
# Realising Global Water Futures: a Summary of Progress in Delivering Solutions to Water Threats in an Era of Global Change

May 2024

Photo: Aeria view observatory site in  Wolf Creek Research Basin, Yukon. Photo by Mark Ferguson

# Message from the Director

*Realising Global Water Futures: a Summary of Progress in Delivering Solutions to Water Threats in an Era of Global Change*

In 2016, with initial funding through the Canada First Research Excellence Fund, the Global Water Futures team set out to produce actionable scientific knowledge on how we can best forecast, prepare for and manage water futures in the face of dramatically increasing risks. The aims of the programme were set to place Canada as a global leader in water science for cold regions and to address the strategic needs of the Canadian economy in adapting to change and managing the risk of uncertain water futures and extreme events. Knowledge users told us that adaptation to change and mitigation of water threats would require new science, new predictive modelling tools, new monitoring systems, and more effective mechanisms to translate new scientific knowledge into societal action. We designed a three-part mission to improve disaster warning, predict water futures, and inform adaptation to change and risk management. This began with an extensive discussion with hundreds of user groups across the country that informed specific research priorities to diagnose and predict change in cold regions, develop big data and decision-support systems, and design user solutions.

Central to the programme's planning was the principle of research co-production: potential users of any research carried out would be engaged in setting priorities for investigation, reviewing progress, and, as much as possible, in working together with researchers throughout the research process to co-create knowledge. Global Water Futures research was designed to be of the highest scientific quality and publicly accessible, relevant, and a source of solutions for addressing risk management solutions in a time of increasing resource use and climate change challenges. Since 2016, 65 GWF projects and core teams have emerged with plans to be transformative through excellent science and real innovation, transdisciplinary by involving stakeholders, rightsholders, and knowledge users in the definition and delivery of research, relevant to the overall GWF objectives and deliverables, and pan-Canadian in ambition, by addressing local and regional issues whilst aspiring to national and international impact. Now in 2024, the knowledge mobilized through Global Water Futures' science advances is beginning to change policy priorities, laws and management practice across Canada. But these are turbulent times for scientific advice. While it has never been so important to make decisions informed by the best available knowledge, the ready access to a wide range of opinions and competition for attention made possible by ever-faster information systems are challenging scientists to translate their findings and recommendations in ways that are accessible and useful to the needs of all stakeholders.

In 2023, The Canadian Foundation for Innovation recognised the value of the network of instrumented sites and laboratories developed, maintained, and used by the Global Water Futures Program by contributing to support for these observatories to 2029. This investment enabled Global Water Futures Observatories (GWFO), through a partnership of nine universities, to provide open access water observation data to inform development and testing of water prediction models, monitor changes in water sources, underpin the diagnosis of risks to water security, and help design solutions to ensure the long-term sustainability of Canadian water resources. This requires continual updates on changing user needs and methods to best deliver research results in actionable forms to knowledge users. The GWFO User Advisory Panel guides this by providing insights into users' science and decision-support needs, offering recommendations and avenues for translating GWF's research results into real-world impacts, supporting scientific exchange with private and public sectors and Indigenous organisations and communities, and providing strategic advice.

Over the eight years of its research, GWF has amassed a large amount of knowledge through its research and is working with more than 500 partners and collaborators, including across knowledge systems with Indigenous communities. GWF has become the most productive freshwater research group in the world as measured through scientific publications. Beyond publications, we have developed the first continental-scale water prediction models for Canada and GWF water models are forecasting the impacts of climate change on water supply and quality, providing decision-support for improved water management. Our sophisticated predictive modelling platforms support strong collaboration with provincial and territorial flood-forecasting agencies and Environment and Climate Change Canada. We are applying these modelling and prediction systems in other parts of the world in partnership with UNESCO and the World Meteorological Organisation (WMO). GWF's water forecasting and hydrological modelling capacity is now engaged with the NOAA Cooperative Institute for Research to Operations in Hydrology (CIROH) to apply our modelling tools in development of the US National Water Model as well as projects in the European Union.

GWF has also achieved policy and management influence in Canada, working closely with federal and provincial and territorial partners, directly engaging parliamentarians, and informing policy through the translation of GWF science outcomes. We have, in partnership with the Forum for Leadership on Water, proposed a revitalized water strategy for Canada, and through our efforts under the Water Security for Canadians: Solutions for Canada's Emerging Water Crisis initiative, the federal government has initiated the Canada Water Agency.

Internationally, GWF has worked with local scientists, knowledge holders, and decision makers to build capacity, raise awareness and exchange new information on water futures on all inhabited continents and has worked with UNESCO, WMO, Future Earth, the Water and Climate Coalition and various other organisations and countries to help gain support for a resolution at COP27 for enhanced climate monitoring and early warning systems, especially in cold regions, and in the United Nations General Assembly for a resolution declaring 2025 as the International Year of Glaciers' Preservation and March 21st as the World Day for Glaciers.

The content of this briefing book documents this work through descriptions of the project-level activities that are the foundation for these achievements. We continue to synthesise our research findings through workshops, sectoral meetings, model applications, and publications. We carry out these synthesis activities in collaboration with our research partners whilst continuing our communication and outreach through regional and sectoral science discussions and custom knowledge translation applications. In 2024, we are assembling a broad synthesis of all GWF program findings that will pull together the most relevant new knowledge produced from the program with completion of the synthesis in 2025 as GWF draws to completion.

We cannot sufficiently express our appreciation of the work that students, staff, researchers, faculty, and partners have undertaken over the last six years. This document is dedicated to you and your efforts in ensuring a sustainable water future for Canada. I also want to thank Dr. Corinne Schuster-Wallace for her substantial contributions as Associate Director of GWF and wish her well in applying her capabilities as the Executive Director of the Global Institute for Water Security at USask.

We are open to comments and suggestions that will help our Knowledge Mobilization Team and User Advisory Panel in both facilitating productive knowledge exchange among our scientists and potential users, and further sharing Global Water Futures research findings.

Yours truly

Professor John Pomeroy, PhD, AGU Fellow, FRGS, FRSC
Canada Research Chair in Water Resources and Climate Change
UNESCO Chair in Mountain Water Sustainability
Distinguished Professor, Dept. of Geography & Planning
Director:
CFREF Global Water Futures Programme
CFI Global Water Futures Observatories Project
USask Centre for Hydrology
USask Coldwater Laboratory, Canmore Alberta

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# How to Use this Briefing Book

Over the past six years the Global Water Futures program has produced a wide range of scientific findings and engagements with multiple types of potential users of the research. This briefing book provides a snapshot of some of the science advancements and user engagement that have taken place to date. Annual reports to the funding agency are the most up to date source of information: this compilation has been created from reports submitted by projects in 2023, representing both completed and current project work. The briefing book aims to provide quick access to information about GWF projects in a single place for GWF's User Advisory Panel: we hope that knowing more about the research being produced will spark conversations about how to make the best use of the new knowledge in both policy and practice. Names of partners, collaborators, and knowledge users are in bold blue text throughout the briefing book to highlight engagement of GWF researchers beyond the academy.

A Partner refers to the involvement of an institution or organization, rather than an individual. Partners are government, *industry*, associations, non-profit organizations, indigenous organizations or government bodies, or other institutions that have contributed or committed in-kind or cash contributions to support the CFREF initiative. A partner has a defined and very concrete role to play in the implementation of the CFREF initiative.

A Collaborator refers to the involvement of an individual (from academia or from other sectors) who plays an active role in the research and research-related activities of the CFREF initiative, but is not a CFREF investigator.

A Knowledge user is a receptor (an individual or organization including stakeholders or rights holders) of the CFREF's outputs and findings who does not have an active role in the CFREF research activities.

Please contact the Knowledge Mobilization team leads with questions or suggestions as to how to improve this resource:

Monica Morrison: monica.morrison@usask.ca; 306-491-8875

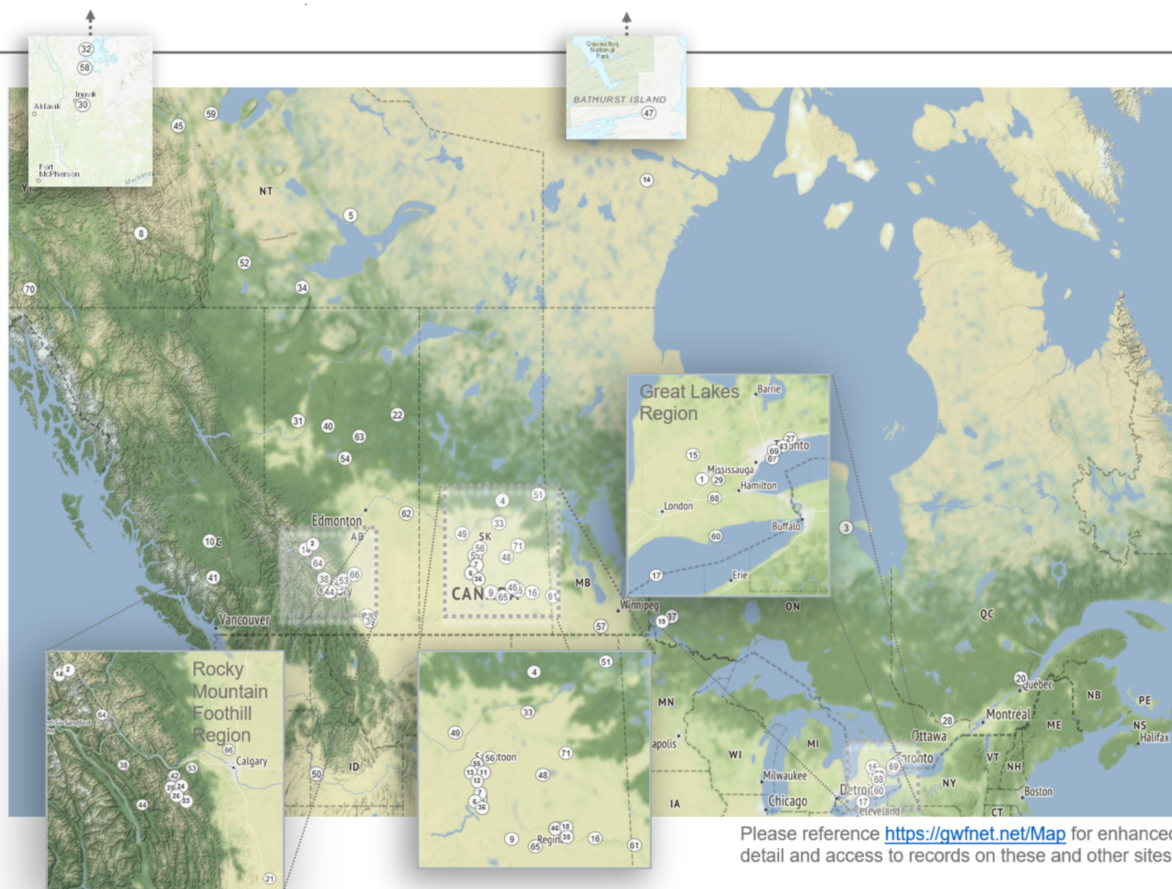
Nancy Goucher nancy.goucher@uwaterloo.ca

Christina Tjandra ctjandra@wlu.ca or Lisa Atkinson latkinson@wlu.ca;  519-885-3333

# Global Water Futures Research Sites

## GWF Research Sites

1 Alder Creek
2 Athabasca Glacier
3 Attawapiskat
4 BERMS
5 Baker Creek
6 Brightwater Sec13
7 Brightwater Sec30
8 Brintnell-Bologna Icefield
9 Buffalo Pound Lake
10 Cariboo Alpine Mesonet
11 Clavet Crop (Barley)
12 Clavet Forage (New)
13 Clavet Forage (Old)s
14 Columbia Icefield
15 Conestogo Lake
16 Crooked Lake
17 Eastern Lake Erie
18 Echo Lake
19 Experimental Lakes Area
20 Foret Montmorency
21 Fort Macleod
22 Fort McMurray
23 Fortress Junction Service
24 Fortress LiDAR
25 Fortress Mountain
26 Fortress Powerline
27 Ganetsekaigon Creek
28 Gatineau River and Saint-Maurice River Watersheds
29 Grand River Watershed
30 Havikpak Creek
31 Helen Lake
32 Inuvik to Tuktoyaktuk Highway
33 James Smith Cree Nation
34 Kakisa and Tathlina Lakes
35 Katepwa Lake




36 Kenaston/Brightwater Creek Mesonet Site
37 Lake 227
38 Lake O'Hara
39 Lethbridge Irrigation Demonstration Farm
40 Lubicon Lake Cree Nation
41 Marian Lake Watershed
42 Marmot Creek
43 Morningside Creek
44 Nipika Mountain Resort
45 Norman Wells/Tulita Area
46 Pasqua Lake
47 Polar Bear Pass
48 Quill Lakes, Saskatchewan
49 Redberry Lake Biosphere Reserve
50 Reynolds Creek
51 Saskatchewan River Delta
52 Scotty Creek
53 Sibbald Wetlands
54 Slave Lake
55 Slough Evaporation
56 St. Denis National Wildlife Area
57 Tobacco Creek
58 Trail Valley Creek
59 Tsa Tue Biosphere Reserve
60 Turkey Point
61 Upper Qu'Appelle
62 Vermilion Basin
63 Wabasca
64 Wapta Icefield/Peyto Glacier
65 Wascana and Upper Qu'Appelle
66 West Nose Creek
67 Western Basin Lake Ontario
68 Whitemans Creek
69 Wilket Creek
70 Wolf Creek
71 Yellow Quill First Nation

Please reference https://gwfnet.net/Map for enhanced detail and access to records on these and other sites.

# Issues Important to Knowledge Users

As a Canada First Excellence Fund (CFREF) program, Global Water Futures is by mandate expected to address the strategic needs of the Canadian economy, addressing issues of importance to diverse potential knowledge users. The following table summarizes these issues that were identified at the beginning of GWF's work, and links to the regions and projects described in the briefing book.

| Issues | User Communities | Region | Projects |
| --- | --- | --- | --- |
| Forecasting and predictive modelling | Agriculture<br>Electric Utilities<br>Emergency Response Organisations<br>Federal Government<br>Provincial Governments<br>Research NGOs<br>Water Utilities | Mountain West<br>Prairies<br>Northern<br>Great Lakes<br>Atlantic | Agricultural Water Futures<br><br>Managing Urban Eutrophication Risks under Climate Change<br><br>Winter Soil Processes in Transition<br><br>Saint John River Experiment on Cold Season Storms (SaJESS)<br><br>Storms and Precipitation across the Continental Divide Experiment (SPADE)<br><br>Short-Duration Extreme Precipitation in Future Climate<br><br>Paradigm Shift in Downscaling Climate Model Projections<br><br>Integrated Modelling Program for Canada<br><br>GWF Core Modelling Team<br><br>Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds<br><br>Lake Futures<br><br>Evaluation of Ice Models in Large Lakes: Using Three-Dimensional Coupled Hydrodynamic-Ice Models<br><br>Planetary Water Prediction Initiative (PWPI)<br><br>Collaborative Modelling Framework for Water Futures and Holistic Human Health Effects<br><br>Improved Estimates of Wetland Evaporation<br><br>Mountain Water Futures<br><br>Significance of Groundwater Dynamics Within Hydrologic Models |

| Issues | User Communities | Region | Projects |
|---|---|---|---|
| | | | Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision Support |
| Climate change, impacts and risk identification | Agriculture<br>Electric Utilities<br>Federal Government<br>Forestry<br>Mining<br>Municipal<br>Provincial Governments<br>Water Utilities | Mountain West<br>Prairies<br>Northern<br>Great Lakes<br>Atlantic | What is Water Worth? Valuing Canada's Water Resources and Aquatic Ecosystem Services<br><br>Paradigm Shift in Downscaling Climate Model Projections<br><br>Climate-Related Precipitation Extremes<br><br>Short-Duration Extreme Precipitation in Future Climate<br><br>Lake Futures<br><br>Southern Forests Water Futures<br><br>Prairie Water<br><br>Mountain Water Futures<br><br>Northern Water Futures<br><br>Boreal Water Futures<br><br>Geogenic Contamination of Groundwater Resources in Subarctic Regions<br><br>Core Modelling Team<br><br>Planetary Water Prediction Initiative (PWPI)<br><br>Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds<br><br>Groundwater, Climate Change and Water Security in the Canadian Prairies<br><br>Crowdsourcing Water Science: Distributed Water Science Application<br><br>Prairie Drainage Governance: Diagnosing Policy and Governance Effectiveness for Agricultural Water Management during Times of Change<br><br>Agricultural Water Futures |
| Best Management Practices (BMPs) | Agriculture<br>Civil Society Organisations<br>Extractive Industry<br>Federal Government<br>Municipal | Mountain West<br>Prairies<br>Northern<br>Great Lakes<br>Atlantic | Lake Futures<br><br>Agricultural Water Futures<br><br>Boreal Water Futures |

| Issues | User Communities | Region | Projects |
|---|---|---|---|
| | Research NGOs<br>Water Utilities | | Managing Urban Eutrophication Risks under Climate Change: An Integrated Modelling and Decision-Support Framework<br><br>Towards Saskatchewan Well Water Security: Knowledge and Tools for People and Livestock Health<br><br>Prairie Drainage Governance: Diagnosing Policy and Governance Effectiveness for Agricultural Water Management during Times of Change |
| Adaptations | Agriculture<br>Municipal<br>Indigenous<br>Federal Government<br>Provincial Governments | Mountain West<br>Prairies<br>Great Lakes<br>Northern<br>Atlantic | Linking Water Governance in Canada to Global Economic, Social and Political Drivers<br><br>Prairie Water<br><br>Agricultural Water Futures<br><br>Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime Across the Southern Boreal Forest<br><br>Crowdsourcing Water Science: Distributed Water Science Application<br><br>Lake Futures |
| Past/Future Scenarios | Agriculture<br>Electric Utilities<br>Extractive Industry<br>Fisheries<br>Forestry<br>Insurance/Engineering<br>Municipal<br>Provincial Governments<br>Water Utilities | Mountain West<br>Atlantic<br>Great Lakes | Core Modelling Team<br><br>Short-Duration Extreme Precipitation in Future Climate<br><br>Linking Water Governance in Canada to Global Economic, Social and Political Drivers<br><br>Planetary Water Prediction Initiative (PWPI)<br><br>Agricultural Water Futures<br><br>Global Water Citizenship: Integrating Networked Citizens, Scientists and Local Decision Makers<br><br>What is Water Worth?<br><br>Lake Futures |
| Land/Water Interactions | Agriculture<br>Federal Government<br>Forestry | Prairies<br>Great Lakes<br>Atlantic | Prairie Water<br><br>Agricultural Water Futures |

| Issues | User Communities | Region | Projects |
|---|---|---|---|
| | Water Utilities | | Lake Futures<br><br>FORecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes (FORMBLOOM)<br><br>Significance of Groundwater Dynamics Within Hydrologic Models<br><br>Winter Soil Processes in Transition<br><br>Hydrological Processes in Frozen Soils<br><br>Evaluation of Ice Models in Large Lakes: Using Three-Dimensional Coupled Hydrodynamic-Ice Models<br><br>Southern Forests Water Futures<br><br>Geogenic Contamination of Groundwater Resources in Subarctic Regions<br><br>Hydrology-Ecology Feedbacks in the Arctic: Narrowing the Gap between Theory and Models<br><br>Sub-Arctic Metal Mobility Study (SAMMS)<br><br>Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime Across the Southern Boreal Forest<br><br>Improved Estimates of Wetland Evaporation<br><br>Mountain Water Futures<br><br>Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision Support |
| Surface/Groundwater Interactions | Municipal | Mountain West<br>Prairies<br>Atlantic | Winter Soil Processes in Transition<br><br>Hydrology-Ecology Feedbacks in the Arctic: Narrowing the Gap between Theory and Models<br><br>Sub-Arctic Metal Mobility Study (SAMMS)<br><br>New Tools for Northern Groundwater Vulnerability Assessment |

| Issues | User Communities | Region | Projects |
|---|---|---|---|
| | | | Groundwater, Climate Change and Water Security in the Canadian Prairies<br><br>Old Meets New: Subsurface Connectivity and Groundwater Protection<br><br>Significance of Groundwater Dynamics Within Hydrologic Models |
| Human Health | Civil Society Organizations<br>Indigenous<br>Federal Government | Prairies<br>Northern<br>Great Lakes | Artificial Intelligence Applications for Rapid and Reliable Detection of Cryptosporidium oocysts and Giardia cysts<br><br>Sensors and Sensing Systems for Water Quality Monitoring<br><br>Developing 'Omic' and Chemical Fingerprinting Methodologies Using Ultrahigh-Resolution Mass Spectrometry for Geochemistry and Healthy Waters<br><br>Ohneganos Co-Creation of Indigenous Water Quality Tools<br><br>Is our Water Good to Drink? Water-Related Practices, Perceptions and Traditional Knowledge Indicators for Human Health<br><br>FIShNET (Fish & Indigenous Northern Health) Healthy Water, Healthy Fish, Healthy People<br><br>Towards Saskatchewan Well Water Security: Knowledge and Tools for People and Livestock Health<br><br>Collaborative Modelling Framework for Water Futures and Holistic Human Health Effects<br><br>Crowdsourcing Water Science: Distributed Water Science Application |
| Decision Support Tools (often with reference to multi-stakeholder needs) | Agriculture<br>Federal Government<br>Forestry<br>Water Utilities | Prairies<br>Great Lakes<br>Atlantic | Data Management Team<br><br>Core Computer Science Team<br><br>Integrated Modelling Program for Canada<br><br>Managing Urban Eutrophication Risks under Climate Change: An Integrated Modelling and Decision-Support Framework |

| Issues | User Communities | Region | Projects |
|---|---|---|---|
| | | | Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision-Support<br><br>Global Water Citizenship: Integrating Networked Citizens, Scientists and Local Decision Makers<br><br>Crowdsourcing Water Science: Distributed Water Science Application<br><br>Agricultural Water Futures<br><br>Lake Futures<br><br>Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision Support |
| Indigenous knowledge | Federal Government<br>Indigenous | Northern<br>Great Lakes | Ohneganos Co-Creation of Indigenous Water Quality Tools<br><br>Is our Water Good to Drink? Water-Related Practices, Perceptions and Traditional Knowledge Indicators for Human Health<br><br>Matawa Water Futures: Developing an Indigenous-Informed Framework for Watershed Monitoring and Stewardship<br><br>FIShNET (Fish & Indigenous Northern Health) Healthy Water, Healthy Fish, Healthy People<br><br>Water Knowledge Camps: Building Capacity for Cross-Cultural Water Knowledge, Research, and Environmental Monitoring<br><br>We Need More than Just Water<br><br>Water Knowledge Camps<br>Prairie Water<br><br>Northern Water Futures |
| Sensors | Electric Utilities<br>Federal Government<br>Industry<br>Provincial Governments | Mountain West<br>Prairies<br>Great Lakes | Transformative Sensor Technologies and Smart Watersheds for Canadian Water Futures (TTSW)<br><br>Sensors and Sensing Systems for Water Quality Monitoring<br><br>Developing ‘Omic’ and Chemical Fingerprinting Methodologies Using Ultrahigh-Resolution Mass |

| Issues | User Communities | Region | Projects |
|---|---|---|---|
| | | | Spectrometry for Geochemistry and Healthy Waters<br><br>Remotely Sensed Monitoring of Northern Lake Ice Using RADARSAT Constellation Mission and Cloud Computing Processing<br><br>Linking Stream Network Processes |

# Projects by Region

Many Global Water Futures projects cross geographic boundaries with their results applicable at regional, national, and global levels. Regional groupings here often reflect a concentration of field studies that support more general research and modelling. If you are interested in a specific research topic or place, please check the index at the back of the briefing book.

Participants at the Indigenous Water Gathering, Mistawasis, April 2023. Photo by Mark Ferguson

# Canada Wide


Photo: GWF at World Water Day Panel, Ottawa, 2022.Photo by Mark Ferguson

# What is Water Worth? Valuing Canada's Water Resources and Aquatic Ecosystem Services

Web Link: Home | Valuing Canada's Water Resources and Aquatic Ecosystem Services | University of Waterloo (uwaterloo.ca)

Region: Canada

Total GWF funding support: $300,000

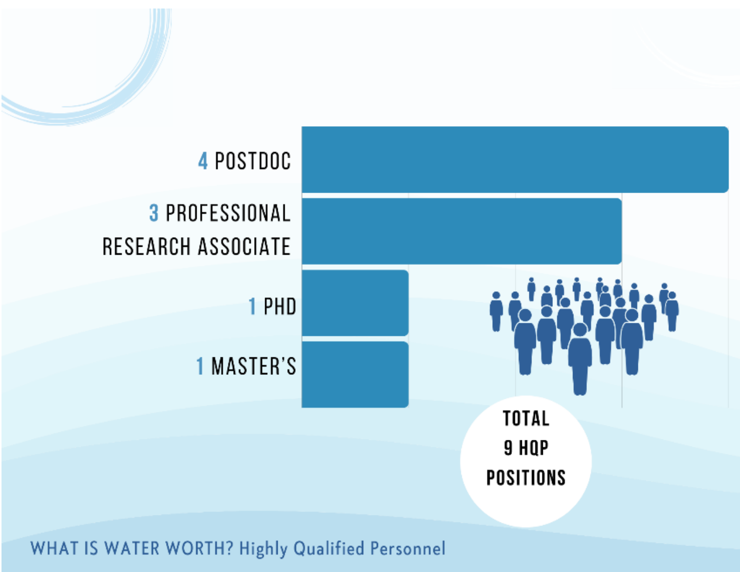
Project dates: August 2020-July 2023

## Investigators

Roy Brouwer, University of Waterloo Contact: rbrouwer@uwaterloo.ca
Patrick Lloyd-Smith, University of Saskatchewan
Vic Adamowicz, University of Alberta
Diane Dupont, Brock University
Helen Jarvie, University of Waterloo

## Partners, Collaborators and Users

Alberta Environment and Parks -- Jessica Lai
Clark University – Robert Johnston
Environment and Climate Change Canada – Ann Cavlovic
Land, Environment, Economics and Policy Institute (LEEP) -- Ian Bateman




Highly Qualified Personnel: **Professional training and research positions funded by What is Water Worth?**

# Science Advances

Water is abundant in Canada, but there is increasing pressure on its availability and quality due to a mix of factors, including climate change and its impact on water availability and water population because of population and economic growth, urbanization etc. To protect water resources, it is important to understand its value. The project aims to make the value of water more visible using economic valuation methods. Reviews were conducted of existing water valuation approaches in Canada, in which the valuation methods and approaches and the values themselves were synthesized. This provides an important benchmark for the development of new valuation approaches to capture the value of water in Canada. This includes the development of alternative water quality valuation ladders, moving away from the traditional 'use based' ladders such the famous Resources for the Future's water quality ladder reflecting boatable, fishable, swimmable and drinkable water quality. Economic valuation of changes in the water system in the future will be crucial to be able to assess the economic efficiency of these water changes. That is important in understanding the extent to which they are beneficial for Canadian society as a whole. This refers to 'exogenous' changes related, for example,to the impacts of climate change, and 'endogenous' changes related, for example, to water quality improvement policies. Economic valuation hence informs what benefits (or costs) water futures bring.

## Link to Publications List

## Knowledge Mobilization (KM)

The project launched a webinar series, “The Value of Water in Canada,” to highlight state-of-the-art water valuation practices in Canada. Since it began in 2022 the project hosted close to 40 sessions that have attracted between 20 and 100 viewers to the live sessions. Each webinar was recorded and uploaded to YouTube, where it can be accessed on demand. The number of views on each video tends to be between 50 and 200. Participants in the webinar series vary from academia to non-government agencies ~~and~~ to practitioners who are interested in better understanding the value of water in Canada from a broad social science perspective. The presentations cover a broad range of topics from valuation methodology development to policymaker demand for different types of water values to inform decision-making processes. Water issues furthermore range from water recreation to urban flood risks, water quality in the Great Lakes, and water use and values in Canadian mining industry.

The webinar series continues through the first part of 2024. View the schedule: https://uwaterloo.ca/water-institute/events/webinar-series-value-water-canada . Recordings of past webinars can be found here: https://uwaterloo.ca/valuing-canadas-water-resources-and-aquatic-ecosystem-services/presentations.

Project members have been meeting with Alberta Environment and Parks to discuss recreation and water quality research and to discuss how the project can contribute to ongoing modelling initiatives and future work.

# Paradigm Shift in Downscaling Climate Model Projections

Web Link: Paradigm Shift in Downscaling Climate Model Projections: Building Models and Tools to Advance Climate Change Research in Cold Regions - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Canada

Total GWF funding support: $170,000

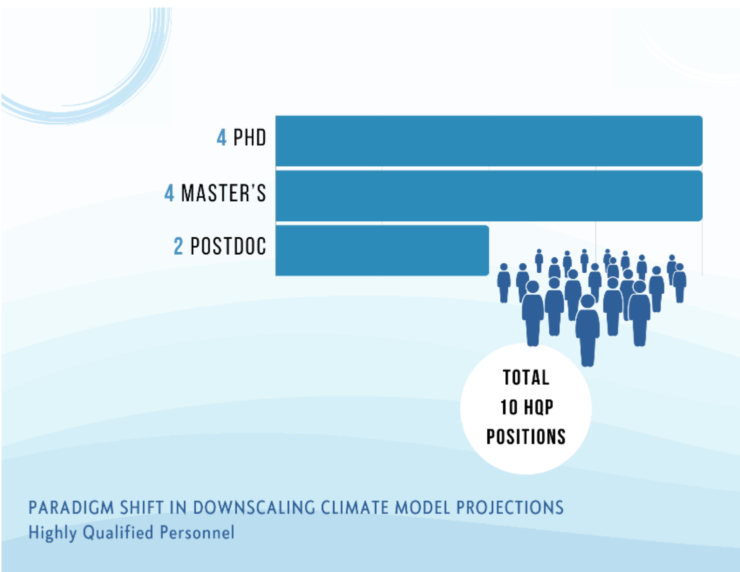
Project dates: August 2020-July 2023 COMPLETED

## Investigators

Simon-Michael Papalexiou, University of Calgary
Global Institute for Water Security / University of Saskatchewan Contact: sm.papalexiou@usask.ca

## Partners, Collaborators and Users

Concordia University -- Ali Nazemi
Environment and Climate Change Canada -- Alex Cannon
National Research Council Canada -- Abhishek Gaur
Newcastle University -- Francesco Serinaldi
University of California Irvine --Efi Foufoula-Georgiou and Amir Aghakouchak




**Highly Qualified Personnel: Professional training and research positions funded by Paradigm Shift in Downscaling Climate Model Projections**

## Science Advances

Climate models aim to predict hydroclimatic changes and help assess their impacts. To reliably describe regional climates, model projections must be adjusted (bias correction) and downscaled—their spatial and temporal resolution is too coarse (~100 km$^2$, 1 day) for real-world applications and finer resolutions are typically needed (e.g., ~4 km$^2$, 1 hour). There is a pressing need for fine-resolution climate projections for Canada to meet more local forecasting needs. This project has evaluated the CMIP6 simulations for Canadian regions, bias corrects, and downscaled them using a transformative approach. The outcome is supports GWF researchers and core teams to progress in their research agenda by providing reliable and easy-to-use bias corrected and downscaled CMIP6 projections.

Project researchers used computer models to predict Canadian weather from 2015 to 2100 through bias corrected and downscaled CMIP6 projections for the country. Accuracy was improved through bias correction of temperature and precipitation CMIP6 simulations using a Semi-Parametric Quantile Mapping (SPQM) method for the period. The EMDNA dataset (0.1°×0.1°) was used as the basis for bias correction. The original CMIP6 simulations were regridded using a bilinear interpolation method to match the spatial resolution of EMDNA. The bias correction was performed on a daily scale. A total of 759 simulations for precipitation and 652 simulations for maximum and minimum temperature covering four Shared Socio-economic Pathways (SSP 1-2.6, SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5) were considered. All bias corrected and downscaled simulations are available and stored in the Narval supercomputer.

Link to Publications List

## Professional Development and Technology Transfer

Software development: Leader of the open-source CoSMoS R-package (Complete Stochastic Modelling Solution). CoSMoS is a scientific software that enables easy and precise time series and random fields generation of hydroclimatic processes such as precipitation, streamflow, and, temperature. Since its release in April 2019, CoSMoS has more than 18,000 official downloads from CRAN and thousands of users.

# Artificial Intelligence Applications for Rapid and Reliable Detection of Cryptosporidium oocysts and Giardia cysts

Web Link: [Artificial Intelligence Applications for Rapid and Reliable Detection of Cryptosporidium oocysts and Giardia cysts - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Canada

Total GWF funding support: $150,000

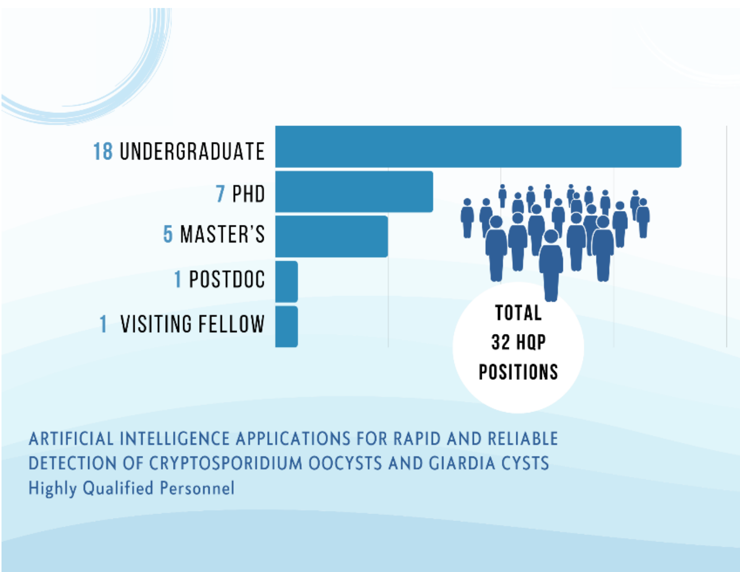
Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators

Younggy Kim, McMaster University Contact: younggy@mcmaster.ca
Qiyin Fang, McMaster University
Herb Schellhorn, McMaster University
Chang-qing Xu, McMaster University
Radhey S Gupta, McMaster University

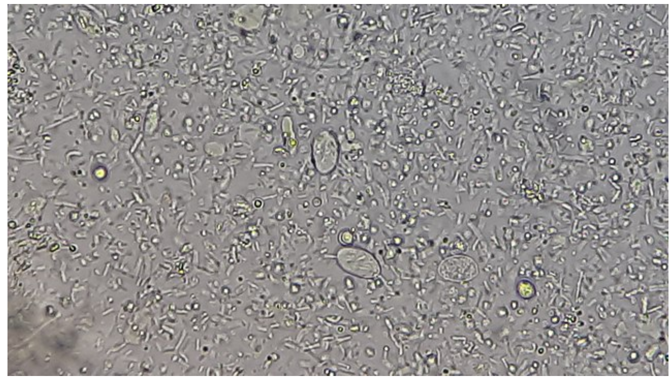
## Partners, Collaborators and Users

Forsee Instruments Ltd. -- Tianyi Guo
SUEZ Water Technologies & Solutions -- Sylvain Donnaz




Highly Qualified Personnel: **Professional training and research positions funded by Artificial Intelligence Applications for Rapid and Reliable Detection of Cryptosporidium Oocysts and Giardia cysts**

## Science Advances



Cysts of Giardia lamblia in saline wet mount of feces microscopy at 1600X magnification

Protozoan cysts (Cryptosporidium oocysts and Giardia cysts) cause serious human health risks in both urbanized areas and in cold and remote regions. Infection causes diarrhea, weight loss, dehydration, stomach cramps or pain, and nausea, and chronic infection can cause long-term health problems. Since they are hardly inactivated in conventional drinking water treatment, reliable and rapid detection of these pathogenic cysts is urgently demanded, especially for communities without access to advanced disinfection processes, such as ozonation. This project aims to develop a novel sensor system where water samples are examined under optical/fluorescent microscopes and the pathogenic cysts on the microscopic images are detected by artificial intelligence (AI). Analysis of genome sequences from Cryptosporidium species to identify highly specific molecular markers is underway and shouldprove useful in the rapid and reliable identification of these parasites in water resources.

Analysis of genome sequences from Cryptosporidium species to identify highly specific molecular markers that should prove useful in the rapid and reliable identification of these parasites in water resources continues.

[Link to Publications List]

# Climate-Related Precipitation Extremes

Web Link: Climate-Related Precipitation Extremes - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Canada

Total GWF funding support: $1,100,000; $500,000

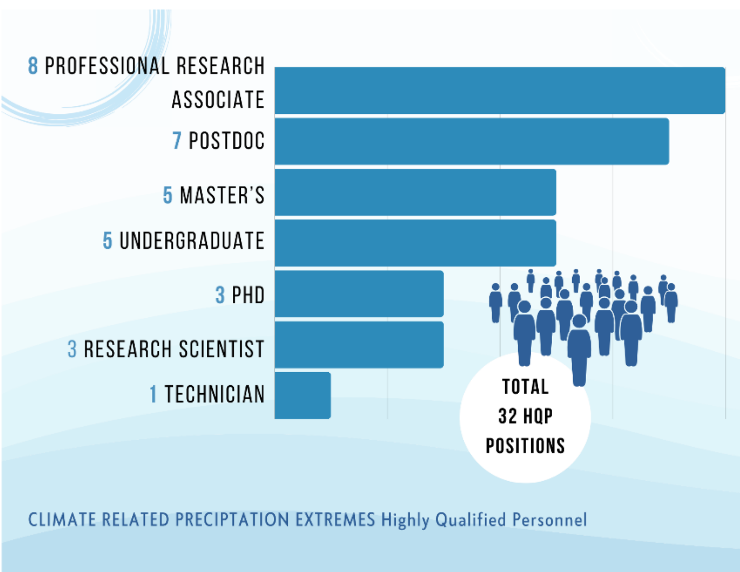
Project dates: June 2017-August 2023 EXTENDED to August 2024

## Investigators

Ronald Stewart, University of Manitoba Contact: ronald.stewart@umanitoba.ca
Francis Zwiers, Pacific Climate Impacts Consortium, University of Victoria (PCIC/UVIC)
John Hanesiak, University of Manitoba
Mary Kelly, Wilfrid Laurier University
Julie Thériault, Université du Québec à Montréal
Yanping Li, University of Saskatchewan

## Partners, Collaborators and Users

Agriculture and Agri-Food Canada (AAFC) -- Budong Qian
British Columbia Ministry of Transportation and Infrastructure (BC MOTI) -- Ian Pilkington
CatIQ -- Laura Twidle
Environment and Climate Change Canada (ECCC) -- Barrie Bonsal, Bob Kochtubajda, Julian Brimelow, Lawrence Mudryk, Xuebin Zhang
Institute for Catastrophic Loss Reduction (ICLR) -- Dan Sandink
Manitoba Hydro -- Kristina Koenig
NB Power -- Jim Samms
Pacific Climate Impacts Consortium (PCIC) -- Francis Zwiers
Université du Québec à Montréal -- Julie Thériault
University of Manitoba -- John Hanesiak
University of Manitoba -- Ronald Stewart
University of Saskatchewan -- Yanping Li
University of Victoria -- Francis Zwiers
Wilfrid Laurier University -- Mary Kelly




Highly Qualified Personnel: Professional training and research positions funded by Climate Related Precipitation Extremes

## Science Advances

Climate extremes have many effects, across Canada, on agriculture, electrical utilities, infrastructure engineering, health, and insurance. This project has provided new insights into the future occurrence of precipitation-related extremes including drought, intense precipitation events, and hazardous winter precipitation.

## Progress related to the electrical utility sector

The project team focused initially on the impact of hazardous accreting precipitation on electrical transmission lines operated by Manitoba Hydro and New Brunswick Power (NB Power), although the project has extended its view country-wide.

Analyses made with Manitoba Hydro have been accomplished through three studies. Findings of the first were that many accreting storms are associated with synoptic systems passing south and/or east of the province but the spatial distribution of accreting precipitation was significantly affected by local, but less than 400 m high, topography. Second, a study of a snowstorm over southern Manitoba in October 2019 that led to unprecedented damage to Manitoba Hydro infrastructure from accretion found a suite of factors ranging from an unusual storm track to lake effect precipitation led to the hazardous conditions within this storm. Third was extension of the October 2019 Manitoba storm study to examine the same hazardous conditions of adhering snow across Manitoba and Saskatchewan in the current and future climate using CONUS I information. Findings were that, between CTRL and PGW, the spatial distribution of this precipitation, including its relation to topographic features, did not change dramatically, and associated winds continued to be from the north or northeast. East-west aligned transmission lines continue to be especially vulnerable to adhering snow.

NB Power analyses have been accomplished through two recently completed studies , with another underway. First, a study of the January Ice Storm of 2017 in the Maritime Provinces was carried out; this storm caused long-duration and widespread power outages. Highest amounts of freezing rain were associated with 2-m temperatures slightly below 0°C. The release of latent heat from freezing of supercooled drops at the surface during freezing rain contributed to these temperatures and, over some areas of the province, this heating was opposed by cold air advection. Second, seven freezing rain events were studied over New Brunswick. These illustrated the impact of cold air damming on the province's east coast due to local topography. The pattern within these events was different from that occurring during the 2017 ice storm; that storm propagated more slowly and no cold air damming was diagnosed. Third, a study is currently underway analyzing snowfall events that caused major power outages recorded by NB Power, comparing their features with other significant snowfall events that caused little impact.

Since precipitation near 0°C is often related to major impacts on infrastructure anywhere, the team also examined how such temperatures and their associated precipitation vary across southern Canada within the CONUS I domain in the current and PGW future climate. Findings were that occurrences of near-0°C conditions, and their associated precipitation, only increase slightly from CTRL to PGW (about 5%) and the general spatial patterns are largely maintained. The research also pointed out that near-0°C occurrences can represent a peak (either primary or secondary) in the temperature distribution at locations across southern Canada. Overall, 95.7% of southern Canada is covered by such a near-0°C peak in either or both CTRL and PGW. Collectively, increasing temperatures do not necessarily lead to major changes in near 0°C occurrences, including the preference of these to represent peaks in temperature distribution. Impacts from freeze-thaw cycling and associated precipitation are therefore expected to continue over many areas of the country. As one specific follow-up, the evolution of air temperature with and without precipitation is being investigated over Quebec to better understand the patterns identified.

## Progress related to engineering design

While engineering design has not been a primary focus of the project, much work has been done that is motivated by engineering design questions or is informed by work on precipitation extremes performed within the project. A continuing concern for engineering design, particularly as Canadian engineering practice moves towards a 'uniform risk' engineering approach, is whether very long period (e.g., 1000-year) return levels can be reliability estimated with existing extreme value analysis methods. These methods typically assume conditions that allow the adoption of extreme value models that exhibit 'max-stability' as a key property (this means that the maximum of a collection of maxima has a distribution with the same shape parameter as that from which the maxima are drawn). It is this key assumption that allows the extrapolation of extreme value distributions to return periods that are much longer than the period of record for which there are observations. Researchers have attempted to develop an alternative approach for extrapolating observations of extreme precipitation to very long return periods, and have tested the approach using observed time series of precipitation extremes from long station records at representative locations across Canada. The empirical approach developed also requires strong assumptions because it relies on behaviour seen in climate models, but it has the advantage that this assumed behaviour can be evaluated, and improved upon, as climate models continue to improve. The team is carrying out further theoretical development.

In parallel, there has been a thorough evaluation of the ability of the statistical downscaling method that is used extensively at the Pacific Climate Impacts Consortium (PCIC) to reliably downscale projected changes in extreme precipitation. This has direct implications for engineering applications, as PCIC is now frequently being asked to aid engineers in developing design values for future extreme precipitation amounts. For example, PCIC was asked to provide projections of changes in extreme precipitation that might be expected in the Cariboo Highway (BC Highway 97) corridor between Williams Lake and Quesnel. Statistical downscaling at PCIC proceeds by calibrating a climate simulation of the present climate with a gridded daily observational dataset, and then applying that calibration, which performs bias correction in spatial scales that is required, to a climate simulation with the same model performed under future conditions. Thus a strong assumption is that the transfer function that results from the calibration exercise is not affected by climate change. The study uses the CONUS I control simulation for the recent climate to develop a dataset of pseudo-observations that is used to calibrate simulations from the CanRCM4 regional climate model. Future simulations with the same model are then downscaled with the calibrated downscaling scheme, and these are evaluated against the CONUS I PGW simulation. The evaluation is challenging for several reasons but suggests that, in the case of extreme precipitation, there should be concern about the stability of the transfer function that is deduced from the relationship between climate model simulated variability and observed variability over the historical period when observations are available.

The 2021 flooding event in British Columbia severely impacted roads in the southwest of the province, including the main surface transportation corridor between Vancouver and Kamloops in the interior, which connects the port of Vancouver to the rest of Canada. Project team members had an opportunity to participate in a rapid attribution study of that event, which assessed the role of human-induced climate change on the atmospheric river that delivered moisture to the region, the extreme precipitation that ensued, and the extreme discharge result in the Cold Water and Coquihalla Rivers, amongst others. While basin precondition played a clear role (antecedent conditions where wet, and snowmelt from the previously established snowpack contributed importantly to discharge) it was clear that anthropogenic climate change contributed substantially to increasing the likelihood and magnitude of all three aspects studied (atmospheric river-induced moisture transport into the region, the ensuing precipitation, and the resulting discharge). Zwiers has had a number of opportunities to present results from this work and was invited to testify to the Canadian Senate Standing Committee on Agriculture and Forestry, which recently investigated the event and its implications.

Finally, PCIC has released the operational version of its Design Value Explorer in both official languages (https://www.pacificclimate.org/analysis-tools/design-value-explorer), which provides estimates Canada-wide of the climatic design values that are used in the National Building Code of Canada, and how these may change in a warming climate. These include several precipitation-related design values. While there is not a direct GWF contribution to this work, research on extreme precipitation supported by the GWF helped to inform development of the tool.

### Progress related to the insurance sector

The project has been analysing the future occurrences of severe hail events, which are among the most serious weather events for the insurance industry.

High-resolution output (4 km) from the HAILCAST algorithm driven with CONUS I control and PGW simulations has been analyzed for future changes in the occurrence and severity of hail over the Canadian Prairies and United States Northern Plains. Future changes in hail occurrence (especially severe hail) are statistically significant in some parts of Alberta and southeastern Saskatchewan and southern Manitoba, with increasing occurrences in Alberta and decreasing in the eastern Prairies. However, when hail does occur in the eastern Prairies, it will likely be larger and more severe. The project has also identified why these changes are expected. For Alberta, convective available potential energy (CAPE) is expected to increase due to increased low level moisture, with very small changes in convective inhibition (CIN), overall leading to greater occurrence of hail, including severe hail. For the eastern Prairies, CAPE is also expected to increase due to increased low level moisture. However, CIN is also expected to be larger, thus reducing the occurrence of hail but increasing hail size. The larger CIN in the eastern Prairies is primarily due to increased dew point spreads during the daytime period in a warming climate.

The team has also identified the large-scale (synoptic) patterns associated with hail in Alberta and the eastern Prairies. Notable results suggest that, for Alberta, an upper trough over B.C. produces a southwest flow perpendicular to the Rocky Mountains and places central Alberta within the left exit west of a jet streak (known for producing synoptic-scale lift) that can enhance thunderstorms. In addition, the low-level flow direction produces upslope flow into the foothills that can feed moisture into thunderstorms and promote their initiation and intensity. For the eastern Prairies, the upper flow is more zonal but also demonstrates a left-exit jet streak enhancement of lift that can promote stronger storms. A distinct low level jet (LLJ) runs from the Gulf of Mexico to the eastern Prairies that promotes strong moisture advection, but also promotes strong lift since the nose of the LLJ is positioned in North Dakota. The research continues to analyse composite vertical thermodynamic and kinematic profiles to assess these critical features so better understand their controls on hail occurrence and severity in Alberta and the eastern Prairies.

The project's recent findings were presented at the 2022 CMOS congress as well as the 2022 AMS Severe Local Storms (SLS) Conference. The team will continue to work with CatIQ to provide updated results so this work can be used by the insurance sector.

Progress related to WRF model simulation

The Li et al. research group has contributed to the CONUS II simulation project, which includes historical and future climate simulations at both 4-km and 12-km resolutions covering the period from 1995 to 2015. The 12-km future climate simulation has been completed, and the 4-km future climate simulation was anticipated to be finished in 2023.

The team has been working on the analysis of the CONUS I and western Canada 4-km Weather Research and Forecasting (WRF) data, focusing on evaluating simulated changes in warm season extreme rainfall events. Changes of extreme precipitation events in different geographic regions and seasons have been investigated.

Additionally, high-resolution WRF simulation output to quantify future changes in agriculturally relevant compound drought and heatwave events in Western Canada cropping regions under the RCP8.5 scenario are being used.

Project researchers have applied Time Domain (MODE-TD) as a tool to identify mesoscale convective systems (MCSs) in the western Canada 4-KM WRF simulations. This involved evaluating the properties of WRF-simulated flood-producing rainstorms, including their tracks, size, and lifespan in western Canada and how these properties are expected to change under future climate conditions. Additionally, characteristics of daytime and nighttime MCSs over the Canadian Prairies using an ERA5-forced convection-permitting climate model have been analysed.

Interaction with other GWF projects

Several significant interactions are taking place with other Global Water Futures projects.

A linkage with the GWF Mountain Water Futures (MWF) project is mountain precipitation, especially occurring near 0°C. The techniques developed to examine winter storms over New Brunswick and Manitoba are being used to address related issues in the western Cordillera. For example, detailed analyses are underway to characterize precipitation and surface temperature features at Terrace, British Columbia and surrounding areas.This region is prone to surface temperatures lasting for long periods near 0°C (one out of every 5 hours!) and accompanied by precipitation that includes snow, freezing rain, and freezing drizzle.

Team members also have interactions with the Saint John River Experiment on Cold Season Storms (SaJESS) project, which focuses on the phase of precipitation over the Upper Saint John River Basin during spring storms. The conditions near 0°C and the phase of precipitation affect the snowmelt season, flooding, and ice jam conditions. The data collected and the research outcomes can be placed into perspective with the wet, adhering snow, freezing rain, and near-0°C analysis found in the Extremes project.

## Link to Publications List

# Knowledge Mobilization (KM)

The project team has continued efforts to strengthen relationships with users. The project's research findings have been disseminated through presentations at conferences and workshops to maximize research impact. A few examples of interactions with the user community follow.

Manitoba Hydro is continually informed of the project's progress. Insights about the evolution of historical accretion events, including the role played by local topography, has helped the utility better understand the factors responsible for variations in transmission line impacts across the province. Project interactions in the analysis of the Manitoba October 2019 snowstorm have been even stronger, working together to address the many critical scientific and impact-related aspects of this event. Manitoba Hydro has provided considerable information to the study. The team shared all of its information with them, carrying out sub-projects based on their requests, and shared project insights with them, including through an invited special presentation on project progress. The importance of adhering snow to Manitoba Hydro infrastructure spurred the researchers to specifically examine this type of precipitation across Manitoba and Saskatchewan. As a result, Manitoba Hydro has recently approached the project about potential future interactions regarding improved codes and standards for its infrastructure.

The project team also had strong interactions with NB Power to identify its needs in terms of extreme precipitation events. NB Power provided lists of events damaging to its operations. The project team used these to investigate features of and changes to freezing rain over the Province of New Brunswick. A particular focus was placing the extreme freezing rain storm in January 2017 into perspective with the other identified storms. Findings were shared with NB Power to support improved decision making during extreme events and better adaptation to the warming climate. The project's contact person at NB Power has now retired but has encouraged the team to continue collaborating with the new responsible person.

The project's ongoing research on the occurrence of near 0°C temperature and associated precipitation conditions will further contribute to Manitoba Hydro's and NB Power's plans for more resilient electrical transmission systems. Because this research has spanned the country, insights from the work may also contribute to such plans for other electrical utilities.

There have also been opportunities to educate some key utility industry groups about climate change (including extreme precipitation) and how projected changes may translate into risk for utility infrastructure. This included delivery of the opening keynote address at the November 2022 CEATI Transmission Conference held in Atlanta, Georgia, a briefing and extended discussion with the CEATI Leadership Council, which includes representatives from a broad spectrum of utilities across North America, at the same meeting, and a briefing to the FortisBC climate change adaptation team in December of 2022. In addition, Zwiers serves on a CSA task group that is tasked with considering the Canadian Electrical Code Part III, which concerns electrical distribution and transmission systems, from a climate change perspective.

The project team has maintained communication with CatIQ about project results. However, due to the extremely slow progress in the past year (mainly due to statistical significance tests and data formats), there has not been any formal presentation to this group in the past year. Results, were expected to be presented to this organization and their partners some time in 2023.

Project collaboration with ECCC and AAFC scientists has been instrumental, as they serve as both knowledge users and partners who can benefit from the research. The outcomes of this study may offer valuable insights for future climate adaptation strategies.

# Public Outreach

## Julie Thériault

• L'imprévisible pluie verglaçante (Rediffusion et mise-à-jour), Émission Découverte, Radio-Canada, 29 janvier 2023: https://ici.radio-canada.ca/tele/decouverte/site/segments/reportage/430712/pluie-verglas-gresil-precipitations

• L'imprévisible pluie verglaçante, Émission Découverte, Radio-Canada, 10 avril 2022 : https://ici.radio-canada.ca/tele/decouverte/site/segments/reportage/397553/lac-champlain-neige-gresil-phenomene-atmospherique

• Presenter, Soapbox Ottawa, Downtown Ottawa, September 2022: https://soapboxscienceotta.wixsite.com/website

• Presenter, Raconte-moi l'hiver, Soirée Sciences et contes, Coeur des sciences, UQAM, Dec. 2022: https://coeurdessciences.uqam.ca/component/eventlist/details/1079-raconte-moi-hiver.html

## Yanping Li

• The thesis work on dryline of a former PhD student of Yanping Li was featured at the Research Highlight section at Nature Climate Change (https://rdcu.be/ctsEt). Drylines most often occur in the Plains east of the Rockies and can trigger thunderstorms that produce tornadoes.

SEVERE WEATHER

## Stronger and more drylines

*Clim. Dynam.* https://doi.org/gj8f2q (2021).

Drylines are atmospheric boundaries where moist and dry air masses meet. An example is in the USA, where dry air from the west flows over the Rocky Mountains and encounters warm, moist air from the Gulf of Mexico. These air masses have different densities, influenced by moisture and temperature, and their interaction can create unstable conditions and severe weather. However, identifying drylines is still subjective and varies regionally, and high-resolution simulations are needed to capture them.

Lucia Scaff at the University of Saskatchewan, Canada, and co-authors adapt an algorithm to identify drylines and apply it to high-resolution simulations of present-day and future North American weather. Most occur in spring and summer, and climate change is expected to increase their frequency and intensity. In the northern US and Canada, drylines will occur later in the year, suggesting an extended dryline season into the autumn. Further south, morning drylines will grow as strong as afternoon drylines, possibly extending the diurnal window of convective activity. These findings give insight into how severe weather environments will change with climate warming. *BL*

https://doi.org/10.1038/s41558-021-01116-4

Published summary of thesis work about drylines

# Next Generation Solutions to Ensure Healthy Water Resources for Future Generations

Web Link: EDNA - eDNA - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Canada (Saskatchewan, Manitoba and Ontario Provinces, North Saskatchewan River and Great River, and irrigation district watersheds in Alberta Province)

Total GWF funding support: $1,391,228; $785,486

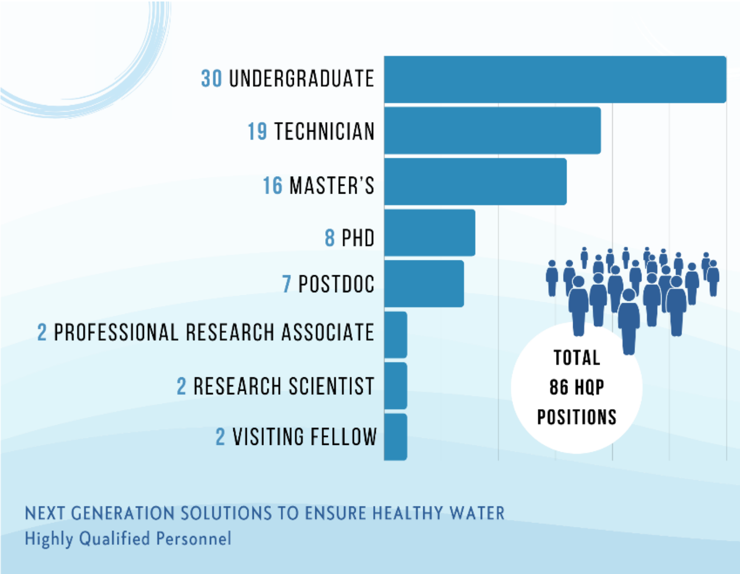
Project dates: June 2017-August 2023 EXTENDED to August 2024

## Investigators

John J. Giesy, Department of Veterinary Biomedical Science and Toxicology Centre, University of Saskatchewan Contact: jgiesy@aol.com
Mark R. Servos, Department of Biology, University of Waterloo
Paul Jones, School of Environment and Sustainability and Toxicology Centre, University of Saskatchewan
Markus Hecker, School of Environment and Sustainability and Toxicology, University of Saskatchewan
Timothy Jardine, School of Environment and Sustainability and Toxicology, University of Saskatchewan
Bram Noble, School of Environment and Sustainability, University of Saskatchewan,
Paul Craig, Department of Biology, University of Waterloo
Barb Katzenback, Department of Biology, University of Waterloo
Andrew Doxey, Department of Biology, University of Waterloo

## Partners, Collaborators and Users

Agriculture and Agri-Food Canada -- Allan Howard
Alberta Agriculture and Forestry -- Jannelle Villeneuve
City of Saskatoon -- Mike Sadowskio
City of Saskatoon -- Twyla Yobb
Delta N90 Trappers -- Denise MacKenzie
Friends of the Grand River -- Larry McGratton
Grand River Conservation Authority (GRCA) -- Crystal Allan
IISD-Experimental Lakes Area (ELA) -- Vince Palace
Middle Grand Chapter of Trout Unlimited Canada -- Larry Halyk
Nanjing University -- Xiaowei Zhang
Ontario Federation of Anglers and Hunters -- Tom Brook
Ontario Ministry of Environment, Conservation and Parks -- Steven Carrasco
Ontario Ministry of Natural Resources and Forestry (MNRF) -- Ken Cornelisse
Ontario Ministry of the Environment, Conservation and Parks (MECP) -- Sonya Kleywegt
Orano Canada Inc. (Former name: AREVA Resources Canada Inc.) -- Arden Rosaasen
Public Health Agency Canada -- Anil Nichani
Rare Charitable Research Reserve -- Jenna Quinn
Saskatchewan Health Authority -- Valarie Mann
Saskatchewan Ministry of the Environment Fish and Wildlife Branch -- Ron Hlasny
Six First Nation communities
Six Nations of the Grand River Wildlife Management Office -- Weylin Bomberry
Southern Ontario Water Consortium (analytical and exotox nodes) -- Brenda Lucas
Tai Lake Riverine Pollution Prevention and Management Office, Chinese Ministry of Science and Technology, China -- Hongzia Yu
Trout Unlimited National -- Jack Imhof




Highly Qualified Personnel: Professional training and research positions funded by Next Generation Solutions to Ensure Healthy Water

## Science Advances

Protection of aquatic ecosystems requires reliable and rapid detection of changes to these environments within the context of natural variability. This allows prediction of future trends so that managers can develop adaptive schemes to maintain and enhance sustainability of ecosystems. This project has advanced emerging and transformative technologies in biology and bioinformatics, such as environmental DNA (eDNA) and next generation sequencing (NGS), that enable the previously challenging study of aquatic life and its habitats.


Saskatchewan

**Saskatoon sewage testing now city's best look at COVID-19 toll**

*"This is a problem across the country where the individual, clinical testing is breaking down."*

Zak Vescera
Jan 10, 2022 • January 10, 2022 • 3 minute read • Join the conversation

Dr. John Giesy is one of the academics helping to lead wastewater testing to measure the spread of COVID-19. PHOTO BY MATT SMITH /Saskatoon StarPhoenix

Saskatoon's sewers may now be the best place to find out how COVID-19 is spreading in the city.

Article in the News Phoenix 10 January 2022

An eDNA platform was optimized and is being used and available to all collaborators and other GWF projects for relative complete biodiversity assessment from bacterial, algal, protozoan, macrobenthos, amphibia, and fish communities in aquatic ecosystems. Forty-four Standard Operating Procedures for eDNA have been made available.

Because Environmental RNA (eRNA) was shown to be a potential sensitive biomarker of stress in fish exposed to wastewater, in a study of remediation of diluted bitumen spilla novel indicator of normalized vitality, sequence counts of RNA metabarcoding normalized by that of DNA metabarcoding, was developed for assessment of ecological responses. A barcode database of Canadian freshwater fishes, macrobenthos and bitumen was established. Experiments on the relationship of eDNA with target species presence were conducted in several small streams and rivers: Environmental DNA was shown to be an effective alternative to traditional collections that are very difficult to conduct in remote locations. eDNA metabarcoding of fishes was compared with results of multiple projects and the tool developed is currently in the final stages of in situ validation by testing predicted performance of eDNA with field-collected specimens and voucher specimens obtained from the Royal Ontario Museum. Measurements of trout samples produced the first report of successful isolation and profiling of miRNA from fish mucus or samples of ambient water informing status of fish health.

Key findings include: 1) marvelous biodiversity in irrigation waters, including, bacteria, fungi, algae, protozoa and metazoan; 2) sites under high risk of cyanobacterial blooming identified; 3) potential cyanotoxin producing cyanobacteria detected for typing of blooming; 4) Changes in plankton communities showed a temporal and spatial pattern; 5) Spraying Mag H altered the plankton communities in studied areas.

In March of 2020 when COVID caused all other project work to be suspended, the project team began monitoring of wastewater for the SARS-Cov-2 virus that causes COVID-19. The team started with the Saskatoon Wastewater Treatment Plant (WWTP) then was asked to expand that to include Prince Albert and the Battlefords as well as six First Nations communities. The First Nations requested that the data be sent directly to them and not be shared with the general public.

The project team developed technology to measure viral RNA in wastewater and coordinated efforts with the Saskatoon WWTP and Office of Emergency Planning and Saskatchewan Health Authority. To serve the public, a dashboard (COVID-19 Early Indicators - Global Institute for Water Security | University of Saskatchewan (usask.ca)) was developed to post wastewater surveillance results of City of Saskatoon, City of Prince Albert, and City of North Battleford. The team published its methods so that other groups could replicate the work. For almost two years, this was the only source of monitoring of status and trends in COVID-19 for the province. In 2023, the project team worked with personnel of the Romnanov Provincial Laboratory of the Saskatchewan Health Authority to validate their methods to monitor for SARS-Cov-2 virus in wastewater of 38 WWTPs, and transferred the monitoring program to them.

While initially GWF funds supported this work, Public Health Agency of Canada stepped in with further funding, renewed every six months and terminating in September of 2023.

## Link to Publications List

## Knowledge Mobilization (KM)

The project has conducted parallel, linked processes of technology development. Engaging knowledge users early and integrating them into the project team enabled knowledge mobilization through co-creation of information. The project identified the challenges and requirements of routine biomonitoring for Alberta Agriculture and Forestry (AAF), which is responsible for a monitoring program focused on surface waters used for irrigation. Water samples collected from South Caligari Irrigation District was used to prepare eDNA metabarcoding, and water physical and chemical data to support development of models to predict algae bloom.

When project researchers pivoted their research to COVID-19 wastewater surveillance early in the pandemic, they developed methods and applied them to SARS-CoV-2 surveillance in collaboration with many municipalities and First Nations in Saskatchewan and Ontario, and communicated and shared resources with managers of wastewater treatment plants, universities, and public health, and preventive medicine doctors supporting government in Covid-19 response. Both John Giesy and Mark Servos were on the Canadian Water Network Advisory Committee and directly engaged in major programs developed provincially and nationally. Public dashboards to share results with the public were developed for the City of Saskatoon, City of Prince Albert, City of North Battleford, Waterloo Region (Waterloo, Kitchener, Cambridge), York Region (Humber AMF; Warden) and Peel Region (GE Booth, Clarkson) as well as the student residences on the University of Waterloo campus. Weekly wastewater-based epidemiology (WBE) reports were generated for each of these partners and for most of them weekly meetings have continued since the summer of 2020. As the pandemic intensified, the GWF team worked with other labs across Canada to transfer methods to an emerging network of academic and commercial labs. They led workshops, openly shared methods, and mentored laboratories to accelerate adaptation of the approach.

Researchers also continued to engage with NGOs working to improve fisheries resources in Ontario's Grand River watershed, participating in events and work with the Ohneganos program at Six Nations of the Grand River to apply next generation technologies (eDNA) to bioassessments of the McKenzie Creek and Grand River. Training of water sampling for eDNA analysis was provided to personnel of Saskatchewan Ministry of Environment. The trained personnel contribute to early warning of invasive species in Saskatchewan. Cooperating with the Water Quality Section of Alberta Agriculture and Forestry and Alberta Irrigation Districts Association, the project identified specific demands of knowledge users for assessment of irrigation waters, for instance, harmful algae, effects of one herbicide (Mag H), plankton communities and nutrient availability. Two-year filed monitoring plans were developed and conducted from June 2019 to August 2020, using customized eDNA tools.

To boost cooperation with industrial knowledge users, Dr. Hecker, Dr. Xie and Ms. DeBofsky visited uranium mining company Orano Canada Inc. (Former name: AREVA Resources Canada Inc.) on Feb. 27, 2018. Dr. Hecker gave a presentation about environmental DNA. Dr. Xie provided baseline training and introduced SOPs for field sampling of water and sediments for eDNA analyses in remote areas. Subsequently, Orano Canada Inc. contracted a consulting company to apply these eDNA field sampling methods for the collection of sediments and surface water samples as part of their routine monitoring activities under their mandate to comply with Canada's environmental effects monitoring (EEM) program. The first field campaign was successfully completed and samples were received in good condition by the project team, demonstrating successful translation of eDNA field collection methodology to a key industry partner.

The project team was commissioned to work with the public in northern and indigenous communities to place GeneXpert systems to monitor wastewaters. The instruments are now in place and local citizens trained to do the testing.

Professor Giesy met with Dr. Hongxia Yu, Vice President of the Jiangsu Province Department of Environmental Protection, the only Chinese jurisdiction to have implemented eDNA into monitoring of aquatic environments. Giesy was asked to participate in developing water quality standards and environmental goals and monitoring programs for the most industrialized province in China.

Professor Giesy has participated in four national panels on monitoring of wastewater for COVID-19, hosted by the Public Health Agency of Canada (PHAC) and National Microbiology Laboratory (NML).

## Professional Development and Technology Transfer

The project's eDNA solution for field monitoring was delivered to knowledge users. Yuwei Xie and Renata Giovanini attended Agriculture-Water Research Expo to present the latest research of eDNA for monitoring water quality in the Prairies.

# Integrated Modelling Program for Canada: Integrated Modelling for Prediction and Management of Change in Canada's Major River Basins

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p3-impc.php

Region: Canada

Total GWF funding support: $1,650,000; $900,000

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## Investigators

Saman Razavi, University of Saskatchewan
Contact: saman.razavi@usask.ca
Karl-Erich Lindenschmidt, University of Saskatchewan
Amin Elshorbagy, University of Saskatchewan
Yanping Li, University of Saskatchewan
John Pomeroy, University of Saskatchewan
Tim Jardine, University of Saskatchewan

Graham Strickert, University of Saskatchewan
Carl Gutwin, University of Saskatchewan

Alain Pietroniro, University of Calgary
Howard Wheater, University of Saskatchewan
Patricia Gober, University of Saskatchewan
Tricia Stadnyk, University of Calgary
Simon Papalexiou, University of Calgary
Masoud Asadzadeh, University of Manitoba
Roy Brouwer, University of Waterloo

Bryan Tolson, University of Waterloo
Paulin Coulibaly, McMaster University

## Partners, Collaborators and Users

### Academic

Australian National University Institute for Water Futures -- Saman Razavi
Colorado State University -- Jose Salas
Concordia University -- Ali Nazemi
Cornell University -- Richard Vogel
Czech University of Life Sciences, Prague -- Yiannis, Markoni, Martin Hanel
Newcastle University -- Francesco Serinaldi
Pacific Institute for the Mathematical Sciences (PIMS) 2018-2020 -- Ruth Situma
Roma Tre University -- Elena Volpi
Tribhuvan University, Nepal -- Dhiraj Pradhananga
Tufts University -- Steve Chapra
UNBC -- Stephen Dery, Rajtantra Lilhare
Univ. of Edinburgh, ESMSnowMIP -- Richard Essery
Universidad Nacional de Colombia -- Erasmo Rodriguez
University of Alberta -- Monireh Faramarzi, Pouya Khalili, Badrul Masud, Quan Cui
University of Bologna -- Alberto Montanari
University of Calgary -- Herve Awoye, Mohamed Ahmed, Alain Pietroniro
University of California Irvine -- Efi Foufoula -- Georgiou, Amir Aghakouchak
University of Guelph -- Prasad Daggupati
University of Illinois Urbana Champaign -- Murugesu Sivapalan
University of Manitoba -- Masoud Asadzadeh, Yinlong Huang
University of Massachusetts -- Sungwook Wi
University of Montreal -- Christoforos Pappas
University of Nebraska Lincoln -- Tirthankar Roy, Sinan Rasiya Koya
University of New Brunswick-- Allen Curry
University of Patras, Greece -- Andreas Langousis
University of Saskatchewan -- Mohamed Elshamy, Amin Haghnegahdar, Shervan Gharari
University of Saskatchewan 2017 -- 2024 (CRC Support)

University of Waterloo -- Juliane Mai, Nandita Basu, Meghan McLeod, Jimmy Lin, James Craig
Vienna University of Technology -- Günter Blöschl
Western University -- Mohammad Reza Najafi, Melika Rahimimovaghar

### Industry

Aski Holistic Adventures -- Michela Carriere
Climate Smart Services -- Aaron Kichurka
Cumberland Wood Products -- Nadina Gardiner
Fifth Business Consulting -- Tim Nickle
Fortress Mountain Holdings Ltd. -- Chris Chevalier
Manitoba Hydro -- Kevin Gawne, Kristina Koenig, Shane Wruth, Phillip Slota, Mark Gervais, Kevin Sagan
SaskPower – Bruce Howard, Wade Bryson

### Federal Government Departments and Agencies

Canada Research Chairs, Tri-Agency Institutional Programs Secretariat 2017-2024
Canada Sustainable Development Goals Unit -- Ugo Therien
Canada's Chief Scientific Officer -- Mona Nemer
Canadian Space Agency -- Laurent Giugni
Environment and Climate Change Canada -- Erika Tetlock, Bruce Davison, Dan Selinger
Environment and Climate Change Canada -- Wendy Monk, Daniel Peters
Environment and Climate Change Canada (2020-23) -- Vincent Fortin, Jean-Michel Lariviere
Environment and Climate Change Canada (Burlington) -- Frank Seglenieks, André Guy Temgoua, Narayan Shrestha
Environment and Climate Change Canada (Dorval) -- Étienne Gaborit, Nicolas Gasset
Fisheries and Oceans Canada-- Eva Enders, Doug Watkinson
National Research Council Canada -- Abhishek Gaur, Thomas Puestow, Paul Barrette, Ali Khan
National Sciences and Engineering Research Council (NSERC) Discovery 2019-2024
National Sciences and Engineering Research Council (NSERC) Discovery 2019-2024
Natural Resources Canada -- Paula McLeod, Elaine Dehamel, Carolyn Mann
Natural Resources Canada (2018-20) -- Elaine Dehamel, Carolyn Mann
Public Safety Canada-- Patrick Tanguy
Statistics Canada-- Francois Soulard
U.S. Army Corp of Engineers -- Emily Bradley, Jonathan M. Waddell Christopher J. Warren
U.S. EPA -- Ni Xiaojing, Yuan Yongping
Western Economic Diversification -- Abdul Jalil

### Provincial Government and Agencies

Alberta Environment and Parks -- Khaled Akhtar, Tom Tang, Babak Farjad, Jennifer Nafziger
Government of NFLD and Labrador -- Ali Khan

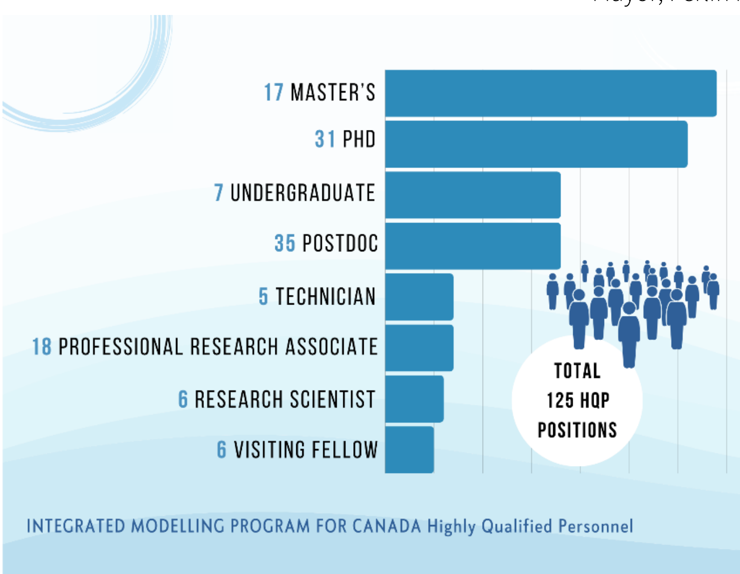
Manitoba Agriculture and Resource Development -- Mark Lee
Manitoba Transport and Infrastructure -- Bin Luo, Chris Propp
New Brunswick Government -- Brent Newton
Saskatchewan Ministry of Highways and Water Security Agency -- Jeremy Cockrill
Saskatchewan Ministry of Parks, Culture and Sport -- Thuan Chu
Saskatchewan Ministry of the Environment -- Chad Doherty
Saskatchewan Water Security Agency -- Curtis Hallborg, Ameer Muhammad, Jeff Sereda, John, Mark Davies, Gary Neil, Glen Merkley, Jeff Woodward, Doug Johnston
SaskWater -- Ingrid Newton

Non-Governmental Organizations

Parks and Wilderness Society -- Caitlyn Anhorn, Kelsey Olsen
Ducks Unlimited Canada -- Shaun Greer
We Are Fire -- Natasha Caverley

Treaty 5 Communities and Businesses

Big Eddy Lodge -- Solomon Carriere
Charlebois Community School -- Lily McKay-Carriere, Renee Carriere, Ingrid MacColl
Cumberland House Cree Nation -- Julius Crane
Cumberland House Delta Stewardship Committee -- Lilly McKay Carriere
Cumberland House Fishermen's Co-op -- Gary Carriere
Metis Local 42 -- Denise McKenzie
N28 Trappers -- Les Carriere, John Carriere
Niska Lodge -- Terry and Murdoch Carriere
Northern Village of Cumberland House -- Kelvin McKay, Mayor, Ferlin McKay, Councillor




Highly Qualified Personnel: Professional training and research positions funded by IMPC

# Science Advances

Water models have been developed for many disciplines, each capturing separate snapshots of hydrologic systems. However, hydrology is complex and in constant flow. It is inefficient and costly to model water in many separate pieces. There was a need to combine the strengths of different water-related disciplines into integrated tools, and soon for northern regions such as Canada where climate change is already having an impact. To attempt this in a practical way, IMPC broke out its work into four themes informed by users in government, industry, and other researchers who use computer-driven scenarios and forecasts to manage water and reduce risks.

IMPC has been a transdisciplinary, user-led collaborative research program developing integrated modelling capability for forecasting, prediction and decision-making under future water uncertainty for Canada's major river basins. Overall, research under each theme of IMPC has developed user-driven tools to support development of informed water management policies and practices that balance the needs of different stakeholders and support sustainable water use. The program has also emphasized the importance of integrating information from multiple sources and engaging stakeholders in decision-making processes to support effective and equitable water management.

This summary covers scientific research progress where IMPC directly funded the research outcomes or researchers, or where the researchers who were funded externally contributed to IMPC objectives. Taking an inclusive approach, the IMPC team approached the 'integration challenge' in a variety of ways. Over six years, 15 investigators led 16 sub-theme projects with the support of 55 graduate students, 32 postdoctoral associates, 41 other experts in climate science, water resources management, engineering, snow hydrology, ecology, economics, social sciences, computer science, and traditional ecological knowledge. The work under IMPC would not have been possible without the collaborative spirit of external researchers, practitioners, and stakeholders from academia, government bodies, boundary organizations, and the private sector. These projects included:

- Climate model downscaling
- Coupling hydrologic, irrigation, and economic models
- Delta Dialogues
- Ecological indicators and sustainable flow boundaries
- Flood inundation mapping
- Incorporating local perspectives and TEK into modelling
- Indicators and mechanisms of spring flood generation
- Model Intercomparison projects
- Permafrost mapping
- Refining routines for snow and glacier hydrology
- River ice flood forecasting
- Sensitivity and uncertainty analysis
- Water quality modelling
- Water quality-hydraulic model coupling

## VARS-TOOL

Dr. Razavi: **Sensitivity and uncertainty analysis continues with the VARS-TOOL** and its applications to Saskatchewan River Basin (SRB) and Great Lakes. New achievements: (1) developing new methods to handle correlation among model parameters National Center for Atmospheric Research (2) one of the first methods to utilize 'recycled data' (i.e., previous model runs) in the process of sensitivity and uncertainty analysis; (3) an efficient and comprehensive **Python library** for VARS-TOOL, sparking interest from more than 500 users in 50 countries. Collaborations on this work with international groups have also led to *policy-relevant exploration of Sensitivity analysis* approaches. https://vars-tool.com/

THEME A – Integrated Earth Systems Modelling

The objective of theme A has been to develop and integrate next-generation hydrological and land surface models to address changing cold region processes and associated societal risks. Many projects under this theme were initially piloted within IMPC and are now led/funded by the GWF core modelling team, so personnel under this theme have been shared, with significant collaboration. Two questions drove this theme: 1. "How can models of cold regions be improved and integrated to better simulate system interactions and feedbacks, and observed variability and change?" And 2. "How will these models perform under future change and new extremes?" In other words, how models for cold regions could be designed to be more realistic, and still be useful in the future?

Integrating Atmospheric Modelling

To study climate change in detail, high-resolution data on meteorology forcing is needed: close-up information on how the atmosphere influences climate, wind patterns, and ocean currents. Dr. Yanping Li's team has accomplished this by completing the Continental U.S. (CONUS) II simulation, bias correction of CONUS I and western Canada 4-KM output from the Weather Research and Forecasting Model (WRF). Li reported, "Our major contribution is the completion of CONUS II simulation, which includes historical and future climate simulations at both 4-km and 12-km resolutions covering the period from 1995 to 2015." So far, the 12-km future climate simulation has been completed, and the 4-km future climate simulation is anticipated to be done by May 2023. For this second phase, Dr. Li's team has been cooperating with the National Center for Atmospheric Research (NCAR) hydrometeorology group to conduct the 4-km WRF CONUS II simulation, covering most of the United States and Canada.

Dr. Simon Papalexiou's team has been downscaling climate projections for Canada with advanced stochastic techniques, using multiple large-scale climate models to predict conditions at local scale. To accomplish this, they have delivered bias corrected and downscaled Coupled Model Intercomparison Project, Phase 6 (CMIP6) projections for Canada. In technical terms, temperature and precipitation CMIP6 simulations were bias corrected using a Semi-Parametric Quantile Mapping (SPQM) method for the period 2015 to 2100. The EMDNA dataset $(0.1° \times 0.1°)$ was used as the basis for bias correction. The original CMIP6 simulations were regridded using a bilinear interpolation method to match the spatial resolution of EMDNA. The bias correction was performed on a daily scale. A total of 759 simulations for precipitation and 652 simulations for maximum and minimum temperature were considered,covering four Shared Socio-economic Pathways (SSP 1-2.6, SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5): scenarios of projected socioeconomic global changes that can inform climate policy. All bias corrected and downscaled simulations are available and stored in the Narval supercomputer, Quebec, CA.

Integrating Snow and Glacier Simulations

Cold regions involve hydrological processes that are not often addressed appropriately in hydrological models. The Core Modelling team has led development on the Cold Regions Hydrological Modelling platform. CRHM was initially developed in 1998 to assemble and explore the hydrological understanding developed from a series of research basins spanning Canada and international cold regions. Hydrological processes and basin response in cold regions are simulated in a flexible, modular, object-oriented, multiphysics, platform. The CRHM platform allows for multiple representations of forcing data interpolation and extrapolation, hydrological model spatial and physical process structures, and parameter values. It is well suited for model falsification, algorithm intercomparison and benchmarking, and has been deployed for basin hydrology diagnosis, prediction, land use change and water quality analysis, climate impact analysis, and flood forecasting around the world. CRHM's capabilities have been updated, and model applications provide insights in concert with process hydrology research, using the combined information and understanding from research basins to predict hydrological variables, diagnose hydrological change, and determine the appropriateness of model structure and parameterisations.

Results show that, counterintuitively, seasonal sublimation losses decline with increasing temperatures and can become negligible under many future climates. This is because of increased cohesion of snow surfaces, increased blowing snow transport, shortened snow seasons, decreased snowpack depth, increasing winter rainfall, and the increased unloading and melt of intercepted snow from canopies as temperatures more frequently approach or exceed 0°C in the future climate. To some degree, reduced sublimation losses counter the shift in precipitation phase from snowfall to rainfall with warming, but this is not generally sufficient to overcome the impact of reduced snowfall on snowpack accumulation. Dampened redistribution and sublimation will shorten the melt season due to a reduction in spatial variability of spring snow cover and a loss of deep snowdrifts and snow patches.

Permafrost mapping is a time-sensitive matter that evaluates human impacts on future water supply. To improve understanding of frozen soils and the cryosphere, Dr. Tricia Stadnyk's team integrated regulation into model projections, improving understanding of cold regions processes. They remapped permafrost across Canada, adapting the HYPE model to have seven soil layers instead of three. This provided a more complete view of thermodynamic transfer/distribution through the soils in response to changing air temperature. Driving this model into the future with climate scenarios has provided better understanding of permafrost distributions under climate change. Stadnyk says that future investigations could involve testing frozen soils and regulation routines (outflow calculation methods) for pan-Arctic basins.

### Integrating Water Quality

Dr. Karl-Erich Lindenschmidt's team has coupled multiple models and run scenarios for sediment flows, flood hazards, water quality, and collaborative water management. They have modelled flood hazards for the town of Fort McMurray using a 2D HEC-RAS model, and developed quasi-2D water quality model for Lower Athabasca Region before that. In the Saskatchewan River Delta (SRD) they collaborated in a knowledge-braiding project where 2D HEC-RAZ scenarios were co-developed with residents of the Saskatchewan Delta Stewardship Committee applying their traditional ecological knowledge (TEK). This project resulted in several flow management scenarios and facilitated the beginnings of a data partnership between Delta residents, Saskatchewan Ministry of Highways, Water Security Agency, and SaskPower. As well, sediment flow outputs from the MESH-SED model were coupled with the WASP model in collaboration with the Core Modelling Team. They have completed the coupled HEC-RAS and WASP water quality model for the South Saskatchewan River (from Gardiner Dam). Currently, this is being used to model heavy metals in that area. The Gardiner hydroelectric dam sits at Lake Diefenbaker, Saskatchewan, so they are also running MESH scenarios of naturalized (above-lake) inflows and Lake Diefenbaker lake model scenarios to simulate regulated (below-dam) outflows.

### Integrating River Ice Processes

In cold regions, mid-winter ice-cover breakup can cause flooding, so forecasting is needed. To answer this call, Dr. Karl-Erich Lindenschmidt's team has set up a framework to forecast mid-winter ice-jam flooding. Future work may assess impacts of climate change on future mid-winter breakup occurrences. To date, Lindenschmidt's team has conducted river ice flood risk forecasting for the Athabasca River near Fort McMurray. They have also developed a geospatial model to identify potential ice-jam locations and a preliminary ice-jam location prediction model for the Saint John River. This was achieved by introducing a machine learning tool to classify hydraulic, geomorphologic, and river ice factors to forecast real-time probable ice-jam locations for a given year. They are exploring machine learning further for the Athabasca and Red rivers to improve uncertainty by improving model parameters and boundary conditions.

### Analysis of Extremes

This work focused on extreme hydroclimatic variables, particularly past and future precipitation and streamflow. The intention was to conduct a Canada-wide analysis of precipitation data, characterize the dependency of the tail behavior of streamflow to other climatic variables, and develop a hydraulic modelling toolkit for flood mapping in select flood sensitive areas. To accomplish this, Dr. Elshorbagy's team has assessed seven flood indicators/descriptors of the key hydro-climatic components contributing to spring flood generation in the Canadian prairies, characterized nine flood generation mechanisms, and showed their spatial and temporal variability across the Canadian Prairies. To simulate various scenarios of floods in the Canadian Prairies, they also demonstrated a statistical simulation of interaction among various basin conditions and their changing role in generating peak spring streamflow using a seven-dimensional Copula model. Dr. Coulibaly's team has been investigating new approaches for high-resolution flood inundation mapping in semi-urban environments. Physically-based hydraulic models have a high computational cost when it comes to fast-developing inundation maps for urban flash floods, so alternative methods have been assessed, including a hybrid machine learning approach based on Nonlinear AutoRegressive eXogenous (NARX) and Self-Organizing Maps (SOM) models, as a surrogate for a quasi-2D urban flood inundation model based on SWMM for the Don River basin (Greater Toronto Area). His team has found that the surrogate model can be used as an alternative method for generating flood inundation at a lower computational cost than physical hydraulic models.

### Model Intercomparison and Analysis

Some hydrologic models are more suitable than others, depending on the context. To achieve the most realistic answers it is necessary to know which model to use and when. A model intercomparison evaluates each model based on its capability and the quality of results. It asks, "which model can best represent the real world, in a given context?" Two model intercomparison projects were conducted by several IMPC researchers, in collaboration with industry partners. The Nelson-

Churchill Model Intercomparison (Nelson MiP) project was led by Dr. Tricia Stadnyk whose team compared the performance of eight hydrologic and land surface models over various unregulated headwater basins in the Nelson-Churchill River Basin. Using a standardized set of input data, model performance was compared against streamflow, actual evapotranspiration, and snow-water equivalent observations. All models failed to reproduce streamflow adequately and accurately (process-based testing) across the Canadian Prairies. These highlighted structural limitations of current models, a need for a proper representation of the non-contributing area dynamics, and a need for a model agnostic approach. Dr. Bryan Tolson worked on the multi-institutional Great Lakes Runoff Intercomparison Project (GRIP-GL; managed by Dr. Juliane Mai). The final study included 20 collaborators, from 10 institutions (CA, US, EU) that resulted in comparison of 13 models for the Great Lakes watershed domain including Ottawa River (965, 561 km2). Using one common forcing dataset (for DEM, soil, landcover, and meteorological forcings) they evaluated models' capability to simulate streamflow, actual evapotranspiration, surface soil moisture, and snow water equivalent. The basin-aggregated model outputs are available at hydrohub.org.

### Characterizing Uncertainty

It is also important to know which model parameters have the strongest influence over model outputs. Dr. Razavi's team has developed a sensitivity and uncertainty analysis toolbox: Variogram Analysis of Response Surfaces (VARS)-TOOL (http://varstool.com), and translated it from MATLAB to with new added features. VARS-TOOL can be downloaded from github.com>varstool, along with tutorials. Educational VARS-TOOL videos are also available on the YouTube Razavi Science Lab channel.

### THEME B - Coupling Human-Driven and Natural Systems

The objective of theme B of IMPC has been to develop water resources assessment tools that integrate human factors, including economic trade-offs and ecosystem constraints, with natural systems models. The questions driving this theme were 1. "How can models of natural and human-driven components of the Earth be integrated to represent their interactions and feedbacks, including human activities and values?" And 2. "How can we develop and unite socio-economic and hydro-ecologic performance models for integrated water resources management?"

### Water Resources Management Modelling

As economic scenarios change, irrigation demand changes so non-water related sectors can either benefit or suffer based on hydrologic changes. To explore this, Dr. Saman Razavi's team has coupled the Water Resources Management Model (MODSIM) and with an irrigation model (ISIO) to estimate water consumption at different nodes in the Saskatchewan River Basin, coupling the WRMSask Model with an irrigation water demand model and an inter-regional hydro-economic model (an economic Input-Output model). This work applied policy scenarios developed by Dr. Patricia Gober's team. These scenarios are being used to address Saskatchewan's recent $4 billion irrigation expansion and assess who stands to benefit.

Another team has been simulating Manitoba's river- reservoir system to understand the extent of climate change impact on this province's water resources and energy production. To accomplish this, Dr. Masoud Asadzadeh's team has been developing the Manitoba Water Resources Management Model: a coupled model set up to simulate the extent of changes in the future using 19 scenarios. The main challenge was that the current models of Manitoba Hydro cannot be directly used for climate change analysis because they need the daily amount of stored water in the system. Dr. Asadzadeh's group developed the MODSIM model of the system and used regression models to predict the target storages based on the current regulation of the system. In the next step, the configuration of this model of the Winnipeg River system will be used across the river-reservoir system in Manitoba. Then it will be used to analyze the impact of climate change on hydroelectricity generation in Manitoba.

### Integrating Aquatic Ecosystems

Aquatic ecosystems are changing in response to human-altered flows, so Dr. Tim Jardine's team has been examining deviations from naturalized flows at locations across the Saskatchewan River Basin. Recently they have, in partnership with Fisheries and Oceans Canada, quantified fish stranding downstream from EB Campbell Dam on the Saskatchewan River, and linked streamflows to walleye and sturgeon production These findings will serve as ecological performance indicators for flow models. Ecological performance indicators using MESH daily flows and future flows were developed, including percent deviation from natural flow and Indicators of Hydrologic Alteration (IHA) variables. This work offers a first look at likely ecological consequences of altered flows. The team has also produced naturalized flow presumptive standards (sustainable boundaries) from naturalized daily flows and future flows produced by a new version of the MESH model (15 climate scenarios, three time periods) for 28 sites in Alberta, five sites in Saskatchewan, and two sites in Manitoba.

### Integrating Hydro-Economic Modelling

Different water futures have broad economic implications. Macro-economic models for river basins in Canada did not exist until Global Water Futures but, now, Dr. Roy Brouwer's team has developed sets of similar multi-regional and multi-sectoral input-output models. These models show the importance of direct/indirect economic impacts of water policy interventions (large-scale) by simulating the impacts of climate change on river basin economies. Economic input-output models have been developed for the Great Lakes and Nelson-Churchill regions. In the Nelson-Churchill, the I-O model has been coupled with MODSIM, and model performance has recently been tested for different climatic conditions. This work translates water resource stress to economic impact, such as water supply shortages at different scales. Work continues toward linking Water Quality Valuation Models (WQVM 2.0). So far, a Canada-specific water quality valuation function has been included, and this team can spatially aggregate/disaggregate drainage basins to watersheds and vice versa. This team collaborates directly with Environment and Climate Change Canada.

## THEME C - Decision-Making Under Uncertainty and Non-Stationarity

Theme C of IMPC has focused on generating future scenarios for decision-making under uncertainty. The central objective of Theme C was to use models as vehicles to explore alternative futures, highlight critical trade-offs, and to support policy and management processes.

### Future Scenario Generation

Different potential water futures need to be plausible as well as mathematically possible. As a prelude to scenario development and complex systems modelling, Drs. Patricia Gober and Saman Razavi's team canvassed stakeholder ideas about future policychanges by performing a content analysis of a wide range of stakeholder documents in the Saskatchewan River Basin. Later, a live survey of eight practitioners and 16 researchers was conducted during the 2021 IMPC Annual Meeting to identify plausible future policy scenarios. The final shortlisted policy variables accounted for future changes in crop mix, irrigation expansion in Alberta and Saskatchewan, and irrigation efficiency in Alberta and Saskatchewan. These variables were used to guide the Water Resource Management MODSIM framework developed above.

### Optimizing Policy and Decision Analysis

In addition to modelling the physics of nature, computers can be used to simulate the interactions among people, things, and places over time. To achieve this, decision-making entities called 'agents' are shaped by the relationships among them. Drs. Saman Razavi and Amin Elshorbagy's team completed an agent-based model that explores water-social behavior in the farming sector in response to polices around modernizing traditional irrigation systems. The geographical focus of this work has been on the Bow River Basin, a sub-basin of South Saskatchewan River Basin in Alberta. The result that drew particular stakeholder interest and media attention is the 'Rebound Phenomenon', focusing on human adaptation to drought.

## THEME D - User Engagement and Knowledge Mobilization

Under theme D, Investigators and their teams carry out partner engagement activities where possible over several stages of the research. The questions driving this theme were: 1. "How can our users become partners in scientific discovery and development?" And 2. "How can we optimize the transfer of scientific findings into practice and decision-making processes?"

### Outreach and User Engagement

The Saskatchewan River Delta, the largest freshwater delta in North America, is home to multiple Indigenous communities who depend on the local ecology for food and income. A range of and collaborative projects including qualitative interviews exploring the values, insights, and perspectives of water resources in this region have been led by Drs. Graham Strickert and Tim Jardine. They had been working with the Delta before IMPC was launched and these collaborations support all Delta-related projects in IMPC, including the 2D HEC-RAZ scenario project led by Dr. Karl-Erich Lindenschmidt. In collaboration with IMPC project management, the Delta Dialogues meeting and workshop series have led to ongoing collaboration with Delta residents. These meetings are facilitated by a third-party and serve as neutral ground for local residents, industry partners, government representatives, and NGOs to share information on the condition of the Delta. Impending results that have been a long time in the making include:

- two gauging stations installed in the Delta in collaboration with the Saskatchewan Water Security Agency
- local residents pursuing a LiDAR data acquisition collaboration
- a 'Delta Restoration' meetup facilitated by IMPC in 2023 to discuss future actions and available capacity among stakeholders. In the latest meeting with Delta partners, Dr. Strickert discussed the EB Campbell tool with residents of Cumberland House, with the resulting goal of zeroing in on a 30-day flow period with onion-skin plots of layers to display a 30, 60, 90-day snapshot of Tobin Lake in 2011, 2013, and 2020, to improve fish spawning conditions.

Visualisation Tools and Decision Support Systems


Collaborative user interface of the Water Explorer decision-support tool, displaying different MODSIM outputs for irrigation expansion scenarios in Saskatchewan

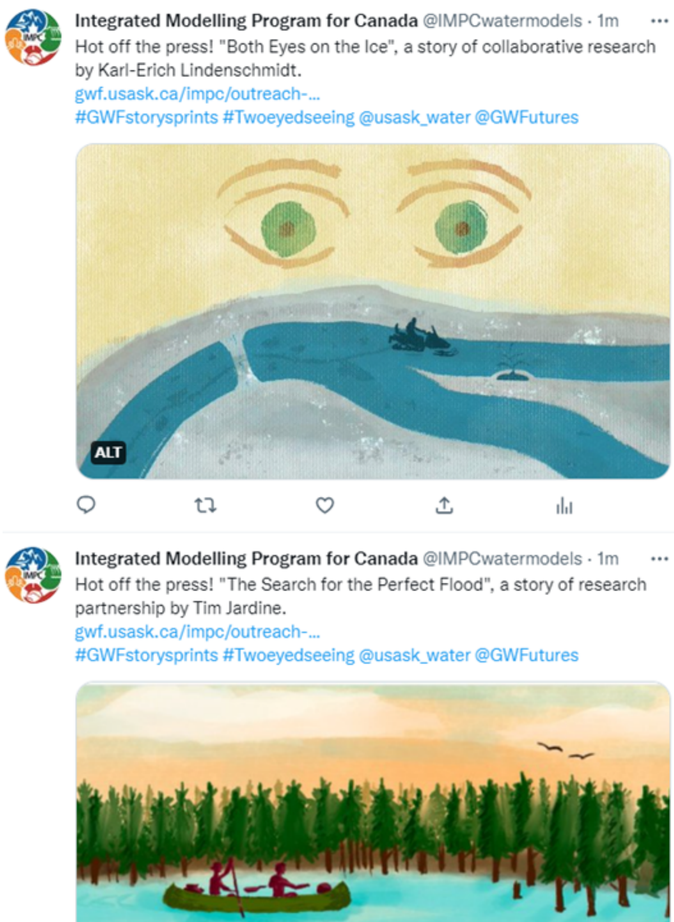
Data visualisations are a user-friendly way to display information, but few understand just how visual representations affect group communication. Dr. Carl Gutwin's team has worked to remedy this and specifically, to apply this knowledge toward informing the community of Cumberland House about water levels in the Delta and at the EB Campbell dam. First, they developed the Water Explorer decision-support tool. Then they incorporated new modeling outputs created by Leila Eamen for exploration of several scenarios motivated by the provincial government's expanded Diefenbaker irrigation plan. They added new visualisations to show several possible model outcomes based on different selections for three different factors, and interactions to allow more detailed analysis within these scenarios and outcomes - both for individuals and for connected remote users. Second, they developed the Saskatchewan River Delta visualisation tool, and have added new visual displays indicating river levels, media icons that show water levels, and an enhanced time-series viewer that allows users to both select past periods for analysis and look at current and recent conditions. Both tools have been demonstrated to stakeholders with ongoing discussions about possible new features and the need for long-term support.

One challenge faced by IMPC has remaining connected despite its size and pan-Canadian nature. With four institutions across Canada, coordination has been spread across 14 sub-themes, each running activities in parallel. Considerable progress on each individual project was made while still finding ways to collaborate when possible. Sharing personnel and project work with the Core Modelling Team has contributed to this connectivity. The COVID-19 pandemic interrupted workspaces, conferences, and routines and limited visits to study sites, particularly in northern regions. Project team members adapted well to working together remotely.


[Link to Publications List]

## Knowledge Mobilization (KM)

In addition to Theme D work, a diverse range of engagement activities have taken place at broad and local levels. Stakeholders and rightsholders have encouraged individual project leaders to correspond directly. Therefore, IMPC outreach was often led by the investigators themselves. At the program level IMPC project management maintained a Twitter (X) account @IMPCModels, a seasonal e-newsletter with over 250 subscribers, and a program website with new publications, in-house news stories, and KM workshop products such as the GWF Story Sprints work.




Social media posts about INMPC stories of research engagement

At the project level, modellers actively use GitHub to share code and converse with the broader modelling community. The GRIP-GL MiP project has its own webpage: https://hydrohub.org/mips_introduction.html#grip-gl. As well, most of the team's investigators manage their own independent social media accounts where they share publications, collaborate with and answer questions from other climate and coding communities. For basin-wide modelling results such as Dr. Brouwer's work, interviews for television and newspapers have been helpful.

Dr. Masoud Asadzadeh's team has worked closely with Manitoba Hydro on major reservoir operations and integrated resource planning for future decades. Manitoba Hydro has expressed interest in this partnership specifically to add to their understanding of long-term system operation adaptation to climate change impacts on hydrology (including upstream regulation); systems modelling for integrated resource planning; and development of water resources system modelling capacity and highly qualified professionals through mutual/collaborative training opportunities. Manitoba Hydro has directly participated in the research by providing systems data and review, and has used research outcomes in its monitoring operations.

In both the MiP sub-projects, all participants in the research team have provided in-kind time, models and data, and they are co-authors on resulting papers and posters. Both teams have partitioned the research process into phases for more effective engagement (increasing partner motivation and time to participate). Generally, the research team communicates with interested parties on a monthly basis via Zoom and WebEx online meetings. The team also uses an online GitHub repository (for GRIP) and SharePoint folder (for Nelson MiP), where project information, data and co-created content and material are shared.

The data visualisation team led by Dr. Carl Gutwin provided in-house expertise in user-friendly web applications, collaborating with Drs. Razavi and Eamen to develop the Water Scenario Explorer platform for visualizing outputs of the WRMSask model displaying impacts of various policy scenarios for the entire Sask River Basin.

IMPC's program manager Ashleigh Duffy has been a primary developer, facilitator, and editor of KM user-engagement storytelling educational workshops: the knowledge mobilization initiative: GWF Story Sprints. To date, 30+ GWF Investigators and 20+ HQP have attended one of the five workshops, producing general audience GWF research story products, complete with in-house illustrations at GIWS by Fred Reiben. All GWF engagement stories will be published in a book format and a sample have been developed into narrated animations.

IMPC's target audience is broad. By revolving around the goal of 'integration', IMPC research needs to be collaborative. In the process of coupling models many of the project's knowledge users are researchers themselves, but not all. IMPC's high-level forecasting tools are designed for operational departments and are particularly useful for regional, municipal, and rural governments that wish to mitigate flood risk. The coding and uncertainty analyses packages can be used by a global audience of coders, engineers, and software developers. The visualisation tools have been designed for community engagement, but also interdepartmental collaboration within provincial governments. The Delta Dialogues initiative has focused on building local networks that will maintain multi-stakeholder dialogue beyond the life of this project. Audiences include policy-makers (eg. Ministers of Environment in multiple Canadian jurisdictions), decision-makers (e.g. Alberta Environment and Parks), water resource practitioners (eg. the Water Security Agency), industry (eg. Manitoba Hydro), local government (eg. Northern Village of Cumberland House; City of Calgary), local recreational stakeholders (eg. avalanche control, Canmore), federal departments (namely Environment and Climate Change Canada), regional agencies (eg. International Joint Commission, Great Lakes). Some examples of IMPC's knowledge mobilization results follow here.

- All phases of the GRIP as well as the Nelson MiP have enjoyed substantial participation from collaborators. For example, GRIP-GL compared the performance of models with the direct participation of 20 collaborators from 10 institutions in Canada, the USA and Austria. The Nelson MiP has also garnered interest from a wide range of collaborators that include both academic and government/industrial representatives.
- Making CRHM available on GitHub allowed for stakeholders to observe and contribute to the project, in particular postdoctoral associates and grad students from the wider hydrologic and modelling communities.
- In 2019 Leila Eamen met with the Saskatchewan Chamber of Commerce to discuss the overlap between water management and economy: "The Council had a lot of important insights to offer," Leila adds. "Some of our discussion focused on how water reuse and recycling opportunities are important in Saskatchewan because they reduce input costs and costs associated with water treatment. The Council pointed out that many industries in Saskatchewan are trade-exposed, so this could be a competitive advantage." The Council was also interested in multi-year drought scenarios and climate change impacts. Collaborations with the Water Security Agency and Agriculture Canada were integral leading up to this meeting (Carlson, H., Eamen, L., (January 2019) *IMPC PhD student meets with Chamber of Commerce to further hydro-economic research*, GWF: IMPC Articles.)
- Dr. Karl-Erich Lindenschmidt's stochastic modelling approach to ice-jam flood risk assessment and hazard mapping of rivers has been adopted by the KGS Group. This model is gaining popularity with other engineering consultants.
- Recent collaborations between Dr. Lindenschmidt and Manitoba Transportation and Infrastructure have resulted in a new project: a collaborative assessment on ice-jam flood risk for the lower Red River.

Meetings with governments, decision makers, practitioners

- Dr. Graham Strickert:
  - July 6th, 2022. Zoom meeting with Northern Village of Cumberland House 10:30 - 12:00pm
  - July 14th, 2022 - Zoom Meeting with Northern Village of Cumberland House 2:30 - 3:00pm
  - October 28th, 2022 Delta Modelling Zoom Meeting Delta Stewardship Committee. 1:30 - 2:30pm
  - December 18 - 19th, 2022 Meeting Ministik Community School Cumberland House, and
  - December 19th, 2022 Meeting with Cumberland House Cree Nation and Partners January 18th, Research Update with Cumberland House Cree Nation in Prince Albert
- Dr. John Pomeroy:
  - Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023
  - Great Lakes roundtable discussion with the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada, Niagara Falls, Canada, September 28, 2022
  - Science Briefing on the Water Resources of the South Saskatchewan River to the Saskatchewan Party Caucus MLAs and Meewasin Valley Authority Board of Directors, Saskatoon, Saskatchewan, June 28, 2022
  - Panelist, High-level panel on the Canada Water Agency, towards innovative water management, Global Water Futures (GWF) Annual Open Science Meeting, Virtual, May 16, 2022

Articles in popular media

- Pomeroy, J. (June 2022). History of Canadian Hydrology and Relation to Operational Water Resources Management (Magazine Article). Canadian Water Resources Association (CWRA) Water News, Vol. 41(3)
- Singh, B. and Pomeroy, J. (April 2022). Opinion: Time running out to secure Saskatchewan's water prosperity (Newspaper Article). Saskatoon StarPhoenix

- Pomeroy, J.W., Axworthy, T. and B. Sandford (March 2023). Opinion: Spring is here, where is the Canada Water Agency? (Newspaper article). Globe and Mail
- Axworthy, T., Pomeroy, J.W., Hines, E. (December 2022). Canada must not waste opportunities at COP15 in Montreal. (Newspaper article) Hill Times.
- Duhatschek, P. (2023, April 14). What a dry winter in the Rockies could mean for the spring. CBC. https://www.cbc.ca/news/canada/calgary/dry-winter-rockies-spring-1.6809994
- Pike, H. (2022, December 24). UN to recognize glacier preservation in 2023 thanks to Canadian researchers. CBC. https://www.cbc.ca/news/canada/calgary/john-pomeroy-bob-sandford-glacier-research-canmore-coldwater-lab-1.6315283

Interviews (broadcast or text)

- Dr. Saman Razavi:
- Langager, B. (2022, August 5). University of Saskatchewan researchers collaborate on global paper on flood, drought mitigation. Global News. https://globalnews.ca/news/9040737/usask-researchers-global-paper-flood-drought-mitigation/
- Dr. John Pomeroy:
- World Water Day: the importance of fresh water, Broadcast Interview, CBC Radio Calgary, Mar 2023
- After the floods: Rebuild or relocate?, Broadcast Interview, CBC The National, Jan 2022
- Will it Snow this Christmas?, Broadcast Interview, CBC News, Dec 2022
- Opportunity to advance Arctic infrastructure strategy in response to increased defence threats, say NDP MP, CSG senator, Text Interview, The Hill Times, Dec 2022
- Research-powered climate adaptation and water security solutions, Text Interview, The Globe and Mail, Nov 2022
- Q+A: U of S water expert delivers talks to COP27 climate conference, Text Interview, Saskatoon StarPhoenix, Nov 2022
- Funding for USask-led water monitoring network will help understand, manage floods, drought: director, Broadcast Interview, CBC News Saskatoon, Aug 2022
- USask major scientific centres awarded $170M of MSI funding, Text Interview, USask News, Aug 2022

Public workshops and presentations

- Visualizing WRM model results: Exploring the “Water Scenario Explorer,” by Dr. Carl Gutwin, Dr. Saman Razavi, Dr. Leila Eamen, Ana-Pietje Du Plessis, Online, July 5th 2022. https://youtu.be/zgxzzJXeQaY.
- Community-based models and tools in IMPC: What we’ve done so far and how can we do better? by Dr. Graham Strickert, Dr. Tim Jardine, Pouya Sabokruhie, Ana-Pietje Du Plessis, Online, July 6th 2022. https://youtu.be/_kPgwW5ya_Q.
- Cumberland House Cree Nation Open House, booth & visualisation tool display: Dr. Strickert & IMPC PM January 18, 2023
- Pomeroy, J.W., Presentation on severe weather and changing climate, Canmore Collegiate High School, Canmore, Canada, February 14, 2023

Promotional videos

- (9) Video Tutorials for VARS-TOOL toolkit, August 2022 to September 2022 @RazaviScienceLab, https://www.youtube.com/@RazaviScienceLab/videos
- IMPC 5th Annual Meeting: Opening Talk, https://www.youtube.com/watch?v=DoHwUVG8HJs

## GWF Water Scenario Explorer

Drs. Gutwin and Razavi's HQP developed a user-friendly interface that provides information on the **consequences of future water management decisions** in the Saskatchewan River Basin. Simulations are the product of integrated water management modeling capabilities IMPC has developed thus far. It aims to improve understanding of water resource availability under various future scenarios such as **crop mix changes, irrigation expansion in Saskatchewan, irrigation efficiency changes, and climate change.** With this tool users can easily control model variables to visually display flow outputs that reflect competing water use and demand. **This tool is valuable for decision-making in the context of a stressed water system.** Follow this link to view the latest version; in its final stage of development: https://gwf-hci.usask.ca/

## EB Campbell Flow Visualization Tool

Dr. Carl Gutwin's team also produced a tool that presents a breakdown of **inflow and outflow associated with Tobin Lake,** along with an **interactive geographical map where photo and water level snapshots associated with specific time periods. As well, outflows are embedded** to provide the viewer a better understanding of flows as well as the operation of the E.B. Campbell Dam. (Follow this link to view the latest version; please note that the tool is still under development: https://gwf-hci.usask.ca/eb-campbell/

## Great Lakes Model Intercomparison Results via HydroHub

In leading Great Lakes Runoff Intercomparison Projects (GRIP-GL & GRIP-E), Dr. Julie Mai also developed a state-of-the-art interactive map-based website for GRIP-GL (http://www.hydrohub.org/mips_introduction.html#grip-gl) that visualizes and compares models to each other and to data such as streamflow. Basin-aggregated model outputs and data (Snow Water Equivalent, Surface Soil Moisture, and Actual Evapotranspiration) are also available for users to explore through an interactive maps and time series plots. Archival websites for the GRIP-E (https://doi.org/10.5281/zenodo.4584120) and for GRIP-GL (https://doi.org/10.20383/103.0598) provide all study input data so future researchers can replicate results and add their own models to the intercomparisons!

Citizen science

- Pomeroy, J.W., Ivanov, G. & Davies, T.D. (November 2022). Cold Regions Warming – A Transitions Exhibition: Global Water Futures [Artistic Exhibition]. Whyte Museum of the Canadian Rockies, Banff, Canada

Access of tools by users

https://gwf.usask.ca/impc/resources/impc-tools.php

- EB Campbell tool: demonstrated to and used by Cumberland House community members
- Water Scenario Explorer: https://gwf-hci.usask.ca/#/?_k=qaqrur
- HydroHub - Hydrologic Models for Everyone: https://hydrohub.org/mips_introduction.html#grip-gl
- VARS-TOOL: A toolbox for comprehensive, efficient, and robust sensitivity and uncertainty analysis: https://vars-tool.com/
- IMPC/GWF DAta Visualisation Project (DAVIS): http://gwf-demo.usask.ca/v-12/

# GWF Core Modelling Work

Web Link: [Water Resources Management - Core Modelling and Forecasting Team - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Canada

Total GWF funding support: $10, 114,249, $1,5000,000 (Planetary Water Prediction Initiative)

Project dates: 2016-2024; 2020-August 2025 (PWPI)

## Investigators

### Leadership

Martyn Clark, University of Saskatchewan
Al Pietroniro, University of Calgary
Shervan Gharari, University of Saskatchewan
Joy Mitsogianni, University of Saskatchewan

### Theme leaders

Julie Thériault, Université du Québec à Montréal
Martyn Clark, University of Saskatchewan
Bruce Davison, Environment and Climate Change Canada
John Pomeroy, University of Saskatchewan
Tricia Stadnyk, University of Calgary
Al Pietroniro, University of Calgary
Roy Brouwer, University of Waterloo
Phillipe Van Cappellen, University of Waterloo

### Investigators

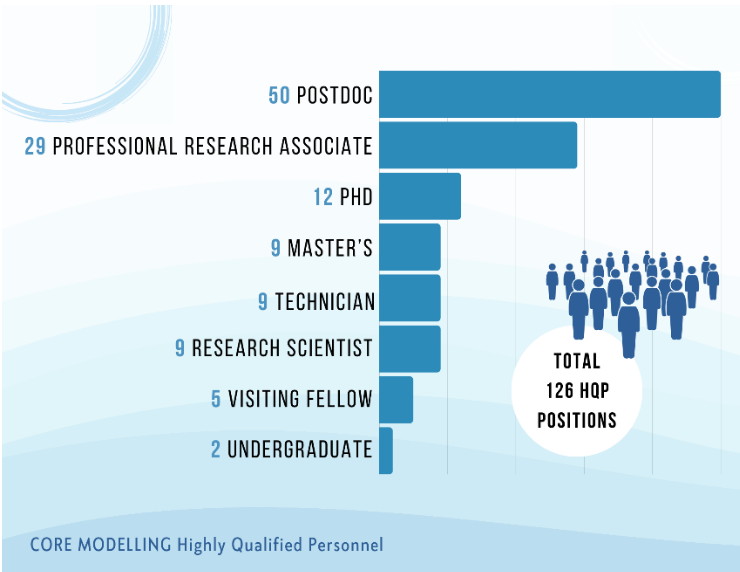
Helen Baulch, University of Saskatchewan
Yanping Li, University of Saskatchewan
Simon Papalexiou, University of Calgary
Karl-Erich Lindenschmidt, University of Saskatchewan
Lawrence Martz, University of Saskatchewan
Saman Razavi, University of Saskatchewan
Markus Schnorbus, Pacific Climate Impacts Consortium
Nandita Basu, University of Waterloo
James Craig, University of Waterloo
Helen Jarvie, University of Waterloo
Homa Kheyrollah-Pour, Wilfrid Laurier University
Bruce MacVicar, University of Waterloo
Bryan Tolson, University of Waterloo
Mark Servos, University of Waterloo
Sean Carey, University of Waterloo
Pauline Coulibaly, McMaster University
Francis Zwiers, Pacific Climate Impacts Consortium
Raymond Spiteri, University of Saskatchewan
David Rudolph, University of Saskatchewan

## Partners, Collaborators and Users

Aquanty Inc. -- Steve Frey
Canada Research Chairs, Tri-Agency Institutional Programs Secretariat 2017-2024
Canada's Chief Scientific Officer -- Mona Nemer
Cenovus Energy -- Chris Salewich
City of Kitchener -- Bu Lam
Centre for Ecology and Hydrology, UK -- Rosie Lane
Consortium of Universities for the Advancement of Hydrologic Science -- Jerad Bales
Deltares -- Albrecht Weerts
Government of the Northwest Territories – Bruce Hanna
Government of the Northwest Territories Environmental Studies Research Fund (ESRB) -- Andrew Applejohn
Environment and Climate Change Canada -- Alex Cannon, Bruce Davison, Daniel Princz, Vincent Vionnet, Vincent Fortin, Muluken Yeheyis, Xu Yan, Diogo Pinho da Costa, Jean-Michel Lariviere
Government of Yukon 2023 -- Anthony Bier
Grand River Conservation Authority -- Mark Anderson
Helmholtz-Centre for Environmental Research -- Luis Samaniego
McGill University -- Jeffery McKenzie
Ontario Minister of the Environment, Conservation and Parks -- Heather Brodie-Brown
National Center for Atmospheric Research (United States)-- Naoki Mizukami, Andy Wood
National Sciences and Engineering Research Council (NSERC) Discovery 2019-2024
Princeton University -- Ming Pan
Regional Municipality of Durham -- Tavis Nimmo
Regional Municipality of Waterloo -- Eric Hodgins
Sahtu Renewable Resources Board -- Alyssa Bougie, Catarina Owen
Saskatchewan Water Security Agency -- Shawn Jaques
Solinst Canada -- Jim Pianosi
Statistics Canada -- Francois Soulard
SaskWater Strategic Planning, Risk and Policy Board of Directors -- Ingrid Newton
Canada Sustainable Development Goals Unit -- Ugo Therien
Swedish Meteorological and Hydrological Institute -- Berit Arheimer, David Gustafson
Toronto and Region Conservation Authority -- Krista Chomicki, Katja Winger
TU Delft, Netherlands -- Gerrit Schoups

Claude Duguay, University of Waterloo
Corinne Schuster-Wallace, University of Saskatchewan
Dustin Garrick, University of Waterloo

Université du Québec à Montréal -- Alejandro Di Luca
University of Arizona -- Andrew Bennett
University of Bristol -- Gemma Coxon, Sarah Shannon, Tamsin Lockwood, Louisa Oldham
University of Melbourne -- Keirnan Fowler
University of Tokyo -- Dai Yamazaki
University of Washington -- Bart Nijssen
University of Waterloo -- Kevin Boehmer, R. Lemieux , Jimmy Lin, Walter Illman, Mario Coniglio
United States Geological Survey, USA -- Brent Alunbach
Utah State University -- David Tarboton
Wilfrid Laurier University -- Jenn Baltzer, Phil Marsh
Xcalibur Multiphysics -- Adam Smiarowski




Highly Qualified Personnel: Professional training and research positions funded by GWF Core Modelling

# Science Advances

The Core Modelling and Forecasting Team has been positioning the GWF and Canada as a global leader in water studies. The highly trained and motivated individuals within the core modelling team are responsible for building the computational tools for large-domain hydrological modelling and prediction. The GWF core modeling tasks are grouped by themes. The theme leads – expert faculty members – have been responsible for completing the necessary tasks to accomplish the GWF deliverables. The core modeling program includes the following research topics:

- Climate forcing data, including historical variables, corrected or gap filled station data, and future climate scenarios (the spatial meteorological forcing data theme)

- Hydrological modeling, using existing models as well as developing new modelling capabilities and modelling infrastructure to better represent hydrological processes (the themes of current generation modelling, next generation modelling, and geospatial intelligence)

- Water quality research to understand the processes and sources of pollution that deteriorate the water quality for human use or natural healthy environment (the water quality theme)

- Water management and the human dimensions of water in which the human induced changes such as water abstraction from river or reservoir operation changes the flow, nutrients, and sediment regimes (the themes of water management, socio-hydrology, and human dimensions)

- Short and long term prediction to use the computational tools developed in other modelling themes to predict relevant hydrological variables such as streamflow on short (seconds to seasons) and longer timescales (decades to centuries). GWF prediction capabilities are intended to be used and adapted by federal, provincial and territorial governments.

The leadership of GWF core modeling and forecasting has enabled organizing themes to ensure that tasks are aligned with the core modeling deliverables. Cross cutting activities have included tasks such as preparing climate scenarios and preparing data. Knowledge transfer across the core modelling theme has maximized the time spent on science advancement.

Collaboration with government institutes and agencies such as Environment and Climate Change Canada have provided scope to increase efficiency at the national level through data sharing, infrastructure for model setup, and knowledge mobilization. This has provided operational benefits well beyond those that are reported in scientific publications.

Core Modelling Themes

Spatial Meteorological Forcing datasets

Overview of downscaled or bias corrected products: The project team delivered bias corrected and downscaled CMIP6 projections for Canada. Temperature and precipitation CMIP6 simulations were bias corrected using a Semi-Parametric Quantile Mapping (SPQM) method for the period 2015-2100. The EMDNA dataset (0.1°×0.1°) was used as the basis for bias correction. The original CMIP6 simulations were regridded using a bilinear interpolation method to match the spatial resolution of EMDNA. Bias correction was performed on a daily scale. A total of 759 simulations for precipitation and 652 simulations for maximum and minimum temperature were considered covering four Shared Socio-economic Pathways (SSP 1-2.6, SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5). All bias corrected and downscaled simulations stored in the Narval supercomputer, as well as various methods for bias correction for high-resolution climate model simulations of the continental US (CONUS) regions I and II, as well as western Canada, produced by the Weather Research and Forecasting (WRF) model. Many hydrological and agricultural applications of WRF-CONUS-II simulations require bias-correction before use. The project team conducted a comparison of the WRF-CONUS-II 4km data against major reanalysis datasets (ERA5), observational analyses (CaPA, RDRS), and selected meteorological observation sites. In addition, the team has developed a new method based on MBCn and machine learning to bias-correct the dynamically downscaled climate projection by the convection-permitting WRF. This method preserves the large-scale features of observed patterns in reanalysis while adding detail from RCM simulations and maintains the climate change signals between the future projection and the historical simulation.

CONUS 2: As part of the collaboration with the US National Center for Atmospheric Research (NCAR) hydrometeorology group, the team conducted the second phase of the 4-km WRF CONUS II simulation, which covers most of the US and Canada. This simulation utilized a newer version of the WRF model, version 3.9.1.1, with 51 vertical levels, and included new features such as the Xu-Randall and Thompson cloud fraction scheme and a new groundwater scheme with the saturated aquifer added to the bottom layer. The dataset includes both control (historical) and future PGW simulation data with a resolution of 4km and 12km, and is available to the GWF community via the GWF project directory ~/projects/rpp-kshook/Model_Output/wrf-conus/CONUSII on the Graham cluster of Compute Canada.

GEM simulations over the Canadian Rockies: Work is underway to evaluate the Canadian regional climate model (CRCM6/GEM5) over western Canada. As for all climate models, an evaluation of simulated variables is required to ensure reliability of the model and its validation conditions. The simulated precipitation from CRCM6 must be evaluated and compared to observations: a methodology to compare datasets among them, which includes satellite and gridded datasets, is being designed. Multiple year simulations are being conducted and will be evaluated with these datasets.

Propagation of uncertainties in spatial meteorological forcing data into simulations of hydrologic processes: Evaluation of how uncertainties in spatial meteorological forcing data impact simulations of hydrological processes across large domains has been completed. A process-based hydrological model was driven with the recently-developed Ensemble Meteorological data for Planet Earth (EM-Earth) over global cryospheric basins and for the global land area. The results illustrate that forcing data uncertainties are damped in both snowmelt-dominated river basins (where uncertainties in individual storm events cancel out during the snow accumulation season) and in larger river basins (where uncertainties cancel out because of the spatial averaging process). The research also illustrates uncertainty hotspots where additional station observations will be particularly helpful.

Current generation modelling

Non-contributing area: The recently developed Hysteretic and Gatekeeping Depressional Model (HGDM), which is based on the known hysteretic relationships of prairie depressions, was integrated into Canada's MESH land surface model. The modified MESH model (with HGDM, referred to as MESH-HGDM) and the MESH model with its conventional/conceptual prairie algorithm (MESH-PDMROF) have been tested on several prairie basins in Canada. Results show that MESH-HGDM produces improved streamflow simulations compared to the MESH-PDMROF. The HGDM implementation methods proposed here are designed for use in any hydrological or land surface modelling system, to improve simulation of the complex prairie hydrology and streamflow. Additionally, a model-agnostic variable contributing area algorithm was developed as a spatially distributed (the ensemble-depression model) and a spatially lumped model (the meta-depression model). These developments were the basis for new variable contributing area algorithms implemented in the Hydrological Predictions for the Environment (HYPE) model and evaluated in the Canadian Prairies. The local lake module of HYPE was replaced with a hysteretic depressional storage connection algorithm to estimate the variable contributing fractions of sub-basins. The modified model showed significant improvements in simulating streamflow of the Smith Creek Research Basin and St. Denis National Wildlife Area in Saskatchewan, Canada. The development has been communicated with SHMI and the global HYPE modelling community can now simulate an important hydrological phenomenon, previously unavailable in the model.

Application of CRHM for studying changes: The Cold Regions Hydrological Model is being used for several applications (1) evaluating the elasticity for two basins with contrasting biophysical and meteorological characteristics typical of eastern Canada: a forested boreal climate basin (Montmorency) versus an agricultural hemiboreal basin (Acadie) Projected peak SWE were highly sensitive to warming, particularly for milder baseline climate conditions and moderately influenced by differences in biophysical conditions. Biophysical conditions mediated a wide range of differing hydrological processes and streamflow responses to climate change. Under current conditions, precipitation and discharge were found to be more synchronized in the greater relief and slopes of the forested basin, whereas under climate change, they were more synchronized in the agricultural basin due to reduced infiltration and storage capacities. These findings help diagnose the mechanisms controlling hydrological response to climate change in cold regions forested and agricultural basins. In a separate study, the impact of projected changes in climate and glacier cover on the hydrology of several natural flowing Bow River headwater basins in the Canadian Rockies using CRHM. Hydrological models were constructed and parameterised in CRHM from local research results to include relevant streamflow generation processes for Canadian Rockies headwater basins, such as blowing snow, avalanching, snow interception and sublimation, energy budget snow and glacier melt, infiltration to frozen and unfrozen soils, hillslope sub-surface water redistribution, wetlands, lakes, evapotranspiration, groundwater flow, surface runoff and open channel flow. Surface layer outputs from Weather Research and Forecasting (WRF) model simulations for the current climate and for the late 21st century climate under a 'business-as-usual' scenario, Representative Concentration Pathway 8.5 (RCP8.5) at 4-km resolution, were used to force model simulations to examine climate change impact. Under the RCP8.5 climate change scenario, the basins of the Bow River at Banff and Elbow River at Calgary will warm up by 4.7 and 4.5°C respectively and receive 12% to 15% more precipitation annually, with both basins experiencing a greater proportion of precipitation as rainfall.

Application of MESH for studying detailed hydrology and changes: A mountain version of MESH has been developed to account for slope and aspect that is essential for radiation adjustment for mountain hydrology simulations. The experimental design included benchmark model runs with the default configuration and parametrizations alongside optimized model parameters, through both model calibration and model validation across space and time. The spatial validation also confirmed improved model performance. Comparison of point annual mass balance of glacier and snow water equivalent simulation showed that Mountain MESH was better than the benchmark version. The results reveal the need to incorporate some level of detail sub-grid variability accounting for high mountain basins to properly represent the water and energy budget in these complex landscapes.

MESH has also been used to assess the impact of phase change in precipitation for Saskatchewan River Basins (SRB) from their headwaters in the Canadian Rockies to its lower reaches in the Canadian Prairies and boreal forest using meteorological data from 1971 to 2100. Using the psychrometric energy balance phase partitioning method, the changing characteristics of snowfall and rainfall were shown to cause substantial changes in runoff generation mechanisms and streamflow over time that depended on elevation and ecozone. The uncertainty introduced by temperature-based phase partitioning methods was substantial for the historical period and became even more pronounced in the future, suggesting that empirical phase partitioning methods are a large and unnecessary contributor of uncertainty for large scale hydrological predictions of climate change impacts. MESH has also been used for studying the Mackenzie River Basin (MRB), which is underlain by permafrost for much of its extent. The MESH hydrological land surface model was set up over the MRB, from the Columbia Icefields to the Arctic Ocean, forced with bias-corrected downscaled RCM forcings and parameterized with deep soil profile (to 50 m) and organic soil, to simulate permafrost dynamics. Some parameters were then fine-tuned to reproduce the spatial distribution of permafrost occurrence provided by several gridded datasets, and model was validated using site-based active layer depth or soil temperature observations. The model was partially calibrated against streamflow observations in selected sub-basins. The resulting high-fidelity model was then used to simulate both the hydrology and permafrost dynamics in the basin under the RCP8.5 climate change scenario. The results show alarming rates of permafrost thaw, to the extent that most of the basin will be permafrost-free by the 2080s. Streamflow hydrographs show shifts to earlier and higher peaks in response to projected increases in precipitation and temperature. Baseflow discharges are projected to increase, partly due to improved connectivity because of permafrost thaw and partly due to increased precipitation.

A vector-based version of MESH, including mountain formulation is being used for Upper Columbia and Okanagan River basins that are characterized by irrigation, communities, and the functioning of hydropower dams and reservoirs in British Columbia and the northwest United States. The vector setup was then used to evaluate the effect of logging, disease and forest fires, and the subsequent forest disturbance and regeneration on the hydrology was studied. Forest representations were segregated into four species classes: Spruce, Pine, Fir, and Hemlock. In addition, forest harvesting, mountain pine beetle impact on pine, regrowth, and wildfire were parameterized separately. The methodology developed to model forest disturbance and regrowth is innovative at a continental scale.

Another MESH setup was used in New Brunswick's Saint John River Basin (SJRB), an important transboundary coastal river basin in northeastern North America. Model benchmarking for the SJRB using four different meteorological forcing datasets were carried out. Using the best performing forcing data and model parameters, the water balance of the basin was studied. Results showed meteorological forcing data play a pivotal role in model performance and can introduce a large degree of uncertainty in hydrological modelling. The simulation of future flows projects higher winter discharges, but summer flows are estimated to decrease in the 2041–2070 and 2071–2100 periods compared to the baseline period (1991–2020). However, the evaluation of model errors indicates higher confidence in the result that future winter flows will increase, but lower confidence in the results that future summer flows will decrease.

Sensors and observations: The overall motivation for this aspect of the GWF project, Transformative Sensor Technologies and Smart Watersheds, was to develop methodologies for remote and near real time data collection at the watershed scale in support of advanced modeling applications. Along with the data focus, development and application of new modeling tools for integrated watershed modeling and the simulation of groundwater hydrology within discontinuous permafrost environments was undertaken with approaches such as Machine Learning. The work has illustrated both the applicability and limitations of Artificial Intelligence (AI)-based models to predict local hydrologic phenomena. Solinst Canada is considering approaches to integrate the AI methods into their novel commercial data logging systems. In addition to AI, data-based modeling, low elevation geophysical surveys (air-borne electromagnetics, AEM) to map permafrost continuity were completed in collaboration with a new partner, Xcalibur Multiphysics, the GNWT, and First Nations partners within the Sahtu Renewable Resources Board within the Bogg Creek GWF Observatory in the Central Mackenzie Valley region of the NWT. Finally, additional advancements in a new generation of numerical modeling tools based on thermal, mechanical, hydraulic and solute transport processes as applied to permafrost thaw dynamics have been realized during the past project year. The combined results of data collection and new modeling tools are being adopted to inform the role of shallow and deep groundwater flow systems on land surface processes, ecology, and surficial hydrology through the use of watershed scale models.

### Next generation modeling

HGDM model: The Prairie Pothole Region of western North America has unusual hydrology and hydrography. Due to low permeability substrates, depressions are not connected by sub-surface flow and, only when runoff is occurring from one to the next, do ephemeral drainage networks become active. Existing models are either computationally intensive and require high-resolution Digital Elevation Model (DEM) data that may not exist, or require calibration and cannot reproduce the hysteresis between the basin connected fraction and depressional storage. The Hysteretic and Gatekeeping Depressions Model (HGDM) has been developed to simplify modelling of prairie basins with variable connected/contributing fractions.

The model uses 'meta' depressions to model the hysteretic responses of small depressions and a discrete model of large depressions, which cause ‘gatekeeping’, meaning that they prevent upstream flows from reaching the outlet until the depressions are filled. Similar to MESH, the HGDM was added to the Cold Regions Hydrological Modelling (CRHM) platform using CRHM’s built-in macro capability. It is demonstrated that CRHM+HGDM can reproduce the relationship between the connected/contributing fractions of a basin and its depressional storage at least as well as existing models. By using two meta-depressions, the effects of wetland drainage can also be simulated. Importantly, it appears that HGDM can be used with coarse-resolution Digital Elevation Models (DEM)s, which may permit its use in the many locations where higher-resolution data is unavailable.

Wind mapper: Estimates of near-surface wind speed and direction are key meteorological components for predicting many surface hydrometeorological processes in water models. However, observations of near-surface wind are typically spatially sparse. The use of these sparse wind fields to force distributed models, such as hydrological models, is greatly complicated in complex terrain, such as mountain headwater basins. In these regions, wind flows are heavily affected by overlapping influences of terrain at different scales. This can have significant impact on calculations of evapotranspiration, snowmelt, and blowing snow transport and sublimation. The use of high-resolution atmospheric models allows for numerical weather prediction (NWP) model outputs to be dynamically downscaled. However, the computational burden for large spatial extents and long periods of time often precludes their use. A wind-library approach was presented to aid in downscaling NWP outputs and terrain-correcting spatially interpolated observations, preserving important spatial characteristics of the flow field at a fraction of the computational costs of even the simplest high-resolution atmospheric models. This approach improves on previous implementations by scaling to large spatial extents, approximating lee-side effects, and fully automating creation of the wind library. Overall, this approach was shown to have a 3rd quartile RMSE of 1.9 m·s^(-1) and a 3rd quartile RMSE of 60.23^∘ versus a standalone computational fluid dynamic (CFD) model. The wind velocity estimates versus observations were better than existing empirical terrain-based estimates and computational savings were approximately 100-fold when compared with the CFD model.

### Geospatial intelligence

Workflow, CWARHM and packages: There have been substantial advancements in coding infrastructure. Work on streamlining and standardization on model configuration code has led to development of model-agnostic workflows called Community Workflows to Advance Reproducibility in Hydrologic Modeling (CWARHM). These workflows are collections of model configuration code that separate data processing steps that do not depend on any idiosyncrasies of a given hydrologic model (i.e., processing steps that are model-agnostic) from those steps that do impose model-specific requirements on the data. The result is that much of the processing code can be shared freely between different models. Adapting the workflow code to a new model only requires writing a new model-specific interface layer, while most of the preprocessing code can remain as is. This concept was developed using the SUMMA model as an initial implementation and has now been expanded to the MESH and HYPE models. The benefits of adopting a model-agnostic workflow approach are that (1) the time costs of model configuration for a new domain are drastically reduced, (2) model configuration becomes much more transparent, (3) reproducibility of modeling experiments is ensured, and (4) a community-based approach to modeling is encouraged.

Across the core modeling computational infrastructure, Digital Research Alliance of Canada (formerly known as Compute Canada), tools have been developed that help modellers to use command line to extract geospatial data from a unified location. These datasets are gridded climate forcing data, satellite data on landcover and soil type, for example. The data tool has been developed to allow the GWF core modeling tool to redo subsetting of various forcing variables, such as precipitation and temperature, from various datasets for a region of interest on multiple cores that can speed up the forcing presentation for modelling and other analysis. In addition, there are packages that are in use for remapping the gridded data to any shape such as sub-basins or point data (EASYMORE). One aspect of set up surface water models is generating statistics of geospatial data for various datasets such as landcover, soil type, or average elevation for a given region within defined subbasin(s). for that purpose, and based on a very efficient zonal statistic code. A GIS tool was developed based on the command line interface on Digital Research Alliance of Canada computational resources for GWF core modellers.

Benchmarking dataset: In addition to the built infrastructure for model building and data preparation, large-domain modelling efforts (e.g. continental, global) need to balance the depth of analysis with the breadth of available simulations. Evaluation of model simulations on smaller, dedicated benchmarking data sets that contain a representative subset of basins from the larger domain enable more detailed analysis while retaining generality of conclusions. Such datasets have become increasingly common over recent years but these typically focus on simpler surface water hydrological models by providing only a limited selection of meteorological variables at daily time resolutions, and typically treat catchments as single, lumped entities. The CAMELS-spat project has addressed these concerns by creating a benchmarking dataset for the North American continent that specifically targets spatially-distributed process-based hydrologic models. The dataset includes (near-)natural basins in the United States and Canada, as identified by the United States Geological Survey and the Water Survey of Canada respectively. Basins in the dataset are broken into sub-basins to allow spatially distributed modeling, and meteorological data provided contains those variables needed to run process-based hydrological models at sub-daily time steps. The CAMELS-spat data set will enable targeted evaluation of the spatially-distributed, process-based models that are required to simulate and predict hydrologic behavior across the North American continent, over timescales from seconds to centuries.

Space-based, global-extent digital elevation models (DEMs) are key inputs to many Earth Sciences applications. Many of these applications require the use of a 'bare-earth' DEM versus a digital surface model (DSM), the latter of which may include systematic positive biases due to tree canopies in forested areas. Critical topographic features may be obscured by these biases. Vegetation-free datasets have been created by using statistical relationships and machine learning to train on local-scale datasets (e.g., lidar) to debias the global-extent datasets. Recent advances in satellite platforms coupled with an increased availability of computational resources and lidar reference products has allowed for a new generation of vegetation- and urban-canopy removals. One of these is the Forest And Buildings removed Copernicus DEM (FABDEM), based on the most recent and most accurate global DSM Copernicus-30. Amongst the more challenging landscapes to quantify surface elevations are dense forested mountain catchments where even airborne lidar applications struggle to capture surface returns. The increasing affordability and availability of UAV-based lidar platforms has resulted in new capacity to fly modest spatial extents with unrivalled point densities. These data make it possible to validate global sub-canopy DEMs against representative UAV-based lidar data. In this work, the FABDEM is validated against an up-scaled lidar data in a steep and forested mountain catchment considering elevation, slope, and Terrain Position Index (TPI) metric, allowing comparisons of FABDEM with SRTM, MERIT, and the Copernicus-30 dataset. It was found that the FABDEM had a 24% reduction in elevation RMSE and 135% reduction in bias compared to the Copernicus-30 dataset. Overall, the FABDEM provides a clear improvement over existing de-forested DEM products in complex mountain topography such as the MERIT DEM. This study supports the use of FABDEM in forested mountain catchments as the current best-in-class data product for hydrological modelling.

Parameter estimation using sensitivity: For the parameter identification, various efforts have been underway to: (1) assess geospatial representation by comparing various model configurations using different levels of geospatial data in model set up (2) analyse sensitivity and uncertainty. The model workflow, CWARHM, allows setting up the models in various spatial configurations in a very fast and efficient way. For example, a model can include slope and aspect and be more detailed in comparison to another setup which treats the sub-basins as flat-earth concepts. A modeller can then evaluate adding or removing geospatial complexity to find the 'best' geo-spatial detail representation based on model simulation for a given purpose. Additionally to estimate model parameters, is a critical step in setting up a functional model, sensitivity methods are utilized and developed. A frugal sensitivity analysis method called VISCOUS has been proposed. The advantage for the VISCOUS method is the ability to reuse any historical model simulation without a specific structure in sampling. VISCOUS is now available for public users as a Python package on PyPI (the new package is named pyVISCOUS).

### Forecasting

Canadian operational forecasting: Operational flood forecasting in Canada is a provincial responsibility. However, the increasing costs and impacts of floods require better and nationally coordinated flood prediction systems. A more coherent flood forecasting framework for Canada can enable advanced prediction capabilities across the different entities with responsibility for flood forecasting. Recently, Canadian meteorological and hydrological services were tasked to develop a national flow guidance system. Alongside this initiative, the Global Water Futures program has been advancing cold regions process understanding, hydrological modeling, and forecasting. A community of practice was established for industry, academia, and decision-makers to share viewpoints on hydrological challenges. Taken together, these initiatives are paving the way towards a national flood forecasting framework. Forecasting challenges have been identified (with a focus on cold regions), and recommendations made to promote creation of this framework. These include the need for cooperation, well-defined governance, and better knowledge mobilization. Opportunities and challenges posed by the increasing data availability globally are also highlighted. Advances in each of these areas are positioning Canada as a major contributor to the international operational flood forecasting landscape.

Snowcast: Large-extent estimates of snow water equivalent (SWE) are of significant value for water resource estimates in mountain headwaters. Substantial temporal and spatial variability in snow accumulation and ablation in complex terrain makes these estimates challenging. Long-term research to understand and simulate the spatial and temporal variability in energy and mass associated with cold regions hydrology has resulted in the Canadian Hydrological Model (CHM), a distributed multiphysics model development and deployment framework. It is capable of a multi-scale surface discretization to permit greater spatial resolution where it is warranted, such as in high mountains. CHM includes snow phase partitioning, wind redistribution, avalanching, canopy interception, sublimation, accumulation, and ablation processes as well as sophisticated spatially variable wind and energetics calculations for complex terrain and forest canopies. The Canadian Hydrological Model was applied to simulate late winter snow covers at snowdrift resolving scales across the Canadian Cordillera (1.3 million km2) forced by Environment and Climate Change Canada's High Resolution Deterministic Prediction System (HRDPS) meteorology at 2.5 km. Model results show headwater basin scale snow dynamics and their spatiotemporal variability. The model outputs were compared with Sentinel and Landsat imagery to evaluate snow-covered area predictions during winter and ablation periods. These represented snow-covered area quite well.

MESH Yukon: A vector-based MESH setup for the Canadian portion of the Yukon River Basin down to Eagle, Alaska was further developed for operational flow forecasting. In forecast mode, MESH is driven by the Environment and Climate Change Canada Global Multiscale Model (GEM) weather model forecasts with precipitation replaced with the Canadian Precipitation Analysis (CaPA) that assimilates local precipitation observations where they exist, collectively referred to as GEM-CaPA. A pilot study of the potential benefits of snow data assimilation into the existing MESH forecast system was conducted, using historical data and the gridded MESH product that is used operationally by Yukon Environment. This test showed benefits to assimilating surface snowpack observations into MESH to correct winter precipitation. Outputs with assimilation showed improved snowpack simulations and improved streamflow forecasts.

Data assimilation can be used to improve snowpack simulations by supplementing uncertain model forcing data with more certain snowpack observations. This work measured snow water equivalent (SWE) and daily snow depth (ds) with estimates of snowpack density (ρ) assimilated into a physically based snow hydrology model using an ensemble Kalman filter (EnKF). The Cold Regions Hydrological Modelling platform (CRHM) was forced by Global Environmental Multiscale (GEM) model 2.5 km output. Multiple DA experiments were conducted in the well instrumented Marmot Creek Research Basin in the Canadian Rockies, which is subject to snow interception and blowing snow redistribution. Assimilating frequent ds measurements alone improved SWE very little due to the sometimes-poor prediction of ρ by the CRHM snowpack module. Assimilating SWE alone generally improved the accuracy of the SWE simulation, but due to infrequent SWE observations, the improvement was small during the early accumulation and late melt periods and in dry years. A combined DA approach using both SWE and ds provided better results than assimilating ds alone but was not as good as assimilating SWE alone, indicating that assimilating more information doesn't always lead to better results. Assimilation of ds and historical or simulated snowpack density together was close to the performance of assimilating SWE alone in parts of the basin where CRHM simulated ρ poorly, suggesting an alternative when SWE measurements are not available. The DA experiments strongly suggest that data assimilation is beneficial when using numerical weather prediction model output to force CRHM.

Data Driven Seasonal Forecasting: Work is underway to develop workflows for data-driven seasonal hydrological forecasting. The work is prepared in a Jupyter notebook and is based on basin classification to nival or glacial regime, discharge estimation based on WSC HYDAT, snow water equivalent or SWE for forecasting and hindcasting verification. Currently the workflow is being extended to USA.

Water quality modeling

Coding infrastructure; OpenWQ | Improving OpenWQ and coupling it to SUMMA, CRHM and MizuRoute. A one way coupling strategy for integration of OpenWQ (multi-chemistry model) into the three main hydrological systems of the GWF project - CHRM (Cold Regions Hydrological Model), SUMMA (Structure for Unifying Multiple Modeling Alternatives), and MESH (Modélisation Environnementale Communautaire - Surface Hydrology) was developed. A generic coupler compromising a series of coupler and wrapper-interface functions that can be used with the different hydrological models have been prepared. Established procedures for mapping data structures between OpenWQ and the different hydrological models were created. The codes, scripts and coupler were tested for SUMMA-OpenWQ and CRHM-OpenWQ for 10 synthetic tests.

Human water dimension

This theme was formed in 2022 to function as an interdisciplinary theme that studies the inter-related ways that societies and people are impacted directly by water resources. Human Dimension of Water, as an important and wrapping up theme, looks into four major aspects (1) Infectious disease: (2) Vectorborne disease: (3) Flood and drought resilience: (4) Governance metrics. Three HQP were hired in second half of 2022 and are continuing to 2024 to build based on the other themes findings.

HQP have been involved in developing work plans and carrying out literature reviews on disease vectors and climate change and on the impacts of flood and droughts. A systematic review aimed to assess the current state of knowledge on the mechanisms through which climate change affects water-related vector borne diseases in temperate regions. Analysis, revealed that climate change could intensify pathogen development and infectivity, create favorable vector breeding habitats, make the temperature suitable for vectors development and abundance, increase geographic distribution of vectors, and increase vectors-to-hosts contact or exposures. The review highlighted the importance of reducing climate driven risk factors of vector borne diseases such as mitigating greenhouse gas emission to limit global warming. Further research is needed to understand the effect of climate drivers on the fundamental biological processes and mechanisms involved in transmission dynamics. A second thrust focuses on flood vulnerability in the Saskatchewan River Basin (SRB) and the need for adaptation planning due to increasing frequency and intensity of extreme weather events caused by climate change. The study is developing a Flood Vulnerability Index (FVI) based on physical and social vulnerability factors, consisting of four dimensions: social, economic, environmental, and hydrological vulnerability. The FVI is based on 18 indicators that were assigned an equal weight after normalization. The results identify high-risk areas of flooding based on the socioeconomic and hydrological characteristics of the region, which policymakers can use to prioritize flood risk reduction strategies and improve community resilience to flooding.

#### Water management

The water management team had one HQP in the last year, mostly focused on IMPC deliverables. The water management deliverables are either delivered in earlier years or is in publication process (such as mizuRoute-Lake, Planetary Water Prediction Initiative, PWPI).

#### Hydro-economics

Impact of environmental regulation on the economy: More than a third of Canada's GDP is generated in and around the Great Lakes region (GL). Economic interests affected by pollution and pollution control are high. New policies to reduce pollution are often insufficiently informed due to the lack of integrated models and methods that provide decision-makers insight into the direct and indirect economic impacts of their policies. The impacts of different total phosphorus (TP) restriction policy scenarios across the GL were evaluated on GDP. A first of its kind multi-regional hydro-economic model was built for the Canadian GL, extended to include TP emissions from point and non-point sources. This optimization model was furthermore extended with a pollution abatement cost function that allows sectors to also take technical measures to meet imposed pollution reduction targets. The latter is a promising new avenue for extending existing hydro-economic input-output modeling frameworks. The results show decision-makers the least cost-way to achieve different TP emission reduction targets. The estimated cost to reduce TP emissions by 40% in all GL amounts to a total annual cost of 3 billion Canadian dollars or 0.15% of Canada's GDP. The cost structure changes substantially as policy targets become more stringent, increasing the share of indirect costs and affecting not only the economic activities around the GL, but the economy of Canada as a whole due to the tightly interwoven economic structure.

[Link to Publications List]

## Knowledge Mobilization (KM)

The work on the Water Quality Evaluation Model (WQVM) is conducted in direct collaboration with Environment and Climate Change Canada (ECCC).

The model agnostic framework is accessible through GitHubUsers (who are currently also partners in developing) are University of Saskatchewan, University of Calgary, and ECCC.

#### Events

- Collaborative visit at the Alberta Weather Forecasting Agency, Edmonton, April 2023

- Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023
- Collaborative visit at the Environment Climate Change Canada (ECCC) in Montreal, February 2023
- Great Lakes roundtable discussion with the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada, Niagara Falls, Canada, September 28, 2022
- Science Briefing on the Water Resources of the South Saskatchewan River to the Saskatchewan Party Caucus MLAs and Meewasin Valley Authority Board of Directors, Saskatoon, Saskatchewan, June 28, 2022
- Panelist, High-level panel on the Canada Water Agency, towards innovative water management, Global Water Futures (GWF) Annual Open Science Meeting, Virtual, May 16, 2022
- Expert Review Panelist, Swiss Federal Institute WSL for Forest, Snow and Landscape Research evaluation panel, ETH Zurich, Mar 2022 - Feb 2023

# Transformative Sensor Technologies and Smart Watersheds (TTSW)

Web Link: https://uwaterloo.ca/transformative-technologies-smart-watersheds/

Region: Canada

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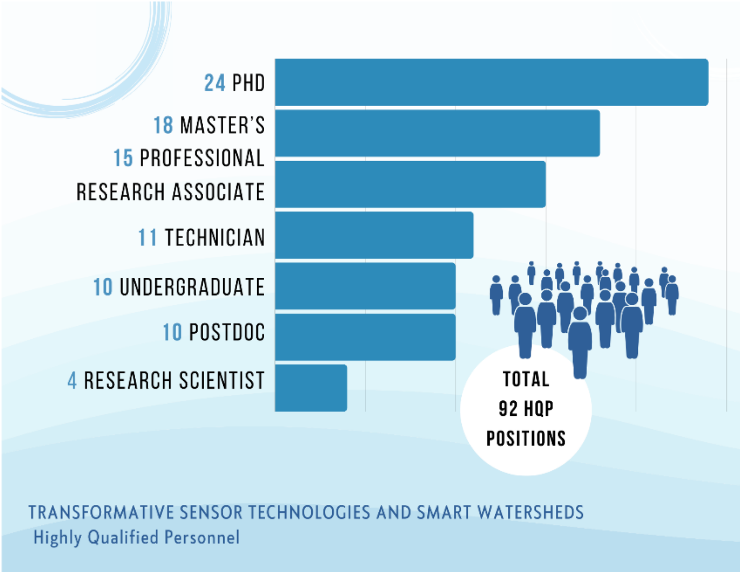
## Investigators

Claude Duguay, University of Waterloo
Contact: crduguay@uwaterloo.ca
David Rudolph, University of Waterloo
John Pomeroy, University of Saskatchewan
Richard Kelly, University of Waterloo
Aaron Berg, University of Guelph
Armaghan Salehian, University of Waterloo
Carolyn Ren, University of Waterloo

## Partners, Collaborators and Users

Campbell Scientific -- Carl de Leeuw
Canada's Chief Scientific Officer -- Mona Nemer
Cenovus Energy -- Chris Salewich
Department of Earth Sciences, Indiana University-Purdue University -- Lin Li
DraganFly -- Zenon Dragan
Environment and Climate Change Canada (CCIW) -- Caren Binding, Chris Derksen, Josh King, Erica Tetlock
Fortress Mountain Holdings Ltd. 2012-2022 -- Chris Chevalier
German Research Centre for Geosciences -- Milad Asgarimehr
Govt. of the Northwest Territories/ESRF -- Andrew Applejohn
Lake Central Air Services -- Jim Hodgson
MetaSensing BV -- Adriano Meta
National Aeronautics and Space Administration (NASA) -- Nima Pahlevan
National Oceanic and Atmospheric Administration (NOAA-GLERL) -- Andrea Vander Woude
Plymouth Marine Laboratory -- Stefan G. H. Simis
Regional Municipality of Waterloo -- Eric Hodgins
Sahtú Renewable Resources Board -- Alyssa Bougie
Skaha Remote Sensing -- Maik Wolleben
Solinst Canada-- Jim Pianosi
Spire -- Philip Jales
Statistics Canada -- Francois Soulard
Sustainable Development Goals Unit -- Ugo Therien
The Image Processing Laboratory, University of Valencia -- Antonio Ruiz Verdú
U.S. Geological Survey Earth Resources Observation and Science (EROS) Center -- Christopher J. Crawford
Université du Québec à Rimouski Département de biologie, chimie et géographie -- Simon Bélanger
Université du Québec à Trois-Rivières -- Alexandre Roy
University of Waterloo -- Jimmy Lin
Water Security Alliance -- Andrew Schofield
Western Economic Diversification -- Abdul Jalil
Wilfrid Laurier University -- Jennifer Baltzer
Wilfrid Laurier University -- Phil Marsh
Wisconsin Department of Natural Resources -- Daniela Gurlin
Xcalibur Multiphysics -- Adam Smiarowski




Highly Qualified Personnel: Professional training and research positions funded by Transformative Sensor Technologies and Smart Watersheds

## Science Advances

Canada's water resources are vast and span an enormous range in geography, climate and ecosystems. Understanding and adapting to short and long-term water threats in the face of climate change requires a transformative enhancement to the way environmental data are collected and communicated. The goal of the TTSW project was to deliver these enhancements through collaboration with industry and government to develop, test, and implement technologies for monitoring water quality and quantity. This included ground-based, drone, and airborne sensors, satellite remote sensing technologies, and artificial intelligence (AI) – machine learning/deep learning algorithms, as well as "smart" sensor communication modems intended to deliver valuable environmental data in near-real time.

The TTSW project was set up to accomplish five tasks. Key accomplishments, with an emphasis on the last year of activities, and contributions in advancing water science in Canada and globally, follow.

1. Improvement of measurements of environmental parameters in cold regions by developing new sensors and improving existing sensors

a) Development of microwave microfluidics-based sensing method for the detection of lead ions in drinking water: A microwave resonator coated with gold nanoparticles was developed that can sense concentrations as low as 1 ppb of lead ions in both DI water and tap water that passes through the microchannel, which is perpendicularly arranged with the resonator's capacitive gap. The method is reliable for Point of Care (POC) applications because it has demonstrated similar sensing performance when using a high-precision commercial vector network analyzer (VNA) and a low-cost, portable Nano-VNA although more improvements can be made to improve the accuracy and resolution of the Nano-VNA. The continuous flow nature and no contact between the sensor and sample are appealing as compared to many electrochemical sensors for metal ion detection.

This work contributes to the solving of water related challenges in Canada and globally. The sensor developed has been designed to monitor water quality and to provide warning to people about water quality, which is important for improving disaster warning. The utilization of microfluidics and portable devices allows the development of POC devices that create opportunities for broad use of the sensor for heavy metal detection in water systems. In the future, efforts are planned to improve the current sensor design and development: (1) The microwave sensor substrate may be replaced with PCB boards which are less expensive in fabrication and can be produced in large quantities to maintain a uniform quality. (2) To improve the sensors' selectivity, some bio-probes could be used to operate with microwave microfluidic sensor to improve sensor selectivity.

b) Design and deployment of specialized data collection platform: In close collaboration with industry and academic partners both in Canada and internationally, a novel platform equipped with radiometers was recently designed and deployed to precisely measure the water leaving reflectance of water bodies in Saskatchewan. This effort is aimed at refining atmospheric correction models applied to satellite observations for improving the accuracy of water quality assessments (e.g., chlorophyll-a and phycocyanin) in water bodies, which can be highly beneficial to other GWF projects (e.g. Lake Futures, FORMBLOOM) and for informing work on the development of AI-driven algorithms for the measurement of water quality parameters globally from current and upcoming international multi- and hyperspectral satellite missions.

2. Establishment of pan-Canadian cold regions' environmental sensor network testbeds

The overall motivation for this task was to develop methodologies for remote and near real time data collection at the watershed scale in support of advanced modeling applications. Along with the data focus, development and application of new tools for integrated watershed modeling and the simulation of groundwater hydrology within discontinuous permafrost environments was undertaken. Over the last year, emphasis has been placed on data analysis utilizing machine learning (ML) and aspects of artificial intelligence (AI) with terrestrial hydrologic applications. Time series data sets from the Alder Creek GWF Observatory have been utilized to develop a series AI predictive model for groundwater level fluctuation and the initial manuscript on these results has been submitted. The work has illustrated both the applicability and limitations of AI-based models to predict local hydrologic phenomena. Industrial partner Solinst Canada is considering approaches to integrate the AI methods into their novel commercial data logging systems, partially created through this project

In addition to the AI, data-based modeling, low elevation geophysical surveys (airborne electromagnetics, AEM) to map permafrost continuity were completed in collaboration with a new partner, Xcalibur Multiphysics, the GNWT and First Nations partners within the Sahtu Renewable Resources Board within the Bogg Creek GWF Observatory in the Central Mackenzie Valley region of the NWT. Survey results showed the AEM methods' ability to map permafrost continuity at a regional scale and illustrated the relationships between permafrost continuity, geology and occurrence of surface water features.

Finally, additional advancements in a new generation of numerical modeling tools based on thermal, mechanical, hydraulic and solute transport processes as applied to permafrost thaw dynamics have been realized during the past project year. Currently, the AEM data combined with additional local subsurface information (surficial and bedrock geology, surface hydrology) are being used to inform predictive groundwater models in discontinuous permafrost terrain. The combined results of the data collection and new modeling tools are being adopted to inform the role of shallow and deep groundwater flow systems on land surface processes, ecology and surficial hydrology through the use of watershed scale models.

3. Assessment and improvement of drone technology to operate in cold weather and to provide an intermediary scale of environmental measurements for monitoring

Airborne, remotely controlled drones provide a flexible platform from which to collect high-resolution geospatial data on a user-defined temporal scale. To assess the utility of high-resolution, drone-based LiDAR for the study of snow accumulation and redistribution in a forested sub-alpine region, various land surface properties such as leaf area index, canopy coverage, snow-on-trees and sampling resolution were quantified and their agreement between LiDAR and in-situ observed snow depth was measured. In situ and drone-based measurements of snow depth were captured approximately every two weeks over two winters on a subalpine ridgetop. In situ snow depth measurements were taken at fixed locations between-trees and within tree-wells across the study site. High-resolution drone-based LiDAR was collected and processed into snow depth rasters at 5 cm, 10 cm and 50 cm resolution. LiDAR snow depths in open areas were found to have a consistent negative bias compared to in situ snow depths (mean bias 2 cm – 32 cm at 5 cm resolution). The strongest agreement between LiDAR and in situ snow depths was for 5 cm raster resolution at sites between trees (average agreement of 9.8 cm), and 50 cm resolution within tree-wells (average agreement of 5 cm). The results suggest differing optimal data collection and processing practices for LiDAR snow measurements between trees and under canopies, and the resulting errors for various practices and land surface conditions.

Whilst LiDAR can estimate snow depth, there remains an inability to measure snow water equivalent (SWE) at high spatial resolutions using remote sensing. Passive gamma ray spectrometry is one of the only well-established methods to reliably remotely sense SWE, but airborne applications to date have been limited to observing km-scale areal averages over shallow snow covers. Noting the increasing capabilities of remotely pilot uncrewed aerial vehicles (UAVs) and miniaturization of passive gamma ray spectrometers, the ability of a UAV-borne gamma spectrometer and concomitant UAV-borne LiDAR to quantify the spatial variability of SWE at high spatial resolutions was assessed. Gamma and LiDAR observations from a UAV were collected over two seasons from shallow, wind-blown, prairie snowpacks in Saskatchewan with validation data collected from manual snow depth and density observations. Gamma-based SWE estimated the areal average SWE within the uncertainty of the reference observations for all flights. However, the ability of UAV-gamma to resolve the spatial variability of SWE was sensitive to flight characteristics. Flights flown at a velocity of 5 m s-1, altitude of 15 m, and a line spacing of 15 m were unable to capture the spatial variability of SWE. Slower, lower and denser flightlines at a velocity of 4 m s-1, altitude of 8 m and line spacing of 8 m were able to represent it well at resolution greater than 20 m. Using a combination of UAV-based gamma SWE and UAV-based LiDAR snow depth permitted estimation of SWE at high resolutions, with the ±14 mm SWE error within the ±14.7 mm SWE error of the reference SWE dataset. UAV-borne gamma spectrometry to estimate SWE is a novel technique that has the potential to improve the measurement of shallow prairie snowpacks and when combined with UAV-borne LiDAR snow depth provides high resolution, high accuracy estimates of SWE than can provide the variances in SWE needed to calculate snow cover depletion curves during subsequent snowmelt. However, more research is needed to resolve hardware, data processing limitations, and interpretation challenges.

4. Improvement of spatially distributed measurements of snow water equivalent and near-surface soil moisture/freeze-thaw state

a) Snow Water Equivalent (SWE): A novel aircraft deployable synthetic aperture radar (SAR) system operating at Ku and L-band frequencies, called CryoSAR, was acquired from industrial partner MetaSensing through a CFI grant (PI: R. Kelly, U. Waterloo) to measure snow and ice properties. Due to delays in the delivery of the system and certification to fly the instrument package on a Cessna 208B (Caravan) platform, deployments only started in late 2022. Engineering/preliminary science flights took place from November to the end of March 2023 in conjunction with correlative measurements at two target field sites in Ontario: Powassan (Ontario) to represent land-based seasonal snow; and Haliburton Highlands for field experiments representing snow-covered lake ice. CryoSAR overflights were conducted when field crews were measuring snowpack microstructure and bulk snow properties. The majority of the acquisitions have been made in the 2022-2023 winter season under a Canadian Space Agency (CSA) project with support from GWF. A deployment of the CryoSAR system wasanticipated in May with some further testing in Fall 2023 to run intercalibration tests with other Ku-band instruments available through NASA and other partners. This intercomparison is in support of the Terrestrial Snow Mass Mission (TSMM) in development at ECCC/CSA with the primary objective of estimating SWE from space. The majority of effort through GWF and the CSA project will now be to create science-ready data that are calibrated for analysis and use with a land surface model that is being leveraged at ECCC as part of the TSMM mission.

b) Near-surface soil moisture/freeze-thaw state: In partnership with the Jet Propulsion Laboratory (JPL), we participated in a field experiment for improved retrieval of soil moisture in the boreal forest. The experiment, undertaken in summer 2022, involved the deployment of 34 weather stations including numerous in situ soil moisture probes and field-based teams to monitor and record vegetation properties. NASA's Passive Active L and S (PALS) sensor was flown on an aircraft during the sampling campaign to retrieve the spatial and temporal variability of L-band brightness temperature and backscatter for the refinement of operational algorithms for soil moisture retrieval over this environment. This research reveals that the satellite retrievals from the current NASA SMAP mission are significantly dry bias related to some parameterization issues in the current retrieval model. A demonstration of how these parameters could be optimized for improved retrievals in the boreal forest was demonstrated.

c) Drone-based L-band passive microwave radiometer for soil moisture retrieval: A prototype for an L-Band radiometer designed for deployment on UAVs was delivered and tested in October 2022. The radiometer was developed by industry partner Skaha Remote Sensing. Plans to deploy and operate this sensor were underway for Summer 2023.

5. Development of sensors and design concept of Microsatellite Water Mission

a) Microsatellite Water Mission design: Through an international collaboration (NASA and Plymouth Marine Lab in the UK, we evaluated the accuracy of remote sensing reflectance (Rrs) derived from three different atmospheric correction algorithms applied to the Sentinel-3 Ocean and Land Colour Instrument (OLCI) satellite observations over western Lake Erie (WLE) through comparison to a regional hyperspectral radiometric dataset resampled to OLCI spectral resolution. The effects of uncertainties in Rrs products on the retrieval of near-surface concentration of pigments, including chlorophyll-a (Chla) and phycocyanin (PC), from Mixture Density Networks (MDNs) were subsequently investigated. Results suggest the atmospheric correction algorithm most suitable for operational monitoring programs in WLE.

In addition, the data collection platform containing radiometers that the team has designed and deployed in lakes in Saskatchewan (see description under 1b above), in collaboration with the FORMBLOOM project, can make a significant contribution to the development of the Microsatellite Water Mission or similar concepts. Specifically, the hyperspectral radiometers installed on the platform can be used to determine the optimal bands and wavelengths for retrieving water quality parameters. This information can be used to design and develop the sensors required for the mission. By providing

accurate and reliable measurements of the water leaving reflectance in water bodies, this platform can aid in refining the algorithms and models that would be used for data analysis and processing. This, in turn, can enhance the accuracy and efficiency of the overall mission. Finally, the team has also conducted extensive analysis of data from medium-resolution satellite sensors, such as Landsat-8 and Sentinel-2, as well as commercial high-spatial resolution microsatellites such as PlanetScope. Through this analysis, we have determined the opportunities, advantages, and challenges of using current microsatellites for developing monitoring systems for water quality management in Canadian lakes. This information can aid in the development of the Microsatellite Water Mission's sensors and in refining the algorithms and models used for data analysis and processing. Overall, the work to date has contributed to the development of AI/ML algorithms and processing tools relevant not only to the microsatellite mission concept proposed at the beginning of the project, but also for consideration by the Canadian Space Agency (CSA) with their proposal of the WaterSat hyperspectral mission.
b) Hyperspectral instrument testing for water quality analysis: Hyperspectral remote sensing of water quality is anticipated to improve the accuracy of water quality retrievals through differentiating between optical characteristics of various algal pigments and optically active water constituents. In addition to testing new airborne-based instruments (sensors for consideration on future satellite missions) over Lake Erie in collaboration with NRC, the team has been investigating the challenges of synergistically using hyperspectral and multispectral satellite images for retrieving water optical characteristics (e.g., chlorophyll-a concentration; Chla). PRISMA images, and multispectral satellite datasets from MSI and OLCI onboard Sentinel-2A/B and Sentinel-3A/B, respectively, were acquired over five European water bodies. Chla field data were collected concurrently with the satellite observations, through an international collaboration with INRS-CNR (in Italy). The ACOLITE atmospheric correction model has been employed to reduce atmosphere interferences in all images. Mixture Density Networks (MDNs) have been applied to ACOLITE-corrected data to estimate Chla concentration. Other atmospheric correction models are being tested, again with the intent of delivering state-of-the-art atmospheric correction algorithms applicable to current and future multispectral and hyperspectral satellite missions.
c) GNSS-Reflectometry for the retrieval of soil moisture, lake ice phenology and thickness: Over the course of the project, the team developed and deployed a GNSS (L-band frequency) antenna aboard a drone and successfully demonstrated how reflected signals from land could be processed to estimate soil moisture. Similarly, the work showed that reflected signals measured by a GNSS antenna mounted on a mast on the shore of a lake could be used to estimate ice thickness as well as ice and overlying snow properties. In the past year, the project obtained GNSS-R satellite data from international industry partner Spire to explore the sensitivity of reflected GNSS signals to the presence of lake ice and its ability in lake ice phenology analysis. The study areas include Great Bear Lake and Great Slave Lake. Data have been processed and results were to be presented at IEEE GNSS+R workshop in May 2023 (Boulder, Colorado). In addition, GNSS-R data obtained from CYGNSS (a NASA-funded mission) have been processed and shown to be suitable for determining lake ice phenology). Moreover, the potential of upcoming GNSS-R missions, including HydroGNSS and Muon Space (new international collaborations), in monitoring lake ice physical properties have been evaluated in a short paper (IGARSS Proceedings), presented in July 2023, in Pasadena, CA. A new study includes the analysis of CYGNSS waveforms through machine-learning algorithms to detect lake ice cover over Qinghai Lake, Tibetan Plateau, using CYGNSS SNR observations which will then be tested with data from HydroGNSS and Muon Space satellites soon after launch (2023-2024) over Canadian lakes.

Link to Publications List

## Knowledge Mobilization (KM)

Project research results have been shared through traditional journal publications, presentations at technical scientific meetings, and with an extensive network of collaborators and partners.

One publication was a specific explanation of the value of Traditional Knowledge in groundwater.

The team has also provided summaries of the work in plain language through virtual meetings and written annual reports to partners within the GNWT and with the Sahtu Renewable Resources Board.

Industrial partners are making immediate use of the results from combined studies. Xcalibur Multiphysics is using the results from the project's airborne geophysics surveys as a promotional tool to expand their scope of work and applications of their technologies globally. Cenovus Energy is using results to understand more about natural hydrologic cycling and the fate of natural hydrocarbons within their areas of interest for exploration. Solinst Canada is working to integrate new AI modeling tools into their Smart Data logging systems. Finally, Aquanty Inc. is utilizing the results of the project's modeling activities to advance and modify their commercial hydrologic modeling platforms to expand applications for their clients and for new clients.

The project's First Nations collaborators in Norman Wells and Tulita have been interested in the results from the point of view of understanding potential impacts on the landscape that may influence, hunting, fishing and travel on the landscape.

Over the last three years, the team has worked with several GWF projects, governments, and partners, and disseminated research through meetings, workshops, and publications on the way to making transformative research solutions a reality. The team has collaborated with the GWF Northern Water Futures project, the Government of NWT, local Indigenous communities, as well as industrial partner Husky Energy at the Norman Wells Observatory (NWT).

Project researchers collaborated with the FORMBLOOM project via a PhD project and postdoctoral fellowship, the Canada Centre for Inland Waters (CCIW), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) on collection and processing of multi-scale hyperspectral/multi-spectral data over Lake Erie, Buffalo Pound Lake, and other lake regions of the world. Machine learning algorithms developed by GWF research scientist Dr. Kiana Zolfaghari in collaboration with CCIW, NASA and NOAA are now being considered for generation of cyanobacteria map products from future international satellite missions, including the concept being developed in by TTSW. TTSW is also informing both water quality and snow satellite mission concept studies for the Canadian Space Agency (CSA), led by project collaborators Dr. Caren Binding (water quality) and Dr Chris Derksen (snow) at Environment and Climate Change Canada (ECCC). Project work on GNSS-R is also informing industry (coll. Spire) about the capabilities of this technology for the monitoring of lake ice, inundation and soil moisture.

Meetings with governments, decision makers, practitioners

- Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023
- Great Lakes roundtable discussion with the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada, Niagara Falls, Canada, September 28, 2022
- Science Briefing on the Water Resources of the South Saskatchewan River to the Saskatchewan Party Caucus MLAs and Meewasin Valley Authority Board of Directors, Saskatoon, Saskatchewan, June 28, 2022
- Panelist, High-level panel on the Canada Water Agency, towards innovative water management, Global Water Futures (GWF) Annual Open Science Meeting, Virtual, May 16, 2022
- Expert Review Panelist, Swiss Federal Institute WSL for Forest, Snow and Landscape Research evaluation panel, ETH Zurich, Mar 2022 - Feb 2023.

Three articles in popular media
Public workshops and presentations

Kiana Zolfaghari: ECMWF–ESA Workshop on Machine Learning for Earth Observation and Prediction, Reading, UK, 14-17 November 2022

# Professional Development and Technology Transfer

The University of Saskatchewan Centre for Hydrology with the assistance of the Canadian Society for Hydrological Sciences offered an intensive course on the physical principles of hydrology with particular relevance to Canadian conditions. Factors governing hydrological processes in Canadian landscapes were be discussed including precipitation, interception, energy balance, snow accumulation, snowmelt, glaciers, evaporation, evapotranspiration, infiltration, groundwater movement and streamflow routing and hydraulics. These processes were framed within the context of distinctly Canadian landscape features such as high mountains, glaciers, peatlands, prairies, tundra, boreal forests, frozen rivers and seasonally frozen ground. Students were exposed to an overview of each subject, with recent scientific findings and new cutting-edge theories, tools and techniques. They completed numerical and essay assignments to develop skills in problem solving and in synthesizing complex hydrological concepts. Students emerged from the course with a deeper understanding of physical hydrological processes and how they interact to produce catchment water budgets and streamflow response. Number of HQP involved: 27

# Agricultural Water Futures: Stressors and Solutions

Web Link: https://uwaterloo.ca/global-water-futures/agricultural-water-futures-canada-stressors-and-solutions; https://publications.uwaterloo.ca/agricultural-water-futures/home/

Region: Canada (Great Lakes and Prairies)

Total GWF funding support: $1,193,550; 1,498,700

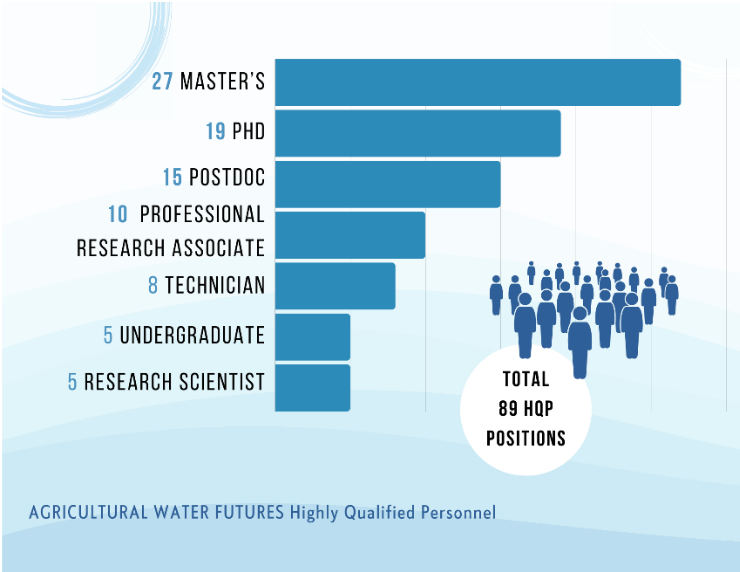
Project dates: June 2017-August 2023 EXTENDED to August 2024

## Investigators

Merrin Macrae, University of Waterloo Contact: mmacrae@uwaterloo.ca
Helen Jarvie, University of Waterloo
Rob Gordon, Wilfrid Laurier University, University of Windsor
Warren Helgason, University of Saskatchewan
Jane Elliott University of Saskatchewan
Helen Baulch, University of Saskatchewan
Rob de Loe, University of Waterloo
Terry Fonstad, University of Saskatchewan
Yanping Li, University of Saskatchewan
John Pomeroy, University of Saskatchewan
Rich Petrone, University of Waterloo
Roy Brouwer, University of Waterloo
Peter Deadman, University of Waterloo
Derek Robinson, University of Waterloo

## Partners, Collaborators, and Users

Agriculture and Agri-Food Canada (AAFC) -- Henry Wilson, Andy VanderZaag, Ward Smith, Budong Qian, Aston Chipanshi
Canada's Chief Scientific Officer -- Mona Nemer
Clavet, Livestock and Forage Centre of Excellence -- Ernie Barber
Croptimistic Technology Inc. -- Cory Willness
Environment and Climate Change Canada (ECCC) -- Jane Elliott
Grain Farmers of Ontario -- Josh Cowan
Grand River Conservation Authority -- Louise Heyming, Mark Anderson
International Plant Nutrition Institute (IPNI) -- Tom Bruulsema
Lower Thames Valley Conservation Authority -- Colin Little, Ryan Carlow
Nature 4.0 -- Riccardo Valentini
OMAFRA -- Kathryn Carter, Rebecca Shortt, Kevin McKague
Ontario Grape and Wine Research Inc. -- Eleanor Hawthorn
Sask. Farmer -- Dwight Odelein
Saskatchewan Cattlemen's Association -- Marianne Possberg
Saskatchewan Irrigation Projects Association -- Sandra Bathgate
Saskatchewan Ministry of Agriculture -- Andy Jensen, Abimfoluwa Olaleye
Statistics Canada -- Francois Soulard
Strategic Planning, Risk and Policy at SaskWater, Board of Directors -- Ingrid Newton
Sustainable Development Goals Unit -- Ugo Therien
United States Department of Agriculture: Agricultural Research Service (USDA-ARS) -- Peter Kleinman, Kevin King, Doug Smith, Mark Williams
University of Guelph -- Wanhong Yang
University of Guelph Andrew Reynolds
University of Manitoba -- David Lobb Don Flaten
University of Tuscia -- Ricardo Valentini
Water Security Alliance -- Andrew Schofield
Western Economic Diversification -- Abdul Jalil




Highly Qualified Personnel: Professional training and research positions funded by Agricultural Water Futures

# Science Advances

The fate of Canadian agriculture depends strongly on water availability, patterns of water use, and water quality. Key drivers include hydro-climatic and geomorphic factors, crop choices, land management practices, and governance systems. With a changing climate and changing hydrology, this fate is uncertain. This project is developing predictive tools, policy instruments and governance strategies to support the sustainable management of water resources in the agricultural regions of Canada. Improved understanding of how climate change will modify water supply, use and quality should improve adaptation, help identify which management practices and governance approaches can be implemented now and in future to ensure sustainable food supplies while maintaining healthy soil and water systems.

## Current and future water use in Canada

The goal of this piece of work is to improve ability to accurately calculate the water use and water productivity for crop and livestock production systems throughout Canada. Helgason's team has created unique datasets of Prairie agricultural crops (forages, pulses, cereals, canola). These observations have been used to investigate water use-efficiency, at a field scale with eddy covariance observations, considering differences and dynamics in crop type, environmental stressors and soils (paper under revision for Ag and Forest Meteorology). Observations have also been utilized to synthesize ag-water interactions from a water balance perspective highlighting the important dynamics contributions of crop water use from winter processes in the cold and water limited Canadian prairies (paper in preparation). Helgason and Pomeroy's team have been advancing the modeling of ag-water interactions in the cold and semiarid Prairies.  Validation is ongoing for the AquaCrop-OS crop growth model – a water limited crop growth model from the FAO. The AquaCrop-OS model has also been coupled with the Cold Regions Hydrological Model (CRHM) platform to create the Cold Regions Agricultural Hydrology Model (CRAHM) framework to address unique Canadian Prairie =and agriculktural practices and hydrological processes. CRAHM= simulate and evaluate the efficacy of agricultural management practices to improve water use efficiency, specifically the implications of stubble and residue management and tillage. The development of CRAHM provides a tool kit with which agricultural stakeholders can test strategies to maximize water for crops to improve production and reduce risks. Ongoing work is validating the CRAHM framework with available observations as well as testing the mitigation capacity of ag management practices to limit the impact of ag-water extremes, and quantify differences between current and future ag-water interactions. Li's team used high-resolution WRF simulations to evaluate future changes in agriculturally relevant compound events in Western Canada cropping regions under the RCP8.5 scenario. Additionally, they analyzed the characteristics of daytime and nighttime MCSs over the Canadian Prairies using an ERA5-forced convection-permitting climate model. This research will contribute to the study of climate change impacts on agricultural production in the region. Moreover, they developed a Noah-MP LSM (v4. 4) for simulating spring wheat, which is a significant crop type grown in the Canadian Prairies, and also investigated the growing season dynamics of spring wheat and its response to temperature stress. Petrone's team established new flux measurement sites at two vineyards along the Niagara Beamsville Bench to test the use of small novel independent and integrated sensor systems called TreeTalker Wine (TT-W) supplied by project non-profit partner Nature 4.0. TT-W sensors were installed directly on vines, and included embedded spectrometers (12 spectral bands) for quantifying spatial variability in canopy greenness, grape soluble solids and phenolics. Preliminary data thus far suggests that this platform will create an innovative tool that can also employ multi-scale remote [unmanned aerial vehicles (UAV, drone), satellite] sensing of crop water use and crop stress and grape health and quality for improved adaptive management of vineyards to ensure continued productivity of quality grapes. This team also continued EC and meteorological measurements at the two Niagara vine sites and also at a corn-alfalfa field site near Maryhill, ON. In partnership with collaborators at USDA-Ohio branch, two new EC-met stations in agricultural fields were deployed in Chatham, ON. The team also set up data storage for the USDA's Ohio sites at the University of Waterloo. Over the next year, work will continue in the implementation of AquaCrop-OS and its potential integration with the C3C4 photosynthesis model developed by this group.

#### Current and future water quality in Canadian agriculture

Excess nutrients in aquatic ecosystems are a major water quality problem globally. Worsening eutrophication issues are notable in cold temperate areas, with pervasive problems in many agriculturally dominated catchments. The goal of this work is to improve understanding of the impacts of climate, landscape drivers and land management on water quality. Baulch and Elliott's team with partners/collaborators Wilson and Costa have been working towards answering the question of whether we can better manage soil phosphorus to help address water quality issues in the Prairies. They also launched new work, associated with soil phosphorus variability, aiming to understand within-field P variability to better understand options for improved P management agronomically, and environmentally (through new support via a new industry-funded grant). They sampled multiple sites in SK and MB, including manured and non-manured, dryland and irrigated, and sites with variable topography. Additional sampling and analyses are planned for 2023, hence major results will come in the next 1-2 years. Macrae and Jarvie's team continued work on the potential mobilization of phosphorus from soils and riparian vegetation grown in wetlands receiving effluent, which have considerable legacy P. An HQP published a paper characterizing within-field differences in soil P forms to characterize their risk of remobilization in stormflow runoff. This paper compared fields in Ontario, Ohio and the Canadian Prairies. In addition, one HQP commenced his doctoral research in exploring the mobilization of legacy P from tile drained agricultural fields and watersheds. Another HQP began a study of seasonal and event-related drivers of groundwater-surface water interactions in tile drained landscapes and their impacts on water quality. A final HQP has undertaken an exploration of the eutrophication risk potential of agricultural runoff in the Grand River watershed, using a combination of existing nutrient data from the Provincial Water Quality Monitoring Network and field sampling campaigns. The combined roles of climate and landscape drivers and management practices has been a central theme of their work, developing and promoting the targeting of conservation practices.

#### Strengthening capacity for adaptation in agricultural water decision-making

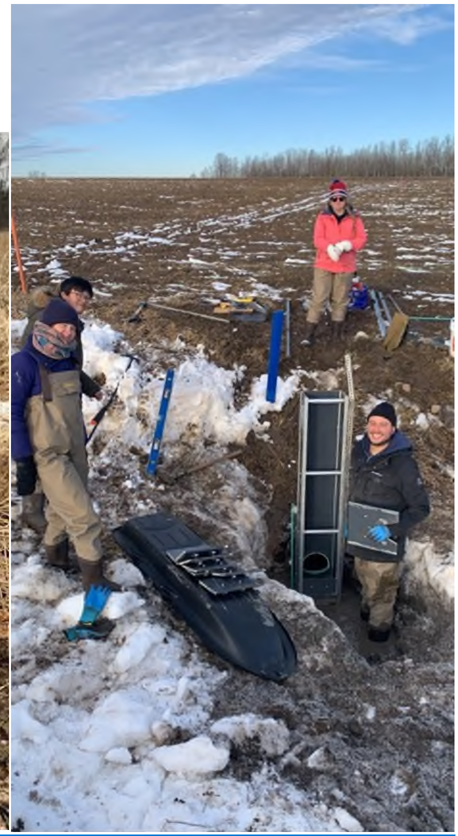
Here, the research team is working to strengthen the foundation for adaptation in agricultural water decision-making in Canada, focusing on water quality in the Great Lakes region. HQP are working with Deadman and Macrae is in the final stages of exploring the potential for phosphorus losses in agricultural watersheds in Ontario under contemporary and future climates, in coupled human and natural systems (CHANS). Brouwer's team has completed a review of water quality trading programs across North America and identified success and fail factors. Their analysis of a farmer survey that looked at the drivers of BMP adoption in Ontario to explain current and future uptake of BMPs and model the drivers behind different types of BMPs has also led to a publication. In addition, a new spatial economic optimization procedure has been developed, coupled to SWAT, that identifies the spatially optimal design of BMPs in agricultural watersheds, with the Grand River watershed as case study. This work is currently under revision. An attempt is made to replicate the SWAT analysis in the Grand River watershed also in the Thames River watershed, another major agricultural watershed of Ontario.

Link to Publications List

## Knowledge Mobilization (KM)

Extensive within- and cross-work programme communications work throughout the project has resulted in numerous papers either published and others submitted for publication. Several of these publications are multi-authored and cross work packages, as this was a goal for this phase of the project (i.e., syntheses and integration). As a project focused on knowledge user needs, the project team continued to engage with partners, collaborators, and stakeholders. In WP1, Harder, Helgason and Pomeroy have had a developing collaboration with CropPro Consulting, the developers of , a precision ag management system focused on soil-water topography interactions and exploring options to transfer knowledge of the spatial variability of crop growth and crop water usage developed within AWF work. Harder has a developing relationship with Crop Intelligence, an ag service provider with a Prairie-wide network of weather and soil moisture stations providing producers near real-time information on crop available water, mobilising knowledge of agricultural and Prairie hydrology. Harder presented AWF research on agricultural management and hydrology interactions to a wide range of ag producer groups and agronomists with 15 presentations spanning SK and AB in the reporting period; with a number providing continuing education credits for PAgs. Helgason continued collaborations with AAFC on modelling. Helgason and Pomeroy maintained current and established new collaborations with industry users including: Clavet Livestock and Forage Centre of Excellence; Saskatchewan Irrigation Projects Association; Croptimistic Technology; and SaskWater Strategic Planning, Risk and Policy. Li's research findings were disseminated through presentations at various conferences and workshops to maximize research impact. Her collaboration with AAFC scientists has been instrumental in her studies, as they serve as both knowledge users and partners who can benefit from Li's research. Indeed, the outcomes of Li's work may offer valuable insights for future planting strategies. Petrone's group worked extensively with partner Rosewood Estates Winery as well as partners from OMAFRA to further develop education around the impacts of climate on viticulture in Ontario. Outputs from this include establishing signage at the winery regarding AWF, maintaining a blog post, and weather data posted in real-time online. Baulch and Elliott's team participated in regular meetings with stakeholders and partners. Of particular note, they had an enthusiastic first meeting with an extension group within SK Agriculture and agreed to ongoing meetings to help mobilize some of their key messages via their social media and other efforts.

The team continued working on developing a number of extension materials related to agricultural nutrients and water quality in the Prairies. These are hosted on a University of Saskatchewan site that provides research-based recommendations to crop and livestock producers in sustainable nutrient management. Moving forward this team also hope to deepen their focus on communications and KM, with major accomplishments in the past year really around increased interest of government (increasing dialogue with WSA and inquiries of SK Ag), transitioning their website (required by USask), and publishing workshop reports. Baulch and Elliott worked to advance their workshop reports (keeping P on the land) with plans to further promote them in 2023. Finally, both Elliott and Baulch provided invited talks at "Soils and Crops" a major meeting for agricultural audiences, including continuing education credits for PAgs, and others. Macrae presented at (and participated in) various workshops, conferences and meetings with industry partners and end users, including farmers, decision-makers, policy makers and conservation specialists. Brouwer continued his collaboration with researcher Wanhong Yang at the University of Guelph for model development, and the Grand River Conservation Authority, and has commenced a new collaboration with the Upper Thames River Conservation Authority .

PhD students installing monitoring equipment for tile drainage chemistry and flow in Ontario. Photo by J. Plach

Meetings with governments, decision makers, practitioners

- Pomeroy - Water Science and Growth Plan with Government of Saskatchewan MLAs, Regina, Canada, March 20, 2023
- Pomeroy - Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023
- Pomeroy - Great Lakes roundtable discussion with the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada, Niagara Falls, Canada, September 28, 2022
- Pomeroy - Science Briefing on the Water Resources of the South Saskatchewan River to the Saskatchewan Party Caucus MLAs and Meewasin Valley Authority Board of Directors, Saskatoon, Saskatchewan, June 28, 2022
- Pomeroy - Panelist, High-level panel on the Canada Water Agency, towards innovative water management, Global Water Futures (GWF) Annual Open Science Meeting, Virtual, May 16, 2022
- Harder - "Quantifying Crop Water Use and its Spatial Variability" and "Quantifying the Spatial Variability of Snow". Water Security Agency All Staff Meeting. Regina, SK, Oct 26. 2022
- Harder - Snow and Crops: Understanding and Optimizing Production from an Agro-Hydrology Perspective. Westgreen Agronomy Grower Meeting. Saskatoon, SK. April 5 2022
- Harder - Agrohydrological implications of Shelterbelts. Saskatchewan Institute of Agrologists Annual Convention, Virtual. Mar 29 2022
- Harder - Snow and Crops: Understanding the water potential for the 2023 growing season. Agronomy Den Conference. Simplot, Rosetown and Lucky Lake SK, Mar 22-23 2022
- Harder - Agrohydrology in the Palliser Triangle. Chinook Applied Research Association Weather and Water Seminar, Consort, AB. Mar 13 2022
- Harder - Snow and Crops: Understanding and Optimizing Production from an Agro-Hydrology Perspective. Crop Opportunity: Western Applied Research Corporation. North Battleford, SK. Mar 2 2022
- Harder - Understanding and Managing the Hydrology behind Dryland Crop Production. Max Ag Consulting Winter Grower Meeting, Plenty, SK. Feb 8-9 2022

- Harder - The implications of changing stubble and crop residue management practices from a water perspective. Indian Head Agricultural Research Foundation Soil and Crop Management Seminar, Balcarres, SK. Feb 1 2022
- Harder - Agrohydrology on the Canadian Prairies: Crop Water Use and Infiltration and Retention Dynamics. Ultimate Yield Management Institute Agronomy Certification Academy, Saskatoon, SK. Jan 18 2022
- Harder - Understanding and Managing Water in Canadian Prairie Dryland Agriculture. Nutrien Western Canadian Regional Agronomist Meeting. Saskatoon, SK. Dec 14 2022
- Harder - Understanding and Managing Water in Canadian Prairie Dryland Agriculture. Winfield United Agronomy Academy 2022, Saskatoon, SK, Dec 1 2022
- Harder - Understanding and managing water in dryland crop production, Discovery Farm VIP Experience & Farm Forum. Langham, SK, August 3 2022
- Harder - The LFCE weather and climate story: unlocking the mystery of moisture. LFCE Field Day, Livestock and Forage Centre for Excellence, Clavet, SK, June 21 2022
- Macrae – Regional conservation practice guidance for effective Phosphorus management. Conservation Tillage Conference (80 attendees), Ohio, USA, March 2023.

Four articles in popular media

29 interviews (broadcast or text)

Social media

Phillip Harder Twitter (@harder_water): ongoing presence communicating knowledge about prairie hydrology and agriculture. Current follower count: 2130.

Merrin Macrae Twitter (@merrinm): ongoing presence communicating knowledge about agricultural water quality. Current follower count: 2008.

# Professional Development and Technology Transfer

The University of Saskatchewan Centre for Hydrology with the assistance of the Canadian Society for Hydrological Sciences offered an intensive course on the physical principles of hydrology with particular relevance to Canadian conditions. Factors governing hydrological processes in Canadian landscapes were be discussed including precipitation, interception, energy balance, snow accumulation, snowmelt, glaciers, evaporation, evapotranspiration, infiltration, groundwater movement and streamflow routing and hydraulics. These processes were framed within the context of distinctly Canadian landscape features such as high mountains, glaciers, peatlands, prairies, tundra, boreal forests, frozen rivers and seasonally frozen ground. Students were exposed to an overview of each subject, with recent scientific findings and new cutting-edge theories, tools and techniques. They completed numerical and essay assignments to develop skills in problem solving and in synthesizing complex hydrological concepts. Students emerged from the course with a deeper understanding of physical hydrological processes and how they interact to produce catchment water budgets and streamflow response. Number of HQP involved: 27

- Petrone taught the evapotranspiration component of the Principles of Hydrology short course offered by UofS (led by J. Pomeroy) for research professionals and graduate students.
- Macrae and Jarvie delivered lectures to the WATER class at the University of Waterloo, and Jarvie gave a lecture at the UW "Summer School" (through the Water Institute) to inform young professionals on current water quality issues and the impacts of climate and land use change on these issues. (approx. 150 HQP reached overall)
- Macrae gave a seminar to students at the Leibniz P School (virtual) on Phosphorus dynamics in cold regions (60 attendees).

# FORecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes (FORMBLOOM)

Web Link: [https://gwf.usask.ca/formbloom/](https://gwf.usask.ca/formbloom/)

Region: Canada

Total GWF funding support: $860,000; $672,0975

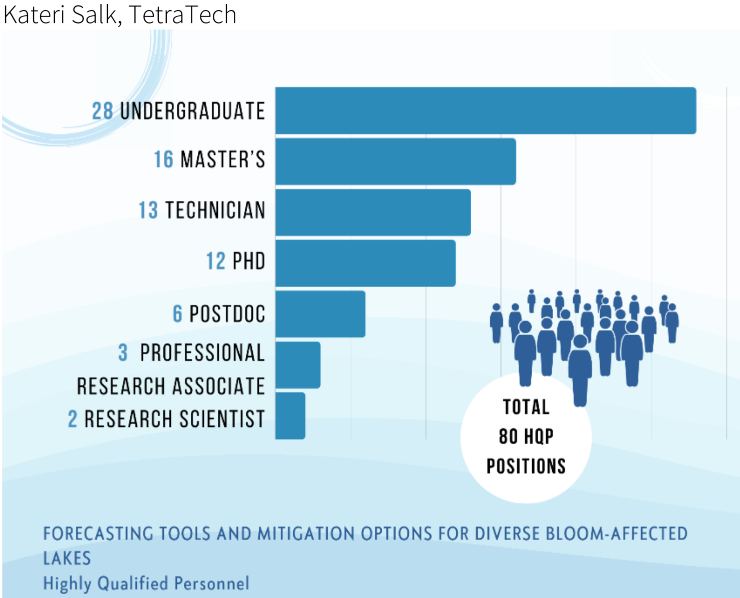
Project dates: June 2017-August 2023 EXTENDED to August 2024

## Investigators

## Partners, Collaborators, and Users

FORMBLOOM engages expertise from eight universities across Canada and the US, as well as watershed groups, NGOs, First Nations, industry and provincial ministries and international research institutes.

Helen Baulch, University of Saskatchewan Contact: [helen.baulch@usask.ca](mailto:helen.baulch@usask.ca)
Lalita Bharadwaj, University of Saskatchewan
Lori Bradford, University of Saskatchewan
Raoul-Marie Couture, Université Laval
Claude Duguay, University of Waterloo
Sherry Schiff, University of Waterloo
Jason Venkiteswaran, Wilfrid Laurier University
Scott Higgins, IISD-Experimental Lakes Area
Brian Ingalls, University of Waterloo
Patrick Lloyd Smith, University of Saskatchewan
Kateri Salk, TetraTech




BlueLeaf Inc -- Barry Husk
Buffalo Pound Water Administration Board -- Blair Kardash
Grand River Conservation Authority
International Institute for Sustainable Development -- Scott Higgins
James Smith Cree Nation -- Bill Marion
Lac Bromont River Basin Conservation Authority
Lower Qu'Appelle Watershed Stewards -- Alice Davis
Lower Souris Watershed Committee -- Tyler Fewings
McGill University -- Sébastien Sauvé (previously at Universite de Montreal)
National Aeronautics and Space Administration, U.S.A. (NASA) --Nima Pahlevan
Saskatchewan Ministry of Health -- Tim Macaulay
Saskatchewan Water Security Agency -- John Mark Davies
Universite de Montreal -- Jesse Shapiro, Dana Simon
University of Missouri -- Rebecca North
University of Regina -- Peter Leavitt
University of Saskatchewan -- Colin Whitfield
University of Waterloo -- Richard Elgood
University of Winnipeg -- Nora Casson
Yellow Quill First Nation -- Myron Neapetung
York University -- Lewis Molot

Highly Qualified Personnel: Professional training and research positions funded by FORMBLOOM

# Science Advances

Freshwater lakes and reservoirs across Canada provide numerous services for local communities ranging from drinking water to recreation. Unfortunately, these same ecosystems are susceptible to a changing climate and nutrient loading. Cyanobacteria, a common photosynthetic group of microbes in freshwater lakes, are known to grow in excess (or bloom) when nutrients loads are high. Under these conditions, cyanobacteria may have detrimental effects on human, animal, and ecosystem health. This project is studying key environmental factors that drive bloom onset, duration, and cessation while evaluating the impact blooms have on ecosystem services, working with ecosystem managers to understand how to mitigate blooms, and how to manage bloom risk. Solving the problem of blooms requires an understanding of how the physical environment links to geochemistry and bloom ecology, and this understanding must exist on the timescale upon which blooms develop and collapse – minutes to hours to weeks.

Harmful cyanobacterial bloom risk is increasing in many areas of the globe, and Canada is no exception, with reports of blooms in all areas of the nation. While nutrient pollution from urban areas and agriculture is known to increase bloom risk, the exact factors that trigger cyanobacterial blooms are not known. Similarly, the factors that cause blooms to be toxic, with potential effects ranging from skin irritation to death, are complex, and not adequately understood. Nationally, capacity to monitor and understand blooms is limited, particularly among our millions of small lakes. Yet currently, blooms are annual, extended occurrences in many lakes. Similarly, capacity to warn water users, and compliance with warnings is uneven. Solving cHABs is a grand challenge. Within FORMBLOOM, the work has aimed to help manage their impact, and to set the groundwork for bloom mitigation. Key outcomes related to understanding toxins and cHAB risk include:

● Demonstrating that flood events and flow management broadly are related to cHAB risk in diverse reservoirs. There is evidence of important tradeoffs in flow management impacting key attributes of water quality and drinking water quality specifically.

● Through detailed study, the research shows that seasonal community succession leads to high variation in toxin risk over time. Importantly, there is high diversity of cyanobacterial metabolites, including toxins, in high use systems, including a drinking water source. While many are of low concentration, they are largely unmonitored, unregulated, and some have poorly known toxicity. The project team has shared results with water treatment and watershed groups, and helped identify key periods of toxin risk, and tools that may help understand variation in risk over time.

● Experimental evidence demonstrates a role of nitrogen in toxicity risk, suggesting nitrogen management is important to cHAB risk. Importantly the exact effects vary by toxin, and with community composition. (In sum, overarching advice to "manage nitrogen prudently" remains the best advice). A broader systematic review is ongoing, but it again shows a major gap in monitoring of the wide array of cyanobacterial metabolites, even in small scale experiments.

● Genomics brings tremendous potential for understanding the microbial community of blooms, triggers of blooms, and triggers of toxicity. Project researchers have been able to see an important role of picocyanobacteria in blooms, links between environmental conditions and taxa, and also among environmental conditions, taxa, and toxins, providing new insights about antecedent conditions to bloom and toxicity with insights into toxicity risk that span beyond discrete samples. 2023-4 will be the major period of focus to tie together this expansive data. This data was gathered in partnership with the Algal Blooms, Treatment, Risk Assessment, Prediction and Prevention Through Genomics (ATRAPP) program, and FORMBLOOM work represents among the most temporally intensive datasets (and highest toxin diversity) from this program.

● Modelling approaches for blooms are scientifically challenging due to the interaction of physical, chemical and biological effects. FORMBLOOM is advancing ensemble modelling by developing tools that quantify the importance of different drivers to lake mixing and bloom conditions. The team's research has identified how and when floating solar panels can alter a lakes phytoplankton biomass and composition. The thermal structure of a lake can be significantly altered by floating solar panels and the siting of the panels can be done to reduce phytoplankton biomass to minimise negative impacts and maximise co-benefits. Commercial products, such as the lanthanum modified bentonite material available as Phoslock™, have been used to reduce eutrophication by permanently removing phosphorus from lake water and trapping it in sediments. This treatment has been successful in some types of lakes and not in others. The efficacy of lanthanum-based products has been questioned in the high dissolved organic carbon water typical of many boreal lakes. The project team has quantified how dissolved organic carbon and iron have a complex relationship with how lanthanum-based products work to produce a long-term stable sink for phosphorus and thus reduce eutrophication.

● Remote sensing approaches have also been advanced for challenging conditions, showing the benefit of regionalized approaches in helping to improve remote-sensing-based bloom monitoring from optically-similar waterbodies.

● The project has also worked extensively on tools for decision making,  from short-term forecasting tools to pragmatic decision trees that have become integrated into water treatment, and extensive work to curate data needed to plan for future water treatment while also supporting long-term data analyses. Team members interact regularly with key partners on their needs, and have helped inform a major water treatment upgrade, as well as operationalization of decision trees and sensor-based warnings for water treatment.

● Whole-lake experiments are underway, showing very rapid bloom induction with addition of phosphorus. This is important, as expected, only 'small' doses are required to induce blooms in the context of watershed loads - and the team has identified this as a key area of messaging for communications with watershed and agricultural audiences. Interestingly, the pandemic required a re-set of the experiment, with a one year gap, and then an added year of phosphorus only loading. This study year (2022) showed more mixed results in preliminary analyses to date with one strong bloom and one lake which did not behave according to expectations, indicative of potential metal (or grazer) limitation of blooms.

● Project work on economics shows a very high willingness to pay for water quality improvement, which would support substantive investment in direct lake treatment and best management practices (BMP). This high willingness to pay is consistent with the small number of lakes in Canada where similar work has been done. The project's knowledge mobilization and communications efforts also reflect a very high interest in direct lake treatment, despite often high costs.

Delays and changes: Much of the project work is field and lab based, or involves interaction with people. As such, we have had substantive delays associated with factors ranging from extended site closures and reduced access (e.g., IISD-ELA, NHRC), along with impacts on HQP / investigators(parenting, health, lab delays, and immigration delays). As noted in the 2021 report,  these delays will extend well past a one year extension, associated with a delay in getting a genomics Postdoctoral fellow recruited, and a three year delay in whole lake experimentation due to the need to 'prime' the lake with phosphorus, and a full site closure year, followed by a Covid-19 outbreak interrupting sampling in 2022.

● Unfortunately, the work on extracting indicators of scum formation from satellite images and photographs is on hold, as the HQP engaged in this work was delayed, and then recruited to a new position. In the longer-term, new cameras on 'superbuoy' will provide enriched opportunity to work on this with further seasons' data. In addition, past HQP have partnered with Saskatchewan Water Security Agency to implement added monitoring in aid of remote sensing, demonstrating how FORMBLOOM has helped build interest, and capacity, in extended (and broader) use of its methods.

● Work on lake typologies and risk indicators is advancing. A geochemical lake survey clearly shows very high variability across Canada in internal loading risk (in progress, lab delays due to ~1.5y closure). Unfortunately the extended closure of the Canada-US border meant loss of the Fulbright scholar who would have led spatially extensive work on developing preliminary virtual mass balance models to understand broad scale bloom risk. It is hoped to advance WPD1 with a separate Postdoctoral Fellow in 2023 (pending degree completion and successful hire).

● Genomics work was delayed by lab and border closures. This work is now underway via new Postdoctoral Fellow who is working between FORMBLOOM and ATRAPP, initially focused on Buffalo Pound Lake.

## Link to Publications List

# Knowledge Mobilization (KM)

FORMBLOOM's knowledge mobilization plan continues to follow a hub-and-spoke model, where investigators and HQP continue to work closely with individual partners. As with all projects, there have been challenges with partner time and PI/HQP time, associated with the pandemic. Project team members have nevertheless sustained strong relationships with many of the original partners, and show growing traction in their ability to continue to mobilize knowledge with these groups, and work on communications for broader audiences as well.

Capital Region District (CRD): Spence worked with the Victoria Capital Region District (the regional government for 432,000 residents on southern Vancouver Island), community members, and different interest groups related to Elk/Beaver Lake to help inform understanding of the lake, and key attributes of her survey. Her ongoing interactions include reporting back to the CRD and asking community members and government for feedback, which will also be integrated into a final report for partners. In sum, the research has been well-timed, and supports decision-making related to the restoration of Elk/Beaver Lake. Anticipated benefits of restoration were compared to costs of restoration, and results strongly suggest that benefits will outweigh costs, suggesting that community (in general) supports restoration, and that additional interventions to restore Elk/Beaver Lake may be justifiable. Additionally, nearby lakes have been suffering similar issues (increasing frequency and duration of HABs–one lasted from May 2022–January 2023 in Lower Thetis and Prior Lakes). Outcomes of this research support the creation of a watershed management and/or lake remediation plan for these lakes. Beneficiaries include those who hold value for the lake–many people in the community cherish this lake and fear continued worsening of water quality–and the government, which can use this to help inform and justify restoration). Challenges in knowledge mobilization for this project have included turnover in government workers, difficulty getting in touch with new personnel, and arranging meetings.

Buffalo Pound Water Treatment Corporation (BPWTC): Links to the BPWTC were initially centered on a 'boundary object", a lake monitoring buoy that has been deployed since 2014, and that has been used to help inform plant operations. This instrumentation has become central to helping to avoid incidents akin to one in 2015 that led to major water shortages, and the plant has worked with FORMBLOOM researchers to co-develop and operationalize decision support and warning tools. This has led to major new investments of the BPWTC in research infrastructure (2022 purchase of superbuoy, 2023 investment in CFI match for Baulch, Jardine and Whitfield). FORMBLOOM researchers are in close contact with BPWTC, engaging in data management and curating their long-term data for benefit of research, and support of their ongoing planned upgrade. This close relationship has helped to identify multiple new priority areas, including understanding the impacts of flow management to water quality and water treatment – work that has also been of interest and co-developed with the Saskatchewan Water Security Agency. Through this three-way interaction and learning about flow management, FORMBLOOM is bridging important conversations about options and tradeoffs within hydrological management of the lake. FORMBLOOM researchers and plant staff collaborate in numerous areas, from sensor deployment to design of data management systems to supporting monthly communications to staff, and team members have been keenly interested in design and progress of the upgrade.

Saskatchewan Water Security Agency (WSA): Co-created work has helped advance key conversations about flow management impacts on source water quality. FORMBLOOM has also helped enhance capacity for remote sensing of blooms – a very strong interest of WSA given the potential for improved monitoring. The next phase work of Saskatchewan WSA should help further advance both local (Buffalo Pound) and broader scale work on remote sensing, pending sufficient organizational and research capacity. Strong links to past HQP are aiding in this, with next steps under continued discussion. More broadly, links to WSA have helped improve the team's science capacity (via deep knowledge of prairie systems), and to improve management understanding (via detailed monitoring, and modelling approaches). The team is in early stage conversations about next research steps needed in the province.

IISD Experimental Lakes Area (IISD-ELA): continues to play a major role in co-mentoring students, and co-designing scientific work aimed at bloom mitigation with deep involvement of multiple staff scientists. In 2022, FORMBLOOM's work at ELA was restricted due to Covid-19 protocols and outbreaks, but supported as best as possible by onsite staff and limited HQP. In 2023, extensive support of IISD-ELA will allow important meso-scale experiments to understand nitrate dosing for a key next step of whole-lake NO3 - addition. Engagement with IISD-ELA focuses on co-development of science as noted, with an important role also in helping train HQP, and advance scientific outputs.

BlueLeaf and Barry Husk: FORMBLOOM has worked extensively with BlueLeaf via Husk -- in particular on one exemplar lake – where the project helped advance understanding of short and long-term changes related to watershed management and bloom risk. Husk also continues his extensive fork on cHAB communications, with multiple conversations among researchers via email on key areas of interest. As noted, changes in staffing in some organizations and pandemic/health-related restrictions on PI time have limited engagement.

Team members have worked to engage with the Vancouver Island Capital Region District (and connect with new CRD staff) and have connected with watershed stewards in Saskatchewan. Towards project completion, the aim is to support further integration of AWF/PW/FORMBLOOM messaging to support the needs of Saskatchewan agencies, as well as the Grand River Conservation Authority (GRCA) (where key contacts have also left the organization, so renewal of partnerships is required). FORMBLOOM's water quality toolbox and discussion of message framing has been well received by multiple agencies (including positive comments from Saskatchewan Agriculture), with key insights noted by agricultural consultants around

“We want to support Dr. Baulch’s continued research in limnology (the study of lakes) at Buffalo Pound. In doing so, we also get the benefit of having real-time monitoring for rapid changes in water quality, as well as the benefits from her long-time research on cyanobacteria,” Kardash said in a statement. The importance of sensor monitoring can also be highlighted by a situation in the spring of 2015 when thermal stratification in Buffalo Pound Lake affected water clarifiers in the plant, cutting treatment capacity in half, and leading to an emergency water restriction in Moose Jaw and Regina. Baulch and Kardash have since developed ‘decision trees’ on how to use sensor data to adapt plant operations during periods of stratification extremes, and to advise cities to have enough water in their reservoirs to ride out any potential treatment slowdowns.” Blair Kardash, Manager of Laboratory and Research, BPLWTP

messages about how many kilograms of phosphorus it takes to eutrophy a lake (less than is often spilled when filling equipment each day), and messaging that eutrophication and blooms are a 'problem with lakes, not a problem with farms – lakes are just too sensitive'.

Workshops

- Instructional Skills Workshop, U. of Saskatchewan (Painter)
- Internationalization: Inclusive and Responsive Teaching, U. of Saskatchewan (2022)
- Introduction to Online Teaching, U. of Saskatchewan (2022)
- Interrupting Bias, U. of Saskatchewan (2021)

International Exchanges

Spence: Transdisciplinary International Learning Laboratory (TILL)—summer school in the Brandenburg Biosphere Reserve. The learning laboratory involved collaborating with students from University of Saskatchewan, universities in Germany, and universities in South Africa, as well as various stakeholders and the biosphere reserve, to understand local sustainability issues and work together to find strategies to overcome those issues. Organized by Transdisciplinary Education Collaboration for Transformations in Sustainability (TRANSECTS). 1 HQP involved. https://senstest.usask.ca/transects/learning-opportunities/offerings/tills.php

Public Outreach

Access of tools by users: Continued use of buoy (‘big buoy’ and ‘superbuoy’) and data, and refinement of decision support systems for Buffalo Pound Water Treatment Plant. Investment of up to $250,000 in new instrumentation (“superbuoy”) was announced by the plant and promoted via their media contractor, with deployment in summer 2022. The plant has also supported a CFI grant that will intensify catchment and lake monitoring.

Meetings with governments, decision makers, practitioners: FORMBLOOM PhD graduate worked with the Saskatchewan Water Security Agency and with support of Baulch to help design new radiometer deployment for Buffalo Pound for the Water Security Agency. There has been continued regular interaction with BPWTC. Monthly reports to the plant staff include research updates from FORMBLOOM, with ongoing communications on needs, and changes in source water quality. Baulch is invited to the first board meeting (May 2023). Ongoing interactions with Lake Bromont catchment conservation authority (Action Conservation du Bassin Versant du lac Bromont). Knowledge transfer regarding longevity and efficacy of lanthanum-based internal load treatment and of onset and timing of anoxia. Spence met with the Capital Region District in May 2022 and March 2023 to discuss opportunities for disseminating research and gain feedback. FORMBLOOM has had ongoing meetings with Saskatchewan WSA, including participation of WSA scientist Dr. Davies on the student committee studying flow-management impacts on water quality (and co-development of that work, including WSA-sampling support). Davies is the key contact on Buffalo Pound but there are several other links to WSA for the water quality work.

Articles in popular media:

- 2022: Support of art on water security: contributions noted in article on Susan Shantz’s exhibition in Moose Jaw:● https://news.usask.ca/articles/colleges/2022/we-t ake-water-for-granted-usaskprofessor-highlights-human-relationship-with-water-through-artwork.php
- 2022: Buffalo Pound -- collaborative work, and launch of superbuoy with water treatment plant, plant upgrade (multiple articles, some noting work on new sensor system, as well as benefits of ongoing work with the plant and next steps.
- https://regina.ctvnews.ca/buffalo-pound-water-treatment-plant-invests-250-000- in-a-state-of-the-art-buoy-1.5729844
- https://globalnews.ca/news/8491368/superbuoy-buffalo-pound-water-treatmentplant/

- https://fox26newshenry.com/2022/01/05/new-superbuoy-coming-to-buffalopound- water-treatment-plant-regina/
- https://www.cbc.ca/news/canada/saskatchewan/water-treatment-buffalo-pound- 1.6058322
- https://eminetracanada.com/the-new-super-buoy-at-the-buffalo-pond-watertreatment- plant/381402/
- https://canada-news.ca/regina/new-superbuoy-coming-to-buffalo-pound-watertreatment- plant/
- https://news.usask.ca/articles/research/2021/usask-researchers-cutting-edgebuoy-aims-to-secure-water-source-for-regina-and-moose-jaw.php
- https://twnews.ch/ca-news/new-superbuoy-coming-t o-buffalo-pound-water treatment- plant
- https://bluzz.org/new-superbuoy-coming-to-buffalo-pound-water-treatment-plant- 1998923.html
- https://newztrends.com/new-superbuoy-coming-to-buffalo-pound-watertreatment- plant-globalnews-ca/
- https://hashtaggenerator.in/new-superbuoy-coming-to-buffalo-pound-watertreatment- plant/
- https://esemag.com/water/high-tech-buoy-water-quality-buffalo-pound-lake/
- https://www.producer.com/crops/finding-nitrogen-and-phosphorus-losses-inrunoff/
- 2022 Community partnerships https://www.producer.com/crops/finding-nitrogen-and-phosphorus-losses-inrunoff/

Spence sent out a summary of choice experiment results to interested research participants and is currently preparing presentations and a report for the government and the community. (in addition to meeting with CRD as noted).

# Professional Development and Technology Transfer

Spence: Teacher Scholar Doctoral Fellowship (TSDF) at the University of Saskatchewan: “mentored graduate teaching fellowships available to doctoral students through an open university-wide competition supported by the College of Graduate & Postdoctoral Studies (CGPS)”. One HQP developed and taught a third-year undergraduate class in aquatic ecology: https://students.usask.ca/money/awards/graduate-awards.php?award=301368GS04

Spence sent out a summary of choice experiment results to interested research participants and is currently preparing presentations and a report for the government and the community. (in addition to meeting with CRD as noted).

FORMBLOOM has built research capacity, undergraduate and graduate degrees, as well as developing experience of post-doctoral fellows, professional research associates, and research scientists. Technicians have been trained.

Launching the Super Buoy at Buffalo Pound Lake, 2022

# Sensors and Sensing Systems for Water Quality Monitoring

Web Link: [Home | Global Water Futures - Sensors and Sensing Systems (gwfsensors.com)]

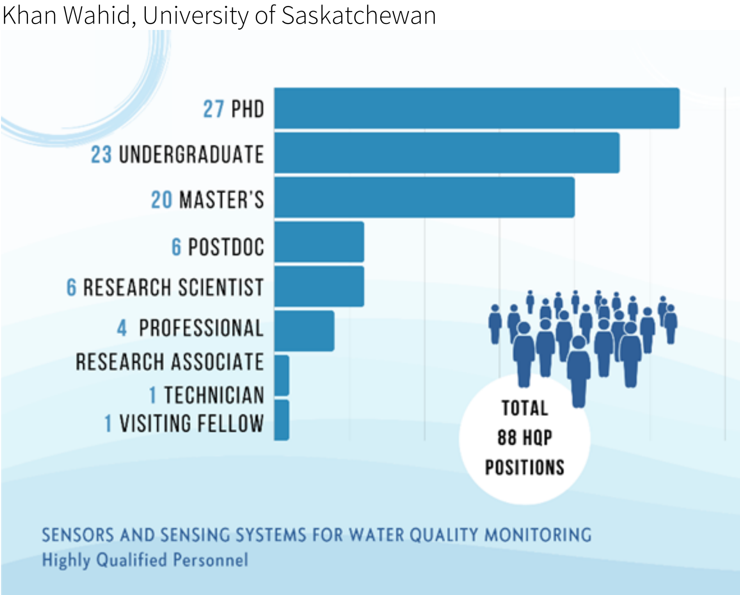
Region: Canada

Total GWF funding support: $1,800,000

Project dates: December 2017-November 2020 COMPLETED

## Investigators

Ravi Selvaganapathy, McMaster University Contact: selvaga@mcmaster.ca
Peter Kruse, McMaster University
Charles DeLannoy Assistant Professor Y McMaster University
Jamal Deen, McMaster University
Chang-qing Xu, Professor McMaster University
Dawn Martin-Hill, McMaster University
Emil Sekerinski, McMaster University
Philippe Van Cappellen, University of Waterloo
Carolyn Ren Professor, University of Waterloo
Juewen Liu Professor, University of Waterloo
James McGreer, Wilfrid Laurier University
Scott Smith, Wilfrid Laurier University
Karsten Liber, University of Saskatchewan
Khan Wahid, University of Saskatchewan




Highly Qualified Personnel: Professional training and research positions funded by Sensors and Sensing Systems for Water Quality Monitoring

## Partners, Collaborators, and Users

Atlas Scientific Efrem Press
Carolinian Canada -- Michelle Kanter
City of Saskatoon -- Mitch McMann
Environmental Bio-Detection Products Inc. (ebpi.ca) -- Will Lush
Forsee Instruments Ltd. -- Guo, Tianyi
Hoskin Scientific -- Scott Brown
International Copper Association -- Dr. Robert Dwyer
International Lead Association -- Dr. Jasim Chowdhury
International Zinc Association -- Dr. Eric Van Genderen
McMaster University -- Emil Sekerinski, Zeinab Hosseini-Doust
McMaster University Centre for Continuing Education -- Lorraine Carter
McMaster University Indigenous Student Services -- Shylo Elmayan
McMaster University Indigenous Studies Program -- Jordan Carrier
Mohawk College -- George Miltenburg, Marilyn Powers
Nickel Producers Environmental Research Association -- Dr. Chris Schlekat
Orano Canada -- Dale Huffman
QuantWave -- Dr. Alex Chen
Saskatchewan Water Security Agency -- Dr. John-Mark Davies
SHAD Canada -- Melissa Bruno
Six Nations Band Council -- Mark Hill
Six Nations Confederacy Council -- Rod Whitlow
Six Nations Environmental Office -- Peter Hill/Clynt King
Six Nations Health Services -- Nicole Bilodeau
Six Nations of the Grand River -- Dawn Martin Hill, Lori Davis Hill, Michael Montour
Six Nations Polytechnic STEAM Academy -- Christopher Martin
Six Nations Public Health -- Lori Davis-Hill
STEAM Academy -- Christopher Martin
Zhejiang University -- Hao Jin hjin

## Science Advances

There is a critical need to gain a detailed understanding of the effect of human activities on the ecosystem and water in particular. A crucial part of that strategy involves the use of sensors and sensing systems that can be deployed in the environment to monitor for the presence of contaminants and their variation over the short and long-time scales. Although sensors and sensing systems for long term monitoring exist for many of the parameters of interests (such as dissolved oxygen, pH, turbidity, conductivity, nitrates), they are not sufficiently low in cost and require technical expertise for operation and maintenance. In other cases, such as some metals, phosphates and bacteria, continuous monitoring systems have yet to be developed. This project has focused on development of low-cost sensing systems and implementation for long term monitoring of water quality parameters, and development of specific low-cost sensors that are capable of detecting pathogens, heavy metals, oxidants and nutrients and integration of them in the sensing system. The sensors and sensing systems are field tested in collaboration with identified potential users who have expressed interest in partnering with this project as well as partners in other GWF funded projects.

Major achievements of sensors and sensing water quality monitoring system are completion of sensors prototyping, lab testing, and their field deployment (in a limiting way, deployment delayed, and impacted by COVID 19). Some of the highlights are:

Testing instruments in the field

- Development of a highly sensitive solid state phosphate sensor. A new electrochemical sensing approach to phosphate can allow detection as low as 10^-7 M. Prototype is ready to be field tested. This work has led into a new start-up company “Phosphosense”.
- A novel pre-concentration approach for sensitive colorimetric monitoring of trace level detection of copper and iron has been established using passive aliquoting and cost effective-readily available materials. This method can detect copper at 10 ppb, and experiments are ongoing for low level lead (at 1-10 ppb levels) detection.
- A chemiresistive sensor that utilized exfoliated graphite to form a few-layer graphene (FLG) film is developed to detect trace levels of copper, and silver cations in aqueous solution. Detectable range for silver ions is in range of 3-1000 ppb in solution. When tested in environmental waters (Spencer Creek, Hamilton ON), recovery values were similar to that obtained by ICP-MS. Work is underway to identify suitable ligands to detect lead in aqueous solution.
- A working DNAzyme GR5 sensor has been developed for bioavailable fraction of lead sensing. DNAzymes is found to respond to Pb2+, PbOH+, and PbCl+ species. DNAzyme can be used for understanding the effect of dissolved organic matter (DOMs) on metal binding and sensing.
- LoRa sensors, and enclosures for long-term continuous housing of sensors are designed for continuous monitoring of water quality along rivers and creeks of Six Nations. Biofouling in the lab on sensors is simulated to identify impact of biofouling and establishing ways to eliminate fouling on sensor surfaces.
- Fluorescent sensor to detect low concentration cyanobacteria has been successfully achieved to measure Chl-A and multiple algae species (Spirulina, Chlorella, mixed species) and tested at field site (Buffalo Pound). This has important application for early warning of potential cyanobacterial blooms.
- Efficient communication protocol and Dynamic clustering algorithm for IoT-UAV platform developed and tested at lab. IoT WSN for wide area remote monitoring (WARM), developed full IoT platform with LoRa connectivity; tested at North SK River site; fully deployed and working.
- Performance analysis of LWC algorithms for IoT platform; developed and tested at the lab; field trial not possible due to COVID-19.
- A prototype for new and improved portable microwave sensor coupled with microfluidic chip and palm-size signal analyzer has been developed for detection of lead at 1 ppb concentrations in water.

- A fully integrated free chlorine sensing system that include reagent-less operation with reusable sensing electrodes, and complete elimination of pH and temperature calibration has been developed to measure free chlorine with high sensitivity. The free chlorine sensor has also been demonstrated in preliminary fashion in Six Nations to be used in different community locations for measuring free chlorine in drinking water. The validation of the sensor system and training of the use of the sensor system are currently underway, which was delayed due to Covid-19 restrictions.
- Development of the field version of the oxygen sensing system has been completed, in partnership with Hoskin Scientific Ltd. The Multi Fiber Optode (MuFO) microsensor, and photo-logging systems were deployed in two agricultural field-controlled lysimeter systems located at University of Guelph's Elora Research Station and the subsurface Oxygen (O2) dynamics together with soil and air temperature, snow, precipitation, moisture content, and pore water geochemistry are monitored over four seasons (October 2018 to August 2019). The analyses of porewater samples from the lysimter experiments is completed in February 2020 using Ion Chromatography (Dionex ICS-5000), Inductively-Coupled Plasma Optical Emission Spectrometry (Thermo iCAP 6200 Duo ICP-OES), and a TOC analyzer (Shimadzu TOC-LCPH/CPN).
- Libelium based network has been deployed in lakes downstream of mining operations in collaboration with Orano (previously Areva Resources, a uranium mine in northern Saskatchewan). Functioning water quality sensors for temperature, dissolved oxygen, pH, ORP, turbidity and conductivity, calibrated in the Aquatic Toxicology Research Facility (ATRF) have been used in this study. Analysis of all samples from 2019 is now completed and analysis of water samples collected from McClean Lake during March 2021 are presently being processed. The outcome of these analysis will help elucidate the research hypotheses of seasonal differences (summer vs winter) in selenium bioaccumulation and trophic transfer.
- The first phase of the virtual reality (VR) storytelling experience is completed. The experience utilizes a virtual sensor and water quality station at the knowledge centre to train users on water quality analysis. Demos can be viewed on the Ohneganos website.
- The project team has been working with partners at Mohawk College to develop a local water treatment plant operator training curriculum at Six Nations that incorporates Indigenous and Local Knowledge (ILK) as well as Traditional Ecological Knowledge (TEK). A program for high school students has been approved by the Ontario Ministry of the Environment, Conservation and Parks.

Field testing of some of the sensors prototypes and analysis of pending samples are ongoing. Some sensors are in the final stages of their development. The team is working completion of all pending projects, specifically field testing of phosphate and heavy metal sensing.

## Link to Publications List

# Knowledge Mobilization (KM)

Citizen Science:

- Worked with First Nations partners to install water sensors and monitor surface water data
- Six Nations Public Health Community Educators - water collection organization across reserve
- STEAM Academy outreach – introducing students to sensors and water quality
- Six Nations water day.

Access of tools by users:

- Chlorine sensor training: the low-cost chlorine sensors that been developed via this project are planned to undergo iterative design based on feedback from Six Nations community partners. This user-led design will be facilitated by workshops with Community Educators from Six Nations Health Services.
- Additional sensor system kits and training modules (e.g., Standard Operating Procedures (SOP) and video tutorials) on how to use the integrated Free Chlorine sensing system
- Virtual reality storytelling experience: the development of the virtual reality training and education tool 'Journey Down the Grand River' has been going through iterative user-led design by obtaining feedback from Youth, Elders, and community members from Six Nations of the Grand River. This tool contains sensor information, water testing information, along with a variety of other knowledge components.

Meetings with governments, decision makers, practitioners:

- Designing the Canada Water Agency for Successful Co-development and Collaboration with Indigenous Peoples (Martin-Hill, D. - September 10, 2020).
- Canada Water Agency Key Stakeholder Meeting (Martin-Hill, D. -October 20, 2020).
- Canada Water Agency and Ohneganos meeting with McMaster University (Martin-Hill, D. - November 24,
- 2020).
- Team meeting with Six Nations of the Grand River Elected Council on March 9, 2021.
- Six Nations band council meetings to discuss water sensors piloting, data collection, data housing
- Akwesasne community leaders meeting to discuss water sensors for drinking water from wells and cisterns.

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**Indigenous action highlighted in new Wellington Water Watchers' billboard**

A message from the Haudenosaunee Confederacy Council on the billboard says "Stop the illegal removal of our waters"

Keegan Kozolanka
Aug 19, 2020 9:00 AM



*The Wellington Water Watchers' new billboard on Gordon Street in Guelph includes a message from the Haudenosaunee Confederacy Council. Keegan Kozolanka/GuelphToday*

PUSLINCH – The Wellington Water Watchers' (WWW) new billboard puts Indigenous action at the forefront of the fight against water taking for bottled water.

The new billboard on Gordon Street near the water bottling plant purchased from Nestlé Waters Canada by Ice River Springs includes a message from the

Article in Guelph Today, 19 August 2020

15 articles in popular media

Interviews (broadcast or text)

- Toronto Star, https://www.thestar.com/news/investigations/2019/11/26/oneida-residents-say-the-tap-water-is-making-them-sick-but-across-the-road-their-neighbours-have-safe-clean-water.html
- Tyee, https://thetyee.ca/News/2021/02/23/BC-Tests-Found-Unsafe-Lead-Levels-Water-35-First-Nations-Schools

Public workshops and presentations

- Reo, N. (January 13, 2021). 'Western Science and Indigenous Science – Indigenous Knowledge as a Science. Presentation as part of a Seminar Series for Six Nations Polytechnic STEAM Academy.
- Clark, E., Clark, R. (January 26, 2021). Vulnerability Assessments – Climate Change Vulnerability Tool and White Cedar Cultural Connection. Presentation as part of a Seminar Series for Six Nations Polytechnic STEAM Academy.
- Brown, M. (February 1, 2021). Eel Elder Project – Virtual Reality, Artificial Intelligence, Indigenous Futurisms, and Cultural Connections to Eels. Presentation as part of a Seminar Series for Six Nations Polytechnic STEAM Academy.
- Presentations and demo of the Free Chlorine sensing system to First Nation community.

Promotional videos

- Mahtab Taheri, Green approach for fabrication of a cost-effective pH sensor, GreEN 180 sec Videos
- Competition 2021, NSERC Green Electronics Network, May-2021

Looking Horse, M. (2020) Ohneganos: Let's Talk Water video series. Season 1-3. Accessible via YouTube:https://youtube.com/playlist?list=PLV0pWnAsC2xCls5M628FY6AoZM54Pv2Zu

- Looking Horse, M., Selvaganapathy, R. (2020) Ohneganos: Let's Talk Water – Season 1 Episode 7. Accessible
- via YouTube: https://www.youtube.com/watch?v=ndGtyisBvJY&list=PLV0pWnAsC2xCls5M628FY6AoZM54Pv2Zu&index=10
- Mahtab Taheri, Green approach for fabrication of a cost-effective pH sensor, GreEN 180 sec Videos

# Professional Development and Technology Transfer

Training students at the STEAM Academy to install, monitor and use surface water sensors.

# Developing 'Omic' and Chemical Fingerprinting Methodologies Using Ultrahigh-Resolution Mass Spectrometry for Geochemistry and Healthy Waters

Web Link: [Chemical Fingerprinting - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Canada

Total GWF funding support: $250,000

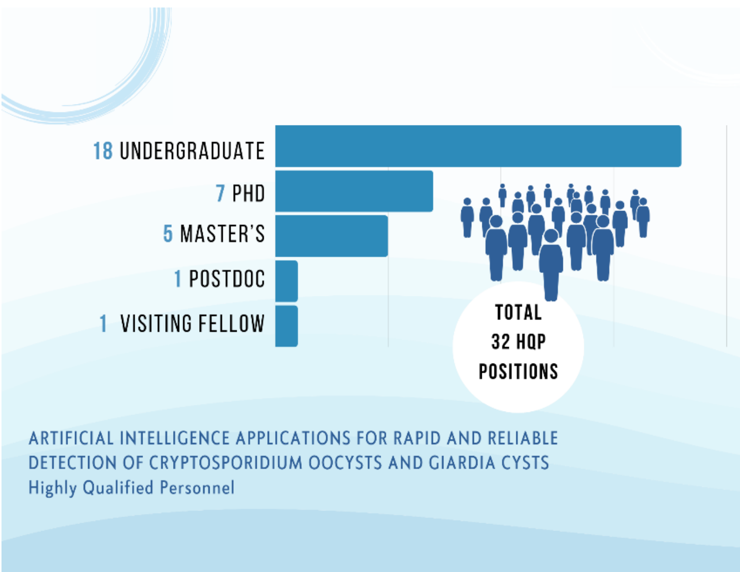
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Paul Jones, University of Saskatchewan Contact: paul.jones@usask.ca
Jon Giesy; University of Saskatchewan
Markus Hecker, University of Saskatchewan

## Partners, Collaborators, and Users

Environment and Climate Change Canada -- John Headley
University of Alberta -- Nesma Allam
University of Lethbridge -- Steve Wiseman




**Highly Qualified Personnel: Professional training and research positions funded by AI Applications for Rapid and Reliable Detection of Cryptosporidum Oocysts and Giardia Cysts**

## Science Advances

'Omics' approaches such as proteomics, lipidomics, and metabolomics along with chemical fingerprinting technologies can be used as powerful tools to monitor the current status and to predict future trends in ecosystem structure and function. For example, organisms living in Canada's northern and high altitudes, annually adjust their metabolisms and lipid components in their cellular membranes to adapt to changing temperatures. Alterations in magnitude, timing of temperature change, or food sources could severely impact organisms, entire ecosystems, and the services humans rely on. Nutrient cycling that is associated with harmful algal blooms (HABs) is controlled, in part, by organic forms of phosphorus and nitrogen and dissolved organic matter that can be better characterized by UHR-MS. This project developed and validated methods that take full advantage of the new state-of-the-art equipment, while also providing support and training for other on-going GWF projects and personnel. A longer-term goal is to work with researchers to apply these techniques to assess aquatic resources in support of end-user needs and priorities of the GWF platform.

A high-resolution mass spectrometry facility at University of Saskatchewan with state-of-the-art systems for liquid and gas chromatography applications was established and used to characterize dissolved organic matter in samples collected in collaboration with Alberta Agriculture and Forestry from the southern Alberta irrigation district. These samples are used to assess changes in water quality and dissolved organic matter characteristics across a variety of relatively pristine to highly impacted waterways throughout the prairie agricultural landscape. Research is also being done on the fate of hormones and pharmaceuticals from cattle feed-lots, the impacts of perfluorinated compounds on salmonid reproduction, dioxin analysis, fatty acids as ecological biomarkers, impacts of the 2016 Husky oil spill, characterization of oil sands associated naphthenic acids, impacts of exposure to the flame retardant TBCO on fish, and monitoring of the impacts of Alberta oil sands activities on fisheries resources in the Northwest Territories. A technique has been developed for the organic/inorganic speciation of mercury in environmental samples.

While work continues, funding for the project ended in December 2020. The new facility ensures that GWF and other University of Saskatchewan researchers have access to up-to-date technologies for identification and quantification of contaminants that impact water quality and indicators of aquatic environmental quality. Once completed, analysis of dissolved organic matter data will allow the identification of key indicators of aquatic environmental health that may be monitored in a more targeted fashion and will be available to investigators with less sophisticated equipment.

## Link to Publications List

## Knowledge Mobilization (KM)

KM activities for 2020-2021 were severely impacted by the COVID-19 pandemic, with conference attendance cancelled due to travel restrictions, and all planned collaborative field activities in the Northwest Territories cancelled.

# Short-Duration Extreme Precipitation in Future Climate

Web Link: Extreme Precipitation - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Canada

Total GWF funding support: $298,000

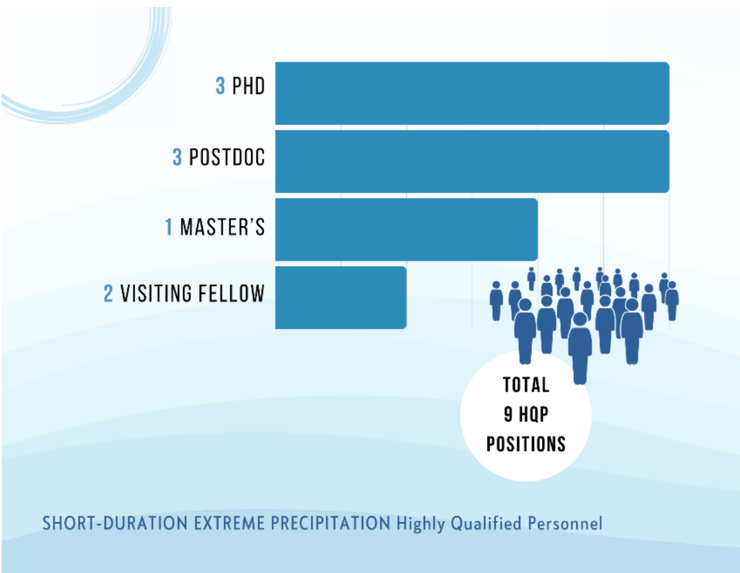
Project dates: December 2017-November 2021 COMPLETED

## Investigators

Yanping Li, University of Saskatchewan Contact: yanping.li@usask.ca
Francis Zwiers, PCIC, University of Victoria
Jean-Pierre St Maurice, University of Saskatchewan

## Partners, Collaborators, and Users

ECCC -- Xuebin Zhang
NCAR -- Andreas Prein
NCAR -- Ethan Gutmann
PCIC -- Francis Zwiers
Univ of Victoria -- Francis Zwiers
University of Saskatchewan -- Yanping Li
University of Saskatchewan -- Jean-Pierre St Maurice




**Highly Qualified Personnel: Professional training and research positions funded by Short Duration Extreme Precipitation in Future Climate**

## Science Advances

Understanding of the physical processes affecting short-duration (less than 24 hours) extreme precipitation and their possible changes in the warming world is critical for many of GWF's knowledge users. However, most global and regional climate models do not directly simulate the processes that produce extreme precipitation due to their coarse resolutions, which hinders the proper interpretation of the precipitation projections produced by these models. Such questions can be addressed by making extensive use of a convection-permitting modeling tool running in a pseudo-global warming mode, and comparing it with existing simulations by global and regional climate models. This project made extensive use of a convection-permitting modeling tool running in a pseudo-global warming mode, and comparing it with existing simulations by global and regional climate models to respond to the following four questions: i) Does temperature scaling work at convective-permitting resolutions for short-duration local precipitation extremes? ii) How will the characteristics of mesoscale convective systems (MCSs) such as the precipitation intensity, size, and life-span of storms change in the future? iii) What are the underlying physical processes that result in changes in MCSs and storm properties? iv) How do extreme precipitation features scale across resolution from GCMs to RCMs to convective permitting WRF? The research should lead to a better understanding of the physical soundness of future precipitation projections by climate models, thereby providing a scientific foundation for the proper use of model projections that many GWF's users depend on.

Precipitation and temperature relationships: Based on a large ensemble of Canadian regional climate models (CanRCM4), the project compared scaling of precipitation extremes across different durations (3-hour, 12-hour, and 24-hour), temporal scales (annual, winter, and summer), and spatial scales (local and regional scales). Findings demonstrated that the binning scaling cannot project the long-term change in precipitation extreme, with the disagreement of spatial pattern and magnitude between the binning scaling and trend scaling regardless of the durations, seasons, and spatial scales. Trends of annual maximum daily precipitation over global land have been updated. By including recent decadal data, more stations started to show statistically significant increasing trends, and fewer stations with decreasing trends. On the other hand, the nonstationary extreme value analysis showed a statistically significant positive association with global mean temperature, with 6.7%/°C and 5.54%/°C of the sensitivity of RX1day and RX5day to global warming respectively. Results from this study have made an important contribution to the extreme chapter of the forthcoming IPCC Working Group 1 contribution to the 6th Assessment Report. This global collection of long daily precipitation records has been used to conduct a detection and attribution analysis to quantify the impact of human influence on the observed changes in extreme precipitation. The influence of anthropogenic forcings on extreme precipitation was detected over the global land area, three continental regions (western Northern Hemisphere, western Eurasia and eastern Eurasia), and many smaller IPCC regions, including C. North-America, E. Asia, E.C. Asia, E. Europe, E. North-America, N. Europe, and W. Siberia for Rx1day, and C. North-America, E. Europe, E. North- America, N. Europe, Russian-Arctic, and W. Siberia for Rx5day. Anthropogenic influence is estimated to have substantially decreased the waiting time between extreme annual maximum events in regions where anthropogenic influence has been detected, which has important implications for infrastructure design and climate change adaptation policy.

Changes in MCSs and characteristics of storms: The Object-based algorithm MODE-TD was applied to get spatiotemporal information in addition to traditional information such as precipitation amount and intensity that can be obtained at grid point. The precipitation features derived from the project's western Canada 4-KM WRF simulation were compared with features derived from three other datasets. The results show that the western Canada WRF simulation can well depict precipitation features such as its size, track length, duration, and propagation speed. The statistical results derived from the WRF historical simulation (CTRL) and future climate (PGW) were compared to identify the potential changes in MCSs and characteristics of storms that may be caused by climate change.

Physical processes underlying the changes in MCSs: It is known that precipitation would be less frequent but more extreme in a warmer climate as warmer air can hold additional moisture. Warm season precipitation (March to August) over the plains east of the Rockies were chosen to examine precipitation systems with fewer topographical impacts. Statistical analysis shows that heavy precipitation events are the main contributor to the eastward propagation of precipitation systems. The PGW simulations demonstrate additional occurrence of extreme precipitation in the central region (over 100 mm/hr) for June, July and August.

Physical realism of GCM and RCM simulated extreme precipitation: the project investigated the observed characteristics of extreme precipitation events over the Canadian Prairies and explored the impacts of climate change on future extreme precipitation events by comparing CONUS I Pseudo Global Warming (PGW) simulation against the historical simulation (CTRL). To understand projected changes in extreme precipitation events under changing climate conditions, several thermodynamic indices underlying the MCSs were investigated. Frequencies of occurrences of convective indices CAPE and LI under different conditions were compared between two simulations during summertime (June to August), to show the response of deep convections to future warmer climate. Analyzing features of these indices and their future changes helps to explain the fundamental mechanisms that contribute most to the changes of the future MCSs-related extreme precipitation.

## Link to Publications List

# Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds

Web Link: [Model Uncertainty - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Canada

Total GWF funding support: $85,000

Project dates: December 2017-November 2020 COMPLETED

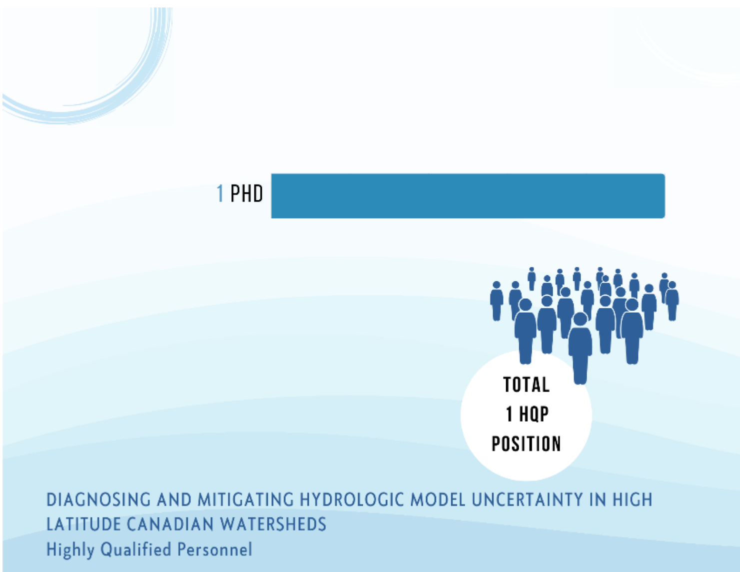
## Investigators

Tricia Stadnyk, University of Manitoba Contact: tricia.stadnyk@ucalgary.ca

## Partners, Collaborators, and Users

Canada Foundation for Innovation -- Olivier Gagnon
ECCC – funding for Innotech lab analyses -- Al Pietroniro
Innotech Alberta -- John Gibson

International Atomic Energy Agency -- Luis J. Araguás
University of Calgary -- David Goldblum




**Highly Qualified Personnel: Professional training and research positions funded by Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds**

## Science Advances

It has been the recommendation of several international collaborative research projects that stable water isotope (SWI) data could be leveraged to "develop a methodology and monitoring network … to understand hydrological processes in large river basins" (IAEA, 2003). SWIs (δ18O, δ2H) have proven to be useful diagnostic variables for hydrological modelling, with some uncertainty as to the degree of usefulness for parameter constraint. There is a need to quantify the effectiveness of isotope data from large scale monitoring networks, applied in conjunction with observed streamflow, at enhancing hydrologic model calibration and optimization. The benefit, should such soft data methods prove successful, would be enhanced knowledge of model parameter uncertainty, and more realistic parameterization of hydrologic models. Such methods could prove especially value in the cold, vast and complex pan-Canadian watersheds.

This project attempted to leverage Stable Water Isotope (SWI) data for development of a methodology and monitoring network to aid in understanding hydrological processes in large river basins. Core objectives were to:

- quantitatively define the value added by isotope-enabled hydrological modelling (IEHM) over conventional techniques
- improve water balance estimation, particularly for climate change (long-term) analyses
- establish recommendations for data networks that best supporting IEHM, including guidelines for the proper use, application and evaluation of IEHMs.

Progress was made through the following activities and findings.

Advancing operational isotope networks in Canada: Results from an operational pilot network (2013-2019) were released in a series of publications, providing the first comprehensive characterization of streamflow across Canada for watersheds ranging in size from 10 to 10,000 km2. An analysis of the regional controls on water balance and signals across the Canadian continent was shared , and these data are now disseminated for use in the hydrologic community. W work to increase their uptake and application is ongoing through (1) continued participation and development of a national graduate course on isotope tracers in catchment hydrology, (2) integration of isotope dataset into the Canadian HydRology package (an R hydrologic code package for Canadian hydrologists).

Analytical modelling techniques: A watershed-based assessment of vapour and runoff partitioning was presented for 103 watersheds across a diverse range of climate and landcover types, spanning 25° latitude and 86° longitude. An isotope-based methodology is applied for estimating evaporation/ inflow (E/I) and transpiration/evapotranspiration (T/ET) utilizing offset between isotope values in streamflow and precipitation, augmented by regional climate reanalysis data. Isotopic enrichment in streamflow serves to differentiate direct, abiotic evaporation, mainly arising from open water evaporation from lakes and wetlands, from transpiration by natural vegetation and cropland, which has previously been recognized as principally non-fractionating. Sensitivity analysis suggests only a minor influence of interception losses on T/ET. Systematic variations in evaporation losses, transpiration losses and gauged runoff are revealed across the major hydrometric regions of Canada. A new water loss classification revealed that 19 of 103 watersheds were runoff dominated, 54 were transpiration dominated, five were evaporation dominated, and 27 had more than one dominant water loss mechanism.

Isotope-enabled hydrologic modelling: Application of the isoWATFLOOD model form the Nelson River basin to the Athabasca River basin was expanded. The primary objectives of work in this area were to explore and define the value-added by isotope-enabled multi-objective optimization (calibration) over conventional streamflow-only calibration, and to offer guidance in how best isotopes can be incorporated into hydrologic models. More than 100,000 iterations of the model at various spatial scales have been run, with data analysis using a combination of more than 30 metrics to evaluate model performance.

## Link to Publications List

# Knowledge Mobilization (KM)

A new hydrologic dataset for Canada, the Canadian isotope monitoring network, integrated with the HydRology R code package to facilitate user uptake and analyses, was distributed. Team members participated the in the Research Coordination Meeting (March 2021) and coordination of research objectives for the multi-member state teams, as well as coordination of modelling advances for distributed isotope-enabled hydrologic modelling with the International Atomic Energy Agency modelling team.  There are now three member states who will be using isoWATFLOOD and the project's tracer-aided methods for operational modelling of regional water balance.

# Professional Development and Technology Transfer

Dr. Stadnyk contributed to the following short course, which offers a professional certification: ENV S898 Isotope tracers in catchment hydrology (J McDonnell, U Sask): 2017, 2018, 2020; 2021.

# Data Management

Web Link: https://gwf.usask.ca/outputs-data/data.php

Region: Canada

Total GWF funding support: $1,782,987

Project dates: June 2017-August 2023

## Investigators

John Pomeroy, University of Saskatchewan
Contact: john.pomeroy@usask.ca
Stephen O'Hearn University of Saskatchewan
Laleh Moradi, University of Saskatchewan
Michael Steeleworthy, Wilfrid Laurier University
Mike Waddington, McMaster University
Krysha Dukacz, McMaster University
Jimmy Lin, University of Waterloo
Bhaleka Persaud, University of Waterloo
Gopal Saha, Wilfrid Laurier University

## Partners, Collaborators, and Users

## Science Advances

The work of the DM team has been largely focused on outreach and metadata collection and cataloging. Additional work included collaborating with other teams, as well as providing ongoing DM support to the GWF Researchers and Highly Qualified Personnel (HQP).

Research Data Management (RDM) Community Relationship Building: Nationally, the GWF DM Team has significant involvement with the Canadian research data management (RDM) community. It has brought considerable knowledge on the rapidly changing RDM policy and infrastructure landscape to GWF and worked to communicate and resolve DM issues and barrier faced by GWF researchers.

- Engaging with the Smart Great Lakes Initiative, a Great Lakes Observing Systems (GLOS - NOAA) program promoting a collaborative approach to managing data to benefit all stakeholders in the Great Lakes region as an input and driver to policy and scientific innovation in data collection. More details can be found in the Common Area Strategy document for the Great Lakes.
    - UW DM - Data and Information team
    - MU DM – Leadership team.
- Participating in RDM grant - UW DM along with two research groups at the University of Waterloo (the Ecohydrology Research Group and Smith Research Group) to advance RDM in the emerging field of microplastics. The team received $38,000 for microplastics metadata template development and a workshop.

The DM Team will continue to engage with stakeholders from the Canadian RDM community to facilitate GWF data management advancement and to add the GWF researchers' voice to the conversations. There are many organizations working to make water data more accessible and more interoperable and it remains important that GWF be a part of these conversations and activities now and after the program's conclusion through its legacy.

GWFNet: The dynamic nature of water science research—in which approaches to observation, modelling, and prediction of Earth systems are continuously evolving—shapes the present data and re-shapes, through reanalysis, the legacy data that has been collected over many years. The team's interactions with well-managed data--past and present--leads to new discoveries, new made-to-order solutions, and a sustainable process of iterative refinement of knowledge and research questions. This process inevitably results in future data which will become tomorrow's important legacy.

Global Water Futures (GWF) is thus steadfastly committed to data stewardship and, to this end, has created a template-based form of data catalogue, GWFNet (https://gwfnet.net), able to incorporate legacy information and future information (of a to-be-determined form) as easily as it handles information from the present day. GWFNet is a catalogue of linked, template-based information records on water science associated with the Global Water Futures program, other important foundational programs that led to Global Water Futures, and to follow-on programs that will be inspired by Global Water Futures.

GWFNet is, and always will be, under active maintenance and development. Its evolution is gradual, continuous, and governed (and strongly motivated) by user satisfaction and whatever enhancements are necessary for the representation of information sought after by the programs it serves. GWFNet is designed to endure long after Global Water Futures and to serve as an important information resource in follow-on water science programs inspired by Global Water Futures.

The vision for GWFNet is to enable a variety of information seekers--from the general public to highly specialized scientists--to easily zero in on trails of information and obtain publications, data sets, near-real-time hydrometeorological data sources, along with other related information that delivers context to the results associated with their searches (including basins, observatories, research sites, stations, model inventories, software, principal investigators, projects, and much more).

GWFNet has been spawned as an output of Global Water Futures, but its mission is to persistently bridge and synthesize information from Canadian programs on water science from the past (https://gwfnet.net/legacy):

- MAGS: The Mackenzie Global Energy and Water Cycle Experiment (GEWEX),
- DRI: Drought Research Initiative,
- IP3: Improving Processes and Parameterization for Prediction in Cold Regions Hydrology,
- CCRN: Changing Cold Regions Network, and
- INARCH Ph1: The International Network for Alpine Research Catchment Hydrology present (https://gwfnet.net/gwfpublications):
- GWF: Global Water Futures ( www.gwf.usask.ca ); INARCH Ph2, COPE, GIWS, and future:
- GWFO, future INARCH programs and other programs yet to be determined.

Today's legacy is tomorrow's future: the collection of metadata remains a critical component of protecting the data legacy of GWF. The DM team continues to engage with researchers to generate metadata for GWF data assets from all project pillars.

Compute Canada/Digital Research Alliance of Canada allocations: Compute Canada provides high performance computing resources and temporary long-term storage for very large volumes of data. In 2023, GWF was allocated $362 K of Digital Research Alliance of Canada resources:

- HPC allocations [rpp-kshook : Manage RAP memberships]
- 1,381 core years on the graham-compute system
- 2,500 TB of project storage on the graham-storage system
- 30.0 /project inode Quota (Millions) on the graham-storage system
- 1,200 TB of nearline storage on the graham-storage system
- 67 core years on the narval-compute system
- 400 TB of project storage on the narval-storage system
- 5.0 /project inode Quota (Millions) on the narval-storage system
- 150 TB of nearline storage on the narval-storage system
- 20 core years on the niagara-compute system
- 50 TB of project storage on the niagara-storage (Graham) system
- 150 TB of nearline storage on the hpss-storage system
- Cloud allocations [cpp-kshook : Manage RAP memberships]
- 28 VCPU years on the arbutus-persistent-cloud system

- 5 Number of cloud instances on the arbutus-persistent-cloud system
- 38 GB of RAM on the arbutus-persistent-cloud system
- 6 volumes on the arbutus-persistent-cloud system
- 6 snapshots on the arbutus-persistent-cloud system
- 4 Floating IP addresses on the arbutus-persistent-cloud system
- 1 TB of cloud shared filesystem storage on the arbutus-persistent-cloud system
- 4,900 GB of cloud volume and snapshot storage on the arbutus-persistent-cloud system.

Monthly reports about usage are received by members of the University of Saskatchewan Data Management team who, in turn, analyze the information to ensure that users consume a fair share of the available storage resources. The aim of the Compute Canada Management Committee was to assess storage statuses and determine actions for the enforcement of fair resource utilization and resolve any issues that may arise.

Copernicus Coordinating Committee: Meets regularly with members of Information and Communications Technology (ICT), the Global Institute for Food Security, and the Global Institute for Water Security to discuss issues related to the Copernicus infrastructure at the University of Saskatchewan and resolve any issues and special requests. The University of Saskatchewan Data Management team helps users determine the amount of compute and storage needed and fields Copernicus Access Requests to ICT for implementation. The USask DM also participates and meets with a Copernicus User Group to discuss issues that arise (especially with the compute scheduler).

WISKI: In the GWF data portal, Water Information System Kisters (WISKI) is used for accessing hydrometeorological, hydrometric, soil moisture, snowpack, water quality, and groundwater raw data. Work has been ongoing to ensure the Web interface is kept up to date with the latest visualisation and web service features.

Dataset Publications to Long-Term Repositories: The team promotes and supports dataset publication through providing advice about suitable repositories, pre-curation review of metadata, and the actual uploading to selected repositories ( such as the Federated Research Data Repository, GF DataStream, Scholars Portal Dataverse). The full list is available at http://giws.usask.ca/meta/ListPubs.php.

Collaboration with other GWF Core Teams: The team is working with Core Modelling on the development of model benchmarking datasets for the WECC observatories (http://www.ccrnetwork.ca/science/WECC/index.php). Through consultation with Core Modelling , a data overview dashboard has been generated for each site to aid researchers in benchmarking site selection. Dashboards have been completed for Baker Creek, Brightwater Creek, Marmot Creek, Wolf Creek, St. Denis, and Peyto Glacier.

The DM team is collaborating more and more with Knowledge Mobilization (KM), as would be expected, as the GWF program comes closer to its conclusion so the legacy of foundational research in context with the myriad information records on observatories, sites, stations, researchers, models, and publications will be known, understood, and prepped for follow-on endeavours which will rely on the GWF legacy: “we are our data”.

Measuring Compliance with GWF DM Policy: The Findable, Accessible, Interoperable and Reusable (FAIR) principles have been adopted by many publishers in hydrology and climate sciences, including the GWF Program. Compliance with the FAIR principles is becoming a requirement for funders. However, determining metrics that measure compliance to a Data Management Policy is still unclear in the community. Journals nowadays seldom accept data as additional files in supplementary materials. Instead, publishers usually request that data supporting publications be submitted to trustworthy repositories and connected to the corresponding papers via digital object identifiers (DOIs).

Work will continue in these areas as well as planning and execution of activities to support the preservation of the GWF legacy.

## Link to Publications List

# Knowledge Mobilization (KM)

The Data Management team produced many publications, posters and presentations for internal and external audiences to increase knowledge around data management policy, practices and trends. Especially notable was : Persaud, B. D., Dukacz, K. A., Saha, G. C., Peterson, A., Moradi, L., O'Hearn, S., ... & Lin, J. (2021). Ten best practices to strengthen stewardship and sharing of water science data in Canada. Hydrological Processes, 35(11), e14385. https://doi.org/10.1002/hyp.14385. This paper won an award from Wiley Publishing: "Among work published in an issue between 1 January 2021 – 31 December 2021, yours received some of the most downloads in the 12 months following online publication".

The DM team also worked to collaborate more closely with the Canadian research data management community as well as other organizations managing water data. Nationally, the team has significant involvement with the Canadian RDM community. It has brought considerable knowledge on the rapidly changing RDM policy and infrastructure landscape to GWF and worked to voice the DM issues and barriers faced by GWF researchers to the overarching RDM network of organizations.

# Professional Development and Technology Transfer

Fostering Research Data Management (RDM) Community Relationship Building: Nationally, the University of Waterloo Data Manager continued to engage with the Canadian RDM community. In 2022 she served as Co-Chair, on the Alliance Data Management Assistant and is also a member of Curation Expert Group with the Alliance. It has brought considerable knowledge on the rapidly changing RDM policy and infrastructure landscape to GWF and worked to voice the DM issues and barriers faced by GWF researchers to the overarching RDM network of organizations. University of Waterloo DM also provided inputs into the development of UWaterloo RDM Strategy. Training: Continuing to organize and facilitate RDM training to individual GWF researchers (> 50) and several lab groups (5) at University of Waterloo.

Through to 03/2023, the WLU Faculty Lead for Data Management co-led the development and publication of Laurier's Institutional RDM Strategy, a requirement of the 2021 Tri-Agency Research Data Management Policy. Through to 09/2022, the WLU Faculty Lead was the co-chair of the Digital Research Alliance of Canada's Curation Expert Group (CEG).The WLU Faculty Lead for DM also sits on the Digital Research Alliance of Canada's Dataverse North Expert Group (DVNEG). Through to 02/2023, he participated in its Metadata Working Group (DVNMWG), represents the University within the Statistics Canada Data Liberation Initiative (DLI), and is its ICPSR Official Representative.

# Core Computer Science

Web Link: [Computer Science Team - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Canada

Total GWF funding support: $2,469,584

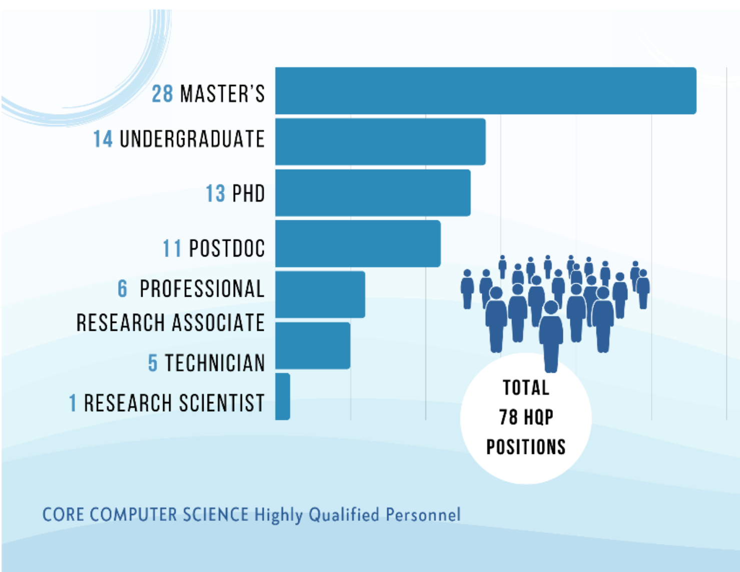
Project dates: January 2018-August 2023 EXTENDED to August 2025

## Investigators

Kevin Schneider, University of Saskatchewan Contact: kevin.schneider@usask.ca
Chanchal Roy, University of Saskatchewan
Banani Roy, University of Saskatchewan
Raymond Spiteri, University of Saskatchewan
Debajyoti Mondal, University of Saskatchewan
Carl Gutwin, University of Saskatchewan
Jimmy Lin, University of Waterloo

## Partners, Collaborators, and Users

Environment and Climate Change Canada – Diogo Costa, Chris Spence
University of Calgary -- Alain Pietroniro
University of Saskatchewan -- John Pomeroy
University of Saskatchewan -- Kevin Shook
University of Saskatchewan -- Logan Fang
University of Saskatchewan -- Peter Lawford
University of Saskatchewan -- Tom Brown
University of Saskatchewan -- Martyn Clark
University of Saskatchewan -- Colin Whitfield
University of Saskatchewan -- Grant Ferguson
University of Saskatchewan -- Helen Baulch
University of Saskatchewan -- Chris Marsh
University of Saskatchewan -- Ali Bahrami
University of Saskatchewan -- Wouter Knoben




Highly Qualified Personnel: Professional training and research positions funded by Core Computer Science

## Science Advances

The Core Computer Science team was established to deliver software platforms and tools for integrating hydrological, water quality and economic models, and developing decision-support systems and scientific processing pipelines for these integrated models. In collaboration with other GWF projects and core technology teams, the core computer science team delivers core computing functionality and expertise, provides high performance computing, software, visualisation, decision-support, and interaction innovation along with software development support to establish new computing platforms and tools for use by GWF scientists. Recent activities include the following.

Hydrological Modelling Software Infrastructure: Migration of CRHM from Borland C++ to modern C++ continued from last year with version 1.3 released on August 25, 2022 after user acceptance tests, and augmented with several new features. This version contains improvements to the parameter editing interface to make it more manageable. The product now features an interface for consolidation parameters and a TeeChart graph refresh option that allows an ongoing simulation to be interrupted mid run. All functions in Borland CRHM are now available and can be applied to observations and variable outputs. Summary files can be produced for both CLI and GUI versions and users can export outputs in all formats Borland CRHM supported. CRHM v1.3 documentation is available at https://wiki.usask.ca/display/CRHMdoc . The report will be helpful for the developers who work on migrating legacy software.

The team continues to develop a program comprehension tool to help new developers understand CHRM code, exploring various natural language processing techniques such as TF-IDF and Word2Vec to create an Abstract Code Summary (ACS) tree that is an indexed data structure for searching and exploring the codebase in a guided way. An MSc student joined to conduct further research in this area. The focus is on how to make the tool usable for developers by supporting features such as comparing CRHM versions, using both static and dynamic representations of the code, generating more useful node names in the concept cluster tree, applying state-of-the-art natural language processing techniques, and integrating comments and nodes to summarize the node's purpose.

Along with an MSc student, the team started exploring federated learning models for localizing bugs in CRHM Code and other open-source software systems. Federated Learning (FL) is a novel machine learning paradigm that enables organizations to collaboratively train models while addressing privacy concerns by keeping data private and secure. Name-based identifiers, such as variable names and function names, contain valuable natural language information that provides insights into a developer's intended semantics and is crucial for program understanding. Most program analysis tools, including bug detection tools, often ignore identifier names. This limitation can lead to overlooking bugs that would be apparent to humans. Deep learning techniques have been employed to address this challenge, and a proposed system leverages FL to develop and evaluate models using a dataset containing accidentally swapped function arguments. Furthermore, the system proposes automating data collection by training and updating the models automatically at specified intervals, using personal data. This approach has the potential to create unified models for specific programming languages, frameworks, and syntaxes. Findings from this work reveal that increasing the number of clients leads to improved results for the federated model, while the dataset size also plays a crucial role. Adjusting the training configuration for clients with comparatively smaller datasets is necessary to ensure optimal performance. The proposed system offers several advantages for collaborative machine learning projects, particularly in overcoming data availability challenges. It eliminates the limitation of specific training data by allowing access to open-source data from diverse sources. Furthermore, the system reduces overall costs by automating the time-consuming tasks of data collection and pre-processing. The results demonstrate the potential of FL for name-based bug detection and emphasize the importance of incorporating natural language information in program analyses to enhance software quality.

As there are now multiple releases of CRHM, a PhD student is looking at how to automatically generate release notes using various software artefacts such as commits, pull requests, and issues. It is often time consuming and erroneous to write a release note manually, and many GitHub projects don't come with release notes. Because release notes are important to give ideas to the developers and other stakeholders regarding the changes that are made in a certain release, the project is exploring various rules based, information retrieval based, and deep learning-based techniques to generate a usable release note.

Hydrological model acceleration and coupling: During the 2022-2023 period, the Canadian Hydrological Model (CHM) received further computational refinement, building on major improvements achieved during the 2021-2022 period. Inclusion of a new snow model, the Factorial Snow Model (FSM v2.0) into CHM was a significant advancement. FSM is a performant, three-layer snow model with a a more modern code design. Testing has shown it provides better predictive capacity than SNOBAL and runs more quickly. The avalanche routine in CHM, SnowSlide, was originally developed as a non-parallel algorithm. It was modified to be applicable to the partitioned MPI approach developed during the previous reporting period. Major efforts were made to streamline the deployment of CHM by leveraging native Compute Canada build systems for the entire CHM toolchain. These refined capabilities are critical for simulating demanding spatial configurations such as large and high-resolution spatial extents. Expanding on the work from the previous year, the SnowCast domain was further increased from 186,00 km^2 to 1.3M km^2. This domain covers western Canada and northwestern United States at snowdrift-permitting resolution and provides unprecedented high-resolution snow cover predictions.

Applying AI techniques to the management of textual data and metadata: The team has been exploring automatic techniques to identify and link entities that appear in free text to a knowledge graph. For example, if an abstract or a metadata description of a dataset mentions 'Grand River', we are able to automatically link the mention to Q1542855 in Wikidata. This then provides the starting point for automatic management and curation of scientific publications and datasets. As a demonstration: MMEAD, or MS MARCO Entity Annotations and Disambiguations is a resource for entity links for the MS MARCO datasets. A format for how links for the MS MARCO document and passage collections can be stored and shared has been developed. Following this specification entity links are released to Wikipedia for the document and passage for both MS MARCO collections (v1 and v2). Links have been produced by the REL and BLINK systems. MMEAD is an easy-to-install Python package, allowing users to load the link data and entity embeddings effortlessly. Using the MMEAD data takes only a few lines of code. Finally, the team has demonstrated how MMEAD can be used for IR research that uses entity information. On the MS MARCO v1 passage dataset, recall@1000 and MRR@10 is improved on more complex queries by using this resource. A demonstration has been prepared to show that entity expansions can also be used for interactive search applications.

Visualisation: To advance the model-agnostic workflow, GWF modelers are closely collaborating with the computer science team to evaluate a model-agnostic approach to collaborative, scalable and interactive visualisation of model outputs. The team has continued work on the GWF visualisation platform that aims at supporting modelers to interrogate their models, to understand observed or predicted scenarios, and to communicate scientific discoveries to stakeholders. The team has actively contributed by providing necessary model simulation data for development of the platform, and have been participating in evaluation of the visualisations generated by various models such as MESH, SUMMA, and output to ensure generalizability to other models within and potentially beyond GWF core modeling. Some of these model outputs have a large number of data dimensions while some have hundred millions of features that needs to be rendered in real time. This poses a significant challenge to the scalability and interactivity of the visualisation. Consequently, this evaluation is an important milestone that would help in understanding expectations and in setting boundaries of the model-agnostic visualisation concept.

The visualisation platform initially targeted GWF core modelers as primary users due to the domain-specific knowledge required to create a sustainable model agnostic approach. The visualisation platform currently consists of three components: the programmable interface, the interactive visual analytics display generated by the programs, and the backend user management system. A demo of the platform is at https://github.com/river-flow-vis/docs. The platform allows modelers to use the data processing scripts and APIs to create programs that can generate the visual analytics dashboard. The dashboard is configurable through the programming interface. Different teams working on different types of models can use the same platform to visualize their data by with configuration that best suits their needs. The platform functionalities can be used to share the interactive visual analytics dashboard as a web link : users do not need to know about the programming part of the interface. In the long run, this idea has the potential to support scientists as they can better understand their model functionalities through the model output visualisation, to inspire collaboration in a multi-disciplinary team and with stakeholders, and to improve dissemination of scientific knowledge to a broader audience for better water risk management and decision support.

The visualisation platform is likely to be extended beyond core modelers once it is properly tested by the modelers and reviewed by the knowledge mobilization team. As a proof of concept, a collaboration with Prairie Water project investigators was set up to see whether the platform could be generalized to support use cases beyond the core modeling team. While the tool was able to visualize Prairie Water data, some key differences and commonalities among the needs of various user groups were observed. The similarities are mainly at high-level visualisation needs, where the visual dashboard must have some support for creating charts for temporal dimensions, rendering geospatial features on different layers, scenario comparisons, data filtering, and selection. The differences come from the ways different user groups structure their data, interact with the data, and interpret the data at different granularities with different goals. Analysing these produced some valuable insights and a knowledge base of visualisation, interaction, dashboard components, and features that can be integrated into the system over time as the platform matures to support more scientific teams.

The visualisation tool is expected to improve based on user feedback and the hope is to build a community of developers that would continue the open-source development and create a forum around the platform to sustain its community. To achieve this goal, key backend components that such a system should have such as user management to manage user specific programs and visualisations have been integrated, including security checks to prevent unexpected server attack or computational load, ensuring visualisations that are not only scalable while rendering but also during interaction. The next phase should involve structured interviews with modelers and one-to-one interactions to evaluate the system. This would help to test the functionalities of the current system as well as to create a pipeline for making video tutorials and training materials, which are the first step towards organizing webinars and workshop that would allow the project to introduce the platform to a broader community of modelers.

## Link to Publications

## Knowledge Mobilization (KM)

The team's work was featured as part of the Star Phoenix's young innovators series in the article https://www.cs.usask.ca/news/2022/building-a-tool-for-more-efficient-software-coding-usask-research.php.

## Professional Development and Technology Transfer

A brief demo of the visualisation platform can be accessed at https://github.com/river-flow-vis/docs.

The latest version of CHRM is available at https://research-groups.usask.ca/hydrology/modelling/crhm.php.

# Winter Soil Processes in Transition

Web Link: https://gwftest.usask.ca/projects-facilities/all-projects/p1-winter-soil.php

Region: Canada

Total GWF funding support: $300,000

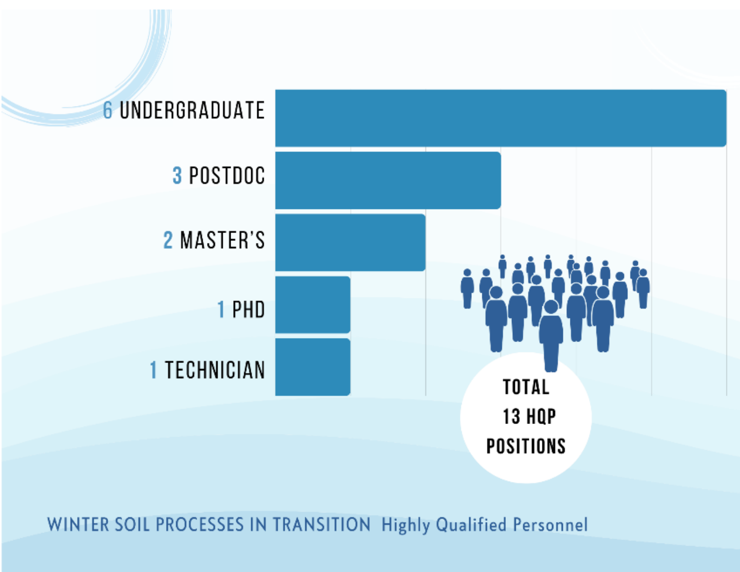
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Fereidoun Rezanezhad, University of Waterloo
Contact: frezanez@uwaterloo.ca
Laura Hug, University of Waterloo
Phillipe Van Capellen, University of Waterloo
Dave Rudolph, University of Waterloo
Scott Smith, Wilfrid Laurier University

## Partners, Collaborators, and Users

Canadian Forest Service Great Lakes Forestry Centre (CFS -- GLFC)
Natural Resources Canada -- Kara Webster
Environment and Climate Change Canada -- Chris Parsons
Lawrence Berkeley National Laboratory – Susan Hubbard
Memorial University of Newfoundland -- Christina Smeaton
RARE Charitable Research Reserve -- Jenna Quinn
Technical University of Munich, Germany -- Carsten W. Mueller
University of Manitoba – Ronald Stewart
University of Saskatchewan – Chris Spence
University of Waterloo -- Merrin Macrae
University of Waterloo – Nandita Basu
University of Waterloo & University of Toronto -- Colin McCarter
Wilfrid Laurier University -- Jennifer Baltzer
Wilfrid Laurier University -- William Quinton




Highly Qualified Personnel: Professional training and research positions funded by Winter Soil Processes in Transition

## Science Advances

In an uncertain future climate, both the quantity and quality of water supplied by headwater wetland source areas in cold regions are expected to change significantly. However, knowledge of how climate change will impact the biogeochemical functioning and hydrochemistry of these source areas remains limited. This project worked to elucidate the role of winter soil processes on the export of carbon (C) and nutrients (N, P, S, Fe) to the river network under changing climate conditions. Soils from field sites of the GWF Northern Water Futures, Mountain Water Futures and Sibbald Research Wetlands were analyzed. The data and insights gained through laboratory-controlled experimental and modeling activities yielded a better conceptual understanding of shallow subsurface biogeochemical processes and strengthened their representation in coupled biogeochemical-hydrological catchment models. Overall, the project has enhanced the ability to evaluate the impact of different potential climatic scenarios on C and nutrient export and speciation along the aquatic continuum.

An analysis of work on microbial community compositional stability in agricultural soils during freeze-thaw and fertilizer stress, and impact of winter soil processes on nutrient leaching in cold region agroecosystems was completed. The project has achieved the following:

- A series of controlled laboratory experiments to understand in what processes the carbon and nutrient stocks, species, and fluxes in agricultural soils will be affected by a warming winter climate and what changes to the microbial community and their activities can be expected in a warming winter. Microbial community analyses are important in determining the impact of climate change for winter soils on how: 1) unexpectedly, microbial activities in frozen or near-frozen soils impact nutrient cycles, 2) renewed activity becomes even more prominent during thaw events with bursts of respiration and denitrification leading to the production of greenhouse gases, 3) increased microbial activity during freeze-thaw transitions may consume fall-amended fertilizer, reducing its efficacy come the growing season, and 4) shifts in microbial diversity in response to freeze-thaws may change the active metabolisms in soils, impacting crop growth. The analyses and interpretations of the results were integrated with reactive transport modeling in hydrology-biogeochemistry models to simulate and predict the biogeochemical transformations of nutrients in winter soils under changing climate conditions. Findings from this study will ultimately be used to bolster winter soil biogeochemical models by elucidating nutrient fluxes over changing winter conditions to refine best management practices for fertilizer application.
- Results from the above-described soil column experiment indicated fertilizer nitrogen is susceptible to nitrification and loss via leaching. To better understand the biogeochemical processes of nitrate leaching under winter conditions, MSc and PhD students conducted a series of sacrificial soil jar batch experiments to assess the efficacy of nitrification inhibitors in fertilized agricultural soil during the non-growing season. Results showed that nitrification inhibitors were effective at reducing nitrification under thaw conditions but were less effective under freeze-thaw conditions. $NO_3$- concentration increases in the unfertilized jars under the freeze-thaw condition were comparable to the $NO_3$- concentrations increases in the fertilized and inhibited jars. This suggests that freeze-thaw cycling enhanced N mineralization in the soil jars. Findings from this study indicate best management practices regarding Fall fertilizer application may need to account for changing winter processes.
- Investigating the impact of variable winter and fertilizer conditions on microbial activity rather than community composition, using gene expression monitored via metatranscriptomics, shed light on the specific response of the soil microbiome through the winter in terms of gene expression and metabolic capacity, clarify microbial impacts on biogeochemical cycling, providing end-users with concrete information on the impacts of winter freeze-thaws on agricultural best-practices for fertilization.
- Simulation of observed aerobic microbial respiration rates versus the soil moisture contents allows further expansion of the mechanisms to account for soil biogeochemical processes as a function of temperature or frozen water in pore spaces.

Link to Publications List

## Knowledge Mobilization (KM)

In the past three years of the project, the team produced progress updates outlining the winter soil processes project activities through news items, conference presentations, websites and blog postings.

Soil and water samples for the laboratory experiments were collected from the Rare Charitable Research Reserve, a 900+ acre land reserve located in the Region of Waterloo. Staff from Rare participated in site visits, soil sampling and facilitated open access to a large geospatial information database and participated in conference calls and meetings to discuss the project work plan, to provide and receive feedback to/from the project team. The project team supported the staff from rare with project-specific information for their communications materials (e.g., a public level news item published on the rare Charitable Research Reserve blog: “Our Soils Get Colder – Will this Affect Plant Growth and Water Quality?” (https://raresites.wordpress.com on April 9, 2019). Through these channels, the project is increasing public awareness about soil and aquatic resource issues and highlighting GWF excellence and global reach.

Given the current limited knowledge on the effects of changing winter conditions on soil biogeochemical processes and fluxes, the research team have been actively involved in the organization of conference sessions and/or workshops highlighting the importance of this topic (organized one workshop and one session in conference on the topics related to the aspect of hydrobiogeochemical dynamics of terrestrial and aquatic systems and the winter processes have been included in the workshop/session outlines). The outcomes of this project and activities will form the core of future international research collaborations and therefore contribute to the international stature of GWF as a global leader in sustainable water futures.

Articles in popular media:

WaterResearch Newsletter, The Water Institute, University of Waterloo. Arctic found to be a CO2 source, not a sink study reveals, Issue 8, 2020. https://uwaterloo.ca/water-institute-research/issue-8/feature/A -found-be-co2-source-not-sink-study-reveals

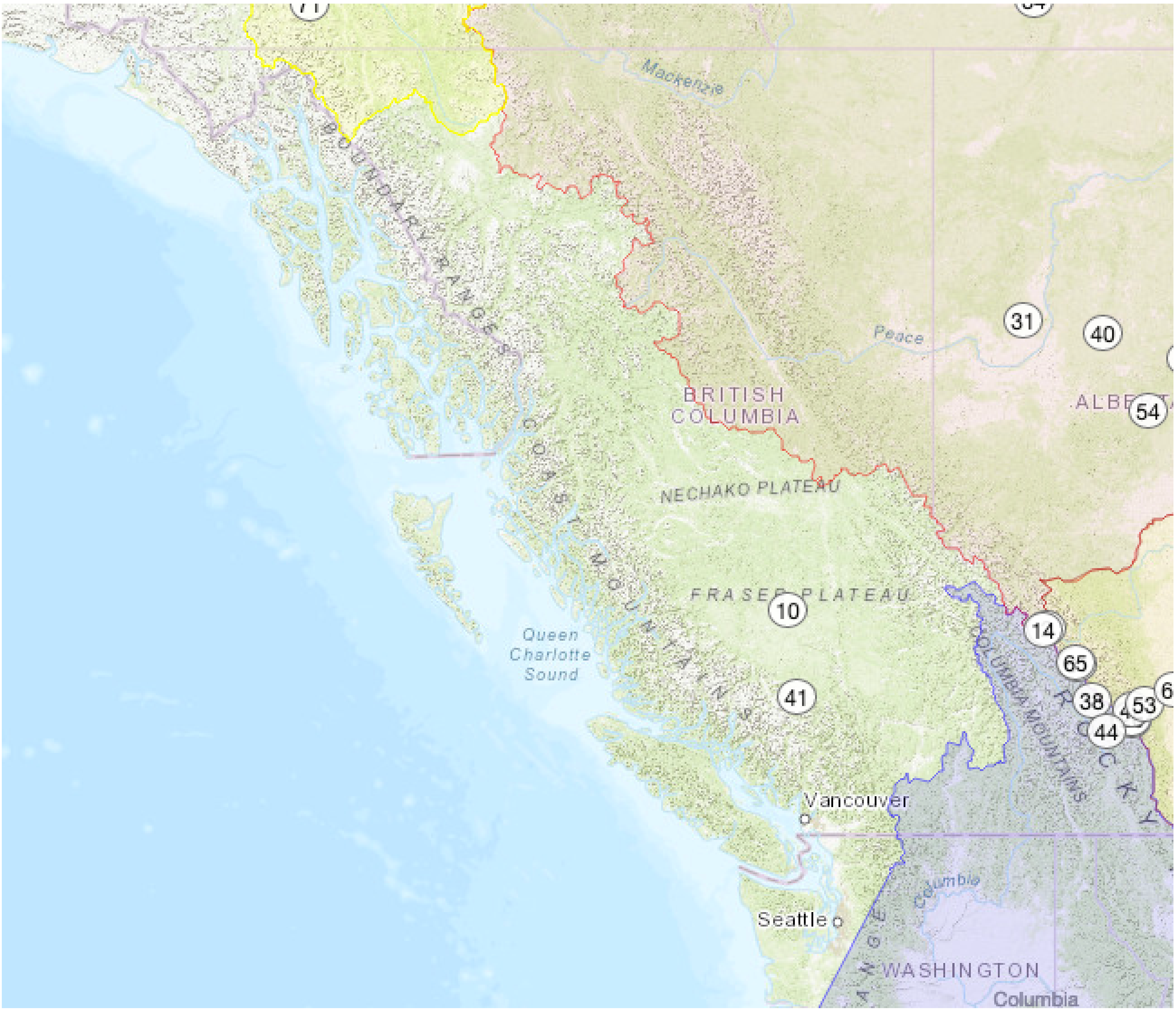
Press Release/News Interview with University of Waterloo, June 2021. Climate warming to increase carbon loss in Canadian peatland by 103 per cent. https://uwaterloo.ca/news/media/climate-warming-increase-carbon-loss-canadian-peatland-103

Innovation News Network. Developing innovative techniques to investigate winter soil processes. July 22, 2022. https://www.innovationnewsnetwork.com/developing-techniques-investigate-winter-soil-processes/23392/

Interviews (broadcast or text): Arts & Science Community Showcase on rare Charitable Research Reserve blog (Enhancing the protection of soil and water resources through integrated environmental research), October 8th, 2020, https://raresites.wordpress.com/2020/10/08/enhancing-the-protection-of-soil-and-water-resources-through-integrated-environmental-research/

Two workshops.

# Mountain West Region



# Storms and Precipitation across the Continental Divide Experiment (SPADE)

Web Link: [SPADE - Global Water Futures - University of Saskatchewan (usask.ca)](https://gwf.usask.ca/projects-facilities/all-projects/i1-schusterwallace.php) https://gwf.usask.ca/projects-facilities/all-projects/i1-schusterwallace.php - Investigators

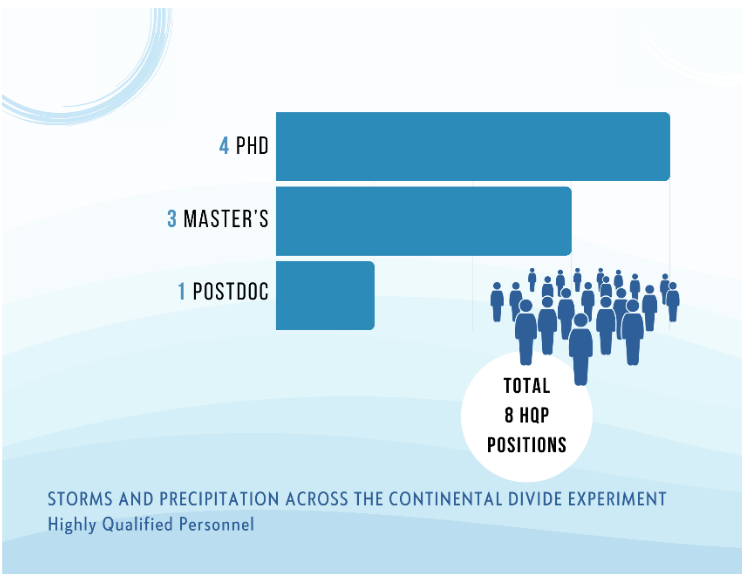
Region: Pacific

Total GWF funding support: $280,000

Project dates: December 2017-November 2020 EXTENDED to August 2024

## Investigators

Julie Thériault, Université du Québec à Montréal Contact: theriault.julie@uqam.ca
Stephen Déry, University of Northern British Columbia
John Pomeroy, University of Saskatchewan
Ronald Stewart, University of Manitoba




Highly Qualified Personnel: Professional training and research positions funded by SPADE

## Partners, Collaborators, and Users

Canada Research Chairs, Tri -- Agency Institutional Programs Secretariat 2017 - 2024 -- John Pomeroy
Canada Sustainable Development Goals Unit -- Ugo Therien
Canada's Chief Scientific Officer -- Mona Nemer
Environment and Climate Change Canada -- Peter Rodriguez, Zen Mariani, Stella Melo (2019 – 2024)
Natural Sciences and Engineering Research Council (NSERC) Discovery 2017 -- 2019 -- John Pomeroy,
Natural Sciences and Engineering Research Council (NSERC) Discovery 2019 -- 2024 -- Julie Thériault
Natural Sciences and Engineering Research Council (NSERC) Discovery 2016 -- 2022 -- Ron Stewart
Natural Sciences and Engineering Research Council (NSERC) Discovery 2016 -- 2021 -- Stephen Déry
Statistics Canada -- Francois Soulard
University of Calgary -- Shawn Marshall
University of Saskatchewan 2017-2024 (CRC Support) -- John Pomeroy
University of Saskatchewan 2017-2020 (GIWS CFI match) -- John Pomeroy
Water Security Alliance -- Andrew Schofield
Western Economic Diversification -- Abdul Jalil

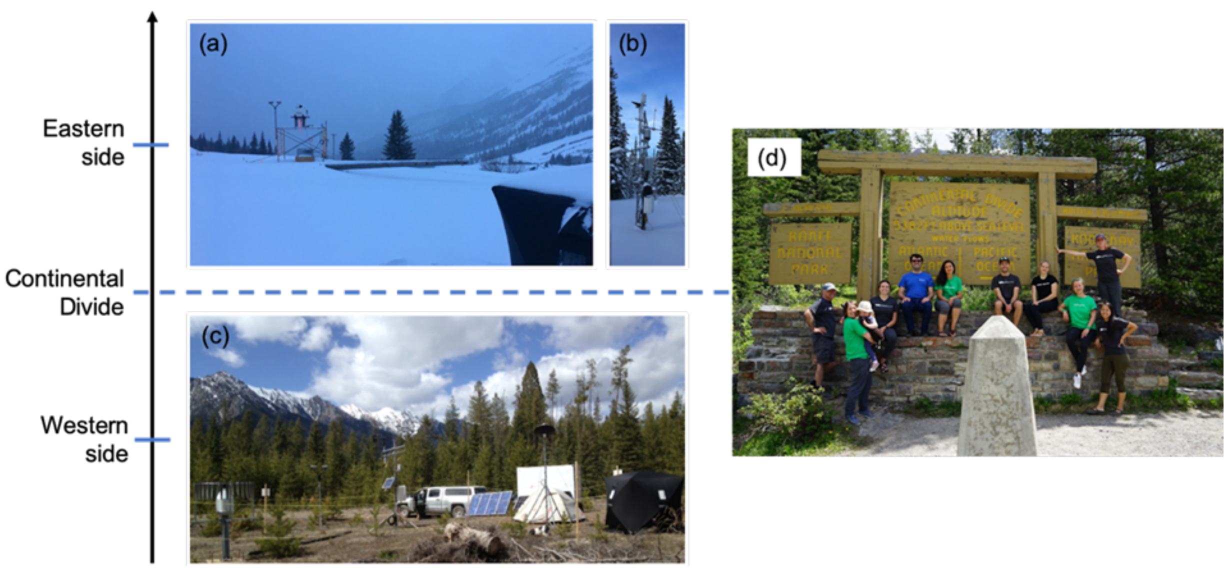
# Science Advances

The Storms and Precipitation Across the Continental Divide Experiment (SPADE) has addressed key questions related to water availability and processes associated with water partitioning over a major continental divide using special observations obtained within an April to June 2019 field experiment. The Canadian Rockies form a triple continental divide, separating drainages into the Arctic, Pacific, and Atlantic Oceans. Their high, partly glacierized peaks are the water towers for rivers that support vast areas of western Canada and the northwestern United States. Seventeen per cent of North America lies within river basins receiving water from this region. The region's hydrology is dominated by a cold, snowy winter from October through March, followed by the melt of the seasonal snow cover from April to July; this latter period is also associated with peak precipitation, which may fall as rain or snow. This wet period is then followed by a drier late summer period during which streamflow is dominated by groundwater discharge, glacier melt, and rainfall-runoff. Despite the importance of precipitation distribution in this region, little is known about the atmospheric processes in this extreme event-prone region, where few observations linking surface meteorological features, precipitation, and atmospheric conditions have been obtained. SPADE addressed this for the first time.

The SPADE study region lies along the continental divide that forms the southern border between the Canadian provinces of British Columbia and Alberta, encompassing sections of Banff, Kootenay and Yoho National Parks as well as Kananaskis Country. Mount Assiniboine is the highest peak within the area, with an elevation of 3,618 m above mean sea level. To quantify storms and precipitation across the continental divide, observational sites were installed on both sides within the study area. Two sites were installed on the eastern side and one site on the western side.

## SPADE experimental design

Thirteen precipitation events were documented over the two-month experimental period. The drastic difference in the atmospheric conditions across the continental divide was stunning. Even if it is known that predicting precipitation processes in complex terrain is challenging, SPADE allowed researchers to study them in unprecedented detail by documenting precipitation type and phase at the surface and aloft over these sites simultaneously. Based on an examination of all the collected information, including measurements and re-analysis of larger-scale atmospheric conditions, it is apparent that the relative amount of precipitation and condensate crossing the divide depended on the weather pattern, precipitation characteristics, as well as moisture and condensate fluxes. Weather patterns led to a range of moisture flux alignments relative to the divide. When the moisture flux was perpendicular, either from the east or the west, more precipitation was, not surprisingly, produced on the side from which the moisture originated. Precipitation only occurred on both sides when sufficient moisture crossed the divide and when the associated condensate did not sublimate or evaporate while falling into relatively dry conditions. Whether precipitation did or did not cross the divide also depended on finer-scale processes, including condensate features. For example, during easterly flow, particles were slightly larger when precipitation occurred on both sides of the divide simultaneously. These particles were produced within deeper precipitation layers over the eastern side and because they were higher in elevation, were more likely to drift over the divide. They would continue to grow through deposition, aggregation, and riming and, because they were larger, they would also be less likely to evaporate or sublimate completely before reaching the surface.




SPADE study sites

The results from SPADE led to the need for additional research. First, it was found that the precipitation-gradient varies on either side of the divide, and it vanishes when only the continental divide's western side is considered. This could be explained by the atmospheric patterns leading to variable precipitation in the Canadian Rockies but this needs to be explored. Second, the process and rate of moisture conversion into condensate is particularly important in mountain areas. Various ice crystal habits often occurred simultaneously, and these should be included into models as this can affect particle drift aloft, growth/decay processes along their trajectories, and in turn, the distribution of precipitation at the surface. Third, local water cycling is impacted by these precipitation-related mechanisms because surface water is being re-distributed among major drainage basins. For example, moisture evaporated from the Canadian Prairies could lead to precipitation that can cross the continental divide and flow into the Pacific Ocean instead of remaining within the same drainage basin. This would have significant implications on water availability across the often-dry Canadian Prairies. Fourth, the SPADE data can be used to evaluate Global Precipitation Measurement constellation of satellites using the optical-laser disdrometer and the Micro-rain radar in complex terrain. Fifth, water distribution across the continental divide may be substantially impacted by climate change. Assuming no difference in wind speed, warmer and more moist conditions may lead to deeper precipitation layers and consequently more precipitation crossing the divide. In contrast, these warmer conditions could also produce more fast-falling rain leading to reduced horizontal transport, and less precipitation crossing the divide. It is recognized that experiments using high-resolution modeling with advanced microphysical parameterizations are ultimately needed to precisely assess the atmospheric conditions leading to precipitation crossing the divide. Future efforts should also explore the degree to which these findings are applicable to other snowmelt seasons, to other periods of the year, and to other major watershed divides globally.

SPADE contributed to advanced disaster prevention by better understanding conditions leading to precipitation across the continental divide, which can lead to extreme events. The prediction of the precipitation amount and phase, as well as their timing, including the height of the 0oC-isotherm are critical for water managers to support emergency responses to flooding.

## Link to Publications List

# Knowledge Mobilization (KM)

All knowledge mobilization activities were conducted during the field experiment. Over the course of the field campaign, the team wrote 31 blog posts on the project website (https://gwf-spade.weebly.com/), posted 34 Instagram photos (@gwf_spade), and tweeted 45 times (@GwfSpade). Researchers presented to the community in four different presentations/workshops and were the subject of six news articles/press releases. Most notably, team members were interviewed in local newspapers in Canmore the Columbia Valley. Following the field campaign, preliminary research findings were shared at 12 conferences/public presentations/government workshops. The team is continuing to post on social media and have written an additional five blog posts, posted 28 Instagram photos, and tweeted 36 times. There are nearly 100 followers on Instagram and Twitter, and Twitter posts have been retweeted by UNBC, UQAM, GWF, and Ski Fortress, which has allowed them to reach a broader audience.

On 10-11 May 2019, SPADE researchers participated in Canmore's Science Odyssey at the Canmore Museum, where community members had the opportunity to learn about Canadian achievements in science, technology, engineering, and math. Three HQP were part of the Global Water Futures display, and they discussed the field campaign and research, as well as demonstrated how some weather instruments work. A pamphlet explaining the project was also made available to community members.

SPADE hosted a workshop on 23 May 2019 with middle school students at Lawrence Grassi school in Canmore where three HQPs gave three presentations (two in English, one in French) that showcased the research conducted in the area, and provided some background information about precipitation, cloud formation processes, and local climate. They also did a small experiment/demonstration with the students to make a "cloud in a jar".

### Citizen Science

### Meetings with governments, decision makers, practitioners; policy

- Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023
- Expert Review Panelist, Swiss Federal Institute WSL for Forest, Snow and Landscape Research evaluation panel, ETH Zurich, Mar 2022 - Feb 2023

#### Interviews (broadcast or text)

- World Water Day: the importance of fresh water, Broadcast Interview, CBC Radio Calgary, Mar 2023

- How a former ski hill in southern Alberta has become an important key to climate study, Broadcast Interview, CBC News Calgary, Jan 2022
- Will it Snow this Christmas?, Broadcast Interview, CBC News, Dec 2022
- Research-powered climate adaptation and water security solutions, Text Interview, The Globe and Mail, Nov 2022
- Researchers turn to artificial intelligence to model how snow cover is shrinking, Broadcast Interview, CBC News, Nov 2022
- Q+A: U of S water expert delivers talks to COP27 climate conference, Text Interview, Saskatoon StarPhoenix, Nov 2022
- Funding for USask-led water monitoring network will help understand, manage floods, drought: director, Broadcast Interview, CBC News Saskatoon, Aug 2022
- USask major scientific centres awarded $170M of MSI funding, Text Interview, USask News, Aug 2022

Public workshops and presentations

- Pomeroy, J.W., Presentation on severe weather and changing climate, Canmore Collegiate High School, Canmore, Canada, February 14, 2023

Other Outreach

- Pomeroy, J.W., Ivanov, G. & Davies, T.D. (November 2022). Cold Regions Warming – A Transitions Exhibition: Global Water Futures [Artistic Exhibition]. Whyte Museum of the Canadian Rockies, Banff, Canada
- Presenter, Soapbox Ottawa, Downtown Ottawa, September 2022: https://soapboxscienceotta.wixsite.com/website
- Presenter, Raconte-moi l'hiver, Soirée Sciences et contes, Coeur des sciences, UQAM, Dec. 2022: https://coeurdessciences.uqam.ca/component/eventlist/details/1079-raconte-moi-hiver.html

# Professional Development and Technology Transfer

The SPADE database is available publicly on the Federated Research Data Repository (FRDR).

## Mountain Water Futures (MWF)

Web Link: http://www.mountainwaterfutures.ca/

Region: Pacific

Total GWF funding support: $1,726,083; $1,164,000

Project dates: June 2017-August 2023 EXTENDED to August 2024

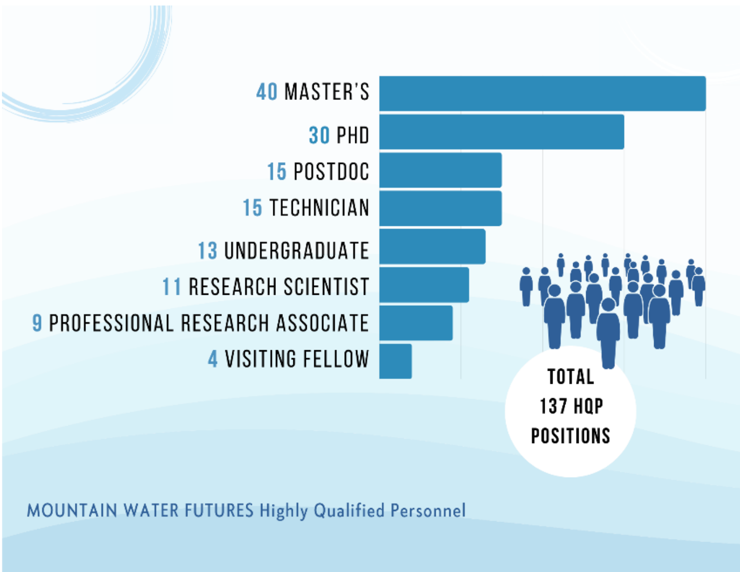
### Investigators

Sean Carey, McMaster University Contact: careysk@mcmaster.ca
Stephen Déry, University of Northern British Columbia
Masaki Hayashi, University of Calgary
Jeffrey McKenzie, McGill University
Brian Menounos, University of Northern British Columbia
Richard Petrone, University of Waterloo
John Pomeroy, University of Saskatchewan
Joseph Shea, University of Northern British Columbia
Ronald Stewart, University of Manitoba
Julie Thériault, Université du Québec à Montréal
Cherie Westbrook, University of Saskatchewan
Francis Zwiers, University of Victoria

### Partners, Collaborators, and Users

Alberta Innovates -- Brett Purdy
Ann and Sandy Cross Conservation Area -- Greg Shyba
BC Hydro -- Frank Weber
Canada Foundation for Innovation (John R. Evans Leaders Fund) 2018-21
Canada Research Chairs, Tri-Agency Institutional Programs Secretariat 2017-24
Canada's Chief Scientific Officer -- Mona Nemer
Canadian Mountain Network -- Matt Berry
Carleton University -- Stephan Gruber
CFI Adaptable Earth Observing System -- Julie Thériault
Connect Charter School -- Cherie Westbrook
Cows and Fish -- Norine Ambrose
Environment and Climate Change Canada 2019-24 -- Stella Melo
Fortress Mountain Holdings Ltd. 2016-22 -- Chris Chevalier
Government of Yukon 2023 -- Anthony Bier
Hakai Institute -- Eric Peterson
Miistakis Institute -- Danah Duke
MLFNRORD -- Marten Geertsma, Alex Bevington
National Sciences and Engineering Research Council (NSERC) Discovery 2019-24
National Sciences and Engineering Research Council (NSERC) Discovery 2019-24
Natural Resources Canada -- Paula McLeod
Natural Resources Canada (NRCan) 2018-20 ---– Elaine Dehamel, Carolyn Mann, Monica Harvey, Mary-Ann Wilson
Pacific Institute for the Mathematical Sciences (PIMS) 2018-21 -- Ruth Situma
Spanish National Research Council -- Juan Ignacio Lopez Moreno
Spray Lake Sawmills 2016-2019 -- Jason Mogilefsky
Statistics Canada -- Francois Soulard
Stoney Nakoda First Nation -- Bill Snow
Strategic Planning, Risk and Policy at SaskWater, Board of Directors -- Ingrid Newton
Sustainable Development Goals Unit -- Ugo Therien
UNESCO Chairs Programme -- Anil Mishra
Université du Québec à Montréal -- Julie Theriault
University of Alberta -- Augustana -- Hood, Glynnis

University of Saskatchewan 2017 -24 (CRC Support)
University of Saskatchewan 2017-20 (GIWS CFI match)
University of Tuscia -- Riccardo Valentini
Alberta Innovates 2020-22 -- Richard Petrone
Water Security Alliance -- Andrew Schofield
Western Economic Diversification -- Abdul Jalil
Western Economic Diversification Canada 2017-21 -- Jennifer Stelzer
Yukon Water Resources Branch -- Heather Jirousek, Director
Yukon University -- Benoit Turcotte




Highly Qualified Personnel: Professional training and research positions funded by Mountain Water Futures

# Science Advances

Mountains source water for more than half of humanity, and Canada's western mountains are the headwaters of the Saskatchewan, Mackenzie, Yukon, Columbia, and Fraser rivers that flow to the Atlantic, Arctic, and Pacific oceans. These river drainage basins cradle much of Canada's economic activity west of the Great Lakes. Critical pressures include rapid population growth, climate change, hydroelectricity, fisheries, mining and agriculture. This region is undergoing dramatic change as glaciers recede, snowpacks diminish, permafrost thaws and vegetation regimes change. The goal of this project is to understand future water for the mountains of Western Canada and to improve the ability to predict future hydrological regimes and plan appropriate adaptation. The project is developing a user-driven mountain west observation and prediction system for snow, glaciers and hydrology in mountainous terrain. This includes montane and alpine environments in the Rocky, Coast, Columbia, Mackenzie and Richardson Mountains that are the major headwaters of western Canada's east, west and north flowing rivers.

Area and mass change for western Canadian glaciers.: A postdoctoral student produced work on coupling a physically based snow model (SNOWMODEL) to ice-dynamics that was used for reanalysis of the Place and Peyto mass balance records. That work showed notable discrepancies in observed vs. modeled mass balance in both records, primarily in the 1980s. The team believes the discrepancies relate to errors in the reported mass balance, which is important since both records are often used to validate/calibrate physically based models (e.g. glacier mass balance and hydrological models). This research also contributed to a global assessment of glacier mass change for the period 2000-2020. Accelerated mass loss over the last 10 years, with an acceleration over the period 2015-2020 was observed. This accelerated mass loss coincides with warm, dry conditions over western Canada. The team's geodetic data was used to calibrate an ice dynamics model (flowline) that evolved glaciers out to 2100 CE under the newest IPCC emission scenarios. The model includes debris cover and models frontal ablation (mass loss due to calving) and, in addition to modeling the projected mass change in western Canada, these results also provide Canada with a Pan Canadian assessment of projected changes in glaciers for the remainder of the century.

Surface water – groundwater interaction: Overall goals of the SGW theme of MWF were to: (1) identify unique aquifer systems that represent common conditions of the MWF domain; (2) quantify the hydrogeological response of these systems to water inputs by glacier melt, snowmelt, and rainfall; (3) characterize the effects of stream-groundwater exchange processes on distribution and extent of thermal refugia; (4) incorporate new understanding of these processes in the models developed in MWF; and (5) develop practical tools to estimate groundwater contribution and its sensitivity to climate change and land-use practices. The team conducted detailed field studies at several alpine catchments in the Canadian Rockies to identify major types of aquifers and their roles in sustaining the baseflow of mountain rivers, and generated a new conceptual framework for understanding alpine hydrogeology (objectives 1 and 2). A detailed field study at the Fortress Ski Area was carried out to demonstrate the role of a seasonal headwater lake in regulating the temperature of a headwater stream (objective 3). Using the findings of the Fortress study, the team developed a simple mathematical equation to represent the storage-discharge characteristic of an alpine aquifer complex, which can be easily incorporated in large-scale hydrological models developed in MWF (objective 4). Project researchers are in the process of building a practical tool to parameterize the mathematical equation above using readily available geospatial information (objective 5). These results will provide the scientific basis for understanding the response of stream baseflow to climate change and land-use practices to the user group, as well as practical tools for the development of water resources policies. Further research will focus on implementation of the simple mathematical equation in practical hydrological models and the validation of the updated hydrological models.

Impact of future climate and glacier change on glacierized basin hydrological processes and streamflow generation: By combining remote mountain fieldwork with state-of-the-art process-based hydrological modelling, project researchers diagnosed impact. A new automated salt dilution system in the Peyto Glacier Research Basin collected critical streamflow. A new way to calculate the thickness of loose rock debris covering glaciers was developed using thermal IR imagery. The compensating influence of forest fire activity on glacier melt was investigated and found that, due to the deposition of smoke particles on the glacier ice, the melt can increase by up to 10%. Building upon the knowledge gained by these innovative data collection and analysis techniques, a physically based glacio-hydrological model was developed and tested in the Peyto Glacier Research Basin, a 53% glacierized headwater basin (as of 2013) located in the Canadian Rockies. This glacio-hydrological model was used to investigate the recent past and current (1990-2020) hydrology of the basin based on weather observations collected in the area. Over these 32 years, the streamflow at Peyto Glacier was highly variable due to the variable weather conditions. Despite this high variability, snowmelt always provided the largest fraction of annual streamflow (44 to 89%), followed by glacier melt (10-45% of annual streamflow). Interestingly, in years with high streamflow, snowmelt contributed less to the streamflow, and ice melt contributed more. Years with high streamflow were on average 1.43˚C warmer than low streamflow years, and high streamflow years had lower winter snow accumulation, earlier snowmelt and higher summer rain than years with low streamflow. By 2085, the Peyto Glacier Research Basin is expected to be almost completely glacier-free, 5°C warmer and with 16% more precipitation. This increase in precipitation, mainly expressed as an increase in rainfall at the expense of snowfall, will nearly compensate for the decreased ice melt associated with glacier retreat. Overall, the annual streamflow is predicted to decrease by 7% annually. The timing of streamflow will advance substantially, with the timing of peak flow shifting from July to June, and August streamflow dropping by 68%.

Researchers also diagnosed the impact of projected changes in climate and glacier cover on the hydrology of several natural flowing Bow River headwater basins in the Canadian Rockies. The basins are: the Bow River at Lake Louise (~420.7 km2), the Pipestone River near Lake Louise (304.2 km2), the Bow River at Banff (~2192.2 km2) all of which drain the high elevation, snowy, partially glaciated Central Range, and the Elbow River at Calgary (~1191.9 km2), which drains the drier Front Ranges and foothills. Diagnoses used models created in the Cold Regions Hydrological Modelling platform (CRHM). Hydrological models were constructed and parameterised in CRHM from local research results to include relevant streamflow generation processes for Canadian Rockies headwater basins, such as blowing snow, avalanching, snow interception and sublimation, energy budget snow and glacier melt, infiltration to frozen and unfrozen soils, hillslope sub-surface water redistribution, wetlands, lakes, evapotranspiration, groundwater flow, surface runoff and open channel flow. Surface layer outputs from Weather Research and Forecasting (WRF) model simulations for the current climate and for the late 21st century climate under a 'business-as-usual' scenario, Representative Concentration Pathway 8.5 (RCP8.5) at 4-km resolution, were used to force model simulations to examine the climate change impact. Projected glacier cover under a 'business-as-usual' scenario (RCP8.5) was incorporated to assess the impact of concomitant glacier cover decline. Uncalibrated model simulations for the current climate and glacier coverage showed useful predictions of snow accumulation, snowmelt, and streamflow when compared to surface observations from 2000-2015. Under the RCP8.5 climate change scenario, the basins of the Bow River at Banff and Elbow River at Calgary will warm up by 4.7 and 4.5°C respectively and receive 12% to 15% more precipitation annually, with both basins experiencing a greater proportion of precipitation as rainfall. Peak snow accumulation in Bow River Basin will slightly rise by 3 mm, whilst it will drop by 20 mm in Elbow River Basin, and annual snowmelt volume will increase by 43 mm in Bow River Basin but decrease by 55 mm in Elbow River Basin. Snow covered periods will decline by 37 and 46 days in Bow and Elbow river basins respectively due to suppressed snow redistribution by wind and gravity and earlier melt. The shorter snow covered period and warmer, wetter climate will increase evapotranspiration and glacier melt, if the glaciers were held constant, and decrease sublimation, lake levels, soil moisture and groundwater levels. The hydrological responses of the basins will differ despite similar climate changes because of differing biophysical characteristics, climates, and hydrological processes generating runoff. Climate change with concomitant glacier decline is predicted to increase the peak discharge and mean annual water yield by 12.23 m3 s-1 (+11%) and 11% in the higher elevation basins of the Bow River but will decrease the mean annual peak discharge by 3.58 m3 s-1 (-9%) and increase the mean annual water yield by 18% in the lower elevation basin of the Elbow River. This shows complex and compensatory hydrological process responses to climate change with reduced glacier contribution lessoning the impact of higher precipitation in high elevation headwaters. Drier soil conditions and lower spring snowpacks will reduce peak discharges despite increased precipitation during spring runoff in the Front Range and foothills headwaters under a warmer climate.

Whether or not the impact of warming on mountain snow and runoff can be offset by precipitation increases has not been well examined, but this is crucially important for future downstream water supply. Using the Cold Regions Hydrological Modelling Platform (CRHM), elasticity (percent change in runoff divided by change in a climate forcing) and the sensitivity of snow regimes to perturbations were investigated in three well-instrumented mountain research basins spanning the northern North American Cordillera. Hourly meteorological observations were perturbed using air temperature and precipitation changes and were then used to force hydrological models for each basin. In all three basins, lower temperature sensitivities of annual runoff volume (≤ 6% °C-1) and higher sensitivities of peak snowpack (-17% °C-1) showed that annual runoff was far less sensitive to temperature than the snow regime. Higher and lower precipitation elasticities of annual runoff (1.5 – 2.1) and peak snowpack (0.7 – 1.1) indicated that the runoff change is primarily attributed to precipitation change and, secondarily, to warming. A low discrepancy between observed and simulated precipitation elasticities showed that the model results are reliable, allowing sensitivity analysis. The air temperature elasticities, however, must be interpreted with care as the projected warmings range beyond observed temperatures and, hence, it is not possible to test their reliability. Simulations using multiple elevations showed that the timing of peak snowpack was most sensitive to temperature. For the range of warming expected from North American climate model simulations, the impacts of warming on annual runoff, but not on peak snowpack, can be offset by the size of precipitation increases projected for the near-future period 2041-2070. To offset the impact of 2°C warming on annual runoff, precipitation would need to increase by less than 5% in all three basins. To offset the impact of 2°C warming on peak snowpack, however, precipitation would need to increase by 12% in Wolf Creek in Yukon Territory, 18% in Marmot Creek in the Canadian Rockies, and an amount greater than the maximum projected at Reynolds Mountain in Idaho. The role of increased precipitation as a compensator for the impact of warming on snowpack is more effective at the highest elevations and higher latitudes. Increased precipitation leads to resilient and strongly coupled snow and runoff regimes, contrasting sharply with the sensitive and weakly coupled regimes at low elevations and in temperate climate zones.

Shifts in ecosystems and changes in hydrological regimes from thawing permafrost and shifting precipitation patterns: In Canada's northern mountains, climate is rapidly changing. As part of the VEG and SGW themes, projects were developed in consultation with Yukon Government and the Tr'ondëk Hwëch'in (TH) First Nation to tackle some of these important issues. To examine the role of thawing permafrost on subsurface flow pathways and interactions, project researchers instrumented multiple catchments along the Dempster Highway as well as enhancing observations in the Wolf Creek Research Basin to characterize watersheds in distinct physiographic and permafrost settings. They observed long term hydrological and chemical fluxes from these basins and worked to understand hydrological connectivity and the influence of setting on flow-chemistry relations. This work is ongoing, yet results in WCRB suggest that the catchment is well connected throughout the year, and that hydrological and chemical responses are not threshold-mediated in most circumstances. Headwaters and alpine regions result in the greatest source of water for downstream ecosystems. Other work in these watersheds aims at understanding the influence of permafrost and vegetation change on stream thermal regimes, including through examination of historical records throughout the territory. There has been a focus on wetlands in the second phase of the project, and in Wolf Creek, study of the role of valley bottom and isolated wetlands in WCRB found that isolated wetlands relied solely on snowmelt to sustain their water table, and dried throughout the summer as rainfall was insufficient to exceed evaporation. In contrast, valley bottom wetlands were sustained from upland recharge throughout the year, and consequently are much less susceptible to drying.

Rapid vegetation change is ubiquitous across northern latitudes. Research identified rapid shrub expansion in Wolf Creek through repeat LiDAR measurements with field validation. The role of vegetation, and vegetation change, on water, energy and carbon cycling is critical and many activities in GWF are examining coupled ecohydrological interactions. As part of MWF, the WCRB established a transect of three eddy covariance stations that are examining the influence of vegetation on water/energy partitioning. In this work, eddy covariance, direct sap-flux measurements, and stable isotopes were used to understand how shifts in vegetation can impact catchment hydrology. This suggests that advances in treeline will increase overall ET and lower interannual variability. ET was considerably less at the cooler higher elevation shrub sites, which exhibited similar ET losses over six years despite differences in shrub height and abundance. ET rates between the two shrub sites were similar throughout the year, except during the peak growing season. Greater interannual variability in ET at the short, sparse shrub site indicates the reduced influence of vegetation controls on ET. Results suggest that predicted changes in vegetation type and structure in northern regions will have a considerable impact on water partitioning and will vary in a complex way in response to changing precipitation timing, phase and magnitude, growing season length, and vegetation snow and rain interactions. Using direct measures of sapflow for three different species, researchers were able to evaluate how contributions of T to ET vary between sites and years and their predominant controls. Results indicate that in the mid growing season, mean T rates were higher and dense shrub sites than a white spruce forest, accounting for ~80% of total ET compared with ~50% for the forest. Analysis suggests that overall seasonal wetness is an important influence on T for shrub species, and that distinct differences in sap flux densities, sensitivities to environmental drivers, and stomatal resistances exist among shrub species. This likely means that warming temperatures, increases in growing season length, and increased rainfall will cause differences in evaporative response and partitioning over complex, heterogenous alpine watersheds.

This work further used stable water isotopes to assess the role of soil moisture, frozen ground status, precipitation dynamics, and plant species on the timing, magnitude, and sources of plant water uptake at three sites across WCRB. Soil and xylem water were sampled from pre-leaf out to post-senescence over two hydrologically distinct years to assess: 1) the seasonal and interannual changes in the isotopic composition of soil and xylem water across a range of subarctic vegetation covers 2) where in the soil profile subarctic plants access water within and among seasons and 3) how the seasonal origin of xylem and soil water varies across a cold, subarctic ecosystem. While $\delta^2H$ and $\delta^{18}O$ of volume weighted precipitation became more depleted with elevation, the opposite was true in xylem water, where $\delta^2H$ and $\delta^{18}O$ became more enriched. Plant water uptake was more reflective of snow water at the forest site than both shrub sites. Near-surface bulk soil water had more negative lc-excess at the forest throughout the season and with depth, highlighting increased contributions from soil evaporation. Of particular note, willow and birch shrubs had distinct lc-excess values, and indicate shallower, more evaporatively enriched sources for birch. Mixing analyses reveals that subarctic plants were opportunistic, using both snow and rain dependent upon season and timing of precipitation. These findings advance understanding of the storage and fluxes of water across vegetation types, which is essential to predicting how future vegetation change will impact future hydrological cycling in cold regions.

Precipitation phase and surface air temperature features over the Western Cordillera and on atmospheric rivers (AR) and their consequences: For the first focus on precipitation phase and near-0°C surface air temperatures, an emphasis was placed on Terrace, British Columbia, a location prone to surface temperatures lasting for long periods near 0°C accompanied by precipitation that includes snow, wet snow, freezing rain, and freezing drizzle. Using Environment and Climate Change Canada climate data, near-0°C conditions were analyzed from 1956 to 2021. Events with such temperatures had an average duration of 11 h that increases substantially with any type of precipitation (18 h), and even more with freezing precipitation (39 h). Several factors contribute to such long-lived occurrences, including the ocean's proximity, the surrounding topography, latent heat exchange and persistent cloudy conditions. Mixed precipitation instances with temperature inversions are supported by ARs that enhance melting aloft with below 0°C temperatures at the lower levels. Case studies associated with long-near-0°C conditions with precipitation are currently being investigated using sophisticated meteorological equipment installed at the UNBC Campus in Terrace.

The changes in occurrence and features of near-0°C conditions and rain-snow transition regions over the Western Cordillera were also examined using the pseudo-global warming approach, which assumes the end of the 21st century climate conditions using the CONUS I Weather Research and Forecasting model simulations produced through GWF. First, the focus was on the January-April 2010 period of the 2010 Winter Olympics as previously reported. It was found that precipitation transition regions occurred on 93% of days within the current climate and 94% in the future one. These regions are 374 m and 240 m higher in the future climate over the Coast and Interior Mountains, respectively. Such increases would lead to major impacts on the area's many ski resorts. Second, a study of the rain-snow transitions aloft was also conducted across the continental divide, at the Kootenay and the Calgary stations, respectively. The 0°C-isotherm, often the top of the rain-snow transition, will increase at both sides but slightly higher at Calgary than Kootenay. It will also occur more often during the winter in the warmer conditions. Third, an examination of near-0°C across southern Canada was completed. The Western Cordillera experiences some of the highest number of occurrences of such conditions and some of the largest changes (either fewer or greater) in a warmer climate. The same features apply to the associated near-0°C precipitation plus this region contains the highest fractions of near-0°C conditions with precipitation in both the current and warmer climate.

The second focus, on atmospheric rivers (AR), led to several studies. One component involves placing into a climatological context the mid-November 2021 floods in southwestern BC compared to those occurring over the last 21 years. Over the past year, this project was extended to include an additional 17 extreme flood events; therefore, accounting for 37 flood events occurring from 2000 to 2021 in British Columbia (BC), including the mid-November 2021 flood event. These flood events were well documented by peer-reviewed articles, news articles, technical reports, and federal databases, which provided detailed information about the insured cost, number of evacuations and casualties associated with each flood. Details regarding the population of the affected region and affected area of each flood event have been obtained from Statistics Canada. This study also utilized information from more than 200 climatological stations across the province of BC. Eighteen floods were related to heavy rainfall, 10 were associated with rain-on-snow, six were associated with an ice jam, two were associated with snowmelt, and one associated with snowmelt and ice jam. A map of the dates of these flood events showed a bi-modal pattern of flood occurrences with a primary season (spring to early summer with 16 floods) and a secondary season (fall to early winter with 21 floods). The mid-November 2021 flood had distinct features. Its values of average total precipitation and integrated water vapour transport (IVT) were higher than for > 90% of the other 28 floods related to rainfall. This event was one of the only four rainfall related flood events that occurred in the secondary season with IVT ≥ 400 kg m-1 s-1. It also led to the largest number of injuries (up to 40), fatalities (up to five), and evacuations as compared to the other 36 floods, thereby costing the province up to $9B Canadian dollars. These results indicate that the mid-November 2021 flood was influenced by the climatology and human-related factors associated with the flood regions.

Further research has explored the impact of ARs on British Columbia's Nechako River Basin (NRB). Results show that ARs play a significant role in replenishing water resources in the NRB, contributing to approximately one-fifth of the total precipitation in the region. There is an overall reduction in mid-intensity AR events near the NRB, with September and October exhibiting higher AR activity and November presenting the highest average AR intensity. The results also show an increasing trend in total precipitation linked to low-intensity ARs for the north and west sectors of the watershed. Rainfall trends related to low-intensity ARs in the Upper Stuart, and non-AR-related systems in the Upper Stuart and the Upper Nechako, indicate an increase in rainfall contribution to the snow/rainfall ratio of these nival sub-basins. The Upper Nechako and Stellako are particularly affected by AR-related rain, with approximately one-third of their annual rain linked to ARs. The Upper Stuart is the most affected by AR-related snow and snow water equivalent (SWE), particularly in the fall and winter, due to its mountainous terrain and northern location within the NRB. While AR-related rain is more common during AR events in spring, the Upper Nechako and Upper Stuart receive higher totals of AR-related snow. AR-related rain is the only form of precipitation during the summer. The NRB receives a significant proportion of its total precipitation from ARs in the fall, linked to 45% and 24% of the seasonal rain and snow. AR-related snow prevails during the winter in all sub-basins, with the Upper Nechako and Upper Stuart receiving the highest totals for the season. However, the AR-related SWE is relatively higher in the fall due to the increased frequency and intensity of ARs, despite the often-warm temperatures affecting the snowpack.

Additional work on the hydrological impacts of ARs makes use of PCIC's VIC-GL simulated streamflow for 1948-2012 for 67 Water Survey of Canada (WSC) hydrometric stations spanning British Columbia's Coast and Insular Mountains. Preliminary findings indicate that, for most stations, the percentage of high flows (90th percentile of daily runoff) ranges from 4-7% during summer except for some of the stations over Vancouver Island. Each station's annual and seasonal runoff trend analyses were performed for three horizons 1948-2012, 1948-1980, and 1981-2012 using the Mann-Kendall (MK) test. Trend results revealed a shift toward positive trends in annual and seasonal (spring and summer) runoff from 1948-1980 to 1981-2012 for most of the stations over Vancouver Island and the Northern coastal areas. The study also quantifies the contribution of ARs to the 90th percentile of daily runoff. On Vancouver Island, ARs contribute 15-30% of the 90th percentile of daily runoff for most stations; during autumn, ARs contribute 30-62% of the high-flow events. This study provides additional insights into the hydrological response to landfalling ARs across British Columbia's coast.

Link to Publications List

## Knowledge Mobilization (KM)

The project team presented preliminary results of its work at the annual science forum of the Bow River Basin Council, which was attended by representatives from local user groups. The presentation prompted a new collaboration between Alberta Environment and Protected Areas (EPA) and the project team for implementation of the approach to estimate catchment-scale groundwater storage-discharge characteristics developed in MWF. A new grant from Alberta EPA and NSERC Alliance will support implementation. This will help to mobilize MWF-generated knowledge and influence the water policy of Alberta.


RD | October 26, 2022 | October 26, 2022 | HANS

**In recognition of Wolf Creek research basin**

**Hon. Mr. Clarke:** I rise today on behalf of the Yukon Liberal government and on behalf of the Official Opposition to pay tribute to the Wolf Creek research basin, which celebrated its 30th anniversary this year. Thank you all for being here today and for the work that you do in supporting the research efforts of the Wolf Creek research basin and on climate change and water resources generally in the Yukon and Canada's north.

The Wolf Creek research basin was established in 1992 as part of Indian and Northern Affairs Canada's Arctic environmental strategy in partnership with Environment Canada's National Hydrology Research Centre. I want to acknowledge the pioneering efforts of Ric Janowicz, John Pomeroy, and Sean Carey, who are responsible for establishing the Wolf Creek research basin project.

Ric Janowicz knew 30 years ago that there was something special and important happening in the Yukon that would greatly impact our understanding of climate change in Canada's north. To truly understand the effects of climate change, he had the foresight to know that scientists then, now, and into the future would need an observation area to measure changes in hydroclimatic conditions in the north.

As a result of the Wolf Creek multidisciplinary monitoring project that was created in 1992, initially the project focused on the water cycle in northern climates. Over the years, the research has expanded into multiple sciences to include climate and climate change, vegetation, forestry, fisheries, and wildlife. Research generally at the Wolf Creek basin has helped us understand the impacts of freeze-and-thaw patterns on our waters and the sensitivity of our alpine vegetation and habitats to climate change.

Important hydrological cryospheric and atmospheric research continues in the basin to the present day. Research is supported by the Department of Environment's Water Resources branch, McMaster University, and the Centre for Hydrology at the University of Saskatchewan through its Global Water Futures program, the largest water and water-related climate research initiative of its kind in the world. The Wolf Creek basin has also become an internationally renowned climate change research area.

The data produced is used in cold regions around the world to understand, plan, and prepare for the impacts of climate change. Your commitment to scientific knowledge is supporting us to make better decisions for our future.

The Wolf Creek research basin, through the cooperation and partnerships of governments, First Nations, and academics, is an example of how we have come to work together to understand and address the biggest challenge of our time.

Mr. Speaker, I had the honour of attending the anniversary celebration this past summer, and I am honoured again to stand in this House today to pay tribute to the 30th anniversary of the Wolf Creek research basin. This important project has proven the Yukon's leading role in studying climate change. Thank you to Ric Janowicz, John Pomeroy, and Sean Carey for establishing this important project and to all scientists, the employees of the Water Resources branch, McMaster University, and others who have contributed to making the Wolf Creek research basin a truly special example of innovative research and collaboration.

The Wolf Creek research basin has supported and will continue to support scientists, policymakers, local residents in the Yukon, and others around the world to understand and respond to climate change impacts in northern regions.

*Applause*

**Ms. Blake:** I rise on behalf of the NDP to pay tribute to the Wolf Creek research Basin. I must admit that I had not known anything about the incredible work being done in this watershed until today. Like many Yukoners, I am only familiar with Wolf Creek for its beautiful campground amenities that help to bring family and community together. I have been visiting the basin for over a decade to hunt and fish in the Coal Lake area. I had no idea of the scale of research being done there.

I was very excited to learn about the important work being conducted across the beautiful alpine area. In 1992, Ric Janowicz and Dr. John Pomeroy understood the need for better hydrology and water-quality data to help with things like flood forecasting. The Wolf Creek basin, with its easy logistics and established access road, made for an obvious candidate. They pushed to establish the first forecasting system of its type north of 60 and one of the most complex models in the world at the time.

They didn't know, at that time, that their work would last more than a few years, let alone become such an important research hub. I was struck by the quality of students and researchers conducting research at the basin. As one of the longest tenured research sites in Canada, the data provided by the basin's many gauges and stations is clearly attracting a variety of bright researchers with a diversity of experiences and new ideas.

Much of the work being conducted in the basin relates to our changing climate — 30 years and counting of hydrology and water-quality data tells an important story. It tells us how the Whitehorse area is rapidly changing and the impact that has had and will have on our homes, local wildlife, and more.

I am grateful for all of the researchers working to better understand the impacts of this. We don't always recognize the importance of scientific research like this, but I can tell that the results of this work will be used to fuel new policy for decision-makers for years to come, from protecting fish populations to flood forecasting and prevention to the important role of wetlands in storing carbon and water table regulation. I hope that their work is used to protect this beautiful region and others for future generations.

From now on, when I travel through the area by quad or snowmobile, I will look at the snow, creeks, and wetlands in a new way. I will appreciate them for their contributions to science and to helping us better understand the world we live in. Mahsi'.

*Applause*

Recognition by Yukon Legislative Assembly of Wolf Creek Research Basin after 30th Anniversary event on August 3, 2022

Another noteworthy event was public celebration of the 30th year of research in Wolf Creek Research Basin, Yukon Territory, held on August 3, 2022. Wolf Creek is one of Canada's longest continuous running research watersheds that has significantly advanced understanding of cold regions hydrology. GWF and McMaster University has permanent staff based in Whitehorse, and a formal partnership with the Yukon Government for shared resources and scientific priorities. The 30th anniversary event was attended by senior government ministers, staff, scientists, and approximately 100 members of the public. Following this, Wolf Creek Research and the science that it contributed was formally thanked in the Yukon Legislative Hansard by two political parties for contributions to research in the Territory and a commitment to northern Canadians.

The project team worked with Yukon Parks to develop an interpretive sign to be placed permanently at the Wolf Creek campground and created a website to reach the public about activities in (www.wolfcreekresearchbasin.ca). The team also worked with Yukon Government, Water Resources Branch and other GWF investigators to hold a third annual fireside chat at the Tombstone Territorial park.

Promotional poster for Wolf Creek Watershed research

As part of ongoing efforts to improve monitoring and better understand the impacts of climate change on water security in British Columbia's Nechako Watershed, dedicated efforts have been made to share knowledge with communities including First Nations, stakeholders, and knowledge users, including industry partners. A primary user of findings from this research is Rio Tinto, which is especially concerned about the impacts of climate change on precipitation in the mountainous, upper portion of the Nechako Watershed the company regulates. Dr. Déry meets on a regular basis with Rio Tinto staff to convey latest research findings. He is also fully involved in the Water Engagement Initiative (WEI; www.getinvolvednechako.ca), a community engagement group initiated by Rio Tinto. Since the fall of 2020, Dr. Déry has participated in the monthly meetings of the WEI, bi-weekly meetings of its technical working group, and periodic meetings of its climate researchers. Other industry partners and end users include Imperial Metals (Huckleberry Mine), Tatuk Lake Resort, and Nadina Lake Lodge. Knowledge exchanges also continue with several First Nations across the Nechako Watershed including the Cheslatta Carrier Nation, Stellat'en, Nak'azdli Whut'en, Binche Whut'en and Tl'azt'en First Nations. Government officials are also regularly consulted. Ongoing research on atmospheric rivers was presented to the Terrace City Council in June 2021. Finally, interactions continue with Fisheries and Oceans Canada's Nadina

River Spawning Channel that have facilitated installation of equipment to track hydrometeorological extremes in the upper Nechako Watershed.

Meetings with governments, decision makers, practitioners

- Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023

- Great Lakes roundtable discussion with the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada, Niagara Falls, Canada, September 28, 2022

Interpretive sign erected in Wolf Creek Campground

- Panelist, High-level panel on the Canada Water Agency, towards innovative water management, Global Water Futures (GWF) Annual Open Science Meeting, Virtual, May 16, 2022

- Expert Review Panelist, Swiss Federal Institute WSL for Forest, Snow and Landscape Research evaluation panel, ETH Zurich, Mar 2022 - Feb 2023

Articles in popular media

- Menounos, B. 2021 was a bad year for glaciers in western North America — and it's about to get much worse. The Conversation.

- Pomeroy, J. June 2022. History of Canadian Hydrology and Relation to Operational Water Resources Management (Magazine Article). Canadian Water Resources Association (CWRA) Water News, Vol. 41(3)

- Pomeroy, J.W., Axworthy, T. and B. Sandford. March 2023. Opinion: Spring is here, where is the Canada Water Agency? (Newspaper article). Globe and Mail

- Axworthy, T., Pomeroy, J.W., Hines, E. December 2022. Canada must not waste opportunities at COP15 in Montreal. (Newspaper article) Hill Times.

**Interviews**

- Menounos, Brian. January, 2023: The Charlatan, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: Peninsula News Reviews, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CBC Daybreak South, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CICK Radio, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CBC - J. Wagstaff, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: Globe and Mail, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CBC Vancouver, Early Edition, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CKNW Radio, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CBC Victoria, Radio, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CBC Daybreak, Radio, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: VISTA Radio, 'Projected loss of Earth's glaciers and sea level rise'

- Menounos, Brian. January, 2023: CHEK TV, 'Projected loss of Earth's glaciers and sea level rise'

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- Hayashi, M. Groundwater in the Lake O'Hara watershed: Hidden water reservoir. Evening talk presented at Le Relais day shelter at Lake O'Hara, Yoho National Park, August 17 and 26, 2022.

- Lilhare, R., Wu, J., and Déry, S. J. (2022). Update on climate change research for the Nechako Watershed.

Main Table meeting of the Water Engagement Initiative, Prince George, Canada.

- Pomeroy, J.W. (February 14, 2023). Presentation on severe weather and changing climate, Canmore Collegiate High School, Canmore, Canada.

- Pomeroy, J.W. (November 19, 2023). The Science behind Cold Regions Warming – A

Transitions Exhibition. Public Session on Cold Regions Warming hosted by the Whyte Museum of the Canadian Rockies, Banff, Canada.

- Pomeroy, J.W. (March 18, 2023). Tour of Marmot Creek Monitoring Station, Generate/Navigate: Youth Water & Environmental Leadership Youth Summit, Inside Education, Kananaskis, Canada.

Promotional videos

- Tahtsa Ranges Atmospheric River Experiment - What is it? (12 July 2022)
- Tahtsa Ranges Atmospheric River Experiment - Weather Stations (20 July 2022)
- Tahtsa Ranges Atmospheric River Experiment - The fieldwork experience (10 August 2022)
- Tahtsa Ranges Atmospheric River Experiment - Preliminary Modelling (13 October 2022)

Other outreach

- Presenter, Soapbox Ottawa, Downtown Ottawa, September 2022: https://soapboxscienceotta.wixsite.com/website
- Presenter, Raconte-moi l'hiver, Soirée Sciences et contes, Coeur des sciences, UQAM, Dec

. 2022: https://coeurdessciences.uqam.ca/component/eventlist/details/1079-raconte-moi-hiver.html

# Professional Development and Technology Transfer

The University of Saskatchewan Centre for Hydrology with the assistance of the Canadian Society for Hydrological Sciences offered an intensive course on the physical principles of hydrology with particular relevance to Canadian conditions. Factors governing hydrological processes in Canadian landscapes were to be discussed, framed within the context of distinctly Canadian landscape features such as high mountains, glaciers, peatlands, prairies, tundra, boreal forests, frozen rivers and seasonally frozen ground. Students were exposed to an overview of each subject, with recent scientific findings and new cutting-edge theories, tools and techniques, emerging from the course with a deeper understanding of physical hydrological processes and how they interact to produce catchment water budgets and streamflow response.

# Prairie Region

# Towards Saskatchewan Well Water Security: Knowledge and Tools for People and Livestock Health

Web Link: [Towards Saskatchewan Well Water Security: Knowledge and Tools for People and Livestock Health - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Prairie Region

Total GWF funding support: $140,000

Project dates: August 2020-July 2023 EXTENDED to August 2024

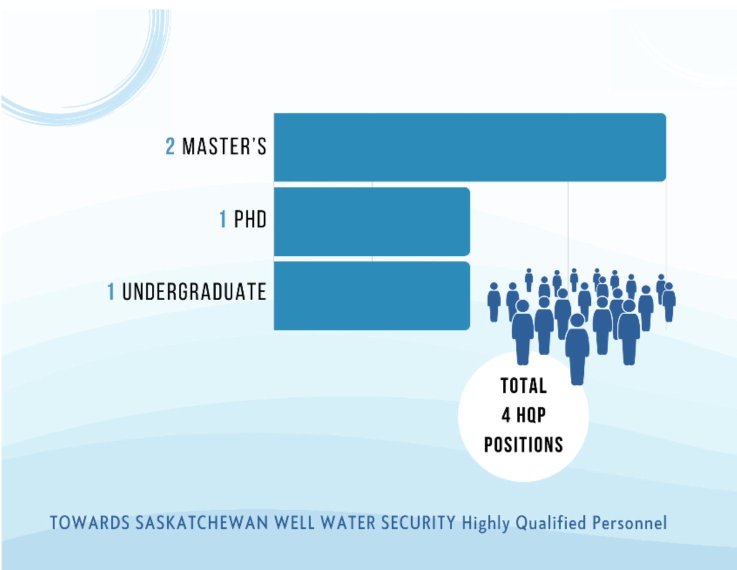
## Investigators

Corinne Schuster-Wallace, University of Saskatchewan
Contact: cschuster.wallace@usask.ca
Sarah Dickson-Anderson, McMaster University
Lalita Bharadwaj, University of Saskatchewan
Monica Emelko, University of Waterloo
Simon Papalexiou, University of Saskatchewan
Greg Penner, University of Saskatchewan
Spencer Smith, McMaster University
Phillip Bailey, Roy Romanow Provincial Laboratory, Saskatchewan Health Authority
Katherine Finn, North Saskatchewan River Basin Council

## Partners, Collaborators, and Users

Hydrology and Groundwater Services, Saskatchewan Water Security Agency -- Kei Lo

Saskatchewan Ministry of Health
Water Quality Branch, Saskatchewan Water Security Agency -- Lorelei Ford




**Highly Qualified Personnel: Professional training and research positions funded by Towards Saskatchewan Well Water Security**

## Science Advances

In Saskatchewan, private wells often provide a diversified and sustainable source of water for agricultural operations and rural life. While multiple government agencies (e.g., Saskatchewan Ministry of Health, Saskatchewan Health Authority, Ministry of Agriculture, and Water Security Agency) support private well users through testing, consultation, or education, a coordinated, data-driven management approach to private well water stewardship is currently lacking. The project is working to develop and demonstrate a decision-support tool to enhance well stewardship, and therefore improve management of groundwater resources and protect health, under changing water futures. An online survey was circulated in the fall of 2021 and garnered approximately 200 responses from across SK. Data are currently being analyzed.

Link to Publications List

# Groundwater, Climate Change and Water Security in the Canadian Prairies

Web Link: [Groundwater, Climate Change and Water Security in the Canadian Prairies - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Prairie Region

Total GWF funding support: $140,000

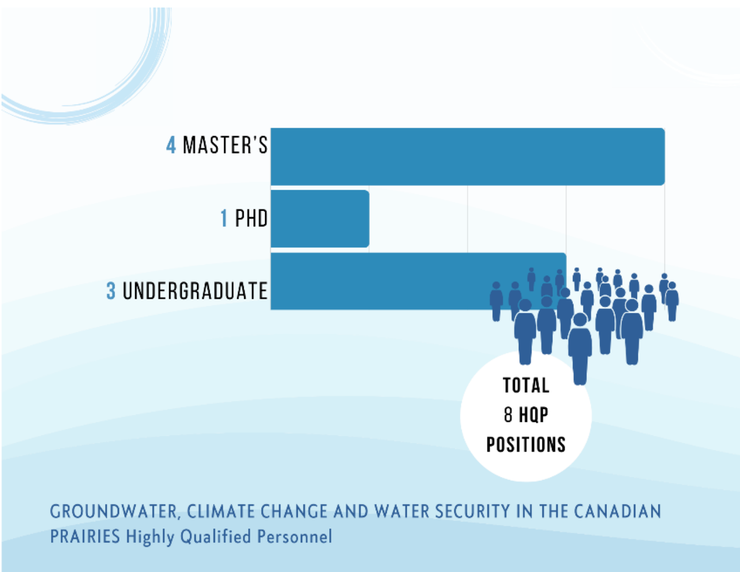
Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators

Grant Ferguson, University of Saskatchewan
Contact: grant.ferguson@usask.ca
Andrea Brookfield, University of Waterloo
Matt Lindsay, University of Saskatchewan
Randy Stotler, University of Waterloo
Laura Smith, University of Saskatchewan

## Partners, Collaborators, and Users

Geological Survey of Canada-- Hazen Russell
Kansas Geological Survey -- Rolfe Mandel
Saskatchewan Water Security Agency -- Kei Lo
University of Arizona -- Jennifer McIntosh




Highly Qualified Personnel: Professional training and research positions funded by Groundwater, Climate Change and Water Security in the Canadian Prairies

## Science Advances

In the Canadian Prairies and other areas of western North America, changes in the timing and magnitude of streamflow are altering water availability. Increased use of groundwater resources could help in addressing this problem but the extent to which these resources could be sustainably developed is unclear. This project has improved understanding of how typical hydrogeological settings in the Canadian Prairies will respond to both groundwater pumping and climate change. An integrated hydrologic model of an alluvial aquifer system characteristic of the Canadian Prairies was developed, and results are being synthesized. Further climate scenarios will be simulated shortly.

A monthly baseflow trend analysis across Canada, including the Prairies, is complete and published. A machine learning model was developed to associate these trends in baseflow with climate predictors. Ongoing efforts are analyzing these trends and predictors to interpret implications for the Canadian Prairies under future climate conditions.

The project team has sampled a series of observation wells in the Saskatchewan Water Security Agency's network for various age tracers. These results have been published in a PhD thesis and project researchers are currently preparing an additional manuscript based on these results.

Link to Publications List

# We Need More than Just Water: Assessing Sediment Limitation in a Large Freshwater Delta

Web Link: [i4-jardine - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Prairie Region

Total GWF funding support: $200,000

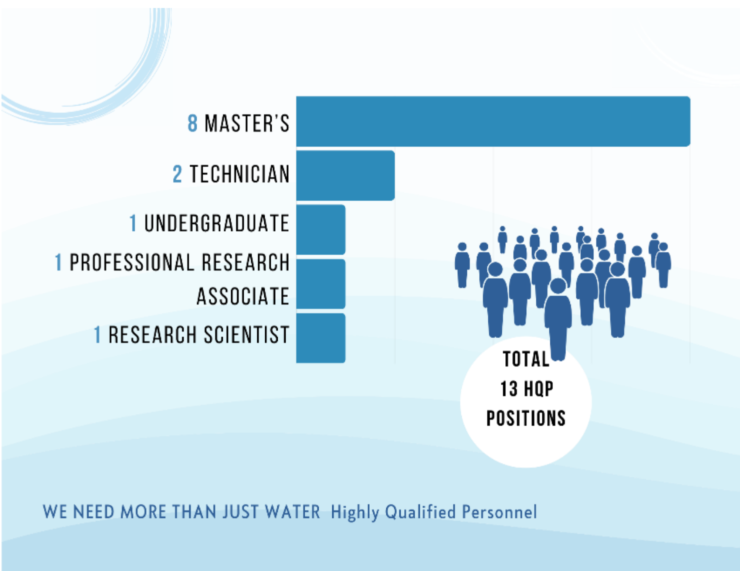
Project dates: December 2018-November 2021 COMPLETED

## Investigators

Tim Jardine, University of Saskatchewan Contact: tim.jardine@usask.ca
Graham Strickert, University of Saskatchewan
Karl-Erich Lindenschmidt, University of Saskatchewan
Markus Brinkmann, University of Saskatchewan
Robert Patrick, University of Saskatchewan
Carl Gutwin, University of Saskatchewan
Lorne Doig, University of Saskatchewan

## Partners, Collaborators, and Users

Big Eddy Adventure Camp -- Solomon Carriere
Charlebois Community School --Lily McKay-Carriere, Renee Carriere, Ingrid MacColl
Cumberland House Cree Nation -- Nadina Gardiner
Cumberland House Fishermen's Co-op -- Gary Carriere
Cumberland House Metis Local 42 -- Denise MacKenzie
Northern Village of Cumberland House -- Kelvin McKay
Saskatchewan Metis Nation -- Ryan Carriere
University of Nebraska -- Norm Smith
University of Saskatchewan -- Helen Baulch




Highly Qualified Personnel: Professional training and research positions funded by We Need More than Just Water

## Science Advances

The Saskatchewan River Delta is under threat from upstream water resource development such as irrigation and hydropower dams. A major issue is the loss of sediment due to its deposition in upstream reservoirs. Before dams were built, this sediment once reached the delta, carried by the river, where it would form new river channels and replenish the delta with nutrients that came along with the sediment. Now, the water coming from the dams has little sediment, a phenomenon called 'hungry water'. This hungry water erodes the river's bed and banks, making the main channel that runs through the delta deeper and wider, meaning that small side channels and their wetlands less often receive water, sediment and nutrients. The long term fate is for the delta to disappear, replaced by a single deep channel, which would take away its wildlife productivity and diversity and affect the very identity of Swampy Cree and Metis people who live there. Community members wanted to make progress on understanding how sediment moves through the system and what might be done to fix the problem.

The project's main activities were to test sediment for toxic chemicals to ensure it would be safe to return to the delta should that restoration option be made feasible. The project team also developed a hydraulic model to determine how water moves in the delta and to assess the erosive potential of the water in different places, gathered data in the field about sediment concentrations, and used interviews with local experts to gain insights into different water-sediment processes.

There were five main findings over the course of this project. First, researchers learned that while there are remnants of toxic chemicals (mostly polycyclic aromatic hydrocarbons) in the sediments of the reservoirs, these are at low enough concentrations that they could likely be moved back to the delta without great issue. Concentrations were 'patchy' and partly explained by sediment texture (grain size), meaning that careful mapping could be used to locate and move the sediments with the highest benefit while minimizing contamination of the delta. Secondly, researchers confirmed that sediments are not moving through the delta naturally. Suspended sediment concentrations are low immediately downstream of EB Campbell Dam, and concentrations begin increasing again in an area of active erosion near Big Eddy Lodge (approximately 60 km from EB Campbell Dam). This "hotspot" of erosion would be a place to monitor in the future if sediment restoration goes ahead. Third, researchers found that the flow model was effective in representing flows and water levels throughout the delta, meaning that it is possible to predict how those flows might change in the future under different scenarios (climatechange, new infrastructure) and the likely consequences for sediment movement and deposition in the delta. Fourth, researchers learned that it is difficult (and not wise) to examine the sediment question in isolation from the water flow question. In other words, any changes to flows will affect sediments and vice versa. As such, collaborations with the Integrated Modelling Program for Canada allowed the project team to consider the delta system more holistically. Local experts also revealed winter erosion processes under ice that the researchers were not expecting, providing more to think about as models are refined. Finally, there was progress on scoping some restoration options for the delta, including sediment restoration. A preliminary analysis suggests that sediment restoration appears feasible (sourced from either Codette and Tobin reservoirs or far upstream in Lake Diefenbaker) but costly, and would involve dredging sediment from reservoirs, moving it by barge to a railway line, and transporting it to the delta for release in the spring and summer when flows are high.

These findings highlight the value of university-community partnerships and action-oriented water research. The solution orientation taken and the co-design and co-production processes used are increasingly being applied in Canada and elsewhere. This fits with GWF's mission of delivering water science for Canadians.

Link to Publications List

# Knowledge Mobilization (KM)

As a co-led project, the University of Saskatchewan and Cumberland House researchers worked closely together throughout. There was constant communication among participants. Jardine and Strickert have phone calls with G. Carriere, McKay, R. Carriere and S. Carriere weekly and sometimes daily in busy periods. There is steady information exchange and forward planning during these phone calls. At a community level, there were several meetings of the Delta Stewardship Committee held over the course of the project, roughly three per year. These were carried out in person at the beginning of the project, switched to online meetings during Covid restrictions, and then returned to in-person meetings at the end. Topics of discussion at these meetings included the sediment work but also questions of natural resource governance, flow releases from upstream dams, other ongoing University of Saskatchewan research such as fish stranding and other topics of interest and importance. Maintaining these meetings, even when their focus is not strictly on the identified research, is an important feature of a durable relationship. These meetings are intended for information exchange, with research updates, flow forecasts, and project overviews featuring regularly. They offer a collegial opportunity to raise important issues with those who make decisions that affect the health and sustainability of the delta.

One of the major challenges facing restoration efforts in the delta is the fractured nature of governance. There are many actors both within and outside of the community and it is encouraging to see the level of interest in doing something right for this special place. However, the sheer number of stakeholders and rightsholders makes communication difficult and can lead to frustration when individuals and organizations learn of projects that are underway that they hadn't been notified of earlier. The University of Saskatchewan can play an important role in facilitating knowledge exchange among actors, but ultimately this is a shared responsibility, and there does not appear to be a sole authority that could coordinate decision-making about restoration options. Cumberland House Cree Nation is increasing its sovereignty over the delta, including a recent public declaration, which brings opportunities for a unified voice from the community, and the University of Saskatchewan can continue to build capacity to achieve that reality. The looming irrigation expansion at Lake Diefenbaker has created an impetus for the Water Security Agency to better engage and consult with Cumberland House, and project researchers remain hopeful that it will play a lead role in ensuring that any new water management practices do not negatively affect the delta.

# Prairie Water

Web Link: https://gwf.usask.ca/prairiewater/

Region: Prairie Region

Total GWF funding support: $1,700,000; $870,000

Project dates: June 2017-August 2023 EXTENDED to August 2024

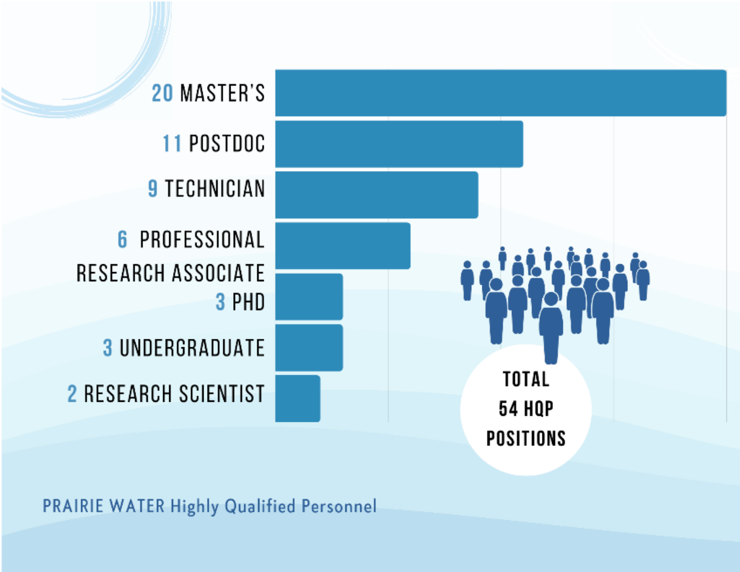
## Investigators

Colin Whitfield, University of Saskatchewan
Contact: colin.whitfield@usask.ca
Chris Spence, Environment and Climate Change Canada
John Pomeroy, University of Saskatchewan
Grant Ferguson, University of Saskatchewan
Helen Baulch, University of Saskatchewan
Bob Clark, Environment and Climate Change Canada
Graham Strickert, University of Saskatchewan
Kevin Shook, University of Saskatchewan
Masaki Hayashi, University of Calgary
Nandita Basu, University of Waterloo
Christy Morrissey, University of Saskatchewan
Karsten Liber, University of Saskatchewan
Angela Bedard-Haughn, University of Saskatchewan
Ken Belcher, University of Saskatchewan
Lalita Bharadwaj, University of Saskatchewan
Maureen Reed, University of Saskatchewan
Andrew Ireson, University of Saskatchewan
Patrick Lloyd-Smith, University of Saskatchewan
Diogo Costa, Environment and Climate Change Canada
Philip Loring, University of Guelph

## Partners, Collaborators, and Users

Agricultural Producers Association of Saskatchewan -- Todd Lewis, Duane Haave
Agriculture and Agri-Food Canada SK -- Allan Howard, Aston Chipanshi, Kim Hodge, Henry Wilson, Shathi Akhter
Agriculture and Agri-Food Canada -- Claudia Sheedy
Alberta Agriculture and Forestry -- Jacqueline Kohn, Virginia Nelson, Daniel Itenfisu
Alberta Agriculture and Forestry - Water Quality Section -- Shaun Cook, Greg Piorowski, Madison Kobryn, Barry Olson
Alberta Biodiversity Monitoring Institute -- Stephen Lougheed
Alberta Environment and Parks -- Thorsten Hebben, Cynthia McClain, John Orwin
Alberta Geological Survey -- Jessica Liggett
Alberta Land Use -- Ken Calbick
Alternative Land Use Services -- Rhonda King
Arrell Food Institute (Guelph) -- Phil Loring
Assiniboine River Basin Initiative -- Wanda McFadyen
Bow River Watershed Council -- Mike Murray
Canada's Chief Scientific Officer -- Mona Nemer
Canadian Rural Revitalization Foundation -- Laurie Brinklow
Canadian Wildlife Service, Alberta and Saskatchewan -- Mike Watmough, Blake Bartzen
Clavet Livestock and Forage Centre of Excellence -- Ernie Barber
Ducks Unlimited Canada (SK, AB, IWWR) -- Pascal Badiou, Jim Devries, Lauren Bortolotti
Environment and Climate Change Canada -- Cathy Nielsen, Kevin Cash, Jane Elliott
Environment and Climate Change Canada Water Science and Technology Directorate, SK -- John V. Headley, Kerry Peru
Environment and Climate Change Canada
Environment and Climate Change Canada -- Ram Yerubandi
Environment Canada and Climate Change (LWBP) 2018-2020 -- Michelle Duval
Federation of Sovereign Indigenous Nations -- Kyle Prettyshield
Geological Survey of Canada -- Steve Grasby
International Institute for Sustainable Development -- Dimple Roy
Lake Winnipeg Basin Stewardship Foundation
Lower Qu'Appelle Watershed Stewards -- Alice Davis
Lower Souris Watershed Committee --Tyler Fewings
Manitoba Association of Watersheds -- Lynda Nicol
Manitoba Sustainable Development -- Elaine Page

Mistawasis Nêhiyawak -- Anthony Johnston, Michelle Watson
Moose Jaw River Basin Stewards -- Janine Heinrich (past)
Muskeg First Nation (Beardy's and Okemasis First Nation) -- Alfred Gamble
North Saskatchewan River Basin Council -- Katherine Finn
Prairie Habitat Joint Venture -- Deanna Dixon
Prince Albert Model Forest Association Inc. -- Sarah Schmid
Red Deer River Watershed Association -- Josee Methot
Red River Basin Commission -- Steve Strang, Rebecca Trowell
Redberry Lake Biosphere Redberry Lake Biosphere Region -- John Kindrachuk, Katherine Finn
Sask. Farmer -- Dwight Odelein
Saskatchewan Water Security Agency (Water quality) -- Etienne Shupena- Soulodre
Saskatchewan Association of Watersheds-- Bridget Andrews
Saskatchewan Ministry of Agriculture -- Ron Eley
Saskatchewan Ministry of Environment -- Shawn Francis
Saskatchewan Water Security Agency -- John Fahlman, John-Mark Davies
Saskatchewan Water Security Agency (Hydrology) -- Kei Lo
Saskatchewan Water Security Agency -- Heather Davies, Corie White, Doug Johnson
Souris River Watershed District -- Dean Brooker
South Saskatchewan River Watershed Stewards Inc. -- Juliane Schultz
Statistics Canada -- Francois Soulard
Strategic Planning, Risk and Policy at SaskWater, Board of Directors -- Ingrid Newton
Sturgeon Lake First Nation -- Jeff McLeod
Sustainable Development Goals Unit -- Ugo Therien
University of Alberta -- Scott Jeffry
University of Calgary Alberta -- Paul Galpern
University of McGill (ResNet project) -- Elena Bennett
University of Saskatchewan, Andrew Watson
University of Waterloo -- Jeremy Pittman
Upper Assiniboine River Conservation District -- Ryan Canart
Wascana Upper Qu'Appelle Watershed Association -- Joe Ralko
Water Security Alliance -- Andrew Schofield
Winnipeg Metropolitan Region -- Michael Miltenberger
Western Economic Diversification -- Abdul Jalil
Western Economic Diversification Canada2017-2021 -- Jennifer Stelzer




Highly Qualified Personnel: Professional training and research positions funded by Prairie Water

# Science Advances

Water management in the Canadian Prairies is faced with a long list of challenges that are unique to the region: the climate is characterized by temperature extremes and cycles of wet and dry conditions, there is widespread reliance on groundwater but recharge is poorly understood, climate change is expected to affect water availability, and diverse groups of people with different values are affected by water and land management outcomes. The people making water-related decisions often lack the knowledge required to promote sustainable water management and decision-making is often conflict-ridden. At the outset of Prairie Water, researchers met with stakeholders and rightsholders (project partners) to identify their water management questions and needs. Led by these questions, Prairie Water began research and tool-development to support decision making while prioritizing continuous collaboration with partners.

Prairie Water is organized into three teams—Water Availability, Aquatic Ecosystem Health, and Water Management Practices and Governance, which have completed much of their work towards project goals. Synthesizing what the teams have learned and applying this to key operational issues experienced by partners remains a focus, while exploring opportunities with partners to understand how research outputs can be crafted and shared in useful, and usable ways.

To date, a key outcome from Prairie Water as a whole is a synthesis paper on the impacts prairie wetland drainage, including impacts on water quality, flooding, biodiversity and socioeconomics.

## Water Availability

The water availability team has focused on characterizing groundwater recharge, risk to groundwater resources, and effects of agricultural water management (including wetland drainage) and climate changes on hydrological regimes. Groundwater hydrology studies in Alberta have shown the importance of topographic depressions for groundwater recharge which has implications for wetland (depressions) management. This is significant as the project researchers have also found that deep groundwater in the prairies is not well connected to surface hydrology. Considerable demands from the oil and gas industry are placed on groundwater resources, and studies of historic and existing oil wells are shedding light on their risk to groundwater. These studies highlight that current groundwater monitoring and investigations are not adequate to assess the risk of contamination.

Currently, there are few tools that account for the complexities of prairie hydrology and hydrography available to hydrological practitioners for calculating return-period flows and flooding at small scales on the Canadian Prairies. The need for such tools is especially great due to non-stationarity from the effects of climate change and surface drainage. The Prairie Hydrology Design and Analysis Product (PHyDAP) uses research results of the Prairie Water Project to produce a spatial dataset that will allow practitioners to determine return-period flows and flooded areas in a scientifically defensible manner, while incorporating changes in the local climate and land use. PHyDAP uses the classificationof Canadian prairie basin types undertaken by Prairie Water for 4175 basins, each having an area of approximately 100 $km^2$. This work identified seven basin classes based on biophysical characteristics, with the classes subsequently shown to have a range in hydrological behaviours. For each class, a Cold Regions Hydrological Modelling (CRHM) platform "virtual" basin model was created and parameterized. These virtual basin models have been used by Prairie Water to investigate the effects of changes in climate and wetland drainage throughout the region.

The intent is that the PHyDAP datasets can be used as forcings for hydraulic models of detailed local conditions to determine changes in return-period flows and flooding due to changes in climate and/or local depressional storage. However, it is probable that the PHyDAP values may have other uses, such as forcing basin-scale hydraulic models for analyses and design of local infrastructure under extreme runoff events. In these cases, the limitations of the modelled streamflows will likely be critical as they incorporate the mean depressional storage for each basin class, rather than the actual depressional storage of a given basin. Where the two values are very different, it may be necessary to directly simulate the effects of local depressional storage on the discharges using a model such as the Hysteretic and Gatekeeping Depressions Model (HGDM). The PHyDAP data sets are available online at the Federated Research Data Repository: https://www.frdr-dfdr.ca/, doi: 10.20383/102.0694.

The virtual modelling framework improves on existing hydrological modelling techniques and has allowed project researchers to assess potential impacts of drainage and climate change on runoff regimes at regional scales. This work revealed that for pothole till basins the spatial pattern of drainage has little influence on how much the runoff regime changed; even relatively low levels (e.g. 10%) of drainage can affect the runoff regime (increasing the likelihood of larger floods), and wetter regions or conditions tend to be less influenced by drainage since hydrologic connectivity is already higher. Work is ongoing to expand analysis of the effect of climate change and surface drainage on basins Prairie-wide.

Virtual basin modelling is a novel approach to assessing change in the Prairie region and it relies on the basin classification developed by Prairie Water in early stages of the project. Now that the modelling results are being shared, water decision-makers in the prairies can identify which basin type is in their management area and gain specific information about how their watersheds might look in the future. The classification is now featured in a beta version of a visualisation dashboard under development with the Visforce team.

### Aquatic Ecosystem Health

Climate change and land-use are two important stressors on Prairie aquatic ecosystems.There remain notable challenges for managing land and water to balance the health of aquatic ecosystems with industry needs. The objectives of the aquatic ecosystem health team were to identify broad-scale land-use and climate impacts on water quality, to model wetland drainage impacts, assess the tradeoffs between wetland ecosystem service provision and agricultural production, and develop an interactive decision support tool. Wetland water quality and biodiversity have the potential to be impacted by pesticides, fungicides, and insecticides applied for agricultural land-uses. Across the Prairies, wetlands in wetter regions of the Prairies (central and east) are more likely to be contaminated by these agricultural inputs. Further research is underway to describe links between land-use and wetland water quality and to link pesticide occurrence models with virtual basin modelling.

The project team has connected the virtual modelling scenarios of surface hydrology with information about aquatic ecosystems to assess drainage impacts. So far, this has been done for the Pothole Till basin class. Wetland bird abundance in a basin is predicted to decrease by 50% when less than 20% of the wetlands are drained. In addition, as wetlands are drained, annual nutrient export is predicted to steadily increase in concert with the level of drainage, largely owing to increases in water yield. Predicted annual total phosphorus load more than doubles if 100% of wetlands are drained compared to no drainage. This integrated modelling is being expanded from the Pothole Till class to other watershed classes and to explore how anticipated changes in hydrology associated with climate change can affect aquatic ecosystem services. Modelling outputs are being integrated in the data visualisation tool.

A way to visualize relevant data was frequently requested by project partners, and progress has been made in creating an interactive decision-support tool. This is an interactive data visualisation tool featuring aquatic ecosystem health data and integrated modelling results. Users can select the basin type they are interested in and visualize the impacts of different amounts of wetland drainage or different climate change scenarios on basin characteristics. A live version of the tool was tested with partners in February 2023 and was received positively. Feedback from this demonstration is being used to guide future development of the tool.

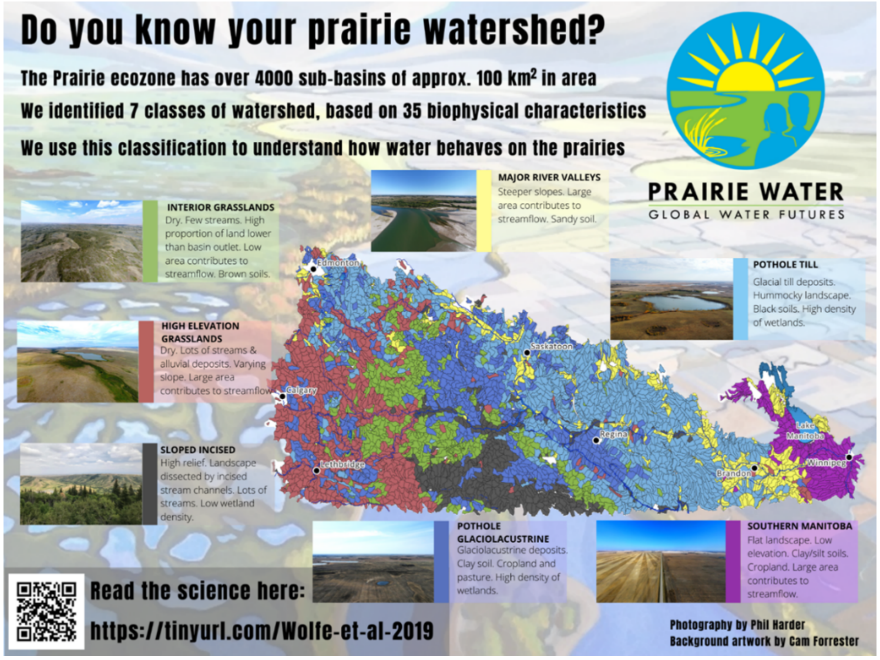
### Water Management Practices and Governance

The resilience of Prairie communities is tightly tied to making decisions for water secure futures. These depend on policies and the associated governance context as well as the behavior and incentives of water users. There is a pressing need to examine the state and effectiveness of current water management practices, to understand the motivations and incentives driving these decisions, and to understand the context within which scientific evidence is used in decision-making in the region. The Water Management Practices and Governance team has been making progress toward these goals. To better understand decisions involving water resources on the prairies, project researchers have been developing participatory models, conducting economic analyses, implementing large-scale surveys, coordinating experimental decision labs, and conducting interviews. They worked with agricultural producers to understand the cost of wetland conservation for net producer income to find that, as the area of wetlands on a quarter section increases, the cost of keeping those wetlands on the landscape increases non-linearly. Market factors such as canola prices also impact wetland conservation costs. The project team created an interactive tool that producers can use to identify how wetland conservation costs fluctuate over time for their specific field. There is still need to integrate this economic analysis with economic benefits derived from wetland ecosystem services and to configure the tool into a user-accessible format. In addition to wetland economics, the researchers examined water management and governance practices that impact rural and Indigenous communities. Three student projects worked together with rural and Indigenous communities in Saskatchewan to understand how different practices like story-telling, participatory modeling, and cutting back on bureaucracy can lead to better source water protection, disaster risk reduction, and environmental policy development. These analyses are being integrated with other GWF teams.

### Challenges and Next Steps

Prairie Water has been successful in connecting and working together with knowledge users. This success is primarily due to the dedication and commitment of co-principal investigators and co-investigators who prioritized engaging with people outside of academia for this project: hosting Annual Partners Meetings was a large part of this effort. However, relationships between Prairie Water and partners were sometimes difficult to maintain due to differences in priorities and resources between organizations and over time. The complex sociopolitical landscapes of water management in the Prairies needs researchers and partners who are committed long-term to finding solutions to problems. Prairie Water outcomes are being taken up by practitioners and decision-makers, but more time and effort are required to ensure continued uptake. Future research priorities are currently being determined with the help of partners. At the 2023 Annual Partners Meeting partners were asked what future work they thought was needed: this was followed by a survey. Responses collected from the meeting and survey will be analyzed and reported to partners.

Two grants funded through AAFC's Living Labs initiative under the Agricultural Climate Solutions program are the product of Prairie Water. *Modelling Co-benefits of* Landcover *Practices for Water Resources* is being carried out as part of Agricultural Nature-based Solutions for the Prairie Ecoregion, led by South of the Divide Conservation Action Plan Inc. This work will apply the virtual basin modelling approach developed under Prairie Water to new land-use scenarios targeted for carbon sequestration in agricultural soils. In another Living Labs project, *A Bridge to Land-Water-Sky: Developing an Indigenous Agricultural Living Lab in Saskatchewan*), researchers are building on the research conducted under the aquatic ecosystem health team of Prairie Water. The goal of this work (2022–2027) is to evaluate how farm management practices that alter land-water transition zones through riparian buffers and spatial connectivity of wetlands can alter wetland functional responses, biogeochemistry, and ecosystem services in terms of drought and flood control, water purification, carbon capture and habitat provisioning.




Spatial distribution of seven different prairie watershed (or basin) classes developed by Prairie Water

Link to Publications List

## Knowledge Mobilization (KM)

Prairie Water's communication and knowledge mobilization has focused on connecting with partners at annual meetings and engaging with the Community Advisory Committee. Since the start of Prairie Water, Advisory Committee members represented at least nine partner organizations. Prairie Water research has been shared within partner organizations through meetings and presentations and uptake is beginning. For example, many people involved in infrastructure design for water management are interested in applying the Prairie Hydrology Design and Analysis Product (PHyDAP) to their work. PHyDAP was shared in a workshop with a targeted group of partners in 2021 and in 2023, PHyDAP datasets were published and made freely available online. Presentations and tutorials of PHyDAP are planned for 2023. Watershed groups are also keen to use the Data Visualisation Dashboard to share information to their members (e.g., Bow River Basin Council); in 2023, partners will be asked to help with beta-testing this tool. Integrated hydrology-ecosystem modelling can be taken up by other organizations doing research to increase resilience of water management in the prairies (e.g., Ducks Unlimited Canada, ECCC). Other partner organizations have expressed interest in working together to create briefing notes or specific information for their organizations. The intention is that, by working with partner organizations, Prairie Water research will trickle up to reach senior government policy-makers.

Table: Organizations represented by members of Prairie Water's Community Advisory Committee from 2018 to now (italics show organizations not currently on the committee)

| Province | Organization |
|---|---|
| Alberta | Alberta Agriculture and Forestry, Bow River Basin Council |
| Manitoba | Assiniboine River Basin Initiative, Souris River Watershed District |
| Saskatchewan | Mistawasis Nêhiyawak, Redberry Lake Biosphere Region, Saskatchewan Association of Watersheds, Water Security Agency, *Agricultural Producers Association of Saskatchewan, North Saskatchewan River Basin Council* (while in existence) |
| National/International | Agriculture and Agri-Food Canada, Ducks Unlimited Canada, Red River Basin Commission |

Annual Partners Meetings have been consistent since the start of Prairie Water, occurring in-person and virtually. These allowed maintenance of connections with a wide variety of partners. In the annual meetings, the number of participants has ranged from 30 to 90 people representing federal government, provincial governments of Saskatchewan, Alberta, and Government of Manitoba, watershed associations, agricultural producers, environmental organizations, and First Nations organizations. Different members of the Prairie Water team have given presentations for many of the project partner organizations, including, Saskatchewan Water Security Agency, Prairie Habitat Joint Venture, Assiniboine River Basin Initiative, Red River Basin Commission, and Canadian Water Resources Association. Prairie Water has also mobilized knowledge by publishing various types of papers and articles reaching different audiences. This includes many journal articles, journalistic-style research articles (*The Conversation*), a plain language synthesis paper, and newspaper articles (The *Western Producer, Manitoba Co-operator*).

Major knowledge mobilization activities in 2022-2023 included:

- Mapping of knowledge mobilization networks (APM 2022 report) specific to the Prairies.

- Three infographics to communicate key findings of Prairie Water:
  - different watershed types across the prairies
  - wetland drainage in a changing climate
  - wetland bird diversity and abundance.

- A three-part series of webinars for Prairie Habitat Joint Venture (PHJV) about science, tools (PHyDAP, Data visualisation dashboard), and contributions for decision making from Prairie Water.

- Collaboration with the Water Security Agency (WSA) on AgH2Onward project and participated in recent workshops hosted by WSA to develop a new Saskatchewan agriculture water management policy.

Prairie Water's knowledge mobilization was assessed in discussions with partners at the 2022 Annual Partners Meeting online, identifying  the challenges and opportunities listed below. These observations guide current knowledge mobilization work.

Challenges

- Communicating science results. There is a need to prioritize using plain language, making data accessible, and social media presence.

- Barriers associated with knowledge mobilization to be aware of:
  - institutional knowledge governance (activities, processes, and relationship that influence availability of information)
  - individual and institutional perceptions, behaviours, and values
  - economics and other externalities (non-water related factors that affect water management decisions).

Opportunities

- Use of  the existing and substantial network of partners for direct and indirect mobilization.

- Work to fill gaps in the existing network. Gaps include: senior government decision-makers, municipal government associations, and Indigenous communities.

Citizen science

- Hayashi's team in Calgary has been running a community-based groundwater monitoring program using citizen science approach in Rocky View County surrounding Calgary since 2008. He has been approached by Bow River Basin Council (BRBC) to implement similar programs beyond Rocky View County boundary. He met with the members of Science Committee of BRBC and discussed the specifics of implementation, which will start in the summer of 2023.

- Pomeroy, J.W., Ivanov, G. & Davies, T.D. (November 2022). Cold Regions Warming – A Transitions Exhibition: Global Water Futures [Artistic Exhibition]. Whyte Museum of the Canadian Rockies, Banff, Canada

Access of tools by users

- Data Visualisation Dashboard demonstration and interactive session. Prairie Water Annual Partners Meeting. February 2, 2023

- PHyDAP presentation and case study. Prairie Water Annual Partners Meeting. February 2, 2023

- PHyDAP — a tool for the Prairies. K. Shook. Assiniboine River Basin Initiative Conference. March 1, 2023

Meetings with governments, decision makers, practitioners; Policy

- Plenary Engagement Session for developing SK Water Security Agency's Agricultural Water Stewardship

Policy, Saskatoon, Canada, April 12, 2023 (Miranda, Spence)

- Water Science and Growth Plan with Government of Saskatchewan MLAs, Regina, Canada, March 20, 2023

- Roundtable discussion with Terry Duguid, Parliamentary Secretary to the Minister of Environment and Climate Change, Saskatoon, Canada, March 17, 2023

- Plenary Engagement Session for developing SK Water Security Agency's Agricultural Water Management Mitigation Policy, Regina, Canada, December 8, 2022 (Spence, Whitfield)

- Great Lakes roundtable discussion with the Honourable Steven Guilbeault, Minister of Environment and Climate Change Canada, Niagara Falls, Canada, September 28, 2022

- Science Briefing on the Water Resources of the South Saskatchewan River to the Saskatchewan Party Caucus MLAs and Meewasin Valley Authority Board of Directors, Saskatoon, Saskatchewan, June 28, 2022

- Panelist, High-level panel on the Canada Water Agency, towards innovative water management, Global Water Futures (GWF) Annual Open Science Meeting, Virtual, May 16, 2022

Articles in popular media

- Pomeroy, J. (June 2022). History of Canadian Hydrology and Relation to Operational Water Resources Management (Magazine Article). Canadian Water Resources Association (CWRA) Water News, Vol. 41(3)

- Singh, B. and Pomeroy, J. (April 2022). Opinion: Time running out to secure Saskatchewan's water prosperity (Newspaper Article). Saskatoon StarPhoenix

- Pomeroy, J.W., Axworthy, T. and B. Sandford (March 2023). Opinion: Spring is here, where is the Canada Water Agency? (Newspaper article). Globe and Mail

- Axworthy, T., Pomeroy, J.W., Hines, E. (December 2022). Canada must not waste opportunities at COP15 in Montreal. (Newspaper article) Hill Times.

Interviews (broadcast or text)

- 'Saskatchewan needs to prepare for climate change', climate expert says, Broadcast Interview, Global News, Mar 2023

- World Water Day: the importance of fresh water, Broadcast Interview, CBC Radio Calgary, Mar 2023

- Sask. Farmers Worry About Spring Melt, Broadcast Interview, CTV News Saskatoon, Feb 2022

- Will it Snow this Christmas?, Broadcast Interview, CBC News, Dec 2022

- Research-powered climate adaptation and water security solutions, Text Interview, The Globe and Mail, Nov 2022

- Q+A: U of S water expert delivers talks to COP27 climate conference, Text Interview, Saskatoon StarPhoenix, Nov 2022

- Funding for USask-led water monitoring network will help understand, manage floods, drought: director, Broadcast Interview, CBC News Saskatoon, Aug 2022

- USask major scientific centres awarded $170M of MSI funding, Text Interview, USask News, Aug 2022

- How current climate change trends are impacting severe weather in Saskatchewan, Broadcast Interview, Global News, July 2022

- From drought relief to filling streams, heavy rain proves beneficial in Sask., Broadcast Interview, CBC News Saskatchewan, June 2022

- After weeks of moisture, drought conditions ease in parts of Prairies, Broadcast Interview, CBC News Saskatchewan, Apr 2022

# Professional Development and Technology Transfer

*Principles of Hydrology* (Oct 31-Nov 10, 2022)

The University of Saskatchewan Centre for Hydrology with the assistance of the Canadian Society for Hydrological Sciences offered an intensive course on the physical principles of hydrology with particular relevance to Canadian conditions. Factors governing hydrological processes in Canadian landscapes were be discussed including precipitation, interception, energy balance, snow accumulation, snowmelt, glaciers, evaporation, evapotranspiration, infiltration, groundwater movement and streamflow routing and hydraulics. These processes were framed within the context of distinctly Canadian landscape features such as high mountains, glaciers, peatlands, prairies, tundra, boreal forests, frozen rivers and seasonally frozen ground. Students were exposed to an overview of each subject, with recent scientific findings and new cutting-edge theories, tools and techniques. They completed numerical and essay assignments to develop skills in problem solving and in synthesizing complex hydrological concepts. Students emerged from the course with a deeper understanding of physical hydrological processes and how they interact to produce catchment water budgets and streamflow response. Number of HQP involved: 27.

# Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime Across the Southern Boreal Forest

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1-adaption-governance.php

Region: Prairie Region

Total GWF funding support: $85,000

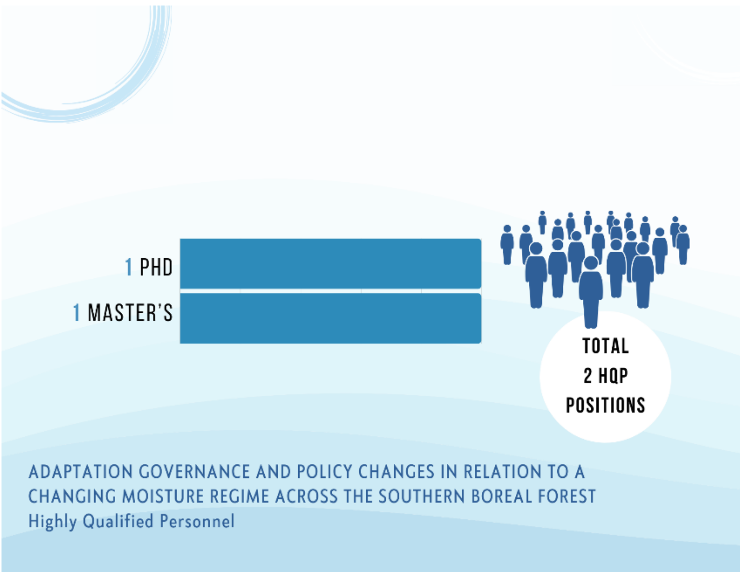
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Colin Laroque, University of Saskatchewan Contact: colin.laroque@usask.ca

## Partners, Collaborators, and Users

Forest Service Branch, Ministry of Environment -- Rory McIntosh
Mistik Management -- Roger Nesdoly




**Highly Qualified Personnel: Professional training and research positions funded by Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime Across the Southern Boreal Forest**

## Science Advances

The Saskatchewan Government is interested in adapting its existing legislative policy guidelines and regulations that forest companies in the province are mandated to follow. The project aimed to provide an improved ground-up framework of vulnerability assessments to improve current provincial and national structures of forest governance and management practices under climate change and future climatic variability. Information and expertise through data and scientific understanding were applied to develop adaptation tools that address priority issues facing industry, government, and Indigenous communities in the southern Boreal Forest.

A vulnerability assessment was conducted, including both current and future risks, of forestry company Mistik's management forest area using the existing Climate Change and Sustainable Forest Management in Canada: A Guidebook for Assessing Vulnerability and Mainstreaming Adaptation into Decision Making guidebook. The study included management aspects of the company's practices as related to climate change. Mistik's response to past and present climate related impacts was analyzed through engagement with company employees in Meadow Lake, Saskatchewan. The results were shared in a PhD thesis by a University of Saskatchewan Environment and Sustainability PhD student, and incorporated into Mistik's new 20-year forest management plan.

## Link to Publications List

## Knowledge Mobilization (KM)

In addition to supporting development of Mistik Management Ltd.'s 2019-2039 20-Year Forest Management Plan, the results of the Mistik vulnerability assessment have been used by the Saskatchewan Environment Forest Service Branch to help guide forest policy direction to increase responsiveness and flexibility and promote adaptation in management in an environment of increasing climatic uncertainty in Saskatchewan.

## Professional Development and Technology Transfer

Following completion of her PhD thesis, the student researcher founded consulting firm Innovative Climate Strategies and has led development, delivery and recruitment activities for the University of Saskatchewan School of Environment and Sustainability (SENS) Graduate Certificate in Climate Change Vulnerability Assessment and Adaptation Action.

# Collaborative Modelling Framework for Water Futures and Holistic Human Health Effects

Region: Prairie Region

Total GWF funding support: $350,000

Project dates: December 2017-November 2020 COMPLETED

Link: Colab-Modelling - Global Water Futures - University of Saskatchewan (usask.ca)

## Investigators

Lalita Bharadwaj, Department of Community Health and Epidemiology, College of Medicine (University of Saskatchewan) Contact: lalita.bharadwaj@usask.ca

Lori Bradford, Assistant Professor, Canada Research Chair (CRC) Tier 2 in Social and Cultural Decision Making in Engineering Design (Candidate) Ron and Jane Graham School of Professional Development (2020)

School of Environment and Sustainability (SENS), University of Saskatchewan

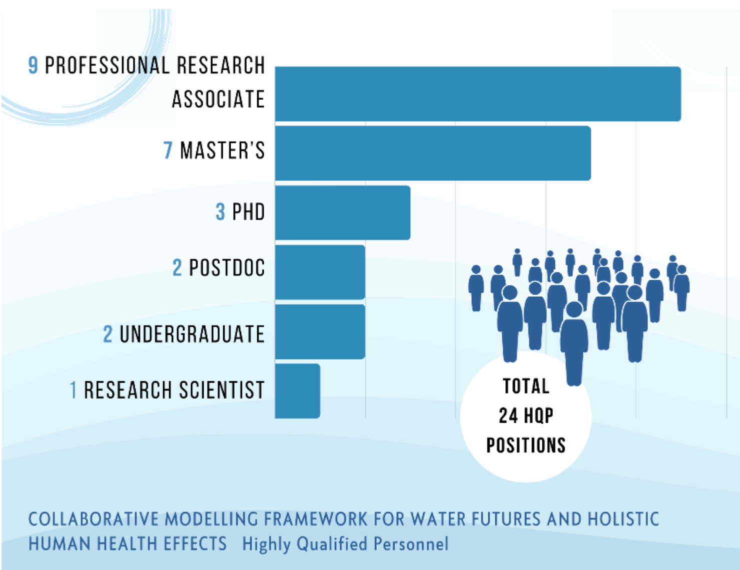
Graham Strickert, SENS, University of Saskatchewan

Cheryl Waldner, Department of Large Animal Clinical Sciences, Western College of Veterinary Medicine, University of Saskatchewan

Nathaniel Osgood, Computer Science, University of Saskatchewan

## Partners, Collaborators, and Users

GIWS -- Jay Famiglietti
Indigenous Services Canada-- Nicholas Girard
James Smith Cree Nation -- Bill Marion; Justin Burns
Lake Winnipeg Basin Program – Environment Climate Change Canadam -- Michelle Duval
Mistawasis Néhiyawak -- Anthony Blair Dreaver Johnston
Saskatchewan First Nations Technical Services Cooperative Ltd. -- Tim Isnana
SSRL -- Geospatial Initiative -- Albert Abeleira
Stantec Consulting Ltd -- Wayne Penno; Riley Morris
University of Saskatchewan Department of Indigenous Studies -- Bobby Henry
University of Saskatchewan School of Public Policy -- Ken Coates
Yellow Quill First Nation -- Myron Neapetung, Tyrone Peeace




Highly Qualified Personnel: Professional training and research positions funded by Collaborative Modelling Framework for Water Futures

## Science Advances

This project developed a model framework using Agent Based Modelling to assess impacts on Indigenous communities from flooding. The research focused on investigating the interactions between human and natural systems, supporting health services, emergency planning, and addressing water challenges faced by Indigenous communities in Canada. Two working ABM models have been running in each community. Community-based research coordinators have been monitoring the usage statistics of the models by community members and tracking information needs. The model outputs contributed to a FN-PIEVC process that occurred in Saskatchewan's Yellow Quill First Nation August 2019. The model was also used in Yellow Quill First Nation by four youth involved in interviewing of reserve personnel involved in emergency management – this was completed to update the reserve's emergency management plan to include a comprehensive set of potential health impacts of flooding. Key findings were:

Water Management Challenges: The study highlighted challenges in managing water across Indigenous reserve lands in Canada due to federal and provincial government competition, leading to cross-jurisdictional conflicts and a lack of accountability. This lack of collaboration impacts community health, cultural sustainability, and financial stability in reserve communities.

Harmful Algal Blooms (HABs): The research explored disparities in managing HABs across Canadian provinces, emphasizing the need for consistent communication of risks associated with HABs to the public. Variations were found in monitoring, managing, and communicating risks across different provinces, with suggestions for improved collaboration and consistent messaging.

Indigenous Agriculture: The project delved into agriculture practices on First Nations reserve lands in Saskatchewan Prairies, highlighting the need for greater autonomy in land management to realize economic benefits and exert control over agricultural activities affecting reserve land base. Themes emerged around Indigenous knowledge, capacity building, partnerships, financing, and policy implications for sustainable agriculture practices.

Community-Engaged Scholarship: The study emphasized the importance of collaborative research approaches like Community-Based Participatory Research (CBPR) to address complex health and environmental issues faced by First Nations communities. It advocated for respectful partnerships, community involvement, and sustainable solutions through equitable involvement of all partners in the research process.

Drinking Water Quality: Disparities between Indigenous and non-Indigenous communities in drinking water advisories were highlighted, with significant factors contributing to advisories including seasonality, location, and community type. The study emphasized the need for increased attention and investment in securing water resources for rural communities at risk

These findings underscore the importance of interdisciplinary approaches, community involvement, policy improvements, and cultural considerations in addressing water challenges faced by Indigenous communities in Canada. The model framework can be applied to other unresolved public health and water issues including Canada's most pressing public health issue- drinking water in Indigenous nations.

## Link to Publications List

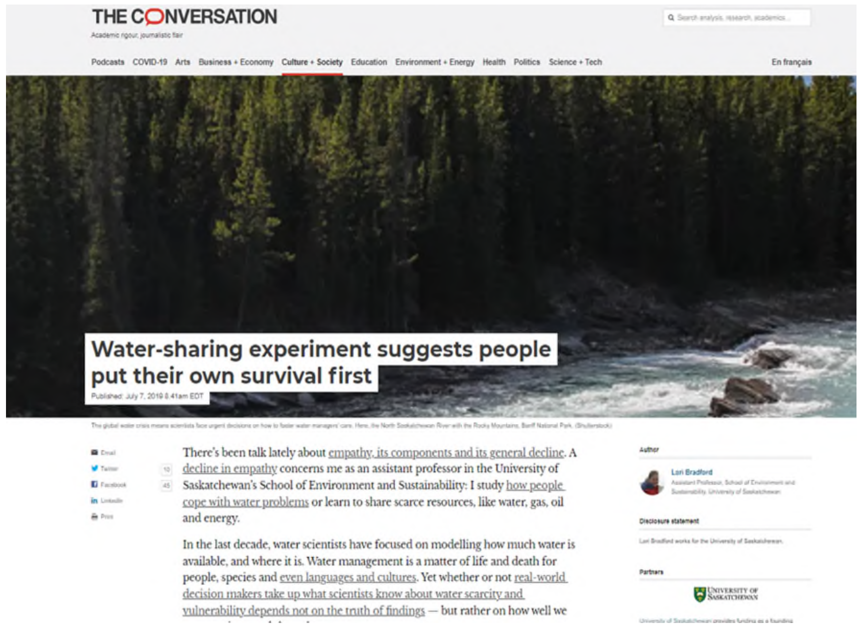
## Knowledge Mobilization (KM)

Overall scientific and KM activities were limited due to the impacts of COVID-19. However, this year two Masters students successfully completed the defense of their proposals and are currently gathering data. Community partners  Burns and Neapetung were trained to collect and analyze water samples in the field throughout the year.

Researchers presented a working agent-based model that incorporated data from all sources in the project (primary and secondary) into the models to the GWF Science Committee on October 25th, 2021. The team held community meetings in James Smith Cree Nation  (September 18th 2019; October 16th 2019; November 14th 2019), trained an additional three community members at James Smith Cree Nation on emergency planning and reporting of environmental health indicators, trained six community members on the Nutrient app, conducted environmental health scan with seven community members at lake and wetlands and discussed preferences for risk communications with councilor and community members.

Individually, Bradford hosted community meetings in Yellow Quill First Nation (August 2nd, 2019; August 19-22 2019; Sept. 24th 2019; November 26th 2019, Jan 15th 2020; Feb 13 2020, March 25 2020). Four youth community members were trained in interviewing, document reviewing, and emergency management planning. They worked with key community members to discuss preferences for risk communications for environmental health issues so that emergency management plans could be updated to include floods.

Citizen Science: Citizen Science activities this year mainly involved the training of Burns and Neapetung to collect and analysis water samples. Seven trips were made to Indigenous communities between September 2019 – March 2020 (James Smith Cree Nation x 4; Yellow Quill First Nation x 3) to set up and monitor the ABM model in use in community. An MOU is in development with James Smith Cree Nation for an environmental monitoring program. ECCC-LWBP grant contract was completed in Sept. 2019 and research initiated. Additional funds were secured from GIWS, Canada 150 Chair for GIS work on identifying elevation and flow index into and out of each reserve in SK Treaty Areas – verification occurring with Federation of Sovereign Indigenous Nations (FSIN) Lands and Resources Secretariat.



THE CONVERSATION

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**Water-sharing experiment suggests people put their own survival first**

Published: July 7, 2019 8.41am EDT

There's been talk lately about empathy, its components and its general decline. A decline in empathy concerns me as an assistant professor in the University of Saskatchewan's School of Environment and Sustainability: I study how people cope with water problems or learn to share scarce resources, like water, gas, oil and energy.

In the last decade, water scientists have focused on modelling how much water is available, and where it is. Water management is a matter of life and death for people, species and even languages and cultures. Yet whether or not real-world decision makers take up what scientists know about water scarcity and vulnerability depends not on the truth of findings — but rather on how well we

Author

Lori Bradford

Disclosure statement

Partners

University of Saskatchewan

Article about water-sharing in The Conversation, 7 July 2019

Access of tools by users: Indigenous Services Canada (ISC) First Nations Adapt program accessing agent-based models for review of access to recovery funds in cases of floods on reserve land.

Meetings with governments, decision makers, practitioners: Lori Bradford reported results to two senators and one Member of Parliament in Ottawa during Water Day on the Hill March 10th 2020.

Four articles in popular media

Promotional videos: Belcher, K. Bradford, L. (May 2020) The Science of Caring. A film for the Let's Talk About Water Film Festival.

# Old Meets New: Subsurface Connectivity and Groundwater Protection

Web Link: Old Meets New - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Prairie Region

Total GWF funding support: $300,000

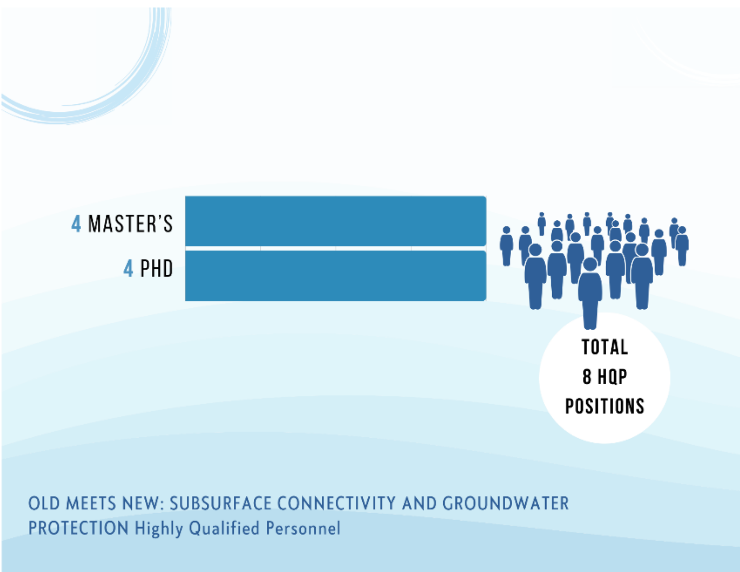
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Grant Ferguson, University of Saskatchewan Contact: grant.ferguson@usask.ca
Jim Hendry, University of Saskatchewan
Lee Barbour, University of Saskatchewan
Matt Lindsay, University of Saskatchewan
Jennifer McIntosh, University of Arizona
Jeffrey McDonnell, University of Saskatchewan

## Partners, Collaborators, and Users

Alberta Energy Regulator --Dan Palombi
Geological Survey of Canada--Steve Grasby
Saskatchewan Water Security Agency --Kei Lo
University of Arizona --Jennifer McIntosh




**Highly Qualified Personnel: Professional training and research positions funded by Old Meets New: Subsurface Connectivity and Groundwater Protection**

## Science Advances

Recent concerns have risen for deeper groundwater systems due to issues related to unconventional oil and gas development and subsurface waste disposal – areas which both suffer from data scarcity. This project has reviewed available data for western Canada to improve understanding of hydrogeological connectivity The project has assembled key databases that are supporting analysis:

Groundwater chemistry: A database of 10,000 major ion analyses from deep hydrogeological units in Western Canada has been compiled from AccuMap, a commercial oil and gas database. This compilation required extensive culling to eliminate samples with excessive charge balance errors and contamination by drilling fluids or other sources. Data for the USA has been obtained from various USGS sources to create a database with a range of salinities covering most oil and gas producing regions. During the past year, isotope (H, O and Sr) measurements have been added to this database.

Hydrogeologic properties: A database of more than 500,000 core measurements of permeability and porosity for western Canada have been compiled from AccuMap. This data adds to a database of several hundred permeability measurements made by Ferguson's research group based on drillstem test data in provincial databases, and the project has added to this database through analysis of drillstem tests. In addition, a database of several hundred hydraulic conductivity measurements from glacial tills has been compiled through a related project funded by the Fedoruk Institute.

Oil and gas activity: A database containing the dates of installation and abandonment of over 700,000 oil, gas and injection wells has been compiled for Western Canada. Compilation of drilling, completion and abandonment regulations for Saskatchewan and Alberta is underway, with the intent of identifying important changes in the regulations that might affect groundwater protection. Annual records of fluid production and injection have been compiled for the oil and gas producing region of Southeastern Saskatchewan. Well records from provincial databases on well construction to assess well integrity issues have been compiled. This compilation includes well location, depths and target formations and a number of tour reports on well abandonment practices for selected wells. An opportunity to add another student arose through a Mitacs program. This allowed the team to look at surficial impacts of the oil and gas industry. They have analyzed a database of spills of oil and produced waters by the oil and gas industry in Saskatchewan made available by the provincial government.

Analyses and Findings to Date

Preliminary analysis of the position of the intermediate zone has been conducted for Western Canada and the United States. Initial findings for Canada indicate variable separation of oil and gas activities from potable groundwater resources, ranging from over 1000 m in some areas to less than a few hundred m in others. More detailed work mapping the intermediate zone in Saskatchewan has been undertaken through Master’s student work.

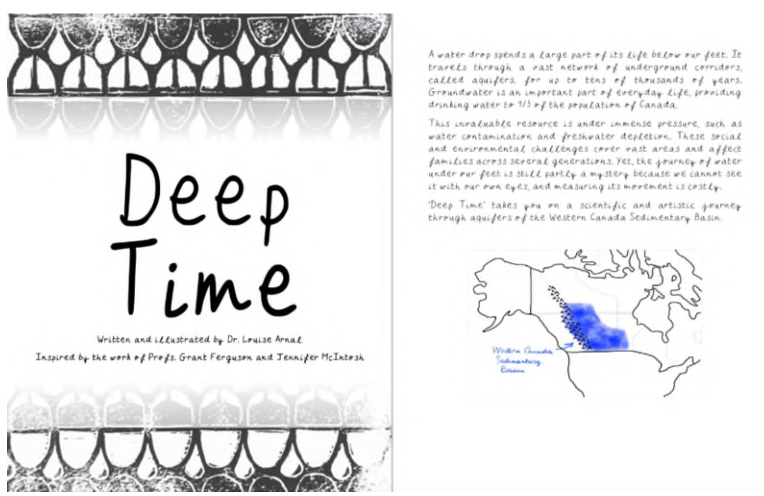
A fluid budget has been produced for Southeastern Saskatchewan by an MSc. student. There is an excess of water in the subsurface in this area, with the Mannville Group gaining significant amounts of water and a significant rearrangement of waters in the Midale Formation. While much of the injected water is water produced by the oil industry, substantial amounts of shallow groundwater and surface water are used for hydraulic fracturing and waterflooding. The exact sources of these waters are not clear but it is clear that the resulting pressures have perturbed background groundwater flow patterns.

Statistical analyses of permeability have been conducted. Conventional statistics have been calculated for nearly 100 different hydrostratigraphic units in Western Canada. These statistics will be used as model input later in this project Several models using different approaches to assess migration of fluids between deep and shallow aquifers have been constructed.An analysis of the potential for abandoned wells to act as pathways for gases and poor quality waters for oil and gas producing zones to shallow groundwaters has been conducted by a Master’s student. Greatest risks appear to be associated with areas where legacy wells targeted deeper formations, creating the possibility of connecting multiple overlying formations.

## Link to Publications List

## Knowledge Mobilization (KM)

Knowledge mobilization in this project has been focused on working with researchers at other universities and government agencies. One of the goals of this project is to translate the team’s experience in Western Canada where there is a long history of oil and gas experience to other regions with either different experiences or no experience. Ferguson and McIntosh continue to work with the Alberta Energy Regulator, the Saskatchewan Water Security Agency, and the Geological Survey of Canada. They are also in regular contact with personnel from geological survey and oil and gas regulators from a variety of



Graphic from Deep Time artwork

jurisdictions, including the United Kingdom and Texas.

During 2021, McIntosh and Ferguson had the opportunity to work with Dr. Louise Arnal as part of the Virtual Water Gallery. Dr. Arnal created the piece “Deep Time” based on the ideas that emerged from the Old Meets New project.

Ferguson and McIntosh have also written two articles based on this research that have been published in *The Conversation*. These articles were republished by a variety of media outlets, including *PBS* and *The National Post*.

# Crowdsourcing Water Science: Distributed Water Science Application

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1-crowdsourcing.php

Region: Prairie Region

Total GWF funding support: $85,000

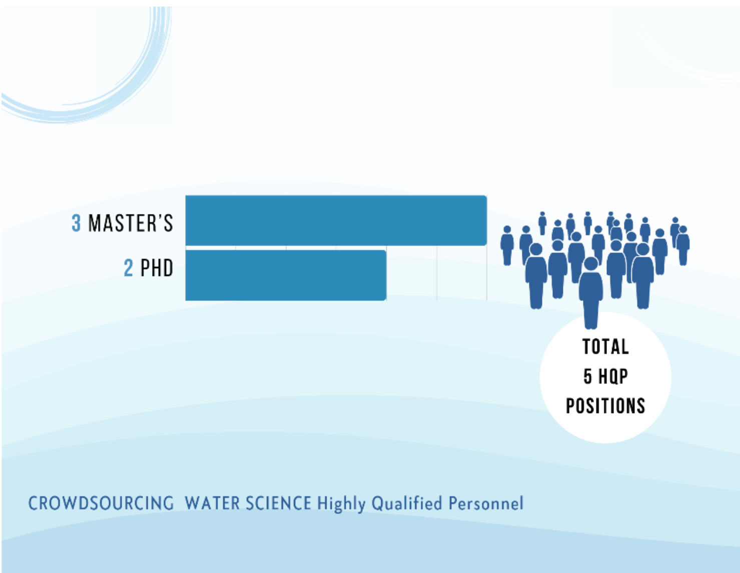
Project dates: 2019-2023

## Investigators

Graham Strickert, University of Saskatchewan
Contact: graham.strickert@usask.ca
Ralph Deters, University of Saskatchewan
Simon Lambert, University of Saskatchewan

## Partners, Collaborators, and Users

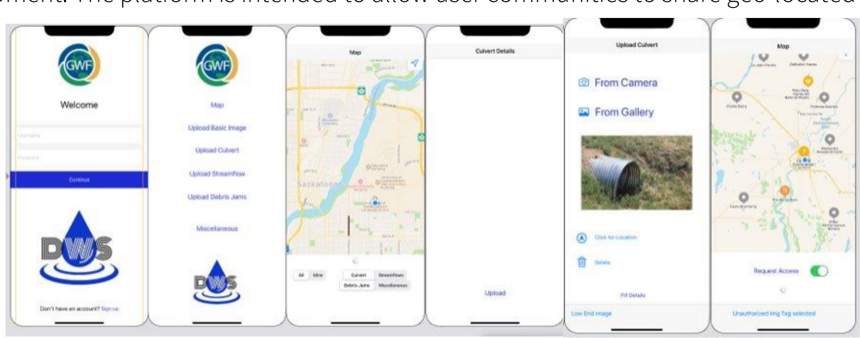
Cumberland House Fishermans Coop -- Gary Carriere
Environment and Climate Change Canada -- Paul Cragg
Mistawasis -- Anthony Johnston
Redberry Lake Biosphere Region




Highly Qualified Personnel: Professional training and research positions funded by Crowdsourcing Water Science

## Science Advances

This project set out to create a crowdsourcing data platform to support contributions from GWF user communities while also serving user needs in application development. The platform is intended to allow user communities to share geo-located and time-stamped photographs, which complement traditional forms of data acquisition. This should provide a way to share sensitive data across trusted networks, to test use case for blockchain on the back end of apps for more secure sharing and data sovereignty, and build understanding of which water science apps could benefit from secure data sharing. Accomplishments include developing




a prototype application tool called distributed water science for sharing sensitive water information within trusted networks, review of other water apps in Canada to find a niche for the distributed water science app, testing integration of blockchain for data sharing, and investigation of integration of app with remote camera networks and scientific observatories.

Link to Publications List

## Knowledge Mobilization (KM)

Team members participated in the 2nd We Are Fire workshop in the Saskatchewan River Delta. The workshop focused on reclaiming fire as a regenerative tool. The team is now going to be monitoring how fires on traplines regenerative native plants and control invasive grasses.

The team had regular meetings with a variety of stakeholders and rightsholders who have been helping to develop the DWS App including: the Delta Stewardship Committee in Cumberland House, the Redberry Lake Biosphere Region, and ECCC. The Delta Stewardship Committee wants to use the DWS App for monitoring within the delta; enabling local people to capture observations of changing conditions such as water level, turbidity, ice conditions, animals impacted by water levels, and impacts to infrastructure. The Redberry Lake Biosphere Region is also keen to use the app for observations, but also to help with recruiting citizen science tourists who can help augment observations linked to a network of trail cameras. ECCC's emergency preparedness meteorologist John Paul Cragg, who has been involved in the development of the DWS App since its inception, has moved to the east coast and is thus envisaging new opportunities for the use of the app including: 1) water level gauges along coastal rivers in Nova Scotia; 2) improving situational awareness of coastal and river inundation during storms on Canada's east coast. The app has been submitted to IOS for beta testing again. Plans are for testing the app in the Saskatchewan River Delta, SK; Redberry Lake, SK; and Halifax, NS.

Mobile phone screens for citizen science data collection app

The team is also pivoting to deploy camera traps at locations in the Saskatchewan River Delta and around the Redberry Lake Biosphere Region and at the GIWS BERMS sites in partnerships with various groups.

We are Fire workshop 2023

# Hydrological Processes in Frozen Soils

Web Link: [Frozen Soils - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Prairie Region

Total GWF funding support: $80,000

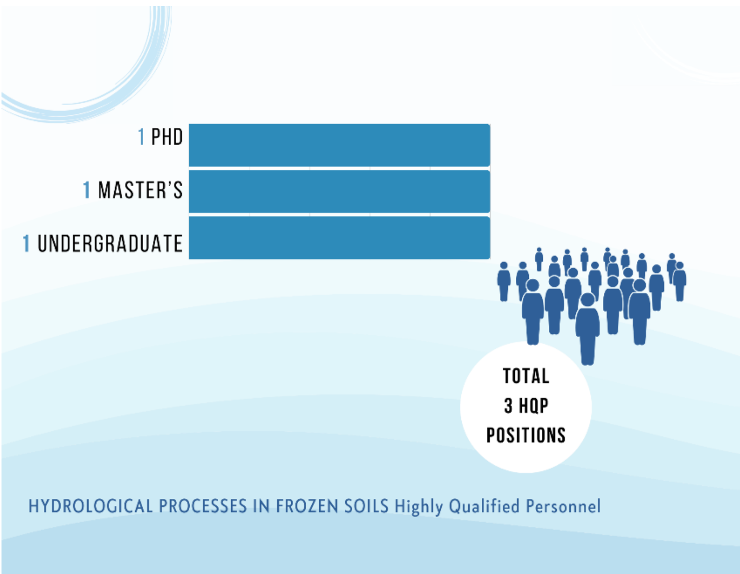
Project dates: September 2018 – August 2023 COMPLETED

## Investigators

Andrew Ireson, University of Saskatchewan Contact: andrew.ireson@usask.ca

## Partners, Collaborators, and Users

Joe Melton, ECCC




Highly Qualified Personnel: Professional training and research positions funded by Hydrological Processes in Frozen Soils

## Science Advances

Soil freeze-thaw processes play a critical role in the surface energy and water balance in cold regions. Partitioning of snowmelt into runoff and infiltration is arguably the single most important control on flood risk and water for crops in the Canadian prairies. Understanding of the physical processes involved is fraught with challenges and there remain major gaps. Perhaps the most basic property is the soil freezing characteristic curve, SFC: a relationship between unfrozen water content and soil temperature (below zero degrees Celsius), analogous to the soil moisture characteristic for unfrozen conditions. This represents the phenomenon of freezing-point depression in soils, and controls the hydraulic properties. However, there is no consensus on why this actually happens. Moreover, there is no simple in-situ method to measure this phenomenon directly in the field – the problem being the inability to interpret most soil moisture instrumentation in frozen conditions. From a hydrological perspective, this understanding is critical to being able to predict the fate of snowmelt, and the overall water balance of a watershed or field.

This project has conducted soil freezing column experiments in the lab, measuring soil freezing characteristic curves under different salinities. Field data from St Denis and Brightwater Creek in the prairies, and the Old Jack Pine BERMS site in the southern boreal forest were analyzed using three approaches to quantify this relationship: the conventional approach using the Generalized Clapeyron Equation (GCE), a novel model based on salt exclusion, and a combined GCE-salt exclusion model. Findings suggest the salt exclusion is likely the dominant control where salinities are non-negligible.

Numerical experiments with a few models found that the CLASS infiltration algorithm seems to outperform many other equivalent models, which typically underestimate infiltration. Infiltration in the CLASS model takes place while the soils are frozen and allows for water to infiltrate beneath the soil frozen zone.

Link to Publications List

# Prairie Drainage Governance: Diagnosing Policy and Governance Effectiveness for Agricultural Water Management during Times of Change

Web Link: https://gwf.usask.ca/drainage/index.php

Region: Prairie Region

Total GWF funding support: $ 200,000

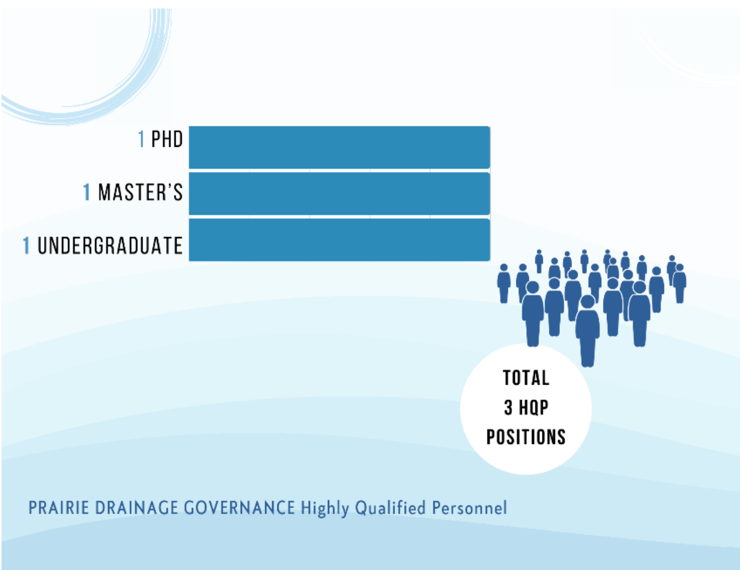
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Philip A. Loring, University of Guelph Contact: phil.loring@uoguelph.ca
Helen Baulch, University of Saskatchewan
Dr. Patricia Gober, Arizona State University
Dr. John Pomeroy, University of Saskatchewan
Dr. Graham Strickert, University of Saskatchewan
Dr. Merrin Macrae, University of Waterloo
Dr. Claudia Pahl-Wostl, University of Osnabrück, Germany
Dr. Bob Clark, University of Saskatchewan
Dr. Li Xu, University of Saskatchewan
Dr. Chrystal Mantyka-Pringle, University of Saskatchewan

## Partners, Collaborators, and Users

Ducks Unlimited – Lauren Borlotti
ECCC – Bob Patrick
Water Security Agency – Etienne Soulodre




Highly Qualified Personnel: Professional training and research positions funded by Prairie Drainage Governance

## Science Advances

Agricultural water management (aka drainage) -- moving water to make land available for agriculture -- provides several societal benefits including increasing the amount of productive land and improving soil conditions. However, agricultural water management can negatively impact wetlands and wildlife biodiversity, as well as water quality, drought, and flood risk. Not surprisingly, agricultural water management is often a contentious topic that divides communities as they debate the best way to manage land, water, and human values. The prairies are hugely important to Canadian agriculture and prairie landscapes are also essential habitat to numerous migratory birds, mammals, and aquatic species. Over the last half century, a significant portion of this habitat has been converted, through land use change, from wetlands to agricultural and residential lands. As such, prairie landowners, agricultural producers, conservationists, and water resource management agencies face diverse and often conflicting set of values and priorities for landscape management. This project engaged stakeholders -- including producers, landowners, watershed associations, stewardship groups, provincial authorities, and numerous interested NGOs -- to understand how to foster collaboration over conflict, support sustainable livelihoods for farmers and ranchers while addressing wildlife and water quality and flow concerns, and deal with a changing climate that includes more extreme swings in water availability.

Building from the extensive literature review and the field research completed in previous years, coding of transcripts proceeded as an inductive thematic analysis looking for re-occurring themes in the data, and then identified the subset of these codes that offered evidence about status of the conflict, based on three levels: simple dispute, ongoing conflict, and deep-rooted conflict. Transcripts were also coded deductively with the concepts offered by the Social Ecological Systems Framework (SESF), to get a sense of how local people's understanding of the conflict maps to conceptual dimensions of conflict. Feedback from key researcher participants was used to ground truth preliminary findings. Methods included one community meeting with Atwater-Kaposvar stakeholders, two knowledge mobilization workshops with academic and academic associated stakeholders (one in 2018 and one in 2019), and several follow up phone calls with individual informants. This research identifies opportunities to transform the conflict over agricultural drainage in Saskatchewan towards collaboration. Findings suggest that processes for governing natural resources, such as those in place for governing drainage in Saskatchewan, need to have mechanisms to facilitate relationship building and shared understandings, need to be adaptable to people's changing needs and concerns, and should focus on inclusivity and empowerment of actors to address conflict.

A second part of the research explored how people entangled in conflicts over natural resources employ and talk about data. Data, as a technology of governance, has a unique risk of becoming a means of empowerment or disempowerment: empowering those with access to data and how it is generated, and disempowering those without such access, often people whose data are collected through alternative systems of knowing (e.g. local knowledge). Data and the best available science influence how power and expertise are mobilized, redefined, and contested, forcing people to change how they seek to legitimize their rights and identities. Stakeholders, for example, can find it necessary to perform their expertise and justify the veracity of their data (often by discounting the data held by other parties). While the process of influencing understanding and practice related to drainage continues to evolve, these findings inform how solutions for governance that benefit from robust data and science can be developed while ensuring people's needs are met, conflicts are avoided, and the rights of all involved are protected.

Link to Publications List

# Knowledge Mobilization (KM)

Collegial relationships with stakeholders of drainage in Saskatchewan are evident. The team's researchers were invited to different events put on by stakeholders and have had many follow up phone calls and meetings with research participants, to further understanding of drainage issues. Collaboration with new partners on drainage research was initiated via NESERC's ResNet research project, in which members ofthe Prairie Drainage Governance team represented the prairies landscape.

The KM strategy was adjusted to emphasize products that can contribute to conflict de-escalation and management. One such example was a community meeting in Atwater, Saskatchewanin April 2019 to respond to questions community members had about the research, and to 'member check' preliminary findings of the project. The workshop was attended by approximately 15 community members representing crop farmers, ranchers, elected officials, municipal staff, and one agricultural group representative from outside the community. This workshop was successful in continuing to build positive research relationships in this community, as well as to partake in two-way knowledge sharing.

A film, *Wetland/Waste Land (*Wetland / Waste Land | A Conservation of Change Documentary (youtube.com)), looked at the emerging conflicts in the Canadian prairies over the apparently-conflicting needs of wetlands and agriculture. The film asks: are trade-offs inevitable, or can these challenges be managed for the mutual benefit of all? The researchers worked with willing research participants, including farmers, environmental scientists, engineers, and Indigenous leaders. The film premiered at the Arrell Food Summit in December, 2019, which was attended by a select group of invitees including two members of the Canadian Senate, the president of the University of Guelph, and 40 other delegates from around the world. Since its premiere, it has been viewed more than 18,000 times at the time of writing. The film has been described as 'game changing' by partners in government by helping create a more constructive dialogue.

Public workshops and presentations:

- Minnes, S. (2019, November). Conflict and Agricultural Water Management in Saskatchewan. Agricultural Drainage & the Environment Conference, Regina, SK.
- Baulch, H.  (2019 November) Overview of water quality impacts of agriculture with a focus on drainage: Highlights of the Qu'Appelle River Study (Lower Qu'Appelle Watershed Stewards) Helen Baulch Global Water Futures, U. of S (invited)
- Drainage Idea Share Workshop in Saskatoon, SK: July 16, 2019, organized by Valencia Gaspard and Sarah Minnes.
- Presentation at the ResNet Monthly Meeting: February 19, 2020, by Helen Baulch, Phil Loring, and Sarah Minnes.

# Improved Estimates of Wetland Evaporation

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1-wetland-evap.php

Region: Prairie Region

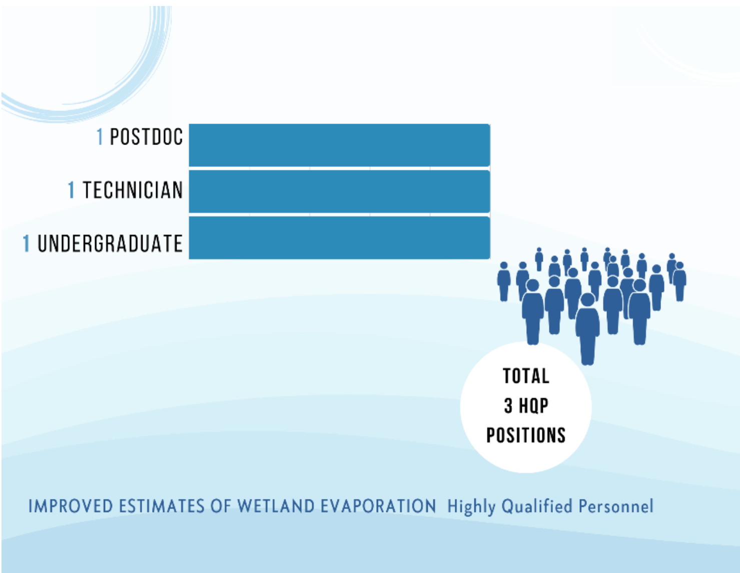
Total GWF funding support: $85,000

Project dates: 2017-2019 COMPLETED

## Investigators

Warren Helgason, University of Saskatchewan
Contact: warren.helgason@usask.ca

## Partners, Collaborators, and Users




Highly Qualified Personnel: Professional training and research positions funded by Improved Estimates of Wetland Evaporation

## Science Advances

The issue of dynamic water storage in prairie wetlands has received considerable attention in recent years. Accordingly, Global Water Futures has learned a great deal about wetland storage, hydraulic connectivity between adjacent wetlands, and the contribution of wetlands to streamflow and groundwater systems. However, there has been scant attention paid to the factors that influence the rates of evaporation from wetlands, or evapotranspiration from wetland-dominated landscapes. Frequently, evaporation estimates are based on simple approaches, using parameters that can't possibly reflect the dynamic nature of prairie wetlands. This project examined factors influencing wetland evaporation in prairie agricultural landscapes, for the purpose of developing more robust techniques for estimating the rate of wetland evaporation.

Two years of eddy covariance energy balance measurements (evaporation flux, sensible heat flux, radiation balance, and energy storage) were collected from a moored raft within a terminal wetland located near the University of Saskatchewan Livestock and Forage Center of Excellence at Clavet, SK. These measurements were supplemented with water balance measurements based on (1) observed changes in wetland water levels, (2) UAV lidar surveys, and (3) changes in wetland solute concentration. This novel suite of measurements produced accurate partitioning of the water balance components of a prairie wetland. This project has collaborated with the Smart Water System Laboratory in the acquisition of LIDAR wetland volume-area quantification. This was followed by work on a novel approach for disaggregating eddy covariance fluxes by adapting and refining the High Resolution Mapping of Evapo Transpiration (HRMET) model, combined with UAV-acquired remote sensing, enabling partitioning of measured evaporation fluxes amongst wetlands, riparian zones, and adjacent croplands.

Link to Publications List

# Northern Region

# Geogenic Contamination of Groundwater Resources in Subarctic Regions

Web Link: [Home - Global Water Futures Geogenic - University of Saskatchewan (usask.ca)]

Region: North

Total GWF funding support: $235,000

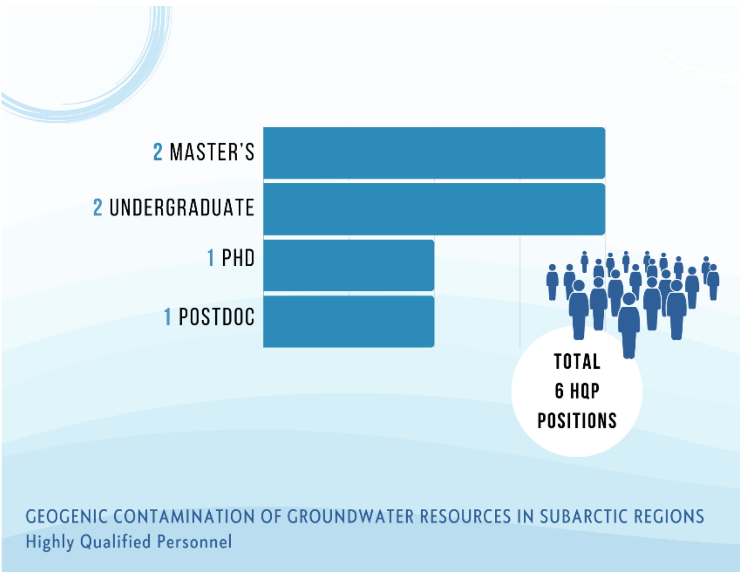
Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators

Matthew Lindsay, University of Saskatchewan
Contact: matt.lindsay@usask.ca
Grant Ferguson, University of Saskatchewan
Sean Carey, McMaster University

## Partners, Collaborators, and Users

Casino Mining Corp. -- Mary Mioska
Newmont Corp. -- Jennie Gjertsen
University of Ottawa -- Clément Bataille
Yukon Gov't (YG) -- Brendan Mulligan




**Highly Qualified Personnel: Professional training and research positions funded by Geogenic Contamination of Groundwater Resources in Subarctic Regions**

## Science Advances

Thawing permafrost and groundwater contamination are major concerns in subarctic and Arctic regions globally. As climate change drives the thaw of permafrost, subsurface groundwater flow paths are changing, leading to disruptions to the hydrological cycle and changing chemical conditions in aquifers that have the potential to mobilize hazardous metal(loid)s. This project's overarching goal was to understand how thawing permafrost will alter metal(oid) mobilization in the Canadian subarctic. The setting for this research included field sites in Canada, where almost all the human population relies on groundwater as a drinking-water supply, and where multiple known occurrences of geogenic metal(loid) contamination from nefarious elements such as uranium and arsenic have been documented.

The project involved a combination of field- and laboratory-based components. One student worked closely with the Yukon Government to build a database of groundwater quality covering the Yukon Territory and project researchers expanded this dataset through targeted sampling of groundwater wells. Results to date show a high proportion of samples exceeding safe drinking-water limits with respect to uranium and arsenic. Ongoing analyses are targeted at unravelling the hydrogeological and geochemical settings where these exceedances occur. A parallel study of metal(loid) mobilization during permafrost thaw was carried out in the Dawson Range of the western Yukon, where there are several prospective mine projects and known elevated uranium and arsenic in groundwater. Through support of the local mining exploration industry, researchers collected permafrost cores from a range of catchments in the Dawson Range. Analysis of these cores showed most samples exceeding safe thresholds for arsenic in water. Elevated uranium was also observed in a subset of cores, in association with specific catchment geology. A laboratory study wherein these permafrost soils are exposed to thaw and water circulation in column experiments is showing a high potential for metal(loid) mobilization during the early stages of permafrost thaw.

In parallel, the team has also collaborated to sample permafrost cores from a wider range of geological settings across Yukon Territory and over a range in permafrost settings that span the sporadic, discontinuous, and continuous permafrost zones. Team members also collaborated to build and analyze long-term seasonal datasets on stream metal(loid) concentrations, major-ion chemistry, and hydrology to advance understanding of metal(loid) mobilization processes in subarctic permafrost catchments.

This study is producing globally significant new knowledge on metal(loid) mobilization processes in permafrost settings. These findings are timely as northern communities face changing hydrological and geochemical conditions as a result of climate change. Through direct interactions with knowledge users, which include the northern mine industry, northern First Nations, and the Yukon territorial government, this project is leading to operational changes in northern water management. For example, results of the research on Dawson Range permafrost is providing northern mine operators with critical insight into changing baseline metal(loid) signatures that result from permafrost disruptions. Findings related to Yukon groundwater quality is leading to enhanced awareness towards geogenic contamination in groundwater and has spurred new research proposals to advance understanding of regional groundwater quality in Yukon. These outcomes directly align with the GWF overarching goals, including predicting water futures in northern regions faced with permafrost thaw and climate change, and aiding in adaptation and management of risk to water resources from geogenic metal(loid) contaminants. Ongoing conversations with the Yukon Government and Yukon First Nations are increasing the capacity of administrators to adapt to growing water demands in their jurisdictions and to better regulate industrial activities where permafrost disturbance can change water quality. It is also delineating hydrogeological and permafrost conditions that control groundwater quality, aiding communities to optimize long-term access to safe groundwater resources. Through ongoing fieldwork and conversations with Yukon Government and First Nations, the research team also identified new field sites vulnerable to changes in water quality that will form the basis for future research proposals. Although this project produces one of the most important global contributions on metal(loid)s in permafrost regions, much work remains to be done. This study has identified the value of baseline water-quality monitoring, and the need for long-term datasets in areas with sparse data coverage such as northern Canada. Ongoing collaboration with academic, government, and industrial partners is leading to enhanced valorization and use of the existing long-term datasets and identification of future opportunities to build new datasets. The laboratory experiments have also identified some of the key geochemical processes that control metal(oid) mobility during incipient stages of permafrost thaw, helping refine future research projects.

Climate change and thawing permafrost are occurring faster in subarctic Canada than the global average, with changes to water resources that often outpace the ability of scientists to acquire funding, collect data, and provide analyses. A major challenge over the coming decades will be to ensure that sufficient human and capital resources are available to understand and adapt to rapidly changing water quality in the Canadian and global North.

## Link to Publications List

## Knowledge Mobilization (KM)

The most effective knowledge mobilization during this project resulted from the team's close involvement with northern communities, the knowledge users. The research team closely interacted with Yukon Government, First Nations, and mining industry, which provided opportunities for knowledge exchange among these groups. These exchanges provided direct opportunities for knowledge users to steer current and future research goals. For example, interactions with Yukon Government and First Nations in the Whitehorse area have spurred a new research proposal to examine groundwater quality issues that are of high local concern. These conversations are also leading the research team to begin to develop future proposals to fund work at field sites in northern and central Yukon where metal(loid) mobilization to water resources has been identified as a likely concern in the face of thawing permafrost. All knowledge users have benefited from increased awareness around metal(loid)s in groundwater and some of the previously unanticipated considerations regarding the impact of thawing permafrost on water quality.

Permafrost slump near highway in Yukon. Photo by Mark Ferguson

The most successful aspects of the knowledge mobilization plan in this regard included a commitment to maintain close communication with all knowledge user groups. Throughout the length of the project, these relationships were nurtured by including a presence of team members in the field, whether at mining exploration sites or within Yukon Government's Water Resources Branch (WRB). WRB's commitment to support HQP fieldwork led to numerous exchanges between WRB staff and field personnel, collaborative sampling efforts, and data-sharing. To plan and execute fieldwork at remote mineral exploration sites, the team committed to ongoing meetings with the Yukon mining industry who have emphasized the value of the research to their operations. Participation of HQP in local conferences, including the North Yukon Permafrost Conference in Dawson City in 2022, provided the team with direct opportunities to discuss water-quality concerns with Yukon First Nations, Yukon citizens, and geoscientists. These conversations have spurred new research opportunities and new partnerships. Groundwater sampling across Yukon, including publicly and privately operated monitoring wells, provided HQP with the opportunity to discuss groundwater research with a wide range of citizens across the territory. The team also was present at an annual public outreach water event organized by the Yukon Government at the Tombstone Territorial Campground, providing further opportunity to engage the public with the research.

The team also produced locally and nationally significant lay summaries, including a radio interview on CBC's *Quirks and Quarks* program and a presentation on northern groundwater at the Yukon Beringia Centre for World Water Day in 2022. The World Water Day presentation also led to production of a graphical representation of the research by local artists. These outputs produced significant local exposure and dialogue with community members about groundwater concerns.

One of the main challenges in knowledge mobilization has been in increasing active partnership of local First Nations (FN) in the project. While all FNs with whom the team has maintained communication over the length of the project have been supportive and interested in the research, their ability to actively participate has been limited by their capacity. Nevertheless, the ongoing communication between the research team and local FN governments has provided local governments with a better understanding of the team's expertise and how it can be applied to local water concerns. This communication has produced new opportunities for the FNs to propose involvement of the team in high-priority water-related issues in their respective jurisdictions and, over the long-term, should continue to improve local capacity-building and technical capability.

As the project enters its final year, a key area of focus is to ensure public dissemination of key new knowledge gained. The team would benefit from direct GWF support where possible on producing KM outputs. In winter 2022, Skierszkan worked with GWF artists and storytellers to produce a story and visual representation of this research. In the final stages of the GWF program, producing lay factsheets and a publicly viewable video would provide a compelling public record of new knowledge gained. One of the challenges for producing these outputs will be to acquire the necessary technical support from communication specialists and working within a timeframe that is possible for team members that are nearing the end of their time as HQP trainees (i.e., students graduate and move on immediately after completing their theses, leaving little time for knowledge mobilization activities after theses are completed).

## Professional Development and Technology Transfer

Special Seminars

- University of Saskatchewan Departmental Seminar, March 2023 (Fellwock). Fellwock presented his research at a Departmental Seminar.
- Invited guest lectures, at Universities of: Ottawa, Carleton, Queen's, Northern British Columbia (Skierszkan). Skierszkan presented this research at numerous invited lectures across Canada.

Workshops

- North Yukon Permafrost Conference, August 2022, Dawson City Whitehorse (Skierszkan). A conference that brought together permafrost scientists with local First Nations citizens to discuss thawing permafrost and its implications, both scientifically and for local citizens.

Cross-institutional placements or internships

- Grunsky spent two field seasons hosted by YG-WRB and worked closely with their hydrogeology team to access data and monitoring wells for groundwater sampling.

User training or tech transfer opportunities

- Grunsky completed EQW in data management software training with the WRB staff in winter 2022.
- Skierszkan and Fellwock adapted a WRB-owned backpack portable rock-coring drill for use in the field as a permafrost-coring tool and for installation of shallow groundwater monitoring wells at remote field sites. Experience gained through this procedure is being shared with WRB staff as a new and low-cost means for shallow subsurface permafrost and groundwater investigations.

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# Hydrology-Ecology Feedbacks in the Arctic: Narrowing the Gap between Theory and Models

Web Link: Hydrology-ecology feedbacks in the Arctic: Narrowing the gap between theory and models - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Northern Region

Total GWF funding support: $271,000

Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators


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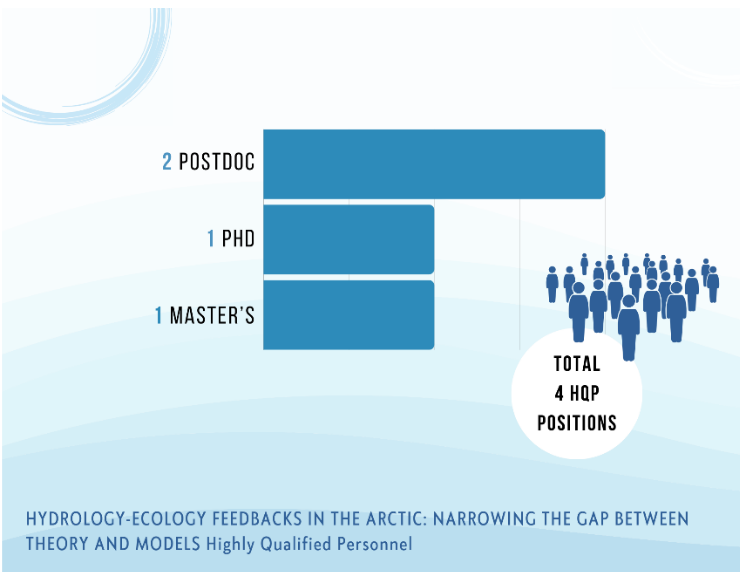
|---|---|
| Martyn Clark, | University of Saskatchewan<br>Contact:<br>martyn.clark@usask.ca |
| Jennifer Baltzer, | Wilfrid Laurier University |
| Sean Carey, | McMaster University |
| Steve Cumming, | Université Laval |
| Philip Marsh, | Wilfrid Laurier University |
| Oliver Sonnentag, | Université de Montréal |


## Partners, Collaborators, and Users

Concordia University -- Ali Nazemi
Environment and Climate Change Canada -- Alex Cannon
National Center for Atmospheric Research -- Andy Wood
National Research Council Canada -- Abhishek Gaur
Newcastle University -- Francesco Serinaldi
University of California Irvine -- Efi Foufoula-Georgiou and Amir Aghakouchak
University of Washington -- Bart Nijssen




Highly Qualified Personnel: Professional training and research positions funded by Hydrology-Ecology Feedbacks in the Arctic

# Science Advances

Rapid Arctic warming is resulting in strong terrestrial responses including vegetation change (e.g., shrub expansion) and intensified disturbance regimes (e.g., wildfire). Understanding how changes in Arctic vegetation cover will modify climate is critical for correctly planning for the impacts of climate-induced vegetation change.

Understanding and predicting the impacts of these long-term changes requires accurate simulation of the links between system change and landscape fluxes of energy and matter. However, these simulations are challenged by complexities inherent to Arctic systems that are not easily implemented in modern land surface models. For example, processes that modify topography such as abrupt permafrost thaw or albedo development independent of leaf area index do not integrate well into current model design structures. In addition to implementation, there are gaps between theoretical expectations of system response and the data required to accurately simulate those expectations.

This project aimed to address these problems by 1) synthesizing the current state of theory related to shrub expansion and disturbance feedbacks, 2) identifying challenges in implementing relevant processes in land surface models and assessing model performance, and 3) developing models which improve on the current capacity for simulation of Arctic ecosystems. There are currently three primary studies developed to address these aims. The first is a review summarizing gaps between theory and model implementation with a goal of bridging the knowledge base and needs of field-based researchers and the modelling community. The second is a formal meta-analysis of the ecological literature that will identify the fluxes and parameters expected to be most modified by Arctic shrub expansion. This will provide robust estimates and ranges of uncertainty of these fluxes and parameters and allow prioritization of the processes which require the most attention in simulations. Finally, a third study is being developed to understand the impact of expansion of Arctic shrub cover on Arctic climate, with a focus on separating the direct impact of vegetation change on surface fluxes from atmospheric responses to terrestrial vegetation change. Using climate model simulations with varied Arctic vegetation cover, it is possible to estimate an 'upper bound' on the potential of changes in woody Arctic vegetation to modify Arctic climate. Using three types of simulations --- one with a land surface model forced by prescribed atmospheric data, one with a freely evolving atmosphere, and one where atmospheric conditions are 'nudged' towards a control state, the climate response to Arctic vegetation change can be disentangled into the components due directly to the land surface, to regional atmospheric changes, and to large-scale atmospheric changes.

These ideas have been developed through a series of meetings at the Coldwater Laboratory in Canmore, AB. To date, a Postdoctoral Fellow has presented project results at one conference, the ArcticNet Annual General Meeting in Toronto, is currently writing a draft of the review manuscript, and will begin data extraction for the meta-analysis work shortly. A Research Associate has presented project results at a collaborative research exchange workshop with Environment and Climate Change Canada scientists in Dorval, QC and is currently working on the shrub expansion modelling output.

## Link to Publications List

# Remotely Sensed Monitoring of Northern Lake Ice Using RADARSAT Constellation Mission and Cloud Computing Processing

Web Link: [Remotely Sensed Monitoring of Northern lake Ice Using RADARSAT Constellation Mission and Cloud Computing Processing - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Northern Region

Total GWF funding support: $250,000

Project dates: August 2020-July 2023 EXTENDED to August 2024

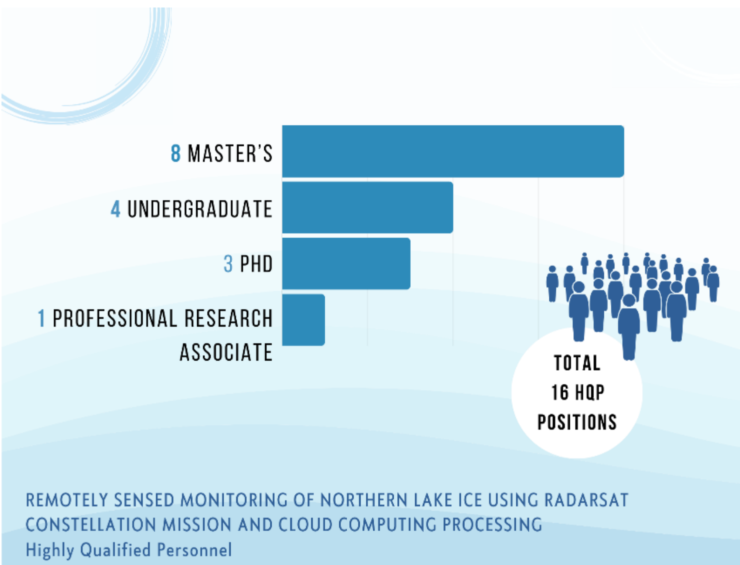
## Investigators

Homa Kheyrollah Pour, Wilfrid Laurier University (WLU) Contact: hpour@wlu.ca
Andrea Scott, University of Waterloo
Grant Gunn, University of Waterloo

## Partners, Collaborators, and Users

Environment and Climate Change Canada -- Steve Howell
Environment and Natural Resources, NWT -- Bruce Hanna and Andrew Applejohn
Environmental Impact Screening Committee, NWT -- David Livingston

North Slave Métis Alliance -- Cat Fauvelle
NWT and Nunavut Chamber of Mines -- Tom Hoefer
NWT Centre for Geomatics -- Mélanie Desjardins
The Wek'èezhìi Land and Water Board -- Ryan Fequet




**Highly Qualified Personnel: Professional training and research positions funded by Remotely Sensed Monitoring of Northern Lake Ice**

## Science Advances

The timing of lake ice freeze-up, break-up, and the duration of ice cover in winter are effective indicators of the annual temperature regime in cold temperate lakes, and the monitoring of them provide a proxy of a change in climate and winter warming. Northern lakes are experiencing significant shifts in ice cover duration as temperature increases are amplified in Arctic environments, however the network of monitoring stations collecting of lake ice phenology and thickness has nearly vanished in North America, replaced by terrestrial automated weather stations. Knowledge of lake ice thickness is also remarkably limited due to logistical difficulties in data collection in remote environments, and challenges in estimating lake ice thickness from remote sensing data.

This project has used several legacy and new satellites to monitor several parameters of lake ice, while developing and improving models and tools to simulate the timing and processes governing lake ice dynamics. Results from this project are critically linked with the aim to understand and predict the thermodynamic regimes and potential future change of northern lakes, which is a key interest for multiple projects under the Global Water Futures umbrella, including Northern Water Futures and Boreal Water Futures. The project has three co-PIs, Dr. Andrea Scott (Systems Design Engineering, University of Waterloo), Dr. Homa Kheyrollah Pour (Department of Geography and Environmental Studies, Wilfred Laurier University) and Dr. Grant Gunn (Geography and Environmental Management, University of Waterloo) and has included contributions HQP.

There are three main objectives of the project:

Objective 1: To confirm microwave scattering mechanisms in ice using polarimetric decomposition (RADARSAT-2). Demonstrate the relevance of these results for lake ice thickness retrieval.

Objective 2: To retrieve Lake Ice Phenology using Synthetic Aperture Radar Data and Google Earth Engine

Objective 3: To develop ice thickness model (CLIMoGrid) for verification of spatial details of ice phenology and thickness:

Objective 1 Summary: Team members have explored backscatter coherence for repeat pass Sentinel-1 dual-pol, Radarsat 2 Quad-pol and TanDEM-X Quad-pol acquisitions in Churchill, Manitoba to assess the capabilities of the sensors regarding interferometric product generation. The temporal resolution of these acquisitions vary, with TanDEM-X pursuit mode having the shortest temporal baseline of 10ms, followed by Sentinel-1 (11 days) and the longest with Radarsat-2 of 24 days. Coherence is retained for TanDEM-X throughout the winter season, and for Sentinel-1 when lake ice approaches its maximum thickness. The coherence values in lakes highlights the utility of the repeat-pass interferometric technique to obtain ice thickness, as well as the potential for RCM to contribute to future retrievals. This technique was tested using three regions of interest (Alaskan North Slope, Tibbit to Contwoyo Ice Road, NWT, and Churchill, MB) and interferometric phase unwrapping successfully retrieved ice thickness parameters. These results are currently being incorporated in a publication to demonstrate the utility of SAR to retrieve change in ice thickness for Canadian northern lakes. An additional study will supplement the ice retrievals from TanDEM-X using RCM acquisitions that have been tasked for the maximum ice season of 2022 and 2023 for Arctic and sub-Arctic regions with high density of small ponds and lakes (Inuvik, Churchill, Old Crow Flats). Results of a review of the physics behind polarimetric decomposition algorithms with respect to target interactions with freshwater ice are consistent with spaceborne SAR acquisitions that surface interactions with the ice-water interface are the dominant source of backscatter in freshwater ice, providing evidence that SAR acquisitions could be used for repeat-pass interferometry and ice-thickness retrieval. The effect of lake morphometry (deep vs shallow), ice composition (clear vs. tubular bubble inclusions) for multiple beam modes have been investigated using polarimetric decomposition algorithms. Regardless of lake morphometry and ice composition the surface bounce component is the dominant source of backscatter in lakes. This result holds significance for the potential operationalization of lake ice thickness retrieval algorithms as the ice-water interface is consistently the source of microwave interaction, allowing for broader application of single algorithms.

Objective 2 Summary: Team members have applied an algorithm to Sentinel-1 SAR backscatter using Google Earth Engine to detect ice on/off that does not require a fixed threshold (e.g. backscatter value). Preliminary results for lake ice phenology based on lakes on Alaska's north slope are promising and agree with thermodynamic ice models. Plans to extend this to lakes over a larger geographic region (e.g., North America) include developing a method to evaluate the efficacy of the method. For example, a thermodynamic ice model, Climo, may be used, as has been done in earlier studies. The team continues to work with deep learning algorithms that can be used to map ice and water for RadarSat-2 lake ice data. There have been several advances in this area over the past year, so a review of the most appropriate method is currently being conducted to conceptualize the most appropriate validation effort.

Objective 3 Summary: A spatially distributed model using remote sensing data has been developed to produce daily ice thickness outputs .Updates are provided on the three major activities necessary to achieve this goal: (i) retrieval of moderate resolution lake surface temperature to serve as model inputs, (ii) reconstruction of the CLIMoGrid model for simulating ice thickness on small/medium lakes using obtained or generated distributed data (iii) collection of field data for model calibration and validation. Notable advancements for these three primary activities include use of an algorithm to retrieve lake surface temperature (LSWT) from the thermal bands of Landsat 5,7 and 8 for 535 lakes in the North Slave region of the Northwest Territories, reconstruction of CLIMoGrid for small lakes, and field studies for calibration and validation.

Link to Publications List

# Knowledge Mobilization (KM)


Homa Kheyrollah Pour working with Guardians in Łutsël K'é in January 2023 to install ice sensors on Great Slave Lake. Photo by Wilfrid Laurier University

As part of its KM activities, in addition to the project's current partners, the team has established contact with Łutsël K'é (pronounced "loot-sell-kay") community. Ice is essential for survival for these communities. In April 2022 and January 2023, Kheyrollah Pour and her research team travelled to Łutsël K'é to partner with environmental stewards of Thaidene Nëné, known as Guardians, to share knowledge, and installed sensors in two locations on Great Slave Lake. They worked with Guardians (Chase Lockhart and Kevin Fatt, and Rubin Fatt) to promote the community capacity building on ice monitoring. The sensors collect ice thickness data every 15 minutes, letting the community know when it is safe to travel in real time. These sensors will help communities to gauge from year to year how the ice thickness is changing over time, and how researchers can prepare and protect their safety and well-being. By collecting real-time cumulative data, the expected impact of this project on northern decision-making will be significant. This supports fulfilling the GWF goal contributing to strong decisions on natural resources and sustainable development in the Canadian north.

The project team also contributed to the 13th annual NWT Water Stewardship Strategy Implementation Workshop and Annual Climate Change Gathering held on October 25-27, 2022 in Chief Drygeese Centre –Dettah, NWT. Dr. Kheyrollah Pour participated in the panel discussion on "Our NWT Waters: Resilience and adaptation Panel Presentation – Researchers, Regulators and Water Partners Share Their Work". Link: https://www.nwtwaterstewardship.ca/en/2022-workshop.

Articles in popular media

- Laurier News Hub: https://www.wlu.ca/news/spotlights/2023/march/laurier-researchers-partner-with-nwt-indigenous-guardians-to-provide-real-time-monitoring-of-lake-ice-for-safe-travel.html
- Global News: https://globalnews.ca/news/9618957/team-wilfrid-laurier-university-lifesaving-technology-remote-village/
- Simba the apparatus — not the lion — helping measure ice thickness in N.W.T. (CBC)
- Duo hope to use research data to make ice travel safer (NNSL Media)
- Team from Wilfrid Laurier University helps install lifesaving technology in remote northern community (Global News)
- Laurier researchers partner with NWT Indigenous Guardians to provide real-time monitoring of lake ice for safe travel (Laurier News Hub)
- Lifesaving tech installed at Canada's deepest lake by Wilfrid Laurier researchers (CBC K-W)

Trucks on NWT ice road. Photo by Wilfrid Laurier University

Interviews (broadcast or text)

- Laurier research near Yellowknife aims to improve ice safety through real-time measurements of lake ice
- Research Chat Season 2, Episode 10: Gifty Attiah Wilfrid Laurier research team install lifesaving ice sensors along Great Slave Lake (CBC K-W).

# Is Our Water Good to Drink? Water-Related Practices, Perceptions and Traditional Knowledge Indicators for Human Health

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/i1-schusterwallace.php#Investigators

Region: Northern Region

Total GWF funding support: $200,000

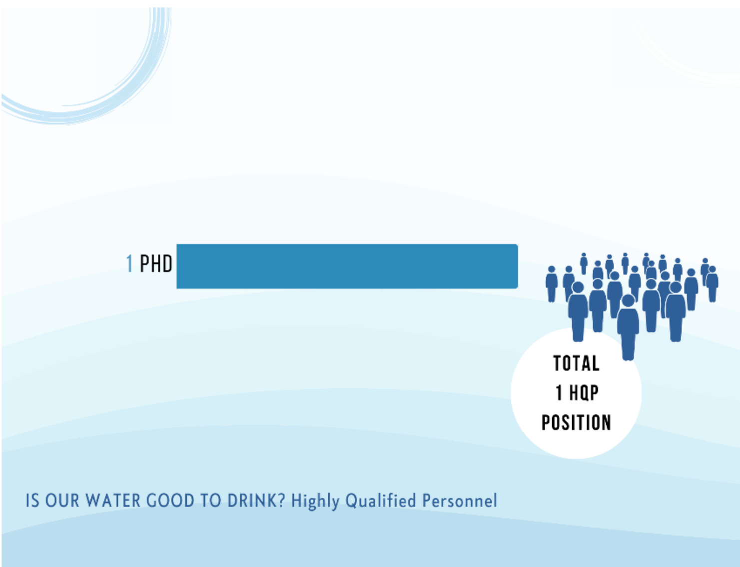
Project dates: December 2018-November 2021, EXTENSION to August 2024

## Investigators

Diane Giroux, Akaitcho Territory Government
Contact: aarom.coordinator@akaitcho.ca
Corinne Schuster-Wallace, University of Saskatchewan
Lalita Bharadwaj, University of Saskatchewan
Sarah Dickson-Anderson, McMaster University
Mike Tollis, Akaitcho Territory Government

## Partners, Collaborators, and Users

Akaitcho Territory Government -- Diane Giroux
Deninu K'ue First Nation
Lutsel K'e Dene First Nation
Yellowknives Dene First Nation




Highly Qualified Personnel: Professional training and research positions funded by Is Our Water Good to Drink?

## Science Advances

While many Indigenous communities recognize Western Science (WS) standards for drinking water quality, potability as a concept is not sufficient enough to address the Indigenous concepts of “good” or “bad” in relation to water. Despite recognition of colonialism having shaped both water governance and water research, Indigenous Knowledge and information needs are overlooked or only used when ‘validated’ by western science. As such, this project begins with local and Traditional Knowledge to understand how water is identified as good to drink. This was addressed by soliciting this knowledge through questionnaires and interviews (qualitative as well as quantitative data).

The purpose of this collaborative research project is to develop Traditional Knowledge (TK) indicators by exploring the similarities and differences between WS indicators of what is considered 'safe to drink' and the Traditional Knowledge concept of what is 'good to drink'. Through this process and its outcomes, communities should be able to better understand and assess water-related health in Indigenous communities through a TK system and be able to share this with government agencies currently responsible for water management, remediation, and quality monitoring.

This research project was put on complete hold with the onset of COVID-19. Planned field travel was postponed in March 2020. The team has continued to engage regularly, but in early 2020 realized that outbreaks in community would lead to further postponement. Re-connecting post-COVID has been most challenging. Plans were to re-begin community visits in summer 2023, with data collectionfollowing relatively soon after that, to complete by August 2024.

Link to Publications List

# Matawa Water Futures: Developing an Indigenous-Informed Framework for Watershed Monitoring and Stewardship

Web Link: [I1-schusterwallace - Global Water Futures - University of Saskatchewan (usask.ca)]

Region: Northern Region

Total GWF funding support: $399,528

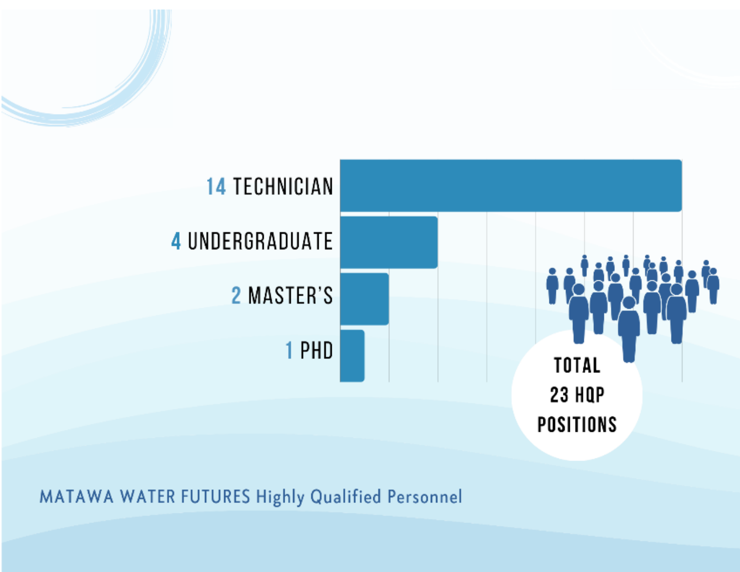
Project dates: December 2018-November 2021 EXTENDED to August 2024

## Investigators


Sarah Cockerton, Matawa First Nations Management
Contact: scockerton@matawa.on.ca
Terry Mitchell, School of International Policy and Governance Balsillie School of International Affairs, Wilfrid Laurier University
Peggy Smith, Lakehead University
Darren Thomas, Wilfrid Laurier University
Miguel Sioui, Wilfrid Laurier University
Kelly Munkittrik, University of Calgary
Alex Latta, Wilfrid Laurier University
David Pearson, Laurentian University
Andrew Conly, Lakehead University
Michael Rennie, Lakehead University
Robert Stewart, Lakehead University
Amanda Diochon, Lakehead University


## Partners, Collaborators, and Users

Aroland First Nation
Centre for Indigenous Environmental Resources (CIER) -- Kristy Anderson
Constance Lake First Nation
Dehcho First Nations
Eabametoong First Nation
Ginoogaming First Nation
Long Lake #58 First Nation
Marten Falls First Nation
Matawa Four Rivers -- Sarah Cockerton
Neskantaga First Nation
Nibinamik First Nation
Webequie First Nation
Wildlife Conservation Society (WCS) -- Cheryl Chetkiewicz




Highly Qualified Personnel: Professional training and research positions funded by Matawa Water Futures

## Science Advances

The homelands and traditional territories included in the Matawa Water Futures project encompass more than 180,000 km2 in northern Ontario, serving as the basis for their livelihoods since time immemorial. Within this region, which is part of a larger 380,000 km$^2$ of related watersheds, there are no conservation authorities or other water governance frameworks. Matawa Water Futures (MWF) brings together Indigenous and non-Indigenous forms of knowledge to promote the development of an Indigenous-informed water monitoring framework that will help Matawa member First Nations (MFN) prepare for climate change and future industrial development.

In response to the combination of changing climate, with forecasted Ring of Fire development in northern Ontario, the important watersheds within the MFN territories are subject to unprecedented change. Matawa First Nations is actively engaging leadership, communities and students to develop the capacity to identify, draw upon and link Indigenous values and traditional knowledge (ITK)K) with Western science to respond effectively to contemporary challenges and water priorities in their communities. This project has advanced capacity within Matawa First Nation members through post-secondary education, internships, technical training, certification, faculty mentorship, and field work. MWF has engaged community members to respond to community identified water concerns through visits, interviews, and community specific mapping in response to community identified priorities in partnering communities. Development of sustainable capacity within Matawa communities is meant to produce a lasting benefit of greater community capacity to monitor water, produce GIS mapping, and work with drones as well as identify and mobilize ITK through community visits and interviewing.

The overarching purpose of the MWF project was to support advancement of Indigenous-informed water science. This is an ongoing process that requires continual support beyond the scope of the project. In order to achieve this, the MWF project depended on the support of the co-investigators and partner organizations through various forms of collaboration. This collaborative effort took shape using various methods, as the project had to adapt significantly in response to the COVID-19 pandemic.

Four Rivers Group has been essential through their support and initiative in working towards the outlined objectives for the project. The pivot towards more organic development of monitoring and management was primarily carried out by Four Rivers from 2020 to present day, as they were able to find ways of adapting their own programs to appropriately engage community members while following COVID-19 protocols. They remain central in supporting efforts to build relationships between communities and researchers, as well as connecting and distributing knowledge in creative and engaging ways.

Through Four Rivers, efforts towards supporting development of water monitoring and management frameworks within communities were directed in building on existing programs, and re-evaluating existing data and information (specifically data management and drone program). This shift in how scientific data was gathered and stored evolved out of long-standing interest within Four Rivers to build out a GeoHub to store community data, and make it accessible based on sensitivity classifications: https://www.fourrivershub.ca/. This data hub has developed alongside the Four Rivers drone program; during the 2021-2022 field season, the Four Rivers drone team were successfully able to travel to all nine MFN communities and capture drone imagery that has been stored on the GeoHub. The development of the GeoHub is ongoing, but functions as an active database for monitoring and management data, as well as TEK and community information to be stored securely.

Four Rivers have also implemented the use of Survey123, a service available through ArcGIS that allows staff to generate surveys based on ongoing monitoring programs during field work and by community members. The use of this app has allowed for more citizen science to take place by community members regularly during on-the-land outings. For example, a survey was developed to collect information on fish health throughout the MFN homelands and traditional territories. Community members are able to access the survey through the phone app, and are asked a series of questions about fish observed, are encouraged to take a photo and to mark the location a fish was caught. The surveys are designed to be convenient and easy to complete within five minutes. The data collected through these surveys are also plotted into dashboards through ArcGIS that are also uploaded to the GeoHub for reference.

Moving forward, there is potential for branches of this project to continue carrying out the core activities listed in the initial project proposal in order to maintain the overall outcomes over time. As described above, the process of consolidating and mobilizing scientific data is ongoing with the development of the GeoHub. Further support for collecting and depositing data to this GeoHub will both make this data more accessible within MFN community members, as well as supporting future monitoring and management programs to provide supporting baseline data. Ongoing work within monitoring and management programs, as well as an Indigenous-led framework will also depend on the capacity to maintain these relationships with MFN community members as well as researchers and other professionals.

## Link to Publications List

# Knowledge Mobilization (KM)

Due to the COVID-19 pandemic, project co-investigators and partner organizations were not in a place to develop a framework for Indigenous-led water monitoring. Instead, the methodological approach shifted more towards featuring what work is happening within the MFN homelands and traditional territories, and having monitoring and management programs evolve more organically. This was achieved through recognizing the importance of oral culture within the MFN communities, and the insights this had on the data collected. Additionally, in these efforts towards braiding Western and Indigenous science and knowledge, it was decided that the importance placed on trusted relationships between environmental researchers and technicians with community members was a priority, therefore for this component of the MWF project, the focus was directed towards building and maintaining these relationships.

The inability of university researchers to travel to communities meant that there was a massive shift to creating a stronger presence and awareness of the work carried out by Four Rivers (such as regular updates for the website or social media page), as well as bringing together perspectives from other regions across Canada to build the trust and acceptability of building out monitoring and management programs in the Matawa homelands and traditional territories. A significant outcome of this project has been the progress made by MWF students. University-level credits were received, and the progress made by the students supports the goal of actively braiding Western and Indigenous knowledge, a two-way intercultural knowledge exchange in the university classrooms, the workplace, and in community.

As part of the knowledge mobilization plan for this project, two environmental gatherings were held. Four Rivers has led the way in organizing these gatherings and bringing together MFN community members. Updates and information on current and upcoming programs run by Four Rivers were shared, and researchers were brought in (in-person and virtually) to give presentations. No gatherings were held in 2020 and 2021 due to COVID-19. However, to maintain the intentions of the gatherings for information and knowledge sharing with MFN community members, a webinar series was created, each episode featuring a new topic relevant to the MFN homelands and traditional territories. Both approaches to sharing knowledge, as well as bringing community members together have proven effective in establishing more familiarity with monitoring and stewardship practices. A final water gathering was planned for June 2023, to include MFN communities, researchers and partners from other environmental monitoring research programs in the region, Indigenous communities and tribal councils from northern Ontario, Indigenous guardians and representatives from NWT, BC, and the east coast provinces of Canada, as well as representatives from New Zealand. This gathering will be to celebrate the value and sacredness of water, as well as share observations and scientific knowledge about the water, and share progress in water and environmental stewardship programs.

### Workshops

- Aki kikinomakaywin (learning on the land) program hosted through Lakehead University o Some team members participated in a one-week program that brought together elders, knowledge holders and youth for on-the-land and in-lab teaching and learning about environmental science: https://akikikinomakaywin.com/what.

### International Exchanges


2022 Environmental Gathering

In June 2023, a large water and environmental gathering was planned to be held in Thunder Bay, hosted by Four Rivers (Matawa First Nations Management) in collaboration with Mushkegowuk Tribal Council, and including speakers and workshops facilitated by researchers and Indigenous groups working throughout Ontario, Northwest Territories, and New Zealand. The goal of this workshop is to bring together Matawa First Nation communities in learning and sharing knowledge related to the water and environment, as well as to build relationships with the presenters/speakers attending the gathering to support future engagement, research, and knowledge sharing.

Public Outreach

- Four Rivers conducted education and outreach efforts targeting youth at a Science Carnival hosted in Thunder Bay in winter 2023, where environmental research efforts were highlighted on the waterfront.
- December 2022 Environment Gathering: Matawa member First Nation lands and resource staff, environmental monitors and stewards, Elders, youth, Leadership, community communication liaison officers, former MMTC members, and other interested membered gathered for workshops to reflect on 10+ years of regional environmental programming and data collection, to share knowledge, build capacity, and participate in discussions on what's to come. A graphic artist attended and created interactive images documenting overall themes from the gathering.
- A series of five training videos were and shared via USB with Ginoogaming, Long Lake 58 and Webequie during the Winter 2022 Gathering. The videos provide training for the following:

o Surface Water Sampling

o Winter Surface Water Sampling

o YSI Water Sampling

o Winter YSI Water Sampling

o How to Install and Use Survey123.

Articles in popular media

- Matawa Messenger – a quarterly publication by Matawa First Nations Management sharing updates, news, and additional information across Matawa First Nations. March 2022 to March 2023: 5 publications—Four Rivers articles
- Living with Us Series (5 articles): Wanatowag (Fungi), Bank Swallow – Riparia riparia, "Blue" walleye – Sander vitreus, Wolverine – Gwiingwa'aage (Gulo gulo), Ma'iikan (Grey Wolf).
- March 2022: Wingtra Distributors, Blastomycosis Sampling Assistance, Climate Change Adaptations, Ice Safety and Rescue Training
- June 2022: Winter Field Update, Chamber of Commerce Nomination, ESRI Calendar
- September 2022: Wabigoon Lake Wild Rice Beds Study, Mapping Section of Broadband Corridor with Drones, Garden Dome, Procurement Project, Environmental Technical Table
- December 2022: Environmental monitoring, seed collection, AFN climate change gathering
- March 2023: Garden Domes, Webinar Series, Environment Gathering 2022
- Living Lakes Canada, International Association for Great Lakes Research (IAGLR) Newsletter, Spring 2021 pg. 11: https://iaglr.org/ll/2021-2-Spring_LL9.pdf
- Four Rivers was featured in the quarterly newsletter issued by IAGLR called "Lakes Letter" to discuss the STREAM project. The article features MWF student Erin Desjardins using water analysis equipment.

Public workshops and presentations

Ongoing outreach and engagement to all member First Nations through the Four Rivers Webinar Series (2022: 6 episodes January-April; 2023: 6 episodes February-April). This webinar series broadcasted environmental information to Matawa First Nation Members to make it accessible (MS Teams platform). Partnering with other organizations/groups to provide valuable presentations that can help build capacity or inform of environmental issues relative to Northern Ontario.

2022 Episode List:

o E1: Environmental Monitoring Essentials: Water

o E2: Environmental Monitoring Essentials: Land

o E3: Climate Change and Food Sovereignty

o E4: Climate Change and Health Impacts

o E5: Climate Change Adaptation & Action

o E6: Environmental Monitoring Essentials: Climate.

2023 Episode List:

o E1: Monitoring the Waters: Sturgeon in the Homelands

o E2: Monitoring the Waters: Brook Lamprey o E3: Caring for the Land: Indigenous Cultural Burning Practices

o E4: Environmental Conversations in the Language

Other

- A water video was created by Four Rivers, featuring photos, videos, and drone imagery from the MFN homelands, and narration in both English and Ojibway.

- A community member from Nibinamik First Nation created a short film, *Journey to the Homelands*, that has been shared throughout MFN member communities, and recently was entered into Vancouver film festival.

- Webequie AGM - Four Rivers hosted a booth at the Matawa Annual General Meeting (hosted in Webequie First Nation in July 2022), bat SAR research throughout the Matawa member First Nation homelands was highlighted. Representatives from all member First Nations were in attendance, including Chief & Council, youth, women, Elders, as well as Matawa First Nations Management staff, managers and CEO.

# Professional Development and Technology Transfer

Ice rescue training participants

- CABIN Training, August 2021: Four Rivers partnered with Living Lakes Canada (LLC) and the World Wildlife Foundation (WWF) to provide this training and was hosted at the Ginoogaming First Nation Training Centre. This training focused on collection of water bugs by following a standardised sampling protocol, Canadian Aquatic Biomonitoring Network (CABIN). Collecting and analysing water bugs enables formation of conclusions about the health of rivers, streams and creeks based on what species are present in samples.

- Swift water rescue training, June 2022—Training was organized by Four Rivers for community monitors to learn hands on safety practices when working in and alongside rivers during fieldwork.

- Ice rescue training, February 2022 – Training organized by Four Rivers staff for learning how to assess ice conditions in order to work safely on the ice surface, as well as learn self-rescue techniques and how to rescue others who fall through the ice.

# FIShNET (Fish & Indigenous Northern Health) Healthy Water, Healthy Fish, Healthy People

Web Link: https://uwaterloo.ca/global-water-futures/fishnet-fish-indigenous-northern-health-healthy-water

Region: Northern Region

Total GWF funding support: $200,000

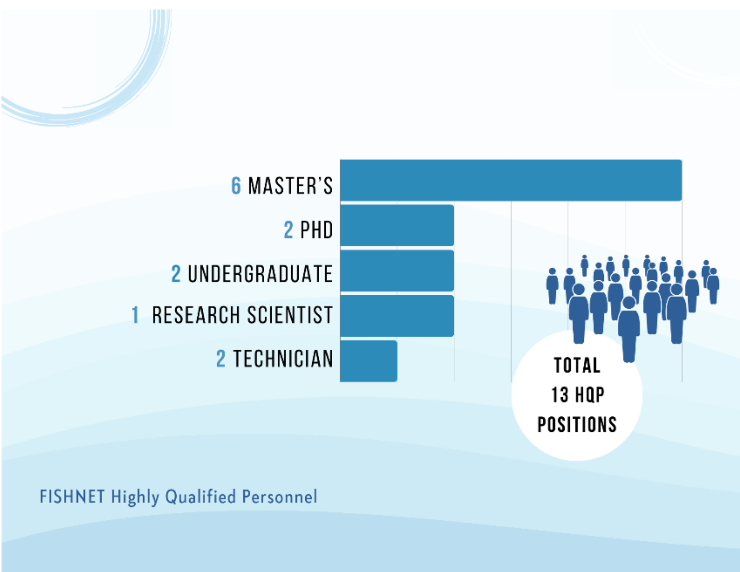
Project dates: December 2018-November 2021 EXTENDED to August 2024

## Investigators

Kelly Skinner, University of Waterloo Contact: kskinner@uwaterloo.ca
Barb Duffin, Mushkegowuk Council
Brian Laird, University of Waterloo
Heidi Swanson, Wilfrid Laurier University
Vern Cheechoo, Mushkegowuk Council
Martin Lawrence, Mushkegowuk Council
Jim Wallace, University of Waterloo
Glenn Ferguson, University of Waterloo

## Partners, Collaborators, and Users

Biotron, Western University -- Brian Branfireun
FEHNCY University of Ottawa -- Dr. Laurie Chan, Lynn Barwin
FEHNCY University of Montreal -- Malek Batal
FEHNCY University of Ottawa -- Dr. Thomas Kovesi
FEHNCY University of Ottawa -- Lynn Barwin
FEHNCY Université Laval -- Melanie Lemire
FEHNCY University of Montreal -- Stephane Decelles
Fort Albany First Nation -- Robert Nakogee, Leo Metatawabin
Intrinsik, Mississauga -- Glenn Ferguson
Laurentian University -- Gretchen Lescord
MRIS Early Researcher Award -- Heidi Swanson
Mushkegowuk Council (MC) -- Vern Cheechoo, Barbara Duffin
Northern Scientific Training Program (NSTP) – Kelly Skinner, Brian Laird
SSHRC Insight Grant -- Kelly Skinner




Highly Qualified Personnel: Professional training and research positions funded by FIShNET

## Science Advances

The purpose of FIShNET is to support efforts that promote consumption of traditional food to lower risk factors for chronic disease while minimizing contaminant exposure among community members in Fort Albany First Nation of the Mushkegowuk Region of Northern Ontario.

In the first year, the project team recruited students and staff to prepare research ethics applications and received ethics approval from the University of Waterloo Office of Research Ethics. The team also worked with Fort Albany First Nation and Mushkegowuk Council to develop Community Research Agreements closely with these community investigators and collaborators to plan for data collection in Fort Albany in the project's second year. During summer and fall of 2019 the FEHNCY (Food, Environment, Health and Nutrition of Children and Youth) team (University of Ottawa/University of Montreal) was also conducting research in Fort Albany, and met with the FishNet team Fort Albany during its engagement field trip in October 2019. The team's original plans to travel and conduct field research with hair sampling and survey data collection in Fort Albany from March22 to April 12, 2020 had to be changed due to COVID-19 and travel restrictions and advisories imposed by Indigenous communities (including Fort Albany), provincial, and federal government agencies.

In preparation for the planned March/April 2020 field work in Fort Albany, Ontario, in collaboration with partners from the Mushkegowuk Council, Fort Albany First Nation, as well as in consultation with the FEHNCY team, the FIShNET team created a survey to collect data about food behaviour and perceptions of adults living in Fort Albany, Ontario. Once given approval by community leadership to continue with this project, there would be a community visit to administer the survey in a community clinic run by community-based local research coordinators and team members from the University of Waterloo to collect data on food insecurity in households (based on an adaption of the Household Food Security Survey Module (HSSFM)), the impact of wild-harvested fish on food security, risk perception, changes to food security and fish health over time, climate change impacts, relationships between fish health and human consumption, and other fish-health concerns.

The FEHNCY team had planned to conduct similar research in Fort Albany, although their primary focus was assessment of child community and school food environments, household environments, and child nutrition and health. The FIShNET team planned to focus on adults, while the FEHNCY team focused on children. The Chief and Council in Fort Albany requested that the FIShNET and FEHNCY teams work together to conduct this research and a data sharing agreement with the FEHNCY team was to be used to match households that also had child participants in FEHNCY's research. For those households that were matched, de-identified data describing participant age, sex, hair mercury results and questionnaire responses would be provided by the FIShNET team to FEHNCY. FIShNET data would then be combined with the data from questionnaires and biological sampling that FEHNCY collects to study links between household mercury exposure, food security, and child health. Compiling these data would allow a more accurate representation of what households in Fort Albany face in terms of food security and environment, fish consumption, and contaminant exposure for adults and youth.

The intention was that data collection field research for hair sampling and surveys would resume in the Spring of 2021, but due to the continued pandemic,this activity remained paused. In 2021-2022 existing archived fish tissue samples provided to the team by Dr. Alex Litvinov underwent analysis for mercury, trace metals and arsenic speciation. A project report was shared with the Mushkegowuk Council in 2022, highlighting the importance of determining levels of arsenic and mercury contamination in fish and mollusca to investigate human exposure to contaminants through traditional food. The level of total arsenic, total mercury, and arsenic speciation in fish and mollusca samples from the Albany River located in the Mushkegowuk Region was reported. Northern Pike samples have the highest mean of total mercury concentration followed by Cisco, Lake Whitefish and mollusca. None of the samples had a mean of total mercury levels above the maximum limit for total mercury in retail fish. Lake Whitefish samples have the highest mean of total arsenic concentration followed by Cisco, mollusca and Northern Pike. Some of the arsenic levels in the Cisco and Lake Whitefish and Northern Pike samples are above the threshold for the Ontario Sensitive Population and above the Health Canada benchmark. All mollusca samples are below both benchmarks. Arsenate and arsenite species were below the limit of detection in all samples. Monomethylarsonic acid was detected in 8% of the Lake Whitefish samples and dimethylarsinic acid were detected in some of the Lake Whitefish, Cisco and Northern Pike samples. This knowledge will assist the assessment of risks and benefits of traditional food consumption in the region. The team used these findings to create a one-pager and several posters to share with community partners.

In late 2022 FIShNET learned that its FEHNCY collaborators were no longer going to collect data in Fort Albany as there had been too much difficulty re-engaging post-pandemic. In addition, the local Fort Albany research coordinator had moved out of the community. The FIShNET team re-engaged with Fort Albany in the late summer of 2022 and had a trip planned in October 2022, but there was an election in early October 2022 with a full leadership change of Chief and Council in the community. FIShNET has since been re-engaging with Mushkegowuk Council and Fort Albany First Nation to determine their continued priorities for the FIShNET project. Vern Cheechoo is now the Interim Executive Director of Mushkegowuk Council and has asked the team to work with Lawrence Martin who is fulfilling Vern's role at Muskegowuk. Efforts to contact the new Chief and Council in Fort Albany have been delayed by flooding and evacuations in April 2023. To complement the project's fish sample collection and analysis, assessment of contaminant exposure through the survey and through biomonitoring by measuring hair mercury in hair samples from participants is planned. These samples will be used to provide a baseline for mercury exposure in the Mushkegowuk Region.

## Link to Publications List

# Knowledge Mobilization (KM)

Once the field research component is completed the team will work towards being able to give residents of Fort Albany better information regarding the safety of the fish they consume and the benefits of fish consumption to food security. This study should contribute to development of public health communication strategies that promote traditional food reliance in ways that maximize nutrient status while limiting contaminant exposure in the Mushkegowuk Region of northern Ontario.

In 2021-2022 a community report prepared for the Mushkegowuk Council summarized the findings from quantification of arsenic and mercury levels in local fish and mollusca. This helped to empower the communities by knowing what fish contain the highest concentration of contaminants and if any species are frequently above accepted thresholds, aiming to protect the health of consumers. The next steps involve nutrients analysis of those samples, to balance the risks and benefits of such food.

Collection of hair and survey data from people in the Mushkegowuk region has been on hold due to the pandemic. As a side project, the team has been working with colleagues at Laurentian University to conduct a systematic review to look at Maximum Residue Levels for Arsenic and fish consumption guidelines.

If Mushkegwouk Council and Fort Albany First Nation wish to continue this project, then the team will continue to train HQP and work with the Council and community partners. HQP are trained in a collaborative, interdisciplinary setting that strengthens and emphasizes integration among the natural, social, and health sciences. Significant training of Indigenous resource monitors, youth, and local research coordinators will occur during surveys and human biomonitoring clinics, when possible during non-pandemic community visits. Community researchers will also be trained on methods related to human biomonitoring and food security research, including randomization methods for participant recruitment, non-invasive sampling methods (e.g., hair collection), implementation of interviews, as well as in obtaining fish tissue samples from harvested fish. This approach will build capacity in the community and foster development of future community-led monitoring initiatives related to environmental health.

Since 2017, the FIShNET team has worked with the collaborators within Global Water Futures' Northern Water Futures (NWF) project. Progress under NWF has included important scientific and knowledge mobilization achievements. For example, levels and determinants of several priority biomarkers (e.g., mercury, cadmium, and polycyclic aromatic hydrocarbons) in the Mackenzie Valley Biomonitoring Project were characterised. Results from the Health Messages Survey (and complementary key-informant interviews) describing contaminant awareness and perceptions as well as preferences for communication strategies were analysed. Pairing the Health Messages Survey results with human biomarker data has shown that community-level responses to messaging (e.g., changing harvest locations) is associated with lower hair mercury levels of project participants. These results are being reported and incorporated into Arctic Monitoring and Assessment Programme 2021 reports. FIShNET is also generating information for Fort Albany First Nation and Mushkegowuk Council complementary to the data and outputs of the NWF project. Plain language materials about contaminants in fish have been shared with community members

## Northern Water Futures

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p3-northern-water.php

Region: Northern Region

Total GWF funding support: $2,000,000; $1,250,000

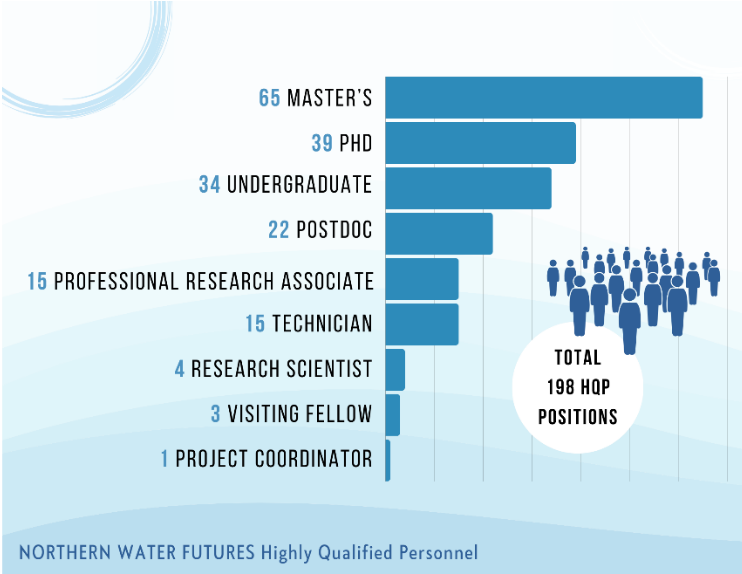
Project dates: June 2017-August 2023 EXTENDED to August 2024

### Investigators

Jennifer Baltzer, Wilfrid Laurier University Contact: jbaltzer@wlu.ca
Aaron Berg, University of Guelph
Alison Blay-Palmer, Wilfrid Laurier University
Joseph Culp, Wilfrid Laurier University
Christopher Derksen, Environment and Climate Change Canada
Michael English, Wilfrid Laurier University
Brian Laird, University of Waterloo
Deborah MacLatchy, Wilfrid Laurier University
Philip Marsh, Wilfrid Laurier University
Jeffrey McKenzie, McGill University
David Rudolph, University of Waterloo
Sherry Schiff, University of Waterloo
Kelly Skinner, University of Waterloo
Oliver Sonnentag, University of Montreal
Christopher Spence, University of Saskatchewan
Andrew Spring, Wilfrid Laurier University
Heidi Swanson, University of Waterloo
Merritt Turetsky, University of Colorado Boulder Institute for Arctic and Alpine Research
Brent Wolfe, Wilfrid Laurier University
Roland Hall, University of Waterloo

### Partners, Collaborators, and Users

Alfred Wegner Institute -- Julia Boike
Aquanty – Steve Frey
Aurora College -- Michael Palmer
Aurora Research Institute – Sarah Rosolen
Carleton University – Elyn Humphries
Canadian Wildlife Service -- Mark Bidwell, John Conkin
Cenovus Energy -- Chris Salewich
Crown – Indigenous Relations and Northern Affairs Canada
Service Canada -- Not provided
Dehcho First Nations Aboriginal Aquatic Resources and Oceans Management -- Mike Low
ECCC – Water & Hydrology Research Division -- Jordan Musetta -- Lambert
Ecology North -- Dawn Tremblay
Environment and Climate Change Canada (ECCC) – Chris Spence, Chris Derksen, Joe Melton
GNWT – Department of Health and Social Services -- Allan Torng, Emma Pike
GNWT – ENR -- Brian Sieben, On the Land Unit -- Jennifer Fresque- Baxter
GNWT – Environment and Natural Resources (ENR) -- Andrew Applejohn
GWNT – Fire Management – Rick Olsen
GNWT – Geological Survey -- Steve Kokelj, Brian Sieban
Government of the Northwest Territories (GNWT) -- Anna Coles, Michael Palmer, Lorraine Brekke, Bruce Hanna
Health Canada Environmental Health Science and Research Bureau, and Co-Chair of Human Health Assessment Group, Arctic Monitoring and Assessment Program -- Cheryl Khoury
Health Canada, Existing Substances Risk Assessment Bureau -- Kristin Macey
Joint Secretariat, Inuvialuit Settlement Region – Kirt Ruben

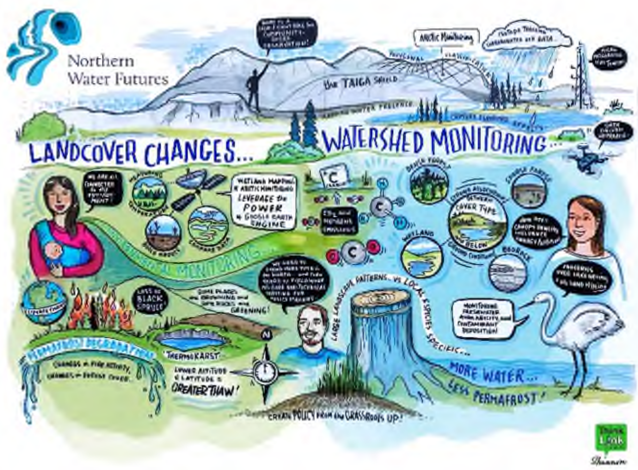



Highly Qualified Personnel: Professional training and research positions funded by Northern Water Futures

Inuvialuit Fisheries Joint Management Committee -- Herb Nakimayak
Inuvik Community Corporation – Gordon Trent, Camellia Gray
Ka'a'gee Tu First Nation, NT -- Chief Lloyd Chicot
Łíídlįį Kų́ę́ First Nation– William Alger
Natural Resources Canada Pacific Forestry Centre – Eliot McIntire
Northern Arizona University – Michelle Mack, Xanthe Walker
Northumbria University -- Nick Rutter
NWT Power Corp -- Matthew Miller
Parks Canada -- Paul Zorn (and Sophie Fillion, Queenie Gray, Rhona Kindopp, Lori Parker)
Sahtú Renewable Resources Board -- Leon Andrew, Alyssa Bougie, Catarina Owen
Salt River First Nation – Elizabeth Westwell
Smithsonian Forest Global Earth Observatory – Stuart Davies
Solinst Canada -- Jim Pianosi
Tlicho Government -- Tyanna Steinwand, Michael Birlea
Tsá Tué Biosphere Reserve – Gina Bayha
Université Laval – Steven G. Cummings
University of Guelph -- Ben DeVries
University of Waterloo -- Mario Coniglio, Bob Lemieux (Dean of Science), Richard Kelly, Richard Elgood
Wek'èezhìi Land and Water Board -- Shawne Kokelj; Ryan Fequet
Wekweeti (Community) – Judas Roy, Adeline Football (Chief)
Wilfrid Laurier University -- Derek Gray, Jason Venkiteswaran, Rod Melnik
Xcalibur Multiphysics -- Darren Burrows, Adam Smiarowski
Yukon University – Jill Johnstone

## Science Advances

Northwestern Canada is one of the most rapidly warming regions on Earth and is particularly sensitive to climate warming. Resources exploration and production in NWT is expected to expand dramatically in the coming years, which will include construction of new highways, pipelines and other infrastructure that will put stresses on water resources. This project has sought to expand the capacity for research and monitoring in the NWT and improve understanding of the long-term sustainability of water resources and predicting future changes in the health of streams, rivers, and lakes, including key waterways used for hydropower, water supplies and transportation.





Selected themes and initiatives across NWF projects

In the past year, the dedicated NWF researchers have made significant scientific contributions, driving understanding of northern water systems and addressing pressing challenges.

Annual frost probing campaign to measure frost and thaw depth in the soil at a 2014 burn scar near Kakisa. Photo courtesy of Ana

**Permafrost Thaw Impacts on Northern Forests**: NWF researchers made significant discoveries regarding permafrost thaw and its effects. They found that while initial permafrost thaw boosts ecosystem productivity, this effect is short-lived. In Baker Creek, NWT, they observed an increase in forest cover and net permafrost aggradation, implying different landcovers can affect basin water balances. The researchers also investigated the aftermath of the 2014 fires, revealing accelerated post-fire thaw and changes in soil processes that could impact water quality downstream. Additionally, they contributed to the NWT Thermokarst Collective (Northwest Territories Thermokarst Mapping Collective | Northwest Territories Geological Survey (nwtgeoscience.ca)), assessing the vulnerability of these landscapes to ongoing warming and thaw.

**Quantifying Arctic and Boreal Changes**: Teams developed techniques to quantify changes in the Arctic and Boreal regions. Using satellite data, they created high-resolution inventories of wetlands and thermokarst surface expressions, and are working on new approaches to estimate soil moisture, providing valuable insights into future changes in these ecosystems.Using micrometeorological towers, other NWF researchers continuously measured carbon, water, and energy exchanges, highlighting the link between thaw-induced forest loss, wetland expansion, and methane emissions.

Understanding Changes in Northern Watersheds: NWF researchers are studying how climate change is affecting Arctic watersheds, including the resulting changes in vegetation, permafrost, and lake drainage. Teams collected high-quality datasets in the Trail Valley Creek watershed, NWT, and tested a high-resolution physics-based model to improve predictions. This work lays the groundwork for evaluating the GWF Next Generation Model, the Canadian Hydrological Model, in the Arctic.

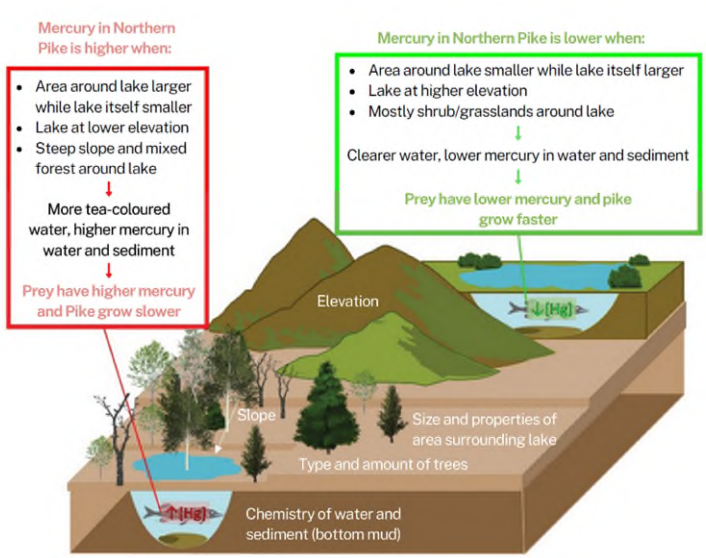
Field sampling benthic macroinvertebrates in a stream impacted by permafrost thaw, Peel Plateau, NWT. Photo by Maria Dolan.

Insights into Northern Alberta Freshwater Landscapes: Research in northern Alberta freshwater landscapes is focused on developing an aquatic ecosystem monitoring program in the Peace-Athabasca Delta and understanding the vulnerability of ponds used by the Aransas-Wood Buffalo whooping cranes to climatechange. This work provides a data-rich foundation for addressing concerns of declining freshwater availability and contaminant deposition from oil sands development. The monitoring program's methods are transferable to other freshwater landscapes subject to multiple stressors.

Improving Drought Predictions Models: The water balance in the Snare River system, NWT was analyzed to enhance the ability to predict drought conditions using hydrological models. This research contributes to better water resource management and planning in the region, as the river system is used for power generation for Yellowknife and other nearby communities.

Road Development and Ecosystem Health: A stream biomonitoring program was established along the Inuvik-Tuktoyaktuk Highway, NWT to study the effects of road development on ecosystem health in sub-Arctic and Arctic streams. The results will provide Inuvialuit decision-makers with tools to better assess and manage water and environmental risks both associated with roadway development and other future freshwater environmental concerns.

Mercury Levels in Fish and Food Security: Researchers conducted a study on mercury levels in fish from different lakes in the Dehcho region of the NWT to address concerns of mercury contamination and its effects on food security and cultural well-being. The study found that mercury levels in Lake Whitefish were generally low across all the lakes sampled, while levels in Walleye and Northern Pike varied considerably. Differences in Northern Pike mercury levels were best explained by variations in growth rates and the amount of mercury at the base of the food chain, influenced by factors such as lake water colour, sediment, surrounding land type, and vegetation. More information available at: *Fish Mercury Studies in the Dehcho*: **Fish Mercury Studies in the Dehcho: 2013-2022 - Google Slides** 2013-2022.




Variations in mercury levels in Northern Pike, using results from the analysis of scientific samples collected from Dehcho lakes and satellite imagery. Figure courtesy of Heidi Swanson.

Associations between Exposure and Biomarkers: Studies in Old Crow, Yukon, and the Dehcho and Sahtu regions of the NWT focused on possible associations between individual exposure determinants (e.g., drinking untreated river water, consuming large animal kidneys or whitefish, smoking, etc.) and key biomarkers such as lead, manganese, cobalt, and Hexachlorobenzene. This research contributes to understanding and mitigating environmental health risks in northern communities.

Climate Change Adaptation and Food Security: Efforts were made to promote sustainable agriculture and knowledge exchange, addressing climate change adaptation and food security. These initiatives contribute to the development of resilient and sustainable food systems.

[Link to Publications List](#)

## Knowledge Mobilization (KM)

Northern Water Futures researchers conducted knowledge mobilization and outreach activities to share their research findings with a broader community and achieve the research impact goals of the project. Some of these activities included:

- Contributing to two on-the-land knowledge sharing events through funding and planning support as well as involvement of NWF participants.
- On-the-land bush camps with Indigenous guardians, cooks, cook helpers, and camp helpers in Fort Simpson, Wrigley, and Jean Marie River in the summer of 2022
- Conducting knowledge mobilization activities within the community of Fort Smith, NWT, which included leading hands-on science and sports activities with grades 4-6 at Thebacha campground culture camp.
- Holding Under the Land: Going on the Land to Learn about Groundwater series of workshops and community meetings.
- Contributing to community events focused on community gardening, in partnership with Ka'a'gee Tu First Nation
- Providing advisory support for the Smithsonian Institute Boreal Forest and Climate Change travelling exhibit
- Collaborating with artists Rhian Brynjolson, Megan Leung and Louise Arnal for a GWF initiative on the Virtual Water Gallery
- Conducting a Canadian Aquatic Biomonitoring Network (CABIN) Field Certification Program, which led to 8 new CABIN certified Inuvialuit monitors and collaborators.
- Publishing 'In My Experience, The Nature of Groundwater Discharge' that includes a specific explanation of the value of Traditional Knowledge in groundwater understanding.
- Developing and distributing parasite guides (i.e., A Guide to Common Parasites of Food Fish Species in the Northwest Territories and Nunavut) and books/posters that summarize mercury projects to communities during in-person meetings held in the Dehcho region.
- Creating a photobook with stories of 10 years of mercury research in Dehcho Region, included an overview of how the projects got started, the types of samples collected, and where these samples have been collected.
- Researchers from NWF have been supporting the development of community-based monitoring efforts along the Tlicho all-season road in collaboration with the Tłı̨chǫ Government.
- Hosting of Dehcho AAROM (Aboriginal Aquatic Resources and Oceans Management) coordinator (Mike Low) and one Indigenous Guardian (William Alger) in Waterloo, ON in November 2022 to receive capacity-building training on laboratory techniques.
- Provision of training to Parks Canada staff and engagement of two local Indigenous members in field sampling methods during the 2022 field season in the Whooping Crane Nesting Region.
- Preparing technical reports for Wood Buffalo National Park and contributing to the Aurora Institute newsletter

Citizen Science

• Harvester Safety App build for Ka'a'gee Tu First Nation (Spring).

• Science booth at Inuvik Saturday Market, June 18, 2022 (Tutton).

• Stream biomonitoring along the Inuvik-Tuktoyaktuk Highway (Fall 2023) - Inuvialuit led field campaign

• On-the-land camps in Kakisa, Fort Simpson, Wrigley, and Jean Marie River, and the Dehcho Youth Ecology camp

Access of tools by users

• Access of data by Government of Northwest Territories and Edezhie Management Board (Swanson).

• Canadian Aquatic D toolkits (Summer 2022) - donated to Joint Secretariat - Community Based Monitoring Programs, Imaryuk Monitors.

Meetings with governments, decision makers, practitioners; policy makers

• Meetings with GNWT monthly (CIMP program). Meetings with deputy Minister of Environment and Natural Resources in February 2023.

• Meeting with lead technical advisor of Edezhie Management Board in September 2022.

• Meetings with Délı̨nę Got'ı̨nę Government: June 27-30, 2022; October 27, 2022; November 18, 2022; December 16, 2022; January 13,2022; February 13, 2022; March 20, 2022.

• Meetings with GNWT Department of Environment and Natural Resources, Climate Change and Air Quality Unit (n Yellowknife: July, September, October, November 2022; January 2023).

• Meeting with Katlodeeche First Nation Environmental Program Coordinator, July 7, 2022.

• Meeting with Norman Wells Economic Development Officer, July 28, 2022.

• Meeting with GNWT Department of Health and Social Services Climate Change Coordinator, October 14, 2022.

• Meeting with Jason Collard, Gonezu Energy Inc., January 12, 2023.

• Meeting with Craig Scott, Climate Hub, January 13, 2022.

• Meetings with community leadership in Enterprise, Kakisa, Sambaa K'e, Jean Marie River and Wekweètì during community visits.

• Meeting with Chief Adeline Football & Lisa Judas, Tlicho Government, January 20, 2023.

• Meeting with Hotıì ts'eeda, March 7, 2023.

• Stakeholder meeting presentation by Neary, L., Remmer, C., Owca, T., Savage, C., Kay, M., Hall, R. and Wolfe, B. 2022. A framework for monitoring hydrology, water quality and contaminant deposition in lakes across the Peace-Athabasca Delta. A presentation for BC Hydro and Scientific Advisors, Vancouver, British Columbia, Canada.

• Meeting with the Tetlit Gwich'in Renewable Resource Council. Presented research plans and goals for 2022 to foster discussion about topics related to biological stream health in permafrost thaw impacted river systems. Discussion related to addressing questions an concerns from community members about the project's research plan, incorporating any additional questions from the community into the research, and planning programs relating to stream health that would provide educational and outreach opportunities to Fort McPherson.

• Presentation prepared for Government of the Northwest Territories Department of Health and Social Services on: Hair to blood mercury concentration ratios and a retrospective hair segmental mercury analysis in the Northwest Territories, Canada.

• Youth Engagement Workshop, designed for the Government of the Northwest Territories, October 2022 (Woodworth).

• Meeting with Ka'a'gee'Tu First Nation Chief and Council & Dehcho AAROM– Discussing and planning Arctic grayling study on the Kakisa River.

Articles in popular media

• Roy interview in the NéoUQTR journal. Forêt boréale: comment les arbres gèrent-ils leur consommation d'eau?

Interviews (broadcast or text)

• Belke Brea interview for the documentary called "Borderlands" about climate change, the shifting tree line in Cana-da's Arctic and the impact on wildlife. The show was produced in French for UnisTV by Nature 360 Productions. Inter-view took place during field work in theNWT in June 2022.

• Lyons interview for Laurier Research Chat Podcast: Fire and Ice: How permafrost thaw and wildfire is impacting the boreal forest in the Northwest Territories

• September 11, 2022: At current rate, 5 key climate tipping points are already possible, new study warns. https://www.cbc.ca/news/science/tipping-point-climate-change-paris-agreement-1.6577630

• September 11, 2022: L'Arctique aux prises avec des eÌclairs. Radio-Canada featured Baltzer's work on zombie fires. https://ici.radio-canada.ca/sujet/changements-climatiques/actualites/document/nouvelles/article/1912614/arctique-eclairs-orage-zombie-fire

• September 9, 2022: Baltzer's research on "zombie fires" was featured on CBC's Quirks and Quarks. https://www.cbc.ca/radio/quirks/sep-10-our-summer-in-the-field-special-1.6577787

• August 11, 2022: What are zombie fires? And what do they mean for the North? Live interview on CBC Trailbreaker. https://www.cbc.ca/listen/live-radio/1-129-the-trailbreaker/clip/15930274-what-zombie-fires-mean-north

• August 9, 2022: What is a 'zombie fire'? Experts describe the cause and concern. CTV News and picked up by multiple other news outlets in Canada and the US. https://www.ctvnews.ca/climate-and-environment/what-is-a-zombie-fire-experts-describe-the-cause-and-concerns-1.6018530

• August 3, 2022: Baltzer's research on "zombie fires" featured in over 60 news outlets across Canada and the US including CBC: "Research team collecting first field data on zombie fires in NWT. https://www.cbc.ca/news/canada/north/zombie-fire-research-nwt-1.6539836

• June 8, 2022: New research chair to study climate change effects on NWT forests. https://cabinradio.ca/95930/news/environment/new- research-chair-to-study-climate-change-effects-on-nwt-forests

• April 19, 2022: Forests are reeling from climatechange – but the future isn't lost. Baltzer's work highlighted in National Geographic.

Public workshops and presentations

• Instructor of the Dendroecology group in the North American Dendroecological Field week (NADEF), June 2022 (Alfaro Sanchez).

• Host & Lecturer, Local capacity-building for climatechange monitoring, Yellowknife (Sonnentag).

• Host & Lecturer, Drone and weather station training workshop, Inuvik, NT, Course (Sonnentag).

• Under the Land: Going on the Land to Learn about Groundwater. Series of workshops and community meetings; Yukon, July 2022

• Field site visits in and around Dawson City with Tr'ondëk Hwëch'in First Nation staff Alex Pysklywec and Karlie Knight, 21 July 2022

• Yukon Government Tombstone Water Weekend, July 2022 (McKenzie, Rudolph, Wiebe, Parker, Mulligan).

• Little Salmon / Carmacks First Nation camp – water and groundwater activities for youth/children, July 2022.

• Field site visits in and around Carmacks with Little Salmon / Carmacks First Nation staff Heather Bellmore and Becky Freeman; met with community members, Chief Nicole Thom, and Elders over lunch, July 2022.

• Met with Elders from the community to discuss water, groundwater, and climate change at the Whatì Cultural Centre; tours of water treatment plant, Environment and Climate Change Canada weather station, sites of cultural significance on islands in Lac La Martre, August 2022

• Organized and Co-facilitated Sahtuǐ Ǩaowe Guardians Annual Strategic Planning Workshop, Délı̨neخ, NWT, January 30-31, 2023

• Organized and co-facilitated Tsá Tué Biosphere Reserve Research & Monitoring Workshop, Délı̨neخ, NWT, February 2, 2023.

• Organized and presented to Tsá Tué Biosphere Reserve Council: November 15, 2022; January 25, 2023; February 22, 2023.

• Presented to Délı̨neخ Got'ı̨nę Government, DKK Members and IPCA Steering Committee, Yellowknife, January 19-20, 2023.

• Presented to Délı̨neخ ?ek'oneخ Kə Council, Délı̨neخ, NWT: June 30, 2022; November 23, 2022; January 31, 2022 (Die-trich).

• Public presentation as part of the Institute for Circumpolar Health Research Lunch & Learn Series, July 26, 2022.

• Presentation to GNWT Food Security Working Group, November 3, 2022.

• Presentation to GNWT ENR Climate Change and Air Quality Unit with Andrew Spring and Alex Latta, March 6, 2023.

• Community presentation Wekweètì, January 19, 2023.

• Facilitated breakout table about Laurier health and food security research at the NWT Association of Communities 2022 AGM, September 2022.

• Ostertag S., Wesche S., Kenny TA., Ramirez Prieto M., Slack C. Food Security Community Presentation (Country Foods for Good Health) in Tuktoyaktuk, NT, February 19, 2023.

• Ethical conduct when working with Indigenous communities: Case Study of an Engaged Research Process. Guest Lecture, HLTH 380: Applied Public Health Ethics. School of Public Health Sciences, University of Waterloo, January 31, 2023.

• Cook Book Sharing Circle. Facilitator. Moose Kerr School, Aklavik, NT. June 6, 2022.

• Exploring Inuvialuit youths' views and perspectives on the country food system. Northern Food Systems Student Symposium. University of Laurier. May 25, 2022.

• World Water Day 2022 across-Canada panel discussion of the importance of groundwater from a national perspective with an emphasis on northern groundwater.

• Inuvialuit Game Council Workshop, December 2022.

• Composting and greenhouse initiatives in Ka'a'gee Tu First Nation, NWT" [1 day workshop within the community of Kakisa]

• Photo Exhibit, Fort Simpson, NT, March 7, 2023 (Woodworth).

Promotional videos

• Stream Biomonitoring along the Inuvik-Tuktoyaktuk Highway (an overview video of CIMP210), March 2023.

• YouTube Video: Arctic Hydrology Research Group 2022 highlight reel. (https://www.youtube.com/watch?v=7okDocWKKhA)

Other

• Two representatives from Dehcho First Nations received training in a UWaterloo lab in: fish ageing, mercury analysis, and fish pathology.

• 13 Guardians and community members from Pehdzeh Ki First Nation, Łíídlı̨ı̨ Kų́ę́ First Nation and Jean Marie River First Nation participated in on-the-land camps that built capacity in collection of fish, water, sediment, zooplankton, and benthic invertebrate samples. Training also involved fish dissection and identification of benthic invertebrates.

• Hosted Laurier booth at the NWT Association of Communities 2022 AGM, September 16-18, 2022.

• Hosted Laurier booth at the NWT Agrifood Conference, February 23-24, 2023.

• Museum Exhibition: Participation in the exhibit "Religieuses, enseignantes et… scientifiques!" at the Site historique Marguerite-Bourgeoys, Montreal, Quebec, Canada

# Professional Development and Technology Transfer

Short-courses open to Professionals

• 3 Minute thesis training & presentation in Fall, 2022 (attended by Gyapay & O'Brien).

Special Seminars

• Southern Alberta Institute of Technology private seminar: Measuring snow and SWE in March 2023 (attended by Walker).

Workshops

• 2023 Canadian SMAP science workshop, Canadian Space Agency, March 16th-17th (attended by Roy).

• Advanced Wilderness First Aid course (attended by Brockett, Fogal, Hould Gosselin, Nikel, Seto, & Walker).

• North American and Indigenous Studies Association workshops, June 22-25, Yellowknife (attended by Gyapay).

• Scientific Writing Workshop – Wilfrid Laurier University ASPIRE (attended by Snook & O'Brien).

• Searching for Scholarly Articles Workshop – Wilfrid Laurier University APIRE – May 31, 2022 (attended by Snook).

• Career Development Workshop– Wilfrid Laurier University, CV writing and advertising transferrable skills to employers (attended by

Chanyi).

International Exchanges

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• Research internship in Columbus, Ohio. Modelling tree hydraulic responses in boreal forest with FETCH3 in the Civil Engineering

department at Ohio State University, with Professor Gil Bohrer and research group, Fall, 2022 (completed by Roy).Cross-institutional placements or internships

• Three month long stay at the GNWT Centre for Geomatics in Yellowknife to collaboratively work on a lichen mapping project for the Northwest Territories, May-July 2022 (completed by Belke Brea).

• Collaboration with the ABoVE Science community through: i) contribution in planning the ABoVE airborne campaigns in NWT, ii)participation in two ABoVE science meetings, and iii) participation in two working groups, i.e. the Spectral Imaging Working Group and the Vegetation Dynamics working group (completed by Belke Brea).

• Internship at Ouranos in Montreal, Summer 2022, working on the uncertainty around the snowmelt algorithm in hydrological models (completed by Graveline).

User training or tech transfer opportunities

• Advanced Drone Operators workshop, September 2022 in Inuvik, NWT (attended by Walker).

• LI-COR Environmental Education Fund (LEEF) training. A 5-day training course in Lincoln, Nebraska, USA to learn how to make photosynthesis measurements using the LI-COR 6800 (attended by Lyons).

Others

• Canadian Water Summit: Downstream Networking Event. Allowed students and early career professionals to learn from water industry professionals through a series of seven 15-minute round table discussions about the future of Canada's waters.

## Water Knowledge Camps: Building Capacity for Cross-Cultural Water Knowledge, Research, and Environmental Monitoring

Web Link: https://northernwaterfutures.wordpress.com/water-knowledge-camps-2/

Region: Northern Region

Total GWF funding support: $330,000

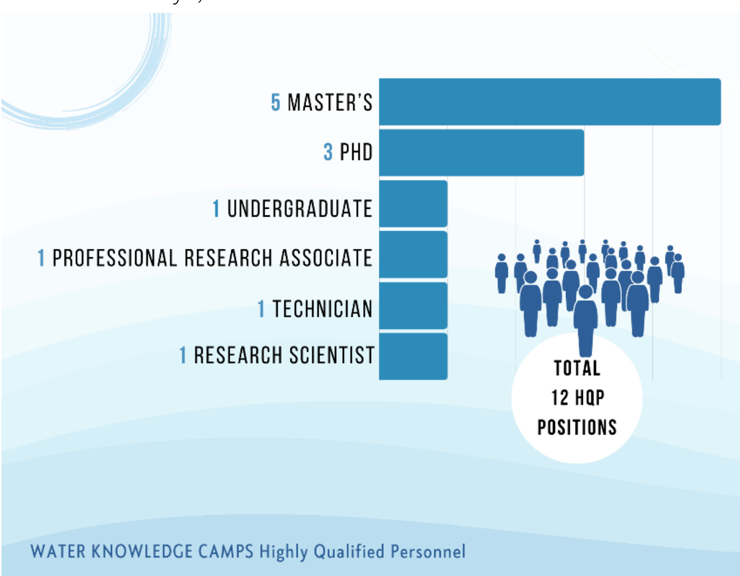
Project dates: December 2018-November 2021 EXTENDED to August 2024

### Investigators

Jennifer Baltzer, Wilfrid Laurier University Contact: jbaltzer@wlu.ca
Leon Andrew, ʔehdzo Got'ı̨nę Gots'ę́ Nákedı -Sahtú Renewable Resources Board
Gina Bayha, Tsá Tué Biosphere Reserve Council
Derek Gray, Wilfrid Laurier University
Harry Harris, Good Hope Renewable Resource Council
Brian Laird, University of Waterloo
Rhea McDonald, Norman Wells Renewable Resources Council
David Rudolph, University of Waterloo
Deborah Simmons, ʔehdzo Got'ı̨nę Gots'ę́ Nákedı -Sahtú Renewable Resources Board
Kelly Skinner, University of Waterloo
Andrew Spring, Wilfrid Laurier University
Gordon Yakeleya, Tulita Renewable Resource Council

### Partners, Collaborators, and Users

Fort Good Hope, Tulita and Norman Wells Renewable Resources Councils
Nę K'ə Dene Ts'ı̨lı̨ Forum
On the Land Unit, Environment and Natural Resources, Government of the NWT
University of Waterloo
Wilfrid Laurier University
ʔehdzo Got'ı̨nę Gots'ę́ Nákedı




Highly Qualified Personnel: Professional training and research positions funded by Water Knowledge Camps

### Science Advances

Communities throughout the Sahtú have expressed concerns about the cumulative impacts of development and climate change on the quality and quantity of the waters in the region and consequent risks to human and ecosystem health. As a result, many have stopped drinking from local water sources, preferring to purchase drinking water imported from elsewhere, and questions about water quality and ecosystem health are common as livelihoods in the Sahtú are closely linked to their land and waters. Researchers, partners, and community members want to better integrate current and planned research initiatives, identify research and capacity needs, and support new and innovative research to address these concerns in the Sahtú. The Water Knowledge Camps work is a step towards the goals of building stronger partnerships through enhanced dialog and understanding among researchers and communities and is helping to build comprehensive environmental monitoring programs. These camps involve shared on-the-land experiences with researchers and community members. The project initiated a thematic analysis of data collected at the 2019 Water Knowledge Camp in Sahtú Də́ (Great Bear River) at Tek'áícho Də́ (Marten River) Tulít'a, NT. Advancements include reviewing transcribed interviews and focus groups to identify key concepts.

Learning on the land

Link to Publications List

## Knowledge Mobilization (KM)

An introductory meeting was held with stakeholders in the community of Fort Good Hope, Sahtú Renewable Resources Board, and UW and WLU researchers to discuss opportunities for on-the-land initiatives and establish community driven questions for the next Water Knowledge Camp. This has been again postponed to 2023 due to COVID-related concerns in the community; it is also noteworthy that the location for the next Water Knowledge Camp, Fort Good Hope experienced a state of emergency due to flooding during break-up in Spring 2021 and similar flooding is anticipated in the imminent 2022 break-up, which may shape questions for the 2022 Water Knowledge Camp planned for the summer of 2023.

# Sub-Arctic Metal Mobility Study (SAMMS)

Web Link: https://www.wlu.ca/academics/research/partnerships/gnwt/global-water-futures/metal-mobility.html

Region: Northern Region

Total GWF funding support: $500,000

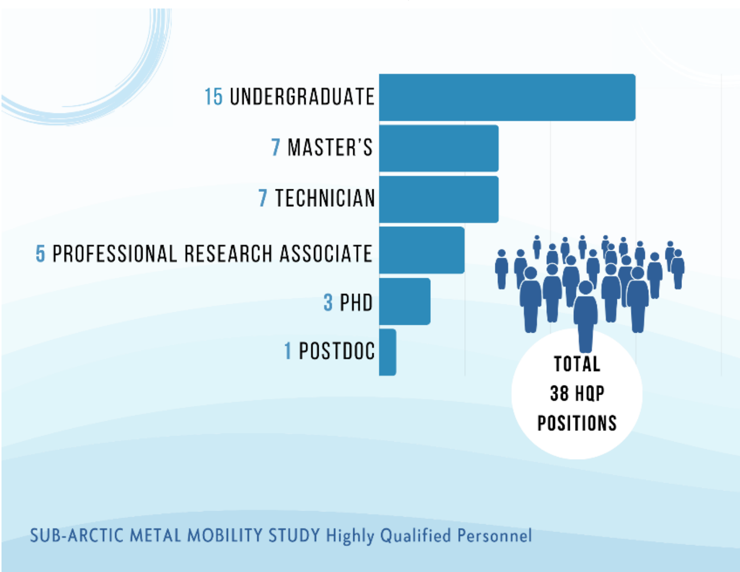
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Brent Wolfe, Wilfrid Laurier University Contact: bwolfe@wlu.ca
Jason Venkiteswaran, Wilfrid Laurier University
Michael English, Wilfrid Laurier University
Roland Hall, University of Waterloo
James McGeer, Wilfrid Laurier University
Sherry Schiff, University of Waterloo
Scott Smith, Wilfrid Laurier University
Kevin Stevens, Wilfrid Laurier University
Colin Whitfield, University of Saskatchewan
Jules Blais, University of Ottawa
Raoul-Marie Couture, Laval University

## Partners, Collaborators, and Users

Environment and Climate Change Canada -- Chris Spence
Environment and Natural Resources, Government of Northwest Territories -- Melanie Williams
Giant Mine Oversight Board -- Kathy Racher
GWF: Sensors and Sensing Systems for Water Quality Monitoring -- Scott Smith
North Slave Métis Alliance -- Nicole Goodman
Swedish University of Agricultural Sciences – Martyn Futter
Tłı̨chǫ Government -- Jessica Hum
Wek’èezhìi Land and Water Board -- Ryan Fequet
Yellowknives Dene First Nation -- Alex Power




## Science Advances

The Northwest Territories (NWT) is rich in minerals including gold and uranium. As a result, many mines, active and abandoned, dot the landscape, leaving a legacy of metal pollution. Using field, laboratory and modelling studies, this project aimed to understand how legacy pollutants from mining activity move through the landscape, with potential negative effects on drinking water and aquatic organisms. The researchers traced the transport and behaviour of dissolved organic matter and metals through terrestrial and aquatic ecosystems along a 200-kilometre stretch between the former Giant Mine site and Whatì, an area of concentrated mining activity. This work should help inform decision-making by governments and Indigenous communities about the legacies of mining activities and the implications of new mining developments on water quality in a changing environment.

Terrestrial Stores of Historical Metal Deposition and Transport to Aquatic Ecosystems: Surface water and sediment arsenic and antimony varied greatly among five sites studied. Spatial analysis was used to quantify the role of landscape characteristics (slope and structure) in explaining these variances. Findings were that dissolved and solid phase concentrations of legacy metal/metalloid pollutants such as arsenic and antimony are higher in peatlands than lakes, and that bedrock ravines may accumulate legacy metals/metalloids from the surrounding catchment area until they can be flushed by a sufficient quantity of precipitation and flow. Relatively large rain events in the late summer or fall can facilitate the export of these pollutants from bedrock ravines into lakes.

Dissolved Organic Carbon Quantity and Quality, Metal Binding, and Toxicology: Exploring the behaviour of the Baker Creek catchment over a relatively short but variable period consisting of wet and dry years provided a foundation to explore how this system could change in response to future hydroclimate. In Baker Creek, modelling suggested that future increases in temperature can positively affect terrestrial productivity, but that microbial activities, water residence time, and catchment connectivity have complementary roles governing dissolved organic carbon (DOC) export. It was predicted that DOC export will decrease under a warmer climate where water residence times increase, but increase if the climate warms and gets wetter, enhancing flow through shallow organic layers and lowering residence time of surface water in the stream network. Notably, simulations under the elevated temperature and precipitation scenario demonstrate increased winter discharge and carbon export associated with a shift in hydrological regime from snow to combined snow and rain. These changes to DOC export could be linked to metal mobility in the catchment.

Metal Depositional History, Pathways, and Processes in Lake Sediments: Researchers analyzed metals in sediment cores to track dispersal of legacy mine emissions. Enrichment of arsenic and antimony were evident beyond the known 30-km radius pollution zone. Distance from source and wind direction influenced contaminant dispersal. Modelling reconstructed the history of arsenic deposition to lake sediments in eight lakes along an 80-km transect from Giant Mine in Yellowknife. Calculation of deposition fluxes reveals anthropogenic arsenic peaks coinciding with the start of the period of high emissions from the mines. In addition, high present-day arsenic fluxes continue in several systems likely in dissolved form. Lakes with lower sedimentation rates allow longer residence of deposited arsenic.

## Link to Publications List

# Knowledge Mobilization (KM)

Meetings with governments, decision makers, practitioners: Smith and McGeer held annual meetings with Environment and Climate Change Canada (ECCC). The meetings included ECCC staff as well as academic partners from Laurier, Montreal, Quebec, Lethbridge and Guelph. These meetings were held regularly between the government and this group of researchers since the NSERC-sponsored Metals in the Environment Research Network (MITE-RN) starting in 1999. The meetings included student presentations and discussion with other academic partners as well as ECCC staff. Meetings were usually in-person in Ottawa (Gatineau) but during the Covid pandemic they were held online.

### Citizen Science

Shad water talk. Scott Smith. July 7, 2021. Shad is a month-long program for grade 10 & 11s, pan-Canadian classrooms with university level STEAM and entrepreneurship content and access to mentors.

# Boreal Water Futures

Web Link: Boreal Water Futures: Modelling Hydrological Processes for Wildfire and Carbon Management - Global Water Futures - University of Saskatchewan (usask.ca)https://gwf.usask.ca/projects-facilities/all-projects/i1-schusterwallace.php - Investigators

Region: Northern Region

Total GWF funding support: $1,582,500; $200,000

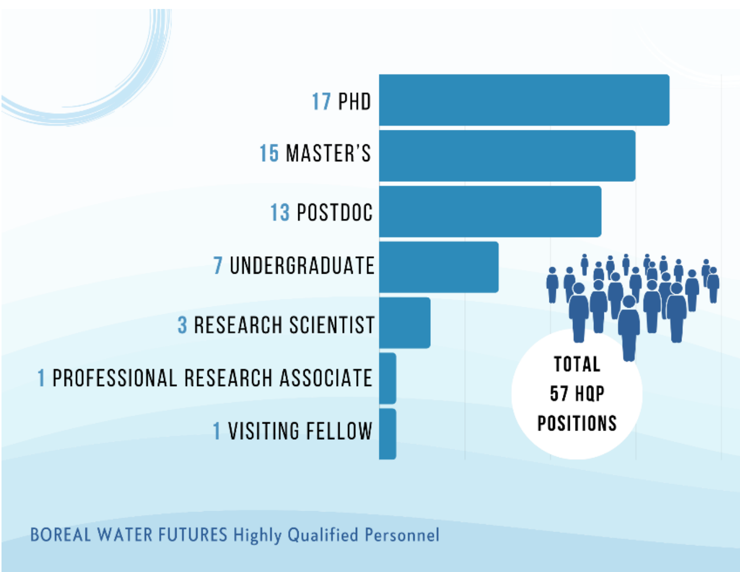
Project dates: June 2017-July 2023 EXTENDED to August 2024

## Investigators

Mike Waddington, McMaster University Contact: jmw@mcmaster.ca
Maria Strack, University of Waterloo
Mike Wotton, University of Toronto
Mike Flannigan, Thompson Rivers University

## Partners, Collaborators, and Users

Alberta Agriculture and Forestry
Canadian Forest Service -- Dan Thompson
Canadian Sphagnum Peat Moss Association -- Asha Hingorani
Ducks Unlimited -- Kristyn Mayner
Environment and Climate Change Canada -- Kelly Bona
FireSmart -- Ray Ault
Global Peatlands Initiative -- Dianna Kopansky
Institute for Catastrophic Loss Reduction -- Glenn McGillivary
Magnetawan First Nation -- Alanna Smolarz
Shawanaga First Nation -- Steven Kell




Highly Qualified Personnel: Professional training and research positions funded by Boreal Water Futures

# Science Advances

Canada's boreal biome, a critically important global freshwater resource and carbon reserve, is undergoing transformative change that is having profound impacts on boreal ecosystem function, source water protection, and wildfire behaviour and management. Natural resources development is expanding the density of wildland-society interfaces (WSI) at the same time as boreal wildfire intensification is placing ever increasing threats and risks on human health and safety, water quality, and global climate regulation. This project responds to the need to incorporate hydrological thresholds and pair the maintenance of ecohydrological services with wildfire management, providing a prediction tool for government agencies, NGOs, and industry. Critical to this research is the modelling of cold regions hydrological processes in black spruce wetlands with thick organic soils.

Through evaluation of a novel dataset that utilizes high-resolution ecosystem mapping from partner Ducks Unlimited the project team delineated emerging fuels of concern on the boreal landscape, namely black spruce treed peatlands. By incorporating expert-opinion and the most current research, we conducted an initial assessment of smouldering fire risk. This methodology was applied in the Boreal Plains (BP) ecozone of Alberta and evaluated with respect to the wildland-urban interface where there is greater exposure to the adverse effects of wildfire such as property damage, smoke pollution, and human health impacts. The team published a peat fire hazard map in a paper about this research and have started to investigate the potential of using this approach for other peatland-dominated regions across Canada, working with collaborators (e.g. Firesmart Alberta Wildfire, Ducks Unlimited) to incorporate this knowledge into local-regional fire management planning and operations. Building on the project's research at the Parry Sound 33 wildfire, the team has created wildfire refugia maps and linked these to ecohydrological controls of landscape moisture distribution (SAGA wetness index, Topographic Position Index) and ecohydrological controls (wetland class, peat depth).

The first round of model development and testing (Wotton and Wilkinson) integrating the Peatland Hydrological Impact model with development of a Peat Moisture Code (PMC) is complete. The PMC operates on a long (up to multi-year) timescale to account for potential multi-year water deficits in peatland moisture status and the long fuel time lag of peat, where the accounting of daily fire weather inputs can cumulatively push peatland fuels past pre-defined thresholds for different fire behaviours. Modelling of the potential for sustained, deep smouldering in peatlands has also begun. The model will soon incorporate (categorical) measures of peat bulk density. Burn severity at the Tomahawk drained peatland wildfire has been measured as a test for the model. Bulk density will be used a proxy for level of decomposition and specific yield, i.e., sensitivity of water table fluctuations (and also groundwater connectivity) to compare different peatlands types. An example of this utility was examined in a publication led by Patrick Deane where peat smouldering potential was compared following peat compression as a fuel treatment in collaboration with FireSmart. The team scaled this work with a meta-analysis of boreal and temperate peatland combustion and carbon exchange research to analyze the effect of wildfire and peatland degradation (drainage) on the northern peatland carbon sink.

A side project, with CSPMA as a stakeholder, was initiated during the 2021 lockdown to examine the management implications of peat extraction sites. McCarter et al. applied the project's hydrological model to investigate the ecohydrological trade-offs induced by multiple disturbances in peatlands. The study highlighted complex interactions multiple disturbances have on peatland ecohydrology and that we urgently need to understand these interactions to better manage peat resources and the large carbon source that peat fires can represent.

Taking advantage of the Tomahawk fire occurring adjacent to existing field sites in May 2021, a burned section of peatland was instrumented to monitor GHG exchange in August – September 2021, the months immediately following the fire. CO2 and CH4 exchange was monitored in the field at both the burned site and an unburned control area and cores collected for an incubation study on methane production and oxidation and role of charcoal. Results were compared with those from a similar study conducted on samples from the Parry Sound fire in 2020. Microbial community analysis was also conducted on samples from Parry Sound burned and unburned sites and data analysis is ongoing. Following fire in the Tomahawk bog, ground layer vegetation productivity ceased and ecosystem respiration increased resulting in greater CO2 emissions to the atmosphere. Methane emissions at the burned site were reduced compared to the unburned control, with small rate of CH4 consumption measured for most plots. This occurred despite a shallower water table position at the burned bog. This decrease is likely due to a reduction in microbial CH4 production as measured in peat samples from the burned site. Charcoal produced during the fire also appears to contribute to this reduction as removing charcoal from burned samples increased CH4 production, while additions of charcoal to unburned samples reduced production. In peat collected from a burned site near Parry Sound, Ontario, the effects of the fire on microbial $CH_4$ cycling were less pronounced, likely due to the lower severity of the fire.

To investigate how management actions affect peatland carbon stocks and uptake over short (several years) to longer (decades to centuries) timescales, disturbance matrices in the Canadian Model for Peatlands (CaMP) are being developed that integrate forest clearing, thinning, soil compaction and mulching. This work is in collaboration with Dr. Kelly Bona at ECCC. In addition to altering soil profiles of density and unsaturated layer thickness, this work has developed trajectories of changing moss cover depending on canopy cover. Initial CaMP model runs are ongoing and will be used to inform longer timescale model scenarios to investigate the interplay between the timing of the application of fuel management strategies and time return intervals.

Given field travel constraints during Covid a working group was formed to identify the minimum set of peatland types that should be tracked by moisture indices within the framework of the Canadian Forest Fire Danger Rating System (CFFDRS). This working group involved scientists from the Canadian Forest Service responsible for the development and implementation of new elements of the system in operational fire management across Canada (and internationally).

## Link to Publications List

## Knowledge Mobilization (KM)

Dr. Sophie Wilkinson and Mike Waddington wrote an article for *The Conversation*. The team continues to work with FireSmart, CILR, and Alberta Wildfire to develop fuel modification treatments appropriate for implementation at the wildland-human interface in the Boreal biome. The project was able to continue to operate a network of three eddy covariance towers and 10 micro-met towers (used in Boreal Water Futures 1) to examine water futures for boreal wetlands, where some instrumentation now covers recently burned areas of the Boreal Shield landscape. One tower is in collaboration with Magnetawan First Nation to monitor climate change. The results of this programme were presented at the Indigenous Knowledge and Species at Risk workshop in conjunction with Magnetawan First Nation at Science North in Sudbury on March 1, 2023, and to the Georgian Bay Biosphere Mnidoo Gamii and Henvey Inlet First Nation-led Ganawenim Meshkiki. A one-minute YouTube video developed with Magnetawan First Nation (MFN) summarizes Boreal Water Futures research for community members. Plans have started to upload these videos to a new web site that weaves Indigenous TEK and Western science (Home Page - Weaving Ways of Knowing for the Environment. (weavingknowledges.ca) ). Given the success of the partnership with MFN, the team has started a project with Shawanaga First Nation (SFN) to expand the water observatory onto their lands. MFN and SFN are now partners and supporters of the Nibi Observatory for Barren and Bog Ecohydrological Landscapes (NOBEL), established to better understand the ecohydrological and hydrometeorological controls on Canadian Shield wetlands and rock barrens ecosystem form and function. NOBEL is situated within the Georgian Bay Biosphere Mnidoo Gamii, a UNESCO biosphere, on traditional Anishinabek territory (Nibi is Anishinaabemowin for Water). NOBEL research takes an integrative water and ecosystem science approach to inform evidence-based boreal wetland conservation, restoration, and management. Two articles about Boreal Water Futures research were produced for the *2023 State of the Bay Report* (Georgian Bay), a publication sent to all residents and cottagers in the eastern Georgian Bay region.

In May 2021 a 2,000+ ha wildfire burned through the Tomahawk, Alberta region including several drained peatlands. The project received a request from Parkland Co. to assist, resulting in a new partnership allowing parameterization of the project's hydrological model in very dry peatland (using drainage as a control on moisture status). The fire also burned a portion of one of the CSPMA stakeholder's member companies and the team will communicate its results to the company through the CSPMA.

Maria Strack is a member of the Nature Based Climate Solutions Advisory Committee, providing expert advice to NRCan, ECCC and AAFC on delivery of the Natural Climate Solutions Fund: https://www.canada.ca/en/campaign/2-billion-trees/nature-based-climate-solutions-advisory-committee.html. She has also participated in the Climate Science 2050 Round tables on Earth System Science and Net-Zero Society, providing input on priorities for Canada's climate science needs. In 2022, Strack was selected as a coordinating lead author for the North American chapter of the Global Peatlands Assessment produced by UNEP. Working with a team of authors, she helped compile information on the state of peatlands in North America, including risks from climate change and changing fire regimes. This assessment provides an important baseline for policymakers when including peatlands in national to international environmental agreements.

While the Peat Moisture code implementation into the Canadian Fire Weather index system framework is still under development, the framework of the new FWI System and the role of the new peat moisture code (and potentially a peatland spread sustainability index) has been presented to operational fire managers as part of early outreach to Canadian fire management agencies about changes to the FWI System.  This early outreach activity is designed to get feedback from operational decision-makers (who will be using the new fire indicators in the FWI System) about the upcoming changes and additions to the system. Project researcher Wotton leads this outreach activity in Canada.

Meetings with governments, decision makers, practitioners

- Canada Wildfire 2022 Annual Meeting (Edmonton, AB), November, 2022.
- Canada Wildfire 2021 Fire Season Lessons Learned Meetings (March, 2022) with Canada Wildfire practitioners
- Parkland County Fire Safety. Meetings regarding overwintering smouldering fire.
- Peatland Ecology Research Group (including Canadian Sphagnum Peat Moss Association; Montreal, QC), February, 2023.

Articles in popular media

- Up in Smoke: Human activities are fuelling wildfires that burn essential carbon-sequestering peatlands (April 20, 2023, The Conversation, Wilkinson and Waddington)
- Peatlands post complex, poorly understood wildfire risk (May 18, 2021, Creative Commons, Eureka Alert, Science Daily). Interviews (broadcast or text)
- Tracking wildfire smoke will be crucial for everyone as the planet warms. Here's why. (CBC, August 22, 2022, Christy Climenhaga interview with Mike Flannigan)
- After subdued summer, Alberta should brace for more wildfires this fall, experts say (CBC, August 25, 2022, Wallis Snowden interview with Mike Flannigan)
- Scientists fear Ukraine war will worsen Siberian wildfires (Axios, April 22, 2022, Andrew Freeman interview with Mike Waddington and Sophie Wilkinson)
- To rate wildfire danger, Britain looks to Canada (CBC, April 22, 2022, Katie Nicholson interview with Mike Wotton)
- Canada's Peatlands are Tinderboxes that are more likely to ignite in a warming world (The Globe and Mail, September 16, 2020, Ivan Semeniuk interview with Mike Waddington and Sophie Wilkinson)
- Peatlands protect against wildfire and flooding, but they're still under attack in Canada (The Conversation, October 12, 2021, E. Struzik interview with Sophie Wilkinson and Mike Waddington)
- Peatlands can fight natural disasters and the climate crisis. Canada needs to stop taking them for granted (The Narwhal, October 18, 2021l E. Struzik interview with Sophie Wilkinson and Mike Waddington)
- Bringing back bogs. Researchers are working to find the best ways to help soggy ecosystems recover (Sierra Club, July 27, 2021, Chloe Williams interview with Sophie Wilkinson and Maria Strack)
- Why wetlands matter in the fight against the climate crisis (National Observer, July 16, 2021, Emma McIntosh interview with Maria Strack)
- Underground "zombie" peat fires release 100 times the carbon of wildfires (Wired Magazine, March 30, 2021, M. Simon interview with Sophie Wilkinson)
- Canada may see more 'zombie fires' as climate warms and winters shorten: experts (CTV News, June 5, 2021, interview with Mike Waddington)
- Blazes that refuse to die: Zombie Fires (New York Times, May 19, 2021, J. Schwartz interview with Mike Waddington)

# New Tools for Northern Groundwater Vulnerability Assessment

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1ph2-groundwater-vulnerability.php

Region: Northern Region

Total GWF funding support: $190,000

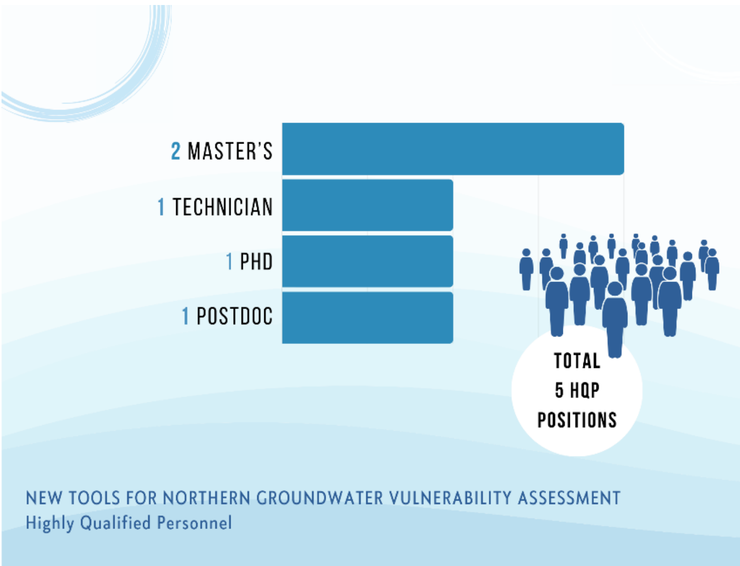
Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators

Jeffrey McKenzie, McGill University Contact: jeffrey.mckenzie@mcgill.ca
David Rudolph, Waterloo University

## Partners, Collaborators, and Users

NWT Government -- Isabelle de Grandpré
Yukon -- Brendan Mulligan




**Highly Qualified Personnel: Professional training and research positions funded by New Tools for Northern Groundwater Vulnerability Assessment**

## Science Advances

This project has worked with the Yukon and Northwest Territories (NWT) governments on co-create groundwater management and vulnerability assessment strategies specific to the challenges of the North.

In the Canadian north, a third of all residents rely exclusively on groundwater for their domestic water and water consumption is significantly higher than in the South (383 m3/day/person in the Yukon versus 184 m3/day/person in Ontario; Statistics Canada, 2020). Almost all Yukoners rely on groundwater for domestic water resources, while people in the NWT and Nunavut almost all rely on surface water, except for three small communities. A critical tool for groundwater management is groundwater vulnerability assessment. Groundwater vulnerability is an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts. While vulnerability assessment often focuses on human impacts, such as contamination, it can also include overextraction and external natural impacts such as climate change.

This project undertook four activities. (1) The first used a numerical model that couples groundwater flow with dynamic freezing of the subsurface and with solute transport. The model allowed examination of how the thawing of permafrost due to climatechange will accelerate the transport of contaminants, including potentially toxic solutes from thawing permafrost. (2) For the Little Salmon Carmacks First Nation, the Hydrogeosphere groundwater model (HGS) was used to examine how flooding of the Yukon River affects the capture zone of domestic and municipal drinking water wells. (3) Working with Yukon and NWT government partners, a program called *Under the Land* involved co-generation of knowledge around groundwater with Northern communities, including visits with three communities, Little Salmon Carmacks and Tr'ondëk Hwëch'in/Dawson City in the Yukon and Whatì in the Northwest Territories. (4) Based on findings from these first three activities, a web-based capture zone program was developed that allows rapid generation of a well's capture zone, with a focus on applications to Northern communities: https://ajwiebe77.shinyapps.io/the-yukon-well-vulnerability-calculator/.

The Global Water Futures (GWF) program mission is to address the question of, "How can we best forecast, prepare for and manage water futures in the face of dramatically increasing risks?" For Northern communities that rely on groundwater, groundwater vulnerability assessment is critical for managing future risks. This research has identified new and emerging challenges for future research in Northern groundwater management, such as the need to understand how climatechange and flooding affect vulnerability, and understanding the risks presented by the many contaminated sites in the north.

## Link to Publications List

## Knowledge Mobilization (KM)

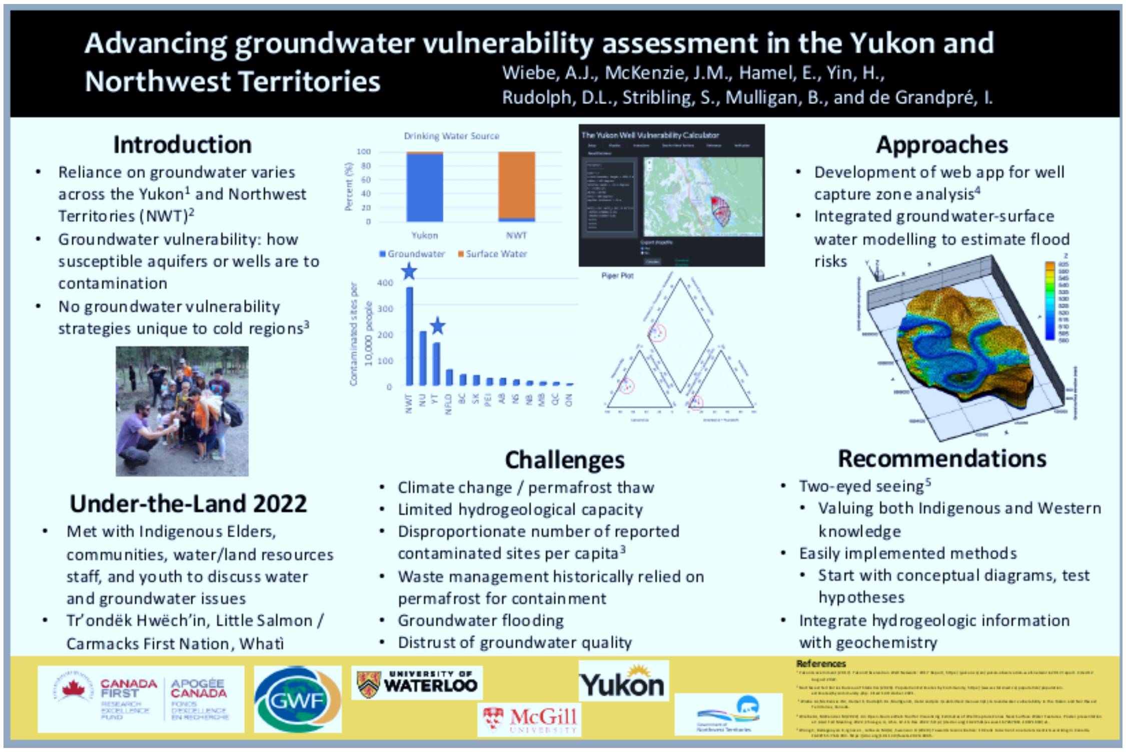
This project directly engaged major groundwater stakeholders ranging from territorial and municipal governments, Indigenous communities, and private water users with the research team to co-create groundwater management and vulnerability assessment strategies specific to the challenges of the North. The major focus is on developing a novel methodology for northern groundwater vulnerability assessment for aquifers and wells in the Yukon and Northwest Territories (NWT).

In conjunction with Yukon and Northwest Territories partners, a series of in-community co-designed knowledge sharing sessions called *Under the Land: Making the Invisible Visible* helped to foster discussion and learning around groundwater in the North. This programme prioritised knowledge and stewardship at the watershed scale and focused on holistic understanding of northern groundwater through two-way knowledge sharing and the co-generation of knowledge. The programmme was first run during the summer of 2022 and involved visiting three communities, Little Salmon Carmacks and Tr'ondëk Hwëch'in/Dawson City in the Yukon and Whatì in the Northwest Territories, in addition to a variety of community outreach activities such as public talks in Tombstone Territorial Park and water activities at a STEM camp for Indigenous youth in the Yukon.

*Under the Land* involved visiting communities, and spending time with community members and band council employees. Following community interests, team members visited different sites with community members, such as springs, sites of contamination, and areas of cultural significance (On the Land) and discussed the role of groundwater at these sites (Under the Land).

Meetings with governments, decision makers, practitioners: Numerous meetings have been held with Yukon and NWT Government staff.

Public workshops and presentations:  McKenzie gave a talk on Northern Groundwater as part of World Water Day in the Yukon (Virtual). Beringia Centre Science Talks, March 22, 2022.




Project poster from GWF Finale meeting, 2023

# Global Water Citizenship: Integrating Networked Citizens, Scientists and Local Decision Makers

Web Link: https://www.wlu.ca/academics/research/partnerships/gnwt/global-water-futures/global-water-citizenship.html

Region: Northern Region

Total GWF funding support: $340,000

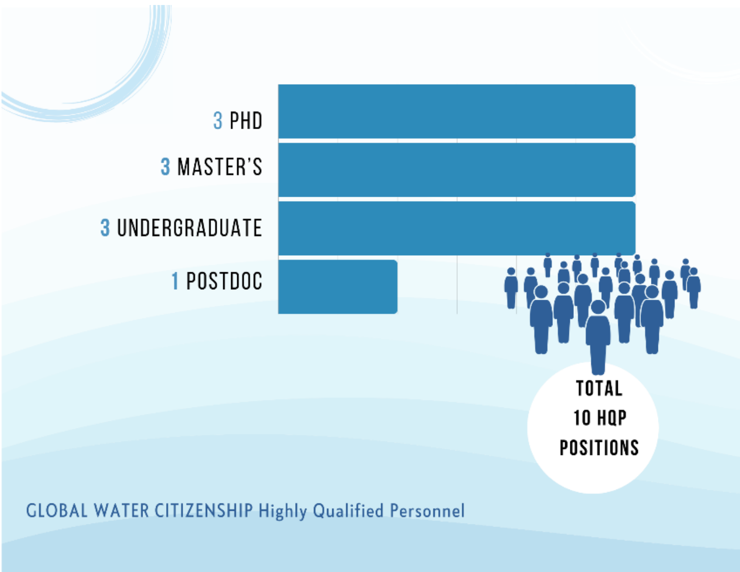
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Colin Robertson, Wilfrid Laurier University Contact: crobertson@wlu.ca
Rob Feick, University of Waterloo
Steven Roberts, Wilfrid Laurier University
Michael English, Wilfrid Laurier University

## Partners, Collaborators, and Users

Canada Department of Fisheries and Oceans
Gordon Foundation
Tsá Tué Biosphere Reserve




Highly Qualified Personnel: Professional training and research positions funded by Global Water Citizenship

## Science Advances

Many communities in Canada's North are increasingly performing their own environmental monitoring. While such community-based water monitoring has numerous benefits, it still often suffers from a major challenge: while increasingly easy to collect, data are often not fully utilized for stewardship and decision-making. This is due to multiple factors such as inconsistencies in spatial or temporal sampling, some scientists' lack of trust in citizen-gathered data, or difficulties in sharing and deriving meaning from collected data. This project aimed to better connect data collected by citizen scientists with scientific modelling and forecasting. While other researchers, including some at Laurier, are helping train community members as citizen scientists and assisting in the implementation of community-based environmental monitoring programs such as Indigenous Guardians, Global Water Citizenship focused primarily on enriching and making use of the data collected in these programs.

Data platform: Novel Big Data architecture, including a data warehouse and associated virtual machine servers, was developed to support integration of heterogeneous monitoring, satellite, and user/citizen data within a common framework.

CBM analysis tool: A tool was designed to enable users to enable users in the CBWM community to quickly analyze their own data. The Roundtable on Community Based Water Monitoring held in Fall of 2018 identified the need for tools that enable citizens and communities to better understand the lakes and rivers they are engaged in monitoring. The team worked with the Gordon Foundation and several user groups to identify needs and incorporate them into the development of the online tool.

Tsá Tué Biosphere Reserve Project Initiation: Participating in a planning meeting for the Tsá Tué Biosphere Reserve, NWT, in February 2019 led to initiation of a collaborative project linking Global Water Citizenship with this ongoing initiative to partner on a new funding application, carry out preliminary work identifying and obtaining satellite-based data products in support of the project. This was used as a case study for the data platform, and expect to integrate fish health monitoring data into the platform in summer 2019. A planned data inventory and access tool for this project was not carried out as a result of the Covid pandemic.

Expansion of Cowichan Lake Project: An ongoing project with Fundy Aqua Services / DFO contractor) in Cowichan Lake led to a collaborative short project around the SARA-listed Cowichan Lake Lamprey and water level change in the lake. Using data from local meteorological stations, lake water level measured at the weir, and recent aerial images from newly identified spawning habitat areas, management regimes were linked to lamprey habitat area at selected sites. It was then possible to retrospectively model habitat changes over time to put recent low-water seasons into historical context. These results were communicated to stakeholders at DFO and the Cowichan Roundtable meeting in April 2019, which includes representatives from the Cowichan Watershed Board, Catalyst Paper (the mill), local conservation groups, Cowichan First Nation, BC Parks and concerned citizens.

Spatially de-correlated extreme precipitation trend analysis: While gridded products to facilitate trend analysis of extreme climate over large regions like Canada are available for many variables, huge uncertainties exist and limit their use in northern Canada. The team developed a method to evaluate the spatial correlation structure of observations as the basis for subsampling.

Permafrost probability mapping: Permafrost probability mapping developed for the Kakisa, NWT community used GIS tools to generate solar radiationstandard datasets combined with digital elevation models and historic and predicted climate variables. This project also explored impacts of predicted changes to permafrost on Indigenous use of the land (through the use of simulated traditional use data). The end result contributed to on-going development of a local resource in the form of a Kakisa community atlas. Ka'a'gee Tu Atlas.

Spatial data assembly :Tlicho and Kakisa communities: Data consolidated for the communities of Behchokǫ̀, Whatì, Wekweètì and Kakisa were used in conjunction with tutorials developed for community workshops focused on building capacity in youth for digital mapping and community-based monitoring.

Safety of the land app – Kakisa: Spatial data were developed in part to enhance an existing community food atlas in Kakisa. These data were also used in a mobile phone app developed to improve safety while individuals are away from their community. This app allows map data concerning predicted permafrost change, shelters, trails, seismic lines, etc. to be used on disconnected mobile devices for both in-field reference in case of emergency and for community members to record observations of permafrost and snow pack change. This work was coordinated with GWF KM specialist Andrew Spring and linked to the Northern Water Futures project.

## Link to Publications List

# Great Lakes Region

# Lake Futures: Enhancing Adaptive Capacity and Resilience of Lakes and their Watersheds

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p3-lake-futures.phpx

Region: Great Lakes Region

Total GWF funding support: $1,578,252; $700,000

Project dates: June 2017-August 2023 EXTENDED to August 2024

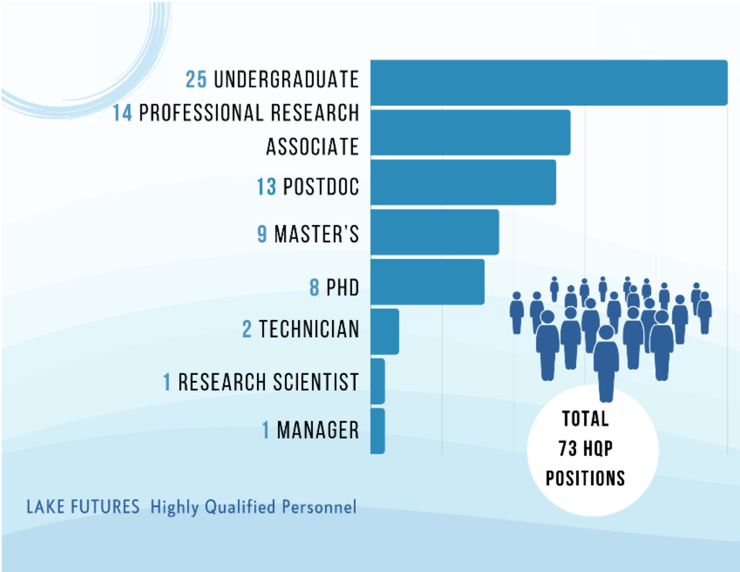
## Investigators

Nandita Basu, University of Waterloo
Contact: nandita.basu@uwaterloo.ca
Phillipe van Cappellen, University of Waterloo
Kevin Lamb, University of Waterloo
Roy Brouwer, University of Waterloo
Simon Courtenay, University of Waterloo
Kheyrollah Pour, Wilfrid Laurier University
Helen Jarvie, University of Waterloo
Jason Venkitswaran, Wilfrid Laurier University
Mark Servos, University of Waterloo
Gail Krantzberg, University of Waterloo
Bryan Tolson, University of Waterloo
Rebecca Rooney, University of Waterloo
Margaret Insley, University of Waterloo

## Partners, Collaborators, and Users

Agriculture and Agri-Food Canada (AAFC) -- Tiequan Zhang, Natalie Feisthauer, Pamela Joosse
China University of Geosciences -- Yanxin Wang
Cold Regions and Water Initiatives at Laurier University -- Kelly Munkittrick
Conservation Halton -- Barb Veale
Council of the Great Lakes Region -- Mark Fisher
Environment and Climate Change Canada -- Sean Backus, Alice Dove, Luis Leon, Vincent Fortin, Marie-Claire Doyle, David Depew, Chris Marvin, Caren Binding, Jean Michel Lariviere, Mohamed Borchetta, Jean-Michel Lariviere and others
Grand River Conservation Authority -- Robert Messier; Janet Ivey; Crystal Allan; Ryan Hamelin; Mark Anderson
Grand River Fisheries Management Plan Implementation Committee -- Crystal Allan (GRCA), Al Murray (MNRF)
Great Art for Great Lakes event, Waterlution -- Christopher McLeod
Haldimand County -- Zach Gable
Helmholtz Centre for Environmental Research -- Sabine Attinger; Jan Fleckenstein
Institute of Surface-Earth System Science, Tianjin University -- Siliang Li
Intact Centre on Climate Adaptation; University of Waterloo -- Blair Feltmate
International Institute for Sustainable Development (IISD) Experimental Lakes Area -- Scott Higgins, Matthew McCandless
Lake Simcoe Region Conservation Authority -- Steve Auger
Lawrence Berkeley National Laboratory -- Haruko Murakami Wainwright
Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany -- Georgiy Kirillin
Ministry of the Environment, Conservation and Parks -- Ryan Sorichetti; Chris Jones; Ling Mark
Muskoka Watershed Council -- Christy Doyle
Ontario Ministry of Agriculture, Food and Rural Affairs -- Dorienne Cushman
Ontario Ministry of Natural Resources and Forestry – LEMU -- Tom MacDougall
Parks Canada -- Trevor Swerdfager
Six Nations of the Grand River-- Weylin Bomberry (Paul General)
Toronto and Region Conservation Authority -- Gary Bowen, Michael Tolensky
University of Guelph, CFREF Food from Thought -- Wanhong Yang
University of Laval -- Raoul-Marie Couture

University of Michigan, Water Centre -- Jennifer Read
University of Windsor Great Lakes Institute for Environmental Research (GLIER) -- Jan Ciborowski, Douglas Haffner




Highly Qualified Personnel: Professional training and research positions funded by Lake Futures

## Science Advances

Canada possesses a huge number of lakes, both large and small, that play a crucial role in water supply, food production, resource extraction, hydropower generation, transportation, recreation, biodiversity, and climate regulation. But despite such water wealth, climate change, agricultural intensification, and shoreline development and urbanization, are exerting mounting pressures on the health and ecosystem services of lakes and their associated social and economic benefits. This project focuses on the causes, impacts and mitigation of southern Great Lakes issues by creating and applying models, determining indicators, and measuring vulnerability, resilience, and recovery of lake ecosystems. Its goal is to deliver risk management solutions that will enhance the resilience and adaptive capacity of Canada's large lake basins under changing climate and land use, and a specific focus on water quality and associated impacts.

Watershed pressures and stressors: The project has made significant progress in watershed-scale development of process models. One of the main contributions of this work is to quantify the effect of nitrogen (N) and phosphorus (P) legacies on water quality. Lake Futures researchers have provided a six-step roadmap for water quality improvement, given nutrient legacies and have developed the process-based ELEMeNT-N and ELEMeNT-P to describe N (T2, F7) and P legacies (F14) across the Grand River Watershed (GRW). Note that ELEMeNT is the ONLY process-based water quality model capable of explicitly considering legacy N and P in watersheds, and predicting how long it will take for water quality to improve following implementation of Best Management Practices. This is transformative and has spurred further collaborations with ECCC. The research used the P model to show that since 1900, the GRW has served as a net phosphorus sink, with approximately 96% of net P inputs retained within the basin. Future simulations suggest that while 40% reductions in P loading in Lake Erie watersheds are possible under aggressive management scenarios, legacy P will continue to elevate P loads to Lake Erie for centuries. Manure management was identified as one of the key levers that will lead the fastest water quality improvement. The simulations also highlighted significant legacy accumulations across reservoirs in the GRW. In two separate projects, researchers are exploring how reservoirs change watershed P dynamics using a combination of data and modelling. Developing water quality models for N and P at the Lake Erie Basin scale should be complete by 2023.

Lake impacts and responses: Satellite derived data for ice-on, ice-off and ice duration for Great Bear, Great Slave and Lake Athabasca 2002-2019 were extracted from the ESA CCI Lakes+ data product. Artificial neural networks (ANN) and random forest (RF) analyses have been carried out to relate lake ice and algal biomass parameters. Auto regression modeling was used to generate short-term future projections on algal growth trends. To better understand the environmental drivers of lake productivity, a dataset on chlorophyll-a concentrations, as well as associated water quality parameters and surface solar irradiance were assembled (period 1964-2019) across 357 lakes, predominantly located north of 40°. Long-term trends show that the algal growth has been occurring earlier in the year, thus potentially extending the growing season and increasing the annual productivity of northern lakes. Mass balance calculations for the water and phosphorus (P) cycles in Lake Erie identified major in-lake inputs of P to the water column. These are attributed to internal P loading from bottom sediments, as well as input of new P from intensifying shoreline erosion. The in-lake inputs are climate-sensitive and expected to increase in the near-future. Additional mass balance estimations further demonstrate the essential role of nearshore processes and inter-basin exchanges in modulating the fate and transport of external P inputs to Lake Erie. Research findings are regularly discussed with researchers and staff of ECCC, MOECP and TRCA.

Socioeconomic drivers and impacts: Transformational research outputs and tools include the development of a new integrated hydro-economic model at aggregated Great Lakes drainage basin scale that can be used to estimate the impacts of climate change on the Great Lakes basin economy, measured as the total direct and indirect costs of water use restrictions on provincial GDP. This model has been extended to include nutrient runoff into the Great Lakes to assess the least-cost way to reduce TP- emissions from point sources (industry, wastewater treatment) and non-point sources (agriculture). Work is ongoing on estimation of welfare measures for water quality improvements in the Great Lakes by applying choice models. Data about willingness to pay for multiple levels of water quality improvement will be integrated into the Water Quality Valuation Model. In addition, a PhD student has developed a temporally varying farmer's decision model to understand farmers' optimal fertilizer application under crop price uncertainty. The farmers' decision model is enhanced by inclusion of additional variables such as rainfall and temperature, in the corn yield model.

Transdisciplinary integrations: Researchers' integration of water quality data (total nitrogen, nitrate, total phosphorus and soluble reactive phosphorus) at more than 400 stations across the Great Lakes Basin (GLB) is now a published dataset. That has been used to develop machine learning models that predict concentrations and loads across all watersheds in the Great Lakes Basin. Results highlight that high livestock and tile drain density can lead to increasing fractions of bioavailable phosphorus that is associated with increasing algal blooms. Water quality trends across the basin, specifically focusing on regions where concentrations are increasing or decreasing and the dominant drivers of these trends, are also being examined. The uniqueness of the machine learning model is that it can be easily linked with outputs from any hydrology model (e.g., climate simulations) to predict seasonal nutrient loads to any of the Great Lakes. Given the availability of multiple hydrology models across the GLB as a part of the GRIP-E project7, this allows Lake Futures researchers to develop real time predictions to run lake models. While this work has focused on the Great Lakes Basin scale, researchers have also expanded to the continental scale to explore how human activities have impacted streamflow patterns using data from thousands of gauges across North America from 1950 - 2009 to show that in 44% of the managed watersheds, human activity has led to significantly higher or lower flows, increasing the risk of drought and flooding. In 48% of the managed watersheds, water management practices have been found to have had a beneficial effect, reducing the risk of droughts and floods. This work resulted in multiple media stories including one in *USA Today*.

Two other projects with supplemental funding from Ducks Unlimited Canada and the New Frontiers Research Exploration Program look at two specific watershed management strategies, wetland restoration and manure management for water quality improvement in the Great Lakes Basin. The goal of the wetland project is to develop a model that quantifies wetland phosphorus removal across the Lake Erie Basin. Researchers are modeling wetland phosphorus cycling and retention capacity using a combination of literature synthesis and field data provided through the partnership with Ducks Unlimited Canada. The goal of this project is to develop recommendations for wetland restoration in the Great Lakes Region that will help reduce phosphorus loading in surface waters and ultimately improve water quality in the Great Lakes. The goal of the manure management project, funded fully by the New Frontiers program, is to explore the potential of using manure in bioreactors across Ontario with the goal of improving water quality and reducing greenhouse gas emissions. This builds directly from LakesFutures modelling where it was found that the key to the fastest improvement in water quality was in improving manure management across the basin.

Link to Publications List

## Knowledge Mobilization (KM)

Lake Futures KM activities have been occurring through a mix of project wide and individual HQP interactions. Key accomplishments throughout the last year include: (1) Launch of Brown Bag virtual presentation series, (2) Engagement with steering committee (3) HQP community engagement (4) water quality workshop and partnership (5) Community-based monitoring program.

The Brown Bag virtual presentation series was launched as a new webinar series in 2022, with goals to share research progress and lessons learned with the Lake Futures research team, to identify potential areas of collaboration, and to collectively discuss how the research could be applied to land and water management in Canada. Lake Futures student researchers are asked to present on a topic of interest, and attendees include students, researchers and staff affiliated with the Lake Futures project, along with external researchers who may be particularly interested in the topic that month. Students are encouraged to focus their presentation on the impact or application of their research and identify who they think might benefit from the work, as well as clearly describe the areas of their research that they believe have real-world application.

The 10-person Lake Futures Steering Committee, consisting of experts in positions that are involved in the implementation of lake, watershed and eutrophication science from ECCC, GRCA, GLIER, IPNI, OMAFRA, IJC, UTRCA, and MECP met for the third time April 21, 2021. One of the goals of the group was identifying collaborative opportunities within the Lake Futures project and opportunities for researchers to engage further with stakeholders such as through expert committees. The purpose of the committee is to ensure that the knowledge produced by Lake Futures is transferred to those who can put it into practice. The outcomes of the meeting included data sharing between researchers and member organizations, strengthening of relationships through improved understanding of individual contributions, distribution of research results, reports and videos to share helpful information across organizations, and identification of future research questions that would be useful to practitioners for further collaboration. A tangible outcome of the meeting has been submission of a project proposal to the NSERC Alliance program that directly builds on the machine learning models developed by Lake Futures. Several committee members were involved in helping to scope the research focus, connect researchers with interested partners, and define potential areas for research application.

Lake Futures HQPs continue to demonstrate commitment to effective knowledge mobilization and strong engagement with stakeholders. A Lake Futures PhD student presented as part of the Watersheds Canada Freshwater Stewardship Community webinar series, to share her work with broader audiences of conservation authorities, farmers, and cottage owners. The talk, titled "The ghost of phosphorus past: How decades of phosphorus use is shaping today's water quality", can be found here.

PI Basu is a member of two working groups of the International Joint Commission, the Manure Management and the Nutrient Synthesis working groups. Brouwer and postdoctoral fellows organised the session "Integrated Modelling and Valuation of Ecosystem Services in the Great Lakes" during IAGLR's 64th annual Conference on Great Lakes Research, 17-21 May 2021. A news article "Ten best practices to strengthen stewardship and sharing of water science data in Canada" from GWF researchers, including Lake Futures investigators Kheyrollah Pour and Van Cappellen was published in an effort to improve data management in water science in Canada. Lake Futures HQP and PI Basu published their study in Nature Sustainability, resulting in 49 media mentions, including *USA Today*, and PI Basu published in *Nature Geoscience* which was picked up by 25 news outlets and mentioned in 942 social media interactions, greatly increasing the public visibility of the research and disseminating the findings to a broader audience.

Lake Futures, in collaboration with The Gordon Foundation, the University of Waterloo's Water Institute organized a two-day workshop (December 2020) on "Data Needs in the Great Lakes" that was attended by 39 participants, including academics and various stakeholders around the GLB. The purpose of this workshop was to define what is needed to improve access to water quality data in the Great Lakes region. Following the data workshop, in 2021 the Gordon Foundation launched the Great Lakes DataStream initiative brings together water monitoring information from 23 monitoring groups across the Great Lakes basin. The workshop also contributed to a recently submitted NSERC Alliance proposal, titled "From Data to Knowledge: Designing User-Driven Water Quality and Nutrient Loading Observatories across the Great Lakes Basin" proposal by Lake Futures PI Basu. The project team includes partners from ECCC, MECP, conservation authorities, and NGOs. The project benefits from significant in-kind contributions from these partner organizations over three years of the project duration who are contributing $2,078,200 in-kind support. The Alliance proposal aims to use grab-sample and high-resolution water quality data, with unique statistical and machine learning (ML) approaches to provide load estimates at monitored and un-monitored locations across the Great Lakes basin. Conversations with all partners have highlighted that these products will be valuable and are well aligned with their individual priorities.

PI Basu's Deford Lecture at the University of Texas, October 2021

The Community-based Monitoring Program: is an outcome of a cumulative effects monitoring framework that occurred as a part of Lake Futures' earlier work. Building on this work, a Elaine Ho collaboratively led development of a new community-based water quality program with Garden River First Nation from March 2021 until February 2022. From this, she has expanded her network in the Upper Great Lakes and is in the process of kicking off a new, larger initiative across lower Lake Superior and the St. Mary's River. Over the next 18 months, this project's purpose is to consider the watershed holistically in the development of coordinated community-based monitoring programs by implementing two neighboring community-based ecosystem monitoring programs (not just water quality monitoring) to demonstrate how multiple objectives and benefits may be achieved while coordinating efforts between independent monitoring programs. These activities will consider interactions between land and water as well as biotic and abiotic factors that influence or demonstrate freshwater quality. Beyond the 18 months, she is in the process of setting up an Upper Great Lakes network of community-based ecosystem monitoring programs across Lakes Superior, Huron, and Michigan.

# Professional Development and Technology Transfer

Special Seminars: Radosavljevic, J. University of Waterloo's "Climate Change and Water Security in Urbanized Watersheds: An Interdisciplinary Perspective" – summer school co-delivered by the Water Institute (WI) and Interdisciplinary Centre on Climate Change (IC3).

Workshops:

Dallosch, M. University of Waterloo Graduate Studies and Postdoctoral Affairs. PhD Candidacy Workshop and Celebration. June 11, 2021, Virtual.
Dallosch, M. Interdisciplinary Freshwater Harmful Algal Blooms Workshop (IFHAB). The Future of Freshwater Harmful Algal Blooms Research. June 7-8, 2021, Virtual.
McLeod, M. "Writing in the Sciences" Course. (Online writing workshop provided by Stanford)

# Managing Urban Eutrophication Risks under Climate Change: An Integrated Modelling and Decision-Support Framework

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1ph2-eutrophication.php

Region: Great Lakes Region

Total GWF funding support: $273,930

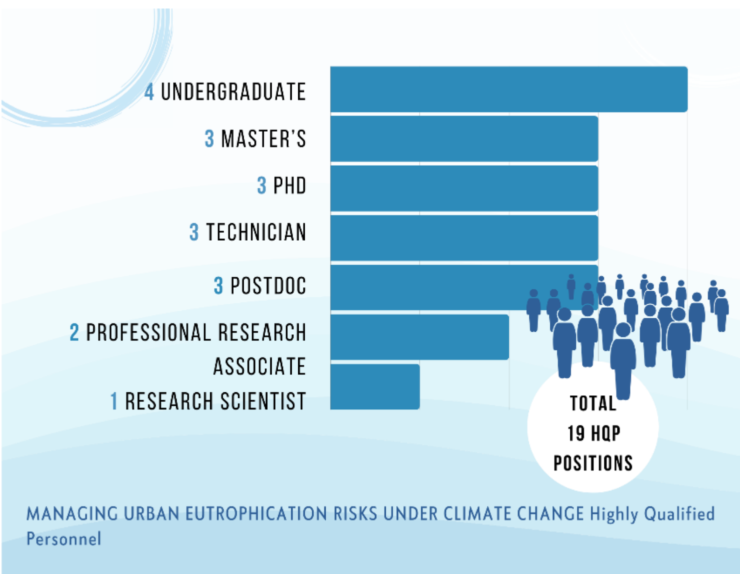
Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators

Phillippe Van Cappellen, University of Waterloo Contact: pvc@uwaterloo.ca
Nandita Basu, University of Waterloo
Roy Brouwer, University of Waterloo
James Craig, University of Waterloo
Helen Jarvie, University of Waterloo
Homa Kheyrollah Pour, University of Waterloo
Bruce MacVicar, University of Waterloo

## Partners, Collaborators, and Users

City of Kitchener -- Bu Lam
Grand River Conservation Authority -- Mark Anderson
Ontario Ministry of the Environment, Conservation, and Parks -- Pradeep Goel
The Regional Municipality of Durham -- Tavis Nimmo
Toronto and Region Conservation Authority -- Krista Chomicki
Water Institute, University of Waterloo -- Kevin Boehmer




Highly Qualified Personnel: Professional training and research positions funded by Managing Urban Eutrophication Risks under Climate Change

# Science Advances

The project aims to provide urban water management teams with a science-based roadmap for prioritizing measures to protect water ecosystems from challenges caused by excess phosphorus (P) exported from urban landscapes. This, combining research efforts within the watershed-lake continuum with economic analyses, is intended to result in a toolbox that can be used to for assessing the cost-effectiveness of different P control strategies for the prevention of eutrophication and algal growth in the nearshore zone of large water bodies. Focus is on the eutrophication risks in the littoral zone of the western basin of Lake Ontario (WLO), leveraging existing knowledge and expertise from ongoing research projects conducted in similar areas. WLO receives urban P inputs from Ontario's Golden Horseshoe, which includes the Greater Toronto Area (GTA). WLO was selected as the study area because (1) the rapid pace of urbanization of the GTA, (2) the availability of data time series, and (3) the team's strong relationships with boundary organizations and stakeholders active in the GTA, Lake Ontario, or both.

Achievements include developing a database of hydrology and water quality parameters, including P species, based on field experiments conducted in three urban catchments that drain into WLO, remote sensing and in-situ data time series on surface Chl-a concentrations and submerged aquatic vegetation coverage as an indicator of phytoplankton biomass and Cladophora growth in WLO.

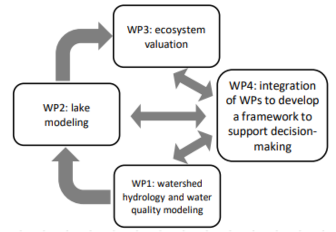



Figure 1. Inter-linkages among work packages

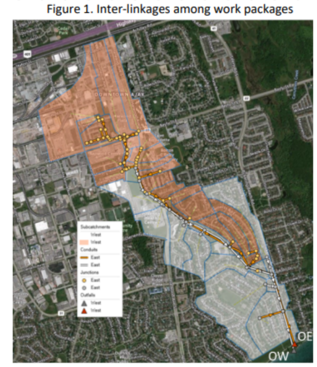



Figure 2. Layout of two modeled Ajax sewersheds where the blue lines identify the sub-basin boundaries, orange and gray circles are stormwater collection nodes, orange and white lines are the main sewers, red and gray triangles (OW and OE) are the stormwater outfalls of the two sewersheds.

Interlinkages in work and layout of stormwater flow in two Ontario sewersheds

## Link to Publications List

# Knowledge Mobilization (KM)

Mahyar Shafii presented an enlightening talk at the GWF annual science meeting (May 2021), titled "Phosphorus dynamics in urban catchments: integrating fieldwork, lab analyses, and modeling". In this talk, he communicated UW-GWF urban phosphorus research to an audience from a diverse set of disciplines.

# Ohneganos Co-Creation of Indigenous Water Quality Tools

Web Link: Ohneganos

Region: Great Lakes

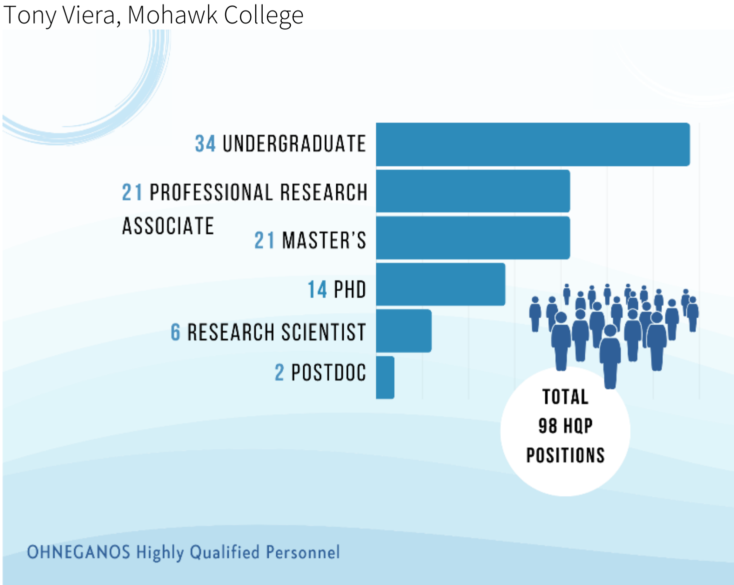
Total GWF funding support: $950,000; $800,000

Project dates: December 2018- August 2023 EXTENDED to August 2024

## Investigators

Dawn Martin-Hill, McMaster University Contact: dawnm@mcmaster.ca
Altaf Arain, McMaster University
Christine Wekerle, McMaster University

Emil Sekerinski, McMaster University
Lori Davis Hill, Six Nations Health Services
Nancy Doubleday, McMaster University
Reo Nicholas, Dartmouth College
Nidhi Nagabhatla, N UNU CRIS
Charles de Lannoy, McMaster University
Christina Moffatt, McMaster University
Patricia Chow-Fraser, McMaster University
Zoe Li, McMaster University
Marilyn Powers, Mohawk College
Karen Stote, Wilfrid Laurier University
Karen Kidd, McMaster University
Mark Servos, University of Waterloo
Tony Viera, Mohawk College




Highly Qualified Personnel: Professional training and research positions funded by Ohneganos

## Partners, Collaborators, and Users

Akwesasne -- Louise McDonald
Cheyenne River Reservation (South Dakota) -- Chief Arvol Looking Horse
Grassy Narrows First Nation -- Judy Da Silva
Digital Democracy -- Rudo Kemper
Envision -- Summer Leigh
First Nations Youth Warrior Program (Warrior Park Athletics) -- John Williams
Haudenosaunee Confederacy Council -- Jock Leroy Hill, Allen McNaughton, Cleveland Thomas
Haudenosaunee Resource Centre -- Jock Leroy Hill, Howard Thompson, Roger Silversmith, Jock Leroy Hill
IndigenousElders and Youth Council-- James Knibb-Lamouche, Clanmother Mary Sandy, Norma Jacobs
Indigenous Knowledge Exchange -- Tehahenteh Frank
Miller
Juddah's Place -- Elva Jamieson
Kawenní:io|Gaweni: yo Private School -- Jeremy Green, Artie Martin, Brian Hill
Kayanase -- Kerdo Deer
Clanmother Norma Jacobs
MANTEC -- Roberto MenegottoMcMaster University -- Lorraine Carter, Nancy Mcquigge, Shylo Elmayan, Adrianne Xavier, Kari Hill, Ravi Salvaganapathy, Bonnie Freeman, Christine Wekerle, Bernice Downey
Mohawk College -- Amy Kelaidis, Joshua Dockstator, Kamala Kruse, Lorraine Vanderzwet-Servos, Bryan Ledgerwood, Sam Scott
Royal Botanical Gardens -- David Galbraith
SHAD Canada -- Matthew Rae
Six Nations Elected Council -- Mark Hill
Six Nations Birthing Centre -- Julie Wilson
Six Nations Health Services -- Lori Davis Hill, Kelly Gordon, Michelle Jamieson, Nicole Bilodeau
Six Nations **Traditional Medicine Clinic** -- Kelly Gordon, Amber Skye, Cam Hill

Six Nations Polytechnic STEAM Academy -- Kali Anevich, Nathan Rowbottom
Six Nations Public Works -- Michael Montour, Steve Lickers
Six Nations Social Services -- Ashley
Six Nations Wildlife -- Bethany Wakefield
Six Nations Youth Mental Wellness Advisory Committee (17 members)
Te Poho o Huturangi Environmental Research Center -- Tina Ngata
University of Toronto -- Jorge
University of Waterloo -- Phillippe van Cappellen
University of Windsor – Beverly Jacobs

## Science Advances

The Ohneganos project employs an innovative research framework and methodology towards improving water security and water management for Indigenous communities. The holistic, community-led, and ecocentric nature of this research project is further reflective of an Indigenous worldview. The emphasis of this approach is reflected in the research findings, citizen science, public outreach, knowledge mobilization, and in the novel outputs of the project.

Six Nations of the Grand River (Six Nations) has the largest Indigenous membership in Canada. Despite its close proximity to major cities, water insecurity is prevalent in the community. For instance, only nine per cent of the on-reserve population live in homes with water supply infrastructure connected to the water treatment plant. Haudenosaunee people at Six Nations are guided by the teachings of the Ohen:ton Karihwatehkwen ('Thanksgiving Address') that instructs human interrelatedness and interdependency of all parts of the natural world. The overall purpose of this project, Co-Creation of Indigenous Water Quality Tools, was to do just that - innovate water-related tools through the harmonization of Indigenous Knowledge and Western Science (i.e. 'co-create'). These 'tools' (used in a general conceptual sense) would serve as innovative grassroots and community-led solutions to address Six Nations' water challenges and the cross-cutting issues that are inextricably linked and associated with water insecurity (i.e. taking a wholistic approach).

This project was administered in two Phases: Phase 1 (2017-2020) and Phase 2 (2020-2023). In both phases, the following broadly-defined goals were identified during co-development of the project with Six Nations. These provided the governing framework to begin understanding the types of tools that the community needed:

● To determine how Canada will address water resource protection and challenges related to development that predominantly impact Indigenous peoples.

● To include Indigenous Knowledge and Indigenous authorities in water resource planning and decision- making and thus develop better science and governance models for watershed management.

● To create an integrated digital atlas and repository of information that can be accessed by individuals, communities, and other stakeholders to better understand the history, context, and present.

● To determine anticipated impacts of climate change on water resources for the Six Nations community, flood or drought management, pest infestations, or extreme heat or cold experienced in these communities.

● To identify possible ways to prevent contamination of drinking water, protect source water, and treat drinking water and preserve fish and wildlife assemblages as food sources for First Nations.

● To identify the human health impacts from water-quality contaminants and suggest ways to mitigate against these.

● To overcome jurisdictional challenges by recommending ways for federal, provincial, local, and Indigenous Nations to work together to strategically adapt, manage and balance water needs, and to address social, economic and environmental challenges.

These goals demonstrate that the tools that the project was seeking to help co-create range from making scientific discoveries to participatory Indigenous mapping and engaging in human/environmental health assessments. Project subthemes are also prevalent across each goal and were woven into each research activity developed to target each of the above objectives. For instance, while language is of critical importance to Haudenosaunee culture, identity, expression, and sovereignty, all six Haudenosaunee languages are endangered. Therefore, all research activities sought to integrate Indigenous language into their methodology (e.g., through report writing, community engagement, data visualisation, etc.). Another prevalent subtheme was reconciliation: learning about both how reconciliation could be woven into the core fabric of the project's methodology and interworkings, but also how deliberate actions of reconciliation could be undertaken by the project team and by the group's various partners and collaborators. For example, local capacity building, youth training, developing forms of accreditation/recognition, and creating pathways for Indigenous youth to encourage consideration in STEM-related post-secondary education were identified as a 'tools' that are necessary, but such activities and pursuits that were undertaken are also clear demonstrations of reconciliation and relationship-building.

The broader project context of learning about how to 'co-create' and engage in meaningful partnerships, collaborations, and relationships with community led to the publishing of a book chapter in a volume, *Indigenous Water and Drought Management in a Changing World* called 'Striving toward reconciliation through the co-creation of water research'.

Indigenous data sovereignty, ethics in data management when working with Indigenous partners (e.g., principles of OCAP), and data/research accessibility and knowledge mobilization were key themes and considerations. The methods and approaches that were taken were iterative and community-led throughout each stage of the research process. Such efforts culminated in the development of an open- access repository where many of the co-developed tools are hosted, denoted as 'Learning Materials' on a tab of the Ohneganos website. One of the tools listed and accessible on the website, the virtual reality experience, is an innovative approach to Knowledge Mobilization (central to the project's Knowledge Mobilization plan) that immerses the user in a Haudenosaunee cultural experience while conveying information from some of the research studies that were undertaken as part of the project, such as findings from the river/creek and ecological assessments and the localized climate change prediction studies. Overall, the methodological approach undertaken by this project has national and international implications as it is a demonstration of how community-led co-creation can be undertaken, while safeguarding community and Indigenous Knowledge and ultimately developing innovative and practical solutions that have real, direct, and tangible impact. Further, Indigenous water insecurity, access to water data and information, and citizen engagement in water management are all Canadian and global challenges that this project provides insights on in terms of innovative approaches, conduct, and best practices in academic and research settings.

## Link to Publications List

# Knowledge Mobilization (KM)

Access of tools by users

- Ohneganos website: https://www.ohneganos.com/research
- Ohneganos on Facebook: https://www.facebook.com/ohneganos
- Ohneganos on Instagram: https://www.instagram.com/ohneganos/?hl=en
- Ohneganos on Twitter: https://twitter.com/ohnegahde
- Ohneganos on YouTube: https://www.youtube.com/c/OhneganosOhnegahd%C4%99gyo
- Let's Talk Water: https://www.youtube.com/playlist?list=PLV0pWnAsC2xCls5M628FY6AoZM54Pv2Zu

Meetings with governments, decision makers, practitioners

- Meetings have been held to discuss the development of Canada Water Agency and plan for an Indigenous arm.
- Four chiefs from the Haudenosaunee Confederacy Chiefs Council formed a water committee to support Ohneganos work and provide direction, particularly with respect to youth initiatives.
- Meetings have been conducted with members from the Grand Traverse Band of Ottawa & Chippewa Indians for a TEK knowledge exchange on dam decommissioning to be hosted at Six Nations in 2022.
- Meetings have been held with the Six Nations Grandmother's Council to support protecting the aquifer

17 articles in popular media

# Significance of Groundwater Dynamics Within Hydrologic Models

Web Link: [Groundwater Models - Global Water Futures - University of Saskatchewan (usask.ca)x]

Region: Great Lakes

Total GWF funding support: $85,000

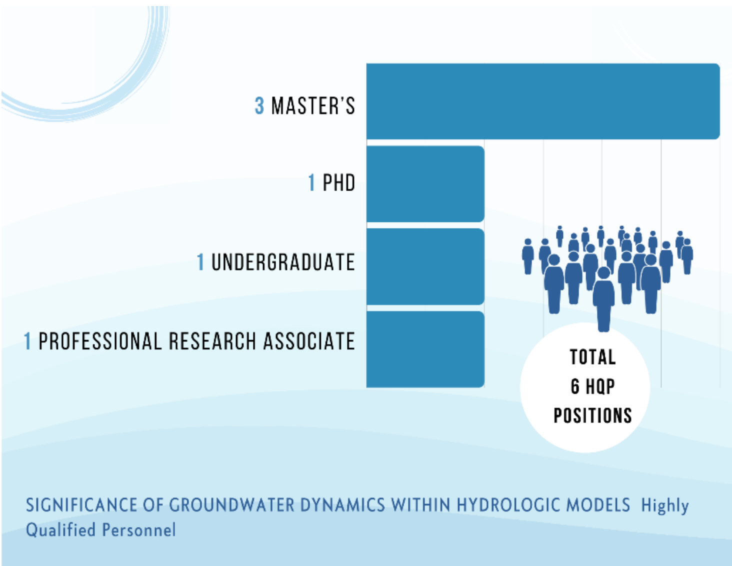
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Walter Illman, University of Waterloo Contact: willman@uwaterloo.ca

## Partners, Collaborators, and Users

Aquanty Inc. -- Steven J. Berg




Highly Qualified Personnel: : Professional training and research positions funded by Significance of Groundwater Dynamics within Hydrologic Models

## Science Advances

This project is studying the significance of spatial and temporal groundwater dynamics on watershed hydrology through high-resolution simulations with a fully-integrated hydrologic model, HydroGeoSphere (HGS). Because of the availability of high-quality data, datasets from the well-instrumented Alder Creek Watershed (ACW) (~79 km2) within the Grand River Basin in Ontario are used to parameterize, calibrate, and validate the model. The watershed is characterized by a humid continental climate, with predominately agricultural land-use, and is thought to have strong surface water and groundwater interaction.

A high resolution two-dimensional (2-D) overland flow model was first developed with HGS for the ACW based on a digital elevation model (DEM). The model was then used to simulate base flow conditions within the ACW with an increasing level of complexity to represent the subsurface. The model was initially spun up to represent steady state conditions and then the result was used as an initial condition for transient simulations to capture temporal variations in natural processes and anthropogenic activities. Five integrated hydrologic models (i.e., Models 1 – 5) using HGS have been developed to highlight the significance of groundwater fluxes on surface water flow within the ACW. These models all share the same high-resolution topography information, landcover representation, temporal precipitation records, evapotranspiration, while Models 3 and 5 share the same subsurface hydraulic parameter assignment and Models 4 and 5 have the same model domain (depth) for model comparison.

Precipitation data between May 1st and October 31st, 2013 from the Roseville Environment Canada weather station (OMNR, 2007) was used in all models for transient simulations. Transient simulations from spring to fall (May 1-October 31, 2013) are considered first, and then simulations for the winter (November 1, 2013 to April 30, 2014) are now being considered by adding winter processes and relevant parameters to the HGS models. Two winter processes are being considered using HGS including surface water flow with snowmelt and groundwater flow with freezing and thawing of pore water.

Estimated discharges at gauging stations from spring to fall are plotted and compared with the observed discharge data. The baseflow of the stream is also estimated at three stations. The estimated baseflow is sometimes larger than actual streamflow especially during the dry period (summer time), which may be due to the overestimation of groundwater discharge or underestimation of evapotranspiration of the surface water. The estimated discharge at three gauging stations in winter is plotted and compared with the observed discharge data. The results are quite similar with the plots from spring to fall, with significantly larger values for Models 1 and 2 at all three locations compared with Models 3, 4 and 5 and observed discharges. Less fluctuation and smaller discharge values are observed especially when temperature drops below 0 °C and the snow starts to accumulate on the ground. The rapid increase in discharge at the beginning of the spring (early April) cannot be captured by all models, which is possibly due to the inaccurate representation of the snow melt process or due to the inaccurate precipitation or temperature data.

A transient simulation with 5 pumping wells with daily pumping rates obtained from the Region of Waterloo's WRAS+ database (locations shown in Fig. 3) was also conducted. ten observation wells (with 17 screens) were selected to investigate the impact of municipal well operations on the subsurface, while results were compared with discharge without pumping events to evaluate the impact on surface water. The streamflow values are nearly identical for all model results at the New Dundee and the Bethel station, so only streamflow values with pumping events for Models 3, 4 and 5 at the Shadybrook gauging station are plotted and compared with streamflow values without pumping events (Fig. 8). The reason behind it may be that the pumping well (K23) is very close to the Shadybrook gauging station with a relatively large pumping rate (around 3,000 m3/day), while the pumping rates of ND4 and ND5 are generally very small (around 200 m3/day). Models 3, 4 and 5 all yield smaller streamflow discharges compared to the results without pumping events, especially for Model 4. Models 3 and 4 also yield different results since the pumping wells are all located at the AFB2 layer which may lead to different subsurface responses.

Findings indicate that the tools/results developed and validated through this project should contribute to the transformational understanding of the significance of groundwater on watershed fluxes for the ACW and similar watersheds. The research should also be complementary to work done by surface water modelers and provide important insights on how deep in terms of the subsurface one should consider in surface water models to achieve accurate surface water predictions. Moreover, the models developed in this study can serve as a reference to further analyze the impact of anthropogenic activities on both surface water and groundwater levels/fluxes, solute/contaminant transport, and winter processes at the watershed scale. Finally, the knowledge gained through this project should help achieve GWF's overarching goal to deliver risk management solutions informed by leading-edge and innovative decision-making tools to manage water futures in Canada and other cold regions.

Link to Publications List

## Knowledge Mobilization (KM)

The project is actively engaging with personnel from the Knowledge Mobilization (KM) team. Discussions with Nancy Goucher on how to mobilize the knowledge gained from this project to other users also took place on several occasions. In particular, the Region of Waterloo (RoW) has been approached to bring it on as a partner for the project with the goal to improve decision-making based on a more comprehensive understanding of surface and ground water interactions. Previous engagements with the RoW have resulted in very good interest from them and the team was successful in obtaining wellfield operation data that could be used to calibrate the HGS model for the ACW. The participation of the RoW and other agencies such as the Grand River Conservation Authority (GRCA), Environment and Climate Change Canada (ENRC), Agriculture and Agri-Food Canada (AAFC), and Ontario Ministry of Environment, Conservation and Parks (MOECP) will be critical in expanding the model developed through this project to examine the importance of groundwater on surface water fluxes at a larger scale.

Most recently, the project team approached the Geological Survey of Canada (GSC)/Natural Resources Canada (NRCan) to collaborate on an extension of this project. This engagement has resulted in the submission of an NSERC Alliance grant. The proposed project will involve the examination of shallow, intermediate, and deep groundwater flow and its impact on surface water fluxes at different scales. The project will provide much needed guidance on the appropriate incorporation of groundwater flow phenomena from small- to large-scale watershed simulations. GSC/NRCan has expressed very strong support for this initiative and has committed ~$1M in in-kind support. Therefore, the Federal Government, the GSC/NRCan (through the Memorandum of Understanding signed between GSC/NRCan and GWF on November 27, 2018), and the International Joint Commission (IJC) could benefit by having a multi-objective integrated hydrologic model that could be utilized for policy-focused water resources management such as the Great Lakes Water Quality Agreement (GLWQA).

There are collaborative opportunities with Professor Tian-Chyi Jim Yeh from the Department of Hydrology and Atmospheric Sciences of the University of Arizona on the development and validation of the Successive Linear Estimator (SLE) algorithm that could be adopted in this project for parameter estimation purposes. SLE is a geostatistical inversion algorithm that could be utilized to map the heterogeneity of subsurface hydraulic parameters, but could also be adapted to surface flow hydrologic parameters.

# Evaluation of Ice Models in Large Lakes: Using Three-Dimensional Coupled Hydrodynamic-Ice Models

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1-lake-ice.php

Region: Great Lakes Region

Total GWF funding support: $170,000

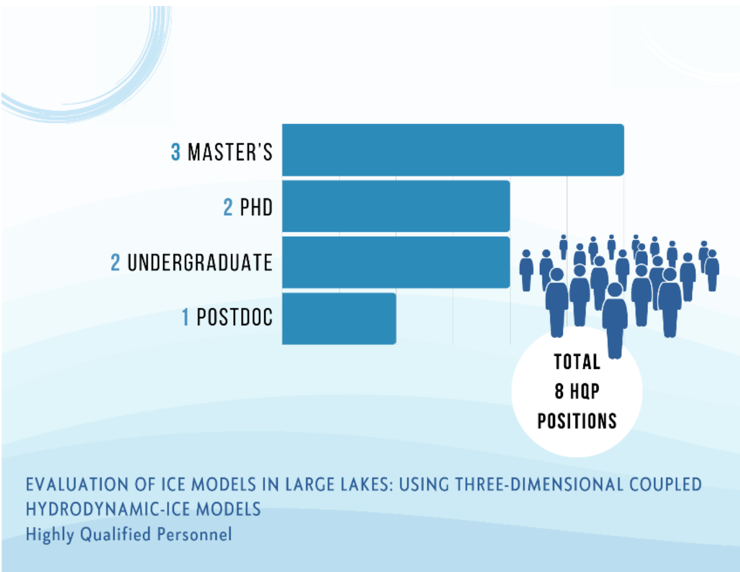
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Kevin Lamb, University of Waterloo Contact: kglamb@uwaterloo.ca
Andrea Scott, University of Waterloo
Marek Stastna, University of Waterloo

## Partners, Collaborators, and Users

Wilfrid Laurier University -- Homa Kheyrollah-Pour




Highly Qualified Personnel: Professional training and research positions funded by Evaluation of Ice Models in Large Lakes

## Science Advances

The nature of ice cover in large lakes is very different from that in small lakes in that (i) large lakes are typically only partially covered; and (ii) ice in large lakes is often fragmented and drifts around the lake under the action of wind. The primary goal of this project is to compare and validate the ability of existing ice models to simulate the evolution of ice cover on large lakes at large and small scales. Simulations using two ice models, both of which include snow, are carried out using the same hydrodynamic core, so that differences observed can be attributed to differences between the ice models, as opposed to the manner in which the hydrodynamics is represented. The primary location of application of the model evaluation is Lake Erie. The partial ice cover common to Lake Erie winters, the differences between the three basins that make up the lake, and the rich biogeochemistry made this the ideal choice for this study. Secondary focus regions are Lake Ontario, and the outflow of the fast flowing, highly turbulent, Niagara River.

A PhD student's work, based on high resolution three-dimensional numerical simulations, explores how heat introduced into cold lake water via shortwave solar radiation is transported with the fluid via convective instabilities in the presence of background sheared currents. The convection is initiated when near surface water below the temperature of maximum density is warmed by shortwave radiation which increases its density leading to a gravitationally unstable density profile. The results of this paper show that for a sufficiently strong shear current, the growth phase of instabilities generated by volumetric thermal forcing (which represents solar radiation) is nearly two-dimensional and that the transition to more vigorous three-dimensional motion is initialized by baroclinic production of vorticity by convective instabilities followed by a rapid increase in streamwise vorticity generated by vortex tilting and stretching. The paper explores how this process is modified by differences in shear strength and thermal forcing attenuation length (i.e., by how rapidly the shortwave radiation is absorbed). This is relevant to wintertime fluid dynamics in ice covered lakes. Grace is currently writing his PhD thesis which he expects to defend in July or August of this year. In addition, it will explore the effects of non-monotonicity of the nonlinear equation of state near the temperature of maximum density and discusses the general evolution of a cabbeling gravity current. Under a particular set of circumstances, an initially positively buoyancy current mixes and generates a coherent bottom flowing current. The characteristics of this process are investigated and quantified.

A Postdoctoral Fellow successfully coupled the three-dimensional hydrodynamic model ROMS-3.7 with the Los Alamos Sea Ice, Model CICE (this is the ice model used by Environment Canada) using the coupling model METROMS. Comparisons modeled and observed ice concentrations were done for the 2013-2014 winter using data from the Canadian Ice Service giving reasonable agreement. However, the model predicts higher ice concentrations in much of the central and eastern basins. Because of lack of HQP to continue this work it remains uncompleted.

Link to Publications List

# Southern Forests Water Futures

Web Link: SOUTHERN FORESTS WATER FUTURES - Home

Region: Great Lakes

Total GWF funding support: $500,000

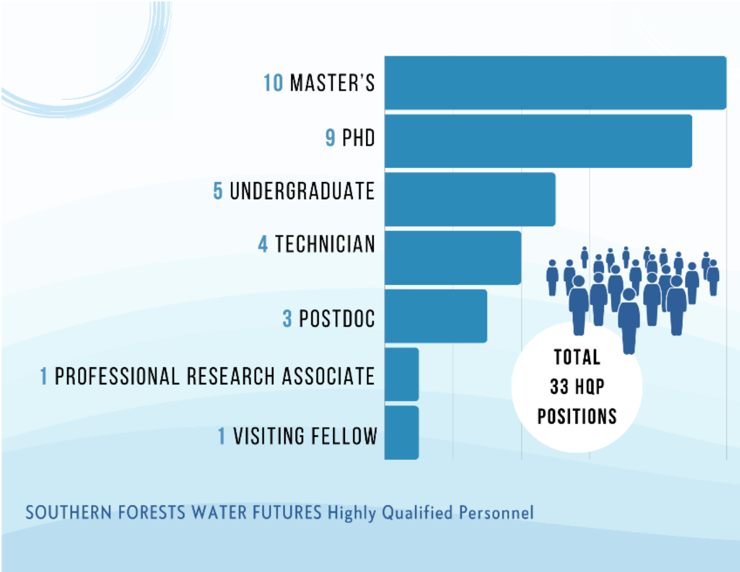
Project dates: December 2017-November 2020 EXTENDED to August 2024

## Investigators

Altaf Arain, McMaster University Contact: arainm@mcmaster.ca
Joe Boyce, McMaster University
Sang-Tae Kim, McMaster University
Greg Slater, McMaster University
Jing Chen, University of Toronto
Michael Pisaric, Brock University

## Partners, Collaborators, and Users

Ameriflux and Global Fluxnet initiatives
Canada Centre for Remote Sensing, Natural Resources Canada -- Shusen Wang
Centre for Inland Waters (CCIW), Environment and Climate Change Canada (ECCC) -- Ram Yerubandi, Luis Leon
Climate Research Division, Environment and Climate Change Canada (ECCC)
Environment and Climate Change Canada -- Paul Bartlett, Joe Melton
Long Point Region Conservation Authority (LPRCA) -- Paul Gagnon
Ontario Climate Consortium (OCC) and Toronto and Region Conservation Authority (TRCA) -- Ian McVey
Ontario Forestry Research Institute, Ministry of Natural Resources and Forestry -- Bill Parker
Ontario Ministry of Environment, Conservation, and Parks (OMECP) -- Chris Charron, Todd, Aaron, Jeff Pickersgill
Ontario Ministry of Environment and Climate Change (OMECC)
Ontario Ministry of Natural Resources and Forestry (OMNRF) Alymer District -- Ron Drabick
St. Williams Conservation Reserve Community Council (SWCRCC)-- Audrey Heagy
The James Hutton Institute, Aberdeen, Scotland, United Kingdom-- Myroslava Khomik
United Nations University - Institute for Water Environment and Health (UNU-INWEH) -- Nidhi Nagabhatla
University of Waterloo -- Dr. Myroslava Khomik




Highly Qualified Personnel: Professional training and research positions funded by Southern Forests Water Futures

## Science Advances

Forest ecosystems cover about 40% (397 Mha) of Canada's surface area and play a major role in providing sustainable water resources and healthy environments for communities in cold regions in Canada and across the world. The goal of the project was to explore how Southeastern Canadian forests will respond to future climate change, extreme weather events and management/disturbance activities.

This region contains ~22 per cent of the world's freshwater. It is home to ~8.5 million Canadians (23% of the total population), ~30.7 million Americans (10% of the total population) and is a major driver of the Canadian economy. Extensive land use changes and forest management and agricultural activities in the region are rapidly changing and constraining water resources. The project has worked to improve understanding of biogeochemical and hydrologic cycles in both conifer and deciduous forests in the region and to develop management strategies that can enhance sustainable development of forest water resources and improve forest's resilience to negative impacts of climate change, providing knowledge, tools and techniques for users and stakeholders across a range of sectors to better manage forest ecosystems and water resources, supporting development of the next-generation of ecosystem and hydrologic models used in Canadian regional and global climate models to predict future climate and hydrologic regimes, and formulating appropriate climate change mitigation and adaptation plans to secure water resources in the region and beyond.

The project carried out energy, water and carbon flux, and meteorological data measurements, using eddy covariance systems, weather stations, sapflow probes, rain gauges and plant physiological and remote sensing sensors. The project team continued energy, water and carbon flux and meteorological data measurements at Turkey Point Observatory, using eddy covariance systems, weather stations, sapflow probes, rain gauges and plant physiological and remote sensing sensors. These data are archived at the GWF Central Data System with the help from GWF Core Data Management team at McMaster University. Relevant metadata are included with the datasets according to the GWF Data Documentation Guidelines. All raw and processed data are automatically backed up daily. These protocols and measured data have been made available to project participants following GWF data sharing policy.

Ecosystem and Land Surface models (e.g. CLASS-CTEM, MESH-CLASS-CTEM-N+) simulated data products are archived for other GWF users. Help from central Data Management and Modelling teams was sought to provide high-resolution atmospheric, boundary or initializing datasets (e.g. from Weather Research and Forecasting (WRF) model data output and regional hydrologic flows) for CLASS-CTEM modeling work. Researchers have also been working on MESH-CLASSIC model simulated streamflow in two watersheds in Ontario.

Dr. Altaf Arain collaborated with Dr. Shusen Wang and the Natural Resources Canada - Canada Centre for Remote Sensing to conduct drone-based remote sensing studies at the Turkey Point Observatory. These studies will be used to develop land use and contribute landcover data sets and maps for Southern Ontario and for modelling studies to explore climate change impacts on flooding events in the Hudson Bay area.

Dr. Altaf Arain collaborated with Dr. Ingo Ensminger for the SpecNet - An Optical Sensor Network for Carbon Flux Analysis across Ecosystems. The goal of SpecNet is to compare optical and flux signals across terrestrial ecosystems having contrasting controls on carbon flux. NDVI and PRI measurements are being done at two of GWF-Turkey Point Observatory sites for long-term monitoring.

Results of this work indicate that the timing, frequency and concurrent or consecutive occurrence of extreme weather events may have significant implications for growth and carbon sequestration in these forests. These results will help in developing climate resilient and sustainable forestry practices to offset atmospheric greenhouse gas emissions and conserve water resources.

## Link to Publications List

## Knowledge Mobilization (KM)

Southern Forests Water Futures researchers have worked closely with the GWF Knowledge Mobilization Team for dissemination of project results to knowledge users and policy makers, providing relevant news items for GWF Newsletter periodically. The Southern Forests Water Futures website posts project information and activities (http://www.southernforestswaterfuture.ca). The project team collaborates with members of McMaster Centre for Climate Change (MCCC, https://climate.mcmaster.ca/) for various activities such as social media posts, sponsored public and academic lectures, conference sponsorship including the Mapping the Global Dimensions of Policy, and student engagement and communication activities. Collaboration with the United Nations University Institute for Water Environment and Health (UNU-INWEH) supports knowledge dissemination to the public and engagement with the global sustainable development and policy processes.

Dr. Altaf Arain established McMaster Carbon Sink Forest in collaboration with McMaster Nature, Trees for Hamilton, Trees for Life, McMaster Sustainability Office and School of Earth, Environment and Society on a 1 ha private land in west Hamilton near McMaster Forest Lands by planting about 1000 trees. The McMaster Carbon Sink Forest is an excellent example and living proof of for excellence in environmental teaching, research and most importantly community engagement. It will provide numerous opportunities for collaboration with research groups, public and private organizations and individuals interested in environmental causes and climate change. Observations of the forest pre- and post-planting will create opportunities for student engagement and future research projects in the carbon cycle, biogeochemistry, hydrology, biodiversity, biological, geographic, and remote sensing studies, and forest ecosystem and human health studies.

https://climate.mcmaster.ca/community-outreach-2/mcmaster-carbon-sink-forest/

### Meetings with governments, decision makers, practitioners

Research conducted by Dr. Altaf Arain‘s HQP in the SFWF Project contributed to meta analyses that make up to the IPCC reports, international policy documents. SFWF research also contributes to the growing body of literature that is published in top journals, which are often referenced by policymakers as they aim to develop policy for governmental action on climate and carbon neutrality.

### Articles in popular media

- The Hamilton Spectator. Planting trees at Mac - Volunteers gather to plant 300 trees at model forest. The Hamilton Spectator, 6 November 2022. (https://www.thespec.com/photos/2022/11/05/planting-trees-at-mac.html)

- Expect ‘more heat waves, more warm days and tropical nights’: McMaster climate expert. The Hamilton Spectator, 27 July 2022. (https://www.thespec.com/news/hamilton-region/2022/07/25/mcmaster-altaf-arain-climate.html)

- Daily News. Faculty and students give journalist in residence a master class in hope - Faculty of Science’s inaugural journalist in residence, Avis Favaro met with dozens of faculty and students. Daily News, 26 October 2022. (https://dailynews.mcmaster.ca/articles/faculty-and-students-give-journalist-in-residence-a-master-class-in-hope/)

- Brighter World. Creating a blueprint for a greener future: Why fighting climate change is not as simple as planting some trees. Brighter World, 20 April 2022. (https://brighterworld.mcmaster.ca/articles/creating-a-blueprint-for-a-greener-future-why-fighting-climate-change-is-not-as-simple-as-planting-some-trees/)

- EarthDay.ca. https://earthday.ca/2022/04/22/earth-day-official-canadian-kick-off-across-the-country-thousands-of-canadians-are-taking-action-for-the-planet/. https://earthday.ca/april-22/events/ceremonial-planting/

- Science Matters. https://mailchi.mp/mcmaster/may2022sciencematters

- David Suzuki Foundation - davidsuzuki.org. Future Ground Prize. The McMaster Carbon Sink Forest was one of the environmental projects shortlisted for the Future Ground Prize. https://davidsuzuki.org/press/david-suzuki-foundation-announces-2022-future-ground-prize-youth-finalists/

Interviews (broadcast or text)

- CHCH TV Interview to comment on United Nations Climate Change 2023: Synthesis Report on 20 March 2023.

- CHCH TV Interview on Heatwave across Southern Ontario and around the world on 19 July 2022. https://www.chch.com/earth-day-events-happening-in-the-hamilton-halton-niagara-regions

# Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1-stressors.phpx

Region: Great Lakes Region

Total GWF funding support: $300,000

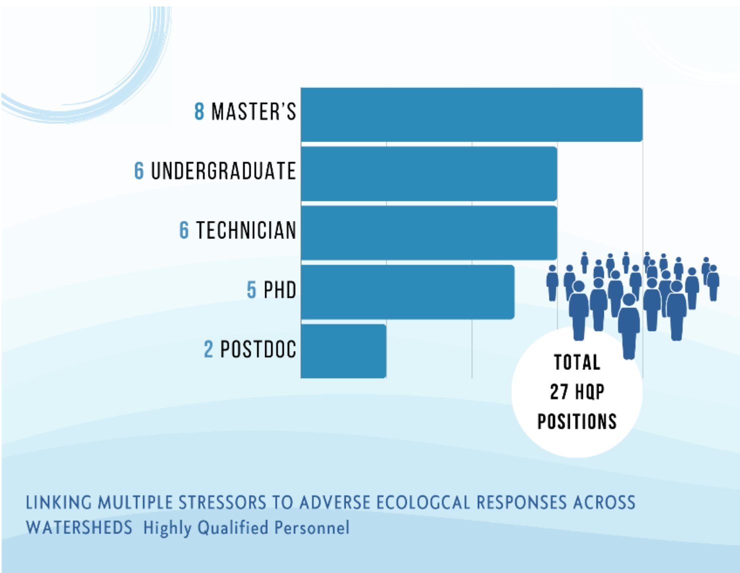
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Mark Servos, University of Waterloo Contact: mservos@uwaterloo.ca
Wayne Parker, University of Waterloo
Paul Craig, University of Waterloo

## Partners, Collaborators, and Users

Region of Waterloo -- Dominika Celmer-Repin




Highly Qualified Personnel: Professional training and research positions funded by Linking Multiple Stressors to Adverse Ecological Responses across Watersheds

## Science Advances

Integration of contaminant fate modelling (including hydrologic variability) with measured biological outcomes has rarely been done, especially in the context of evaluating multiple stressors and natural variability at the watershed scale. This is partly due to the need to have site specific information as well as the need for an interdisciplinary approach (e.g., environmental chemistry, biology, engineering, etc.). The project supports improved monitoring and risk assessment programs through the development of models and tools that can be employed to predict the impacts of contaminants related to changing urban environments and climate on aquatic ecosystems. This work focuses on creating and applying knowledge necessary for predicting and interpreting the impacts of urbanization (e.g., wastewater, storm water, population growthin the context of variability (natural and anthropogenic) in the Grand River watershed. This will form the foundation for building frameworks for consideration of multiple stressors that are a major challenge for watershed management, especially in the face of global environmental change.

This project was directly related to enabling the research to pivot to wastewater surveillance of the SARS-CoV-2 global pandemic. Lake Futures enabled the initial work, while this specific project supported deployments of wastewater expertise and relationships that allowed the work to be done effectively and pivot quickly to address the urgent needs of the global pandemic. The response to the pandemic was a unique combination of support from Lake Futures, Next Generation Solutions, GWF Core and this current project.

Although considerable effort of this project has gone into the COVID-19 response, progress on the original objectives has been made:

Supporting the assessment of major infrastructure projects conducted in the Grand River over the past decade, modelling is using wastewater data and river surveys for chemicals and effects measured in other projects to refine and validate models. The model is a combination of nested models to define sources, wastewater treatment and river processes, incorporating hydrology and environmental processes to predict the release of the representative chemicals from wastewater outfalls and their changes as they flow downstream. It specifically includes sites where past effluent, water and fish collections have occurred. The first version of the model has been published and the improved version is now included in a MSc thesis recently submitted by Zeeb. The model has been applied to the Grand River and compared to a multi-year data set for effluent and river water samples. It is calibrated for dilution based on hydrology and chemical tracers. Several chemicals of concern with different properties have now been examined using the model to predict concentration spatially and temporally (as treatment upgrades have been implemented). The model has also now been extended as far downstream as Ohsweken.

The model is also being applied to interpretation of other biological and chemical endpoints such as fish metabolism as a potential endpoint of concern in the context of cumulative effects. The Region of Waterloo continues to be a key partner through a NSERC CRD grant that is focused on biological responses to treatment upgrades, is now providing historical effluent and biological data for assessment of long-term trends.

The model is expected to be refined to also include the changes in contaminants such as venlafaxine to support interpretation of fate, toxicity and risk. This is the focus of a recently funded National Contaminants Advisory Group, Fisheries and Oceans Canada project. This new work will adapt and apply the current model developed under GWF using data currently generated in experiments and effluent/river monitoring.

Team members also recently worked with the Region of Waterloo to secure funding (NSERC Alliance) to evaluate factors affecting performance of a hybrid MABR process at full scale. This includes an examination of how this unique treatment approach reduces pharmaceuticals and their release into the environment. An additional NESRC Alliance proposal has been submitted to look at the fate and bioavailability of pharmaceuticals in artificial channels (Pine Creek) in collaboration with a large research group in Alberta. The modeling already developed will be applied in these studies.

## Link to Publications List

# Knowledge Mobilization (KM)

Invited by Chief Mark B. Hill to a meeting to discuss Indigenous role in design of a Canadian Water Agency; “Think-Tank on Six Nations role in the Co-Development of the Canada Water Agency.” Oct. 20, 2020. Invited participant.

Promotional video

Collaboration in the Grand River. https://www.youtube.com/watch?v=WtneNmyN2DI

Researchers investigating the Rainbow Darter in the Grand River

## Professional Development and Technology Transfer

ECCC Mixtures Workshop On-line. Jan. 26-28, 2021. Review of emerging and alternate ways to assess complex mixture.

# Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision-Support

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1-stream-network-modelling.php

Region: Great Lakes

Total GWF funding support: $260,000

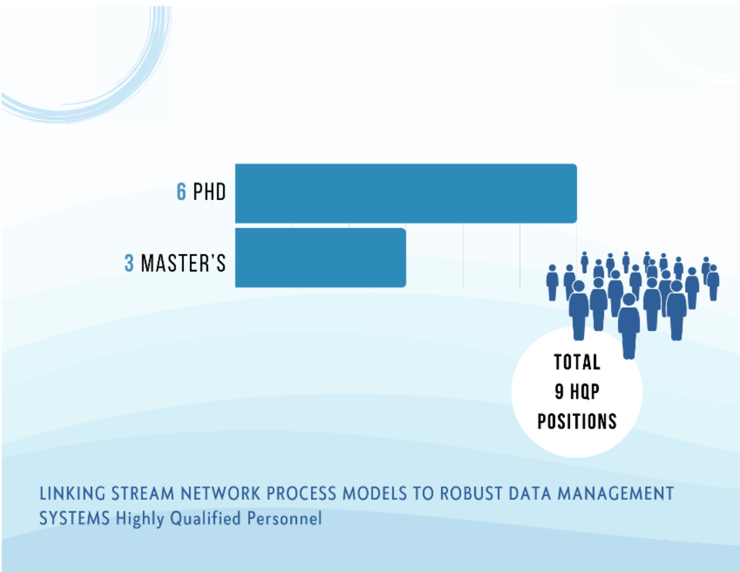
Project dates: December 2017-November 2020 COMPLETED

## Investigators

Bruce MacVicar, University of Waterloo Contact: bmacvica@uwaterloo.ca
Simon Courtenay, University of Waterloo
Stephen Murphy, University of Waterloo
Paulo Alencar, University of Waterloo
Don Cowan, University of Waterloo

## Partners, Collaborators, and Users

Grand River Conservation Authority -- Sandra Cooke (note has since left this position)
Credit River Conservation -- Amanjot Singh
Toronto and Region Conservation Authority -- Laura del Giudice




Highly Qualified Personnel: Professional training and research positions funded by Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision-Support

## Science Advances

The flow and sediment regime of rivers is profoundly altered by urbanization, which means that the physical structure and the nature of disturbance in the environment is different. This concept is well known, yet we know surprisingly little on a process scale about how these changes play out, flood by flood, in urban rivers. Urban rivers are also very different depending on the ethos and regulations of the era in which the landscape was converted to urban uses, which primarily affects how flow off of impervious surfaces is routed to the surface water channels.

This project developed online tools that combine knowledge from different disciplines and sources to inform decision-making regarding issues that could affect the health of urban streams and rivers. Consolidated monitoring and modelling data have been made available through a platform that will enhance understanding of the potential cumulative effects and risks associated with specific decisions such as land use planning, risk assessment (due to changes in climate) and stream restoration. Researchers worked with partners including municipalities and conservation authorities in Wilket, Morningside and Ganatsekaigon creeks in Toronto and Blair Creek in Kitchener to ensure that information was presented in a way that end users can in an easily digest such as through maps, tables and tailored report cards.

Science progress was primarily related to understanding of the flow and sediment regime in urban rivers and the development of data management tools. A new tool, Stream Power Index for Networks (SPIN), was used in an engineering design project and in related urban development research projects. SPIN and related work was integrated with a Risk and Return on Investment Tool, a river stability algorithm for a large engineering research partner was developed, the iEnvironment++ software platform created. The project produced a series of reports for partners Risk Sciences International and Credit River Conservation Authority and worked with them to integrate code. The work has contributed new approaches for modelling the risk related to the risk of erosion in urban areas and the hydraulic uncertainty associated with flood modelling in urban areas. A. Clow (MASc) successfully developed a field methodology and modelling approach for understanding stream stability in remote catchments and integrated his work with a proprietary program developed by SNC Lavalin. This research, combined with the SPIN tool and the project's field work approach were used as the basis for a research application also submitted to the GWF initiative for understanding the current changes occurring in northern rivers as a result of climate change. More and more organizations, including research laboratories, NGOs and water management authorities or conservation authorities are using the iEnvironment++ software platform to store and access data related to surface water. This constant growth in user groups can affect significant changes on the underlying database structure, which can impact literally hundreds of application programs. Thus, every time a change in the database structure occurs, hundreds of users may have to be contacted to ensure that their applications still work. This need creates an "impossible" software maintenance problem. The solution to this problem is to isolate the changes in database structure from the applications. This isolation can be achieved through a complex data application interface (data API), which isolates changes in data structure from applications. An initial version of such a data API has now been developed and tested and improvements are being created based on current use.

## Link to Publications List

## Knowledge Mobilization (KM)

Much of the research ongoing through this current project is related to the title of the application, which essentially states a knowledge mobilization need. Consulting companies, conservation authorities, and others are using this research and integrating it into their problem identification and analysis procedures. The work has been featured at open workshops at CAs and CSA and research communication meetings. Algorithms are being made more widely available through sites such as GitHub and tools such as the RROIT, soon to be available at (https://sustainabletechnologies.ca/home/urban-runoff-green-infrastructure/rroit/) The PI was also recently asked to review the Region of Waterloo's stormwater management in their strategic plan, particularly in an effort to identify risks and opportunities that are created by the ongoing Covid 19 pandemic.

The iEnvironment++ software platform is constantly acquiring new user groups. These groups include research groups in Canadian universities and NGOs as well multiple Ontario conservation authorities. These groups add data to the platform and use it to examine research issues as well as practical problems associated with surface water such as the impact of runoff on fish populations and on structures associated with watercourses.

Meetings with governments, decision makers, practitioners:

- 2020 - MacVicar, B. and E. Papangelakis, Urban Rivers: Sediment transport, erosion risk, and restoration, Stantec Consultants workshop (invited talk), Nov 26 2020.
- 2020 - MacVicar, B. and M. Iannetta, Stormwater, Region of Waterloo - University of Waterloo Symposium on Implications of Covid-19 for the Regional Official Plan, August 18, 2020.
- 2019 - Babaran, D., M. McCarthy, C. Irvine, J. Ivey, D. Armitage, B. MacVicar and S. Courtenay, Impacts of suburban development on fish and benthic invertebrates in Blair Creek subwatershed of the Grand River. University of Waterloo Research Spotlight. GRCA Head Office, Cambridge ON (poster).
- 2019 – MacVicar, B.J. - FrankenRivers: An opportunity to Rethink Urban Rivers, presentation at UW Research Spotlight: The Grand River Watershed, GRCA Head Office, Cambridge ON.
- 2019 – MacVicar, B.J., E. Papangelakis, A. Montakhab, A. Cain, M. Iannetta, P. Ashmore, Sediment Transport in Urban Rivers, presentation at research and direction workshop on erosion and flood risk in urban catchments, Toronto and Region Conservation Authority head office June 18, 2019.
- 2019 – Abedin, S., J. Turecek, B.J. MacVicar, Stream monitoring/Study Design workshop, workshop participant, Southern Ontario Stream Monitoring Research Team (SOSMART), Niagara Region Conservation Authority, Ball's Falls Conservation Area.
- 2019 - Mulholland, D., Progress towards use of the Flowing Waters Information System (FWIS) Stream power modelling of urban impacts on stream systems, Southern Ontario Stream Monitoring and Research Team (SOSMART), Vineland, Ontario, Hosted by Credit Valley Conservation.
- 2019 – Canadian Standards Association Highway Bridge Design Code review – workshop participant July 2019, Mississauga, Ontario.
- 2019 – McCarthy, M. and S. Courtenay, meeting with J. Ivey and S. Cooke for exchange of data on GRCA's macroinvertebrate monitoring program.

Interviews: MacVicar interview, CTV National News, April 24, 2019, Canadian Communities Struggling against Rising Floodwaters, Television Interview

https://www.ctvnews.ca/ video?clipId=1667529.

# Professional Development and Technology Transfer

Turecek, J. 5th Symposium on Urbanization and Stream Ecology, February 12-15, 2020, Austin, TX. Jessica was sent to this symposium, which is part conference with presentations (she presented her research plan there), and part workshop/brainstorming session to discuss ideas for urban stream ecology and restoration possibilities.

# Linking Water Governance in Canada to Global Economic, Social and Political Drivers

Web Link: Water Governance - Global Water Futures - University of Saskatchewan (usask.ca)

Region: Great Lakes

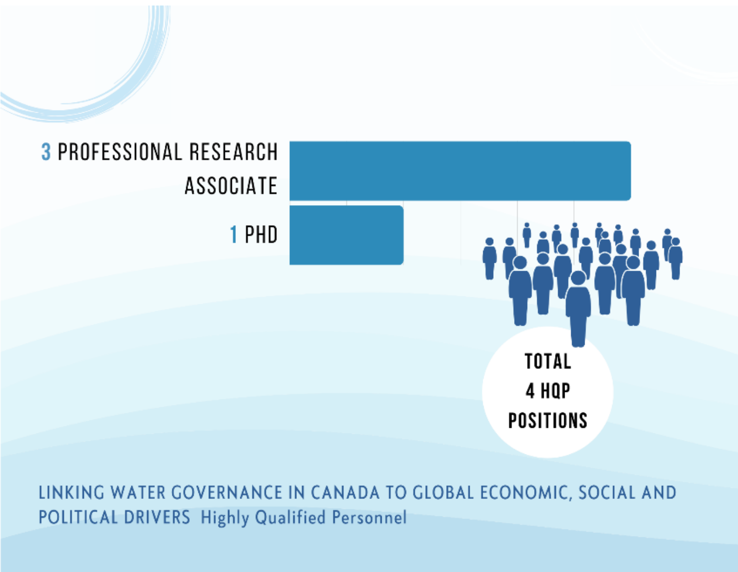
Total GWF funding support: $300,000

Project dates: December 2017-November 2020. COMPLETED

## Investigators

Rob de Loe, University of Waterloo Contact: rdeloe@uwaterloo.ca
Dustin Garrick, University of Oxford

## Partners, Collaborators, and Users




Highly Qualified Personnel: Professional training and research positions funded by Linking Water Governance in Canada to Global Economic, Social and Political Drivers

## Science Advances

In countries around the world, water resources are under pressure from numerous chronic and acute sources. Problems such as overuse and contamination persist despite decades of sustained attention from government and stakeholders. Improving governance is necessary, but the crucial role of external social, economic and political drivers and forces that operate beyond national borders yet impact governance within countries must be accounted for more effectively. Canada's water resources and governance systems are subject to these drivers and forces. Working in Lake Erie Basin, this project is identifying and assessing social, economic and political trends internal and external to the water sector that have, or may have, implications for water governance in Canada, and assessing ways of adapting water governance in Canada to better account for those drivers. Accomplishments focused on two main components:

Identifying external drivers to nutrient management in Lake Erie basin: this work supports and further develops a diagnostic framework through delineating the existing governance system for nutrient management in Lake Erie basin and the scales at which it is operating. It identifies external drivers and the extent to which the existing governance system affects consideration of those external drivers, and explores innovative ways of modifying the governance system to better deal with the effect of external drivers. Document analysis and data collection for Policy Delta surveys were completed, and key informant interviews that support the overall purpose of the study will follow.

Demographic changes as an external driver to water governance in Lake Erie basin: this work addresses potential effects of demographics changes in Ontario, especially as a result of immigration, on water governance processes in the Great Lakes basin. With the growing trend of immigrants with diverse environmental values and attitudes being integrated into Canadian communities, this poses unique challenges and opportunities to water governance structures and processes. A literature review from 2015 to 2019 found that the water governance community has been slow to recognize immigrant voices in research. Building on this, the project is investigating the nature of participation from immigrants on water quality related governance processes in Southern Ontario. For this purpose, the cities of London and Windsor were selected as case studies. The COVID-19 pandemic has severely affected the execution of this part of the work.

Link to Publications List

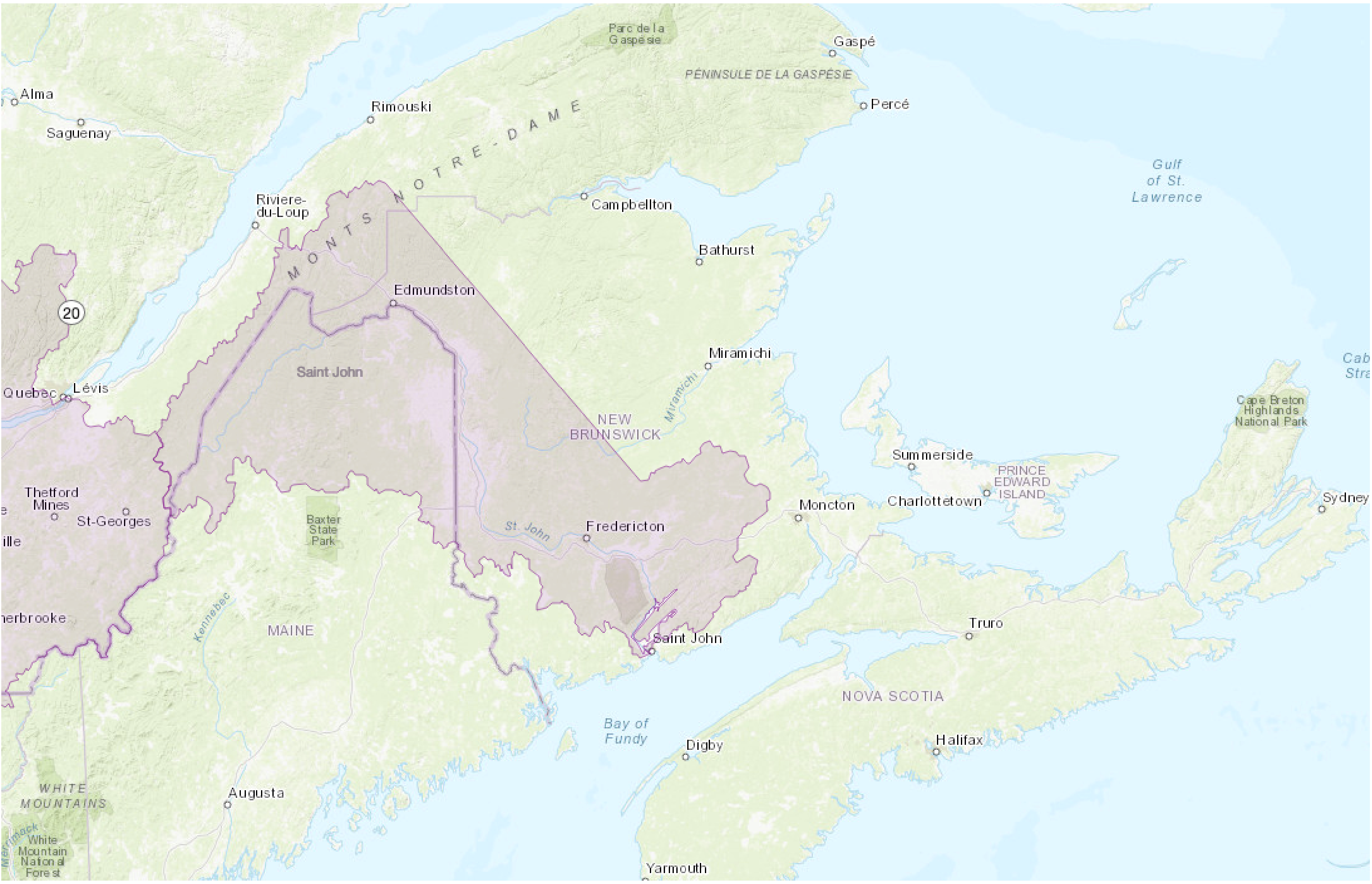
# Knowledge Mobilization (KM)

A project HQP was twice invited to present findings from her research to the Ontario Ministry of Agriculture, Food and Rural Affairs Participants also included staff from the Program Coordination, Research and Partnerships Unit at the ministry. The focus of the presentation was to provide new insights into the various socio-economic and climate related drivers that may affect nutrient management efforts in Lake Erie basin, which is shared by Canada and the United States.

# Professional Development and Technology Transfer

Project HQP attended two workshops: Learning 'R' (Nov 2, 2019), and Introduction to GIS (Nov 30, 2019). The workshops were organized by University of Waterloo Chapter of GWF Young Professionals.

# Atlantic Region



# Saint John River Experiment on Cold Season Storms (SaJESS)

Web Link: https://gwf.usask.ca/projects-facilities/all-projects/p1ph2-sajess.php; https://gwf-sajess.weebly.com/

Region: Atlantic Region

Total GWF funding support: $200,000

Project dates: August 2020-July 2023 EXTENDED to August 2024

## Investigators

Julie Thériault, Université du Québec à Montréal
Contact: theriault.julie@uqam.ca
Stephen Déry, University of Northern British Columbia
Ronald Stewart, University of Manitoba

## Partners, Collaborators and Users

Artys -- Matteo Colli
Brilliant Labs -- Kathleen Rice
Canada Research Chair Tier 2 -- Julie Thériault
CFI Innovation, Adaptable Earth Observation System -- Julie Thériault
École Polytechnique Fédérale de Lausanne -- Alexis Berne
Emergency Measures of the City of Edmundston -- Jacques Doiron
Environment and Climate Change Canada (ECCC) -- Vincent Vionnet, Rick Fleetwood, Eva Mekis, Daniel Michelson, Jason Milbrandt
Météo Suisse -- Yves-Alain Roulet
NB Environment -- Darryl Pupek
NB Power -- Jim Samms
Société d'aménagement de la rivière Madawaska -- Charles-Oneil Crites
Université du Québec à Montréal -- Julie Thériault
University of Manitoba -- Ronald Stewart
University of Manitoba, Ronald Stewart
University of Northern British Columbia -- Stephen Déry
University of Saskatchewan -- Karl-Erich Linderschmidt


Highly Qualified Personnel: Professional training and research positions funded by Saint John River Experiment on Cold Season Storms

# Science Advances

This project focused on cold region processes related to winter and spring storms and their precipitation over the transboundary Upper Saint John River Basin. This area experienced catastrophic flooding in 2008, 2018, and 2019. Despite this, no studies of storms and precipitation and their impacts on snowpack evolution had been conducted in this region.

A climatology of the Saint-John River Basin was conducted for use as a reference for conditions during the SAJESS field campaign (Thompson et al. 2023). The months of December 2020 and January 2021 were warmer than the climatology while still receiving a mixture of solid, liquid, and mixed precipitation. The other months (February-April 2021) were similar to the climatology. Conditions around 0°C occurred 18% of the time and during 33% of the precipitation events. The warmer storms originated from the mainland of North America while the colder storms originated from the Atlantic Ocean.

An examination of factors contributing to floods in three years (2008, 2018, 2019) as well as to the lack of flooding in the SAJESS year (2021) was completed (Rickard, 2023). There are commonalities and differences between flood years as well as between flood years and the non-flood year. When averaged across the upper basin, flood years show consistency in terms of positive winter and spring precipitation anomalies, positive snow water equivalent (SWE) anomalies, and steep increases in April cumulative runoff. However, they show inconsistency in terms of ice jams and positive spring total precipitation anomalies when averaged over the full basin. A comparison of the conditions between flood and non-flood years also reveals commonalities, such as northeastward-moving storms affecting the region and positive winter total precipitation anomalies when averaged over the full basin. There are also differences, such as the early snowmelt and early timing of peak flow and water level in the non-flood year. As well, rain-on-snow events were a prominent feature of the three flood years but not the non-flood year—not because there were no rainstorms, but because there was low SWE when they occurred, due to the early snowmelt.

The precipitation phase can vary drastically from storm to storm. Depending on the time of the precipitation, they can lead to complete snowmelt across the region and ice-breakup on the Saint John River. A sequence of mixed-precipitation storms occurred at the end of March and beginning of April 2021. During this period, a series of five precipitation events coinciding with the 2021 spring freshet have been documented, four of which were associated with a precipitation type transition from snow to rain or rain to snow. During this period, several types of precipitation were observed such as rain, snow and ice pellets. No episodes of freezing rain were reported on the surface. Atmospheric conditions were near-0oC at the surface and aloft during much of this period.

Given the high occurrence of mixed precipitation, their impact on the snowpack is critical. Multiple Precipitation Partitioning Methods (PPM) of varying complexity as well as precipitation phase measurements from the SAJESS project were used to simulate the snowpack evolution (Leroux et al. 2023). Five PPMs commonly used in hydrological models were tested against observations from an optical-laser disdrometer and a micro rain radar. PPMs based on wet-bulb temperature produced the most accurate estimations for rainfall and snowfall occurrence. Mixed precipitation was the most difficult phase to predict. The multi-physics model Crocus was then used to simulate snowpack evolution and to diagnose model sensitivity to snowpack accumulation processes (PPM, snowfall density, compaction). Sixteen snowpack accumulation periods, including nine warm accumulation events (average temperatures above -2oC) were observed during the study period. When considering all accumulation events, simulated changes in SWE were more sensitive to the type of PPM used, whereas simulated changes in snow depth were more sensitive to uncertainties in snowfall density. Choice of PPM was the main source of model sensitivity for changes in SWE and snow depth when only considering warm events. Overall, this study highlights the impact of precipitation phase estimations on snowpack accumulation at the surface during near-0oC conditions.

Examination of the hydrometeor types and characteristics at the surface using the SAJESS Multi-Angle Snowflake Camera (MASC) data is also underway. After 980 hours of operation, a previously published supervised detection algorithm was used to process over 93,000 collected images, with the algorithm detecting solid particles 92% of the time during the mixed phased events. This contrasts with manual observations for the same period that recorded 50:50 rain and snow observations, implying that liquid particles may be seen as solid by the MASC. During snow events, however, when only solid particles were recorded with manual observations, MASC data compare favorably in both precipitation type and timing. Ongoing work includes further analysis of MASC data to investigate the ability to identify liquid and mixed-phase particles.

Finally, precipitation amounts were collected during SAJESS across the region through CoCoRaHS. The measurements showed that the distribution of the amount and phase of precipitation varied across the Upper Saint John River Basin. Higher amounts of precipitation fell upstream of Edmundston and the precipitation phase upstream was predominantly solid compared to more liquid precipitation near Edmundston. Furthermore, CoCoRaHS agreed well with the data collected at the SAJESS automatic measurements. Further analysis will be conducted to assess the added value of higher spatial resolution of precipitation measurements over the SAJESS regions and how it can be used to better estimate snow on the ground.

SAJESS contributed to advanced disaster prevention by better understanding conditions leading to snow, rain and freezing rain as well as how they impact the snowpack and, in turn, the streamflow. Prediction of streamflow and ice jams are critical information for water managers to support emergency responses to flooding.

Link to Publications List

## Knowledge Mobilization (KM)

SAJESS recruited volunteer observers of all ages, from school-aged children to retirees. These contributed to augmenting a community-based monitoring network within the upper Saint John River Basin, called the Community Collaborative Rain, Hail and Snow (CoCoRaHS) Network. Recruitment of volunteers has allowed SAJESS members to disseminate information about precipitation measurements and atmospheric sciences to the local community. Environment and Climate Change Canada (ECCC) was interested in measurements collected during SAJESS, as the CoCoRaHS network provides a database used by the Canadian Precipitation Analysis (CaPA) system. A preliminary analysis showed that the SAJESS CoCoRaHS improved the CaPA product. Also, three ECCC Weather Brain stations, among a network of 200 stations across Canada, were installed in the Upper Saint John River basin. They are hosted by volunteers that continue to collect CoCoRaHS data. SAJESS collaborated with weather forecasters of ECCC (Atlantic Region) because very few measurements are available over the Upper Saint John River Basin. Atmospheric soundings were shared with forecasters in (near) real-time. The information complements the 12-hourly atmospheric soundings available at Caribou, Maine. Up-to-the-minute observations were shared directly from project field observers and data from the precipitation phase observatory.

A student prepares to release a sounding balloon during the Saint John River experiment on cold season storms (SAJESS), in Edmundston, New Brunswick

SAJESS social media KM has been primarily focused on sharing and cross-posting of media exposure of SAJESS, and SAJESS-related Facebook posts by Brilliant Labs and Société d'aménagement de la rivière Madawaska (SARM). When the opportunity arose, SAJESS observers posted on the SAJESS Facebook page (SAJESS-UQAM), and on Twitter (@sajessstorms). These posts were also automatically uploaded to the social media thread of the SAJESS website (gwf-sajess.weebly.com) along with blog posts written by SAJESS members after each event. This allowed project collaborators and partners to monitor the field campaign from afar. The PI, Julie Thériault, sent weekly emails to update the partners, collaborators, and volunteers. Information regarding the current weather, upcoming weather forecast, and snowpack conditions have been communicated to the Emergency Measures Organization (EMO) coordinator (Jacques Doiron) of the City of Edmundston. The city EMO jointly monitors water levels and coordinates the local response to high water events in the Upper Saint John River Basin with the New Brunswick Provincial EMO. The risks of flooding, ice jams, and damage to critical infrastructure affect not only Edmundston, but all communities downstream from the upper basin.

### Interviews (broadcast or text)

- Un spectacle combinera musique et météo à Saint-Basile, Entrevue Radio-Canada Ohdio (4 février 2023)
- L'OPSHL combinera musique et science dans son prochain spectacle, Acadie Nouvelle (1 février 2023)
- Mariage entre musique et science au Nouveau-Brunswick, Actualité UQAM (7 February 2023)

## Other Outreach

- Concert symphonique Climate, tempêtes et passions, Orchestre Philharmonique du Haut Saint-Jean (5 février 2023)

- Presenter, Raconte-moi l'hiver, Soirée Sciences et contes, Coeur des sciences, UQAM, Dec. 2022: https://coeurdessciences.uqam.ca/component/eventlist/details/1079-raconte-moi-hiver.html

- Presenter, Soapbox Ottawa, Downtown Ottawa, September 2022: https://soapboxscienceotta.wixsite.com/website

# International

Laguna del Inca and Los Tres Hermanos in the Andes Mountains, Chile, October 2018. Photo by Chris DeBeer

## Planetary Water Prediction Initiative (PWPI)

Web Link: https://gwf.usask.ca/core-modelling/modelling-domain/planetary-water-prediction-initiative.php

Region: International

Total GWF funding support: $1,500,000

Project dates: June 2020-August 2023

### Investigators

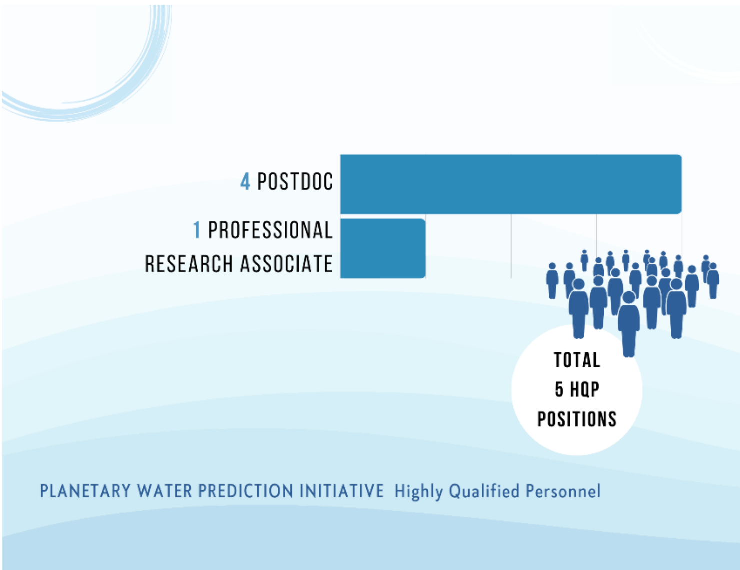
John Pomeroy, University of Saskatchewan Contact: john.pomeroy@usask.ca
Alain Pietroniro, University of Calgary
Martyn Clark, University of Saskatchewan

### Partners, Collaborators, and Users

Arctic Council
Chinese Academy of Sciences and the Third Pole Environment Initiative (TPE)
Future Earth Sustainable Water Future Programme (SWFP)

Raymond Spiteri, University of Saskatchewan
Chris DeBeer, University of Saskatchewan

Government of Tajikistan
Indian Institute of Science, Bangalore (IIS)
International Network for Alpine Research Catchment Hydrology (INARCH)
Spanish National Research Council (CSIC)
Tribhuvan University, Nepal
United Nations Educational, Scientific, and Cultural Organization Intergovernmental Hydrological Programme (UNESCO-IHP)
University of Chile, Santiago
Water and Climate Coalition (WCC)
World Climate Research Programme (WCRP)
World Meteorological Organization (WMO)



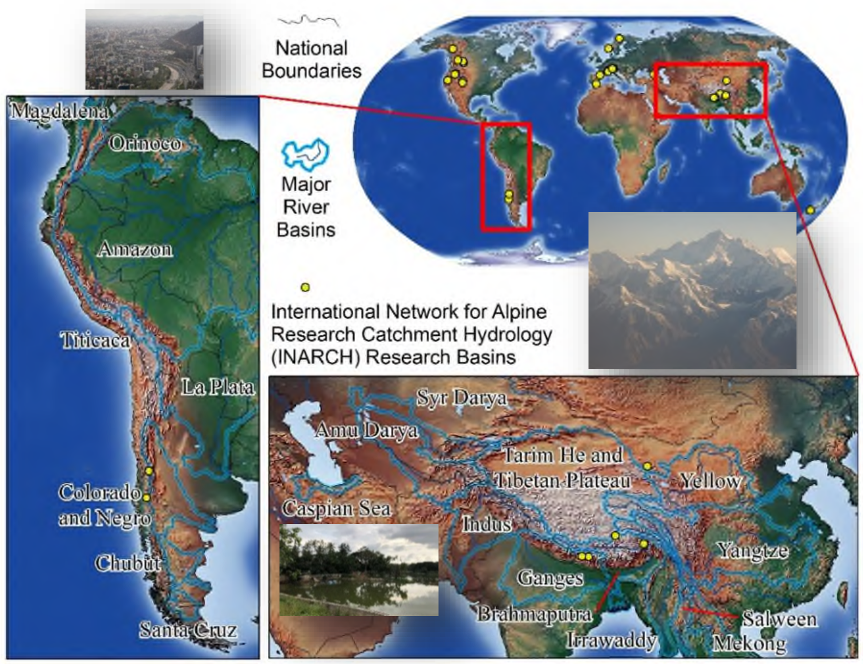

Highly Qualified Personnel: Professional training and research positions funded by Planetary Water Prediction Initiative

## Overview and Vision

Global Water Futures (GWF) and its institutional partners are committed to international leadership in water science for cold regions. The program is developing new transdisciplinary science, new environmental monitoring systems and predictive modelling tools, and novel user-focused approaches to putting new knowledge into action, providing urgently needed risk management technologies, decision-making tools, and other evidence-based solutions to complex water challenges.

In response to the call for action issued by the World Meteorological Organization High Mountain Summit, and UNESCO's IHP-IX strategic plan "Science for a Water Secure World in a Changing Environment", GWF launched the Planetary Water Prediction Initiative (PWPI) as an extension of its core modelling and forecasting team efforts. PWPI advances the computational infrastructure (datasets, modeling capabilities) necessary to produce global-domain simulations and predictions of hydrological risks. Moreover, PWPI will use these state-of-the-art modeling capabilities to develop new and strategic collaborations with organizations and countries, through mutually beneficial, internationally focused projects. PWPI will involve collaboration with countries in the Americas, Asia, Africa, and Europe to develop, support, test, and apply coupled climate–hydrology–water quality–water management models globally with an emphasis on river basins where high mountain water supplies feed local and downstream water demands and ecosystem needs. Major areas of international collaboration and support with GWF will primarily focus on high mountain and cold regions, which are recognized strengths of GWF.

# Science Advances




Location of INARCH research basins

### Geographic focus for the GWF PWPI

Key regions are the Andes of South America and the Asian highlands of the Hindu-Kush-Himalaya and Tibetan Plateau, and Central Asia. Regional activities leverage International Network for Alpine Research Catchment Hydrology (INARCH; https://inarch.usask.ca) activities and field research sites as model testbeds and hydro-meteorological observatories. Efforts will be expanded to the Arctic drainage basin, and other potential high mountain regions may include East Africa and the Atlas Mountains.

PWPI provides international access to the GWF Core Modelling Team's extensive modelling capacity that can be used for global applications in collaboration with international partners. Scientists around the world can use the open-source tools and models that are developed within the core modeling team. This collaboration in turn results in development and enhancement of scientific findings on a global scale. The infrastructure and coding capabilities include several packages and workflows that simplify configuration of models anywhere on the planet. Key tools such as Community Workflows to Advance Reproducibility in Hydrologic Modeling (CWARHM; https://github.com/CH-Earth/CWARHM) help scientists around the world to reduce their time on technical tasks such as model set up and invest more on the scientific questions that they are addressing. The model configuration workflow enables local to global scale simulation. Another achievement has been further development of mizuRoute (https://github.com/ESCOMP/mizuRoute) as a vector-based routing model, providing the capability for flexible simulations of lakes and reservoirs at global domain. The computational efficiency of mizuRoute allows the transition from local to global scales with minimal effort. Under the WMO Water and Climate Coalition (https://www.water-climate-coalition.org/), and with collaboration with the European Centre for Medium-Range Weather Forecasts, mizuRoute has been used to route historical runoff products around the world.

Most recently, progress in PWPI has included collaboration among the GWF Core Modelling Team and INARCH members in other continents. The Canadian Hydrological Model (CHM) has been expanded to include the Northwest United States and preliminary model runs have been conducted in the Spanish Pyrenees and the Andes Mountains. The Cold Regions Hydrological Model (CRHM) is being run across the entire Andes range and MESH (Modélisation Environnementale Communautaire—Surface and Hydrology) is being run in the Andes, central Asia, and other mountain ranges. These are important developments and big steps towards fulfilling goals for multi-model and multi-scale modelling globally.

Central Asia: Spatial mismatches between water availability and land resources are the main triggers for current water conflicts in Central Asia. Projected glacier losses and snow shrinkage, resulting from climate change, will likely further exacerbate this mismatch, limiting water availability in the region. The impacts to the hydrological cycle resulting from the changes in climate in the region have not previously been diagnosed using physically based glacio-hydrological models that can resolve mountain snow and glacier hydrology with confidence. This study assesses the impacts of projected climate change on the hydrology of Syr Darya River Basin, one of the two major basins in Central Asia. Syr Darya originates from the glaciated Tien Shan Mountains, crosses a semi-arid region to the Aral Sea with its water heavily used for water supply and irrigation by four Central Asian countries. Current and future hydrological processes and natural flows were diagnosed using MESH. Due to the lack of observational data across the Syr Darya River Basin, GWF researchers first set up, calibrated and validated a MESH model for the Ala-Archa River basin, a heavily studied headwater basin in the region, and then transferred the modelling concepts and parameters to the Syr Darya model setup. Both MESH Ala-Archa and MESH Syr Darya models were forced by the EM-Earth (0.1°) and ERA-5 (0.25°) datasets. Temperature and precipitation forcing data over 1991-2010 were seasonally perturbed using outputs of CMIP5-AR5 subset based on RCP 8.5 for the region during the 2081-2100 period. The MESH Ala-Archa model performed well on predicting streamflow, with Kling-Gupta Efficiency (KGE) scores above 0.9 and percent bias below ±1% over both calibration and validation periods. Under the climate change scenarios examined, the snow covered period in Sry Darya River Basin decreased by more than three months, and peak SWE declined by 45%. The timing of peak streamflow advanced by a month from mid-June to mid-May, and peak discharge decreased by about 35% for the 2081-2100 period compared to recent conditions, primarily due to reduction of seasonal snow cover and secondarily due to deglaciation. The projected glacier loss was reflected by the reduced runoff in irrigation season. This study allows understanding the role of snow and glacier melt in controlling the water availability in Central Asia and can be used to inform climate adaptation strategies in the region.

Chile: The Salar de Atacama basin in Chile is one of the best-known saline endorheic basins in the world due to the delicate balance between extraction of lithium-rich brine from its core, tourism, and the unique ecosystems of its surrounding lagoons. However, no study to date has quantified the contribution of snowmelt compared to rainfall in supporting groundwater recharge. In this work, satellite information (Moderate Resolution Imaging Spectroradiometer, MODIS) is used to characterize the spatial and temporal dynamics of snow coverage. However, snow equivalent water is not available from remote sensing, so the Cold Regions Hydrological Model (CRHM) was used to simulate snow water equivalent, runoff, infiltration and other hydrological processes governing the water balance and groundwater recharge. CRHM makes it possible to link physical processes to hydrological processes using hydrological response units (HRU) as control volumes for water balances and as a means of discretizing the basin. HRU were defined in the Toconao sub-basin, in the eastern part of the Salar de Atacama and CRHM was parameterized from regional hydrological knowledge and run for several years, forced by reanalysis data. Special attention was paid to better understand the energy balance of snow, including sublimation and wind transport ablation losses, soil infiltration processes, and the role of snowmelt in surface runoff generation and direct and indirect groundwater recharge. Satellite observations of snow cover recorded from 2000 to 2020 showed numerous snowfalls during summer and winter. The greatest extent of snow cover occurred during winter, accounting for 60% of the annual snow-cover extent. Snow cover is generally located above 4500 m asl in summer, while in winter the snow cover is more extensive, covering a large part of the basin. The CRHM simulations show that the greatest amount of precipitation of the year falls as rain in the summer months with the drier winter dominated by snowfall and ephemeral snow cover development. The intense summer rains produce the greatest annual fluxes of runoff and infiltration. In winter, snowmelt infiltration is approximately twice that from rainfall. Snow losses by wind transport and sublimation had little impact on the overall water balance despite the dry environment. Even without measured precipitation data in the elevated zone of the study area, the simulated snow results in the CRHM are considered valid because they agree with the MODIS daily snow cover results in the Toconao sub-basin.

Global Another achievement of GWF was further development of mizuRoute as a vector-based routing model and inclusion of lakes and reservoirs in this routing model with flexibility. This allows restructuring of existing lakes and reservoirs model into one routing infrastructure, mizuRoute, and test those models at local, regional and global scale. The decompositionof the regions based on river network and computational efficiency of mizuRoute allows this transition, from local to global, with minimal effort and simulation time lapse. Under the WMO water and climate coalition and with collaboration with ECMWF European Centre for Medium-Range Weather Forecasts, we are able to route the runoff field from the historical or forecasting efforts globally with lakes and reservoirs (or without).

## Link to Publications List

# Knowledge Mobilization (KM)

The GWF PWPI contributes to many high-level international organizations, including the World Climate Research Programme (WCRP) and its Global Energy and Water Exchanges (GEWEX) project, the World Meteorological Organization (WMO), the United Nations Educational, Scientific, and Cultural Organization (UNESCO) International Hydrological Programme (IHP), the

UN Water Decade, Future Earth, and the United Nations Framework Convention on Climate Change (UNFCCC).In May 2019, John Pomeroy presented Global Water Futures and the MESH Modelling System for Water Forecasting & Prediction at the Regional Environmental Centre for Central Asia (CAREC) Regional Round Table, Almaty, Kazakhstan, May 27, 2019 to May 27, 2019. In June of that year, he participated in Learning from Hydrological Processes Observed in Instrumented Research Catchments to Develop Multi-Scale Hydrological Models. Catchment Science: Interactions of Hydrology, Biology and Geochemistry, in Andover, USA.

GWF and INARCH helped organize and co-hosted the WMO High Mountain Summit in 2019 in Geneva, Switzerland (https://highmountainsummit.wmo.int/en). This led to a Call for Action, "Avoiding the Impending Crisis in Mountain Weather, Climate, Snow, Ice and Water: Pathways to a Sustainable Global Future." Participants agreed on the need for an Integrated High Mountain Observation and Prediction Initiative to improve observations, forecasts, and data exchange in mountain ranges and headwaters around the world.

Participants at the High Mountain Summit, 2019, Geneva

GWF co-chaired the Arctic Earth System Modelling Workshop, Responding to Grand Challenges in the Pan-Arctic, for WMO and the Arctic Council in Reykjavik, Iceland in November 2019 https://www.arcticobserving.org/images/pdf/misc/Arctic_ESM_Workshop_29082019.pdf and helped develop the plan for earth system modelling of high latitudes.

GWF contributed to developing the Global Groundwater Statement – a Call to Action https://www.groundwaterstatement.org/. The Call to Action cites recent scientific breakthroughs that have highlighted the regional and international importance of the issue as well as global connections and threats to groundwater, which is the source of up 99 per cent of the Earth's liquid freshwater, is the drinking water source for more than two billion people worldwide, and provides more than 40 per cent of the water for irrigated agriculture, with nearly 1.7 billion people living above aquifers (geological formations that provide groundwater) that are stressed by overuse.

At the 2019 Future Earth meeting in Bengaluru, India (https://southasia.futureearth.org/water-future-conference/), GWF and INARCH through its Future Earth - Water Futures working group hosted a session and discussions on Global Mountain Water Security and contributed to discussions for a Mountain Water Solutions Laboratory for the Indian Himalaya.

Conference, Bengaluru, 2019

At the United Nations Climate Change Conference in Madrid, Spain (COP25), GWF focused attention on the world's changing mountain snowpacks, glaciers, vegetation, and long-term effects that the thaw of snow and ice are having on the world's freshwater and ocean water (https://gwf.usask.ca/articles/2019/news-the-world-is-losing-its-cool-with-the-loss-of-snowpacks-and-glaciers,-posing-threats-to-water-security.php). Dr. John Pomeroy presented invited talks on the Hydrological Impacts of Climate Change: Mountains, Glaciers, Snow and The Impact of a Melting Cryosphere on Our Water Futures.

The project is actively engaged with the WMO and has joined the Water and Climate Coalition (WCC; https://www.water-climate-coalition.org/), contributing actively to their activity. Dr. Pomeroy serves on the WCC Steering Committee where he represents academia. This is enabling on-the-ground connections to various partners in Asia, South America, and Europe, and to working together in developing and applying models to key local water security challenges. Through the WCC, the project has contributed to the first WMO Global State of Water Report (https://public.wmo.int/en/media/press-release/state-of-global-water-resources-report-informs-rivers-land-water-storage-and), and is providing leadership and guidance to the operational global and regional hydrological modelling community.

Dr Pomeroy presented the keynote talk at the closing session, GW4 Water Security Alliance Annual Conference 2020 in November 2020. GWF organized one science and art session and provided five talks, included an opening plenary talk to the UN COP26 climate meeting in Glasgow, Scotland in early November 2021. The sessions were organized along with UNESCO, WMO, and the Forum for Leadership on Water.

In May 2021, Dr Pomeroy presented *Understanding and Predicting Water Futures in an Era of Global Change: Climate Research Priorities for the Next Decade* at the World Climate Research Programme (WCRP) Climate Research Forum, and in June 2021, *Global Water Futures – a Transdisciplinary Water Research Program Providing Solutions to Water Threats in an Era of Global Change* at the World Environmental & Water Resources Congress (EWRI).

GWF research was presented by its Director to a High-Level event of the UN General Assembly in New York and to the World Climate Research Programme's Americas Conference in Washington, DC, on 22 September, 2021. The Permanent Missions of Hungary, Nepal, Pakistan, Russian Federation, Tajikistan to the UN in cooperation with UNDESA, UNEP, WMO, UNESCO (IHP) and UN-Water held a virtual high-level side event titled, "How changing water availability from ice and snow will impact our societies". John Pomeroy participated in a panel discussion and presented GWF research. In October 2021, he presented *Cold and Pure No More – How Rapid Climate Change is Melting Glaciers* and *Snow and Destabilising the Global Freshwater Supply* at Norwich Science Festive, and the keynote, *Climate Change, Mountain Water Security and Art* at the 43rd Annual Conference of the Association of Canadian Studies in German-speaking Countries (GKS), Grainau, Germany, in February 2022.

As part of GWF Sustainable Development Goal activities and the Canada Water Decade, GWF hosted a high-level panel at the International Conference on the International Decade For Action "Water For Sustainable Development" 2018-2028, held 6-9 June 2022, in Dushanbe, Tajikistan. Titled "Improving knowledge, education and communication: Partnering governments, universities, communities, and private sector for water tools and solutions", the session was co-chaired by Hon. Terry Duguid, M.P., Parliamentary secretary for Water in Canada. The overall premise for the session was that there is a need to invest in knowledge, education, and capacities that build bridges in the interest of more timely data and research breakthroughs and their dissemination to water-related professionals and all stakeholders and rightsholders towards urgent action to achieving water-related SDG targets. Key messages from the session were reported back to the plenary closing event and will inform the final documents developed from the meeting as inputs to the 2023 mid-term review of water-related SDGs in New York in 2023. These contributions have informed planning for the upcoming UN 2023 Water Conference which will be the largest UN meeting on water in 47 years.

At the UN General Assembly in September 2022, GWF informed development of a proposed UN International Year of Glacier Preservation to raise awareness of the loss of snow and ice resources and associated risks, to give impetus at the global level to take action, to mobilize financial resources, and to improve international cooperation and data sharing. Dr. John Pomeroy gave a keynote presentation to the UN General Assembly - High Level Side Event "The Melting Cryosphere: Threats to groundwater buffering of streamflow and the sustainability of water resources management including in SIDS" and an intervention to the Stakeholder Consultation of the President of the UN General Assembly. On December 14, 2022, at the 77th session of the United Nations General Assembly, following introduction by the Republic of Tajikistan, a resolution was unanimously adopted to declare the International Year of Glaciers' Preservation, 2025, simultaneously declaring both the International Day, March 21st, and the International Year of Glaciers' Preservation, 2025.

At the 27th UNFCC Conference of the Parties in November 2022 in Egypt, a non-binding resolution on Implementation of the Global Climate Observing System (GCOS) was adopted, This specifically addresses filling gaps in observations in mountain and polar regions and of the cryosphere, and follows from the case GWF has made at several COPs.

UNESCO-IHP has approved a UNESCO Chair in Mountain Water Sustainability amongst several GWF and INARCH members for initiation in 2023. This will provide a long-term focal point of research and outreach about mountain waters and how to reach the UN SDGs for high mountain catchments under the stress of development and climate change.

# Professional Development and Technology Transfer

GWF has engaged with many partners, collaborators, and other stakeholder groups worldwide to offer training and support for the models developed, to encourage and facilitate uptake of these models for local use, and to work collaboratively on the application of these models for the understanding of hydrological change and the prediction of water futures around the world.

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GLOBAL WATER FUTURES

SOLUTIONS TO WATER THREATS IN AN ERA OF GLOBAL CHANGE