A **watershed** moment

DR ALAIN N ROUSSEAU

An expert in hydrological processes, Dr Alain N Rousseau is using his knowledge to better manage water resources at the watershed scale. Here, he describes the hydrological models his team has developed, the worldwide interest they have garnered and his hopes to help policy makers make more informed decisions

Could you elaborate on the main differences between the PHYSITEL tool and the HYDROTEL model you use?

HYDROTEL is a distributed hydrological model that simulates stream flows and state variables such as snow water equivalent and water saturation using basic meteorological variables. PHYSITEL is a specialised geographic information system (GIS) for supporting the implementation of pixel- or polygon-based distributed hydrological models like HYDROTEL.

Using a digital elevation model and digital river and lake network (DRLN), PHYSITEL calculates a slope, flow direction and flow accumulation matrix. The use of a DRLN is not required, but most DRLNs need to be corrected to ensure connectivity, and tools for this are available in PHYSITEL. Soil type and land cover information can also be integrated.

Your tools have helped forecast impacts of climate change up to 2050. What are the likely scenarios in the context of Québec Hydrological Expertise Center (CEHQ)'s Hydroclimatic Atlas?

Climate change will affect the flow of water in watersheds – the runoff regime. This can be assessed by modelling atmospheric and water cycle processes using a suite of climate and hydrological models. For various climate projections, an ensemble of hydrological scenarios can be simulated and analysed. To

Solutions for **surface water**

Researchers from INRS University, Canada, are developing modelling tools to improve understanding of surface water. This work supports water management decision making and helps solve problems linked to sustainable development and climate change

WATER MANAGEMENT – PLANNING, developing, implementing and managing the optimum use of water resources – aims to reconcile competing demands for water, allocating it in a way that can satisfy all needs. In practice though, it is rarely realised, with almost one-third of the world's population living in water-scarce areas. There are many pressures on water resources, population growth, pollution and climate change, to name a few, which in turn affect social, economic and environmental welfare. The many and varied problems of water management have created a need for hydrological modelling tools, which can model the water cycle in different regions in order to face these challenges.

These tools have a range of uses: forecasting inflows to reservoirs, predicting the risk of contamination of surface drinking water sources, operating dams to manage flooding, and, in the context of sustainable development, evaluating agricultural Beneficial Management Practices (BMPs).

Dr Alain N Rousseau, Professor-Researcher at the Institut national de la recherche scientifique (INRS), is meeting the need for hydrological modelling tools. The work of his team at the Water Earth Environment Centre provides analysts and decision makers with robust tools to solve surface water problems, with a current focus on saturated land, or wetlands. In partnership with students, research associates, and academic and public sector colleagues, Rousseau has developed an innovative research programme to create and improve distributed hydrological modelling tools.

Hydraulic monitoring of a boreal patterned peatland located near LaForge-1, Québec.

MODELLING TOOLS

For uniform analysis of water resource management, standardised data such as remotely sensed land cover and topographic data are needed. In recognition of this, Rousseau's team has furthered the development of two INRS tools: HYDROTEL, a process-based, continuous and distributed hydrological model, and PHYSITEL, a produce the hydrological scenarios and ensuing Hydroclimatic Atlas, CEHQ used the PHYSITEL-HYDROTEL modelling framework.

The Atlas has provided regional impact assessment of climate change on high and low flows throughout the 2050 horizon. This assessment is introduced in terms of three principal components: direction of change (ie. proportion of hydrological scenarios indicating an increase or a decrease), magnitude of change (ie. median value of the ensemble) and dispersion (ie. width of the envelope around the median).

Have you quantified the value of water courses in terms of the ecosystem services they provide? Does this have staying power with decision makers?

With colleagues at the University of Guelph and the University of Alberta, we developed an integrated economic-hydrologic modelling framework that includes an on-farm economic model, a farmer adoption behaviour model, a watershed modelling toolbox and a nonmarket valuation economic model for watershed evaluation of Beneficial Management Practices (BMPs). The framework was specifically designed for the Watershed Evaluation of BMPs (WEBs) project, funded by Agriculture and Agri-Food Canada and Ducks Unlimited Canada. It has been applied to examine trade-offs between on-farm costs, pollution abatement, water quality improvement and societal value in evaluating agricultural conservation practices. This framework is well suited for policy makers and programme managers to improve the design and implementation of conservation programmes to meet environmental and ecological goals more cost-effectively.

Canada is one of the largest producers of hydroelectricity in the world. In your opinion, what are the socioeconomic and environmental benefits and pitfalls of this?

Hydroelectricity represents a renewable source of energy, but studies have shown that large reservoirs can be a source of greenhouse gases; while ongoing discussions have argued that they have a water footprint because of evaporation. They can also be a source of mercury released from inundated soils, which can become toxic to humans who consume fish that contain concentrations above the recommended limits.

The construction of a reservoir is associated with opportunity costs, such as the loss of carbon sink by forests, loss of sport fishing in dynamic rivers, displacement of wildlife habitat and in certain cases displacement of populations. However, the alternative means of producing energy are not all renewable and those that are, such as wind turbines and solar energy, are still not consistantly efficient sources. It is fair to say that nothing comes without cost, but hydroelectricity certainly represents one of the best steady and renewable sources of energy to societies that have access to large sources of flowing water.

Collaboration has been crucial to the successful development of your modelling tools. Who has been most influential throughout your career?

Numerous individuals have shaped my professional career. My undergraduate, MSc, PhD and postdoctoral advisors taught me the core values that guide me on a daily basis: respect, integrity and thoroughness. In terms of our modelling tools, Jean-Pierre Fortin and Jean-Pierre Villeneuve, two professors that pioneered the field of hydrological modelling at the Institut national de la recherche scientifique (INRS), have been great inspirations. My colleagues from Hydro-Québec, CEHQ, Ouranos (Consortium on Regional Climatology and Adaptation to Climate Change), the University of Guelph and Université Laval have inspired me on several technical levels, and all of INRS, along with our graduate students and postdoctoral fellows, have provided daily support and ideas.

specialised geographic information system (GIS) to support its implementation.

HYDROTEL uses both remote sensing and GIS data and, running on either a three-hour or daily time step, simulates the water cycle of watersheds at sub-watershed or hill slope level and the flow of water in river segments. Together, the PHYSITEL-HYDROTEL modelling framework represents a unified repository of standardised data and universally applicable algorithms for regional hydrological modelling. It is currently used by Québec's primary power utility, Hydro-Québec, for inflow and hydrological forecasting, as well as the Québec Hydrological Expertise Center (CEHQ), which is responsible for the management and safety of publicly-owned dams.

Outside of Canada, PHYSITEL-HYDROTEL is used by the Mexican Institute of Water Technologies for operational and strategic planning of water management. Furthermore, in 2009 the modelling tools were identified by the World Bank in the terms of reference for the report: Identification and Preliminary Evaluation of Small and Mini Hydro Projects in the Piaxtla River Basin.

As part of Agricultural and Agri-Food Canada (AAFC)'s Watershed Evaluation of BMPs (WEBs) and Environment Canada's National Agri-Environmental Standards Initiative (NAHARP) projects, Rousseau built on the PHYSITEL-HYDROTEL framework to further develop GIBSI, an integrated modelling platform. Agricultural BMPs are employed to reduce sediment, pesticide and nutrient losses, while simultaneously improving water quality and biological integrity. And through using GIBSI, it is possible to evaluate both their environmental and economic performance.

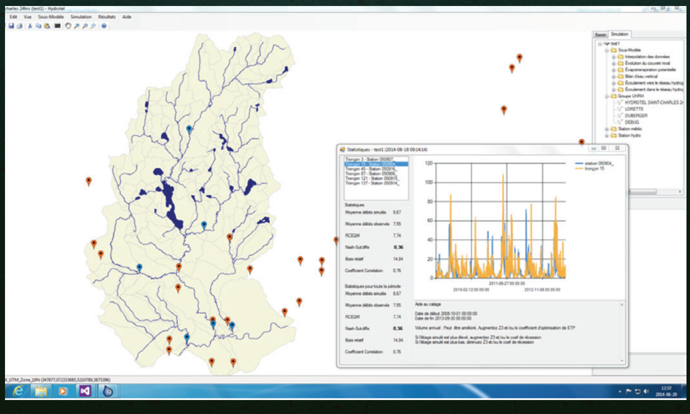
The platform has already been trialled by the University of Barcelona, Spain, to characterise the water quality of a complex watershed, and closer to home, Montreal University's Veterinary School have used GIBSI to simulate the hydrological transport of the parasite responsible for toxoplasmosis.

CLIMATIC LINKS

The climate is inextricably linked to the cycles of water, and thus changes to climate are of great interest to Rousseau. Recently, CEHQ used PHYSITEL-HYDROTEL to develop a 'Hydroclimatic Atlas', predicting the regional impact of climate change on water flow through to 2050, making some predictions. "In southern Québec, summer and fall low flows will likely decrease by 15 per cent and occur over a longer period (15 to 30 days)," Rousseau clarifies.

In addition to climate change, anthropogenic changes have important implications for watersheds. Land cover changes, from forest to farming and rural to urban, limit the ability of meltwater and precipitation to penetrate the ground. Indeed, Rousseau's modelling found that land conversion has a high impact on watershed hydrology. "Simulations showed strong correlations between land cover changes and water discharge at the outlet of watersheds," he states. "We showed a homogeneous effect of land cover on annual runoff, and simulated annual and seasonal low flows were strongly correlated to agricultural and forested land cover changes." On a global scale, results have corroborated that land cover is a controlling factor for watershed hydrology, suggesting it could represent a means of buffering the impact of climate change.

In a similar vein, wetlands can act as effective buffers against flooding, and using PHYISTEL-HYDROTEL, Rousseau has shed new light on their hydrological role at the watershed scale. In a collaborative project, his team integrated new modules into the framework, able to model the hydrological services provided by both



Print screen of HYDROTEL – a semi-distributed hydrological model.

INTELLIGENCE

DEVELOPMENT OF DISTRIBUTED HYDROLOGICAL MODELLING TOOLS TO SOLVE SURFACE WATER PROBLEMS RELATED TO SUSTAINABLE DEVELOPMENT AND CLIMATE CHANGE

OBJECTIVES

- To quantify basin-wide hydrological services of wetlands with respect to their potential to mitigate floods and low flows under changing climate conditions
- To further develop a hydrological model to design riparian buffer width in agricultural watersheds
- To implement a distributed hydrological modelling framework to evaluate the probable maximum flood on a very large boreal watershed

KEY COLLABORATORS

Éric van Bochove; **Georges Thériault**, Agriculture and Agri-Food Canada • **Richard Turcotte**, Québec Hydrological Expertise Center • **Paul Jiapizan**; **Patricia Chambers**; **Pierre-Yves Caux**, Environment Canada • **Marc B Parlange**, University of British Columbia • **Daniel F Nadeau**, École Polytechnique de Montréal • **René Roy**; **Louise Rémillard**; **Marie Minville**; **Brou Konan**, Hydro-Québec • **Sergio Armando Trelles Jasso**, Instituto Mexicano de Tecnología del Agua • **Anne Frigon**, Ouranos • **Silvio J Gumiere**; **Dennis W Hallema**; **Sylvain Jutras**; **Carolle Coursolle**; **Hank Margolis**, **Serge Payette**, Université Laval • **Richard Fournier**, Université de Sherbrooke • **Peter Boxall**, University of Alberta • **Wanhong Yang**; **Yongbo Liu**, University of Guelph • **Jacques Deschênes**; **Julie Deslandes**, Ville de Québec • **Gwenael Carrer**; **Maxime Fossey**; **Pierre-Érik Isabelle**; **Stéphane Savary**; **Alain Royer**; **Sébastien Tremblay**; **Alain Mailhot**; **André St-Hilaire**; **Jean-Pierre Fortin**; **Jean-Pierre Villeneuve**; **Pierre Lafrance**; **Michel Slivitzky**; **Iris Klein**, Centre Eau Terre Environnement – Institut National de la Recherche Scientifique

FUNDING

Hydro-Québec • Ouranos • Natural Sciences and Engineering Research Council of Canada (NSERC) • CEHQ • Agriculture and Agri-Food Canada • Environment Canada • Ville de Québec

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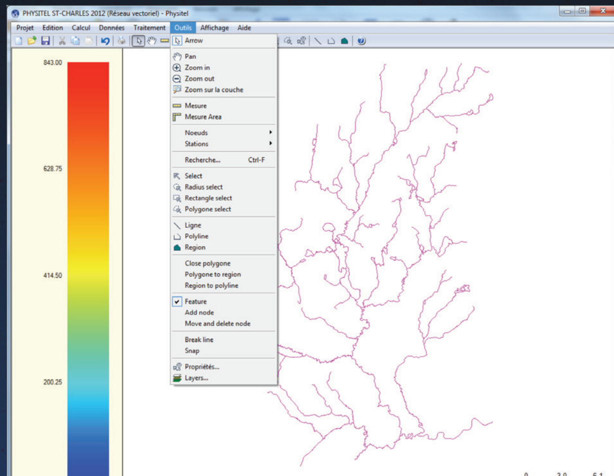


Print screen of PHYSITEL – a specialised geographic information system (GIS) for supporting the implementation of hydrological models.

isolated wetlands and those adjacent to rivers and streams – riparian wetlands. Preliminary results show that wetlands do indeed provide a buffering capacity, for both high and low flows, with isolated wetlands playing a more important role than their riparian counterparts. "Hydroclimatic modelling has also shown that wetlands represent an attractive option for the development of adaptation strategies to mitigate the impacts of climate change on watershed hydrology," Rousseau summarises.

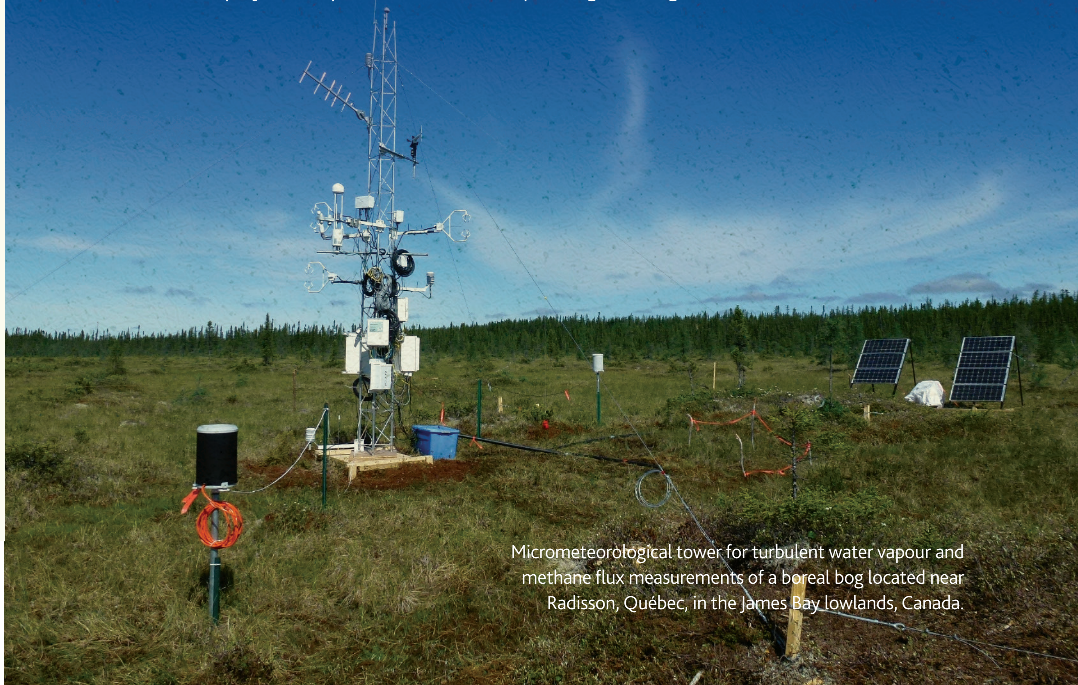
PROBING POLLUTION

Another growing problem, and one of great significance for hydrological modelling, is pollution. Water pollution fate models are becoming increasingly important for regulatory purposes, but are severely limited by the monitoring data available to them. Modelling and analysis of observed data by Rousseau highlighted the need for flow-dependent monitoring systems in this area; increasing water sampling during periods of runoff. Although recognised as a promising way forward, such a method has not yet been fully implemented. "Because of maintenance and labour costs, governments have not been able to deploy the required resources," he explains. "However, research teams have been able to implement such systems on study watersheds, and subsequent analysis and modelling by our team have been used to assess the impact of land covers and BMPs on water quality."

Rousseau's models represent a big step forward and have shed new light on the processes of pollution, showing that most pesticide losses take place during the first two to three rainfall-producing runoff events following application. Overall, between 1 and 3 per cent of the applied mass found its way in the stream network. The study also illustrated that concentration values at the outlet of six Canadian watersheds for eight pesticides following implementation of BMPs were usually less than ecological thresholds of good condition, when available.

More recently, the team developed a novel, deterministic hydrological modelling tool, called Travel Time (Temps de Parcours). Presently used by Québec City, this forecasts of the minimum time of travel between the point of contaminant discharge and downstream water intakes, indicative of the short-range forecasting (nearcasting) capabilities offered by all of Rousseau's models.

Considering all this work together, it is evident that Rousseau has developed a comprehensive and impactful programme to develop distributed hydrological modelling tools to solve surface water problems. And it is clear from the widespread acceptance of these tools that they are successfully able to meet these challenges. Furthermore, meeting the need for a better understanding of watershed hydrology, the programme is supporting effective decision making, and some of today's most pressing challenges.



Micrometeorological tower for turbulent water vapour and methane flux measurements of a boreal bog located near Radisson, Québec, in the James Bay lowlands, Canada.