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GLOBAL WATER FUTURES - CORE MODELLING STRATEGY

BRIEFING NOTE

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Introduction

Climate warming and human actions are altering precipitation patterns, reducing snow levels, accelerating glacier melting, intensifying floods, and increasing risk of droughts, while pollution from population growth and industrialization is degrading water systems. With such unprecedented change, it is clear that the historical patterns of water availability are no longer a reliable guide for the future. In the GWF proposal, it has been argued that adaptation to these changes will require new science to understand the changing earth system (changing climate, land, water and ecosystems and their interactions); new modeling tools that capture these interconnected forces and their societal implications; new monitoring systems with greater capacity to warn of critical environmental changes; and more effective mechanisms to translate new scientific knowledge into societal action.

The following plan highlights the necessary components for establishment of the modelling needed to deliver the "new modeling tools" and "new monitoring systems" for Canada and the cold regions of the world that were identified as key programme deliverables. A core modelling effort (hereafter referred to as CORE) has been resourced to support a nationally-coordinated modelling strategy and the development of common modelling methodology and tools. This will include pan-Canadian applications of existing models, using a common framework, as well as the development of new modelling tools with new capabilities. However, CORE resources fall well below the needs for both model development and applications, hence a closely coordinated effort will be needed from the CORE and Pillar 3 activities. Pillar 3 proposals that contribute to the core GWF modelling needs, through model development and/or application to meet local, regional and basin-scale needs, are therefore welcomed. And while alternative tools and methods are also welcomed, it is highly desirable that there should be an element of inter-comparison with core tools and/or applications.

The modelling tools being developed will support the following objectives:

- **Improved disaster warning**: Currently, we lack the scientific knowledge, monitoring and modeling technologies, and national forecasting capacity to predict the risk and severity of potentially catastrophic events in Canada. These knowledge gaps and technology barriers have resulted in significant loss of life and property in recent years.
- **Prediction of water futures**: The world lacks water data on a scale to make informed decisions, and we cannot forecast future climate impacts without better models to assess

changes in our human/natural land and water systems. These limitations create risks for water supplies, water quality and sustainability.

- **Adaptation to Change and Risk Management**: Nationally and globally, we lack the governance mechanisms, management strategies, and policy tools needed to reduce the risk of water threats, design adaptive strategies to cope with uncertainty, and take advantage of economic opportunities that arise as change unfolds.

In order to accomplish these objectives, the following elements of the modelling systems need to be developed through the CORE and Pillar 3 outcomes:

Atmospheric models or forcing: A series of coupled, uncoupled, historical or re-analyzed forcing data are required to drive the water, ecosystem, and energy modelling systems. These data can be derived from numerical weather prediction models (NWP), NWP reanalysis models, and climate models using various forms of interpolation, ensemble outputs, statistical downscaling and dynamical downscaling.

Hydrological and Water Quality Models: These are focused around hydrological models and land-surface schemes that can resolve the coupled energy and water budget of the land surface at multiple scales, including features pertinent to cold regions such as lakes, wetlands, snow, frozen ground and glaciers. These models are coupled to or may include detailed models of groundwater storage and flow, permafrost, glacier dynamics, catchment biogeochemistry, ecosystem landscape dynamics, fire, crop growth and nutrient/contaminant export.

River Models: These models will be coupled physical/chemical/biological schemes dealing with flow, velocity, depths, energy (temperature and ice formation), ice break-up, and important physical, biological and chemical attributes such as sediment transport, BOD, DOC, nutrients and contaminants.

Small Lake/Large Lake/Reservoir Models: These models will simulate inflow/outflow processes, biogeochemical transformations, oxygen, temperature, physical structure and mixing, storage, algal blooms and ice cover.

Water Management Models: These models simulate anthropogenic impacts on water resulting from small and large storages, drainage, irrigation and other abstractions, including groundwater extractions. At a basic level, these effects will be represented in land surface schemes and hydrological models. More generally, integrated water management modelling is needed to address long term planning and short term operational management of water resource systems under varying hydroeconomic conditions. Decision-making must integrate climate change, land management, water quality and hydrological considerations to meet human and ecosystem needs. Water management models can provide a new level of integrated modelling to support Canada’s needs in these areas.

These various modelling systems require consideration of time-prediction elements within their design and implementation. Prediction systems for watershed management require different consideration for short-term forecasting, seasonal or longer term forecasting and “open loop” simulations. The latter are characterized as either analysis of either past events or future climate projections.

Now-casting and forecasting: These use 0-10 day ensembles of simulations for assessing floods, high and low flows, snowcover and snowpacks, soil moisture, river ice breakup, wind-setup on large lakes, irrigation scheduling, reservoir operation, hydroelectricity production, in-stream flow needs, water quality, sediment transport, contaminant transport from spills, BOD and environmental flows. Day-0 simulations (now-casting) are typically required for assessing ungauged or unmeasured basins. Projections can be extended from 10 day to multiple months.

Open Loop Simulations: Long-term simulations are used for planning, design and/or climate projections. In a hind-cast (historical model), these types of simulations are used for management studies, carrying out “what if scenarios”, assessing ungauged attributes, examining land and water management impacts, assessing future cryosphere, vegetation and water quality implications, calculating risk and probabilities and looking at trends. In a future climate context, these type of simulations are used to understand and ascribe future impacts on water and river basins and look at management implications including potential mitigation. Ideally these would be extended to include coupled modelling of land-atmosphere feedbacks.

Proposed CORE modelling team

Support for a CORE modelling effort has been agreed, as specified below. The aim is to develop a strategic capability for pan-Canadian modelling. The CORE modelling staff and funding being allocated for the first three 3 years will focus on three main elements as outlined below.

1. Hydrological & Water Quality Forecasting

Purpose - Real-time forecasting of streamflow, lake levels, snowpack, soil moisture, drought and flood, water quality episodes at multiple scales across Canada. It is well understood that there are many issues in forecasting resulting from sparse stream gauge and precipitation station networks, poor DEMs, inadequate inclusion of cold regions processes in most models. Many researchers are acutely aware of the difficulty in characterizing e.g. variable contributing area in the prairies, arctic and Canadian Shield and river ice, as well as opportunities to assimilate snowpack, water levels, water storage, streamflow, into models for real time forecasting.

Approach and Resources Needed –

- **Flood Forecasting (1 Research Scientist; 1 Postdoctoral Fellow):** The flood forecasting team (RS and PDF) will work closely with the Canadian Meteorological Centre - Dorval group at the Environment and Climate Change Canada, Quebec.
  - **U of S:** A RS based at Dorval will focus on real-time forecasting systems and development in GEM-Hydro
  - **U of S:** A PDF will focus on snow processing in forecasting models
- **Seasonal and drought Forecasting (1 Postdoctoral Fellow):**
  - **U of S:** The PDF will work with teams at UVic/UQAM and also use the US-WRF model and will work closely with ECCC on teleconnectivity and snow-covered area and soil moisture impacts on forecasts.
- **Flood Modelling (1 Postdoctoral Fellow):**
  - **McMaster:** The PDF will coordinate the modelling effort at McMaster and link to relevant FloodNet activities. The aim is to develop a pilot state-of-the art system for flood modelling using a system like Deltares FEWS to bring multiple models and forecast data sources together for operational flood forecasting by provincial agencies.
- **Data Assimilation (2 Postdoctoral Fellows):**
  - **U**W: One PDF will focus on lake model initialization and data assimilation systems (nutrient loads, algal growth, air temperature, water temperature, wind stress), analysis/forecast cycling, output data visualization,
  - **U of S:** One PDF will work on GRACE, SWOT, drone-based observations, ground and satellite derived snow data and other relevant products
- **River Ice Modelling (1 Postdoctoral Fellow):**
  - **U of S:** The PDF will focus on forecasting river ice processes and their effect on flooding.
- **Water Quality (1 Research Scientist and 1 Postdoctoral Fellows):**
  - **UW:** A RS will focus on forecasting nutrients and contaminants using reaction network models, and representation of reactive interfaces in coupled hydrology-biogeochemistry models.
  - **U of S:** A PDF will focus on forecasting nutrient and contaminant runoff in prairie environments and river and lake water quality including the effects of oil spills.

2. Climate and Diagnostic Hydrological & Water Quality Modeling

Purpose – new high resolution atmospheric modelling of water futures will provide a) a new paradigm for modelling climate using dynamical downscaling, including for the first time realistic convection-explicit future precipitation, and b) a new era of coupled hydrological-atmospheric modelling of cold region processes in complex terrain. The hydrology/water quality modelling will deliver in the first 3 years a multi-model framework that will enable unified pan-Canadian modelling to build on existing regional efforts and tools. Applications will include water budget estimation, ungauged basin prediction, water quality, streamflow/ snowpack/ glacier/ permafrost/ soil-moisture/ surface-storage/ groundwater-storage synthesis for previous century, examination of hydrological, lakes and water quality sensitivity to climate and land use changes and streamflow/ snowpack/ glacier/ permafrost/ soil-moisture/ surface-storage/ groundwater-storage synthesis for future climates. This will be followed by a new state-of-the-art modelling system built on advanced computer systems, data assimilation and user-focussed cloud-based outputs.

Approach and Resources Needed –

- **Climate Change (1 Postdoctoral Fellows, 1 PhD):** The proposed team will work mostly on dynamic downscaling using WRF in collaboration with the National Center for Atmospheric Research, USA
  - **U of S :** A PDF will focus on pan-Canadian high resolution WRF simulations
  - **U of S :** A PhD student fellow will focus on pseudo-global warming climate futures, with potential extension to coupled simulations of future climate
- **Hydrological Modelling (1 Research Scientist; 2 Postdoctoral fellow):** This will be a pan-Canadian modelling team that will focus on development of a modular multi-model system to include MESH, VIC, HYPE, and CRHM.
  - **U of S:** One RS focused on MESH with linkage to CRHM and link to HYPE water quality modelling (below)
  - **UNBC/U of S :** One PDF focused on VIC
  - **UW:** One PDF focused on MESH/GL focused on watershed-scale hydrological modeling, coupling hydrology to atmospheric forcing and landscape processes, climate scenarios, coupling hydrology-water quality
- **Next Generation Modelling (1 Research Scientist; 1 Postdoctoral Fellows, 1 Technician):**
  - **U of S:** The RS will be responsible to supervise a postdoctoral fellows who will work on CHM hydrological and water quality (nutrient) models.
  - **U of S:** The Technician will be responsible for coding developments on CHM
  - **U of S:** The PDF will work on algorithm development on CHM
- **Catchment, River, and Lake Systems (2 Postdoctoral Fellows; 3 research Scientist):** One postdoctoral fellow each will be based at UofS and McMaster, and 2 postdoctoral fellows will be based at UW. The team will work on model development/revision for algal bloom prediction, linked lake-landscape models for DOM, and lake physical structure.
  - **U of S :** One RS will work on atmospheric and nutrient loading and delivery as well as in-stream processes, to include SPARROW, MAGIC, HYPE, CHM nutrient

- **U of S:** One PDF will work on atmospheric and nutrient loading and delivery as well as in-stream processes, and dynamic river water quality models, and forecasting of blooms.
- **UW:** One RS will focus on the watershed-lake continuum, lake hydrodynamics and trophic interactions, ice dynamics, nutrient and carbon cycling, response to climate/land use change scenarios.
- **UW:** One PDF will focus on the modeling of regional groundwater flow systems, groundwater-surface water interaction phenomena and the integration of atmospheric, surface hydrologic and subsurface hydrogeologic systems in support of project-based research within GWF. The emphasis will be on the linking of transient, near surface hydrologic drivers with the movement of water and chemical fluxes within the variably saturated subsurface.
- **McMaster:** One RS to work on activities related to water quality. Focus will be on the implementation of new routines to simulate water temperature across scales.

3. Water Resources Modeling

Purpose - We envision the emergence of a new paradigm of water resource systems modelling, which integrates water quality and quantity, addresses environmental flow needs, and economic valuations and trade-offs. We also see a new era of stakeholder engagement whereby public participation in water resources modeling is an iterative, collaborative, two-way exchange, and scientific knowledge is co-produced. There is a clear need to address the human dimensions that will determine water futures by: (1) integrating human behaviour, economic valuation, and policy decisions into water resource models, (2) building adaptive governance models to deal with problems of uncertainty, (3) developing and testing economic tools and incentives for managing water futures, (4) conducting basic social science research into the social processes and learning embedded in stakeholder engagement, and (5) building an indicator system that enables benchmarking performance for governance deficiencies, policy transfer, and social learning.

Approach and Resources Needed –

- **Water Resources (1 Research Scientist; 2 Postdoctoral Fellows):**
  - **U of S:** A RS to develop a framework to address areas such as decision making under uncertainty, water quality and environmental flow needs, and hydro-economics.
  - **U of S:** A PDF to focus on decision making under uncertainty, water quality and environmental flow needs,
  - **UW:** A PDF focused on coupled economic and environmental flows, cost-benefit analyses, ecosystem services valuation, water accounting.

Pillar 3 Proposals - Modeling Development Strategy

To ensure that knowledge transfer from GWF research to users, we recommend that if your proposal requires the use or exploitation of CORE modelling outputs, algorithms or simulations, or seeks to enhance CORE capabilities, it is important that a Proposal Model Development Strategy (PMDS) is included in projects from the outset, starting with the proposal stage.

The Core Modelling sub-committee of the GWF-SMC recommends that the following rules and procedures for preparing proposals developed under the *Transformative Solutions to User and Stakeholder Needs* call:

- The PMDS should identify the specific end-user needs and tie the modelling efforts to these needs. Proposals should demonstrate how end users and partners are contributing to or assisting in the development or specifications of simulation models outlined in the proposal.
- The PMDS must outline the specific strategies and mechanisms that will be used to address end user modelling needs and to show if, or how dependencies on the CORE modelling team and models takes place throughout the life of the project, and after if appropriate.
- The PMDS will describe how the project modelling efforts contribute to or enhance CORE model development and modelling operations.
- The use of other models outside of CORE models can be effective in algorithm development and assessment or incorporated via linkages into existing CORE modelling systems. PMDS need to clearly identify which models will be used, why they are needed, how they will be supported and how these models can benefit the CORE modelling efforts and/or overall outcomes of the GWF programme.
- If sequencing of model development, application and reliance on CORE models or CORE model outputs are an important element in the overall success of the proposed program, then the proposal must clearly identify the dependency on simulation models and model outputs, and define milestones associated with the proposal deliverables that will rely on CORE modelling efforts.

Proposal Evaluation for modelling/simulation activities

The following rules and procedures will be used for evaluating proposals developed under the *Transformative Solutions to User and Stakeholder Needs* call:

- The quality and appropriateness of the PMDS is evaluated for consistency with GWF outcomes and enhancement of GWF CORE modelling activities and tools listed above
- The sequencing of the PMDS and the dependency on CORE model development, applications and/ or outputs is clearly articulated.

Project Implementation for modelling/simulation activities

Research teams that succeed at the proposal stage must be accountable for ensuring they meet milestones and deliverables outlined in their PMDS given the inter-dependency between CORE and project based activities, and the interdependencies between programs.

The SMC recommends that the following accountability rules and procedures be used for projects supported under the *Transformative Solutions to User and Stakeholder Needs* call.

- The Principal Investigator(s) for every project is responsible for ensuring that PMDS strategy outlined in the proposal is implemented.
- The Principal Investigator(s) for each project must submit a progress report on PMDS including successes, failures, challenges, and changes as part of the project's annual report. Where appropriate, evidence of successful Knowledge Mobilization should be provided.
- Teams will be allowed to adjust or amend their PMDS strategies to respond to changing circumstances and field- experiences and evolving constraints. However, if major changes or challenges are needed, the PI(s) must contact the SMC and make them aware of the potential impacts of these changes on the overall GWF deliverables.
- Future funding will be contingent upon satisfactory progress in meeting targets and milestones outlined in the PMDS