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GEOLOGICAL SURVEY OF CANADA
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Canada1Water
2022 progress report

Edited by
A. Kirkwood

2023

Canada

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CANADA1WATER

2022 Progress Report

March 2023

Editor: Andrew Kirkwood

Canada1Water

Project co-leads

- Geological Survey of Canada – Natural Resources Canada
- Aquanty Inc.

Project funders

- Canadian Safety and Security Program – Defence Research Development Canada
- Geological Survey of Canada – Natural Resources Canada
- Agriculture and Agri-Food Canada
- Aquanty Inc.
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  - University of Waterloo

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- Natural Resources Canada
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  - Canadian Forestry Service
  - Survey General Branch
- Environment Canada Climate Change

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The background illustration on the next page shows an irregular finite element mesh used by HydroGeoSphere modelling software for modelling groundwater–surface-water flow.

Canada1Water is a three-year research and development project to build the first-ever physics-based model of the complete water cycle for continental Canada, Baffin Island and transboundary watersheds with the U.S.

The final modelling framework will give community decisionmakers, infrastructure planners, researchers, the public and other interested users a long-term view of how Canada's water resources will change throughout the 21st century.

This report provides an update on the status of the project as of December 2022 — and looks ahead at what's to come.

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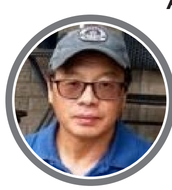
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The background photograph on the next page tells a story about dynamic river flow and the integral relationship between groundwater and surface water. River flow represents a low-flow condition with the predominant contribution by groundwater to baseflow. Gravel banks and rafts of forest debris (right side) highlight higher river flows during the spring freshet (snow melt dominant flow) and river response to precipitation events. Image from Rivera 2014.

Contents

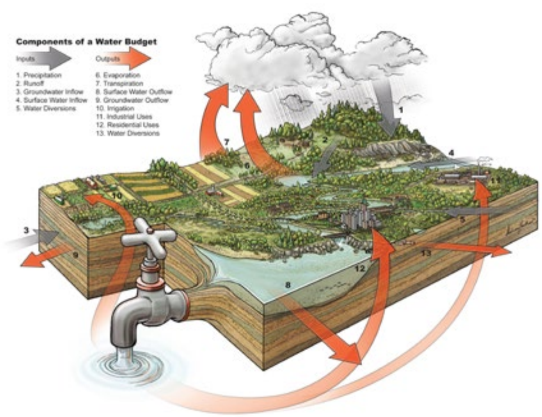
Modelling the future of our most precious resource

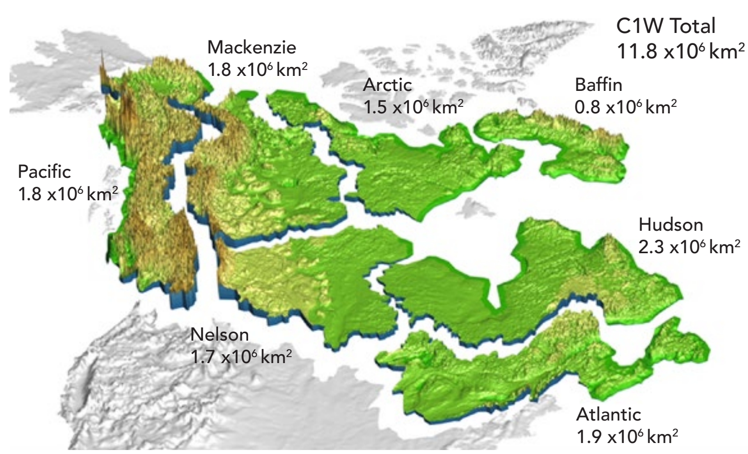
Water is an irreplaceable necessity for human life — and directly affected by climate change, with long-term consequences for everything from food and energy supplies to ecosystem health. Canada1Water (C1W) will give decisionmakers the sound scientific information they need to prepare climate change mitigation and adaptation strategies for Canadian communities.

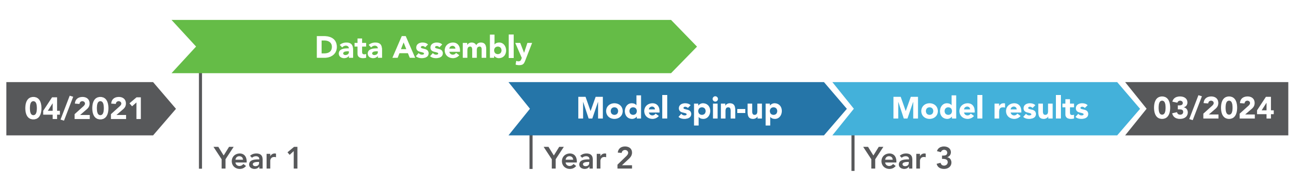
With a development timeline from 2021 to 2024, Canada1Water will provide a modelling framework and decisionmaking support tool representing the country's complete groundwater and surface-water system. It will cover seven regional drainage domains — Pacific, Mackenzie, Arctic, Nelson, Hudson, Baffin Island and Atlantic — and more than 10 million square kilometres from the far North to southernmost Canada and including transboundary watersheds in the U.S.

C1W's final, integrated conceptual hydrologic model will run on HydroGeoSphere (HGS), the groundwater–surface-water simulation engine developed by project co-lead Aquanty. The final climate change analysis and projected water resource impacts will be published on an open-access web portal for use by policymakers, infrastructure planners, researchers, the public and other interested users.

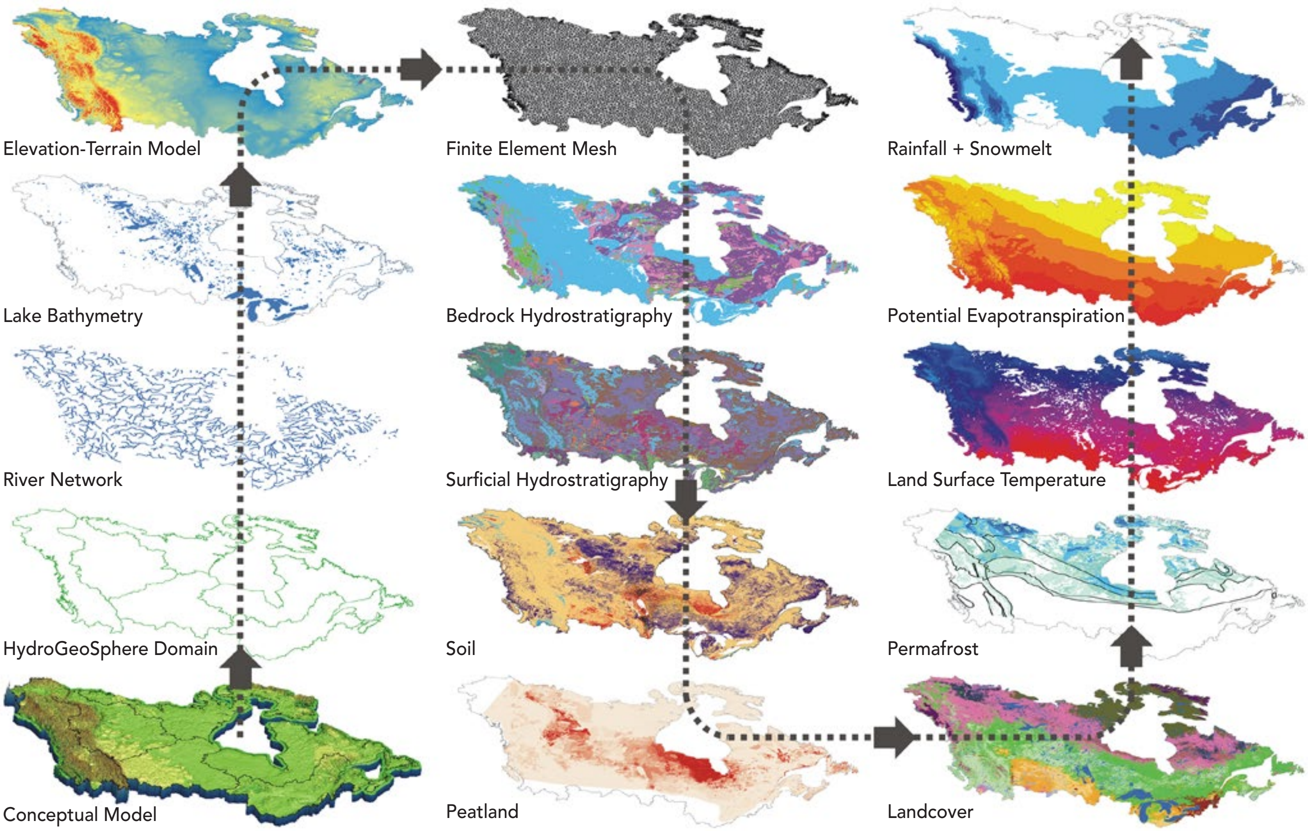
Integrating many disparate datasets including climate, soil, bedrock, lakes and snow, and simulating three time periods — historical (1981 to 2020), mid-century (2045 to 2060) and end-of-century (2085 to 2100) — C1W will be one of the most sophisticated models of a continental hydrologic system ever produced. The regional climate modelling outputs generated by the Weather Research and Forecasting Model feed into the Community Land Model, and together those combined outputs feed into HGS. As the various component models are integrated, they will be further tuned to represent observed conditions accurately.







Canada1Water will model the continental water cycle across seven regional drainage domains including Baffin Island. The project is approaching its halfway point, in the model spin-up stage.



Canada1Water hydrogeologic and climate inputs will be integrated into a single, comprehensive simulation of the entire Canadian groundwater–surface-water system.

Progress to date

On December 12, 2022, Canada1Water team members held their second progress meeting of the year to share updates on advancements in seven key areas of the project:

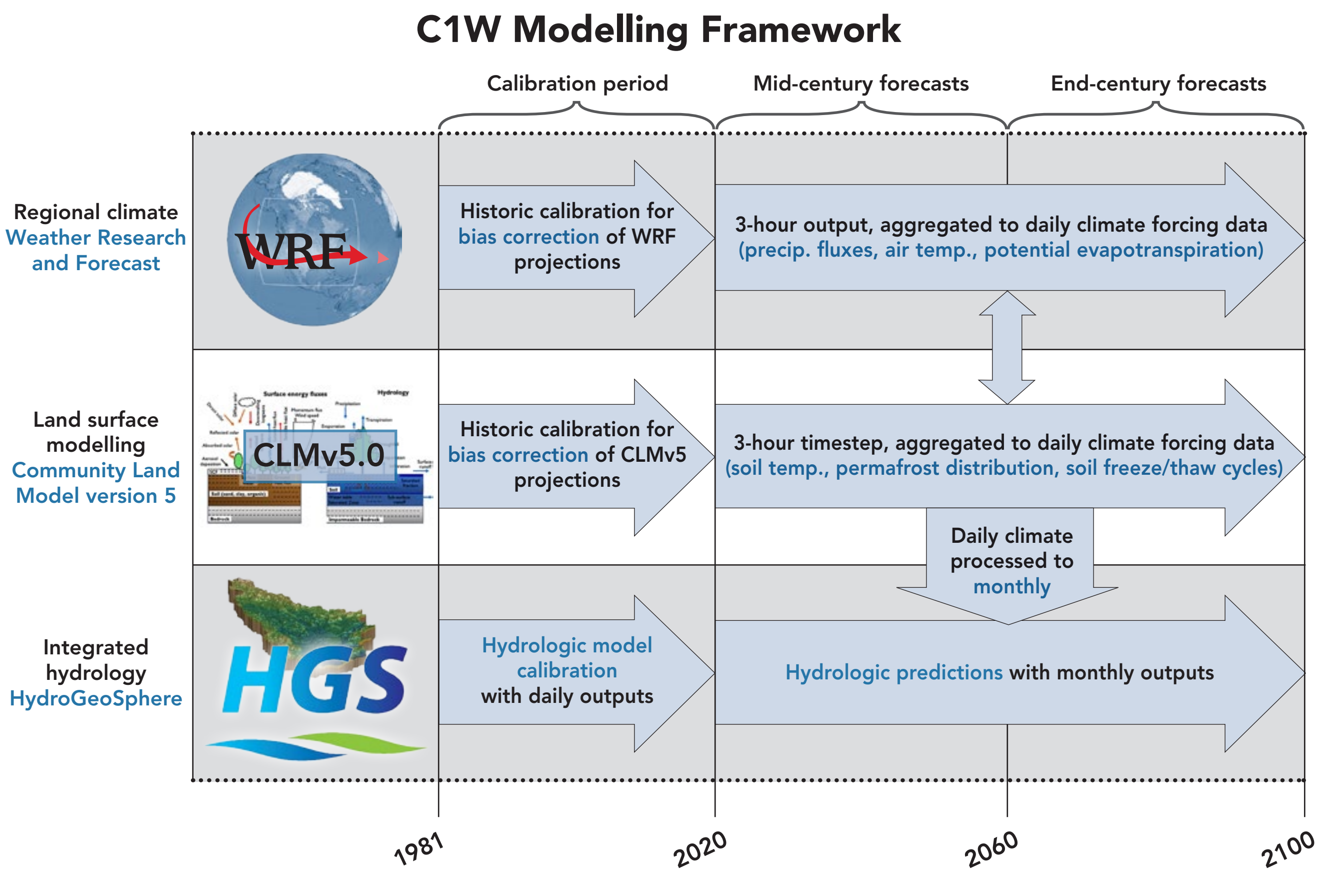
Model development

1. Future climate modelling
2. Historical climate data and land surface modelling
3. Hydrostratigraphic modelling
4. Soil maps, bedrock outcrops and peatlands
5. HydroGeoSphere mesh assembly and model spin-up

Engagement and outreach

6. Preparing for First Nations engagement
7. Communication and outreach

The foundational work of assembling all required datasets and component models was approaching its end by the time of the progress meeting. Construction of the integrated HGS model is on track, and finite element mesh construction has been completed for the low-resolution versions of all seven regional drainage domains. The following pages provide more detail on progress made in each area of the project.



C1W incorporates regional climate modelling with land surface modelling to provide atmospheric and temporal land surface data for HGS to model changes in groundwater and surface water out to the end of the century.

Model development

Update: Future climate modelling

Progress at a glance

TARGET	STATUS	NEXT STEPS
Deploy Weather Research and Forecast (WRF) regional climate model	ACHIEVED	• Develop tools to couple WRF with future climate data for different models • Run simulations using historic and future data with varied settings to resolve uncertainties • Advance lake modelling study to improve simulation quality
Develop tools and download historical and future climate datasets	ACHIEVED	
Run repeated North American continental simulations for historical and future time periods	UNDERWAY	
Bias-correct historic WRF simulation outputs to match historic observations	ACHIEVED	
Determine which lake model performs best	UNDERWAY	

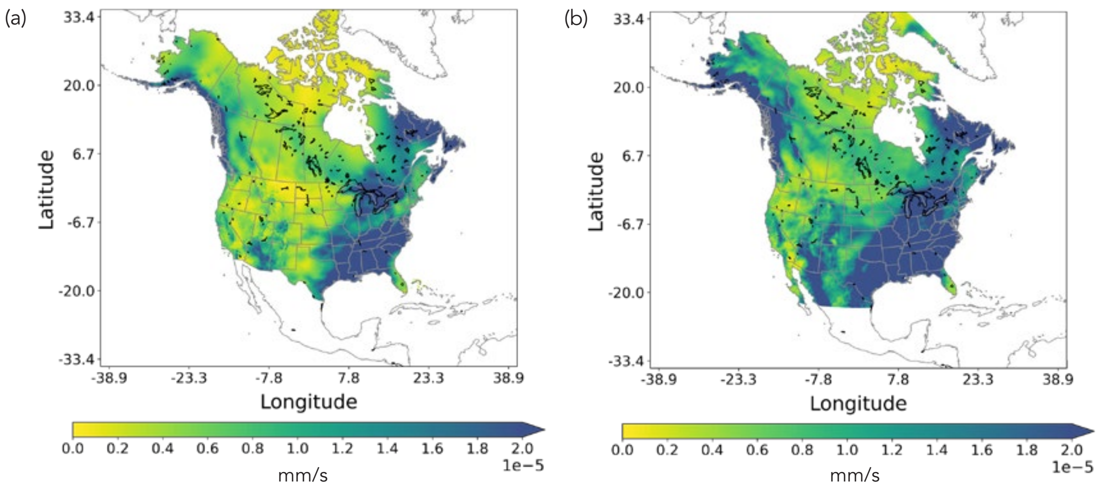
Canada1Water aims to produce dynamically downscaled climate modelling outputs based on the popular, state-of-the-art Weather Research and Forecasting Model (WRF) software. These outputs will accurately represent natural systems, and model results will be publicly available through open-access licences. As of December 2022, the C1W team had developed tools for using WRF at an initial resolution of 22 km^2, working toward an ultimate resolution of 11 km^2.

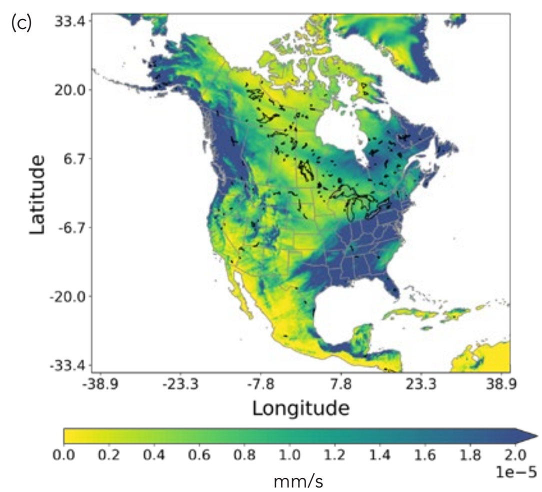
Historical and future boundary conditions for the WRF model have been set using ERA5 and CMIP6, respectively:

- ERA5 — the fifth-generation global climate atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts — covers the period from 1981 to 2020 in Canada1Water.
- CMIP6 is the latest Coupled Model Intercomparison Project dataset that includes global climate simulation results from models originating in Canada, the U.S., Germany, Japan and other countries. It supports projections to the end of this century. For future simulations, the CMIP6 data and WRF will be combined.

For C1W most lower-resolution (22 km^2) historical simulations have been completed, with ongoing validation using alternative simulation scenarios to explore the effects of the various components and configurations. Higher-resolution (11 km^2) models are partially complete, and future simulations will begin in 2023.

For model simulations to date, precipitation, temperature and ice cover distributions show small biases compared to various observations, especially at higher resolutions. Biases are common and expected in model outputs like these and the fact that they are small here is encouraging.





Comparing NRCan observations (a) with ERA5 reanalysis (b) and WRF simulations (c) for average monthly precipitation in January 1985 shows that WRF simulation results are in overall agreement with observations except in mountainous Western Canada, which is notoriously hard to model. WRF simulation results also provide higher levels of resolution and structural patterns compared to observations and reanalysis.

Since lakes have strong effects on regional climates, a well-chosen lake model is critical to the overall accuracy of the climate simulation. Three lake models are being investigated: the WRF default model; the Great Lakes Environmental Research Laboratory (GLERL) model; and the freshwater lake (Flake) model. The GLERL model adapted for C1W has been found to produce superior results for summer lake surface temperatures, while the Flake model has outperformed others for winter lake surface temperatures and ice cover. Both the GLERL and Flake models have proved superior to the WRF default lake model.

Going forward, the team will run further ERA5 variations as well as future simulations with varied settings to resolve uncertainties, and will continue to advance the lake modelling to improve simulation quality.

Update: Historical climate data and land surface modelling

Progress at a glance

TARGET	STATUS	NEXT STEPS
Format and post-process homogenized historical daily climate data for WRF validation and HGS forcing[1]	ACHIEVED	• Interpolate snow observations into historical gridded dataset • Bias-correct WRF outputs and CRCM5 data • Bias-correct permafrost maps • Complete operationalization of CLM5
Bias-correct Canadian Regional Climate Model version 5 (CRCM5) data using new techniques developed by Canada1Water	ACHIEVED	
Confirm high-res permafrost models reproduce observed trends	ACHIEVED	
Operationalize Community Land Model 5 (CLM5) outputs	UNDERWAY	

Climate data for C1W is provided by the Canadian Forest Service (CFS), the University of Waterloo, the University of Toronto and Aquanty. The CFS team has developed and completed the quality assurance process for key historic North American climate station measurements, specifically daily data for minimum and maximum daily temperatures and total precipitation.

Using the ANUSPLIN algorithm, the team has generated a dataset that provides continuous daily climate fields from 1981 to 2020 at a resolution of 1/12 degree (~100 km^2). This allows for empirical-statistical elevation adjustments, which are critical for the observation-sparse and mountainous regions of northwest Canada. Work is now being completed on similar gridded fields for snow depth from 1981 to 2020 for all domains.

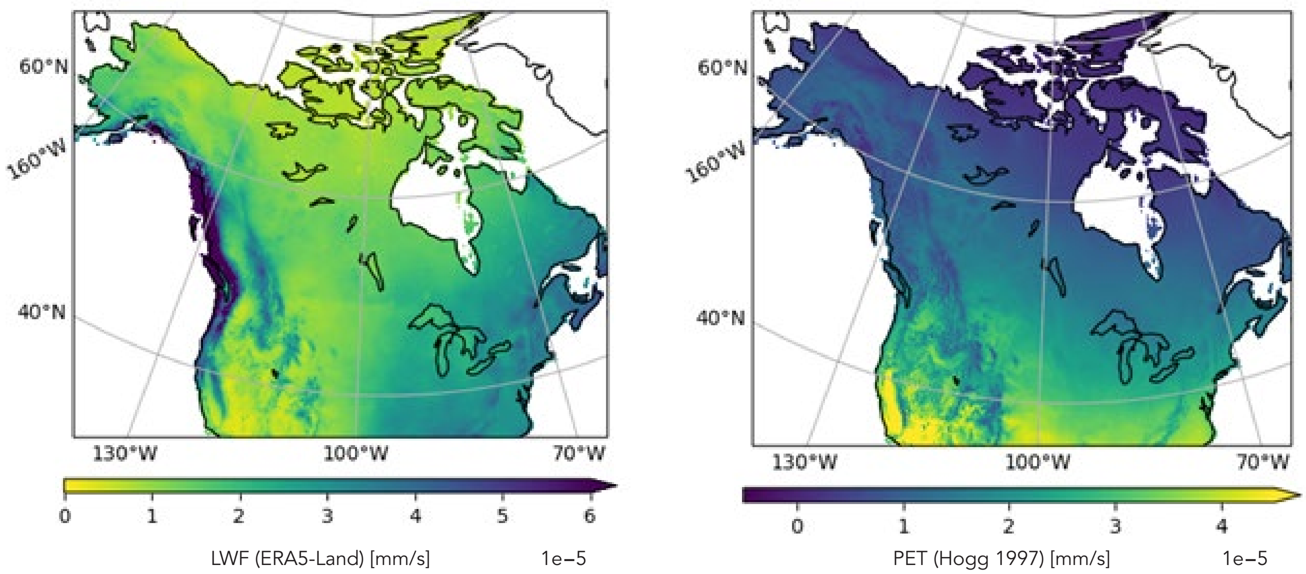
The process for estimating snow-water equivalents is in the initial scoping phase. Using snowmelt from the state-of-the-art ERA5 land reanalysis product, the team has been able to derive liquid water forcing (rain plus snowmelt) and potential evapotranspiration estimates from minimum and maximum temperatures, following the Hogg (1997) method.

These CFS data products are being used extensively for climate model validation.

[1] 'Forcing' in hydrological modelling refers to the mathematical representation of external water fluxes that drive (force) how the simulation behaves.

When comparing regional climate model data to the CFS ANUSPLIN dataset, the University of Waterloo team found notable biases — and addressed them by developing a novel machine learning-based bias-correction technique. Applied to data from the Canadian Regional Climate Model version 5 (CRCM5)[2], this new technique nearly zeroes out average biases that can affect the accuracy of processes such as snowmelt timing, and cuts root-mean-square-error (RMSE) in half.

The same bias-correction technique will likely be applied to WRF-CMIP6 climate projections being generated by the University of Toronto.
The technique will also be used to produce an up-to-date map of permafrost distribution — important because existing gridded reanalyses are colder than observations and thus permafrost. (As well, nearly all observations come from Russia, which makes simple interpolation over the C1W domain impossible.)



The map on the left shows long-term average liquid water flux based on combined CFS ANUSPLIN precipitation and ERA5 land snowmelt. The map on the right shows potential evapotranspiration (PET) using CFS minimum and maximum temperatures based on the Hogg (1997) method over the averaging period from 1981 to 2011.

Update: Hydrostratigraphic modelling

Progress at a glance

TARGET	STATUS	NEXT STEPS
Develop a conceptual hydrostratigraphic model for the subsurface layers in all seven Canada1Water drainage domains	ACHIEVED	• Complete a literature review to fully populate zone maps with hydraulic parameters
Define material zone maps for all layers in each model	ACHIEVED	

[2] CRCM5 predates C1W and was developed by Environnement et Changements Climatiques Canada (ECCC) and L'Université du Québec à Montréal (UQAM).

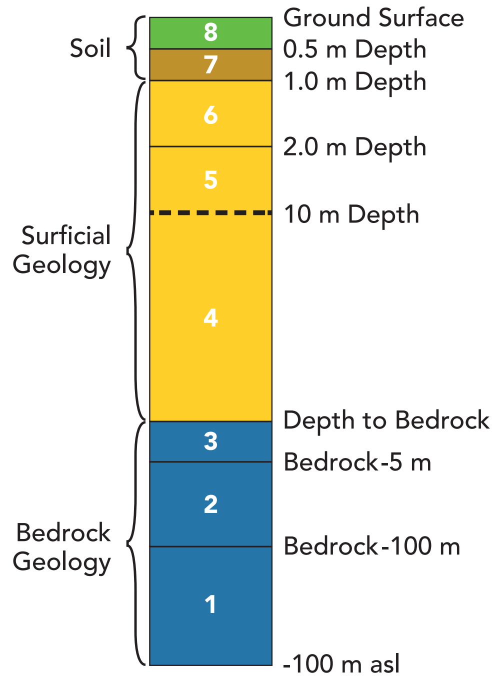
Canada1Water has developed a conceptual hydrostratigraphic model for subsurface layers in each of the seven drainage domains. These layers reside between the ground surface (defined by a digital elevation model) and 100 metres below sea level, and include two soil layers, two or three surficial geology layers, and three bedrock layers. Each of those sub-layers is defined by an elevation map, a material zone distribution map, and a material properties file for each zone.

The hydrostratigraphic modelling team has either defined elevation maps or derived offset elevation maps for all layers, with a key milestone being the creation of a surficial sediment thickness map that provides continuous coverage over the entire model domain. Material zone maps for each layer have been defined — using national-scale Canadian and U.S. datasets for the surficial geology and continental- and provincial-scale datasets for the bedrock geology.

Various maps have been combined to provide the complete continental picture:

- The surficial geology layer merges 1:5 million scale surficial geology maps for Canada, mainland U.S. and Alaska, with a common legend, a gridded dataset, and subsequent population of lakes and other data points. The use of zones accounts for geographic variation in unit characteristics and changes with depth below ground surface.
- The depth-to-bedrock map, which provides continuous coverage for the entire domain, was created from a mosaic of existing drift thickness maps for Canada, the U.S. and the St. Lawrence Valley, with supplementary depth observations from BC and the Northwest Territories. Where datasets had no coverage (such as Alaska), depth was estimated using rules based on the material description associated with the surficial geology map.
- The bedrock geology zonation map combines lithology and formation data from the 1:5 million scale North American map for metamorphic and igneous zones with detailed distributions of sedimentary units from Arctic, provincial and state geological maps, which have varying scales from 1:250,000 to 1:5 million.

Population of the material properties files with hydraulic attributes is ongoing. An essential next step is to complete a literature review to fully populate the zone maps with hydraulic parameters.



For Canada1Water, the first metre of the soil layer is divided into two equal segments. The top of the surficial geology layer occurs at one metre, with one or two additional layers characterizing the underlying sediment. The elevation of the top of the bedrock layer is defined by the total sediment thickness map subtracted from the digital elevation model. The bedrock layers are then defined by offset distances from the top of the bedrock.

Update: Soil maps, bedrock outcrops and peatlands

Progress at a glance

TARGET	STATUS	NEXT STEPS
Vertically average mineral soil maps into two layers from 0–50 cm and 50–100 cm	ACHIEVED	• Construct a fine-resolution model based on lessons learned from coarse-resolution model performance.
Generate soil hydraulic properties at a 250 m x 250 m spatial resolution	ACHIEVED	
Add bedrock outcropping with fractured bedrock hydraulic properties into the new soil maps	ACHIEVED	
Produce a 3D peatland map to add organic/peat soil hydraulic properties to new soil maps	ACHIEVED	
Use new Canada1Water soil maps to assign zonation and hydraulic properties to the coarse-resolution HGS model soil layers	ACHIEVED	

Across the seven regional drainage domains defined for C1W, the first metre of the hydrostratigraphic model may consist of bedrock, mineral and organic soils, or peatland. The soils have two sublayers (zero to 50 cm and 50 to 100 cm) requiring detailed assignments of hydraulic properties such as residual and saturated water content, van Genuchten parameters, and saturated hydraulic conductivity. This has been accomplished by using the pedotransfer Rosetta v3 to process mineral soil textures and properties from various machine learning soil maps.

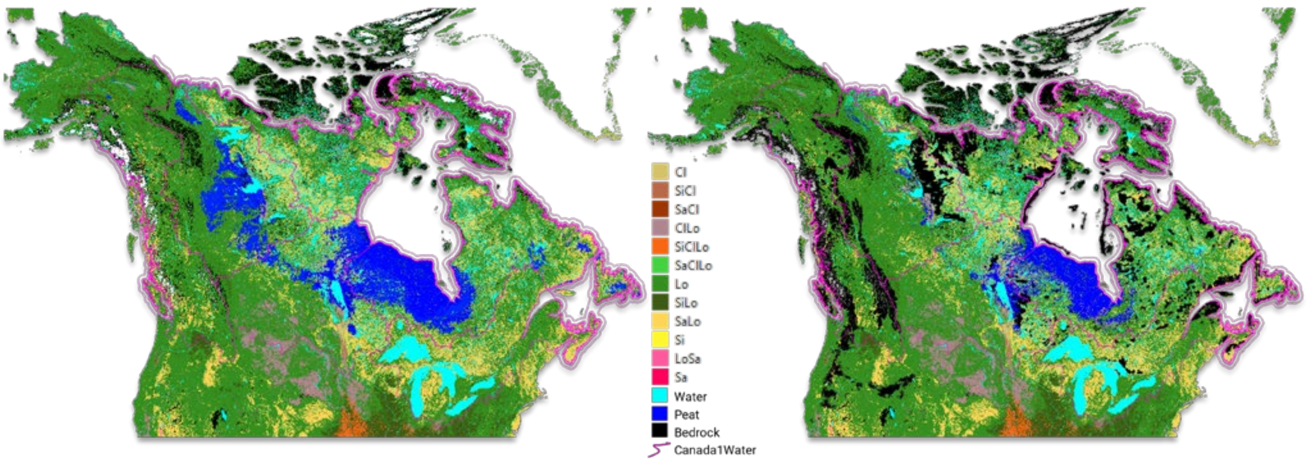
As existing mineral soil maps do not identify hydrological features associated with bedrock outcrops or organic and peat soils, the C1W team merged soil maps with a bedrock outcrop maps and a 3D peatland maps.

Bedrock outcrops were delineated using a combination of landcover and surficial geology maps, while peatland extent was determined using a combination of peatland maps and percent peatland coverage machine learning products. Peat depth was estimated from the soil organic contents corresponding to organic soils within the peatland coverage.

The resulting new soil map was vertically averaged and exploited to assign spatially heterogenous porosity and saturated hydraulic conductivity to the two soil sublayers in HGS. Soil zonation was assigned according to mineral soil texture, bedrock, peatland and waterbody or ocean features, with an average unsaturated hydraulic properties characteristic curve produced for each zonation.

With coarse-resolution models complete, the next steps are to construct the fine-resolution variations, which may require modifications to the related datasets.

Canada1Water Soil Maps



Soil Map 1
0 – 50 cm

Soil Map 2
50 – 100 cm

C1W has two soil sublayers within the first metre of depth, including bedrock, mineral and organic soils, or peatland across the regions of the country.

Update: HydroGeoSphere mesh assembly and model spin-up

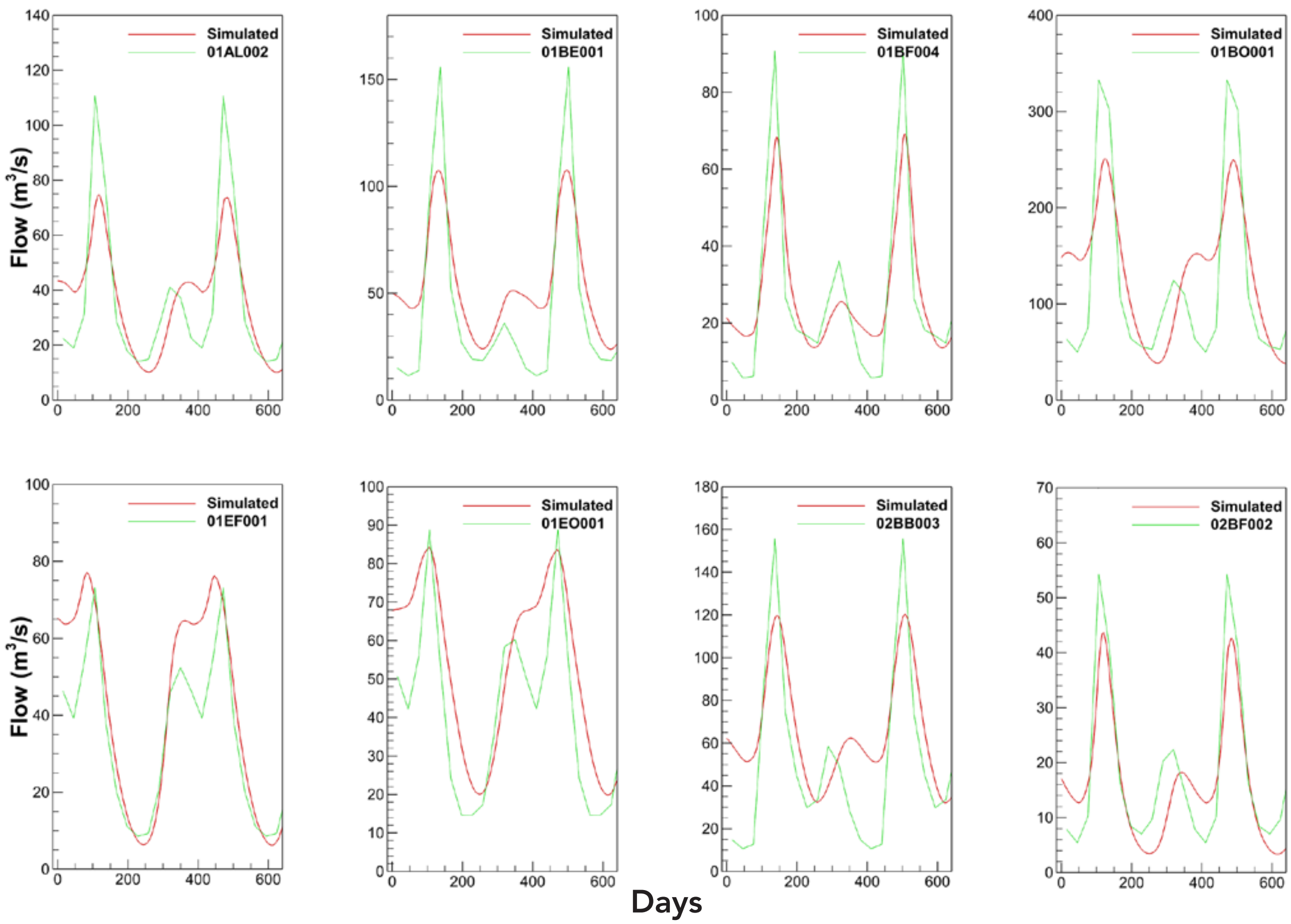
Progress at a glance

TARGET	STATUS	NEXT STEPS
Integrate existing hydrologic data into HGS to generate groundwater–surface-water models for all seven drainage domains	ACHIEVED	• Complete model construction • Calibrate the model

Unstructured 3D finite element meshes are needed to model fluid flows in the seven drainage domains. By December 2022, a coarse mesh (1–5 km edge length) with Strahler fifth-order and higher-order streams had been constructed for each domain with higher resolution in areas of interest such as streams, wells and lakes. Work is underway to produce higher-resolution meshes (0.5 –1 km edge length) to support more refined modelling of watershed hydrology with Strahler fourth-order and higher-order streams.

The 3D meshes for all seven domains extend from the land surface to 100 metres below sea level. These 3D meshes include all layers detailed through the hydrostratigraphic modelling process.

Surface domain zones are based on land cover distribution from the North American Land Change Monitoring System (NALCMS). Surface flow and evapotranspiration parameters such as surface friction, surface storage, evaporation depth and transpiration depth are assigned per zone. Monthly leaf area index maps based on MODIS v6 are used to drive actual calculations in the HGS models.



Preliminary results from the spin-up of the Canada1Water model in HGS show good seasonal correlations between data from illustrative stream gauging stations (green line) and model outputs (red line). For the two-year timeframe of the x-axis, numbering represents the number of days from the start of the illustrative simulation timeframe, with 0 marking January 1.

Initial conditions for the hydraulic heads[3] in the models were set at land surface for groundwater, an initial water depth was set to one millimetre for surface water. For boundary conditions — the water inflows/outflows that 'force' water to flow through the simulated domain — the coastline was set to specified heads equalling mean sea level while land boundaries were set as critical depth boundaries in order to minimize edge effects.

The model was forced using gridded data of liquid water flux (snowmelt plus rainfall) and potential evapotranspiration (Hogg method). The models were run using steady-state forcing, followed by monthly normal forcing until dynamic equilibrium was achieved.

Hydrometric station data from the Water Survey of Canada and the U.S. National Water Information System were used to aid model calibration. Observed flow rates were compared to simulated output from HGS models. Preliminary results show successful model capture of seasonal variability and flow timing and magnitude. These results will further improve with model calibration.

[3] Hydraulic model heads refer to initial water table elevations.

Engagement and outreach

Update: Preparing for First Nations engagement

A core funding component for C1W comes from the Canadian Safety and Security Program of Defence Research Development Canada (DRDC), with the goal of delivering information about groundwater and surface water to communities to support social, geographic, and economic decisionmaking. First Nations communities in particular have many social and geographic concerns about water supplies and ecosystem functions affected by climate change.

Through the Canadian Forestry Service (CFS), C1W is developing an engagement process to improve understanding of First Nations information needs about groundwater and surface water. Activities to date include preliminary meetings and planning sessions with a range of representatives and interested parties, including First Nations communities.

These early engagements will help expand the C1W network, raise awareness of the C1W continental water modelling platform, and illuminate opportunities for cross-cultural collaboration. Ongoing engagement will also promote the use of C1W outputs and contribute to improved transboundary watershed management. Looking ahead, C1W will expand its website to add a First Nations-focused section.

Current water research projects involving CFS project team members will continue to provide opportunities to establish additional pathways for engagement with First Nations communities that can shape the development of C1W.

Update: Project communication and outreach

As the C1W project advances, communication and outreach are increasingly important — to raise public awareness, attract potential users of the platform, and keep government, academic and science community members up to date. Key communication and outreach mechanisms include:

- A three-times-a-year electronic newsletter distributed by email and posted to the multilingual (English, French, Spanish) C1W website, along with a well-populated blog and social media support
- Technical meetings between project team members and representatives of federal and provincial government departments, non-governmental organizations and stakeholder groups such as the National Dialogue on Groundwater and the Prairie Province Water Board
- Science engagement through talks and conferences

Website visitors are principally from Canada, with significant proportions also from the United States (~20%) and internationally (~20%). LinkedIn and Twitter are the main social media platforms, used to rebroadcast web and newsletter content. These have attracted national and international attention, notably via World Water Day coverage of the International Union of Geological Science.

In autumn 2022, the Agriculture and Agri-Food Canada (AAFC) communications team interviewed C1W spokespeople Steven Frey (Aquanty) and David Lapen (AAFC) for the First Sixteen Podcast. C1W will seek further coverage of the project in the popular press and industry-specific publications such as *Ground Water Canada* magazine, which published an article on C1W in early 2023.

Several engagement meetings are currently scheduled to the end of the calendar year, both with federal government department representatives (Statistics Canada, ECCC, DFO, Health Canada, NRCan) as well as provincial government groups.

Next steps

As the data assembly phase of C1W nears completion, work is turning toward model run and output activities. With coarse-resolution models developed, the team will proceed with developing fine-resolution versions for all seven regional drainage domains.

To 'spin up' the models, each has to be filled (numerically) with water to reach a long-term average static hydrologic condition that can be used as a starting point to run the historical and future projections. Calibration of the models will begin in the second quarter of 2023. Terrestrial observation data required for the calibration model is being assembled and vetted, including hydrometric monitoring station data from the Water Survey of Canada, groundwater monitoring data from the Groundwater Information Network, and soil moisture data from Agriculture and Agri-food Canada as well as provincial monitoring networks. Terrestrial observation data will be augmented with remote sensing information based on collaborative research by the University of Toronto and Natural Resources Canada.

As part of the C1W project, advanced 3D visualization techniques are also being developed to communicate modelling results to a wider stakeholder community.

For more information, visit **www.canada1water.ca** or contact:
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