SUPPLEMENTARY TABLES: WATER FUTURES FOR THE WORLD WE WANT

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

SUPPLEMENTARY TABLES: WATER FUTURES FOR THE WORLD WE WANT

Citation

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

Primary Report

Primary report that is supported by the data tables in this companion document:
Schuster-Wallace, C.J., Sandford, R., and Merrill, S. 2019.
Water Futures for the World We Want.
University of Saskatchewan, Saskatoon, Canada

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

Acknowledgements

These summary tables are based upon the Global Water Futures 2018 project reports. This document is a living electronic document that will be updated regularly. 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

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

TABLE OF CONTENTS

APPENDIX I:

LIST OF GLOBAL WATER FUTURES PROJECTS AND CORE INITIATIVES

I

APPENDIX I: List of GWF Projects and Core Initiatives

The Global Water Futures program has provided research funding for the following projects and financial support for Core initiatives. For more information related to a specific project or initiative see the contact information and websites provided.

Table AI.1: List of GWF Projects and Core Initiatives

Transformative Science Projects (Pillars 1 & 2)		
Project Name	**Contact Information**	**Website**
Southern Forests Water Futures	PI: M. Altaf Arain, McMaster University Email: arainmATmcmaster.ca	http://www.southernforestswaterfuture.ca/
Collaborative Modelling Framework for Water Futures and Holistic Human Health Effects	PI: Lalita Bharadwaj, University of Saskatchewan Email: lalita.bharadwajATusask.ca	https://gwf.usask.ca/science/projects/p1-colab-modelling.php
Linking Water Governance in Canada to Global Economic, Social and Political Drivers	PI: Rob de Loe, University of Waterloo Email: rdeloeATuwaterloo.ca	https://gwf.usask.ca/science/projects/p1-water-governance.php
Old Meets New: Subsurface Hydrogeological Connectivity and Groundwater Protection	PI: Grant Ferguson, University of Saskatchewan Email: grant.fergusonATusask.ca	https://gwf.usask.ca/science/projects/p1-old-meets-new.php
Developing 'Omic' an Chemical Fingerprinting Methodologies	PI: Paul Jones, University of Saskatchewan Email: paul.jonesATusask.ca	https://gwf.usask.ca/science/projects/p1-chemical-fingerprinting.php
Evaluation of Ice Models in Large Lakes	PI: Kevin Lamb, University of Waterloo Email: kglambATuwaterloo.ca	https://gwf.usask.ca/science/projects/p1-lake-ice.php
Short-Duration Extreme Precipitation in Future Climate	PI: Yanping Li, University of Saskatchewan Email: yanping.liATusask.ca	https://gwf.usask.ca/science/projects/p1-extreme-precipitation.php
Prairie Drainage Governance	PI: Phil Loring, University of Guelph Email: phil.loringATuoguelph.ca	https://gwf.usask.ca/drainage/index.php
Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision Support	PI: Bruce MacVicar, University of Waterloo Email: bmacvicaATuwaterloo.ca	https://gwf.usask.ca/science/projects/p1-stream-network-modelling.php
Winter Soil Processes in Transition	PI: Fereidoun Rezanezhad, University of Waterloo Email: frezanezATuwaterloo.ca	https://gwf.usask.ca/science/projects/p1-winter-soil.php
Global Water Citizenship	PI: Colin Robertson, Wilfrid Laurier University Co-PI: Rob Feick Email: crobertsonATwlu.ca	http://gwc-gwf.ca/
Sensors and Sensing Systems for Water Quality Monitoring	PI: Ravi Selvaganapathy, McMaster University Email: selvagaATmcmaster.ca	https://gwf.usask.ca/science/projects/p1-wq-monitoring.php

Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds	PI: Mark Servos, University of Waterloo Email: mservosATuwaterloo.ca	https://gwf.usask.ca/science/projects/p1-stressors.php
Crowdsourcing Water Science	PI: Graham Strickert, University of Saskatchewan Email: graham.strickertATusask.ca	https://gwf.usask.ca/science/projects/p1-crowdsourcing.php
SPADE: Storms and Precipitation Across the Continental Divide Experiment	PI: Julie Thériault, Université du Québec à Montréal Email: theriault.julieATuqam.ca	https://gwf-spade.weebly.com/
SAMMS: Sub-Arctic Metal Mobility Study	PI: Brent Wolfe, Wilfrid Laurier University Co-PI: Jason Venkiteswaran Email: bwolfeATwlu.ca	https://specialprojects.wlu.ca/samms/
Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime Across the Southern Boreal Forest	PI: Colin Laroque, University of Saskatchewan Email: colin.laroqueATusask.ca	https://gwf.usask.ca/science/projects/p1-adaption-governance.php
Significance of Groundwater Dynamics Within Hydrologic Models	PI: Walter Illman, University of Waterloo Email: willmanATuwaterloo.ca	https://gwf.usask.ca/science/projects/p1-groundwater-models.php
Diagnosing and Mitigating Hydrologic Model Uncertainty in High-Latitude Canadian Watersheds	PI: Tricia Stadnyk, University of Manitoba Email: stadnyktATcc.umanitoba.ca	https://gwf.usask.ca/science/projects/p1-model-uncertainty.php
Hydrological Processes in Frozen Soils	PI: Andrew Ireson, University of Saskatchewan Email: andrew.iresonATusask.ca	https://gwf.usask.ca/science/projects/p1-frozen-soils.php
Improved Estimates of Wetland Evaporation	PI: Warren Helgason, University of Saskatchewan Email: warren.helgasonATusask.ca	https://gwf.usask.ca/science/projects/p1-wetland-evap.php
User Question-Led Projects (Pillar 3)		
Project Name	**Contact Information**	**Website**
Climate-Related Precipitation Extremes	PIs: Ronald Stewart, University of Manitoba & Francis Zwiers, University of Victoria Project Manager: Dhouha Ouali Email: doualiATuvic.ca	https://gwf.usask.ca/extremes/index.php
Northern Water Futures	PI: Jennifer Baltzer, Wilfrid Laurier University Email: infoATnorthernwaterfutures.ca	https://researchcentres.wlu.ca/northern-water-futures/index.html
Next Generation Solutions to Ensure Healthy Water Resources for Future Generations	PI: John Giesy, University of Saskatchewan Email: john.giesyATusask.ca	https://gwf.usask.ca/edna/index.php

FORMBLOOM: Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes	PI: Helen Baulch, University of Saskatchewan Email: helen.baulchATusask.ca	https://gwf.usask.ca/formbloom/index.php
Agriculture Water Futures	PI: Merrin Macrae, University of Waterloo Email: mmacraeATuwaterloo.ca	https://uwaterloo.ca/agricultural-water-futures/
Boreal Water Futures	PI: Mike Waddington, McMaster University Email: jmwATmcmaster.ca	https://www.borealwaterfutures.ca/
Prairie Water	PI's: Christopher Spence, Environment and Climate Change Canada & Colin Whitfield, University of Saskatchewan Project Manager: Jared Wolfe Email: jared.wolfeATusask.ca	https://gwf.usask.ca/prairiewater/
Integrated Modelling Program for Canada	PI: Saman Razavi, University of Saskatchewan Project Manager: Hayley Carlson Email: hayley.carlsonATusask.ca	https://gwf.usask.ca/impc/
Mountain Water Futures	PI's: Sean Carey, McMaster University; Brian Menounos, University of Northern British Columbia; Masaki Hayashi, University of Calgary Email: mwfATmcmaster.ca	http://www.mountainwaterfutures.ca/
Lake Futures	PI: Nandita Basu, University of Waterloo Project Manager: Kirsten Grant Email: Kirsten.grantATuwaterloo.ca	https://uwaterloo.ca/lake-futures/
Transformative Sensor Technologies and Smart Watersheds (TTSW)	PI: Claude Duguay, University of Waterloo Project Manager: Marie Hoekstra Email: mhoekstrATuwaterloo.ca	https://uwaterloo.ca/transformative-technologies-smart-watersheds/
Co-Creation of Indigenous Water Quality Tools	PI: Dawn Martin-Hill, McMaster University Email: dawnmATmcmaster.ca	https://www.ohneganos.com/
Indigenous Community Water Research Projects		
Project Name	**Contact Information**	**Website**
Is Our Water Good to Drink? Water-Related Practices, Perceptions and Traditional Knowledge Indicators for Human Health	PIs: Corinne Shuster-Wallace, University of Saskatchewan; Lalita Bharadwaj, University of Saskatchewan; Diane Giroux, Akaitcho Territory Government Email: cschuster.wallaceATusask.ca	https://gwf.usask.ca/science/projects/i1-schusterwallace.php

Matawa Water Futures: Developing an Indigenous-Informed Framework for Watershed Monitoring and Stewardship	PIs: Terry Mitchell, Wilfrid Laurier University; Sarah Cockerton, Matawa First Nations Management Email: tmitchellATwlu.ca	https://gwf.usask.ca/science/projects/i2-mitchell.php
FIShNET (Fish & IndigenouS NorthErn health): Healthy Water, Healthy Fish, Healthy People	PI's: Brian Laird, University of Waterloo; Virginia Sutherland, Mushkegowuk Council Email: brian.lairdATuwaterloo.ca	https://gwf.usask.ca/science/projects/i3-laird.php
We Need More than Just Water: Assessing Sediment Limitation in a Large Freshwater Delta	PIs: Tim Jardine, University of Saskatchewan; Gary Carriere, Cumberland House Fishermen's Co-operative Email: tim.jardineATusask.ca	https://gwf.usask.ca/science/projects/i4-jardine.php
Ohneganos – Indigenous Ecological Knowledge, Training and Co-creation of Mixed Method Tools	PIs: Dawn Martin-Hill, McMaster University; Christine Wekerle, McMaster University; Beverly Jacobs, University of Windsor; Lori Davis Hill, Six Nations Health Services Email: dawnmATmcmaster.ca	https://gwf.usask.ca/science/projects/i5-martinHill.php
Water Knowledge Camps: Building Capacity for Cross Cultural Water Knowledge, Research, and Environmental Monitoring	PIs: Jennifer Baltzer, Wilfrid Laurier University; Leon Andrew, ʔehdzo Got'ı̨nę Gots'ę́ Nákedı -Sahtú Renewable Resources Board Email: jbaltzerATwlu.ca	https://gwf.usask.ca/science/projects/i6-Baltzer.php
GWF Core Initiatives		
Team Name	**Leads**	**Website**
Modelling Team	Martyn Clark, USask Lead	https://gwf.usask.ca/about/core-support-teams/forecasting-and-modelling-team.php
Knowledge Mobilization Team	Lawrence Martz, USask Lead Kevin Boehmer, UW Lead Kelly Munkittrick, WLU Lead Sean Carey, Mac Lead	https://gwf.usask.ca/outreach-km/km/about.php
Computer Science Team	Dr. Kevin Schneider, USask Lead Dr. Jimmy Lin, UW Lead	https://gwf.usask.ca/about/core-support-teams/computer-science-team.php#ComputerScienceStrategy
Data Management Team	John Pomeroy, USask Lead Jimmy Lin, UW Lead Michael Steelworthy, WLU Lead Mike Waddington, Mac Lead	https://gwf.usask.ca/about/core-support-teams/data-team.php
Smart Water Systems Laboratory	John Pomeroy, Faculty Lead	https://gwf.usask.ca/science/research-facilities/major-facilities.php#SmartWaterSystemsLaboratorySWSL

APPENDIX II:

Methods, Approaches, and Tools Developed by GWF Researchers

APPENDIX II: Methods, Approaches, and Tools Developed by GWF Researchers

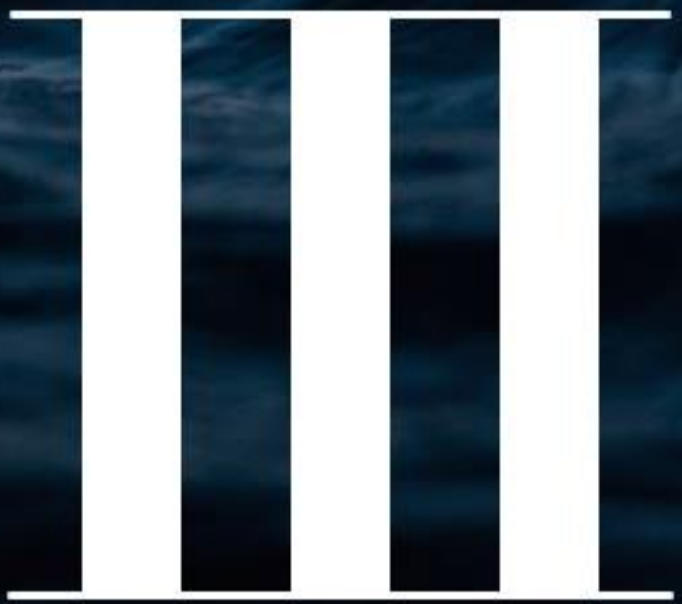
A key contribution to water research emerging from GWF projects is the addition of new and improved methods, approaches, and tools (Table AII.1). These contributions provide new opportunities to think differently about how we collect data and what data can be collected, supporting our advancement of knowledge. This is especially important for measuring elements that previously could not be measured and for expanding the data available in low resource settings.

Table AII.1: Methods, Approaches and Tools Developed by GWF Researchers

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). Colorimetric based water quality test kits (under development).	Crowdsourcing Water Science Global Water Citizenship 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 Acoustic snow water equivalent sensor Gas trap (lake surface and floor methane emission detectors) Non-contact stream sensor (river stage)	Sensors and Sensing Systems for Water Quality Monitoring GWF Core Initiative: Smart Water Systems Laboratory

APPENDIX III:

Models Used, Developed, and Modified by GWF Researchers



APPENDIX III: 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 AIII.1 lists all of the third party models utilized within GWF projects as well as links for additional information.

Table AIII.1: List of third-party models used by GWF researchers

Model	Description	Validation Basin(s)[1]	GWF Project Name
Weather Research and Forecasting (WRF)	Next-generation mesoscale numerical weather prediction system designed for atmospheric research and operational forecasting application https://www.mmm.ucar.edu/weather-research-and-forecasting-model	Pan-Canadian	GWF Core Initiative, Core Modelling Team
	WRF-HYDRO	St. Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
VIC	Large scale semi distributed hydrological model http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml	Mackenzie River Basin	Northern Water Futures
		St. Lawrence River - Great Lakes Basin, Saskatchewan River Basin	Integrated Modelling Program for Canada
		Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
		Saskatchewan River Basin	Hydrological Processes in Frozen Soils
Raven	Generic discretized surface water hydrological model http://raven.uwaterloo.ca/	Mackenzie River Basin	Northern Water Futures

[1] 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
HYPE	Hydrological Catchment Model that simulates water flow and substances through the watershed https://www.smhi.se/en/research/research-departments/hydrology/hype-1.7994	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 https://www.glerl.noaa.gov/res/Programs/pep/dlbrm/lbrm.html	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 https://www.aquanty.com/hydrogeosphere	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. http://www.usask.ca/geography/MAGS/Events/Workshops/Model/CLASS-V30-Background.pdf CLASS- STEM	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin Saskatchewan River Basin	Mountain Water Futures 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. http://hydrology.usu.edu/taudem/taudem5/index.html	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) https://www.mikepoweredbydhi.com/products/mike-hydro-river/hydrology FEFLOW is a groundwater model for flow and contaminant and heat transport https://www.mikepoweredbydhi.com/products/feflow	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin Saskatchewan River Basin	Integrated Modelling Program for Canada Subsurface Connectivity and Groundwater Protection

WATFLOOD	Flood forecasting and long-term hydrologic simulation http://www.civil.uwaterloo.ca/watflood/	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 https://oss.deltares.nl/web/delft3d	St Lawrence River - Great Lakes Basin	Integrated Modelling Program for Canada
PorousMediaLab	Toolkit for reactive transport modelling https://github.com/biogeochemistry/PorousMediaLab	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 https://www.hec.usace.army.mil/software/hec-ras/	St. Lawrence River - Great Lakes Basin Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Linking Stream Network Process Models to Robust Data Management Systems 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 https://www.epa.gov/ceam/environmental-fluid-dynamics-code-efdc	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 https://data.grandriver.ca/downloads/GRSM/GRSM_tech_guidance_V1.pdf	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 https://teamwork.niwa.co.nz/display/IFM/ELCOM-CAEDYM	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 https://www.ceh.ac.uk/services/windermere-humic-aqueous-model-wham	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 http://aed.see.uwa.edu.au/research/models/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 https://uwaterloo.ca/ecohydrology/software	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 https://www.usgs.gov/mission-areas/water-resources/science/sparrow-modeling-estimating-nutrient-sediment-and-dissolved?qt-science_center_objects=0#qt-science_center_objects	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, biological oxygen demand, sediment oxygen demand, algae, periphyton), organic chemicals, metals, mercury, pathogens, and temperature https://www.epa.gov/ceam/water-quality-analysis-simulation-program-wasp	Saskatchewan River Basin, Nelson-Churchill Basin Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin, Yukon River Basin	Integrated Modelling Program for Canada Transformative Sensor Technologies and Smart Watersheds
MyLake	Multi-year lake simulation model http://www.finessi.info/finessi/help.php?id=34&lang=en	Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin St. Lawrence River - Great Lakes Basin	Forecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes 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 http://aed.see.uwa.edu.au/research/models/GLM/	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 GEM-Hydro Runoff modelling platform	Saskatchewan River Basin, Columbia River Basin Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin Nelson-Churchill River Basin, Mackenzie River Basin, St. Lawrence River - Great Lakes Basin	Storms and Precipitation Across the Continental Divide Experiment Mountain Water Futures 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 https://www.fs.usda.gov/treesearch/pubs/26319	Mackenzie River Basin	Northern Water Futures
SUTRA-ice	Saturated and unsaturated freeze-thaw model https://www.usgs.gov/software/sutra-a-model-2d-or-3d-saturated-unsaturated-variable-density-ground-water-flow-solute-or	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin	Mountain Water Futures
Arctic Terrestrial Simulator	Permafrost degradation https://www.lanl.gov/orgs/adtsc/publications/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/ccsm4.0/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 http://giws.usask.ca/rivice/Manual/RIVICE_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/flac3d	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 https://swat.tamu.edu/	Saskatchewan River Basin, St. Lawrence River Basin, Atlantic Basin - Bay of Fundy (NS) St. Lawrence- Great Lakes River Basin	Agricultural Water Futures - Stressors and Solutions 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 https://dl.sciencesocieties.org/publications/vzj/abstracts/17/1/170176	Saskatchewan River Basin (North Saskatchewan River, Red Deer River), Mackenzie River Basin	Prairie Water
SV-FLUX	Groundwater seepage https://soilvision.com/products/svoffice-ge/svflux-ge	Mackenzie River Basin	Northern Water Futures
Wetland DEM Ponding Model (WPDM)	Models the distribution of runoff water on the Canadian Prairies https://www.usask.ca/hydrology/WDPM.php	Saskatchewan River Basin Saskatchewan River Basin Mackenzie River Basin	Agent Based Modelling as a Tool to Investigate Comprehensive Indigenous Health Impacts of Flooding Prairie Water Crowdsourcing Water Science
Peatlands Hydrological Impacts Model (PHI)	Effects of drainage, mining and timber harvesting on stream flow response https://iwaponline.com/hr/article/18/2/79/265/The-Peatland-Hydrologic-Impact-Model-Development	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 https://macaulay.webarchive.hutton.ac.uk/recover/magic.htm	St. Lawrence River - Great Lakes Basin	GWF Core Initiative: Modelling Team

Forest Fire (BurnP3, Canadian Forest Fire Weather Index System, Peatland Smouldering and Initiation Model)	Effects of ignition, fuel availability and moisture and wind on fire behavior and spread http://www.firegrowthmodel.ca/burnp3/overview_e.php; http://cwfis.cfs.nrcan.gc.ca/background/summary/fwi	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 https://www.oracle.com/applications/crystalball/	Mackenzie River Basin	Northern Water Futures
Water Evaluation and Planning Model (WEAP)	Integrated water resources planning assessment tool https://www.weap21.org/	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 https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Water-Resource-Integrated-Modeling-System	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 (https://www.anylogic.com/s/download-free-simulation-software-for-education/) Linked to SWAT Agent-based Agriculture Water Demand Model	Saskatchewan River Basin St. Lawrence River - Great Lakes Basin Saskatchewan River Basin	Agent Based Modeling as a Tool to Investigate Comprehensive Indigenous Health Impacts of Flooding Agricultural Water Futures - Stressors and Solutions 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.

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)[2]. 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 domain[3]. 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.

[2] 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.

[3] Marsh, C. B., Spiteri, R. J., Pomeroy, J. W., & Wheater, H. S. (2018). Multi-objective unstructured triangular mesh generation for use in hydrological and land surface models. *Computers & geosciences*, *119*, 49-67.

Table AIII.2: List of models developed or under development by GWF researchers

Model	Description	Validation Basin(s)[4]	GWF Project Name
Cold Regions Hydrological Model (CRHM)	Integrated physics-based hydrological model http://www.usask.ca/hydrology/CRHM.php	Mackenzie River Basin	Northern Water Futures
		Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River - Great Lakes Basin	Boreal Water Futures
		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

[4] 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 model http://www.usask.ca/ip3/models1/mesh.htm	Mackenzie River Basin	Northern Water Futures
		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 Saskatchewan River Basin	Northern Water Futures Mountain Water Futures Hydrological Processes in Frozen Soils
GEM-CHM	Snow forecasting (under development) http://www.snowcast.ca	Saskatchewan River Basin	GWF Core Initiative: Modelling Team
Variogram Analysis of Response Surfaces (VARS)	A sensitivity analysis toolbox with minimal computational cost https://vars-tool.com/	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 AIII.3).

Table AIII.3: List of models modified by GWF researchers

GWF-Modified Models	Additions	Validation Basins(s)[5]	GWF Project Name
HYPE (Hydrological Catchment Model) https://www.smhi.se/en/research/research-departments/hydrology/hype-1.7994	Reservoir Model (under development) ELEMeNT-HYPE (Exploration of Long Term Nutrient Trajectories; under development) Modifications to represent crop processes (under development) Frozen soils algorithm	St. Lawrence River - Great Lakes Basin Nelson-Churchill River Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds Integrated Modelling Program for Canada
PorousMediaLab	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) http://www.usask.ca/ip3/models1/mesh.htm	MESH-Glacier based on CRHM-Glacier module (under development) Isotope enabling (under development)	Saskatchewan River Basin, Mackenzie River Basin Nelson Churchill River Basin, Mackenzie River Basin	Integrated Modelling Program for Canada Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds

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

APPENDIX IV:

DATA COLLECTED WITHIN THE GWF NETWORK

IV

APPENDIX IV: 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. AIV.1).

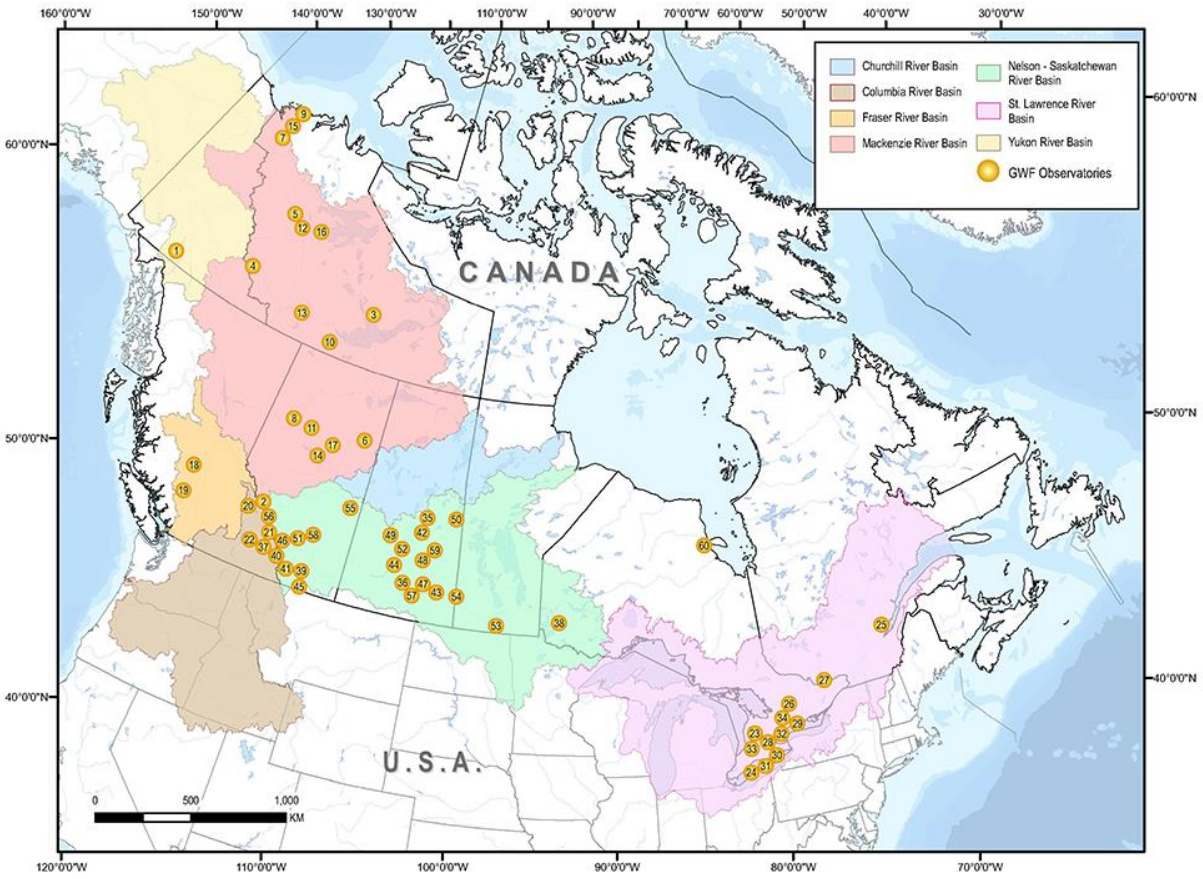


Figure AIV.1: Map of observation sites within the GWF network as of 2018.

The following table (Table AIV.1) provides a summary of the specific environmental, hydrological, and climatological data being collected across the various GWF projects.

Table AIV.1: Data collected by data type, region and GWF project

Data Type	Variables	Site Basins(s)[6]	GWF Project
Genomics	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) Mackenzie River Basin	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds 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

[6] data collected at single or multiple locations that may not cover entire basins

.

	Tree rings	St. Lawrence River Basin (Turkey Point Observatory) Saskatchewan River Basin, Churchill River Basin (Mistik Management Limited's Forest Management Area) Mackenzie River Basin	Southern Forests Water Futures Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime across the Southern Boreal Forest Northern Water Futures
	Physical and chemical soil analyses	Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River)	Boreal Water Futures Mountain Water Futures
	Sediment cores Lakes	St. Lawrence River Basin (Grand River) St. Lawrence River Basin, Great Lakes Mackenzie River Basin (Peace-Athabasca Delta)	Winter Soil Processes in Transition Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds 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	Unspecified	St. Lawrence River Basin, Great Lakes Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River) Mackenzie River Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds Mountain Water Futures 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 Frozen ground	Mackenzie River Basin Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS)	Northern Water Futures Agricultural Water - Stressors and Solutions
	Nitrogen uptake experiments	Saskatchewan River Basin (North Saskatchewan River, Red Deer River), Mackenzie River Basin	Prairie Water
Hydrology	Field based (unspecified)	St. Lawrence River Basin (Grand River) Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin Assiniboine River Basin (Qu'Appelle)	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds Boreal Water Futures 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 (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) Saskatchewan River Basin, Assiniboine River Basin, Red River Basin St. Lawrence River Basin (Grand River) Saskatchewan River Basin	Northern Water Futures Prairie Water Winter Soil Processes in Transition 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) Saskatchewan River Basin, Assiniboine River Basin, Red River Basin	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds Prairie Water
	Effluent quality	St. Lawrence River Basin (Grand River) St. Lawrence River Basin - Great Lakes	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds 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) St. Lawrence River Basin - Great Lakes	Agricultural Water - Stressors and Solutions Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
	Temperature	St. Lawrence River Basin - Great Lakes Saskatchewan River Basin (Buffalo Pound Lake, Experimental Lake Area), St. Lawrence River Basin (Grand River, Conestogo Lake)	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds 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 Saskatchewan River Basin (Qu'Appelle), St. Lawrence River Basin, Yukon River Basin	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds Sensors and Sensing Systems for Water quality Monitoring
	Major ions Na^{+}, $Ca^{2+,}$ Mg^{2+}	Saskatchewan River Basin Saskatchewan River Basin, Assiniboine River Basin	Subsurface Connectivity and Groundwater Protection Prairie Water
	Field-based isotopes (unspecified) ^{3}H, $\delta^{2}H$ and $\delta^{18}O$ Br, ^{14}C, ^{4}He, ^{81}Br,^{37}Cl $^{87}Sr/^{86}Sr$ and ^{129}I. ECCC stable water isotopes	St. Lawrence River Basin (Turkey Point Observatory) Saskatchewan River Basin, Assiniboine River Basin Saskatchewan River Basin Nelson Churchill River Basin, Mackenzie River Basin	Southern Forests Water Futures Prairie Water Subsurface Connectivity and Groundwater Protection 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	Meteorological data (unspecified)	Mackenzie River Basin Prairies Provinces	Northern Water Futures Climate-Related Precipitation Extremes
	Climate data (unspecified)	St. Lawrence River Basin - Great Lakes St. Lawrence River Basin (Grand River)	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds 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 Yukon River Basin, Mackenzie River Basin, Saskatchewan River Basin, St. Lawrence River Basin St. Lawrence River Basin - Great Lakes Pan Canadian	Storms and Precipitation Across the continental Divide Experiment Boreal Water Futures Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds 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) Yukon River Basin (Wolfe Creek), Mackenzie River Basin, Saskatchewan River Basin (Fortress Creek, Helen Creek, Marmot Creek, Elbow River, Bow River) Mackenzie River Basin	Southern Forests Water Futures Mountain Water Futures 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 Global	Climate Related Precipitation Extremes Short-Duration Extreme Precipitation in Future Climate
	GCM CORDEX	Pan Canadian	Short-Duration Extreme Precipitation in Future Climate
	CaPA (precipitation)	Pan Canadian Pan Canadian	Climate Related Precipitation Extremes 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	Economic, demographic, decision making	Saskatchewan River Basin Nelson-Churchill River Basin Saskatchewan River Basin (Clavet, Outlook, Keniston), St. Lawrence River Basin (Grand River), Atlantic Basin - Bay of Fundy (Central Nova and the Annapolis Valley NS) St. Lawrence – Great Lakes Basin Saskatchewan River Basin	Prairie Water Integrated Modelling Program for Canada Agriculture Water Futures – Stressors and Solutions Linking Water Governance in Canada to Global Economic, Social and Political Drivers 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) St. Lawrence – Great Lakes Basin (Six Nations of the Grand River) Saskatchewan River Basin	Is Our Water Good to Drink? Water-Related Practices, Perceptions, and TK Indicators for Human Health Co-Creation of Indigenous Water Quality Tools 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, Délı̨nę 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-SLSTR)	Land and sea temperature	St. Lawrence River Basin - Great Lakes	Lake Futures: Enhancing Adaptive 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, Conestogo Lake)	Mountain Water Futures Forecasting Tools and Mitigation Options for Diverse Bloom-Affected 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

APPENDIX V:

GLOBAL WATER FUTURES AND THE SDGS

APPENDIX V: Global Water Futures and the SDGs

While not an explicit objective of GWF, many projects have actual or potential application to improving our ability to achieve or measure progress towards SDG 6 and other water-related Targets (Table AV.1).

Table AV.1: GWF Research and tools that contribute to meeting identified gaps in meeting SDG 6

Water Goal:				
Goal. Target. Indicator	Topic	Identified Gap[7,8,9]	GWF Research/Tools/ Contributions	GWF Project
6	Water Goal	Data often not made available for reporting at any level. Policies for harmonization of data standards and open data access need to be put in place, to allow establishment of information systems and data sharing to enable intra-and intersectoral cooperation within and beyond national boundaries.	GWF is creating data repositories and data harmonization initiatives across the network.	GWF Core Initiative: Data Management Team
		NA	Integrating atmospheric, hydrological, and ecological processes in modelling to predict future hydrological regimes can improve our ability to assess, predict, and manage cumulative effects at the watershed scale. Understanding controls on alpine river discharge will be critical for ensuring	Mountain Water Futures

[7] Gaps were identified by reviewing the referenced documents that analyzed successes and challenges in meeting SDGs, particularly SDG 6

[8] United Nations. (2018). Sustainable Development Goal 6 Synthesis Report on Water and Sanitation. 195 pgs. Available from: https://www.unwater.org/publications/highlights- sdg-6-synthesis-report-2018-on-water-and-sanitation-2/

[9] UN Water. (2017). Integrated Monitoring Guide for Sustainable Development Goal 6 on Water and Sanitation Targets and global indicators. United Nations, pgs. 40. Available from: https://www.unwater.org/publications/sdg-6-targets-indicators/

			sustainable usage and reducing water scarcity, critical for ensuring safe drinking water for 40% of world's population. Developing culturally-appropriate methods and placed-based solutions for clean water for First Nations, including continuous environmental sensors to monitor source waters and investigating the cause of health issues related to contaminated water. Developing of Traditional Knowledge (TK) indicators of "good" and "bad" water in order for communities to be able to better understand and assess water-related health in Indigenous communities through a TK system and be able to share with government agencies currently responsible for water management, remediation, and quality monitoring	Co-creation of Indigenous Water Quality Tools Is our Water Good to Drink? Water-related practices, perceptions, and TK indicators for human health
6.3	Water quality and Wastewater	The extent of industrial pollution is not known. Few (domestic and industrial wastewater) data are available and aggregated for national and regional assessments.	Understanding wastewater contaminant (i.e. estrogens) interaction; developing of a model that predicts the release, transport and fate of substances from municipal wastewaters in aquatic environments. Identifying targeted best management practices (BMPs) to reduce nutrient exports, given agricultural legacies and a changing climate and development of integrated watershed-lake models for better prediction of Harmful Algal Blooms (HABs).	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds

			Characterizing legacy metal mining arsenic stores and understanding the mechanisms behind its release.	Sub-Arctic Metal Mobility Study
6.3.2	Bodies of water with good ambient water quality	Citizen science networks may provide a useful additional source of data for indicator 6.3.2. It is, however, recommended that training is provided to the citizen groups and that data collection and analysis is coordinated by a designated central organization.	While not developing organized citizen science networks, GWF projects are creating data collection tools (data hubs and smartphone applications), and building capacity within communities to collect data. Advancing eDNA methodology for characterizing water quality has potential to be included as part of a citizen science toolbelt; training with early adopters is underway with more systematic training a future opportunity. Developing the Nutrient Ap is enhancing the potential and accuracy of cheap instantaneous colorimetric based water quality test kits. Testing with community-based organizations is underway with resulting data validated and housed through GWF.	Global Water Citizenship Crowdsourcing Water Science Next Generation Solutions to Ensure Healthy Water Resources for Future Generations Promoting Beneficial Management Practices Acceptance through on-farm Instantaneous Community-Based Nutrient Sampling
		Most developing countries lack capacity to collect and analyze data required to report on the proportion of bodies of water with good ambient water quality.	GWF aims to provide water quality modelling and monitoring tools that, while built and validated in Canada, can be adopted, modified, or transferred to other cold regions around the world experiencing similar water quality issues.	Agricultural Water - Stressors and Solutions

		River basin and sub water body units needed to illustrate national and intra-basin spatial patterns of water quality.	GWF is undertaking large basin-scale modelling, including basic water quality parameters.	GWF Core Initiatives: Modelling Team Integrated Modelling Program for Canada
		Limited availability of data limits the possibility to determine time trends. Need well-established monitoring systems as examples of good practices for countries yet to develop adequate central national databases on ambient water quality; need to incorporate *Escherichia coli* monitoring.	While many GWF projects are time bound, they are often evolved from, and continue on well-established monitoring networks in Canada. They are creating valuable data streams that can be used to inform trends. They are also producing tools (i.e. sensors) that will make long-term, centralized water quality monitoring more assessible and cost effective for developing countries. Integrating water quantity and quality data in real-time; measuring coliform concentration and physical/chemical water parameters to inform Indigenous community holistic strategies for water monitoring as part of response long-term boil water advisories making it readily available to users wirelessly.	Transformative Sensor Technologies and Smart Watersheds Sensors and Sensing Systems for Water Quality Monitoring
		In situ measurements of water quality are also needed to validate water quality models.	Many GWF projects include in-situ water quality data collection across more than 60 observation sites in 7 major water basins of Canada.	See Appendix IV

		Level 2 monitoring can be advanced by measuring additional parameters such as those associated with specific pressures (e.g. arsenic, fluoride) or by using additional approaches to monitoring water quality such as biological or earth observation.	Advancing eDNA technology and methodology to aid bioassessments for water quality characterization. GWF is making cutting-edge Earth Observation technology and model development advancements that can be used to more easily monitor water-related conditions and changes.	Next Generation Solutions to Ensure Healthy Water Resources for Future Generations GWF Core Initiatives: Smart Water Systems Laboratory, Modelling Team and GWF networked projects (see Appendices II, III, IV)
		The use of Earth Observation (EO) data for water quality monitoring is currently advancing but limited to optically detectable water quality parameters like turbidity and chlorophyll, and only in relatively large bodies of water such as lakes and wide rivers.	GWF researchers are exploring several remote sensing techniques to monitor water quality parameters such as the presence of algae and chlorophyll-a. A proposed micro-satellite mission is under development in partnership with Honeywell Aerospace to support and advance water data and research. The current design includes a hyperspectral sensor, GNSS reflectometer, and a terrestrial sensor network.	Transformative Sensor Technologies and Smart Watersheds GWF Core Initiatives: Smart Water Systems Laboratory Transformative Sensor Technologies and Smart Watersheds
		A specific policy focus also needs to be put on groundwater monitoring (a neglected area).	GWF groundwater researchers are improving the understanding of the role of groundwater on watershed fluxes which will enhance spatial and temporal predictions of contaminant transport to surface water bodies. This will aid policy development through better prediction of, for example, the slow release of agricultural chemicals from groundwater to surface water systems.	Significance of Groundwater Dynamics within Hydrologic Models Prairie Water

6.4	Water-use efficiency and scarcity	Information is not sufficient to define detailed policies and to take specific operational decisions to improve the grass-roots efficiency of various water users. Additional indicators reflecting those uses would therefore be most helpful. Indicators that reflect improvements in water productivity and irrigation in agriculture, and reduced losses in municipal distribution networks, industrial and energy cooling processes, are among the main issues that such indicators should monitor.	GWF researchers are creating basin-specific customized management decision support modelling platforms that can aid in understanding cascading changes to water inputs and extractions throughout entire system. Examining how climate will affect water use and water use efficiency in various regional crop and livestock production systems to improve water productivity in Canada's agricultural sector.	GWF Core Initiatives: Modelling Team Integrated Modelling Program for Canada Agricultural Water Future-Stressors and Solutions
		Methods of computation of environmental flow requirements are extremely variable and range from global estimates to comprehensive assessments for river reaches. Need improved estimation of environmental flow requirements by country.	GWF researchers are advancing Environmental Flows science particularly for ecological flow needs for better environmental assessment review process and industrial operations (i.e. hydro generating stations).	Integrated Modelling Program for Canada
		NA	Integrating atmospheric, hydrological, and ecological processes in modelling to predict future hydrological regimes. Understanding controls on alpine river discharge will be critical for ensuring sustainable usage and reducing water scarcity.	Mountain Water Futures

6.5	Integrated Water Resources Management including through transboundary cooperation	NA	GWF researchers are contributing to better integrate water resource management through value added transdisciplinary inclusion, interdisciplinary knowledge, processes and implementation frameworks, including:	
			Engaging with the provisions of the Great Lakes Water Quality Agreement between Canada and the United States to encourage effective management of water resources in an integrated, collaborative and transboundary fashion; providing the management and policy tools needed for best practices in resource stewardship to enhance evidence-based decision making at the federal, provincial and local levels;	Linking Water Governance in Canada to Global, Economic, Social and Political Drivers
			Engaging with academics and public and private stakeholders in Canada and the US through knowledge sharing and active consultations to inform policy and decision making for better protection of our water resources; support the monitoring of physical and ecological systems; tackle transboundary water quantity and quality policy issues often concerned with much larger scales (e.g., political boundaries, or large watersheds and basins); to support integrated water resources management in multi-jurisdictional river basins across Canada; and assist scientists and policy makers in water management decision making;	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds

			Improving the understanding of ice-related biogeochemical processes during the winter and their impact on late-summer, harmful algal blooms by improving our ability to assess, predict and manage cumulative effects at the watershed scale. This may in turn be used to manage water resources, such as determining the relative importance of nutrients entering the lakes in winter versus in summer;	Evaluation of Ice Models in Large Lakes Using Three-Dimensional Coupled Hydrodynamic-Ice Models
			Linking atmospheric, hydrologic, water resources, ecologic, and socio-economic models for more holistic understanding of water resources and implications for management;	Integrated Modelling Program for Canada
			Predicting changes in hydrology and transboundary flows to Canada's north (Northwest Territories); improving the understanding of the long-term stability and resilience of ecosystems; developing tools for cumulative effect aquatic ecosystem monitoring; and assessing and predict food and drinking water safety; and,	Northern Water Futures
			Helping users to create adaptive and integrated water resource management solutions such as the management of dams and reservoirs, and hydroelectric generation for the electrical sector.	Integrated Modelling Program for Canada

6.6	Protecting and restoring water-related ecosystems	Current data-collection systems do not differentiate between natural and artificial water bodies. Reports suggest that the global data currently collected through the SDG process do not reflect the general state or trends known about freshwater ecosystems from other data sources. The global indicator is helpful but broad. Insufficient data are generated by countries to adequately measure progress. Further detailed data will be essential for accurate understanding of water-related ecosystems and the benefits they provide. Earth observations can complement local ground data and support the national burden of data acquisition and reporting.	GWF is contributing to the development of cutting-edge Earth Observation technology that can help refine data needed to assess reality, document trends, and identify priority areas for protection and restoration.	GWF Core Initiatives: Smart Water Systems Laboratory Transformative Sensor Technologies and Smart Watersheds
		Improve data availability and compilation.	The GWF program is building innovative platforms for compiling and sharing pan-Canadian water and climate data. Individual projects are improving data availability in regions and disciplines of need, specifically: Expanding capacity for research in the Canadian north and implementing base monitoring.	GWF Core Initiative: Data Management Team and Computer Science Team Northern Water Futures

			Increasing the knowledge on precipitation processes and how precipitation sustains local features such as glaciers and runoff generation in headwater river basins of the Canadian Rockies. Developing and validating transformative mass spectrometry and chemo-informatics techniques and tools for measurement of aquatic contaminants and investigating new paradigms for monitoring aquatic environments. Understanding unique hydrological processes across a range of altitudes, ecological settings, and latitudes which can further the knowledge of key components of alpine hydrological regimes needed to protect and restore. Designing and testing novel terrestrial sensors to measure various water quality and quantity parameters which will further the understanding of water ecosystems and the threatening effects of climate change to these environments.	SPADE: Storms and Precipitation Across the Continental Divide Experiment Developing 'Omic' an Chemical Fingerprinting Methodologies Mountain Water Futures Transformative Sensor Technologies and Smart Watersheds
		Need to understand the social and economic values of ecosystem services to society.	GWF projects are integrating social and economic data into modelling platforms, coupling hydrological models and economic models, and designing scenario-based decision experiments to better represent human-dominated water systems and the value sets that influence decision making.	Prairie Water Integrated Modelling Program for Canada

		N/A	Quantifying ecohydrological resilience to inform ecosystem vulnerability, adaptation, and restoration Best Management Practices.	Boreal Water Futures
			Exploring the water budget of South Eastern Canadian forests in order to protect freshwater resources.	Southern Forests Water Futures
			Deploying sensors in lakes downstream of mining operations to assess risk of metals on water and invertebrates; monitor contaminants and their variation over the short- and long- time scales.	Sensors and Sensing Systems for Water Quality Monitoring
			Using models to create robust data management systems to enable the protection and restoration of surface waters in urban environments including wetlands, rivers, and lakes.	Linking Stream Network Process
			Advancing and validating emerging eDNA technologies and tools in biology and environmental sciences to provide managers with rapid and reliable new approaches to monitor the changing aquatic communities to improve water quality, promote better management of our aquatic resources.	Next Generation Solutions to Ensure Healthy Water Resources for Future Generations
			Predicting exposure and effects of multiple stressors in watersheds to protect and restore water-related ecosystems.	Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds

			Developing a novel biomonitoring framework that links water quality to ecological impacts in the wetlands, rivers and lakes in the Great Lakes Watersheds which can be adopted for regulatory use. Examining how water quality in agricultural systems will be impacted by a changing climate and what this means for land management practices that can protect soil health and water quality in local and regional watersheds.	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds Agricultural Water - Stressors and Solutions
6.6.1	Water-related ecosystems	In addition to in-situ monitoring, discharge may also be modelled from one of the many available models to estimate both natural and present-day flows. It is recommended that modelled discharge data is complimented by measured in situ-data wherever possible to ensure accuracy.	GWF projects are assessing basin flows and discharge at more than 60 GWF observatories in 7 major Canadian basins that make up a pan-Canadian in-situ data monitoring network to refine hydrological models and to inform site-specific water management, including restoration decisions.	GWF Core Initiatives: Modelling Team, networked projects (see Appendices II, III, IV, and V) Integrated Modelling Program for Canada We Need More than Just Water: Assessing sediment limitation in a large freshwater delta
		For small rivers or for countries with low capacity to monitor discharge, citizen science approaches can be adopted to augment more traditional discharge monitoring data after quality control by national authorities.	GWF supported data hubs and smartphone applications for bringing together citizen and Indigenous science with academic science, and capacity building for citizen-led water monitoring approaches.	Global Water Citizenship Crowdsourcing Water Science Co-Creation of Indigenous Water Quality Tools

		Limited availability of nationally derived data to determine time trends. Improve global data on spatial extent of lakes, reservoirs and estuaries; improve global data on water quality (turbidity and chlorophyll-a); improve country reporting.	GWF is developing cutting-edge Earth Observation technology and using it to collection data that can assess extents and document trends. Once the program is complete, the GWF data legacy may represent one of the largest water and climate related data repositories in Canada. The accessible pan-Canadian data compilation can play a major role in undertaking future national water quantity and quality assessments.	GWF Core Initiatives: Data Management Team; Smart Water Sensors Lab Transformative Sensor Technologies and Smart Watersheds
		N/A	Improved groundwater research for measuring aquifer levels.	Old Meets New: Subsurface Hydrogeological Connectivity and Groundwater Protection
6.A	International cooperation and capacity-building	There is a need to better understand the extent and value of international cooperation, particularly support for capacity development, as this is currently not part of the indicator. Both the target and the indicator are strongly focused on external support and refer to the potential and need for stronger domestic engagement. Defining additional indicators or modifying indicators to take account of this should be considered.	GWF is building a collaborative research network that can contribute value added knowledge, processes, models and implementation frameworks that can be transferred to other cold regions of the world.	GWF Core Initiatives

6.B	Participation in water and sanitation management	More targets needed to recognize that participation cannot be measured by quantity alone. More/clear indicators needed that includes the quality of participation, such as nature, effectiveness and value.	The GWF program is developing and supporting best-practices for knowledge exchange between researchers and water practitioners, including diverse indicators of successful participation and engagement processes which may also be applicable to developing targets for water managers with water users.	GWF Core Initiatives: Knowledge Mobilization Team
		Data underpin the governance elements of accountability, transparency and participation. They enable progress to be monitored and service providers, governments and development partners to be held accountable.	GWF projects are developing the technologies and tools in tandem with participation processes that can generate the data needed for community-level decision makers that are reflective of community concerns, values, timing, sharing in appropriate platforms such as: Well water sampling at Six Nations community in Ontario that is integrating water quantity and quality data in real-time to measure coliform concentration and physical/chemical water parameters and making data readily available to community members wirelessly; Developing a flexible, scalable, and interactive tool that will allow non-scientifically trained users to see data for themselves and understand how local decisions can affect the physical and ecological integrity of surface water bodies;	 Sensors and Sensing Systems for Water Quality Monitoring Linking Stream Network Process Models to Robust Data Management Systems

			Engaging local communities and farmer perspectives on Best Management Practices that will lead to the development of a supported biomonitoring framework and decision-support tools;	Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds
			Examining risks of floods to primary and secondary water sources, cisterns, wastewater systems, traditional practices, and community wellbeing that will enhance Indigenous community planning and strengthen the participation of local communities in improving water and sanitation management;	Agent Based Modelling as a Tool to Investigate Indigenous Health Impacts of Flooding
			Building a community monitoring atlas that enables communities to share their own observations of water resources; developing tools for stakeholders to examine data quality; and facilitate researcher-to-community dissemination of cutting-edge water science from the GWF Program; and,	Global Water Citizenship
			Designing and facilitating data driven, scenario-based decision experiments that can inform and be used with and by water decision makers to invite participation by multi-stakeholder water users. These participation-based processes (i.e. Decision-Making Under Uncertainty) enable shared transparency in decision making and implementation.	Integrated Modelling Program for Canada Prairie Water

GWF projects are producing research that is related to achieving targets in other Goals that are either explicitly related to water or link to water more broadly.

Table AV.2: GWF Research and tools that contribute to meeting the other water related SDGs

Explicitly Water-Related Goals:			
Goal.Target	Theme	Contribution	Project
3.9	Good Health and Well-Being: substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	Characterizing the deposition range, area, and pollution levels from the discharge of 20,000 tons of arsenic (known carcinogen) into the atmosphere and understanding the mechanisms behind its release are crucial for protecting clean water downstream of mining activities on Yellowknife Bay.	Sub-Arctic Metal Mobility Study
11.5	Sustainable Cities and Communities: decreasing impacts of natural disasters	Improving wildfire danger prediction. Developing advanced modelling and decision-making tools to represent interactions across natural and human systems to improve prediction of floods, and droughts. Designing protective actions, tools, and new policy that are informed by Traditional and Western knowledge to reduce the number of deaths and illnesses from water pollution and contamination from flood events in Indigenous communities.	Boreal Water Futures Integrated Modelling Program for Canada Agent Based Modelling as a Tool to Investigate Indigenous Health Impacts of Flooding
15.1	Life on Land: ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services	Quantifying ecohydrological resilience to inform ecosystem vulnerability, adaptation and restoration Best Management Practices for Canada's boreal forest.	Boreal Water Futures:

Other Water-Related Goals:			
Goal.Target	Theme	Contribution	Project
2	No hunger	Improving local food security by understanding the sustainability of northern fisheries; assessing and predicting food and drinking water safety; and enhancing harvester safety	Northern Water Futures
9	Industry, Innovation, and Infrastructures	Improving regional mapping of thermokarst hot spots across the Northwest Territories to improve security of hydrologically sensitive infrastructure in northern communities.	Northern Water Futures
10.3	Reduced Inequalities: Ensure equal opportunity and reduce inequalities	Reducing inequalities in accessing advanced scientific tools for supporting community-level preparations and adaptation to changing water futures for Indigenous communities.	Agent Based Modelling as a Tool to Investigate Indigenous Health Impacts of Flooding
11.6	Sustainable Cities and Communities: reduce the adverse per capita environmental impact of cities	Advancing technologies such as environmental DNA (eDNA) and next generation sequencing (NGS) to monitor current status and predict future trends of structures and functions of environments exposed to stressors.	Next Generation Solutions to Ensure Healthy Water Resources for Future Generations
12.2	Responsible Consumption and Production: achieve the sustainable management and efficient use of natural resources	Improving Best Management Practices for post-mining wetland and forest reclamation.	Boreal Water Futures
12.B	Consumption and Production: Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products	Utilizing emerging transformative technologies and tools in biology and environmental sciences to provide managers with rapid and reliable new approaches to monitor changing aquatic communities, such as those that may support commercial fisheries, recreation or cultural water uses.	Next Generation Solutions to Ensure Healthy Water Resources for Future Generations

13.1	Climate Action: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	Collecting continuous measurements to monitor and report the impacts of climate change on South Eastern Canadian forests and make recommendations for mitigation. Developing ecohydrologically-based fuel treatment Best Management Practices to reduce wildfire disaster severity. Building tools for community monitoring of environmental change that directly engages people in understanding and developing adaptations to climate change impacts. Developing advanced modelling and decision-making tools to represent interactions across natural and human systems to improve prediction of floods, and droughts under climate change.	Southern Forests Water Futures Boreal Water Futures Global Water Citizenship Integrated Modelling Program for Canada
13.2	Climate Action: Integrate climate change measures into national policies, strategies and planning	Integrating water management modelling and decision-making tools support the exploration of future challenges such as climate and land-use change to inform policy and planning, and contributing inputs that consider the emerging risks and impacts of climate change in adaptation planning and the implementation of actions to mitigate risks (e.g. 2020/2021 Canada's next Climate Adaptation assessment and national climate change and health vulnerability assessment).	Integrated Modelling Program for Canada

		Helping insurers to accurately assess risks associated with changing extreme precipitation events; the design of climate resilient infrastructure (buildings, transportation, electrical, health, hydrological and other infrastructure) by collaborating with Environment and Climate Change Canada to develop guidance for the civil engineering community.	Climate Related Precipitation Extremes Project
13.3	Climate Action: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	Working with stakeholders and end users to understand how agricultural systems and practices will be impacted by climate change in order to help them make decisions on what can be done to adapt to changes, reduce impact and minimize risk. Strengthening the capacity of Indigenous communities for early warning, risk reduction and management of health risks related to flooding. Bringing together stakeholders and researchers to build human and institutional capacity to consider climate mitigation and adaptations strategies for water resources.	Agricultural Water - Stressors and Solutions Agent Based Modelling as a Tool to Investigate Indigenous Health Impacts of Flooding Integrated Modelling Program for Canada
15.5	Life on Land: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	Exploring how the water and carbon budgets of southeastern Canadian forests will respond to future climate change, extreme weather events and management/disturbance activities; evaluating carbon uptake potential of different-age conifer plantations and a mature deciduous forest to offset greenhouse gas emissions; improving ecosystem models used in Canadian regional and global climate models.	Southern Forests Water Futures

17.16	Partnerships for the Goal: Enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources	Overall, the GWF program strives to embody many principles that resonate with the 2030 Agenda, including cross-sectoral engagement, emphasis on vulnerable populations, and gender equity, inclusion, and diversity. Co-created research strengthens trans-sectoral and multi-disciplinary collaborations, more effectively mobilizing research tools and knowledge, collaboration processes, and expertise between sectors, stakeholders, and societies. In addition to engagement in multiple international programs, GWF models and approaches are being transferred to other cold regions of the world.	GWF Program Researchers, Partners, Communities, and Institutions