IWI MODELLING INITIATIVE
NEEDS ASSESSMENT WORKSHOP
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INTRODUCTION

On June 28-30, 2010, the International Joint Commission (IJC) sponsored a workshop aimed at assessing the modelling needs of its international boards. The workshop focused on hydrological, hydraulic and water quality modelling. About 30 people attended the workshop. The contributions of the presenters and participants are gratefully acknowledged. The workshop itself and the preparation of this workshop report were funded under the IJC's International Watersheds Initiative (IWI).

Speaking on behalf of Robert Reynolds, Ted Yuzyk provided background information on the *Boundary Waters Treaty*, transboundary water issues, and the International Watersheds Initiative (IJC, 2009). The IWI had its origins in a 1997 IJC report, *The IJC and the 21st Century* (IJC, 1997). This report led to the creation of international watershed boards that adopted integrated ecosystem approaches in the conduct of their work. As a means of assisting these boards the Canadian and United States governments provided special funding for the IWI. The underlying premise of the watershed boards and the IWI is that *"water resources and environmental problems can be anticipated, prevented or resolved at the local level before developing into international issues"*. Under the IWI, projects have been funded in the St. Croix, St. Lawrence, Rainy, Red, Souris and Milk river basins. Funding has also been provided to the International Hydrographic Data Harmonization project, a project aimed at providing seamless hydrographic datasets for watersheds along the international boundary. Several IWI projects call for the development of models or the provision of datasets to support modelling.

Ted Yuzyk gave an overview of the IWI modelling initiative. Under the auspices of the International Joint Commission's (IJC) International Watersheds Initiative (IWI), the Commission has embarked on a series of workshops aimed at assessing numerical models of importance to IJC Boards. The IJC has noted that significant IWI resources are being devoted to modelling and that there may be limited expertise within a board to select the most appropriate model or to evaluate model outputs. A more strategic approach is needed to ensure the successful application of modelling. Accordingly, a ten-member steering committee with membership drawn from several IJC Boards and co-chaired by Robert Reynolds and Ted Yuzyk was established. The steering committee has initiated workshops aimed at examining issues/needs assessment, the data requirements for models, and model selection and application. The results from these workshops will contribute to a framework document synthesizing the workshop results and identifying an implementation plan.

The first modelling workshop was held in Winnipeg, Manitoba on June 28-30, 2010. This Needs Assessment Workshop had as its objectives:

- To determine what are the Boards' priorities that require a modelling approach to address them,
- To determine the Boards' level of knowledge and expertise with regards to applying models, and
- To develop a path forward for building an IJC modelling framework.

The workshop agenda and the list of persons attending appear in this report as Appendices A and B, respectively. The slides used by all presenters are available through the IJC.

> *"All models are wrong but some are useful."*
>
> George E.P. Box, 1976

Commonly Used Hydrological and Hydraulic Models

Many models have been developed to simulate hydrologic processes in a watershed and a number of these have been applied in international basins for flood and flow forecasting, for hydrological studies or for water planning. Hydrological models use the moisture input to a basin, apply basin storage components, and calculate the streamflow at a given location by applying channel routing relationships.

Sometimes the model can be a statistical precipitation-runoff relation with a routing equation, while other models can be much more complex. Models can be classified as lumped or distributed, single event or continuous. Probabilistic models that take data uncertainties into account are also available. Model selection will depend on available data, basin or sub-basin characteristics, and the needs of the user. Hydrological and hydraulic models that have been used in international watersheds are discussed in this section as a precursor to the description of the presentations.

The US Geological Survey supports a large array of surface water and groundwater models, including coupled surface-groundwater models. Details can be found at http://water.usgs.gov/software/

Hydrological Models

HSPF (**H**ydrological **S**imulation **P**rogram—**F**ortran) simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. HSPF uses continuous rainfall and other meteorological records to compute streamflow hydrographs and pollutographs. HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand (BOD), temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. The program can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency-duration analysis can be done for any time series. Any time step from one minute to one day that divides equally into one day can be used. Any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc.

PRMS (Precipitation-Runoff Modeling System) is a modular-design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on streamflow, sediment yields, and general basin hydrology. Basin response to normal and extreme rainfall and snowmelt can be simulated to evaluate changes in water-balance relationships, flow regimes, flood peaks and volumes, soil-water relationships, sediment yields, and ground-water recharge. Parameter-optimization and sensitivity analysis capabilities are provided to fit selected model parameters and evaluate their individual and joint effects on model output. The modular design provides a flexible framework for continued model-system enhancement and hydrologic-modelling research and development.

The Hydrologic Modeling System (HEC-HMS) developed by the US Army Corps of Engineers' (USACE) Hydraulic Engineering Center (HEC), is designed to simulate the precipitation-runoff processes of dendritic watersheds. It replaced the HEC-1 model. HEC-HMS produces runoff hydrographs for complex watershed networks using several methods and incorporating reservoir and channel routing procedures. It has modest snowmelt, reservoir routing and channel routing capabilities. It is essentially an event model with lumped inputs although it can be used in simplified continuous applications. The model is thoroughly documented and has a broad user base.

The WATFLOOD model is a continuous distributed model that uses Grouped Response Units (GRUs) for input parameters. That is, watershed data are discretized over a grid and model parameters are associated with land cover and not sub-watersheds. Gridded data can include remotely sensed data, numerical weather data, and quantitative precipitation estimates from weather radar or weather models. The vertical water balance is calculated for each grid square, infiltrated, and runoff calculated when infiltration capacity is exceeded. Infiltrated water is stored in an upper soil zone then either exfiltrated or transferred to a lower soil zone. The total flow to the river is obtained by adding the surface runoff and interflow from all GRUs and the baseflow and routing to the downstream grid. WATFLOOD has been coupled to the Canadian Land Surface Scheme (CLASS) and with atmospheric models. For many years WATFLOOD was treated as a proprietary model of the University of Waterloo. It has been purchased by Environment Canada thus becoming more generally available to a broader user community. It has been mostly integrated into the National Research Council's Canadian Hydraulic Centre's (CHC) GreenKenue, which provides pre- and post-processing capabilities.

The HBV-model (**H**ydrologiska **B**yråns **V**attenbalansavdelning (Hydrological Bureau Waterbalance-section)) was developed by the Swedish Meteorological and Hydrological Institute and is the standard hydrological model used in Sweden. It is a semi-distributed model designed specifically for flow forecasting in relatively small basins. It can be linked to numerical weather prediction models and has good cryospheric modelling capability. The model has been used in Canada, particularly in British Columbia and to some extent in Ontario. The model has proprietary components but an open source version known as HBV-EC that is fully integrated into the CHC's GreenKenue is available.

The HYDROTEL model a development of Quebec's Institut national de la recherché scientifique (INRS). The model interpolates meteorological data and simulates snow accumulation and melt, potential evapotranspiration, vertical water budget, surface and subsurface runoff and river routing. It is a distributed model that simulates processes in relatively homogeneous hydrological units (RHHU). The model operates in time steps varying from one hour to one day. The model has been applied to some transboundary watersheds in the east.

A specific application of hydrological models is their use in flood forecasting. The United States National Weather Service has a suite of models routinely used in its ensemble flood forecasting. In Canada, flood forecasting is carried out by the provinces and methodologies vary from province to province. Although hydrological models used in planning studies may also be used for forecasting there are subtle distinctions in applying models simply as water balance models versus their use in extreme event forecasting. Not the least of these is the need to operate in near real-time.

Hydraulic Models

Hydraulic models are used to represent open channel flow and depend on the solution of the Saint-Venant equations of continuity and momentum. Solution of these equations can be simplified if it is assumed that flow is steady, that is, there is no flood wave and that flow is one-dimensional. For many years, the model that represents the "gold standard" of steady flow models was the USACE's HEC-2. This model had a broad base of international users. The model has now been replaced by HEC-RAS (River Analysis System). This Windows-based model also replaces UNET and HEC-6 programs. The UNET (UNsteady NETworks) model is a one dimensional unsteady flow model while the HEC-6 model was used to simulate scour and erosion in channels and reservoirs.

Under certain conditions the assumption of steady flow is clearly incorrect and more rigorous solutions of the equations of open channel flow are needed. Models that can perform these solutions are known as hydrodynamic models. Most commonly one-dimensional models are used but for some applications such as analyzing wind effects, two-dimensional models are used. Several one-dimensional hydrodynamic models exist. In general their differences lie in the computational algorithm used to solve the Saint-Venant equations. Among the one dimensional hydrodynamic models of interest are the Danish Hydraulics Institute's Mike-11, the USACE's HEC-RAS Unsteady and the US National Weather Service's FLDWAV.

The USACE's Surface-water Modeling System (SMS) provides an interface to the RMA-2 model, which was written by Ian King in the 1970s. The model is a finite element hydrodynamic model that had been used to resolve two-dimensional flow problems in riverine and estuarine situations. It is well documented and fully supported by the USACE. One recent application was in the modelling of the St. Clair River as part of the IJC's International Upper Great Lakes Study (IJC 2009).

One two-dimensional model that has been used in Canadian riverine and coastal settings is the Telemac-2D model. The model has been used to examine transboundary flooding issues in the lower Pembina River basin under an IWI project. It has also been applied to the St. Clair River as part of the IJC's International Upper Great Lakes Study (IJC 2010). The model was developed by the Laboratoire national d'hydraulique d'Electricité de France in

Chatou, and is one of the most powerful numerical models available for free surface flows. Telemac-2D is a 2-dimensional finite element model capable of reproducing flows during rising flood over dry land, and during the following water recession. It can accept sub- or super-critical flows, which means that flows resulting from a dyke failure where high water velocities are encountered can be modeled accurately. This model has achieved certification and has recently been made open source with the software codes freely available.

Other two-dimensional hydrodynamic models include the proprietary models Mike-21 and FLO-2D.

Other Types of Models

Water Accounting Models. Water accounting models are used by water managers to assist in resolving water demand and river regulation problems in a basin. The models are designed to assist multi-objective planning in river basins by balancing the needs of various users such as hydroelectricity generators, municipal and industrial users, recreational users, irrigators and so on. The models are physically based but not particularly rigorous in a hydrologic sense. A precursor to these types of models was the USACE's SSARR (Streamflow Synthesis and River Regulation) model. The river routing and reservoir regulation components of this model were used in planning studies to simulate diversions into and out of river systems as well as reservoir operations under various scenarios.

More recently, generalized models such as Alberta's WRRM and Environment Canada's REGUSE that use a network flow optimization algorithm and a heuristic database for both planning and operational modelling of flow regulation and multiple-use multi-reservoir/channel networks have been developed. Flow regulation and water use planning studies (basic input requires computed inflow files at model nodes, stage/storage/discharge relationships and heuristic data consisting of rule curves and penalty coefficients for violation of bounds). Basin-wide operational flow regulation studies require selection of an appropriate inflow/runoff model for input in an operational mode.

Other Water Quantity Models. RIVICE is a model created to simulate ice processes such as ice cover formation and ablation, frazil ice formation, anchor ice formation, ice transport, hanging dams, breakup, and jams. It is being developed by a consortium of public and private sector agencies, including the USACE and Environment Canada. The rapidly changing nature of cryospheric phenomena is incompatible with steady-state hydraulic models therefore the model is coupled to a one-dimensional hydrodynamic model

MOBED is an Environment Canada model that simulates scour and deposition in both mobile and rigid boundary channels. Short and long-term changes to river channels that result from natural and man-made changes to the channel may be predicted. The model is currently being used to examine sediment transport under ice cover in the St Lawrence River. It has also been used to examine the effects on channel morphology of removal of the weir on the South Saskatchewan River at the city of Saskatoon (Conly and Martz, 1998).

MODFLOW is a three-dimensional finite-difference groundwater model first published in 1984 and supported by the USGS. Although originally conceived solely as a groundwater-flow simulation code, MODFLOW's modular structure has provided a robust framework for integration of additional simulation capabilities that build on and enhance its original scope. The family of MODFLOW-related programs now includes capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density and unsaturated-zone flow, aquifer-system compaction and land subsidence, parameter estimation, and groundwater management.

GSFLOW is a coupled Groundwater and Surface-water FLOW model based on the USGS Precipitation-Runoff Modeling System (PRMS) and Modular Groundwater Flow Model (MODFLOW-2005). GSFLOW was developed to simulate coupled groundwater/surface-water flow in one or more watersheds by simultaneously simulating flow across the land surface, within subsurface saturated and unsaturated materials, and within streams and lakes. Climate data consisting of measured or estimated precipitation, air temperature, and solar radiation, as well as groundwater stresses (such as withdrawals) and boundary conditions are the driving factors for a GSFLOW simulation. GSFLOW can be used to evaluate the effects of such factors as land-use change, climate variability, and groundwater withdrawals on surface and subsurface flow. The model incorporates well documented methods for simulating runoff and infiltration from precipitation; balancing energy and mass budgets of the plant canopy, snowpack, and soil zone; and simulating the interaction of surface water with ground water, in watersheds that range from a few square kilometres to several thousand square kilometers, and for time periods that range from months to several decades. An important aspect of GSFLOW is its ability to conserve water mass and to provide comprehensive water budgets.

Lake and Reservoir Models. Simulation of lake and reservoir hydrodynamics requires the use of two-dimensional models, three-dimensional inferences being obtained by modelling the interactions between layers of water. Wind induced circulation and thermal (or density) circulation, particularly formation and erosion of the thermocline, are the most commonly modelled aspects on account of the implications for water quality. Both finite element and finite difference methods are used. Examples include the Princeton Ocean Model and CWR-ELCOM (**C**entre for **W**ater **R**esearch **E**stuary and **L**ake **Co**mputer **M**odel).

Presentations

The workshop featured three presentations pertaining to hydraulic and hydrological modelling.

Dr. Syed Moin provided an overview of hydraulic modelling. His presentation included a discussion of the necessary precursors to a modelling task including definition of needs, framing science questions, and setting up a structured approach. He illustrated a modelling strategy using the hydrodynamic modelling conducted for the International Upper Great Lakes Study. He also reviewed the basic architecture of models, their data requirements, and model uncertainties.

He also made the hydrological modelling presentation on behalf of Dr. Alain Pietroniro. The presentation covered water cycle prediction using coupled numerical models. It featured Environment Canada's water cycle prediction framework with examples from the

International Upper Great Lakes Study. The framework features the coupling of upper air and surface meteorological observations through an atmospheric model and land surface scheme to the WATFLOOD hydrological model. The ultimate objectives are to close the water budget on Canadian landscapes and to provide hydrological prediction and ensemble forecasts of water cycle parameters. Several hindcasting examples pertaining to the Great Lakes were provided.

Dr. Wayne Jenkinson provided an overview of Canadian Hydraulics Centre (CHC) and the numerical modelling conducted there. He reviewed the models used and the Kenue family of data assimilation and presentation software. In his presentation he highlighted examples of modelling carried out in international basins such as the Pembina, St. Clair and Rainy river basins. He also provided the results of a model intercomparison study conducted for BC Hydro discussed issues associated with model selection and with model stewardship in considerable detail.

Discussion

Model stewardship generated considerable discussion from the group. Federal agencies in the United States such as the USACE, USGS, and Bureau of Reclamation do a good job of developing and maintaining their models. The situation in Canada is not as good and the initiatives taken by the CHC met with approval of the group. Some Canadian models would not pass the "bus test". (That is, if the principal modeler is hit by a bus, is there anyone to continue the work?) Aside from the high-level stewardship questions, which included discussion of proprietary and open source models, there are also concerns expressed about a home for specific basin model implementations. Who will take responsibility for maintaining and updating these basin models and the associated data?

Other discussion related to linking of models, including the EU's OpenMI envelope. Hydrological or one-dimentional hydraulic models are often linked to water quality models.

Model tradeoffs and using data-appropriate models was discussed. The recent two-dimensional hydraulic work done in the lower Pembina basin could not be carried out without Lidar topography, for example. The one-dimensional work done by the IJC ten years ago was data-appropriate for the time. Prairie hydrology – non-contributing drainage – and hydraulics was raised as a particular difficulty with standard models. A recent Prairie Provinces Water Board study provides some insights into uncertainty related to data inputs (Pomeroy *et al.*, 2009).

Remote sensing provides opportunities for spatially distributed inputs to models. Other issues included incorporation of land use change and reservoir operation

WATER QUALITY MODELS

Overview of Water Quality Models

Dr. Bill Booty provided an overview (prepared with Dr. Glenn Benoy) of water quality models based, in part, on a recent paper (Booty and Benoy 2009). He reviewed the purpose and selection of models and modelling approaches from stochastic or deterministic through Bayesian probability networks. Is a model necessary? What is the simplest model that will perform the task? He reviewed several non-point source models and identified criteria for selection. Examples of several applications were provided.

Attributes of several NPS models are shown in Table 1, which was drawn from his presentation. He also reviewed point source models used to determine transport and fate of contaminants. Examples of applications were provided. He concluded with a discussion of technical and research challenges associated with linking models and an approach to model synthesis.

Table 1. Comparison of Water Quality Models

Model	Nutrients	Sediments	Pathogens	GIS	User Interface	Scenario Analysis	Management Module	BMP Module	Public Domain	Proprietary
AGNPS/ROS	X	X	X	X	X	X	X	X	X	
AnnAGNPS	X	X	X	X	X	X	X	X	X	
ANSWERS-2000	X	X	X	X	X		X	X	X	
BASINS	X	X	X	X	X		X	X	X	
CANWET	X	X		X	X	X	X	X		X
GIBSI	X	X		X	X	X	X	X	X	
GLEAMS	X	X		X	X			X	X	
HSPF	X	X	X	X	X	X			X	
MIKE-SHE	X	X		X	X	X	X	X		X
SWAT	X	X	X	X	X		X	X	X	
WARMF	X	X	X	X	X	X	X	X		X
WEPP		X		X	X	X	X	X	X	
WaterWare	X	X	X	X	X	X	X	X		X

Table 1. Comparison of Water Quality Models (continued)

Model	Event	Time Dependent	Hourly	Daily	Annual	Source Tracing	Canadian Applications	Polygon Delineation	Grid Delineation
AGNPS/ROS	X	X	X	X	X	X	X		X
AnnAGNPS	X	X	X	X	X	X	X	X	
ANSWERS-2000	X	X	X	?	X		?		X
BASINS	X	X	X	X	X		X	X	
CANWET	X	X		X	X		X	X	
GAMES	X	?	?	?	?		X	X	
GIBSI	X	X		X	X		X		
GLEAMS	X	X		?	X		?		
HSPF	X	X	X	X	X		X	X	
MIKE-SHE	X	X		X	X		X	X	
SWAT	X	X	X	X	X		X	X	
WARMF	X	X	X	X	X		?		
WEPP		X		X	X	X	X	X	
WaterWare	X	X	X	X	X		?	X	

Discussion

The particular challenges of modelling Lake Winnipeg water quality were raised. Considerable work is still needed. The SWAT model has been used with success in both the United States and Canada; in Bill's view it is not scalable to large basins such as Lake Winnipeg. Incorporating cryospheric processes into water quality models is also a major challenge. Application of many models is limited by availability of data sets or specifically supported by availability of certain data sets.

The OpenMI approach to linking models shows some promise, but it is very early in development (openmi.org). Water quality models are commonly linked with hydrological and hydraulic models. Some particular needs related to chain-of-lakes modelling. That is, essentially riverine systems that include a series of lakes having relatively short residence times.

Several boards have an interest in water temperature modelling with respect to climate change scenarios. Other modelling needs relate to fish habitat.

BOARD PERSPECTIVES ON MODELLING REQUIREMENTS

Representatives of six IJC boards gave presentations that covered their board's priority modelling issues, modelling expertise within the board, examples of recent modelling projects and identification of board issues that can benefit from a strategic modelling approach.

Board Presentations

International Red River Board. Dr. Gregg Wiche discussed the flat landscape of the Red River basin and illustrated the streamflow heterogeneity of the river using three time periods: 1900-1960, 1900-2010 and 1826-2010. Despite apparent trends in the shorter records, there is no apparent trend overall. He reviewed the hydrodynamic modelling of the lower Pembina basin by the Canadian Hydraulics Centre using the Telemac-2D model. (One of the early uses of ADCP technology in the Red River basin during the 1997 flood indicated 8800 cfs moving upstream on the Pembina River.) Modelling needs related to calculation of natural flow for the Red River included reservoir evaporation, water uses from minor projects, and determination of instream flow needs. Another suite of modelling needs relates to nutrient sources, transport and fate in the basin. Basin models such as SPARROW (Preston *et al.* 2009) and sub-basin models like AGNPS (Agricultural Non-Point Source - USDA) and SWAT may be required.

Questions and comments concerned the approach to modelling the mainstem nutrient loads from the international boundary to Lake Winnipeg rather than using a basin model such as SPARROW. A grad student under the direction of Gordon Goldsborough (University of Manitoba) has examined water quality trend analysis methodology at the international boundary as a precursor. There is a data harmonization issue as well. There was also discussion of the sulphate model of the Sheyenne River in the context of modelling or assessment. What is the priority and at what levels is action required? The board is also considering a two-dimensional hydrodynamic model of the Roseau River, an eastside international tributary of the Red River.

International Souris River Board. Russell Boals discussed the 2007 Directive from the IJC, which transformed the board from a control board to a watershed board. The board has modelling-related expertise through its membership, membership in three standing committees, and through agency affiliations of participants. Board expertise is deep in water management, but not necessarily on modelling. Board activities for which modelling may be required include water balance calculations pertaining to the administration of apportionment, understanding the implications of flood operations and of water development projects, considering aquatic quality objectives at the international boundary crossings, and evaluating the effects of operating Lake Darling at a lower summer level. Models may also be useful as a means of improving public awareness and understanding.

Questions and comments related to distinguishing natural and anthropogenic effects on water quality in light of effects of river regulation and the waterfowl refuges along the Souris loop in the United States. There are public concerns about fish kills at Lake Darling. There were questions concerning funding arrangements for the Rafferty/Alameda dams in Saskatchewan (a contribution from the United States, based on USACE calculations) and public understanding of the economic benefits of the dams. There are visualization needs to support public understanding.

International St. Croix Watershed Board. Bill Appleby discussed the St. Croix watershed noting there are four dams with IJC Orders of Approval plus some other dams that pre-date the Treaty. Agencies affiliated with board members have water quantity and quality modelling expertise although board activity to date has focused only on hydrological and hydraulic modelling. There is a need to respond to stakeholder concerns about flows and reservoir levels during both wet and dry periods. The board has created and verified a HEC-ResSim model of St. Croix reservoirs and an HEC-HMS model of the watershed for use in simulating runoff from large rain events. Lessons learned relate to data requirements and to the need for a 'home' for the model once developed.

Questions and comments related to the idea of a local home for watershed models, once developed. There is a need to identify a manger/custodian for the model. Some work on river ice models by the USACE Cold Regions Laboratory. Is the hydrology of the HEC-HMS model sufficient, peaks are good but water balance not so good. Use of STELLA model for output visualization. The board has concerns about water quality during low flows but this is not a public concern. Some discussion about in-stream flow needs by the board. Some concerns have been raised by Fisheries and Oceans Canada concerning sustainability of elwives populations in the northern part of the basin.

International Rainy River Board. Nolan Baratono and Gail Faveri indicated that the International Rainy River Water Pollution Board and International Rainy Lake Board of Control are currently working together. Several of the boards' members have extensive modelling experience. Examples of modelling carried out for the boards include development of an HEC-RAS model of the 144-km reach from Rainy Lake to Lake of the Woods, a two-dimensional hydraulic model (by the CHC) of the outlet of Rainy Lake to show the relative effects of the dam and the rapids, and a simpler simulation model used to estimate the effects on water levels of releases through the dam at International Falls/Fort Frances and the upstream dams on Namakan Lake. A reservoir simulation/routing model of the Namakan River chain of lakes is proposed to assist with the evaluation of the 2000 Rule Curve which is scheduled to occur by 2015. There is a need to link/improve these models. There are also water quality modelling needs in the basin.

Questions and comments related to linking models and the potential for use of predictive models. One should consider the cost of operating gauging stations versus cost of models. In response to a question on who operates the dams, it was stated that the dams are operated by the owners in accordance with rule curves, but under the direction of the board.

International Osoyoos Lake Board. Dr. Cynthia Barton provided information on the setting of the transboundary Osoyoos Lake on the Okanagan River, a Columbia River tributary. The lake is controlled by Zosel Dam in the United States. The current IJC Order of Approval for the dam expires in 2013. Modelling expertise is available through board members and their affiliated agencies. At present the board has a HEC-RAS model of the lake outlet channel that is maintained by Washington State. The board also uses water supply forecasts prepared by BC Environment and the US National Weather Service as well as Okanagan Lake level forecasts supplied by BC Environment. (In general, modelling pertaining to Lake Okanagan is a direct benefit to the board.) A major need is to monitor drought conditions against three criteria as a greater range in levels is allowed under drought conditions. Other issues requiring modelling include prediction of high water levels, climate change considerations, ecosystem management, and effects of the dam on water quality.

Questions and comments related to data needs, such as Lidar, evapotranspiration and groundwater components of the water balance. The downstream hydraulic regime can affect the operation of the dam. There is a $5.2 million study proposal related to remote sensing in the Okanagan basin.

International St. Lawrence Board of Control. George Cotroneo described the work of the board in regulating Lake Ontario outflows in accordance with an established rule curve. The weekly outflows are highly dependent on upstream supplies, which are subject to the vagaries of nature. The current plan does not adequately consider environmental or recreational boating concerns. The board has considerable modelling expertise through its membership and affiliated agencies. The principal modelling need relates to improved forecasts of net basin supply. Ensemble forecasts some nine months into the future are currently used. Another modelling need relates to the incorporation of operational versions of environmental models that were previously developed for planning purposes. This would be beneficial to an adaptive management framework for the board operations.

Questions and comments concerned adaptive management. Does it apply to development of the plan or operation of the plan? How often could the board change course? Adaptive management implies careful monitoring and consideration of rigorously defined thresholds.

PLENARY ON BOARD REQUIREMENTS

All of the boards have a monitoring and reporting function, either in connection with IJC Orders of Approval, the specific directive of a control board, or the broader mandate of a watershed board. Models form an important component of the boards' activity. Models may be used for planning, operations and forecasting. All of the boards have a duty to consult and inform the public of their activities and findings. Because of this, tools for both scientific and public visualization of model results are required. Such tools can link with consideration of water management scenarios. Stewardship and sustainability of developed models is very important to the boards. Uses or needs pertaining to types of models include:

Hydrological Models

- Simulate streamflow, especially peaks
- Response to hydrologic events
- Predict streamflow or lake levels
- Compute water balance
- Consider scenarios such as reservoir operation or landuse change
- Examine process hydrology, *e.g.* evapotranspiration, snowmelt
- Provide the hydrological component for a water quality model

Hydraulic Models:

- Route flows produced by a hydrological models through a watershed
- Predict water levels and peak timing at a given location
- Consider the effects of hydraulic structures, multiple flow paths and flow obstructions on levels and velocities at given locations
- Consider the effects of channel roughness and morphology on flows and levels, *e.g.* spring, summer and winter flows
- Provide the hydraulic component for water quality models used to examine spills and industrial upsets
- Provide the hydraulic component used to calculate in-stream flow needs
- Vertical datum and detailed typography needs
- Calibration requirements under differing flow conditions, including low flows

Water Quality Models:

- Pertain to physical, chemical and biotic aspect of water quality. Applications may call for loads or concentrations
- Simulate nutrient, sediment, pesticide and pathogen fluxes from non-point sources at various watershed scales. Nutrient issues, including nutrient cycling, appear to dominate water quality concerns in the international basins.
- Identify non-point sources and pathways
- Identify scenarios and outcomes related to application of Beneficial Management Practices
- Simulate transport and fate of contaminants
- Link to species composition models
- Issues related to air transport

Other Models

- Water accounting for natural flow calculations
- Riparian habitat
- Channel losses pertaining to demand releases
- Evaporation
- Climate change
- Channel erosion and deposition

There is a host of data issues related to the application of models. These can relate to data availability, gaps, data formats, harmonization across the international boundary, data standards and metadata, data storage and management, and so on. Consider the concept of seamless, best available data on a watershed basis and the roles of boards and the IJC itself in achieving this. The notion of an IJC web portal for international watershed data is attractive. This could link to other portals such as the proposed Lake Winnipeg Information Portal.

Boards tend to decide on which model to use based on the skill sets available to the board, either from an agency affiliation or a contractor. The selection process is not as rigorous as it should be. A role for the IWI may be to fill gaps, assist boards in adapting to technological change.

Perfect forecasts, optimization and risk management. A perfect forecast used in a planning model gives indication of the best that can be achieved. Also a perfect forecast may not be considered perfect in retrospect. Even with a perfect forecast, would the reservoir have been operated any differently?

Public Understanding: visualization, animation, visualization for communication with the public *vs* scientific visualization – public doesn't understand flows, but more readily identifies with water levels. Decision support, gaming/simulation, narrowing range of feasible outcomes all may assist the public. How can uncertainty be communicated – public may see only the line, not the range in possible values. There are particular challenges of representing water quality results.

What has worked in communicating with the public and decision makers? Example of Pembina two-dimensional modelling, public can relate to visuals; example of time sequence of glacier wastage made into movie; nutrients going into Puget Sound; population change related to land use; satellite imagery; use of respected local person. Public understanding and commitment is an essential aspect of sustainable water management.

Public expectation of what a board can do to satisfy flow and level aspirations is much higher than reality. Does identifying boards as "control boards" lead to a public misunderstanding of how much control is really feasible? The importance of public visualization support is significant.

Modelling Priorities Plenary

The plenary included a discussion of guiding principles related to modelling, how can the IJC assist boards and address immediate board priorities.

Guiding Principles

Principles for selecting and using a model in international watersheds could be considered as a series of questions or as a decision tree.

Define the application

1. Is a model really required, or can the problem be resolved through data analysis and interpretation? What science questions need to be posed to initiate model development?
2. Is the application a one-off or is there a continuing requirement for the model? Is the task considered as planning, operations, or forecasting?
3. Can the scope of the application be refined by running a simple model? Can a structured approach to the development be identified?

Model Selection

4. Is the model widely accepted for the proposed application?
5. Is the model proprietary or open source?
6. Is the model well-documented, peer reviewed or otherwise certified?
7. Is the model currently supported by an agency or vendor?
8. Are the data requirements reasonable?
9. Is the computational effort appropriate to the application?
10. Is the expertise to develop and run the model available?
11. Can other resource constraints be met?
12. What visualization options exist? Consider output to Google Earth?

Post Model Development

13. What arrangements exist for stewardship/archiving of project?
14. How can model output be used to inform the public and decision makers?
15. If the model development was in the realm of research and development, is there a need to operationalize the model? What steps may be needed?

IJC Support for Boards

Persons attending were asked what the IJC can do to support its boards modelling needs. Points raised included:

- Establish guiding principles for model selection and a modelling framework
- Identification of common priorities
- Facilitate or encourage development of a data portal
- Assist in identification of expertise
- Consider model archiving matters
- Initiate projects specifically aimed at model improvement/enhancement
- Annually inform governments of data needs to pertaining to board operations, including modelling. (Prairie Provinces Water Board example)
- Provide a users' forum
- Provide advocacy for good modelling practices
- Provide a perspective on public outreach needs

Board Priorities

Boards were asked to identify some specific priorities. The Red Board had requirements related to hydrological, hydraulic and water quality modelling. The St. Lawrence Board needed improved hydraulic modelling pertaining to the basin supply. The St. Croix Board had an emerging need for water quality modelling. The Osoyoos Board needed improvements to lake level modelling. All boards saw a need for improved visualization and environmental prediction. The possible need for 3D models was mentioned. No needs for groundwater models were identified at this stage.

NEXT STEPS

The record of this workshop will be provided to those attending in draft form. The final version of the workshop report will be made available from the IJC website. All presentations will be made available via Dropbox, http://www.dropbox.com/

A second workshop will be held in November at a location in the United States to be decided. It will focus on data requirements for models. The third workshop, early in 2011, will complete the modelling framework.

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Pomeroy, J., X. Fang, C. Westbrook, A. Minke, X Guo, and T. Brown 2009. *Prairie Hydrological Model Study.* Centre for Hydrology Report No. 7. University of Saskatchewan, Saskatoon, SK.

Preston, S.D., R.B. Alexander, M.D. Woodside, and P.A. Hamilton 2009. *SPARROW MODELING—Enhancing Understanding of the Nation's Water Quality.* U.S. Geological Survey Fact Sheet 2009–3019, 6 p.

Appendix A – Workshop Agenda

IWI Modelling Initiative: Needs Assessment Workshop

Winnipeg, Manitoba June 28-30, 2010

~Greenwood Inn & Suites~
1715 Wellington Avenue

Workshop Objectives:

- To determine what are the Boards' priorities that require a modelling approach to address them.
- To determine the Boards' level of knowledge and expertise with regards to applying models.
- To develop a path forward for building an IJC modelling framework.

AGENDA

Day 1 – Monday, June 28

Item	Time	Topic	Lead
		Welcoming and Background	
1	14:00-14:15	Background on IWI	Bob Reynolds
2	14:15-14:45	IWI Modelling Initiative	Ted Yuzyk
3	14:45-15:30	Overview of Hydraulic and Hydrological models	Dr. Syed Moin & Dr. Al Pietroniro
	15:30 -15:45	**Health Break**	
		Overview: Hydraulic/Hydrological Models	
4	15:45-16:30	Modelling Case Studies	Dr. Wayne Jenkinson
5	16:30-17:30	Plenary on Hydraulic/Hydrological Modelling	Facilitator/All
	17:30	**End of Day 1**	

Day 2 – Tuesday, June 29

Item	Time	Topic	Lead
		Overview: Water Quality Assessments and Models	
6	8:30-9:30	Overview of Water Quality Models	Dr. Glenn Benoy/Dr. Bill Booty
7	9:30-10:30	Plenary on Water Quality Modelling	Facilitator/All
	10:30 - 10:45	**Health Break**	
		Modelling Requirements: Boards' Perspectives	
8	10:45-11:15	International Red River Board	Gregg Wiche
9	11:15-11:45	International Souris River Board	Russell Boals

10	11:45-12:15	International St. Croix Watershed Board	Bill Appleby
	12:15 -13:15	**Lunch (Provided)**	
11	13:30-14:00	International Rainy River Board	Nolan Baratono
12	14:00-14:30	International Osoyoos Lake Board	Cynthia Barton
13	14:30-15:00	International St. Lawrence River Board	George Cotroneo
	15:00 -15:15	**Health Break**	
14	15:15-17:00	Plenary on Boards' Requirements	Facilitator/All
	17:00	**End of Day 2**	

Day 3 – Wednesday, June 30

Item	Time	Topic	Lead
		Synthesis and Boards Modelling Priorities	
15	8:30-9:00	Synthesis and Commonalities	Facilitator
16	9:00-10:15	Priorities Plenary	Facilitator/All
	10:15 – 10:30	**Health Break**	
		Next Steps	
17	10:30-11:00	Principles/Guidelines for Model Applications	Facilitator/All
18	11:00-11:30	IWI Modelling Strategy and Framework Document	Facilitator/All
19	11:30-12:00	Roundtable on Workshop Accomplishments and Wrap-up	Facilitator/All
	12:00	**End of Day 3**	

APPENDIX B – PERSONS ATTENDING

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