Theme A Overview

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THEME A: Integrated Earth Systems Modelling
Theme Leads: Pietroniro/Pomeroy/Wheater/Razavi

Objective is to develop next-generation hydrological and land surface models to address changing cold region processes and associated societal risks.

- How can models of the cold regions Earth system be improved and integrated to better simulate system interactions and feedbacks, and observed variability and change?
- How will these models perform under future change, and new extremes?

We focus on the need to represent key (neglected) features of changing cold regions that have profound effects on changing landscapes, changing water resources and the vulnerability of human populations.

Not just hydrology focused. Looking at riverine processes, wtaer quality, ice and temperature

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So what’s missing – haven't we figured this out yet

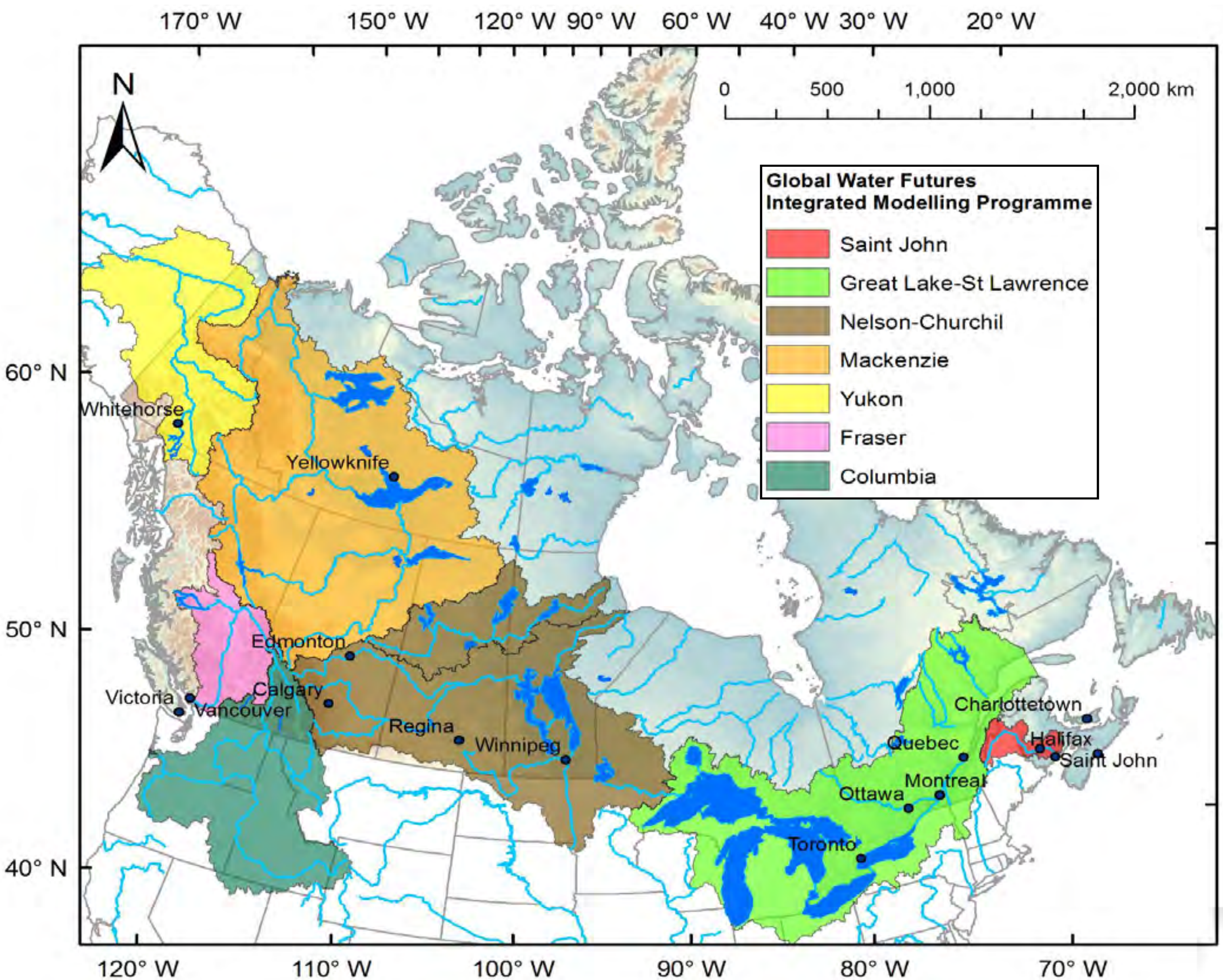
Inductive Approach – Top Down

- Analyses processes based on data (e.g. dominant responses) at larger scales (e.g. basin) and then, if needed, make inferences about processes at smaller scales.

Deductive Approach – Bottom-Up

- Analyses processes at smaller scales using physical laws, and then extrapolates the process at larger scales using aggregation techniques.

Geographic Scope



Theme A1 : High resolution atmospheric modelling to represent scenarios of change and land-atmosphere feedbacks (Li, Razavi, Pietroniro, Pomeroy, Wheater).

Context:

- Global Climate Models are the main tools for simulation of future climate
- The ability to simulate precipitation has been poor and climate change impacts assessment has suffered greatly from high uncertainty in future precipitation.

Objectives and Method:

- Work with the GWF core atmospheric modelling group, in collaboration with the US National Centres for Atmospheric Research (NCAR), to support the development of pan-Canadian high resolution atmospheric modelling of historical climate and future warming, using the WRF model.
- Link with ECCC and deliver both multi-model Canadian Regional Climate Model ensembles and high realization WRF simulations to the Theme C and D basin scale applications.
- Support user focussed Decision Making Under Uncertainty in Themes C and D.

Simulations of historical and future climate from 4km WRF and multi-model RCMs; delivery of scenarios to C and D; preliminary evaluation of land atmosphere feedbacks (to be extended in Phase 2).

Study Areas: Nelson-Churchill, Mackenzie, Great-Lakes St. Lawrence, and Yukon River Basins.

Theme A2- Improving hydrologic process representations for cold regions to better simulate snow and glacier and accommodate hyper-resolution modelling (Pomeroy, Pietroniro, Wheater, Razavi, Stadnyk, Wood).

Context:

- Mountain glaciers and perennial snowpacks, and lowland (prairie/boreal/tundra) ponds are neglected components of Earth system models.
  - The mountain cryosphere can have important implications for sustaining river flows during droughts and delivering runoff in excess of precipitation in floods.
  - In lowland environments, ponds control the variable contributing area for streamflow generation through contributing area – surface storage relationships.

Objectives and Method: This work will incorporate a

- Dynamical glacier component in the ECCC's MESH by porting the Cold Regions Hydrological Model
- Modifying current snowpack algorithms, accounting for density and thermal conductivity changes as perennial snow turns into firn and glacier ice,
- Pond effects on runoff generation in lowland areas will be parameterised using a simplified algorithm that describes the non-linear network behaviour of large numbers of ponds that fill by blowing snow and overland flow and drain by overland and sub-surface flow

Deliverables: Glacier, perennial snow and lowland pond components added to MESH. Impacts of glaciers on runoff and depressional storage on runoff under climate change.

Study Areas: Churchill-Nelson River, Columbia River, Fraser River, Yukon River, Mackenzie River.

A3 - Integrating land-surface and in-stream water quality processes into hydrologic modelling (Lindenschmidt, Baulch, Pietroniro, Pomeroy, Wheater, Razavi, Chapra).

Context: Water quality modelling in Canada is fragmented and often limited to point or non-point problems that are addressed in isolation of the broader needs of basin-scale water management.

Objectives and Method:

- develop new water quality modelling functionality and integration, focusing on large scale modelling needs
- MESH will be extended to include new capability to simulate water quality, focusing on non-point quality issues. HYPE model and extension of the Cold Regions Hydrological Model wil be used for MESH development.
- Adopt the widely-used WASP model to simulate the transformations and fate of nutrients and contaminants in the river channel.
- Examine other models such as SPARROW and MAGIC

Deliverables:

A new large basin-scale water quality modelling toolkit linked to MESH, with initial applications focussed on the Nelson-Churchill system.   Dynamic models will then be developed and tested for the Saskatchewan and Assiniboine rivers; broader application will build on partner funding. Open loop simulations of long-term climate change will be carried out.

Study Areas: Nelson-Churchill basin, with specific management applications to address user needs (Prairie

(A4) - Integrating river ice processes into hydrological modelling for improved operation and flood forecasting (Lindenschmidt, Pietroniro, Pomeroy, Wheater, Razavi).

Context:

An important characteristic of cold regions rivers is ice-cover which causes ice jams and related flooding.

- This research will examine ice-formation and break-up from both a forecasting and climate change perspective and tie these models into the integrated modeling framework described above.

Objectives and Method:

- The river ice hydraulic model selected is RIVICE, a development by Environment Canada proven in many successful applications.
- RIVICE will be used in conjunction with MESH to study the impact of climate change on ice jam flood severity and we will develop new integration of the modelling with remotely sensed ice thickness and condition.

Study Areas: Forecasting will focus on the Red River (end-user: Manitoba Infrastructure) and Porcupine River (end-user: Yukon Environment) in the first instance.

Climate change impacts assessment will include the Nelson-Churchill and Mackenzie basins.

(A5) Hydrologic model inter-comparison and multi-model analysis for improved prediction (Tolson, Stadnyk, Razavi, Pietroniro, Pomeroy, Wheater)

Context:

Advancing and improving land-surface hydrologic modelling requires detailed model intercomparison studies to learn about shortcomings in specific models and ultimately perform multi-model analysis to describe model prediction uncertainties.

Objectives and Method: Benchmark the GWF land surface hydrologic models (MESH, VIC, HYPE, etc.) against each other on multiple distinct modelling case studies.

Research questions include: what amount of monitoring data is needed to distinguish model performance levels? What kind of calibration effort is required to fit the models to the available data? These efforts will be linked to the Great Lakes Intercomparison Project (GRIP) (Gaborit et al., 2017).

Deliverables: Hindcasting prediction quality of the different models assessed and compared in the first three years. In subsequent years the assessment will be from a forecasting perspective.

Study Areas: Nelson-Churchill, Mackenzie and Great Lakes.

A6 - Improving floodplain mapping in flood sensitive watersheds (Coulibaly, Elshorbagy, Pietroniro, Pomeroy)

Context:

- Flood plain simulation and risk mapping are urgently needed by Canadian governments and communities, including effects of climate change.
- Systematic analysis of changes and new approaches to frequency analysis, informed through deterministic and stochastic modelling systems are required, as well as floodplain models that build on recent advances in remote sensing of historical inundation for conditioning hydraulic performance.

Objectives and Method:

- The work will develop and integrated hydrologic and hydraulic modeling toolkit for flood mapping. Watershed modeling will be based on the ECCC MESH model, with the possibility of using other suitable modeling tools
- hydraulic modeling will be based on HEC-RAS.

Deliverables: This sub-theme will produce:

- watershed modeling tools suitable for flood risk assessment in the Prairies and the Great Lakes, taking into account human interventions in the hydrological cycle (e.g., reservoirs and flood control measures), changing climate, and the challenging prairie topography and
- tools for current and future flood quantile estimation at gauged and ungauged sites using advanced statistical methods and watershed modeling-based identification of flood triggering mechanisms.

Study Areas: A pilot study of the Bow and Elbow at Calgary will be funded by Natural Resources Canada in collaboration with the Government of Alberta and City of Calgary.

(A7) Characterization of predictive uncertainty for impact assessment (Razavi, Wheater, Gupta)

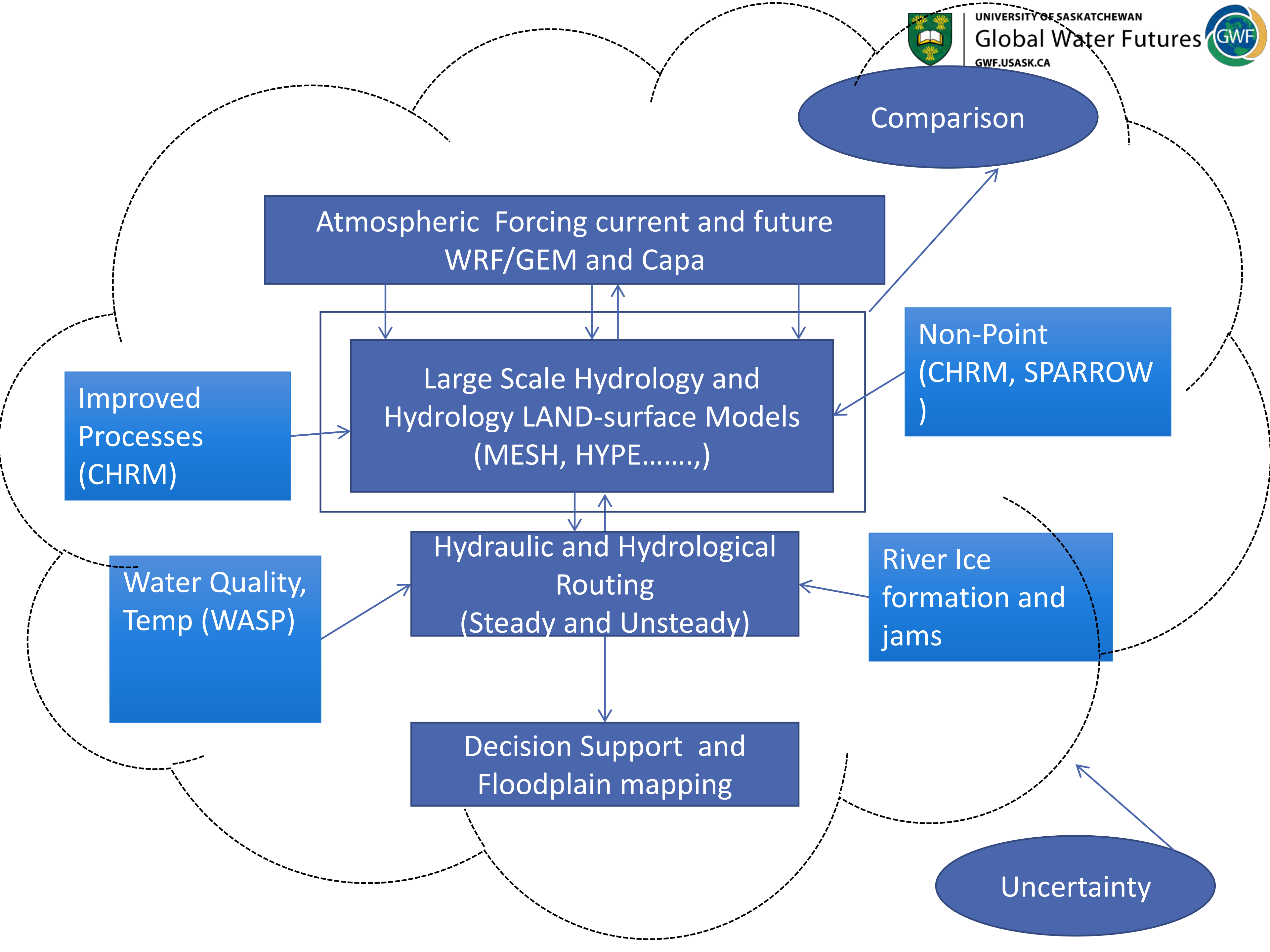
Context: Uncertainty is intrinsic to all aspects and components of the current generation of earth system models. Adequate characterization of uncertainty and its representation in any decision problem formulations is essential.

Objectives and Method:

- Will provide methodology and tools to support characterization and communication of model uncertainties across all Themes.
- Support model development in A2-A6, including diagnostic testing and the identification of major sources of uncertainty.
- We will use Monte-Carlo simulations and state-of-the-art sensitivity analysis tools such as VARS (Razavi and Gupta, 2016) to discover and understand dominant uncertainties in modelling and decision making processes (Herman et al., 2015).

Deliverables: Tools and results for uncertainty and sensitivity analysis of the suite of models developed in Themes A-D.

Study Areas: Nelson-Churchill, Mackenzie, Great-Lakes St. Lawrence, and Yukon River Basins.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Hydraulic and Hydrological Routing (Steady and Unsteady)
Water Quality, Temp (WASP)
River Ice formation and jams
Decision Support and Floodplain mapping
Uncertainty

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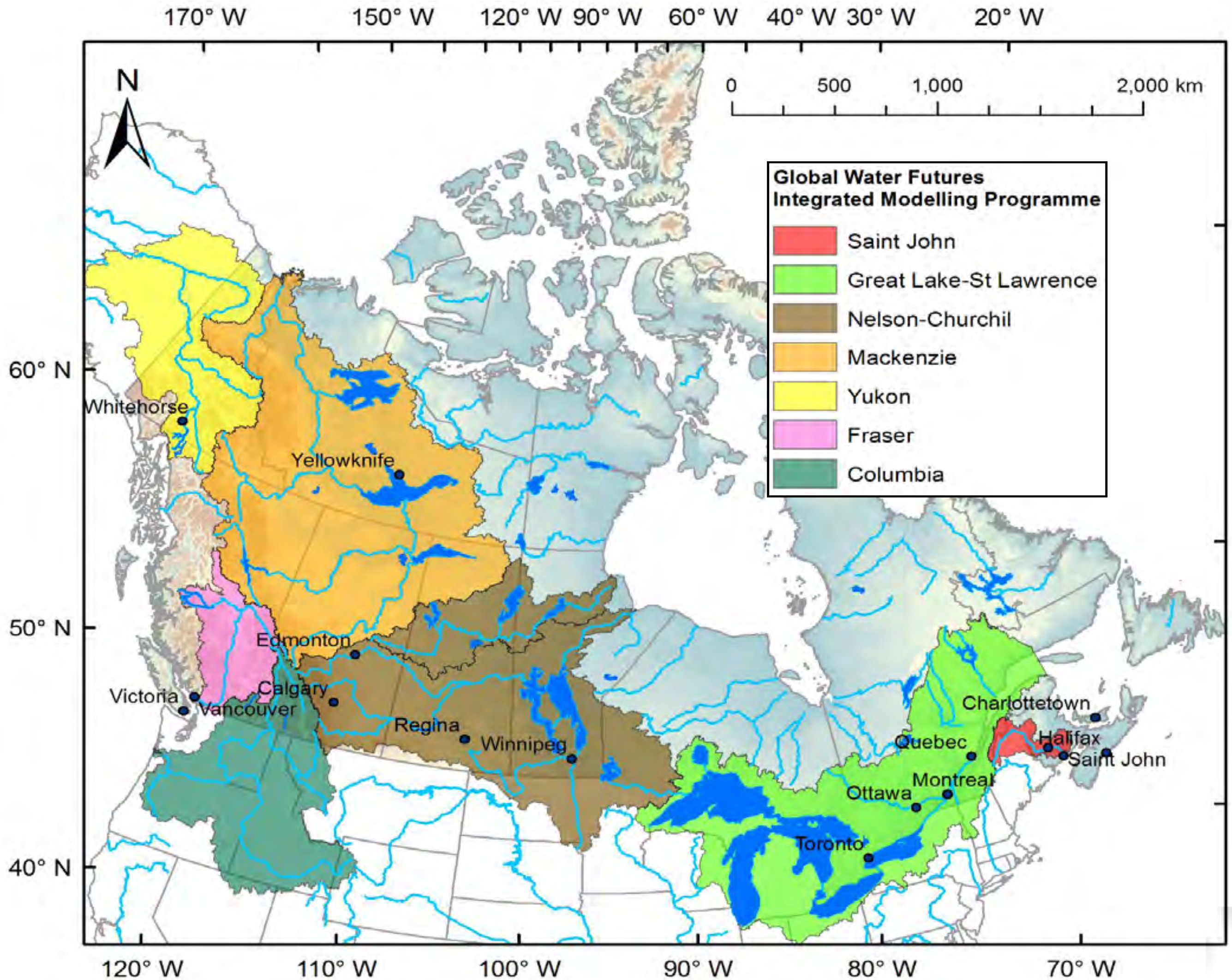

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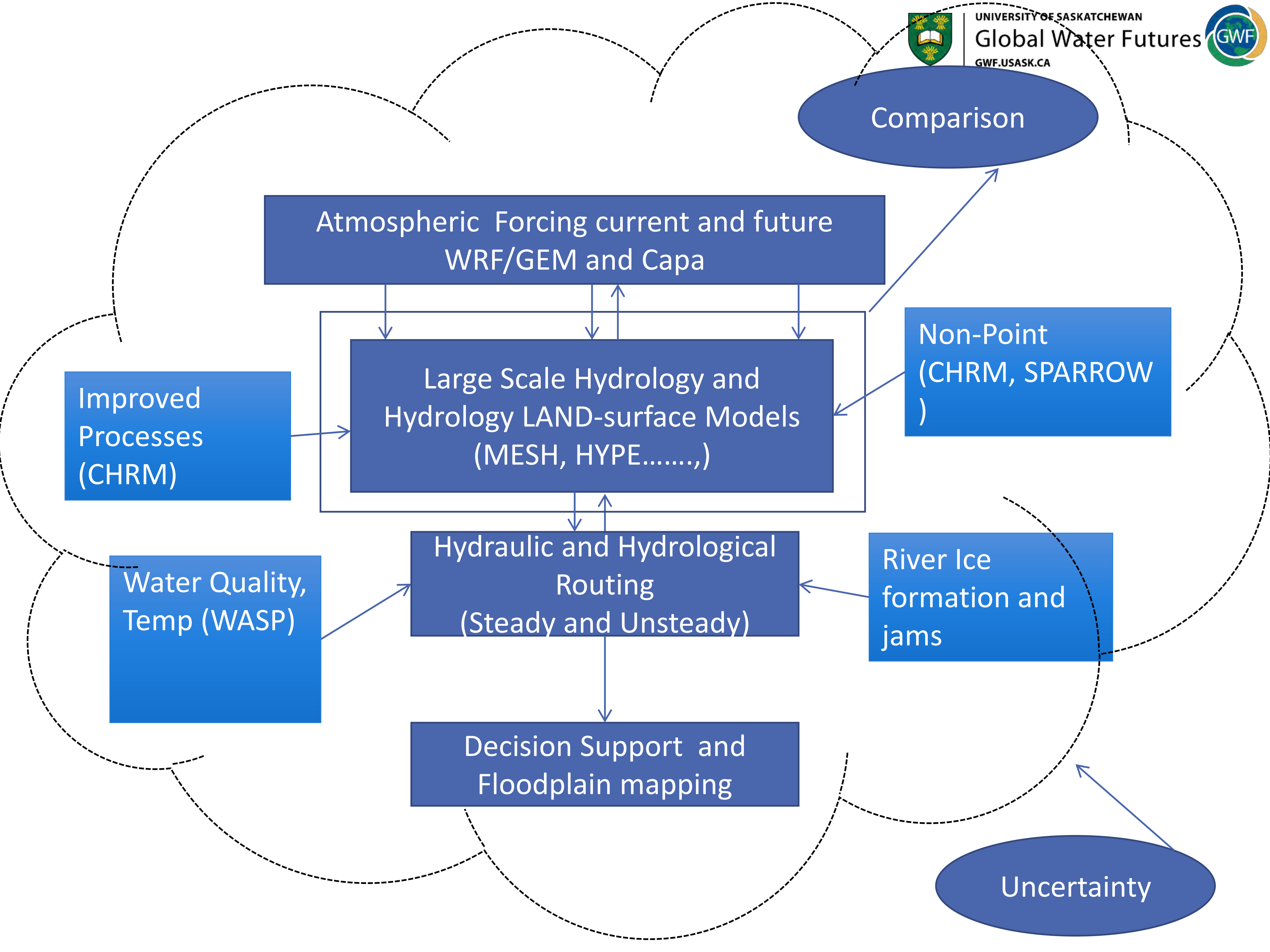
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