CSHS SCSH

Canadian Society for Hydrological Sciences — Société Canadienne des Sciences Hydrologiques

Canadian Water Resources Association — Association Canadienne des Ressources Hydriques

PROGRAM AND ABSTRACTS

OPERATIONAL RIVER FLOW AND WATER SUPPLY FORECASTING

October 6-7, 2011

SIMON FRASER UNIVERSITY - Harbour Centre
515 West Hastings Street
Vancouver, British Columbia V6B 5K3, Canada

Organizing committee

Dave Campbell	BC Ministry of Forests, Lands and Natural Resource Operations, Victoria
Bruce Davison	McGill, Montreal & Environment Canada, Saskatoon
David Garen	USDA Natural Resources Conservation Service, Portland, Oregon
Adam Gobena	BC Hydro, Burnaby
Dave Hutchinson	Environment Canada, Vancouver
Frank Weber	BC Hydro, Burnaby
Scott Weston	BC Hydro, Burnaby

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PROGRAM

OPERATIONAL RIVER FLOW AND WATER SUPPLY FORECASTING

SIMON FRASER UNIVERSITY - Harbour Centre
515 West Hastings Street
Vancouver, British Columbia V6B 5K3, Canada

WEDNESDAY, OCTOBER 5, 2011

2011-10-05 18:30	to	21:00					ICEBREAKER PUB NIGHT Yaletown Brewing Company, in the Pub section 1111 Mainland Street Vancouver http://www.markjamesgroup.com/yaletown.html

THURSDAY, OCTOBER 6, 2011 - Labatt Hall

2011-10-06 7:30	to	8:30					REGISTRATION & CONTINENTAL BREAKFAST
2011-10-06 8:30	to	9:00					WELCOME AND OPENING REMARKS
			SPEAKERS:				**SESSION CHAIR:** Bruce Davison
2011-10-06 9:00	to	9:30	Luc	Perreault	Hydro-Quebec Research Institute	Canada	Assessing hydrological forecasts at Hydro-Québec
2011-10-06 9:30	to	10:00	Greg	West	UBC, BC Hydro	Canada	Evaluation of Deterministic and Probabilistic Meteorological Forecasts for BC Watersheds
2011-10-06 10:00	to	10:30	Adam	Gobena	BC Hydro	Canada	Verification of BC Hydro's short- and long-range reservoir inflow forecasts
2011-10-06 10:30	to	11:00					COFFEE BREAK
							SESSION CHAIR: Bruce Davison
2011-10-06 11:00	to	11:30	Marie-Claude	Simard	Hydro-Quebec	Canada	Inflow forecast at Hydro-Quebec Production
2011-10-06 11:30	to	12:00	Frank	Weber	BC Hydro	Canada	The Ensemble River Forecast System - operational stochastic-dynamic prediction of inflows at BC Hydro
2011-10-06 12:00	to	12:45					LUNCH (provided)
							SESSION CHAIR: David Garen
2011-10-06 12:45	to	13:15	Bruce	Davison	McGill University and Environment Canada	Canada	Short-term hydrological ensemble prediction - design and preliminary results
2011-10-06 13:15	to	13:45	Dominique	Bourdin	UBC	Canada	Member-to-Member Ensemble Hydrometeorological Modeling
2011-10-06 13:45	to	14:15	Darwin	Brochero	Université Laval	Canada	An experience on the selection of members for simplifying a multimodel hydrological ensemble prediction system
2011-10-06 14:15	to	14:45	Peter	Gijsbers	Deltares USA Inc.	USA	Similarities and difference in hydrologic forecasting approaches between Europe and America
2011-10-06 14:45	to	15:00					COFFEE BREAK
2011-10-06 15:00	to	16:25					GROUP DISCUSSIONS
2011-10-06 16:25	to	16:30					WRAP UP
2011-10-06 16:30							ADJOURN
2011-10-06 17:45	to	19:45					DINNER (self-financed) The Old Spaghetti Factory 53 Water Street Vancouver http://www.oldspaghettifactory.ca/locations/british_columbia/

FRIDAY, OCTOBER 7, 2011 - Labatt Hall

2011-10-07 7:30	to	7:55					CONTINENTAL BREAKFAST
2011-10-07 7:55	to	8:00					ANNOUCEMENTS
			SPEAKERS:				**SESSION CHAIR:** Frank Weber
2011-10-07 8:00	to	8:30	Stuart	Hamilton	Aquatic Informatics Inc.	Canada	Accurate Forecasts Begin with Accurate Observations: How Improved Data Production Systems Can Lead the Way
2011-10-07 8:30	to	9:00	Rashawn	Tama	USDA Natural Resources Conservation Service	USA	How much do we trust our models? Memes in streamflow forecast adjustment
2011-10-07 9:00	to	9:30	Hamid	Moradkhani	Portland State University	USA	Implication of Data Assimilation in Ensemble Streamflow Prediction
2011-10-07 9:30	to	10:00					COFFEE BREAK
							SESSION CHAIR: Scott Weston
2011-10-07 10:00	to	10:30	James	Byrne	University of Lethbridge	Canada	High-resolution hydrometeorological modeling in diverse landscapes
2011-10-07 10:30	to	11:00	Michael	Allchin	Mapmatics	Canada	Flow Regime Estimation in UK Ungauged Basins
2011-10-07 11:00	to	11:30	Hamid	Moradkhani	Portland State University	USA	Toward Improving the Multi-modeling Hydrologic Forecasting: Integration of Data Assimilation and Bayesian Model Averaging
2011-10-07 11:30	to	12:30					LUNCH (provided)
							SESSION CHAIR: David Campbell
2011-10-07 12:30	to	13:00	Barbro	Johansson	SMHI	Sweden	Probability spring flood forecasts in Northern Sweden
2011-10-07 13:00	to	13:30	Phillip	Slota	Manitoba Hydro	Canada	Development of an inflow forecasting model for the Pointe du Bois GS Spillway Replacement Project
2011-10-07 13:30	to	14:00	Khalid	Khan	Forest, Land and Natural Resources, BC	Canada	Near Real Time Forecasting of Flood Water Levels along Fraser River during Freshet 2011
2011-10-07 14:00	to	14:20					COFFEE BREAK
2011-10-07 14:20	to	16:15					GROUP DISCUSSIONS
2011-10-07 16:15	to	16:30					WRAP UP
2011-10-07 16:30							ADJOURN

ABSTRACTS

Assessing hydrological forecasts at Hydro-Québec

Perreault Luc[1]*, Gaudet, Jocelyn[1], et Merleau, James[1]

[1] Hydro-Québec Research Institute
Expertise Mécanique, Métallurgie et Hydo-éolien
Institut de recherche d'Hydro-Québec
1800, boul. Lionel-Boulet
Varennes (Québec) J3X 1S1

Hydrological forecasting is crucial for hydropower production and risk management related to extreme events. Since uncertainty can not be eliminated from such a process, forecasts should be probabilistic in nature, taking the form of a probability distribution over future events (Dawid, 1984). Hydro-Québec has been producing probabilistic hydrometeorological forecasts since the early 80's. However, verification tools adapted to such ensemble hydrological forecasting system have only been recently considered. The evaluation of probabilistic forecasts is a challenging task since it involves the comparison of two different quantities: functions (the probability distributions) and real values (the observations). Thus, how can probabilistic forecasts be verified accurately? A quality control system has been developed and recently implemented to assess the probabilistic hydrological forecasts produced daily for more than 90 basins managed by Hydro-Québec. The simple theoretical framework proposed by Gneiting et al. (2007) was employed to provide guidance in the methodological work. In this presentation, the strategies and scoring rules considered to measure the performance of Hydro-Québec's hydrological forecasting system are presented. Monte-Carlo simulation experiments and applications to a real archive of operational forecasts produced at Hydro-Québec is also presented. Finally, future research perspectives and operational challenges on diagnostic approaches for probabilistic forecasts are given.

Dawid, A.P. (1984). Satistical theory : the prequential approach. *Journal of the Royal Statistical Society A*, 147, 278-292.

Gneiting, T., Balabdaoui, F. and Raftery, A.E. (2007). Probabilistic forecasts, calibration and Sharpness, *Journal of the Royal Statistical Society B*, 69, 243-268.

* Corresponding author: perreault.luc@ireq.ca

Evaluation of Deterministic and Probabilistic Meteorological Forecasts for BC Watersheds

Gregory West[1, 2,]*, Dominique Bourdin[1], Katelyn Wells[1], and Doug McCollor[2]

[1] University of British Columbia
[2] BC Hydro

A web-based interface with a variety of measures- and distributions-oriented statistics was completed earlier this year for four operational meteorological forecast systems: the Global Deterministic Prediction System (Canada), the Regional Deterministic Prediction System (Canada), the Global Forecast System (US), and the North American Ensemble Forecast System (Canada and US). Model verification is done at ~60 observing sites in hydrologically diverse watersheds across BC for the 2008-2009 and 2009-2010 water years. Here we present initial findings from a comprehensive evaluation of the statistics. Results show that simple bias correction greatly improves model performance, especially in areas of complex terrain. Canadian deterministic forecasts generally outperform their US counterpart, providing the best forecast out to ~5 days. At greater forecast lead times, the North American Ensemble Forecast System generally performs best, in many cases showing skill out to ~9 days. Results are further broken down, with performance-based recommendations on which models should be employed in different regions and at different forecast lead times.

* Corresponding author: Gregory West; gwest@eos.ubc.ca

Verification of BC Hydro's short- and long-range reservoir inflow forecasts

Adam K. Gobena* and Frank A. Weber

BC Hydro
6911 Southpoint Drive
Burnaby, BC, V3N 4X8

BC Hydro has a long history of using short- and long-range inflow forecasts for reservoir operations planning. The operational short-range forecasts currently in use are generated by the River Forecast System which uses the UBC Watershed Model as the modeling engine. The official forecast consists of deterministic 5-day forecasts for 20 reservoirs. Operational forecasts are available since December 2002. Long-range or seasonal water supply forecasts are produced by two techniques, namely, a principal components based statistical (VoDCa) model and a process-oriented model within the

Ensemble Streamflow Prediction (ESP) framework. Operational ESP forecasts for BC Hydro's two largest reservoirs (Williston and Mica) are available since 1980s. Operational statistical forecasts from the VoDCa system are only available since 2007, but hindcasts are available for a longer period. Long-range forecasts from both modeling systems are probabilistic.

Verification of historical inflow forecasts produced by the various modeling systems was undertaken recently with the aim of answering questions pertaining to user expectations and to provide direction for internal R&D for improving the utility's inflow forecasting system. This presentation discusses the results of the verification project, lessons learned and efforts being made at BC Hydro to mitigate some of the shortcomings of the current forecasting system.

* Corresponding author: adam.gobena@bchydro.bc.ca

Inflow forecast at Hydro-Quebec Production

M-C.Simard*, E.Crobeddu, S.Tardif, M.Durocher, J.Roy, and H.Sansoucy

Hydro-Québec

Hydro-Quebec is the largest producer of electricity in Canada and also the world's largest hydroelectric producer. It possesses 60 power stations for a combined capacity of 34 490 MW, 26 large reservoirs with a storage capacity of 175 TWh, and 571 dams and control structures. Hydro-Quebec Production (HQP) uses inflow forecasts in order to (i) maximize the power production, (ii) protect the public against flooding and (iii) manage water use. Short-term inflow forecasts are used on a daily basis for minimizing flood risks especially during the spring freshet and maximizing power generation. Long-term inflow forecasts are used to create equipment maintenance plans, to secure energy supply, and to manage multi-annual reservoirs.

HQP daily operational process to generate inflow forecast is as follows: (1) a short-term weather forecast (varying from 4 to 9 days) is created by a meteorologist using the forecasts of regional and global weather model from North American and European weather agencies. (2) In parallel, data quality control is done over more than 600 hydrometric stations, 300 meteorological stations and 300 snow survey stations. (3) Finally, forecasters use the hydrologic model HSAMI and the statistical tool HMAPPORT to create three 200-day probabilistic inflow forecasts. HSAMI is a lumped and conceptual model developed at Hydro-Quebec to compute inflow in the Nordic region. HMAPPORT was also developed at Hydro-Quebec and uses the outputs of HSAMI to compute probabilistic inflow forecasts. The three 200-day probabilistic inflow forecasts are computed as follows: 180 inflow forecasts are generated by the hydrologic model HSAMI using the short-term weather forecast combined with historical meteorological series. Then, the 180 inflow forecasts are combined with historical inflows and a statistical treatment is applied to these inflow series.

Inflow forecast accuracy at HPQ is mainly limited by (i) data quality of historical weather and inflow data, (ii), the network density of hydrometeorologic stations (iii) uncertainty linked to the hydrologic model HSAMI considering that Hydro-Quebec manages reservoirs located in vast basins of different biotopes.

With regard to future improvements, HQP intends to improve inflow forecast using the last developments in meteorological forecast and hydrological modeling. For example, HQP would like to explore the potential of using ensemble meteorological forecasting, using high-tech instruments for measuring snow-water equivalent, measuring the uncertainty of different hydrologic models through automatic calibration and evaluating possible improvements through multi-model combination.

* Corresponding author: Hugo Sansoucy; sansoucy.hugo@hydro.qc.ca

The Ensemble River Forecast System - operational stochastic–dynamic prediction of inflows at BC Hydro

Frank Weber[1], Dimeji Omikunle[2], Scott Weston[1]*, and Adam Gobena[1]

[1] BC Hydro
6911 Southpoint Drive
Burnaby, BC, V3N 4X8
[2] Accenture Business Services, Vancouver, BC

Operational forecasting places special constraints on hydrologic modeling software applications. Forecast systems are therefore designed to guide and/or automate the data and process flow, visualize observed and forecasted data, and provide forecast updating and post-processing functionality.

The superior value of probabilistic forecasts over single value ones has been generally accepted amongst hydroelectric reservoir operations planners. To gain more certainty in inflow forecast uncertainty, BC Hydro recently expanded its existing River Forecast System to an Ensemble Prediction System (EPS) for all forecast horizons. The salient features of the EPS include: a suite of watershed model parameter sets for tuning the magnitude of modelling uncertainty, short-range weather forecast ensembles from a number of numerical weather prediction systems, including the North American Ensemble Forecast System (NAEFS) and ensembles of climatologically-possible weather sequences –

both in-situ observed and synthetically-generated – as model input for long-range forecasts that span the period beyond which numerical weather prediction models provide any skill.

Design considerations, key features and limitations of the Ensemble River Forecast System will be presented. Examples of short- and long-range forecasts are given.

* Corresponding author: scott.weston@bchydro.bc.ca

Short-term hydrological ensemble prediction – design and preliminary results

Bruce Davison*

McGill University and Environment Canada

The operational roots of both atmospheric and hydrologic ensemble prediction can be traced back to the 1970s. This presentation will begin with some historical highlights of the operational use of ensemble prediction systems in both atmospheric and hydrologic modelling communities. The presentation will then illustrate the use of both atmospheric and hydrologic ensemble approaches for the purpose of predicting stream flow. The question remains as to whether an ensemble modelling approach can improve short-term (6 hour to 3 day) hydrological prediction in general. One of the key challenges of using a hydrological ensemble prediction system (H-EPS) is to understand and characterize the total uncertainty in the system. The design of an H-EPS will be presented, along with preliminary results showing the impact of characterizing more sources of uncertainty for the purpose of short-term hydrological prediction.

* Corresponding author: bruce.davison@ec.gc.ca

Member-to-Member Ensemble Hydrometeorological Modeling

Dominique Bourdin* and Roland Stull

Dept. of Earth and Ocean Sciences
University of British Columbia

Multi-model ensemble mean forecasts have been shown to outperform individual deterministic forecasts in both weather and hydrologic forecasting applications. Additional value is gained from using the full

ensemble, the spread of which is a measure of forecast uncertainty. This information can be used to generate probabilistic forecasts useful in risk-based decision making. A truly probabilistic approach to ensemble hydrologic forecasting should capture all sources of uncertainty, including initial- and boundary-condition errors, and hydrologic model process and parameter uncertainty. To date, research efforts into hydrologic ensemble forecasting have explicitly included only one or two error sources.

A member-to-member (M2M) ensemble hydrometeorological modeling scheme is proposed for forecasting inflows to hydroelectric reservoirs. The M2M approach combines multiple high-resolution numerical weather prediction (NWP) models with multiple physically based watershed models. Multiple parameter sets will be included to ensure that the ensemble captures uncertainty in the NWP forecasts as well as the hydrologic model processes and parameter uncertainty. Methods for updating hydrologic state and capturing the associated uncertainty will be investigated.

The feasibility of an ensemble inflow forecasting system is investigated for a watershed in the complex terrain of southwestern BC. In this study, various high-resolution NWP models were used to drive the WATFLOOD hydrologic model. Differences in performance between different models vary across the different metrics used in evaluation. This suggests that most, if not all of the NWP models have the potential to add skill to an ensemble forecasting system.

* Corresponding author: dbourdin@eos.ubc.ca

An experience on the selection of members for simplifying a multimodel hydrological ensemble prediction system

Brochero, D*., Anctil F., and Gagné, C.

In hydrology, as in many applications, it is accepted that there is no superior model for every application under all circumstances. In that sense, a multimodel approach may circumvent structural errors or inductive biases of the models. On the other hand, a Hydrology Ensemble Prediction System (HEPS), obtained by forcing a rainfall-runoff model with forecasts from a Meteorological Ensemble Prediction Systems (MEPS), have been recognized as a useful approach to quantify streamflow forecast uncertainties. Larger HEPS may thus be envisioned, simultaneously considering the model structure and the meteorological forecast sources of uncertainty. The complexity of such grand HEPS rapidly becomes an operational burden when one has to evaluate several hundreds of scenarios at each time step. This situation may even be more dramatic considering the current trend of also targeting several MEPS.

The main objective of the current work is to assess the degree of simplification (reduction of members) of a HEPS configured with 16 lumped hydrological models driven by the 50 weather ensemble forecasts from the European Centre for Medium-range Weather Forecasts (ECMWF). Here, the selection of the most relevant members from an initial 800-member grand ensemble is proposed using a Backward greedy technique with k-fold cross validation. This represents a direct measure to evaluate weight that each model must represent within a subset that offers the same or better performance than the reference set of 800 members.

Several statistical measures should be considered concurrently to assess the quality of ensemble forecasts, drawing the following question. Which optimization criterion would lead to the best simplification of a hydrological ensemble prediction system with the proposed technique of selection of members? Results exploiting the following five different optimization criteria are thus confronted: the continuous ranked probability score (CRPS), the ignorance score, the reliability diagram, the rank histogram, and the coefficient of variation. The combination of all of them is also tested.

Results, for ten French catchments, support the idea that selecting HEPS members is viable. It is in general even possible to expect better balance of scores in the 30-member subset than in the original much larger 800-member ensemble. However, the degree of reduction of members may be established in terms of the number of members required (complexity of the HEPS) or of the relationship between the different scores (performance).

The evaluation of five individual scores as criteria for optimizing the selection process revealed the complexity of the relationship between them. In many situations, improving one score is achieved at the expense of another one. For instance, the CRPS – often the primary score used for evaluating HEPS performance – is not a good choice for member selection. In fact, it was often possible to preserve or minimize the CRPS using another objective criterion. The design of a combined criterion turned out to be an important methodological improvement that integrates many characteristics of each score. The ratio of the rank histogram is the best single optimization criteria, not very distant to the achievements of the combined criterion.

* Corresponding author: darwinbrochero@gmail.com

Similarities and difference in hydrologic forecasting approaches between Europe and America

Gijsbers, P.J.A[1*], Welles.E[1], Weerts, A.[2], Ebel, M.[2], Werner, M.G.F.[2]

[1] Deltares USA Inc., Silver spring, Maryland, USA

[2] Deltares, Delft, The Netherlands

Over the last 10 years, Deltares has been involved in developing over 40 operational hydrologic forecasting systems around the world, using the DelftFEWS operational forecasting software platform as a basis for agency and site specific applications.

Having such wide spread application base provides insight in the similarities and differences of forecasting methods used by various agencies, with a noticeable difference between European agencies and North-America agencies. This distinction is most obvious in the organization of the forecast process, the way agencies deal with uncertainty in their forecast products and - in association to that – the usage of ensembles, as wells as the usage of in-house expertise in relation to forcings.

The difference in organization of the forecasting process relates to the forecast frequency (production/issue) and the extend of automation versus active user interaction with the data and the models during the production process. The latter also is reflected in the techniques and tools used for quality control, the type of simulation models that are executed as well as the type of correction techniques used. The difference in the use of ensembles is primarily related to the use of climatology as a basis for the ensemble traces versus the use of Numerical Weather Prediction ensembles. Finally, a difference can be noted in the usage of meteo expertise in relation to forcings.

The presentation will highlight in more detail the similarities and differences, and their implications on the outcome. Where appropriate recommendations may be made.

* Corresponding author: peter.gijsbers@deltares-usa.us

Accurate Forecasts Begin with Accurate Observations: How Improved Data Production Systems Can Lead the Way

Stuart Hamilton[1*] and David Hutchinson[2]

[1] Aquatic Informatics Inc.
[2] Environment Canada

All forecasting systems, no matter what timescale or level of sophistication, have a basic need of observations. In many cases, the forecasting agency is at arms length to the data provider and unaware of site specific factors creating potential for disinformation. Spurious data may look real while valid data may look spurious. Derived data, such as streamflow, can be considerably more complicated to verify due to its dependence on valid water level, rating model, shift and over-ride corrections. Forecaster time spent investigating the fault history of a gauge; currently deployed technology; dynamics of site-specific hydraulic conditions; and local weather and runoff processes to verify suspicious observations is time taken away from forecast analysis and dissemination of warnings.

In this paper, we describe a newly-developed data production system for automated quality control of observations. The system incorporates automated QA/QC procedures, automated alerts and notifications, and carry-forward corrections to provide best-possible observations to end users. Parameterized quality control procedures change the role of the hydrographer from a focus on data reconstruction to predictive analysis; technological optimization; preventive maintenance; and early intervention. Data-driven work planning and decision-making supported by automated station health monitoring and productivity reporting lead to increased responsiveness and accountability for system reliability. Forecasting can feed back to data production systems to improve data collection. An expanded suite of products and services can contribute to improvements in forecast timeliness and dissemination of critical information.

* Corresponding author: stu@aquaticinformatics.com

How much do we trust our models? Memes in streamflow forecast adjustment

Rashawn Tama* and David Garen

USDA Natural Resources Conservation Service
National Water and Climate Center
Portland, Oregon

Hydrologists making operational streamflow forecasts face a critical decision: To believe and accept the results of their models or to disbelieve the results and make adjustments. This decision occurs both for seasonal streamflow volume forecasting with statistical models as well as for short- or long-term forecasting with simulation models. Two questions arise: (1) Do the adjustments improve or degrade forecast skill? and (2) What memes, principles, and considerations should the hydrologist use to judge whether and how much to adjust?

These questions are explored based on the experience of the water supply forecasting program of the USDA Natural Resources Conservation Service. To address the first question, archives of seasonal streamflow volume forecasts for the past 20 years are used to compare raw model results with published forecasts, the latter containing any subjective adjustments made by the hydrologist due to assessments of the appropriateness of the raw model guidance and coordination with other agencies.

Measures of forecast skill are computed and compared for the two series at selected basins and forecast issuance dates.

Based on these results, the second question is addressed. Several possible memes that could guide the hydrologist's thought processes in deciding whether and how much to adjust are listed and discussed. For example:

(1) We always underforecast the wet years and overforecast the dry years, so this should be kept in mind when making adjustments.
(2) We shouldn't forecast very far away from the mean early in the year because there is still so much of the winter yet to come, so if the model results are "too far" away from the mean, the forecast should be adjusted toward the mean.
(3) We should adjust the forecast "some" based on the long-lead weather outlook.
(4) We should adjust the forecast "some" based on anecdotal information from field personnel, such as observations of unusual elevational distributions of the snowpack or the presence of snow in normally snow-free prairie areas.
(5) The forecast generally ought to be in the same vicinity as the snowpack in terms of percent of average, and if it is not, the forecast should be adjusted.

Other heuristics that forecasters might use to inform their judgments about whether the model is performing "correctly" are also discussed. The root issue is understanding the validity of a hydrologist claiming to have experience and knowledge about hydrologic behaviour that is not captured by the model and that provides a sufficient basis for making forecast adjustments.

Based on this analysis and these considerations, some suggestions and guidelines for making forecast adjustments are offered.

* Corresponding author: rashawn.tama@por.usda.gov

Implication of Data Assimilation in Ensemble Streamflow Prediction

Hamid Moradkhani*, C.M. DeChant, and M.R. Najafi

Department of Civil and Environmental Engineering
Portland State University

Within the National Weather Service River Forecast System, water supply forecasting is performed through Ensemble Streamflow Prediction (ESP). ESP relies both on the estimation of initial conditions and historically resampled forcing data to produce seasonal volumetric forecasts. In the western US, the accuracy of initial condition estimation is particularly important due to the large quantities of water stored in mountain snowpack. In order to improve the estimation of snow quantities, this study explores the use of ensemble data assimilation. Rather than relying entirely on the model to create single deterministic initial snow water storage, as currently implemented in operational forecasting, this study incorporates SNOTEL data along with model predictions to create an ensemble based probabilistic estimation of snow water storage. This creates a framework to account for initial condition uncertainty in addition to forcing uncertainty. The results presented in this study suggest that data assimilation has the potential to improve ESP for probabilistic volumetric forecasts.

* Corresponding author: hamidm@cecs.pdx.edu

High-resolution hydrometeorological modeling in diverse landscapes

James M. Byrne*, Ryan J. MacDonald, Evan Booth, Sarah Dalla Vicenza, Sarah Boon, Hester Jiskoot, and Matthew Letts

Department of Geography and Water and Environmental Science Centre
University of Lethbridge, Alberta

The discussion will describe the continued development and application of the physically based hydrometeorological model GENESYS (GENerate Earth SYstems Science input). GENESYS was originally developed to simulate detailed landscape dependent micrometeorology needed for modeling daily snow and rainfall processes in diverse terrain. We have developed routines to model (i) spatial and temporal accumulation and ablation of alpine snowpack; (ii) soil water processes; and (iii) high-resolution spatial and temporal runoff volumes from distinct watershed terrain categories at spatial resolutions of 1 ha – or less as needed.

The model functions well for operational forecasting and water management time frames on high-end desktop workstations. Applications to date over two diverse watersheds on the eastern slopes of Alberta demonstrate that the GENESYS model is able to simulate watershed processes, particularly water supply, with a high degree of accuracy. We have successfully operated at scales of 2000 and 20,000 sq km and expect that operations can be moved to much larger watersheds. Overall the model is an effective tool for operations forecasting and modeling the impacts of environmental change on water supply from mountain watersheds.

Ongoing developments and applications of the model include: soil water associated drought and fire hazard indices; glacial mass balance and glacial melt runoff routines; a surface and groundwater interactive runoff module; and a daily stream channel water temperature model. The stream temperature model is the focus of a PhD thesis that incorporates atmospheric and hydrologic controls to estimate stream temperatures, with an end objective of assessing the impacts of environmental change on the habitat of salmonid species native to the Western Cordillera. Future plans include characterizing resident terrestrial and aquatic species response(s) to land processes and climate driven stream temperatures.

* Corresponding author: byrne@uleth.ca

Flow Regime Estimation in UK Ungauged Basins

Michael Allchin*

Mapmatics

In the United Kingdom, a population approximately twice the size of Canada's exists in a land area equivalent to just over one quarter that of British Columbia. The associated human activity of all types translates into enormous pressures on water resources: as a result, all abstractions, discharges and impoundments are strictly regulated through licensing. When determining whether or not a new permit should be issued, managers assess the ability of the subject-river to support the new pressure without significant impact, and therefore require as accurate as possible a quantification of the flow regime at that location. The preferred representation is provided by annual and monthly flow-duration curves, and this in turn has required the development of methods to synthesise these for any point on the entire river system.

LowFlows Enterprise has been developed by Mapmatics for this purpose, initially on behalf of the UK Natural Environment Research Council's Centre for Ecology and Hydrology at Wallingford and the Environment Agency of England and Wales, and subsequently for Wallingford HydroSolutions Ltd. The system defines and characterises catchments in terms of the principal physical attributes which determine its likely hydrological response, and compares these descriptors with those stored for a pool of gauged reference catchments. By identifying the most similar of these, and applying appropriate weightings, their associated flow regimes may be used to provide a useful estimate of that at the ungauged site. This is initially constructed in terms of normalised values, with flows expressed as proportions of their long-term means: these are subsequently scaled using a value for annual runoff generated for the ungauged site from a national grid, itself developed from a regression-based rainfall-runoff model. Where reliable gauges with long-term records are found within the ungauged basin, or within a limited range downstream of its outlet, uncertainty may be diminished by incorporating their statistics into the estimate. Given the degree to which most flow regimes are influenced by anthropogenic activities, these must then also be taken into account, and the system does so by identifying these and superimposing their impacts on the natural statistics. This provides the best available representation of the available resource, which may then be used to judge the extent to which additional demands may be imposed.

The system has now been in use as the strategic operational toolset for this purpose by the various environment agencies of the UK for some ten years. The same approach has also been used to provide a benchmark for scenario water-use modelling, assessment of total catchment stress, water quality modelling, hydropower potential estimation, and similar purposes.

Whilst there are undoubtedly fine-detail shortcomings in the approach, and it does currently rely quite heavily on continuing stationarity, the degree to which the system is useful still outweighs that to which it is wrong.

* Corresponding author: mia@mapmatics.com

Toward Improving the Multi-modeling Hydrologic Forecasting: Integration of Data Assimilation and Bayesian Model Averaging

Hamid Moradkhani*

Department of Civil and Environmental Engineering
Portland State University

Multi-modeling in hydrologic forecasting has proved to improve upon the systematic bias and general limitations of a single model. This is typically done by establishing a new model as a linear combination or a weighted average of several models with weights based on individual model performance in previous time steps. The most commonly used multimodeling method; the Bayesian Model Averaging (BMA) assumes a fixed probability distribution around individual models' forecast in establishing the prior and uses a calibration period to determine static weights for individual models where the assigned weights do not change for the life of model forecast. More recent work has focused on sequential Bayesian model selection technique with weights that are adjusted at each time step in an attempt to accentuate the dynamics of an individual model's performance with respect to the system's response. However, these approaches still assume a fixed distribution around the individual models forecast. New sequential Bayesian model averaging technique is developed incorporating a sliding window of individual model performance around the forecast. Additionally this new technique relaxes the fixed

distribution assumption in establishing the prior utilizing a sequential data assimilation method that reflects both the performance dynamics of the models' forecasts along with their uncertainty. Results show that methods employing the data assimilation yield higher skill in medium to high stages of volatility.

* Corresponding author: hamidm@cecs.pdx.edu

Probability spring flood forecasts in Northern Sweden

Barbro Johansson[1]*, Susanne Nyström[2]*, and Jonas Olsson[1]

[1] Swedish Metorological and Hydrological Institute (SMHI)
[2] Vattenfall Hydro power AB

The Lule river is located in the northernmost part of Sweden. It starts in the mountain range along the Norwegian border and ends up in the Baltic Sea. 20% of the hydropower production in Sweden originates from this river. At least 50% of the precipitation falls as snow and approximately 60% of the annual runoff occurs during the melt season in May-July. There are several large reservoirs. Accurate and early estimates of the spring flood volume and the initial start point of the melting period are essential input for planning and optimization of the power system.

Since the 1970s spring flood forecasts for the Lule river have been made with the HBV rainfall-runoff model. Forecasts are made for the inflow to the major reservoirs. They are made weekly, beginning in January, and covering the period up to the end of August. The forecasts start from the current model state, representing snow, soil and lake storage. For the forecast period the model is run with historic time series of climate data. Digitized precipitation and temperature observations are available from 1961. 2011 the model is thus run 50 times for the forecast period, with 50 different time series, resulting in an ensemble of 50 inflow forecasts. Statistics on accumulated reservoir inflow are computed and a probability forecast is presented. This is used as input in systems for production planning in mid and long term.

Experience has shown that the uncertainty in the forecasts is higher for years when the precipitation and temperature pattern differs from the ordinary. For forecasts made late in the season, it is the accuracy of the hydrological model and its capability to estimate the current snow pack that is most important. Additional information like snow observations is then used by the forecasters to subjectively assess the model uncertainty.

For the early forecasts in January and February, the expected weather development during late winter and early spring is more relevant. In an ongoing research project, the aim is to link the current year to climatologically analogue historic years. The intention is to identify a reduced ensemble of historic years that is most likely to represent the current forecast period. Two methods are tested. One considers different climate indices (North-Atlantic Oscillation etc.) representing the months before the forecast, the other persistence of large scale atmospheric circulation patterns in the region. In addition, tests to feed the HBV model with ECMWF seasonal forecasts instead of historic weather are being evaluated. The project is carried out in cooperation between the University of Lund and SMHI and is funded by the Hydrological development group (HUVA) – a branch organization for the Swedish Hydro power companies.

* Corresponding authors: Barbro.Johansson@smhi.se; Susanne.Nystrom@vattenfall.com

Development of an inflow forecasting model for the Pointe du Bois GS Spillway Replacement Project

John Crawford, P. Eng. and Phil Slota, E.I.T*.

Manitoba Hydro
Water Resources Engineering Department
360 Portage Avenue (15th Floor)
P.O. Box 815 Stn Main
Winnipeg, MB R3C 0G8

Accurate inflow modeling is integral to Manitoba Hydro's existing operations and future planning. This presentation outlines the development and refinement of an inflow forecasting tool for the Pointe du Bois Generating Station Spillway Replacement Project using the US Army Corps of Engineers Hydrologic Modeling System (HEC-HMS).

In operation since 1911, the Pointe du Bois Generating Station is the oldest generating station on the Winnipeg River. Work has been conducted to develop, calibrate, and validate a hydrologic model capable of forecasting inflow to the generating station as an effort to control risk during the planned spillway replacement project. Using data from the Environment Canada GEM numerical weather predication (NWP) model and scheduled reservoir release information from the Lake of the Woods Control Board, a 5-day forecasting model was developed. This model has been calibrated/validated for the 2009 and 2010 open water periods with promising results.

Current efforts are being directed towards improvement of the model by incorporating snowmelt modeling for continuous runs, and extending the model forecast window to 2 weeks by utilizing ensemble weather forecasts from the North American Ensemble Forecast System (NAEFS) and other NWP products. Knowledge gained from the Pointe du Bois GS inflow forecasting model will be used as the basis for improving operational inflow forecasting models for the rest of Manitoba Hydro's existing Hydraulic System and future stations.

* Corresponding author: pslota@hydro.mb.ca

Near Real Time Forecasting of Flood Water Levels along Fraser River during Freshet 2011

Khalid Wasey Khan*, Lotte Flint-Petersen, and Hannah Chiew

Near real-time flood level forecast modeling of the lower Fraser River was carried out by the flood safety group of the Ministry of Forests, Lands and Natural Resource Operations (FLNR) in the Surrey office for 2011 freshet. A one dimensional Mike11 hydraulic model, developed by Northwest Hydraulics Consultants (NHC) in 2008, was used to provide a 5-day forecast of the Fraser River water levels for the 154 km long reach from Laidlaw to the ocean. The model's output was processed through an Excel database developed by NHC. The predicted tidal levels at Point Atkinson and Sand Heads, published by the Canadian Hydrographic Service (CHS), were used for the downstream boundary conditions. The upstream boundary conditions were provided by the River Forecast Centre (RFC) using their WARNS hydrologic model to provide 5-day forecasted flows at Hope, Harrison Lake inlet and Harrison Lake. The Mike11 model was run daily when the water level at WSC Mission Gauge (08MH024) exceeded 5.4 m geodetic in late May, and continued through to mid July. The water level forecasts were published on the RFC website, which provided municipalities in the Lower Mainland a lead time of up to 5 days to plan for flood emergency response. To track the performance of the Mike11 model, the computed water levels were validated using the observed water levels at 58 gauging stations (34 continuous and 24 staff). More than20 municipalities and agencies participated in providing this observed data. The predicted and observed water levels showed good agreement. The model consistently slightly over predicted water levels upstream of Agassiz Bridge (gravel reach) indicating that the channel geometry in this reach may have changed since 1999 (2008 Mike11 model uses 1999 survey data in this reach). An updated Mike11 hydraulic model, based on 2008 river survey data in the gravel reach (Mission to Hope), is under development. It is expected that once the updated model is calibrated to the 2011 and 2007 freshet data the model's future performance will improve.

* Corresponding author: Khalid.Khan@gov.bc.ca