Hydrologic and Hydraulic Modeling

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1. INTRODUCTION

How do water levels in Lake Ontario and the St. Lawrence River relate to Hydrologic and Hydraulic Modeling?

Water level and flows in Lake Ontario and the St. Lawrence River are primarily influenced by the will of nature. Precipitation, evaporation, spring runoff and ice conditions are each elements of the hydrologic cycle. This cycle must be taken into consideration by the St. Lawrence River Board of Control when regulating of the outflows of the Lake Ontario-St. Lawrence River system. Much of the regulation of the system is accomplished through forecasting seasonal weather conditions, current water level conditions in the Great Lakes basin and downstream of the power project at Cornwall, ON and Massena, NY.

Current regulation criteria requires that the water levels and winter ice conditions at the Port of Montreal, as well as operations during the annual flood discharge from the Ottawa River also be considered when regulating Lake Ontario outflows. Experience has also shown that ice conditions on Lac St. Pierre and spring runoff from downstream tributaries must also be taken into consideration. Other interests impacted by Lake Ontario outflow regulation are commercial navigation, recreational boating and tourism, water uses, riparians and the natural environment.

Due to the complexity of the system and the number of interests affected by water levels and flows, there is a need for computer simulated hydrologic and hydraulic modeling to fairly assess current regulation criteria and allow the International Lake Ontario – St. Lawrence River Study Board to develop and recommend a fair and equitable regulation plan.

Why was the Hydrologic and Hydraulic Modeling Technical Working Group (TWG) created?

The Hydrologic and Hydraulic Modeling TWG was created to develop a comprehensive water supply and routing model that will evaluate and assess Lake Ontario regulation plans, the viability of new, improved or current criteria, and each of the hydrologic impacts on the interests identified by this Study. The water levels and flows assessed will include the entire Great Lakes-St. Lawrence River system through to Trois-Rivières, Quebec, including the influence of the Ottawa River.

What are the Group's goals for the Study?

The Group's primary goals are:

- To provide hydrologic and hydraulic modelling information that will allow other TWGs to develop and evaluate regulation plans.

- To simulate water levels and flows from Lake Ontario and in the St. Lawrence River to Trois-Rivières, Quebec under various regulation plans and water supply scenarios

- To provide weekly average water level and flows and estimate within any given week the potential variability in levels and flows i.e.; peaking and ponding cycles

- To assist in the modelling of detailed hydraulic information, for example velocities and levels, as requested by other TWGs.

The Group will also examine the following variables that affect water levels and flows in the Lake Ontario – St. Lawrence River system:

- hydrologic scenarios; water supply inputs in the Great Lakes, Ottawa River and other key tributaries to the St. Lawrence River
- recorded historical averages
- randomly generated variables
- and climate variability from GCMs (General Circulation Models)

As well as examine the time series of:

- basin supplies to each Great Lake;
- outflows from Ottawa River and other key downstream tributaries;
- hydraulic effects of ice and vegetation;
- and diversions.

2. HYDROLOGY

Great Lakes Net Basin Supply and Ottawa River Inflows Synthetic Generation

In order for the regulation plans being evaluated by PFEG, it is paramount that these plans be tested for robustness, flexibility and system representation. These aspects are evaluated not only by testing the proposed regulation plan against the recorded historical supplies and flows, but also against simulated series of stochastically generated supplies. Stochastic nature of the simulation process implies that the statistical properties of the simulated and historical supplies are generally similar.

Under this project, H & H TWG will provide PFEG and other TWGs 50,000 years of supply sequence. For consistency with the historical series, these 50,000 years of sequence is split into 500 series each 100 years long. These 500 series preserve not only the statistical properties such as the mean, standard deviation, skew, etc. but also embed flow sequences outside of the experienced range or sequences of dry or wet supplies historically not observed. In this simulation process, it is not only required that year to year temporal properties are conserved, but also the spatial relationships are preserved. The simulation should exhibit, for example, wet supply conditions in both lower lakes (Lakes Erie and Ontario) and the Ottawa River system. In order to match the regulation plan time steps for the Great Lakes and operational model time-steps for the Ottawa River system, the stochastic simulation is carried out in four distinct steps. At the first step, yearly time series are computed for the entire system while maintaining Lakes Erie and Ontario's spatial relationship with the southern portions of the Ottawa River system. For the second stage, the yearly supplies are divided into monthly sequences while ensuring the seasonality is preserved. In the third step, monthly sequence of supplies to Lakes Erie and Ontario are temporally disaggregated into quarter monthly equivalents. In the last stage, which is applied only to the Ottawa River and the lower tributaries, the quarter-monthly supplies are further disaggregated into daily flow sequences.

This project is led by Dr. Laura Fagherazzi of Hydro Quebec with expert consultation of Dr. J. Salas, a noted authority from the Colorado State University. The project is also supported by the Great Lakes St. Lawrence Regulation Office of Environment Canada. For the purposes of simulation, the project is carried out in three distinct spatial zones; these are for the Great Lakes, the Ottawa River System and the local tributaries downstream of Lake Ontario control structure and the downstream study limits. These are described briefly:

- <u>Great Lakes</u>

  The supplies into the Great Lakes are characterized by the size of the basins and are spatially represented by four geographic areas. The supply nodes are for Lake Superior, Lakes Michigan and Huron, Lake Erie and Lake Ontario. The spatial dimensions of Lake St. Clair required that it become part of the supply sequence for Lakes Michigan and Huron.

  The final stochastic series for the Great Lakes are based on monthly time steps for the upper lakes, while Lakes Erie and Ontario are simulated at quarter monthly time steps. This is to maintain the consistency with the available hydrologic models for system operations.

- Ottawa River

  With the constraints imposed by the unique features of the Ottawa River watershed and the structure of reservoirs operated by the Quebec Hydro, the system is resolved at finer scales both spatially and temporally. For the stochastic series computations, the Ottawa River is divided into 48 sub-watersheds and the supply sequence will be computed at a daily time step.

  Some of the sub-watersheds in the Ottawa River system will be employed to establish spatial correlation with the Great Lakes basins. For example, the southern sub-watersheds of the Ottawa River exhibit a fairly strong correlation with Lake Ontario supplies and less strong with Lake Erie supplies. Similarly, the south-eastern sub-basins of the Ottawa River have a strong relationship with the local tributaries below Cornwall.

- Local Tributaries

  For the area below Cornwall there are several key streams while individually not significant but collectively are important in the operations of the control structures and the regulation of Lake Ontario. The local tributaries drainage area is characterized by a group of four major streams that characterize the local inflows. These streams are strongly and spatially correlated with several Ottawa River sub-basins. As such, the sequence of supplies will be developed using regression relationships developed from the historical flow records.

Climate Change Scenario Development

This project will interpret the latest general circulation model results over the Great Lakes in hydrological impact estimates for changed climates. These estimates will be used by the International Joint commission's five-year study (2001-2005) of Lake Ontario-St. Lawrence regulation in assessment of candidate regulation plans. This is a multi agency effort where GLERL will extract information obtained through Environment Canada for the Great Lakes and Ottawa River system. The generated climate information will be employed by GLERL to develop

Background:

The International Joint Commission is conducting a Study for Criteria Review in the Orders of Approval for Regulation of Lake Ontario-St. Lawrence River Levels and Flows. In recent IJC and US Global Change Research Program studies, GLERL completed modeling of hydrologic impacts of climate change for the Great Lakes region. This work used meteorological outputs from two GCMs and transformed them into hydrological impacts with models of rain-fall/runoff, lake evaporation, connecting channel flows, lake regulation, and lake water balances. However, climate change projections were not included in this work for the Ottawa River basin and lower St. Lawrence River. In 2001, GLERL made GCM results available over these ex-tended areas and hydrologic modelers at Hydro Quebec extended, in 2002, the estimation of climate change hydrological impacts over these areas. GLERL and Hydro Quebec, under the auspices of the H&H TWG, are now comparing their climate change projections in preparation for a new joint assessment of climate change impacts on hydrology over the entire Great Lakes-St. Lawrence River basin attendant to the latest GCM simulations (the Canadian and U.K. Hadley GCMs).

Brief Description of Proposed Work:

This year, GLERL will work with the Ottawa hydrologic modeling group, consisting of researchers at Hydro Quebec and the Ministère de l'Environnement (Province of Quebec), on future 20-year window for 2050 (2040-2060), as determined of interest to the IJC study by the H&H TWG. GLERL will acquire GCM scenarios for the latest versions of the Canadian and U.K. Hadley models. In order to evaluate the climate change impact fifty-year windows were chosen with four critical scenarios. Of these, there are two scenarios from the third generation Hadley GCM and the other two are from the second generation Canadian GCM. For the purposes of this project these are termed HADCM 3A representing a warm and wet climate regime, HADCM 3B for not so warm and wet condition. For the Canadian GCM, these are CGCM 2A for a warm and dry regime and CGCM 2B for a not so warm and dry conditions. It should be noted that the term dry implies conditions with less precipitation than the Hadley simulations and not necessarily less precipitation than the current climate regime. These models have been refined from the versions used in the U.S. National Climate Change Assessment, carried out in 1999-2001. In particular, the Hadley Centre model now has a better agreement between the effects of atmospheric sulfate aerosols as represented by the simplified parameterization that they routinely use and much more lengthy and precise calculations. The four scenarios that are being considered are labeled as:

Also from these updated models, additional scenarios of the rate of increase of greenhouse gas concentration are available. GLERL will extract, and supply to Hydro Quebec, GCM output changes between a baseline period of 1961-1990 and the future 30-year periods. These changes will be provided for several variables: daily precipitation increase (ratio), minimum daily air temperature increase at 2 m (ºC), average daily air temperature increase at 2 m (ºC), maximum daily air temperature increase at 2 m (ºC), wind speed increase at 2 m (ratio), specific humidity increase (ratio), and cloud cover increase (ratio). GLERL will adjust historical meteorology data for the Great Lakes basin with the GCM climate changes while Hydro Quebec and the Ministère de l'Environnement do the same for the Ottawa River basin. Then GLERL will simulate Great Lakes hydrology under the various scenarios while Hydro Quebec and the Ministère de l'Environnement do the same for the Ottawa River basin.

3. HYDRAULICS

Hydrodynamic Modeling of St. Lawrence River: Kingston/Cape Vincent to Cornwall Reach

To develop and make operational a 2-D hydrodynamic model of the St. Lawrence River system from the outlet of the lake near Kingston/Cape Vincent to the control structure at Cornwall/Massena. The 2-dimensional hydraulic model will be used to determine detailed velocities, levels and flows in the upper St. Lawrence River to support evaluation of the regulation plans by the navigation, recreational boating and tourism, environmental, coastal/riparian, water supply and/or hydroelectric TWGs.

The modelling aspect of this work is now complete. Only item remaining to ensure that all water level and flow selections have enveloped the range of flow and levels employed for testing and simulation purposes. This work will be carried out following input from the hydrologic studies.

Hydrodynamic Modeling of Lake Saint-Louis

To establish the basic hydrodynamic information for the Lake Saint-Louis area by means of 2-dimensional hydrodynamic modelling. These simulations will be used to assess water depths and velocities for defined discharge scenarios, and also to provide basic data for other types of models that are needed by the other TWGs such as sedimentation-erosion, wave action and habitat simulations.

This component is now complete. Results are available and Meta data descriptors will be developed and added.

Hydrological Information and Forecasting Integration

This project will build upon the Year 2 assessment of hydrological monitoring and meteorological forecast information that offers potential application to Lake Ontario-St. Lawrence River regulation and management. The outcome of this task will be a plan for the integration, coordination, and communication of this information in an operational framework for use by the Control Board and its Regulation Representatives.

<u>Background:</u>

During Year 2 of the IJC LOSLR Study, the subcommittee investigating hydrologic forecasting for use in operational decisions 1) assessed user needs, 2) reviewed forecasting methodologies, and 3) assessed monitoring and meteorological information. The Year 2 assessments found that there is an abundance of new observed and forecast information that could be applied to LOSLR management and new ways the information can be used in decision-making. Some gaps in modeling were identified, particularly modeling of the St. Lawrence River local inflows. The low skill of meteorological forecasts was recognized as a significant problem impeding the skill of hydrological forecasts. Use of probabilistic hydrological outlooks and risk assessment is strongly recommended for decisions predicated on long time horizons. There is a strong need to match LOSLR management decisions with appropriate forecasts considering the forecast spatial and temporal resolution and forecast skill.

As a result of these findings, the need for integrating hydrological and forecast information in an operational framework was recognized for both quantitative and subjective assessments for use in managing the LOSLR system.

<u>Brief Description of Proposed Work:</u>

The recent development of new hydrological and meteorological products and models offer potential for application in LOSLR management and regulation. More detailed information on hydrological conditions and outlooks are available today than when Lake Ontario regulation was first conceived and implemented. Many of the products and models could be used quantitatively in LOSLR management while others could be used in subjective assessments. However, the products are produced and the models operated by a variety of agencies in a variety of formats with different distribution mechanisms and different geographic extents. Integration, coordination, and communication of the products and model outputs into an operational framework are required. Specifically, during Year 3, the project will:

a. Link hydrology/hydraulic variables to those LOSLR decision variables identified from assessment of past operational decisions and interviews with Control Board.
b. Match the hydrology/hydraulic variables with the appropriate hydrology/hydraulic model forecast considering temporal and spatial scales.
c. Integrate new meteorological forecast products with weighting technology that allows the joint consideration of meteorology probabilistic forecasts for different variables, time periods, lags, and locations from different agencies with different types of forecast probability information.
d. Plan an operational framework for forecast and observed data integration for quantitative and subjective assessments of the hydrologic conditions associated with the LOSLR decision variables.

Temperature Modelling of Selected Areas

Objective:

The objective of this project is to develop and make operational a tool or suite of tools capable of computing the water temperature regime of Lake Ontario, the Bay of Quinte and the Upper St. Lawrence River. The water temperature model(s) will be applied to develop several time series of water temperature data that in combination with water level data will be used by the Environmental Technical Working Group (TWG) to assess the impact of regulation on the fish species in the region.

Background:

The IJC Lake Ontario - St. Lawrence River Study is a complex project composed of many research efforts investigating the impacts of regulation on numerous interests. One of the most important interests in this study is the Environment. A healthy Environment benefits us all. One component of the research underway within the Environmental TWG is being led by Dr. Ken Minns of the Department of Fisheries and Oceans Canada (DFO). The work is investigating the impact of regulation on the health of fish species in Lake Ontario, the Bay of Quinte and the Upper St. Lawrence River.

Fish require an adequate supply of good quality water to fulfill their life functions. Water must be present in adequate quantities at the right time of year and it must also be of sufficient quality to permit nourishment and spawning to occur. The most important descriptor of water quality relating to fish is water temperature. Water temperature will determine if, when and where spawning will occur.

To permit analyses, the Environmental TWG requires both water level and water temperature data for their study areas in Lake Ontario, the Bay of Quinte and the St. Lawrence River. Water level and flow data will be available from the Hydrology and Hydraulics TWG for three evaluation scenarios; the historic sequence (1900-present), a scenario depicting water levels and flows under climate change derived from the outputs of the latest Global Climate Change models, and a stochastically generated scenario depicting extreme supply conditions that could occur in the future. The water level and flow data for these scenarios will be available at quarter monthly mean time steps. The Environmental TWG requires water temperature time series data that coincides with the water level and flow data to perform their analyses.

The Environmental TWG has also requested water level and water temperature data at the daily time step. Daily time step data, both hydrologic and thermal, will likely only be available for the historic sequence.

Environment Canada Quebec Region is undertaking similar work for the lower St. Lawrence River study area.

The following bullets describe the activities planned for this fiscal year.

a. Undertake extensive discussions with project partners to define the scope of the project. The broad study region, data demands and resource limitations both budgetary and temporal in nature will make the project a challenging task.
b. Conduct an intense literature review of texts and journals to review historic work in the area of thermal modelling for the Lake Ontario - St. Lawrence River study area. The literature review will also entail interviews with prominent researchers in the field of thermal modelling to gain insight as to approaches to be followed to achieve project goals. Extensive expertise in this field lies within Environment Canada's National Water Research Institute.
c. Develop modelling approach (approaches) to obtain the necessary products. One or more approaches may be required to sufficiently characterize the thermal regime of the area. Lake Ontario, the Bay of Quinte and the Upper St. Lawrence River are hydraulically unique areas and it may not be possible to adequately represent by a single model. Therefore, several models may need to be applied and coupled together to determine the thermal structure for the entire study area. Simpler techniques such as one-dimensional models are preferred to more complex two and three dimensional approximations as the data and time requirements are significantly reduced for the simpler models.
d. Gather required data. Bathymetric, meteorological and hydrological data are all required to perform heat budget (water temperature) calculations.
e. Develop application and provide mock output data to DFO to allow them to build the secondary model to be used to assess fish health under proposed regulation plans. The mock data output will be provided at an early stage to DFO to ensure the final products from the water temperature modelling will be adequate for the additional work planned by DFO.
f. Perform calibration and verification of the thermal model to assess performance. Some uncertainty in model outputs is expected and the level of precision achievable is unknown at the outset of the project. The level of uncertainty in the output data will be quantified and accompany the final products.
g. Utilize the thermal model to generate the final water temperature time series data sets. Final data sets will be stored in a readily transferable format. Metadata compliant with IJC study guidelines will be developed and accompany the final products.

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