WATER FUTURES FOR THE WORLD WE WANT

STATE OF GLOBAL WATER FUTURES METHODS, MODELS AND DATA 2019

> MERRILL, S., SCHUSTER-WALLACE, C.J., DEBEER, C., SANDFORD, R.

WATER FUTURES FOR THE WORLD WE WANT

STATE OF GLOBAL WATER FUTURES METHODS, MODELS AND DATA 2019

Citation

Merrill, S., Schuster-Wallace C.J., DeBeer, C., and Sandford, R. 2019. Water Futures for the World We Want: State of Global Water Futures Methods, Models and Data. University of Saskatchewan, Saskatoon, Canada

This report content was originally published as:

Merrill, S., Schuster-Wallace, C.J., and Sandford, R. 2019 Supplementary File – Water Futures for the World We Want University of Saskatchewan, Saskatoon, Canada

The original publication was a companion document that supported the primary report:

Schuster-Wallace, C.J., Sandford, R. and Merrill, S. 2019 Water Futures for the World We Want – Opportunities for Research, Practice and Leadership in Achieving SDG 6 University of Saskatchewan, Saskatoon, Canada

Both original documents are available for download at gwf.usask.ca/sdgreport

Acknowledgements

This report content is based upon Global Water Futures project reports. This is a living document that will be updated annually. It would not have been possible without inputs from GWF research teams and the following individuals: Morgan Braaten, Hayley Carlson, Krysha Dukacz, Stacey Dumanski, Shervan Gharari, Kirsten Grant, Marie Hoekstra, Laleh Moradi, Dhouha Ouali, Amber Peterson, Gopal Saha, and Jared Wolfe.

Front Cover Photos: M. Ferguson, McMaster University, A. Wallace Layout Design: John Ogresko, Media Production, University of Saskatchewan Cover Design: Morgan Braaten, Global Water Futures

©University of Saskatchewan, 2019

E-mail: gwf.project@usask.ca Web: www.globalwaterfutures.ca Twitter: @GWFutures

Disclaimer: The designations employed and presentations of material throughout this publication do not imply the expression of any opinion whatsoever on the part of the University of Saskatchewan (USask), University of Waterloo (UW), McMaster University (Mac), Wilfrid Laurier University (WLU), or the United Nations University (UNU). The views expressed in this publication are those of the respective authors and do not necessarily reflect the views of USask, UW, Mac, WLU, or UNU. Mention of the names of firrms or commercial products does not imply endorsement.



GLOBAL WATER FUTURES





McMaster University

TABLE OF CONTENTS

Introduction1
List of GWF Projects and Core Initiatives3
Methods, Approaches, and Tools Developed by GWF Researchers8
Models Used, Developed, and Modified by GWF Researchers9
Models Used, Developed, and Modified by GWF Researchers10
Data Collected Within the GWF Network27





UNITED NATIONS UNIVERSITY

UNU-INWEH

Institute for Water, Environment and Health

Introduction

Canada and the world are faced with unprecedented water-related challenges. 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. Canada has some of the world's highest rates of climate warming along with associated extreme weather; together they impact infrastructure, institutions, ecosystems, and human health. Half of the world's population and all of Canada are dependent upon water from rapidly warming cold regions. With such unprecedented change, it is clear that the historical patterns of water availability are no longer a reliable guide for the future. Adaptation to these changes requires new science to understand the changing earth system; new modelling tools that precisely 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. This poses a grand challenge for how water science can help forecasting, preparation for and management of water futures in the face of dramatically increasing risks.

Canada has responded to this challenge, in part, through the Canada First Research Excellence Fund research programme, *Global Water Futures: Solutions to water threats in an era of global change* (GWF). The University of Saskatchewan leads GWF in partnership with the University of Waterloo, McMaster University, and Wilfrid Laurier University and draws upon the expertise of water scholars at dozens of academic institutions to work with hundreds of sectoral users in governments, Indigenous communities, and industries to develop transdisciplinary solutions to water security threats.

The overarching goal of GWF is to deliver risk management solutions for water futures in Canada and other cold regions where global warming is changing landscapes, ecosystems, and the water environment. GWF aims to position Canada as a global leader in water science for cold regions and address the strategic needs of the Canadian economy in adapting to change and managing risks of uncertain water futures and extreme events. End-user needs are critical inputs to drive strategy and shape GWF science. Currently, we lack the scientific knowledge, monitoring and modelling technologies, and national forecasting capacity to predict the risk and severity of potentially catastrophic events in Canada, such as floods and droughts. Canada and the world need to predict our water futures in order to ensure water security at home and beyond. However, 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 coupled human-natural land and water systems.

This document represents the 2019 snapshot of a continually evolving inventory of projects, methods, models and data being developed, used and generated through GWF's pan-Canadian research program. We recognize that challenges lie in generating transformative and sustainable change that is more than individual programs, projects, and activities, and as such, are committed to the leadership that is essential to becoming greater than the sum of collective parts. This document can be used as a guide to GWF's scientific effort for those interested in identifying research collaborations, synergies across existing research, and opportunities for applications with partners in operational settings.

Further information: www.gwf.usask.ca or gwf.project@usask.ca

LIST OF GLOBAL WATER FUTURES PROJECTS AND CORE INITIATIVES

List of GWF Projects and Core Initiatives

The Global Water Futures (GWF) program has provided research funding for the following projects and financial support for Core initiatives based at GWF partner institutions and other eligible universities¹ (Table 1.1). For more information related to a specific project or initiative see the contact information and websites provided.

Table 1.1: List of GWF-funded F	Projects and Core Initiatives
---------------------------------	-------------------------------

Transformative Science Projects (Pillars 1 & 2)				
Project Name	Contact Information	Website		
Southern Forests Water Futures	PI: M. Altaf Arain, Mac	gwf.usask.ca/projects-facilities/all-		
	Email: arainmATmcmaster.ca	projects/p1-south-forests.php		
Collaborative Modelling	PI: Lalita Bharadwaj, USask	gwf.usask.ca/projects-facilities/all-		
Framework for Water Futures and	Email: lalita.bharadwajATusask.ca	projects/p1-colab-modelling.php		
Holistic Human Health Effects				
Linking Water Governance in	PI: Rob de Loe, UWaterloo	gwf.usask.ca/projects-facilities/all-		
Canada to Global Economic, Social	Email: rdeloeATuwaterloo.ca	projects/p1-water-governance.php		
and Political Drivers				
Old Meets New: Subsurface	PI: Grant Ferguson, USask	gwf.usask.ca/projects-facilities/all-		
Hydrogeological Connectivity and	Email: grant.fergusonATusask.ca	projects/p1-old-meets-new.php		
Groundwater Protection				
Developing 'Omic' and Chemical	PI: Paul Jones, USask	gwf.usask.ca/projects-facilities/all-		
Fingerprinting Methodologies	Email: paul.jonesATusask.ca	projects/p1-chemical-		
		fingerprinting.php		
Evaluation of Ice Models in Large	PI: Kevin Lamb, UWaterloo	gwf.usask.ca/projects-facilities/all-		
Lakes	Email: kglambATuwaterloo.ca	projects/p1-lake-ice.php		
Short-Duration Extreme	PI: Yanping Li, USask	gwf.usask.ca/projects-facilities/all-		
Precipitation in Future Climate	Email: yanping.liATusask.ca	projects/p1-extreme-precipitation.php		
Prairie Drainage Governance	PI: Phil Loring, UGuelph	gwf.usask.ca/projects-facilities/all-		
	Email: phil.loringATuoguelph.ca	projects/p1-prairie-governance.php		
Linking Stream Network Process	PI: Bruce MacVicar, UWaterloo	gwf.usask.ca/projects-facilities/all-		
Models to Robust Data	Email: bmacvicaATuwaterloo.ca	projects/p1-prairie-governance.php /p1-		
Management Systems for Land-		stream-network-modelling.php		
Use Decision Support				

¹Abbreviations for universities and institutions: University of Saskatchewan: USask University of Waterloo: UWaterloo McMaster University: Mac Wilfrid Laurier University: Laurier Université de Québec at Montréal: UQÀM University of Calgary abbreviated as UCalgary University of Manitoba: UofM University of Victoria: UVic Environment and Climate Change Canada: ECCC University of Northern British Columbia: UNBC University of Guelph: UGuelph

Winter Soil Processes in Transition	PI: Fereidoun Rezanezhad,	gwf.usask.ca/projects-facilities/all-
	UWaterloo	projects/p1-prairie-governance.php/p1-
	Email: frezanezATuwaterloo.ca	winter-soil.php
Global Water Citizenship	PI: Colin Robertson / Rob Feick,	gwf.usask.ca/projects-facilities/all-
	Laurier	projects/p1-gwc.php
	Email: crobertsonATwlu.ca	
Sensors and Sensing Systems for	PI: Ravi Selvaganapathy, Mac	gwf.usask.ca/projects-facilities/all-
Water Quality Monitoring	Email: selvagaATmcmaster.ca	projects/p1-wq-monitoring.php
Linking Multiple Stressors to	PI: Mark Servos, UWaterloo	gwf.usask.ca/projects-facilities/all-
Adverse Ecological Responses	Email: mservosATuwaterloo.ca	projects/p1-stressors.php
Across Watersheds		
Crowdsourcing Water Science	PI: Graham Strickert, USask	gwf.usask.ca/projects-facilities/all-
	Email: graham.strickertATusask.ca	projects/p1-crowdsourcing.php
Storms and Precipitation Across	PI: Julie Thériault, UQÀM	https://gwf.usask.ca/projects-
the Continental Divide	Email: theriault.julieATugam.ca	facilities/all-projects/p1-spade.php
Experiment		
Sub-Arctic Metal Mobility Study	PI: Brent Wolfe / Jason	gwf.usask.ca/projects-facilities/all-
	Venkiteswaran, Laurier	projects/p1-samms.php
	Email: bwolfeATwlu.ca	
Adaptation Governance and	PI: Colin Laroque, USask	gwf.usask.ca/projects-facilities/all-
Policy Changes in Relation to a	Email: colin.laroqueATusask.ca	projects/p1-adaption-governance.php
Changing Moisture Regime Across		
the Southern Boreal Forest		
Significance of Groundwater	PI: Walter Illman, UWaterloo	gwf.usask.ca/projects-facilities/all-
Dynamics Within Hydrologic	Email: willmanATuwaterloo.ca	projects/p1-groundwater-models.php
Models		
Diagnosing and Mitigating	PI: Tricia Stadnyk, UCalgary	gwf.usask.ca/projects-facilities/all-
Hydrologic Model Uncertainty in	tricia.stadnykATucalgary.ca	projects/p1-model-uncertainty.php
High-Latitude Canadian		
Watersheds		
Hydrological Processes in Frozen	PI: Andrew Ireson, USask	gwf.usask.ca/projects-facilities/all-
Soils	Email: andrew.iresonATusask.ca	projects/p1-frozen-soils.php
Improved Estimates of Wetland	PI: Warren Helgason, USask	gwf.usask.ca/projects-facilities/all-
Evaporation	Email: warren.helgasonATusask.ca	projects/p1-wetland-evap.php
User Question-Led Projects (Pillar 3)		
Project Name	Contact Information	Website
Climate-Related Precipitation	PIs: Ronald Stewart, UoM /	gwf.usask.ca/projects-facilities/all-
Extremes	Francis Zwiers, UVic	projects/p3-climate-extremes.php
	Email: doualiATuvic.ca	
Northern Water Futures	PI: Jennifer Baltzer, Laurier	gwf.usask.ca/projects-facilities/all-
	Email:	projects/p3-northern-water.php
	infoATnorthernwaterfutures.ca	
Next Generation Solutions to	PI: John Giesy, USask	gwf.usask.ca/projects-facilities/all-
Ensure Healthy Water Resources	Email: john.giesyATusask.ca	projects/p3-edna.php
for Future Generations		

Forecasting Tools and Mitigation	PI: Helen Baulch, USask	gwf.usask.ca/projects-facilities/all-
Options for Diverse Bloom-	Email: helen.baulchATusask.ca	projects/p3-formbloom.php
Affected Lakes		
Agriculture Water Futures	PI: Merrin Macrae, UWaterloo	gwf.usask.ca/projects-facilities/all-
	Email: mmacraeATuwaterloo.ca	projects/p3-ag-water-futures.php
Boreal Water Futures	PI: Mike Waddington, Mac	gwf.usask.ca/projects-facilities/all-
	Email: jmwATmcmaster.ca	projects/p3-bwf.php
Prairie Water	Pl's: Chris Spence, ECCC / Colin	gwf.usask.ca/projects-facilities/all-
	Whitfield, USask	projects/p3-prairie-water.php
	Email: jared.wolfeAlusask.ca	
Integrated Modelling Program for	PI: Saman Razavi, USask	gwf.usask.ca/projects-facilities/all-
Canada	Email: hayley.carisonATusask.ca	projects/p3-impc.pnp
Mountain Water Futures	Di'a Saan Caroy Maa / Drian	gut usask sa /projects facilities /all
	Monounos LINPC / Masaki	gwi.usask.cd/projects-raciities/all-
	Havashi Hof	
	Email: mwfATmcmaster ca	
Lake Futures	PI: Nandita Basu IWaterloo	gwf usask ca/projects-facilities/all-
	Email:	projects/n3-lake-futures.php
	Kirsten.grantATuwaterloo.ca	
Transformative Sensor	PI: Claude Duguay, UWaterloo	gwf.usask.ca/projects-facilities/all-
Technologies and Smart	Email: mhoekstrATuwaterloo.ca	projects/p3-ttsw.php
Watersheds		
Co-Creation of Indigenous Water	PI: Dawn Martin-Hill, Mac	gwf.usask.ca/projects-facilities/all-
Quality Tools	Email: dawnmATmcmaster.ca	projects/p3-co-create-indg.php
Indigenous Co-led Community Wate	r Research Projects	
Project Name	Contact Information	Website
Is Our Water Good to Drink?	PIs: Corinne Schuster-Wallace /	gwf.usask.ca/projects-facilities/all-
Water-Related Practices,	Lalita Bharadwaj, USask / Diane	projects/i1-schusterwallace.php
Perceptions and Traditional	Giroux, Akaitcho Territory	
Knowledge Indicators for Human	Government	
Health	Email:	
	cschuster.wallaceAlusask.ca	
Matawa Water Futures:	Pls: Terry Mitchell, Laurier / Sarah	gwt.usask.ca/projects-facilities/all-
Developing an Indigenous-	Cockerton, Matawa First Nations	projects/12-mitchell.php
Informed Framework for	Management	
Stewardship		
FISHNET (Fish & Indigenous	Pl's: Brian Laird 11Waterloo /	gwf usask ca/projects facilities/all
NorthErn health): Healthy Water	Virginia Sutherland	projects/i3-laird nhn
Healthy Fish Healthy People	Mushkegowuk Council	
	Email: brian.lairdATuwaterloo ca	

We Need More than Just Water:	Pls: Tim Jardine. USask / Garv	gwf.usask.ca/projects-facilities/all-
Assessing Sediment Limitation in a	Carriere, Cumberland House	projects/i4-jardine.php
Large Freshwater Delta	Fishermen's Co-operative	
	Email: tim jardineATusask ca	
Obpeganos – Indigenous	Pls: Dawn Martin-Hill / Christine	gwfusask ca/projects-facilities/all-
Ecological Knowledge Training	Wokorlo Mac / Povorly Jacobs	projects/iE martinHill php
ecological Kilowiedge, Halling	Wekene, Wac / Beveny Jacobs,	
	Owindsor / Lori Davis Hill, Six	
loois	Nations Health Services	
	Email: dawnmATmcmaster.ca	
Water Knowledge Camps:	PIs: Jennifer Baltzer, Laurier /	gwf.usask.ca/projects-facilities/all-
Building Capacity for Cross	Leon Andrew, ?ehdzo Got'i̯nę	projects/i6-Baltzer.php
Cultural Water Knowledge,	Gots'ę́ Nákedı – Sahtú Renewable	
Research, and Environmental	Resources Board	
Monitoring	Email: jbaltzerATwlu.ca	
GWF Core Initiatives		
Team Name	Leads	Website
Modelling Team	Martyn Clark, USask Lead	gwf.usask.ca/people/core-
Modelling Team	Martyn Clark, USask Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling-
Modelling Team	Martyn Clark, USask Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php
Modelling Team Knowledge Mobilization Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php gwf.usask.ca/people/core-
Modelling Team Knowledge Mobilization Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php gwf.usask.ca/people/core- teams/knowledge-mobilization-
Modelling Team Knowledge Mobilization Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick. Laurier Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php gwf.usask.ca/people/core- teams/knowledge-mobilization- team.php
Modelling Team Knowledge Mobilization Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php gwf.usask.ca/people/core- teams/knowledge-mobilization- team.php
Modelling Team Knowledge Mobilization Team Computer Science Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php gwf.usask.ca/people/core- teams/knowledge-mobilization- team.php gwf.usask.ca/people/core-
Modelling Team Knowledge Mobilization Team Computer Science Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.php gwf.usask.ca/people/core- teams/knowledge-mobilization- team.php gwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team Data Management Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team Data Management Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead John Pomeroy, USask Lead Jimmy Lin, UWaterloo Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team Data Management Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead Jimmy Lin, UWaterloo Lead Michael Steelworthy, Laurier Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team Data Management Team	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead Jimmy Lin, UWaterloo Lead Michael Steelworthy, Laurier Lead Mike Waddington, Mac Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.php
Modelling Team Knowledge Mobilization Team Computer Science Team Data Management Team Smart Water Systems Laboratory	Martyn Clark, USask Lead Lawrence Martz, USask Lead Kevin Boehmer, UWaterloo Lead Kelly Munkittrick, Laurier Lead Sean Carey, Mac Lead Kevin Schneider, USask Lead Jimmy Lin, UWaterloo Lead Jimmy Lin, UWaterloo Lead Michael Steelworthy, Laurier Lead Mike Waddington, Mac Lead John Pomeroy, USask Lead	gwf.usask.ca/people/core- teams/forecasting-and-modelling- team.phpgwf.usask.ca/people/core- teams/knowledge-mobilization- team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- teams/computer-science-team.phpgwf.usask.ca/people/core- team.phpgwf.usask.ca/people/core- team.phpgwf.usask.ca/people/core- team.phpgwf.usask.ca/people/core- team.php

Methods, Approaches, and Tools Developed by GWF Researchers



Methods, Approaches, and Tools Developed by GWF Researchers

A key contribution to water research emerging from GWF projects is the addition of new and improved methods, approaches, and tools (Table 2.1). These contributions are advancing they ways and types of data that can be collected. This is especially important in expanding the data available in low resource or inaccessible settings.

Methods/Approaches/Tools	Details	GWF Project Title
eDNA metabarcoding reference library	Library of known DNA metabarcodes to enable increased accuracy of species identifications	Next Generation Solutions to Ensure Healthy Water Resources for Future Generations
Chemical fingerprinting reference library	Known molecular connectivity and associated atomic elements that enable increased accuracy of chemical identifications	'Omic' and Chemical Fingerprinting Methodologies
Smartphone apps for citizen science	Water quality data, text, images, videos (under development).	Crowdsourcing Water Science Global Water Citizenship
	Colorimetric based water quality test kits (under development).	Promoting Beneficial Management Practices Acceptance through on-farm Instantaneous Community-Based Nutrient Sampling
Sensors	Phosphates and metals (e.g. Hg, As, Se, Cu, Ni, Pb), Nutrients, Cyanobacteria, Pathogens, Dissolved Oxygen, free chlorine	Sensors and Sensing Systems for Water Quality Monitoring
	Acoustic snow water equivalent sensor Gas trap (lake surface and floor methane emission detectors) Non-contact stream sensor (river stage)	GWF Core Initiative: Smart Water Systems Laboratory

Table 2.1: Methods.	Approaches and	Tools Develope	ed by GWF	Researchers
	rippi oucrics und	10015 Develope		nescurencis

Models Used, Developed, and Modified by GWF Researchers



Models Used, Developed, and Modified by GWF Researchers

It can be difficult to identify which model is most appropriate to use for a specific purpose in a specific region. Table 3.1 lists all of the third party models utilized within GWF projects as well as links for additional information.

Model	Description	Validation Basin(s) ²	GWF Project Name
Weather Research and	Next-generation mesoscale numerical	Pan-Canadian	GWF Core Initiative, Core Modelling
Forecasting (WKF)	for atmospheric research and		ream
	operational forecasting application		
	bttps://www.mmm.ucar.edu/weathor		
	Intps://www.ininini.ucal.edu/weather-		
	Tesear chi-and-for ecasting-model		
	WRF-HYDRO	St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
VIC	Large scale semi distributed	Mackenzie River Basin	Northern Water Futures
	hydrological model		
	http://www.hydro.washington.edu/Let	St. Lawrence River - Great Lakes	Integrated Modelling Program for
	tenmaier/Models/VIC/Overview/Mode	Basin, Saskatchewan River Basin	Canada
	<u>lOverview.shtml</u>		
		Yukon River Basin, Mackenzie	Mountain Water Futures
		River Basin, Saskatchewan River	
		Basin	
		Saskatchewan River Basin	Hydrological Processes in Frozen Soils
Raven	Generic discretized surface water	Mackenzie River Basin	Northern Water Futures
	hydrological model		
	http://raven.uwaterloo.ca/		

² Does not necessarily mean that a model is validated for the entire basin area.

		St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
НҮРЕ	Hydrological Catchment Model that simulates water flow and substances through the watershed <u>https://www.smhi.se/en/research/rese</u> <u>arch-departments/hydrology/hype-</u> <u>1.7994</u>	St. Lawrence River - Great Lakes Basin Nelson-Churchill River Basin, Mackenzie River Basin, St- Lawrence-Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds Integrated Modelling Program for Canada
Large Basin Runoff Model (LBRM)	Physically-based, large scale operational model to estimate rainfall/runoff <u>https://www.glerl.noaa.gov/res/Progra</u> <u>ms/pep/dlbrm/lbrm.html</u>	St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
HydroGeoSphere	Integrated hydrologic model including surface and subsurface flow and mass and heat transport <u>https://www.aquanty.com/hydrogeosp</u> <u>here</u>	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin St. Lawrence River - Great Lakes Basin	Mountain Water Futures Significance of Groundwater Dynamics within Hydrologic Models
NOAH-MP	Land surface hydrology model https://ral.ucar.edu/projects/noah- multiparameterization-land-surface- model-noah-mp-lsm	Saskatchewan River Basin	GWF Core Initiative, Core Modelling Team Hydrological Processes in Frozen Soils
JULES	Land surface hydrology model https://jules.jchmr.org/	Saskatchewan River Basin	Hydrological Processes in Frozen Soils
ParFlow	Spatially distributed surface and subsurface flow model that includes land surface processes such as snow and evapotranspiration https://parflow.org/	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, Saskatchewan River Basin	Mountain Water Futures

Canadian Land Surface Scheme (CLASS)	Represents the physical exchanges of heat and moisture between the land surface and the atmosphere. <u>http://www.usask.ca/geography/MAG</u> <u>S/Events/Workshops/Model/CLASS-</u> <u>V30-Background.pdf</u>	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
	CLASS- STEM	Saskatchewan River Basin	Hydrological Processes in Frozen Soils
Terrain Analysis Using Digital Elevation Models (TauDEM)	A suite of Digital Elevation Model (DEM) tools for the extraction and analysis (in ArcGIS) of hydrologic information from topography as represented by a DEM. <u>http://hydrology.usu.edu/taudem/tau</u> <u>dem5/index.html</u>	St. Lawrence River - Great Lakes Basin	Linking Stream Network Process Models to Robust Data Management Systems
MIKE	Hydraulic model; MIKEFLOOD is a toolbox for professional flood modellers (includes MIKE HYDRO, MIKE URBAN, and MIKE21) <u>https://www.mikepoweredbydhi.com/</u> products/mike-hydro-river/hydrology	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
	flow and contaminant and heat transport <u>https://www.mikepoweredbydhi.com/</u> products/feflow	Saskatchewan River Basin	Subsurface Connectivity and Groundwater Protection

WATFLOOD	Flood forecasting and long-term hydrologic simulation <u>http://www.civil.uwaterloo.ca/watfloo</u> <u>d/</u>	Nelson Churchill River Basin, Mackenzie River Basin St Lawrence River - Great Lakes Basin	Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds Integrated Modelling Program for Canada
Delft3D	Hydraulic model, hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments <u>https://oss.deltares.nl/web/delft3d</u>	St Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
PorousMediaLab	Toolkit for reactive transport modelling https://github.com/biogeochemistry/P orousMediaLab	St. Lawrence River - Great Lakes Basin	Winter Soil Processes in Transition
Hydrologic Engineering Centre river analysis system (HEC-RAS)	Normal depth and backwater flow analysis for determining depths and velocities in open channels	St. Lawrence River - Great Lakes Basin	Linking Stream Network Process Models to Robust Data Management Systems
	https://www.hec.usace.army.mil/softw are/hec-ras/	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
Environmental Fluid Dynamics Code (EFDC)	Flow depths and velocities, sediment suspension and deposition and water quality parameters in open channels and lakes <u>https://www.epa.gov/ceam/environm</u> <u>ental-fluid-dynamics-code-efdc</u>	St. Lawrence River - Great Lakes Basin	Linking Stream Network Process Models to Robust Data Management Systems
Stormwater Management model (SWMM)	Urban areas hydrological modelling https://www.epa.gov/water- research/storm-water-management- model-swmm	St. Lawrence River - Great Lakes Basin	Linking Stream Network Process Models to Robust Data Management Systems

Grand River Simulation Model (GRSM)	Water quality model for urban areas that focuses on dissolved oxygen, biochemical oxygen demand, nitrogenous oxygen demand, nitrate, suspended solids, and total phosphorus <u>https://data.grandriver.ca/downloads/</u> <u>GRSM/GRSM tech guidance V1.pdf</u>	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin, Atlantic Basin - Bay of Fundy (NS)	Agricultural Water Futures - Stressors and Solutions
Estuary, Lake and Coastal Ocean Model (ELCOM) and Computational Aquatic Ecosystem DYnamics Model (CAEDYM)	3-D water quality model that focuses on nitrogen, phosphorus, microbes, and sediment <u>https://teamwork.niwa.co.nz/display/I</u> <u>FM/ELCOM-CAEDYM</u>	St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
Biotic Ligand Model (BLM)/ Windermere Humic Aqueous Model (WHAM)	Modelling Dissolved Organic Matter quality and quantity <u>https://www.ceh.ac.uk/services/winde</u> <u>rmere-humic-aqueous-model-wham</u>	Mackenzie River Basin	Sub-Arctic Metal Mobility Study
Aquatic Ecodynamics Modelling (AED2)	Flexible modules for custom aquatic ecosystem conceptualizations of oxygen, silica, phosphorous, nitrogen, chlorophyll-A, organic matter, phytoplankton, zooplankton, pathogens, geochemistry, and sediment diagenesis <u>http://aed.see.uwa.edu.au/research/m</u> odels/AED/	St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
MATSEDLAB	Biogeochemical modelling of early diagenesis of concentrations of species at depth <u>https://uwaterloo.ca/ecohydrology/sof</u> <u>tware</u>	St. Lawrence River - Great Lakes Basin	GWF Core Initiative: Modelling Team

Spatially Referenced Regressions On Watershed Attributes (SPARROW)	Contaminants transport model focusing on nutrient, sediment, and dissolved solids transport <u>https://www.usgs.gov/mission-</u> <u>areas/water-</u> <u>resources/science/sparrow-modeling-</u> <u>estimating-nutrient-sediment-and-</u> <u>dissolved?qt-</u> <u>science_center_objects=0#qt-</u> <u>science_center_objects</u>	Saskatchewan River Basin, Nelson-Churchill Basin	Integrated Modelling Program for Canada
Water Quality Analysis Simulation Program (WASP)	Water quality response prediction of conventional Pollutants (nitrogen, phosphorus, dissolved oxygen,	Saskatchewan River Basin, Nelson-Churchill Basin	Integrated Modelling Program for Canada
	biological oxygen demand, sediment oxygen demand, algae, periphyton), organic chemicals, metals, mercury, pathogens, and temperature <u>https://www.epa.gov/ceam/water-</u> <u>quality-analysis-simulation-program-</u> <u>wasp</u>	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin, Yukon River Basin	Transformative Sensor Technologies and Smart Watersheds
MyLake	Multi-year lake simulation model <u>http://www.finessi.info/finessi/help.ph</u> <u>p?id=34⟨=en</u>	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes
		St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
General Lake Model (GLM)	Distributed one-dimensional lake water balance and stratification model <u>http://aed.see.uwa.edu.au/research/m</u> <u>odels/GLM/</u>	St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds

Global Multi-scale Environmental Model (GEM)	Integrated forecasting and data assimilation system	Saskatchewan River Basin, Columbia River Basin	Storms and Precipitation Across the Continental Divide Experiment
	GEM-Hydro Runoff modelling platform	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
		Nelson-Churchill River Basin, Mackenzie River Basin, St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
Microwave Emission Model for Layered Snow (MEMLS)	Energy flux	Mackenzie River Basin	Northern Water Futures
SnowModel	Spatially distributed snow evolution modelling system <u>https://www.fs.usda.gov/treesearch/p</u> <u>ubs/26319</u>	Mackenzie River Basin	Northern Water Futures
SUTRA-ice	Saturated and unsaturated freeze- thaw model <u>https://www.usgs.gov/software/sutra-</u> <u>a-model-2d-or-3d-saturated-</u> <u>unsaturated-variable-density-ground-</u> <u>water-flow-solute-or</u>	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
Arctic Terrestrial Simulator	Permafrost degradation https://www.lanl.gov/orgs/adtsc/publi cations/science_highlights_2013/docs/ Pg44_45.pdf	Mackenzie River Basin	Northern Water Futures
Northern Ecosystems Soil Temperature (NEST)	Permafrost	Mackenzie River Basin	Northern Water Futures

FroSin	Frozen soil infiltration model	Saskatchewan River Basin	Hydrological Processes in Frozen Soils
Heat Flow SMOKER	Energy flux: freeze-thaw cycles	Mackenzie River Basin	Northern Water Futures
Los Alamos Sea Ice Model	Sea ice, growth, melt and movement http://www.cesm.ucar.edu/models/cc sm4.0/cice/	St. Lawrence River - Great Lakes Basin	Evaluation of Ice Models in Large Lakes
RIVICE	Dynamic wave model for ice generation, ice transport, ice cover progression and ice jam formation <u>http://giws.usask.ca/rivice/Manual/RIV</u> ICE Manual 2013-01-11.pdf	Mackenzie River Basin, Saint John River Basin (NB), Churchill River and Exploits River Basins (NFLD)	Integrated Modelling Program for Canada
FLAC-3D	Shear stresses https://www.itascacg.com/software/fl ac3d	Mackenzie River Basin	Northern Water Futures
Sediment Transport Index calculator	Bed sediment transport	St. Lawrence River - Great Lakes Basin	Linking Stream Network Process Models to Robust Data Management Systems
GEO-SLOPE	Slope stability model https://www.geoslope.com/	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
Soil Water Assessment Tool (SWAT)	Quality and quantity of surface and groundwater and environmental impact of land use and management and climate change	Saskatchewan River Basin, St. Lawrence River Basin, Atlantic Basin - Bay of Fundy (NS)	Agricultural Water Futures - Stressors and Solutions
	https://swat.tamu.edu/	St. Lawrence- Great Lakes River Basin	Integrated Modelling Program for Canada

Versatile Soil Moisture Budget – Depression Upland System (VSMB- DUS)	Coupled soil water balance model that simulates groundwater recharge considering the hydrological coupling of a depression–upland system <u>https://dl.sciencesocieties.org/publicat</u> <u>ions/vzj/abstracts/17/1/170176</u>	Saskatchewan River Basin (North Saskatchewan River, Red Deer River), Mackenzie River Basin	Prairie Water
SV-FLUX	Groundwater seepage https://soilvision.com/products/svoffic e-ge/svflux-ge	Mackenzie River Basin	Northern Water Futures
Wetland DEM Ponding Model (WPDM)	Models the distribution of runoff water on the Canadian Prairies <u>https://www.usask.ca/hydrology/WDP</u> <u>M.php</u>	Saskatchewan River Basin	Agent Based Modelling as a Tool to Investigate Comprehensive Indigenous Health Impacts of Flooding
		Saskatchewan River Basin	Prairie Water
		Mackenzie River Basin	Crowdsourcing Water Science
Peatlands Hydrological Impacts Model (PHI)	Effects of drainage, mining and timber harvesting on stream flow response <u>https://iwaponline.com/hr/article/18/</u> <u>2/79/265/The-Peatland-Hydrologic-</u> <u>Impact-Model-Development</u>	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Boreal Water Futures
Model for Acidification of Groundwater In Catchments (MAGIC)	Process-orientated intermediate complexity dynamic catchment scale model for reconstructing and predicting long term trends in soil and water acidification <u>https://macaulay.webarchive.hutton.a</u> <u>c.uk/recover/magic.htm</u>	St. Lawrence River - Great Lakes Basin	GWF Core Initiative: Modelling Team

Forest Fire (BurnP3, Canadian Forest Fire Weather Index System, Peatland Smoldering and Initiation Model)	Effects of ignition, fuel availability and moisture and wind on fire behavior and spread <u>http://www.firegrowthmodel.ca/burnp</u> <u>3/overview_e.php;</u> <u>http://cwfis.cfs.nrcan.gc.ca/backgroun</u> <u>d/summary/fwi</u>	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Boreal Water Futures
Economic Input-Output Models	Quantitative economic model that represents the interdependencies between different sectors of an economy	St. Lawrence River - Great Lakes Basin St. Lawrence-Great Lakes Basin, Nelson-Churchill River Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds. Integrated Modelling Program for Canada
ECCC Water Quality Valuation Model (WQVM)	Non-market valuation tool based on benefits transfer function	St. Lawrence River - Great Lakes Basin Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds Integrated Modelling Program for Canada
Crystal Ball	Predictive modelling, forecasting, simulation and optimization <u>https://www.oracle.com/applications/</u> <u>crystalball/</u>	Mackenzie River Basin	Northern Water Futures
Water Evaluation and Planning Model (WEAP)	Integrated water resources planning assessment tool <u>https://www.weap21.org/</u>	Saskatchewan River Basin	Integrated Modelling Program for Canada

MODSIM-DSS	General river basin management decision support system	Nelson River Basin, Saskatchewan River Basin	Integrated Modelling Program for Canada
Water Resource Integrated Modeling System (WRIMS)	Generalized water resources modeling system for evaluating operational alternatives of large, complex river basins <u>https://water.ca.gov/Library/Modeling</u> <u>-and-Analysis/Modeling-</u> <u>Platforms/Water-Resource-Integrated-</u> <u>Modeling-System</u>	Saskatchewan River Basin	Integrated Modelling Program for Canada
AnyLogic	Agent-based modelling software that simulates the actions and interactions of autonomous agents to assess effects on the system <u>https://www.anylogic.com/s/downloa</u> <u>d-free-simulation-software-for- education/</u>	Saskatchewan River Basin	Agent Based Modeling as a Tool to Investigate Comprehensive Indigenous Health Impacts of Flooding
	Linked to SWAT	St. Lawrence River - Great Lakes Basin	Agricultural Water Futures - Stressors and Solutions
	Agent-based Agriculture Water Demand Model	Saskatchewan River Basin	Integrated Modelling Project for Canada
ELEMeNT	Pairs a simulation of soil nutrient dynamics with a travel time-based approach – to reconstruct historic nutrient yields and to model future nutrient loading under a range of scenarios	St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds

GWF focuses on the development and application of several key process-based hydrological models and land surface schemes for improved understanding and diagnosis of past Earth system change as well as prediction of future change (Table 3.2).

At fine scales, efforts are directed at improving the functionality and expanding the capability of handling complex cold region processes within the Cold Regions Hydrological Model (CRHM)³. CRHM is a flexible modelling system that can be used to generate a process hydrology model, specific to the needs of the user. A functioning model is built by selecting various process modules from a library based on several decades of hydrological research. CRHM can be applied at point scales and over small to medium sized river basins to simulate system behavior and response to climate and other changes, and is particularly useful for disentangling complex process interactions between climate, vegetation, snow, glaciers, permafrost, land management, surface–atmosphere fluxes, and runoff.

For large scale and large domain simulations, GWF works with partners in Environment and Climate Change Canada (ECCC) to advance the Canadian LAnd Surface Scheme (CLASS) and Modélisation Environmentale Communautaire (MEC) – Surface and Hydrology (MESH) model. MESH is a stand-alone land-surface–hydrology scheme designed for both forecasting and open loop (i.e., without feedbacks to the atmosphere) simulations. As a hydrology modelling system, MESH captures many of the important land-surface processes necessary for cold-regions simulation. It is a flexible modelling framework that facilitates inter-comparison of alternative algorithms and models (e.g., land surface schemes and routing schemes), and can be applied over vast river basins.

Finally, GWF is focused on the development of the multi-scale and multi-resolution Canadian Hydrological Model (CHM). CHM uses a variable resolution mesh to capture fine-scale variability where it exists, while reducing computational demands by reducing resolution in other parts of the domain⁴. It has the design goals of i) multi-scale, multi-physics, variable complexity and domain, ii) assessment of model structural, parameter, and data uncertainty, iii) ability to test multiple hypotheses, avoid rigid model structures, iv) incorporating existing code, and v) contributing to decision support systems. Many existing process algorithms have been ported into CHM, and given its flexibility and robustness, this model represents the next generation in cold regions hydrological modelling with the capability to bridge scales from local to regional to large basin-scale.

³ Pomeroy, J. W., Gray, D. M., Brown, T., Hedstrom, N. R., Quinton, W. L., Granger, R. J., & Carey, S. K. (2007). The cold regions hydrological model: a platform for basing process representation and model structure on physical evidence. *Hydrological Processes: An International Journal*, *21*(19), 2650-2667.

⁴Marsh, C. B., Pomeroy, J. W., & Wheater, H. S. (2020). The Canadian Hydrological Model (CHM) v1. 0: a multi-scale, multi-extent, variable-complexity hydrological model–design and overview. *Geoscientific Model Development*, *13*(1).

Model	Description	Validation Basin(s) ⁵	GWF Project Name
Cold Regions Hydrological Model (CRHM)	Integrated physics-based hydrological model http://www.usask.ca/hydrolo	Mackenzie River Basin Yukon River Basin. Mackenzie River	Northern Water Futures Boreal Water Futures
	gy/CRHM.php	Basin, Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	
		Saskatchewan River Basin	Diagnosing policy and governance effectiveness for agricultural water management
		Saskatchewan River Basin, Assiniboine River Basin, Missouri River Basin, Red River Basin	Prairie Water
		Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
	WINTRA module Crop growth module (DSSAT, AquaCrop-OS, CropSyst) Tile drainage module (HYPE and DRAINMOD)	Saskatchewan River Basin, St. Lawrence River Basin, Atlantic Basin - Bay of Fundy (NS)	Agricultural Water -Stressors and Solutions
	CRHM-Glacier	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures

⁵ Does not necessarily mean that a model is validated for the entire basin area.

MESH (MEC-surface and hydrology system)	Coupled land surface atmosphere hydrological	Mackenzie River Basin	Northern Water Futures
	model http://www.usask.ca/ip3/mo dels1/mesh.htm	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Boreal Water Futures
	MESH-Glacier based on CRHM-Glacier module (under development)	Saskatchewan River Basin	Integrated Modelling Program for Canada
	Isotope enabling (under development)	Nelson Churchill River Basin, Mackenzie River Basin	Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds
	MESH-SED (sedimentation and nutrient loads)	Nelson-Churchill River Basin	GWF Core Initiatives: Modelling Team
	MESH-RBM (stream temperature)	Mackenzie River Basin, Saint John River Basin	GWF Core Initiatives: Modelling Team
	MESH-WASP (water quality)	Mackenzie River Basin, Saskatchewan River Basin	Integrated Modelling Program for Canada
	MESH-RIVICE (ice jams)	Mackenzie River Basin, Saint John River Basin	Integrated Modelling Program for Canada

Water Futures Risk Assessment Framework (WFRA) (under development)	Next generation future climate and extreme weather product and future wildfire regimes prediction tool	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Boreal Water Futures
Canadian Hydrological Model (CHM) (under development)	Multi-scale, variable- complexity hydrological model for cold regions	Mackenzie River Basin Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, Columbia River Basin	Northern Water Futures Mountain Water Futures
		Saskatchewan River Basin	Hydrological Processes in Frozen Soils
GEM-CHM	Snow forecasting (under development) <u>http://www.snowcast.ca</u>	Saskatchewan River Basin	GWF Core Initiative: Modelling Team
Variogram Analysis of Response Surfaces (VARS)	A sensitivity analysis toolbox with minimal computational cost <u>https://vars-tool.com/</u>	Saskatchewan River Basin	Integrated Modelling Program for Canada

In addition to generating new models, GWF researchers are modifying and adding modules to existing models to improve capabilities and expand applications (Table 3.3).

 Table 3.3: List of models modified by GWF researchers

GWF-Modified Models	Additions	Validation Basins(s) ⁶	GWF Project Name
HYPE (Hydrological Catchment Model) https://www.smhi.se/en/research/	Reservoir Model (under development)	St. Lawrence River - Great Lakes Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience
research- departments/hydrology/hype- <u>1.7994</u>	ELEMeNT-HYPE (Exploration of Long Term Nutrient Trajectories; under development)		of Lakes and their Watersheds
	Modifications to represent crop processes (under development)		
	Frozen soils algorithm	Nelson-Churchill River Basin	Integrated Modelling Program for Canada
Porous Media Lab	Toolkit for reactive transport modelling: Winter Mycrobial Dynamics Model (under development)	St. Lawrence River - Great Lakes Basin	Winter Soil Processes in Transition
MESH (MEC-surface and hydrology system) <u>http://www.usask.ca/ip3/models1/</u> mesh.htm	MESH-Glacier based on CRHM- Glacier module (under development)	Saskatchewan River Basin, Mackenzie River Basin	Integrated Modelling Program for Canada
	Isotope enabling (under development)	Nelson Churchill River Basin, Mackenzie River Basin	Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds

 $^{^{\}rm 6}$ Does not necessarily mean that a model is validated for the entire basin area.

DATA COLLECTED WITHIN THE GWF NETWORK

Data Collected Within the GWF Network

Global Water Futures research has so far contributed data from more than 60 observation sites across Canada, in most of the major drainage basins of the country (Fig. 4.1). All metadata that is part of GWF projects are being collated into a centralized, searchable, publicly available catalog (under development).



Figure 4.1: Map of observation sites within the GWF network as of 2018.



Figure 4.2: List of observation sites within the GWF network as of 2018.

The following table (Table 4.1) provides a summary of the different types of data being collected across GWF projects.

 Table 4.1: Data collected by data type, region and GWF project

Data Type	Variables	Site Basins(s) ⁷	GWF Project
Genomics Data	Toxin risk, genomics, taxonomy	Saskatchewan River Basin (Buffalo Pound, ELA), St. Lawrence River Basin (Grand River, Conestogo Lake)	Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes
Ecological / Environmental Data	Ecosystem structure and function (inc. Evapotranspiration)	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin	Boreal Water Futures
	Micropollutants	St. Lawrence River Basin (Grand River)	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds
	Aquatic animals	St. Lawrence River Basin (Grand River)	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds
		Mackenzie River Basin	Northern Water Futures
	Biological indicators (mussels and Cladophora and biomass)	St. Lawrence River Basin, Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	Plant physiology	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
	Sapflow	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures

⁷ Data collected at single or multiple locations that may not cover entire basins.

	Tree rings	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
		Saskatchewan River Basin, Churchill River Basin (Mistik Management Limited's Forest Management Area)	Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime across the Southern Boreal Forest
		Mackenzie River Basin	Northern Water Futures
	Physical and chemical soil analyses	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin	Boreal Water Futures
		Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
	Sediment cores	St. Lawrence River Basin (Grand River)	Winter Soil Processes in Transition
	Lakes	St. Lawrence River Basin, Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
		Mackenzie River Basin (Peace-Athabasca Delta)	Northern Water Futures
	Soil/sediment survey	Saskatchewan River Basin (North Saskatchewan River, Red Deer River), Mackenzie River Basin	Prairie Water
	Sediment toxicology	Mackenzie River Basin	Sub-Arctic Metal Mobility Study

	Soil water potential	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
	Controlled laboratory investigations and short-term field- based manipulations and experiments (eco-hydrological system carbon and nutrient biogeochemistry)	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin	Boreal Water Futures
	Physical habitat and disturbances	St. Lawrence River Basin, Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
Hydrogeological Data	Unspecified	St. Lawrence River Basin, Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
		Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
		Mackenzie River Basin	Northern Water Futures
	Groundwater table	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
	Extent, thickness, hydraulic head, permeability, porosity, storativity of aquifers and aquatards; vertical hydraulic gradients of aquatards	Saskatchewan River Basin	Subsurface Connectivity and Groundwater Protection

	Distribution, age, construction practices, and effective permeabilities of oil, gas and groundwater wells	Saskatchewan River Basin, Assiniboine River Basin	Subsurface Connectivity and Groundwater Protection Prairie Water
	Permafrost	Mackenzie River Basin	Northern Water Futures
	Frozen ground	Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Agricultural Water - Stressors and Solutions
	Nitrogen uptake experiments	Saskatchewan River Basin (North Saskatchewan River, Red Deer River), Mackenzie River Basin	Prairie Water
Hydrologic Data	Field based (unspecified)	St. Lawrence River Basin (Grand River)	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds
		Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin	Boreal Water Futures
		Assiniboine River Basin (Qu'Appelle)	Prairie Water
	Hydrometric data (unspecified)	Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
	Hydrological data (unspecified)	Mackenzie River Basin	Northern Water Futures

	Wave energy	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	Turbulence	Saskatchewan River Basin (Buffalo Pound Lake, Experimental Lakes Area), St. Lawrence River Basin (Grand River, Conestogo Lake)	Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes
	ECCC streamflow	Nelson Churchill River Basin, Mackenzie River Basin	Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude
	Water data, text, images, videos	Saskatchewan River Basin	Crowdsourcing Water Science
	Run-off timing and pathways	Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Agriculture Water Futures – Stressors and Solutions
	Simulated 3-year annual cycle of hydrologic fluxes (under development)	St. Lawrence River Basin (Grand River, Alder Creek)	Significance of Groundwater Dynamics within Hydrologic Models
Water Quality Data (field based)	Microbial and chemical (unspecified)	Saskatchewan River Basin, Mackenzie River Basin, St. Lawrence River Basin (Grand River)	Next Generation Solutions to Ensure Healthy Water Resources for Future Generations
	Water quality (unspecified)	Mackenzie River Basin (Peace-Athabasca Delta)	Northern Water Futures
		Saskatchewan River Basin, Assiniboine River Basin, Red River Basin	Prairie Water
		St. Lawrence River Basin (Grand River)	Winter Soil Processes in Transition
		Saskatchewan River Basin	Subsurface Connectivity and Groundwater Protection

	Water chemistry (unspecified)	St. Lawrence River Basin (Grand River)	Co-creating Indigenous Water Quality Tools
	Nutrients, pesticides	St. Lawrence River Basin (Grand River)	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds
		Saskatchewan River Basin, Assiniboine River Basin, Red River Basin	Prairie Water
	Effluent quality	St. Lawrence River Basin (Grand River)	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds
		St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	Nutrient fluxes, loadings, concentrations (phosphorus, nitrogen)	Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Agricultural Water - Stressors and Solutions
		St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	Temperature	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
		Saskatchewan River Basin (Buffalo Pound Lake, Experimental Lake Area), St. Lawrence River Basin (Grand River, Conestogo Lake)	Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes

	Sediment load	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	Dissolved oxygen	St. Lawrence River Basin- Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
		Saskatchewan River Basin (Qu'Appelle), St. Lawrence River Basin, Yukon River Basin	Sensors and Sensing Systems for Water quality Monitoring
	Major ions	Saskatchewan River Basin	Subsurface Connectivity and Groundwater Protection
	Na ⁺ , Ca ^{2+,} Mg ²⁺	Saskatchewan River Basin, Assiniboine River Basin	Prairie Water
	Field-based isotopes (unspecified)	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
	$^{3}\text{H},\delta^{2}\text{H}$ and $\delta^{18}\text{O}$	Saskatchewan River Basin, Assiniboine River Basin	Prairie Water
	Br, ¹⁴ C, ⁴ He, ⁸¹ Br, ³⁷ Cl ⁸⁷ Sr/ ⁸⁶ Sr and ¹²⁹ l.	Saskatchewan River Basin	Subsurface Connectivity and Groundwater Protection
	ECCC stable water isotopes	Nelson Churchill River Basin, Mackenzie River Basin	Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude
	Water chemistry for water fingerprints	Saskatchewan River Basin	Subsurface Connectivity and Groundwater Protection

	Conductivity, pH and turbidity	Saskatchewan River Basin (Qu'Appelle), St. Lawrence River Basin, Yukon River Basin	Sensors and Sensing Systems for Water quality Monitoring
	Light	Saskatchewan River Basin (Buffalo Pound Lake, Experimental Lakes Area), St. Lawrence River Basin (Grand River, Conestogo Lake)	Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes
	E. coli	St. Lawrence River Basin (Grand River)	Co-creating Indigenous Water Quality Tools
Weather and Climate Data	Meteorological data (unspecified)	Mackenzie River Basin	Northern Water Futures
		Prairies Provinces	Climate-Related Precipitation Extremes
	Climate data (unspecified)	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
		St. Lawrence River Basin (Grand River)	Winter Soil Processes in Transition
	Field based (unspecified)	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
	Wind, air temp, longwave and shortwave radiation, humidity, rainfall	Saskatchewan River Basin, Columbia River Basin	Storms and Precipitation Across the continental Divide Experiment
		Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin	Boreal Water Futures
		St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
		Pan Canadian	Short-Duration Extreme Precipitation in Future Climate

	Wind speed, temperature, humidity at 30m	Saskatchewan River Basin	Improved Estimates of Wetland Evaporation
	Precipitation	Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Agricultural Water Futures - Stressors and Solutions
	Micro Rain Radar (MRR)	Saskatchewan River Basin, Columbia River Basin	Storms and Precipitation Across the continental Divide Experiment
	ECCC Operational Doppler radar	Prairie Provinces, western Cordillera	Climate-Related Precipitation Extremes
			Mountain Water Futures
	Eddy covariance	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
		Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
		Mackenzie River Basin	Northern Water Futures
	Wetland and land based	Saskatchewan River Basin	Improved Estimates of Wetland Evaporation
	Energy balance (over wetland and land based), integrated sensible heat flux	Saskatchewan River Basin	Improved Estimates of Wetland Evaporation

	Wind RASS SODAR	Saskatchewan River Basin	Improved Estimates of Wetland Evaporation
		Saskatchewan River Basin	Short-Duration Extreme Precipitation in Future Climate
	Downscaled climate forcing	Pan Canadian	Climate Related Precipitation Extremes
		Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	WRF data	Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Agricultural Water Futures - Stressors and Solutions
	WRF-CP (convection permitting)	Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	CONUSWRF and CAM 5.1	Southern Canada	Short-Duration Extreme Precipitation in Future Climate
	CMIP6	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin - Great Lakes	Boreal Water Futures
	CRCM/CanRCM	Pan Canadian	Integrated Modelling Program for Canada
	CanRCM 4	Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	CanRCM 5	Pan Canadian	Climate Related Precipitation Extremes

	Complexity Atmospheric Research model (ICAR)	Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
	MITgcm Model data	St. Lawrence River Basin - Great Lakes	Evaluation of Ice Models in Large Lakes
	GCM (CMIP 5, CMIP 6)	Global	Climate Related Precipitation Extremes
		Global	Short-Duration Extreme Precipitation in Future Climate
	GCM CORDEX	Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	CaPA (precipitation)	Pan Canadian	Climate Related Precipitation Extremes
		Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	ELCOM-CAEDYM	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	ANUSPLIN, NARR, GPM	Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	Climate scenarios (derived from GCM/Core Modelling Team)	Saskatchewan River Basin, Churchill River Basin (Mistik Forest Management Ltd. Forest Management Area)	Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime across the Southern Boreal Forest

Socio-Economic Data	Economic, demographic, decision	Saskatchewan River Basin	Prairie Water
	Пакіпg	Nelson-Churchill River Basin	Integrated Modelling Program for Canada
		Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Agriculture Water Futures – Stressors and Solutions
		St. Lawrence – Great Lakes Basin	Linking Water Governance in Canada to Global Economic, Social and Political Drivers
		Saskatchewan River Basin	Collaborative Modelling Framework for Water Futures and Holistic Human Health Effects
	Knowledge, values, attitudes and practices	Akaitcho Territory (Deninu K'ue First Nation, Lutsel K'e Dene First Nation, and Yellowknives Dene First Nation)	Is Our Water Good to Drink? Water- Related Practices, Perceptions, and TK Indicators for Human Health
		St. Lawrence – Great Lakes Basin (Six Nations of the Grand River)	Co-Creation of Indigenous Water Quality Tools
		Saskatchewan River Basin	Prairie Water

Traditional Knowledge and Traditional Ecological Knowledge	Mackenzie River Basin (Ka'a'gee Tu First Nation, Sambaa K'e First Nation and Dehcho First Nation)	Northern Water Futures
	Mackenzie River Basin (Deninu K'ue First Nation, Lutsel K'e Dene First Nation, and Yellowknives Dene First Nation)	Is Our Water Good to Drink? Water- Related Practices, Perceptions, and TK Indicators for Human Health
	Saskatchewan River Basin (Mistawasis Nêhiyawak)	Prairie water
	Saskatchewan River Basin (Cumberland House)	Integrated Modelling Program for Canada
	St. Lawrence – Great Lakes Basin (Matawa First Nation)	Matawa Water Futures: Developing an Indigenous-Informed Framework for Watershed Monitoring and Stewardship
	St. Lawrence – Great Lakes Basin (Fort Albany First Nation)	FIShNET: Healthy Water, Healthy Fish, Healthy People
	Saskatchewan River Basin (Cumberland House)	We Need More than Just Water: Assessing Sediment Limitation in a Large Freshwater Delta
	St. Lawrence – Great Lakes Basin (Six Nations of the Grand River)	Ohneganos – Indigenous Ecological Knowledge, Training and Co- creation of Mixed Method Tools
	Makenzie River Basin (Tulit'a, Délınę and Fort Good Hope)	Water Knowledge Camps: Building Capacity for Cross Cultural Water Knowledge, Research, and Environmental Monitoring

Earth Observation Data			
Source	Product/Variable	Site Location(s)	GWF Project
Drone/aircraft LiDAR with aerial photography	Digital Elevation Model (DEM) and aerial imagery	Mackenzie River Basin	Sub-Arctic Metal Mobility Study Northern Water Futures
		Saskatchewan River Basin	Agent Based Modelling as a Tool to Investigate Indigenous health Impacts of Flooding
		Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
	Wetland morphology, area, surface temperature	Saskatchewan River Basin	Improved Estimates of Wetland Evaporation
	Thermal imagery	St. Lawrence River Basin - Great Lakes (Grand River)	Transformative Sensor Technologies and Smart Watersheds
Leica GPS	Survey of critical locations	Mackenzie River Basin	Sub-Arctic Metal Mobility Study
TIR/VIR (Landsat, MODIS, VIIRS)	Thermal and visual infrared imaging	St. Lawrence River Basin, Great Lakes	Evaluation of Ice Models on Large Lakes
		Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures
	Normalized Difference Vegetation Index	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures

Radiometer (Sentinel 3-	Land and sea temperature	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive
SLSTR)			Capacity and Resilience of Lakes and their Watersheds
Photochemical Reflectance Index (PRI)	Vegetation health, productivity	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
C-band	Relative water content variations	St. Lawrence River Basin (Turkey Point Observatory)	Southern Forests Water Futures
Ku and L-band (CryoSAR)	Large scale distributions of snow water equivalent (SWE), soil moisture and freeze-thaw status	St. Lawrence River Basin - Great Lakes River Basin (Alder Creek, Hopewell Creek, Gatineau River and Saint-Maurice River), Nelson-Churchill River Basin (Canadian Rockies Hydrological Observatory, Brightwater Creek Research Basin, Buffalo Pound Lake), Yukon River Basin (Wolf Creek Research Basin)	Transformative Sensor Technologies and Smart Watersheds
	Ice concentration	St. Lawrence River Basin - Great Lakes	Evaluation of Ice Models on Large Lakes
	Surface conditions	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds

Multispectral/ hyperspectral sensor (Buoy, satellite, drone)	Water quality, water quantity, snow and soil moisture	St. Lawrence River Basin - Great Lakes River Basin (Alder Creek, Hopewell Creek, Gatineau River, Grand River, and Saint- Maurice River), Nelson-Churchill River Basin (Canadian Rockies Hydrological Observatory, Brightwater Creek Research Basin, Buffalo Pound Lake), Yukon River Basin (Wolf Creek Research Basin)	Transformative Sensor Technologies and Smart Watersheds
		Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River) Saskatchewan River Basin (Buffalo Pound, ELA), St. Lawrence River Basin (Grand River,	Mountain Water Futures Forecasting Tools and Mitigation Options for Diverse Bloom-Affected
		Conestogo Lake)	Lakes
MERIS	Chlorophyll concentration and sediment suspension	St. Lawrence River Basin, Great Lakes	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
Reflectometer (ground based, drone based)	Water quality properties, snow, and soil moisture, soil freeze-thaw state, ice thickness and snow-on- ice	St. Lawrence River Basin - Great Lakes River Basin (Alder Creek, Hopewell Creek, Gatineau River, Grand River, and Saint- Maurice River), Nelson-Churchill River Basin (Canadian Rockies Hydrological Observatory, Brightwater Creek Research Basin, Buffalo Pound Lake), Yukon River Basin (Wolf Creek Research Basin)	Transformative Sensor Technologies and Smart Watersheds
Acoustics	Snow properties	Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Mountain Water Futures Transformative Sensor Technologies and Smart Watersheds