess and Cope with Climate Change Impacts on the Châteauguay Watershed in Southern Quebec
by Luc Vescovi, Ouranos; Ralf Ludwig, Department of Geography, University of Munich; Jean-François Cyr, Richard Turcotte and Louis-Guillaume Fortin, Centre d'Expertise Hydrique du Québec; Diane Chaumont, Ouranos; Marco Braun and Wolfram Mauser, Department of Geography, University of Munich

Water and Climate Change in Quebec
by Luc Vescovi, Ouranos; Pierre Baril, Ministry of Transport, Québec; Claude Desjarlais ; André Musy; and René Roy, Hydro-Québec. All authors are members of the Ouranos Consortium

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Ouranos is a research and development consortium that brings together 250 scientists and professionals from different disciplines. It was created in 2001 as a joint initiative by the Quebec government, Hydro-Québec and Environment Canada, with the financial support of Valorisation-Recherche-Québec.

Ouranos' mission is to acquire and develop knowledge on climate change, its impact and related socioeconomic and environmental vulnerabilities, in order to inform decision makers about probable climate trends and advise them on identifying, assessing, promoting and implementing local and regional adaptation strategies

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