Global Water Futures 2021 Operations Team Meeting – Project Reporting Template

Instructions: All GWF projects are asked to provide a summary update on their activities and accomplishments in preparation for the upcoming Operations Team meeting. **Please submit these by email to chris.debeer@usask.ca by no later than December 2.** These will be used to help guide discussions and breakout synthesis activities and will be made generally accessible on our website in advance of the meeting.

Project Name:	Integrated Modelling Program for Canada (IMPC)
Our major accomplishments to date are:	

Following IMPC project accomplishments have been achieved in collaboration with GWF Core modelling teams, in many instances, with shared resources (funding and personnel), as well as participation from partner organizations, external collaborators (and Indigenous community partners in specific sub-projects):

- **Improved hydrological land-surface modelling** (Dr. Pomeroy's team w/Core Modelling): developed and evaluated a 2-D water flow through snow model to advance both the physical understanding of and ability to simulate water flow through snowpacks as well as a 3-D blowing snow model that reduces the computational costs of accounting for the impact of blowing snow on snow water equivalent and snowmelt. The team also used the Cold Regions Hydrological Model to evaluate the response of snow and hydrological regimes to climate warming, with results showing a generalized decoupling of mountain river hydrology from headwater snowpack regimes.
- **Improved representation of permafrost** (Drs. Razavi and Wheater's team): developed new strategies for permafrost initialization and addressing parameter uncertainty in land surface models with a focus on MESH and Liard Basin within the MacKenzie River Basin. The emphasis has been on proper representation of temperature dynamics at the point scale and on how to scale that representation onto a catchment scale.
- **Model Intercomparison** (Dr. Tolson's team): work completed on Lake Eerie and included contributions from 17 models and 34 collaborators from 20 institutions.
- **Water quality and rive ice (**Dr. Lindenschmidt's team): WASP Sediment transport model set up for the lower South Saskatchewan River in preparation for coupling with water management models (MODSIM). Also developed a novel framework for identifiability and identification analyses for cold region integrated models and performed an analysis on water quality models in the Prairies. In terms of river ice research, team developed a graphical-user-interface (GUI) for the RIVICE hydrodynamic model for Monte-Carlo Analysis (MOCA) and data/result visualization in the Athabasca River and Saint John River. MESH-RIVICE was also tested successfully in the Athabasca River in Fort McMurray.
- **Analysis of extremes** (Dr. Elshorbagy's team): defined seven flood indicators to describe the key hydro-climatic components that could contribute to the generation of spring floods in the Canadian prairies, characterized the generation mechanisms of more than 2000 spring-flood events, and identified spring-flood generation mechanisms.
- **Uncertainty analysis** (Dr. Razavi's team): developed VARS-TOOL (https://vars-tool.com/) with applications to Sask River Basin and Great Lakes – the tool has garnered interest from over 500 users in 50 countries. New achievements include developing (1) one of the very first methods to handle correlation among model parameters, (2) one of the very first methods to utilize 'recycled data' (i.e., previous model runs) in the process of sensitivity and uncertainty analysis, and (3) an efficient and comprehensive Python library for VARS-TOOL. Collaborations with international groups have also led to policy-relevant exploration of Sensitivity analysis.
- **Integrated Water Management modelling** (Drs. Razavi & Brouwers' teams): Model integration efforts successfully completed so far combine the MODSIM Water Resource Management framework with the Inter-Regional Supply-side Input-Output (ISIO) economic model to evaluate relative economic impacts in the SRB under changing climate conditions, socioeconomic development, and policy interventions,

to identify opportunities for building resilience into the SRB water system. Several python scripts have been developed to link ecological metrics to the modelling framework as described below.

- **Scoping for policy scenario development based on surveys and the analysis of stakeholders' documents** (Drs. Gober & Razavi's teams): As a prelude to scenario development and complex systems modelling, team developed and implemented a methodology to canvas stakeholder ideas about problem sets and policy preferences and performed quantitative and qualitative analyses of content from a wide range of stakeholder documents in the Saskatchewan River Basin.
- **Socio-hydrology and understanding societal response to policy change in water sector** (Drs. Razavi & Elshorbagy's team): Developed a socio-hydrologic, agent-based model to characterize the coupled water-social behavior in the farming sector in response to polices around modernizing traditional irrigation systems. The geographical focus of this work has been on the Bow River Basin, which is a sub-basin of South Saskatchewan River Basin in Alberta. A particular focus has been on human adaption to drought and a possible emergence of the "Rebound Phenomenon" and its implication in this sub-basin.
- **Ecological modelling** (Drs. Jardine & Strickerts' teams): naturalized daily and future flows from MESH (15 climate scenarios, 3 time periods) were used to produce naturalized flow presumptive standards (sustainable boundaries) for 28 sites in Alberta, five sites in Saskatchewan, and two sites in Manitoba. Ecological performance indicators were developed, including percent deviation from natural flow and Indicators of Hydrologic Alteration (IHA) variables.
- **Visualization** (Dr. Gutwin's team): Pilot version of a web-based user-friendly decision support system was released that allows users to easily control model variables and to visualize model outputs in ways that are reflective of competing water use and demand in the Saskatchewan River Basin (SRB) as well as relevant to decision-making in the context of a stressed water system. Demo of the pilot version of this tool was showcased at GWF Edmonton Science tour meeting (Feb'2020), and at IMPC's 4th annual meeting workshop to identify interested users/stakeholders that can directly benefit from the tool built on integrated water management modelling infrastructure for the SRB with future scenario analysis capabilities.
- **User engagement** (Carlson, Balkhi & IMPC integration team): IMPC recorded a growth from 45 collaborators to more than a 100 in 60 partner organizations involved in various capacities with project activities. The project has also conducted two user engagement surveys so far to track user perceptions over the lifetime of the project (year 1 and year 3) to design partner-specific outreach and engagement strategies and understand changing partner needs. IMPC researchers have had a long-lasting relationship with the Cumberland House's majority Indigenous community that has allowed the IMPC team at large to try and better understand the community's concerns and respond where possible. Although this is an ongoing process, over the past four years of the project, IMPC has been working to enhance its collaborative efforts between the delta stewards, community ambassadors and researchers, including a computer science lead, water modelers, social scientist, and an ecological expert, as well as delta stakeholders including SaskPower and WSA. IMPC has been hosting the meeting series, Delta Dialogues – Finding a Way Forward, (in collaboration with Cumberland House Delta Stewardship Committee) since August 2020 to provide and facilitate two-way dialogue between stakeholders and rightsholders in the Saskatchewan River Delta region and provide knowledge support to the community where needed.
- **Outreach & Knowledge mobilization** (Carlson & Balkhi)**:** Improved online presence of IMPC (website and social media) and increasing profile of various impactful/relevant research outcomes by various communication streams to specific audiences (periodic project newsletter, annual meetings, occasional webinars, online plain language news pieces).

Our current activities are:

- **Improving Modelling and forecasting capacity:** Dr. Li's team has recently been evaluating the impacts of surface coupling strength on regional climate simulation using Fluxnet site observations and the continental scale 4-km WRF CONUS simulations, along with assessment of the uncertainty for the coupled simulations of future climate. Dr. Papalexiou's team is actively performing detailed statistical analysis of gridded products based on the available in situ and gridded observation data over Canada and all available CMIP6 simulations (both historical and future for four SSPs) for precipitation, max and min temperature.

- **Model intercomparison:** now underway for the Nelson-Churchill by Dr. Stadnyk's team to produce scenarios under i) no regulation, ii) with regulation, and iii) under climate change. The team has attracted contributions from many stakeholders, employed a project manager, meets now on a monthly basis, and is receiving results from the first stage of the work.
- **Scenario Analysis:** To create responses to various future events to assist in multi-criteria decision-making under uncertainties in the SRB, Dr. Razavi and Dr. Gober's teams have now selected 15 scenarios that are representative of a range of future events with the use of defined future projections that include a combination of crop mix, irrigation expansion (Saskatchewan), and Irrigation efficiency change scenarios. These scenarios were integrated into the integrated modelling framework and results are currently being fed into the knowledge-support visualization tool being developed as described below.
- **Visualization tool development & user evaluation**: Dr. Gutwin's team is concurrently developing two web-based tools with direct and iterative collaborator and user feedback aimed at maximizing utility of these tools as sources of information to help multi-stakeholder dialogues and water management decision-making: (1) Knowledge-Support-System (Previously, Decision-Support-System, or DSS) tool infrastructure is being expanded from its pilot phase to include MODSIM integrated model results (15 select scenarios, as described above); (2) EBC Flow Visualization tool to respond to place-based community questions, as well as work as a 'boundary object' to assist in multistakeholder facilitation processes between SaskPower, Water Security Agency, Cumberland House residents (and other delta stakeholders) to work towards collective stewardship goals of the delta.
- **Engagement, outreach & KM:** Maintaining (and growing) the quality of engagement alongside a growth in number of partners and knowledge users remains to be priority for the project. The diverse range of engagement and knowledge mobilization activities as described in the section above will continue throughout Phase II at the project level and at the work package or individual investigator. The IMPC project manager provides a supporting or leading role where requested.

Several of these activities span across project Phases I and II and are ongoing, continuous learning processes, heavily influenced by user feedback whenever received and where applicable.

The main accomplishments expected by the end of the project are:

The outcomes of IMPC Phase II are oriented toward projects-level integration of models as well as user engagement and successful knowledge mobilization of research outcomes wherever applicable:

Integration of next-generation hydrological and land surface models to address changing cold region processes:

- Detailed statistical analysis based on the available in situ and gridded observation data, as well as CMIP6 projections; comparison between observation and projections. Downscaled CMIP6 precipitation projections for target regions alone with quality assessment of the downscaled products.
- Complete pan-Canadian high resolution (4-km) atmospheric modelling of historical climate and future warming, the CONUS II simulation; post-processed WRF output; sensitivity test of land–atmosphere feedbacks using existing coupled atmosphere - land surface model. Conduct inter-model comparisons with the ECCC MESH/CLASS modelling system for cold region land surface schemes by collaborating with the core modeling and the ECCC MESH groups. Conduct scenario runs for the assessment of land–atmosphere feedbacks using WRF-MESH/CLASS coupled modeling system to provide additional context of model and scenario uncertainty.

Integrating river ice processes into hydrological modelling for improved operation and flood forecasting:

- Implement a validated MESH-GeoSpace-RIVICE natural and regulated river systems in a platform which allows data streaming and flood warning issuances (Saint John River).

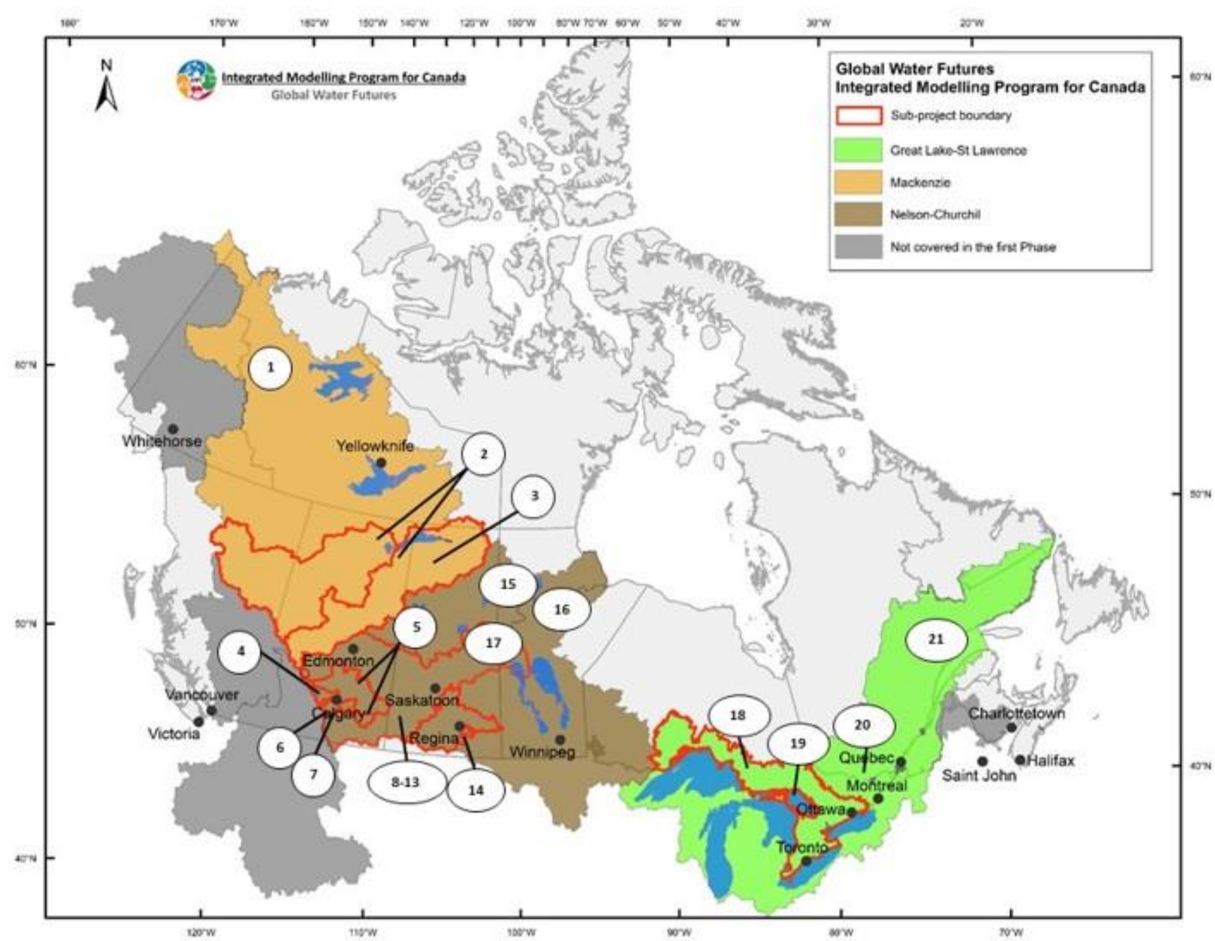
Integration of water quality metrics, ecological metrics, and climate change scenarios into the water management modelling framework:

- Couple flows and fluxes between MODSIM and WASP; calibrate/validate MODSIM-WASP modelling system; complete development of MESH-WASP modelling system. Run water-management and climate-change scenarios with MESH-WASP and MODSIM-WASP modelling systems.
- Deriving a target range of river flows for people and wildlife to thrive in the Saskatchewan River Delta (based on 'presumptive standard method' that estimates sustainable boundaries for flow) and using integrated models to understand how these targets may be met or not.
- Including future climate change scenarios (possible collaboration with Core modelling on use of climate change scenarios) in combination with policy scenarios as described in section above.
- Definition and testing flow-ecology relationships and coupling validated flow-ecology metrics with the MODSIM model.

Hydrologic model inter-comparison and multi-model analysis for improved prediction:

- Apply models in regulated basins with streamflow and process outputs to assess model set up accuracy and performance in representing human impacts in the Nelson-Churchill river basin.

Here is a key visual from the project (figure, photo, table, graph, etc.)



Legend

Nelson-Churchill

(4) MESH with glacier and perennial snow components
(5) MESH with slope-aspect and lowland pond components
(6) Agent-based model for farmer behavior
(7) VARS-TOOL applied
(8) High resolution atmospheric modelling with WRF
(9) Water resources models WEAP, WRIMS, MODSIM developed
(10) MODSIM coupled with economic input-output model
(11) Future scenario generation (stakeholder preferences)
(12) Future scenario generation (flows and climate change impacts)
(13) Visual Decision Support System
(14) MESH with HEC-RAS, MIKEFLOOD, Delft3D
(15) HYPE frozen soil representation improvements (Nelson-Churchill)
(16) MODSIM developed and coupled with WATFLOOD, HEC-HMS
(17) Aquatic ecosystem performance metric

Mackenzie

(1) High resolution atmospheric modelling with WRF (Mackenzie)
(2) MESH coupled with RIVICE
(3) MESH coupled with RBM, WASP, SOL

Great Lake-St Lawrence

(18) Input-Output Model for the Great Lakes region
(19) Comparison of land-surface hydrologic models LBRM, HYPE, WATFLOOD, VIC, MESH, WRF-Hydro, GEM-Hydro
(20) VARS-TOOL applied
(21) Web visualization for spatio-temporal hydro-climatic variables (Pan-Canadian)