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

February 2023

Photo: Researchers from the University of Saskatchewan and McMaster University in the Wolf Creek Research Basin, Yukon Territory. Photo by Mark Ferguson

Message from the Directors

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. Our 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 2022, the knowledge mobilized through Global Water Futures' science advances is beginning to change policy priorities 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.

Global Water Futures requires continual updates on changing user needs and methods to best deliver research results in actionable forms to knowledge users. Its User Advisory Panel guides it 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 first six years of the programme, 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. 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/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 in 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/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 begun initiation of the Canada Water Agency, now developing with a dedicated budget and Transition Office.

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 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 International Day of Glaciers' Preservation.

The content of this Briefing Book documents these initiatives among descriptions of the project-level work that is 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.

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.

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

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Distinguished Professor, Dept. of Geography & Planning
Director:
CFREF Global Water Futures Programme
USask Centre for Hydrology
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Associate Professor, Dept. of Geography & Planning
Associate Director, CFREF Global Water Futures Programme,

Contents

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 2022, 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.

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:

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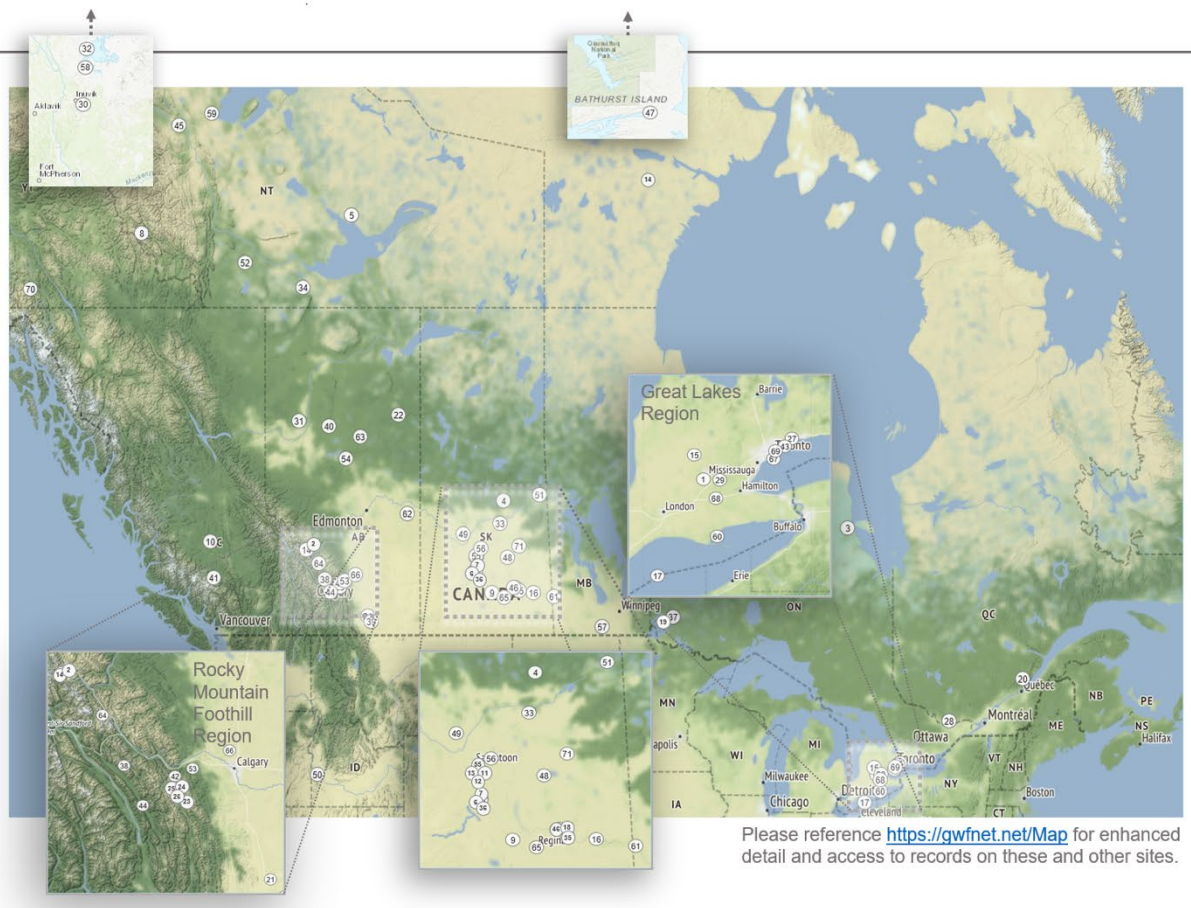
Global Water Futures Research Sites

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



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

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

Issues Important to Knowledge Users

As a Canada First Excellence Fund (CFREF) programme, 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	Mentioned by User Communities	Mentioned by Region	Projects
Forecasting and Predictive Modelling	Agriculture Electric Utilities Emergency Response Organisations Federal Government Provincial Governments Research NGOs Water Utilities	Mountain West Prairies Northern Great Lakes Atlantic	Saint John River Experiment on Cold Season Storms (SaJESS) Storms and Precipitation across the Continental Divide Experiment (SPADE) Short-Duration Extreme Precipitation in Future Climate Paradigm Shift in Downscaling Climate Model Projections Integrated Modelling Program for Canada GWF Core Modelling Team Diagnosing and Mitigating Hydrologic Model Uncertainty in High Latitude Canadian Watersheds Lake Futures Evaluation of Ice Models in Large Lakes: Using Three-Dimensional Coupled Hydrodynamic-Ice Models Planetary Water Prediction Initiative (PWPI) Collaborative Modelling Framework for Water Futures and Holistic Human Health Effects Improved Estimates of Wetland Evaporation Mountain Water Futures Significance of Groundwater Dynamics Within Hydrologic Models 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 Electric Utilities Federal Government Forestry	Mountain West Prairies Northern Great Lakes	What is Water Worth? Valuing Canada's Water Resources and Aquatic Ecosystem Services

Issues	Mentioned by User Communities	Mentioned by Region	Projects
	Mining Municipal Provincial Governments Water Utilities	Atlantic	Paradigm Shift in Downscaling Climate Model Projections Climate-Related Precipitation Extremes Short-Duration Extreme Precipitation in Future Climate Lake Futures Southern Forests Water Futures Prairie Water Mountain Water Futures Northern Water Futures Boreal Water Futures Geogenic Contamination of Groundwater Resources in Subarctic Regions Core Modelling Team Planetary Water Prediction Initiative (PWPI) Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds Groundwater, Climate Change and Water Security in the Canadian Prairies Crowdsourcing Water Science: Distributed Water Science Application Prairie Drainage Governance: Diagnosing Policy and Governance Effectiveness for Agricultural Water Management during Times of Change Agricultural Water Futures
Best Management Practices (BMPs)	Agriculture Civil Society Organisations Extractive Industry Federal Government Municipal Research NGOs Water Utilities	Mountain West Prairies Northern Great Lakes Atlantic	Lake Futures Agricultural Water Futures Boreal Water Futures Managing Urban Eutrophication Risks under Climate Change: An Integrated Modelling and Decision-Support Framework

Issues	Mentioned by User Communities	Mentioned by Region	Projects
			Towards Saskatchewan Well Water Security: Knowledge and Tools for People and Livestock Health Prairie Drainage Governance: Diagnosing Policy and Governance Effectiveness for Agricultural Water Management during Times of Change Linking Stream Network Process Models to Robust Data Management Systems for the Purpose of Land-Use Decision Support
Adaptations	Agriculture Municipal Indigenous Federal Government Provincial Governments	Mountain West Prairies Northern Atlantic	Linking Water Governance in Canada to Global Economic, Social and Political Drivers Prairie Water Agricultural Water Futures Adaptation Governance and Policy Changes in Relation to a Changing Moisture Regime Across the Southern Boreal Forest Crowdsourcing Water Science: Distributed Water Science Application
Past/Future Scenarios	Agriculture Electric Utilities Extractive Industry Fisheries Forestry Insurance/Engineering Municipal Provincial Governments Water Utilities	Mountain West Atlantic	Core Modelling Team Short-Duration Extreme Precipitation in Future Climate Linking Water Governance in Canada to Global Economic, Social and Political Drivers Planetary Water Prediction Initiative (PWPI) Agricultural Water Futures Global Water Citizenship: Integrating Networked Citizens, Scientists and Local Decision Makers
Land/Water Interactions	Agriculture Federal Government Forestry Water Utilities	Prairies Great Lakes Atlantic	Prairie Water Agricultural Water Futures Lake Futures FORecasting Tools and Mitigation Options for Diverse Bloom-Affected Lakes (FORMBLOOM)

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

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

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

Issues	Mentioned by User Communities	Mentioned by Region	Projects
			Constellation Mission and Cloud Computing Processing

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.

Photo: Greta Thunberg and team from USask on the Athabasca Glacier. Photo by Mark Ferguson

Canada Wide

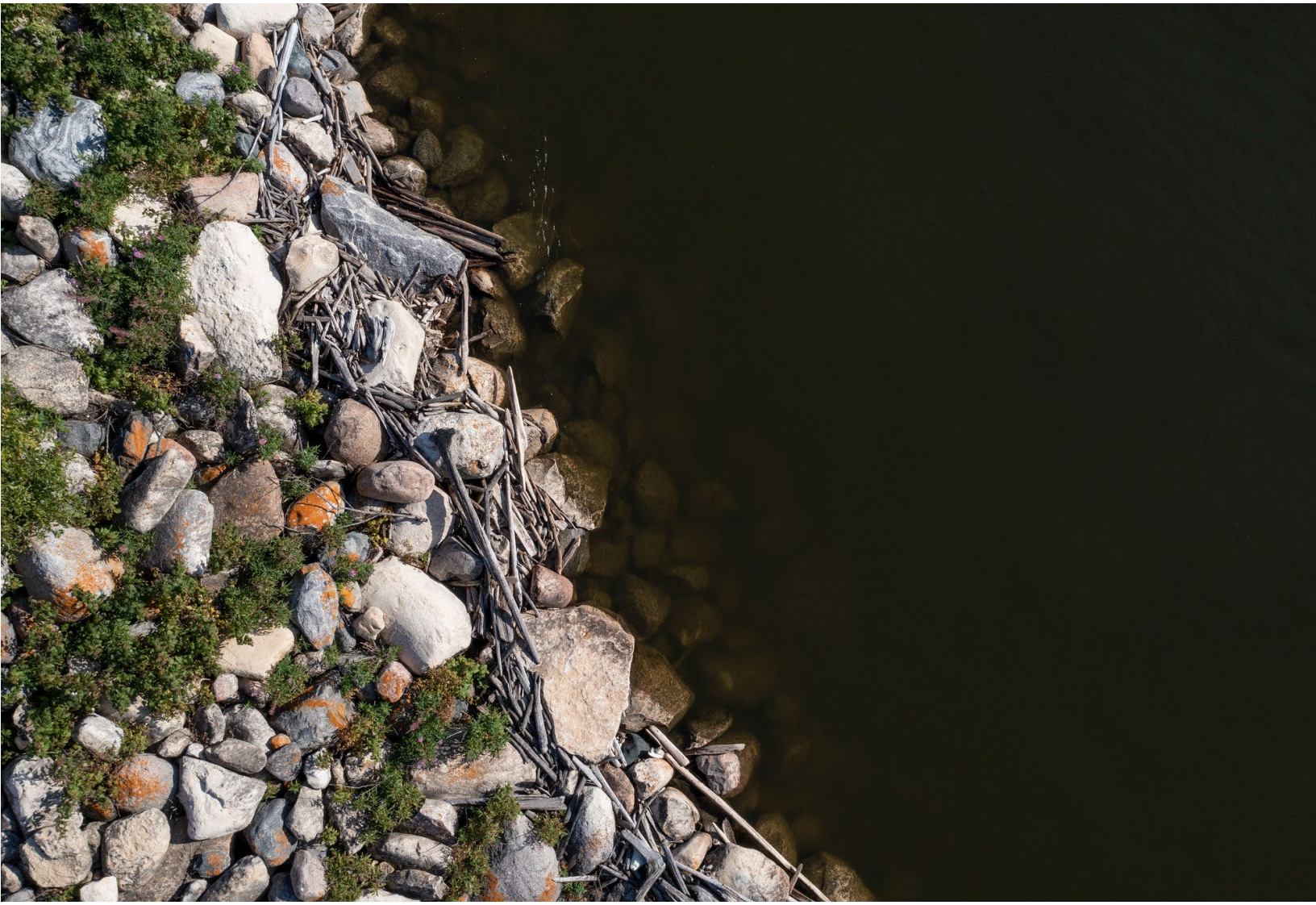


Photo: Near the E.B. Campbell Dam, Saskatchewan. Photo by Mark Ferguson

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

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

Science Advances

Decision-maker demand for the socio-economic value of water has increased significantly over the past years, but there are few value estimates in Canada, and it remains a major challenge to estimate the monetary worth of the flow of goods and services provided by freshwater resources for the Canadian economy and society at large. This lack of economic evidence and decision-making tools seriously undermine ability to efficiently and sustainably manage water resources. The objective of this project is to advance understanding of the socio-economic value of water in Canada by developing best practice guidelines, providing new empirical evidence, and advancing new policy-relevant decision-support tools that help decision-makers and practitioners assess the benefits and return on investment of improving the quality of Canada's freshwater resources. The main efforts over the last year have been focused on:

- synthesizing existing economic valuation literature related to water quality improvements in Canada;
- implementing an economic valuation study of the benefits of restoring the Saskatchewan River Delta;
- continued refining of recreation and water quality analysis;
- further developing and implementing the water quality valuation model for the Great Lakes; and
- designing a stated preference survey to assess use and non-use values for water quality improvements.

Link to Publications List

Knowledge Mobilization (KM)

A new webinar series highlighting state-of-the-art water valuation practices in Canada and identifying practitioners' demand for information about the value of water has been launched. The webinar series targets anyone from academia to non-government agencies and practitioners who are interested in better understanding the value of water in Canada from a broad social science perspective. It will cover how value is captured, acknowledged, and integrated in Canadian water policy and decision-making. The webinars take place on Wednesdays once per month (see here 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.

Professional Development and Technology Transfer

N/A

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

Investigators

Simon-Michael Papalexiou, University of Calgary
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Partners, Collaborators and Users

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

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 evaluates the CMIP6 simulations for Canadian regions, bias corrects, and downscales them using a transformative approach. The outcome is expected to support GWF researchers and core teams to progress in their research agenda by providing reliable and easy-to-use bias corrected and downscaled CMIP6 projections.

Link to Publications List

Knowledge Mobilization (KM)

N/A

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, temperature, etc. 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

Investigators

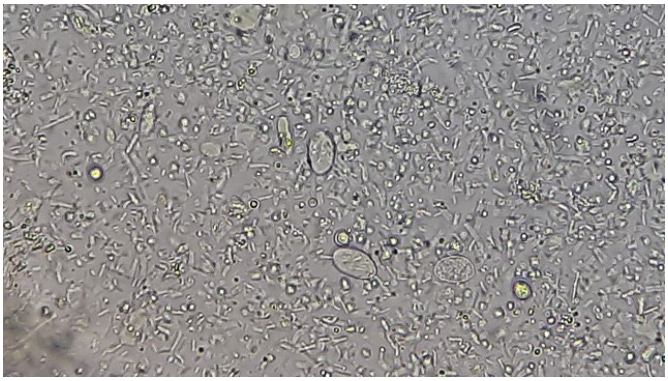
Younggy Kim, McMaster University Contact: younggy@mcmaster.ca
Fang, Qiyin, McMaster University
Herb Schellhorn, McMaster University
Chang-qing Xu, McMaster University
Radhey S Gupta, McMaster University

Partners, Collaborators and Users

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

Science Advances

Protozoan cysts (Cryptosporidium oocysts and Giardia cysts) cause serious human health risks not only in urbanized areas but also 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 these protozoan cysts are hardly inactivated in conventional drinking water treatment, reliable and rapid detection of the pathogenic cysts is urgently demanded, especially for communities without advanced disinfection facilities, 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 should
prove useful in the rapid and reliable identification of these parasites in water resources.



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

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

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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-May 2020; September 2020-August 2023

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

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

Science Advances

Climate extremes have many effects, across Canada, on agriculture, electrical utilities, infrastructure engineering, health, insurance, etc. This project is providing new insights into the future occurrence of precipitation-related extremes including drought, intense precipitation events, and hazardous winter precipitation. The project has made substantial scientific progress during its fourth year: Study of the different stages of drought evolution in the current and future climate completed and insights passed along to AAFC who had initially proposed this project. The impact of hazardous accreting precipitation on electrical transmission lines operated by Manitoba Hydro and New Brunswick Power (NB Power) were analyzed. The project has begun to examine and map how low temperatures and their associated precipitation vary across Canada through detailed analyses of conditions at 39 stations. Work on downscaling future precipitation models has begun. Project researchers also contributed to a rapid attribution study of the November 2021 flooding events in BC, which severed all surface transportation links connecting Vancouver (and the largest port in Canada) with the rest of Canada. Through this work, analyses of moisture transport, precipitation and streamflow as simulated by models suggest that human influence on the climate system has increased the likelihood of similarly intense atmospheric rivers, precipitation and streamflow response by at least 50%. Project researchers are analyzing the future occurrences of severe hail events, which are among the most serious weather events for the insurance industry. The 4-km and 12-km historical Weather Research and Forecasting Model (WRF) simulations covering the North American domain (CONUS II) for the 20-year period from 1995 to 2015 have been completed. The 12-km future climate simulation has also been completed, while the 4-km future climate simulation is still ongoing and is expected to be completed later this year.

Several significant interactions are taking place with other projects: For Mountain Water Futures (MWF), techniques developed to examine winter storms over New Brunswick and Manitoba are being used to address related issues in the western Cordillera. There are also links with MWF via PCIC, which is producing new hydrologic simulations for several BC coastal watersheds that are driven by statistically downscaled forcing data. These simulations are being produced as part of

a DFO supported study of projected changes in the freshwater habitat of Pacific salmon, and thus a key concern will be the evaluation of simulated extreme streamflow and how it relates to snowmelt and extreme precipitation response mechanisms. Interactions with the Saint John River Experiment on Cold Season Storms (SaJESS), put the data collected and outcome to use in analyzing the wet and adhering snow and near-0°C analysis conducted in this project. Collaboration with the GWF Core Modelling Team work to calibrate hydrologic models is enhancing understanding of basins.

Link to Publications List

Knowledge Mobilization (KM)

Manitoba Hydro is continually informed of the project progress, as it is addressing issues of importance to them. Insight on 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 analysis of the Manitoba October 2019 snowstorm have been even stronger, with researchers and the utility working as a team to address the many critical scientific and impact-related aspects of this event. Manitoba Hydro has provided considerable information to the study. All project information was shared with them, and sub-projects were based on their requests. Project insights were shared through an invited special presentation. There are also ongoing strong interactions with NB Power, which has provided lists of events damaging to its operations. There was a short gap in research progress due to personnel changes, but a new RA is making progress and interactions are increasing again to keep them informed of project research outcomes to help improve decision making during extreme events and to better adapt due to the warming climate. The project's ongoing research on occurrence of near 0°C conditions will further contribute to Manitoba Hydro's and NB Power's plans for more resilient electrical transmission systems. Because some of the research now spans the country, it can also contribute to such plans for other electrical utilities.


ACTUALITÉS UQAM

Scruter la pluie, le grésil, le verglas et la neige

Julie Thériault collabore à une étude américaine sur les précipitations mixtes au Québec et dans l'État de New York.

Par Pierre-Étienne Caza

Article in Actualités UQAM, February 22, 2022

The project maintains continual communication with CatIQ (Laura Twidle) about its results, but, due to the extremely slow progress in the past year (mainly due to statistical significance tests and data formats), no formal presentation to this group has been made in the past year. The project expects to present results to the organization and its partners sometime in autumn 2022 or early 2023. Via PCIC, project researchers have also engaged with users at BC Hydro, informing their engineering staff of projected changes in climate, including those related to precipitation extremes. The project also works closely with the BC Ministry of Transportation and Infrastructure, who are interested in the impacts of climate change on extreme precipitation and extreme streamflow as they work to improve the resilience of BC's transportation infrastructure. PCIC has also worked closely with ECCC and the NRC to update the climatic engineering design values that are tabulated in the National Building Code of Canada and project how those design values may change in a future, warmer, climate. These design values include a number that are extreme precipitation related. PCIC has recently released an online Design Value Explorer tool that provides estimates of these design values and their projected changes for locations across Canada.

Five interviews (broadcast or text)

Promotional videos

- Julie Thériault - Immersion dans l'univers du déneigement à Montréal, avec Stéphane Bellavance, full article https://montreal.ca/articles/immersion-dans-lunivers-du-deneigement-montreal-avec-stephane-bellavance-22600
- Interview: https://www.youtube.com/watch?v=9udC88k-0A8&t=31s, Ville de Montréal, 31 Décembre 2021

Professional Development and Technology Transfer

N/A

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-May 2020; September 2020-August 2023

Investigators

John J. Giesy, Department of Veterinary Biomedical Science and Toxicology Centre, University of Saskatchewan Contact: jgiesy@aol.com
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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

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

Science Advances

Successful protection of aquatic ecosystems requires reliable and rapid detection of changes to these environments within the context of natural variability. This will allow prediction of future trends so that managers can develop adaptive schemes to be able to maintain and enhance sustainability of ecosystems. This project advances 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 their 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. To serve the public, a dashboard (COVID-19 Early Indicators - Global Institute for Water Security | University of Saskatchewan (usask.ca)) has been developed to post wastewater surveillance results of City of Saskatoon, City of Prince Albert and City of North Battleford. Because Environmental RNA (eRNA) was shown to be a potential sensitive biomarker of stress in fish exposed to wastewater, a study of remediation of diluted bitumen spill, a 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.

Link to Publications List

Knowledge Mobilization (KM)

The project has conducted parallel, linked processes of technology development. Engaging end-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.

Researchers pivoted their research to COVID-19 wastewater surveillance early in the pandemic. They have been developing methods and applying 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 are directly engaged in the major programs developed provincially and nationally. Public dashboards to share results with the public include 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 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 labs to accelerate the adaptation of the approach.

Researchers continued to engage with NGOs working to improve fisheries resources in the 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 Water Quality Section of Alberta Agriculture and Forestry and Alberta

Irrigation Districts Association, the project identified specific demands of end-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.

Outreach activities included:

- Folkema A., M. Fuzzen, M. Servos. 2022. COVID-19 Wastewater Surveillance in Waterloo Region. COVID-19 Surveillance planning series: Monitoring new and circulating variants, Ontario Public Health (webinar). April 21, 2022.
- Servos, M., K. Kidd, C. Hill (Knowledge Holder). Restoring the Rivers ecosystem. Ohneganos: Let's Talk Water, Presentation and panel discussion, (Ohneganos: Let's Talk Water is a youth-led vodcast hosted by Makasa Looking Horse (Mohawk, Lakota) from Six Nations of the Grand River). April 7, 2022. https://www.ohneganos.com/lets-talk-water; https://www.facebook.com/ohneganos/videos/708904720133635
- Haskell, B., H. Dhiyebi, M. Servos. On-campus sampling for SARS-CoV-2. Ask-Me-Anything, University of Waterloo. Presentation to the residence staff of the University of Waterloo. January 20, 2022. Presentation and panel discussion
- Servos, M. Threats to the Grand River. Ohneganos, Let's Talk Water Livestream, S4E1. This is an indigenous youth led livestream series discussing aspects of water and culture. June 11, 2021. https://www.ohneganos.com/lets-talk-water
- Servos, M. and M. Fuzzen. Wastewater surveillance of Covid-19 in Waterloo Region. Invited to present during the Weekly Region of Waterloo COVID-19 Community Update and Media Briefing with Regional Chair, Karen Redman, and Medical Officer of Health, Hsiu-Li Wang. (livestreamed) January 7, 2022. https://www.youtube.com/watch?v=udeR6DpXAvk
- Folema, A. and M. Servos. COVID-19 wastewater surveillance in Waterloo Region. Region of Waterloo Health Board. May 26, 2021. https://www.youtube.com/watch?v=iX8diKa-eqg Review of the Waterloo Region wastewater surveillance and dashboard presented jointly.
- Servos, M., N. Srikanthan, H. Dhiyebi, M. Fuzzen, S. Hayat, L. Bragg, P. Breadner, S. McLay, K. Nikel, R. Hodgson, E. Burton, N. Harper, P. Craig, W. Parker, P. M. D'Aoust, J. Giesy, T. Graber, R. Delatolla. Wastewater-based surveillance SARS-CoV-2 in support of Public Health action. A year of COVID. Special session and panel discussion hosted by the VP Research, University of Waterloo. May 20, 2021. https://uwaterloo.ca/events/events/research-talks-presents-year-covid-19-innovative-research
- Servos, M. M. Mckay, R. Delatolla. Wastewater 101: Detection of SARS-CoV-2. Wastewater Surveillance Project Information Session, Ontario Wastewater Surveillance Program Webinar. March 26, 2021. Webinar targeted to the public health units across Ontario. Invited presentation.
- Servos, M.R. N. Srikanthan, H. Dhiyebi, P. Breadner, S. McLay, L. Bragg, K. Nikel, E. Burton, S. Hayat, M. Fuzzen, P. Craig, W. Parker. Complexity of sampling in upstream locations. Ontario COVID-19 Wastewater Surveillance Program Webinar. Workshop on Upstream Wastewater Sampling. March 5, 2021. Invited presentation.
- Servos, M. Wastewater surveillance of Covid-19: Addressing the under reporting of clinical data? Modelling Consensus Table, COVID-19 Science Table. Jan 10, 2022. Invited presentation
- Hosted a visit/tour of lab with Jeff Yurek, Minister of Environment, Conservation and Parks and MPP Mike Harris, March 18, 2021. https://twitter.com/JeffYurekMPP/status/1372633086949797893?s=20
- Weekly report for City of Saskatoon and Saskatchewan Health Minister, titled "Monitoring of Primary Effluent in the Saskatoon Wastewater Treatment Plant for SARS-CoV-2 virus that causes COVID-19", from April 09, 2021
- Weekly report for a few First Nation communities (Anonymous due to Tri-Council Policy Statement), titled "Wastewater Analysis Report: SARS-CoV-2", starting from April 28, 2021
- Weekly report for City of Prince Albert and Saskatchewan Health Minister, titled "Monitoring of Primary Wastewater in the Prince Albert Wastewater Treatment Plant for SARS-CoV-2 virus that causes COVID-19", starting from July 27, 2021
- Weekly report for City of North Battleford and Saskatchewan Health Minister, titled "Monitoring of Primary Wastewater in the North Battleford Wastewater Treatment Plant for SARS-CoV-2 virus that causes COVID-19", starting from August 23, 2021

Interviews (broadcast or text)

- The Record, Johanna Weidner. Wastewater signal showing signs sixth wave is peaking in Waterloo Region: Surveillance locally and across Ontario detecting COVID-19 signal plateauing, but at high levels. April 18, 2022.

https://www.therecord.com/news/waterloo-region/2022/04/18/wastewater-signal-showing-signs-sixth-wave-is-peaking-in-waterloo-region.html

- CanIndia. Countries renewing efforts for wastewater analysis to detect Covid surge. April 16, 2022. https://www.canindia.com/countries-renewing-efforts-for-wastewater-analysis-to-detect-covid-surge/
- CTV News, Jennifer Ferreira. Wastewater now 'one of our only reliable tools' to detect COVID-19 prevalence. April 15, 2022. https://www.ctvnews.ca/health/coronavirus/wastewater-now-one-of-our-only-reliable-tools-to-detect-covid-19-prevalence-1.5862546
- CityNews 570 (Radio), Brent Cater. COVID-19 Wastewater surveillance. April 12, 2022.
- CBC News (Kitchener-Waterloo, Radio), Kate Bueckert. Waterloo region hospitals face 'tenuous' time as 6th COVID-19 wave hits workers: Wastewater data shows very high levels of Omicron BA.2 subvariant. April 11, 2022. https://www.cbc.ca/news/canada/kitchener-waterloo/waterloo-region-covid-19-hospitals-sixth-wave-wastewater-1.6413819

Total: 129 articles in popular media
GWF Science Feature

Professional Development and Technology Transfer

The project's eDNA solution for field monitoring was delivered to end-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

Project dates: June 2017-May 2020; September 2020-August 2023

Investigators

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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

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

Federal Government Departments and Agencies

Environment and Climate Change Canada (2020-23) -- Vincent Fortin

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

Provincial Government and Agencies

Water Security Agency -- Curtis Hallborg, Ameer Muhammad, Jeff Sereda, John -- Mark Davies, Gary Neil, Glen Merkley, Jeff Woodward, Doug Johnston
SaskWater -- Ingrid Newton
Saskatchewan Ministry of the Environment -- Chad Doherty
Manitoba Infrastructure -- Bin Luo, Chris Propp
Alberta Environment and Parks -- Khaled Akhtar, Tom Tang, Babak Farjad, Jennifer Nafziger
Government of NFLD and Labrador -- Ali Khan
New Brunswick Government -- Brent Newton
Manitoba Agriculture and Resource Development -- Mark Lee

Treaty 5 Communities and Businesses

Northern Village of Cumberland House -- Kelvin McKay, Mayor, Ferlin McKay, Councillor
Metis Local 42 -- Denise McKenzie, Area Rep.
Cumberland House Fishermen's Co-op -- Gary Carriere, President
Cumberland House Cree Nation -- Julius Crane, Councillor
Niska Lodge -- Terry and Murdoch Carriere
N28 trappers -- Les Carriere, John Carriere
Big Eddy Lodge -- Solomon Carriere
Cumberland House Delta Stewardship Committee -- Lilly McKay Carriere

Science Advances

Climate and environmental changes complicate the prediction and management of water resources from local to international scales. This project provides an integrated platform to forecast, predict, and make decisions under future water uncertainty. We are developing advanced modelling tools that integrate interactions across climatic, hydrological, ecological, economic, and management systems. These tools improve predictions of extreme events such as floods and droughts and provide a new paradigm for model development, integrated water management, and user engagement. IMPC primarily focuses on change in the Nelson Churchill River Basin to support GWF modelling innovations across Canada's seven major river basins. The IMPC research program is organized around four themes: a) integrated earth systems modelling, 2) human drivers, 3) decision tools, and 4) stakeholder engagement (knowledge mobilization).

A: Integrated earth systems modelling: This work was initially piloted within IMPC and is expanded on by the GWF Core Modelling team which now primarily leads GWF model development and improvement at the Pan-Canadian scale.

Dr. Li's team: Pan-Canadian high resolution (4-km) atmospheric modelling of historical climate, the CONUS II simulation, in cooperation with NCAR hydrometeorology group. Together they are onto the second phase of the 4-km WRF CONUS II simulation covering most of the United States and Canada. This work continues through 2022.

Dr. Papalexiou: Downscaling climate projections for Canada using advanced stochastic techniques (over the past year, primarily under Core Modelling). IMPC funding will partially contribute to Core Modelling objectives: (1) detailed statistical analysis of gridded products over Canada; (2) statistical analysis and comparison of CM IP6 simulations with observations. This work continues.

Drs. Pomeroy, Pietroniro, and Stadnyk: Refining routines for snow and glacier hydrology in the Cold Regions Hydrological Modelling Platform – now published, and ported to the MESH modelling system. Testing these routines with MESH against research basin observations showed good performance at alpine ridges, forested sites and on glaciers, including for glacier mass balance. IMPC funding has ceased. The routines are now being used in MESH runs for the Saskatchewan River Basin (SRB) and other basins.

Dr. Lindenschmidt's team: In collaboration with the Core Modelling Team shared HQP has continued work on coupled HEC-RAS and WASP water quality model for the South Saskatchewan River (from Gardiner Dam), currently being used to model heavy metals in that area. Also a Quasi-2D water quality model developed for Lower Athabasca Region; over the past year a 2D HEC-RAS model for flood hazards for the town of Fort McMurray; a geospatial model to identify potential ice-jam locations along the Saint John River by exploring the influence of geomorphological parameters and features of the river; a preliminary ice-jam location prediction model along the Saint John River by introducing a simple machine learning tool to classify hydraulic, geomorphologic and river ice factors to forecast real-time probable ice-jam locations for a given year.

Dr. Elshorbagy: on assessment of seven flood indicators/descriptors of the key hydro-climatic components contributing to spring flood generation in the Canadian prairies this past year provided a characterization of nine flood generation mechanisms and showed their spatial and temporal variability across the Canadian prairies. Also demonstrated: a statistical simulation of interaction among various basin conditions and their changing role in generating peak spring streamflow using a 7-dimensional Copula model that could be used to simulate various scenarios of floods in the Canadian Prairies.

Dr. Coulibaly: progress in investigating new approaches for generating high-resolution flood inundation maps in semi-urban environments. Hybrid machine learning approach models were assessed and applied to the Don River Basin in the Greater Toronto Area. They found an alternative method for generating flood inundation maps that could provide good estimation of flood inundation maps at very low computational cost compared to physical hydraulic models. This research is driven by a demand for fast-developing inundation maps for urban flash floods at low computational cost.

Dr. Tolson's team: the Great Lakes Runoff Intercomparison Project resulted in comparison of 13 models (including Machine Learning based, basin wide, subbasin-based, and gridded models – locally or globally calibrated) for the Great Lakes watershed domain including the Ottawa River. The study evaluated models' capability to simulate streamflow (Q), quality of

simulated actual evapotranspiration (AET), surface soil moisture (SSM), and snow water equivalent (SWE). Results demonstrate the superior quality of the machine-learning-based model for streamflow prediction across over 200 locations in the study, even for the most challenging spatiotemporal validation scenario. In other work, his team conducted a massive empirical study performing almost a million calibration experiments over 463 watersheds to clearly demonstrate long-standing hydrological model building practice needs to be updated. Specifically, better models are built by calibrating to the most recent streamflow data and the best models are built by calibrating models to all available streamflow data.

Dr. Stadnyk: The model intercomparison work on the Nelson-Churchill, , has also moved forward significantly. Call for data in Phase II closed in June 2022 ('under regulation' scenarios). The team is working to engage collaborators from Phase I and others in Phase III. Compared performance of 8 hydrologic and land surface models over unregulated headwater basins in NC river basin-compared with flow, AET, & SWE observations; Results: all models struggle to replicate the streamflow of prairie basins; some have significant errors simulating AET; all reasonably simulated SWE; structural limitations of current models; need for proper representation of non-contributing area dynamics; problems/ limitations of MIPs; need to move toward model agnostic approach. (Ahmed); Permafrost: adapted HYPE model to 7 soil layers for a more complete thermodynamic transfer/ distribution through soils in response to changing air temperature. Validated historical permafrost map –7-layer model did well; future scenarios with permafrost distributions under climate change (Bajracharya).

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; (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 over 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/

B) Human drivers: IMPC provides integrated water resources assessment tools that couple anthropogenic factors with natural systems models, including economic trade-offs and ecosystem constraints.

Dr. Razavi: In collaboration with the GWF Core Modelling Water Resources team, the WRMSask Model has been coupled with an irrigation water demand model and an inter-regional hydro-economic model (an economic Input-Output model), showing costs and benefits to water-using and non-water using sectors for a wide range of policy and climate scenarios (L Eamen); Incorporates policy scenarios from Hayley Carlson and Patricia Gober's previous work; this model now has a user-friendly interface via the Water Scenario Explorer (see Carl Gutwin's work below).

Dr. Tim Jardine: Recent progress has been to quantify fish stranding downstream from EB Campbell Dam on the Saskatchewan River, and to determine links between flows and production of walleye and sturgeon (partnership with Fisheries and Oceans Canada). These findings will serve as ecological performance indicators for flow models. A draft manuscript (led by Jen Lento) that examines deviations from naturalized flows at locations across the basin ins underway.This model is well integrated with flow models (MESH) and offers a first look at likely ecological consequences of altered flows.

Dr. Brouwer: Continues with the Integrated Multi-Regional Input-Output (MRIO) model for the Great Lakes, extending the existing input-output model to include phosphorus flows. It now includes an extension to the rest of Canada and accommodates the inclusion of pollution abatement costs based on pollution abatement technologies. This work will be continued in the coming year. The work on an operational WQVM 2.0 has resulted in; (1) the inclusion of a Canada-specific water quality valuation function; (2) the spatial aggregation and disaggregation of drainage basins into watersheds and vice versa. In direct collaboration with the ECCC, the procedure for this has been illustrated for the Great Lakes.

Dr. Asadzadeh: continues to develop the Manitoba Water Resources Management Model by simulating the province's river-reservoir system to understand the extent of climate change impact on water resources and energy production. A coupled

model was set up to simulate the extent of changes in the future using 19 scenarios. The model has been extended to include Winnipeg River and its control structures and hydropower generating stations.

C) Decision tools: As a prelude to scenario development and complex systems modelling, Drs. Gober and Razavi's team canvassed stakeholder ideas about future policy changes by performing a content analysis of a wide range of stakeholder documents in the SRB and live survey conducted during the previous IMPC Annual Meeting. The final shortlisted policy variables accounted for future changes in crop mix (3 future projections), irrigation expansion in Alberta (3 future projections) and Saskatchewan (3 future projections), irrigation efficiency in Alberta (3 future projections) and Saskatchewan (3 future projections). These policy variables were used for scenario analysis via the MODSIM Water Resource Management framework.

Drs. Razavi & Elshorbagy : completed an agent-based model that characterizes coupled 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. Focus has centered on human adaption to drought and emergence of the 'Rebound Phenomenon' in this sub-basin, garnering wide stakeholder interest and some media attention.

Link to Publications List

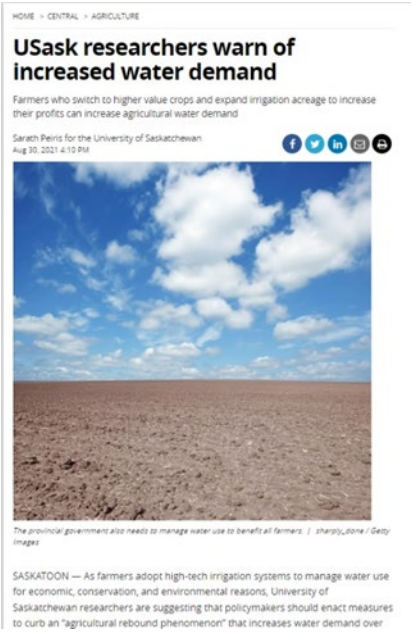
Knowledge Mobilization (KM)

COVID restrictions have limited outreach and engagement activities planned for the project over the past two years and presented significant coordination challenges between research teams. Despite these limitations, the IMPC team has continued to improve the project's online presence (website and social media/Twitter) and increasing profile of various impactful/relevant research outcomes by various communication streams to specific audiences.

D) Stakeholder engagement: A range of engagement activities occurs at the project, work package or individual investigator levels. Investigators and their teams under each theme carry out partner engagement activities where possible over several stages of the research. Some examples of this include the following:

- 8 articles in popular media
- 21 interviews (broadcast or text)
- 13 public workshops and presentations
- 4 promotional videos

Dr. Strickert: Investigating values, insights, and perspectives of water resource changes with Cumberland House Delta communities of the Saskatchewan River Delta, to be better reflected in water management modeling approaches. Qualitative analysis was conducted on interview data to directly inform modelling approaches, identifying and consolidating how community members perceive flow changes that affect the Saskatchewan River Delta's ecosystem and its human and animal populations. Results informed the following:



HOME > CENTRAL > AGRICULTURE

USask researchers warn of increased water demand

Farmers who switch to higher value crops and expand irrigation acreage to increase their profits can increase agricultural water demand

Sarath Peiris for the University of Saskatchewan
Aug 30, 2021 4:10 PM

The provincial government also needs to manage water use to benefit all farmers. | sharply_done / Getty Images

SASKATOON — As farmers adopt high-tech irrigation systems to manage water use for economic, conservation, and environmental reasons, University of Saskatchewan researchers are suggesting that policymakers should enact measures to curb an "agricultural rebound phenomenon" that increases water demand over

Article in SaskToday, 30 August 2021

Dr. Lindenschmidt's team: a 2D HEC-RAS model for Cumberland House Delta which is has been used to study the effect of different flow scenarios on the Delta, such as the addition of a weir near Spruce Island. Erosion and deposition rates in the EB. Campbell Dam have also been simulated, driven by community questions on sediment flow.

Drs. Jardine and Strickert: actively hold one-on-one meetings and calls with various community members. This past year they have visited five times in-person, and met twice virtually with the Cumberland House Delta Stewardship Committee to hear community members' perspectives, present research outcomes, and receive feedback iteratively. Since August 2020 IMPC has continued organizing the meeting series, Delta Dialogues – Finding a Way Forward, in collaboration with the Cumberland House Delta Stewardship Committee to facilitate dialogue between stakeholders, rightsholders, and communities in the Saskatchewan River Delta region. During this time six virtual meetings, attended by 30 to 50 participants have brought together community members (primarily from Cumberland House Delta) with stakeholder groups, including SaskPower, Water Security Agency, DFO, Ministry of Environment, and other local stakeholder groups (DUC), CPAWS, PAMF). A third-party facilitator was solicited by Drs. Jardine and Strickert through IMPC in partnership with SaskPower to act as a mediator in these meetings and maintain neutrality of the GWF project in a multistakeholder context. As a result of collaborative opportunities identified in these dialogues, plans are underway to install three new gauging stations at key locations in the Delta, and obtain LIDAR in partnership with Water Security Agency and SaskPower actively provides update on basin wide conditions to explain the forecast for flows.

Visualization tools make GWF scientific findings more accessible. Those produced under IMPC aim to support decision-making through user-driven research priorities. Over the past year, significant progress has been made in two web-based tools: GWF Water Scenario Explorer and EB Campbell Flow Visualization Tool.

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/

Progress on the Water Scenario Explorer over the last year includes: exploration of visual presentation approaches to enable navigation and selection of model scenarios; and revision of the collaboration infrastructure to better allow multiple users to work synchronously through the tool. The team has organized exploratory meetings with Prairie Provinces Water Board and PrairiesCan members to 1) receive feedback and further document user needs that may translate into useful features in the tool; 2) Identify stakeholders that can directly benefit from the knowledge support provided by the modeling data visualization tool, built on a functional integrated water management modeling infrastructure for the SRB with future scenario analysis capabilities. Dr. Gutwin's team regularly attends the Delta Dialogue meetings (described above) to present on latest/relevant tool development updates when and where appropriate.

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/

Meetings with community partners and industry collaborators highlighted a communication gap between the upstream decision-makers, stakeholders and downstream residents in the Cumberland House Delta. The EB Campbell Flow Visualization Tool was designed to address locally relevant knowledge and multi-stakeholder communication gaps that the large-scale modeling could not directly address.

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!

Now in its 4th phase, GRIP and the Nelson MiP have enjoyed significant participation from collaborators. GRIP-GL has 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.

Dr. Asadzadeh's team works closely with Manitoba Hydro, esp. Kevin Gawne (Manager of Supply Planning) on major reservoir operations and integrated resource planning for future decades. Manitoba Hydro has directly participated in the research by providing system data and review, and they have utilized research outcomes in their monitoring operations at this time.

Dr. Lindenschmidt (and team) maintains frequent communication with collaborators via phone communication and email, including representatives from the Government of Manitoba, the Government of Newfoundland and Labrador and the Saskatchewan Water Security Agency. Input from these organizations has been used by his team to guide research direction, and results are often co-published with external collaborators.

Other 2021 Knowledge Mobilization Activities of IMPC	
4 Tools Accessed by Users	• EB Campbell Flow Visualization Tool [Follow this link to view latest version; tool still under development]: https://gwf-hci.usask.ca/eb-campbell/ • GWF Water Scenario Explorer [Follow this link to view latest version; final stages of development]: https://gwf-hci.usask.ca/ • IMPC DAta VISualization Project (DAVIS) [Pilot concept completed]: http://gwf-demo.usask.ca/v-12/
1 Exhibition, Citizen Science	• [Artistic Exhibition]. Cryosphere Pavilion COP26 United Nations (UN) Climate Change Conference, Glasgow, United Kingdom, Nov 2021
11 Meetings with governments, decision makers, and practitioners	• CRIPE (Canadian Committee on River Ice and Environment), Saskatoon, 29 Aug – 1 Sept 2021. • Monthly Update Open Meetings for collaboration on Multi-model Intercomparison Project on the Saskatchewan-Nelson-Churchill River Basin (Nelson-MiP project). • IAGLR's 64th annual Conference on Great Lakes Research, 17-21 May 2021.

	• House of Commons' Standing Committee on Science and Research on its successes, challenges and opportunities for science in Canada, Virtual, February 2022 • GEWEX Hydroclimatology Panel (GHP) Annual Meeting, Virtual, 8-9 Nov 2021 • Green Party of Canada Leader Annamie Paul roundtable discussion on Climate Change Series, Virtual, 12 Aug, 2021 • Global Water Futures Regional Science Exchange with Manitoba – Virtual, June 22, 2021 • World Environmental & Water Resources Congress (EWRI) – Virtual, 7-11 Jun, 2021 • Northern Village of Cumberland House, local government meeting, Dec 2021 • Dr. Strickert Met with Gary Neil at Water Security Agency in Moose Jaw, meeting for collaborative opportunities.

Professional Development and Technology Transfer

N/A

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; 2020-2024 (PWPI)

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Science Advances

Introduction: The Core Modelling and Forecasting Team is 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 into various themes and initiatives. The theme leads – expert faculty members – are 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 term and long 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.

Leadership and coordination: The leadership of GWF core modeling and forecasting enables organizing the various themes to ensure that their tasks are aligned with the core modeling deliverables. The leadership team tracks progress on cross cutting activities to accelerate advances in critical modelling efforts. Cross cutting activities include tasks such as preparing climate scenarios and preparing data. The knowledge transfer across the core modelling theme maximizes the time spent on science advancement.

Collaboration with governmental institutes and agencies such as Environment and Climate Change Canada, ECCC provide scope to increase efficiency at the national level. These initiatives include data sharing, infrastructure for model setup, and knowledge mobilization. In doing so, the leadership and coordination team provides operational benefits well beyond those that are reported in scientific publications.

Core Modelling Themes

The spatial meteorological forcing data theme: This theme focuses on developing datasets used to conduct hydrological, ecological, and economical modelling and planning. The team uses various data sources, such as national and international station data, numerical weather prediction model output, satellite observations, as well as climate scenarios. Theme members use a combination of statistical and physical models to provide a range of meteorological datasets on historical and future climate. The activities in spatial meteorological forcing data include (1) preparing historical data sets; (2) preparing

climate projection datasets; and (3) collaborating on international efforts to produce very-high resolution regional climate simulations.

The efforts on historical data focus on developing new datasets and understanding historical climate variability. A key accomplishment is the development of ensemble datasets to quantify uncertainties in spatial meteorological fields (e.g., the Ensemble Meteorological Dataset for North America, (EMDNA), and the Ensemble Meteorological Dataset for Planet Earth, EM-Earth). EM-Earth is perhaps the first dataset of its kind that covers the global domain while providing 25 ensemble realizations of temperature and precipitation. This dataset provides scientists with the opportunity to evaluate their model results and conclusions under historical climate uncertainty and variability. The spatial meteorological forcing data theme also investigates the variability of historic data from a myriad of different products, including the Multi-Source Weighted-Ensemble Precipitation (MSWEP), the Climate Prediction Center MORPHing technique (CMORPH), the Global Satellite Mapping of Precipitation (GSMaP), and Integrated Multi-satellite Retrievals for Global Precipitation Mission (IMERG).

The work on regional climate modelling focuses on developing very-high resolution regional climate model simulations. These include short-term simulations using the CRCM6/GEM5 as well as longer-term simulations using the WRF model over the contiguous US (CONUS) and parts of Canada. The most recent simulations with WRF (CONUS-II) cover the USA and most of Canada at a resolution of 4-km, and extend from 1995 to 2015 for a historical period and a future climate simulation from 2080 to 2100 (end of the century).

A critical component of the spatial meteorological forcing data theme efforts is bias correction. It is often the case that global and regional climate models need to be post-processed to remove systematic biases. Such statistical bias correction efforts are done on the CONUS-II dataset and also the global climate models that are used in the Climate Model Intercomparison Project (CMIP6) that encompasses climate scenarios to the end of the century. The final products are close to publication of the datasets.

Current generation modeling: One of the deliverables of the GWF is to evaluate climate scenarios for hydrological variables such as glacial melt, snow, and streamflow by the end of the century. Current generation modeling is heavily reliant on well-established models, particularly MESH, VIC, HYPE, and CHRM. Key contributions include (1) improving the model “ecosystem” to make the models easier to configure and apply; and (2) update the model process algorithms, such as the including slope and aspect for model elements in mountainous regions, the fill and spill of Prairie potholes, groundwater dynamics, and permafrost formulations. In order to better represent the river network, the MESH model is also set up in a vector-based configuration (unlike the typical grid-based configuration). The vector-based configuration is enabled using existing river network datasets, which speeds up and standardizes the model configuration for larger domains.

The MESH model is successfully configured and used for large river networks in Canada, namely the Yukon, Mackenzie, Saskatchewan, and Saint John River. The output of the current generation modelling theme will be used by other themes for water management and human dimension of water.

The Cold Regions Hydrological Modelling platform (CHRM) was used in GWF to simulate snowpacks, glacier dynamics, soil moisture dynamics, evaporation, wetlands, and streamflow. Similar to other models, CRHM has the capability to be used for climate change studies. The modularity and object-oriented code allow CHRM to be used to evaluate the fidelity of process parameterizations and explore alternative hypotheses of hydrological behaviour. The accumulated knowledge embodied in CHRM models can be transferred to other modelling platforms such as MESH. Additionally, CHRM was refactored to be used in modern computing environments. There are now new versions of the CRHM code called CHRMcode CLI, that enables easy execution of code from the command line via a command line interface (CLI) and CHRMcode GUI, that enables user interaction from a graphical user interface (GUI). A complete and up-to-date description of the CRHM software can be found on the CHRM Wiki page, the CRHM website with supporting R utility codes.

Next Generation models: The GWF next generation hydrological modelling strategy is aimed at preparing the scientific and computational infrastructure to simulate processes that are often missing in the current generation models and configuring models at spatial resolutions and spatial extents that have not previously been possible. The two main advancements by next gen models are the Canadian Hydrological Model (CHM) that simulates snow processes across complex terrain and the Hysteretic and Gatekeeping Depressions Model (HGDM) that simulates hydrological processes in Prairie depressional landscapes.

The Canadian Hydrological Model (CHM) focuses on improving multiscale / multi-physics modeling capabilities. This has enabled both flexibility in process representation (multiple representations of a given process) as well as flexibility in spatial configurations (including horizontal interactions [e.g., snow redistribution, runoff processes] and the connectivity of the landscape). CHM uses variably sized triangles to represent the topography, vegetation, soils and drainage network. Each triangle is a computational element with a unique and individually simulated state and flux, e.g., SWE and blowing snow transport flux. This allows the landscape to be represented with often only 1% of computational units needed in fixed-grid models at the same fine resolution and hence reduces the computational burden which in turn allows for simulating larger regions. CHM is currently set up for an area of ~1.3M km2, covering an area from the Saskatchewan border to the Pacific Ocean, and from north-central British Columbia parts of Washington state, Idaho, and Montana.

The CHM effort also focused on simulating the substantial spatial and temporal variability in mountain snow cover. Locally increased precipitation rates, complex snow-vegetation interactions, blowing snow transport, and avalanching all result in a myriad of multi-scale processes interactions. Two key processes that were worked on within the next generation CHM model development is the impact of terrain on windflow and snow redistribution processes. The WindMapper tool was introduced as a wind field parameterization tool that approximates the windflow from a mass-conserving windflow model at a fraction of the total computational cost. These simulated winds approximate the complex windflow patterns required for estimation of blowing snow transport and subsequent avalanching. In a comparison of CHM simulated snow depths against LiDAR snow depth observations at the GWF Canadian Rockies Hydrological Observatory, it was found that both blowing snow and avalanching need to be simulated to predict the spatial patterns of snow accumulation and ablation in the alpine headwaters of the region. The quasi-operational deployment of CHM, "SnowCast" (www.snowcast.ca), provides snow forecasts for the Canadian Rockies and has been recently improved. Snow water equivalent outputs from SnowCast are made available to Alberta Environment and Parks at a 2.5km resolution for use in their forecasting operations.

In collaboration with the Computer Science Team, CHM has been developed using modern coupling methods to take full advantage of multi-processor, clustered, high performance computing systems. Such model coupling/workflow infrastructure follows a hierarchical approach, including adding new capabilities to an existing models, managing exchange of information and time stepping for different model components, allowing for a chain of discrete models with one-way flow of information, and managing/scheduling the flow of information in a complex forecasting system. Careful attention has been paid to developing the coupling/workflow infrastructure in order to avoid ad hoc approaches that plague many large-scale modeling efforts. Rapid progress has been made by leveraging existing community Earth System model couplers and workflow management systems.

The other developments in the next generation model theme are the Hysteretic and Gatekeeping Depressions Model (HGDM). In the Canadian Prairies and the northern US Great Plains, many basins have varying areal fractions that can contribute flow downstream, due to the varying storage of water depressions known as "potholes" or "sloughs". When the depressions are not full, they store overland flow; when they are filled, they transmit water to flow downstream. The behaviour of the depressions is very complex and has not been well represented by most hydrological models, limiting their usefulness in the region. This is particularly important in light of the effects of climate change and the historical drainage of depressions within the region. The Hysteretic and Gatekeeping Depressions Model (HGDM) is designed to simulate the variable contributing fractions of Prairie basins within hydrological models. It combines a simple representation of the hysteretic effects of small depressions on the contributing fraction of a basin, with the "gatekeeping" (blocking) effects of large depressions. HGDM has been incorporated within CRHM as a macro and is in the process of being added to other hydrological models, namely HYPE and MESH, with intention to include in CHM in the near future.

Geospatial intelligence: The geospatial intelligence theme primarily focuses on the tasks that increase the efficiency, effectiveness, and reproducibility of large-domain hydrological modelling. The three main focus areas include (1) development of reproducible model workflows to accelerate the configuration of models across large domains, (2) diagnostic evaluation hydrological process representations; and (3) parameter estimation (parameter sensitivity and parameter inference).

There have been substantial advancements in developing efficient and reproducible model workflows. The efforts to streamline and standardize model configuration code has led to the development of the so-called model-agnostic workflow called CWARHM. These workflows are collections of model configuration code that separate 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 pre-processing 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.

Additionally, tools have been developed that help modellers extract geospatial data from a unified location and use the data in their models. Available datasets include gridded climate forcing data, satellite data on land cover and soil type. The data tool is developed to subset various forcing variables for a region of interest. In addition, the EASYMORE package enables remapping the gridded data to any shape such as sub-basins or point data. Moreover, the gistool was developed to use very efficient zonal statistics code to generate the statistics of land cover, soil type, or average elevation across model elements.

In addition to the computational tools used for model building and data preparation explained in the above paragraphs, the geospatial intelligence theme also focuses in process-based evaluation, where small, dedicated benchmarking data sets are created to comprehensively evaluate the fidelity of large-domain hydrological models. Such benchmarking datasets have become increasingly common over recent years, with existing datasets most suitable to evaluate simpler surface water hydrological models. Existing datasets have only a limited selection of meteorological variables at daily time resolutions, and typically treat catchments as single, lumped entities. The CAMELS-spat project addresses these concerns by creating a benchmarking data set for the North American continent that specifically targets spatially distributed process-based hydrological models. The data set includes hundreds of (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 data set are divided into sub-basins to enable spatially distributed modeling, and the provided meteorological data 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 behaviour across the North American continent, over timescales from seconds to centuries.

The benchmarking effort also focuses on smaller size catchments and observatories that have more detailed measurements of hydrological processes. These observatories include Baker Creek in the Northwest Territories, Brightwater Creek in Saskatchewan, Havikpak Creek and Marmot Creek in Alberta, Peyto Glacier in Alberta, Smith Creek in Saskatchewan, St. Denis National Wildlife Area in Saskatchewan, and Wolf Creek in Yukon. The benchmarking efforts try to set up and compare simulations from various large-domain models, including MESH, HYPE, SUMMA. The benchmarking effort uses CWARHM, datatool and gistool to simplify and standardize model configurations.

For parameter identification, various efforts have been underway to evaluate the suitability of the model configuration and the sensitivity of model parameters. The model workflow, CWARHM, allows setting up the models in various spatial configurations in an 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 using flat Earth concepts. A modeller can then evaluate adding or removing geospatial complexity to find the “best” geospatial detail representation based on model simulation for a given purpose. Additionally, to estimate model parameters (which is a critical step in setting up a functional model) sensitivity methods are utilized and developed. A computational frugal sensitivity analysis method called VISCOUS is developed to understand how model parameters impact indices that describe hydrological processes. The VISCOUS code is now publicly available as a python package on PyPI.

Water resources management: The water management modeling activities primarily focus on developing water management capabilities for large-domain hydrological models. The work is conducted in coordination with IMPC to provide computational tools that bridge the gap between Earth System models and traditional water management models. A key advance in the water management theme is the capabilities to simulate lakes and reservoirs in large-domain models, specifically by (1) incorporating lakes and reservoirs into the vector-based mizuRoute routing model and (2) reservoir operation schemes implemented in HYPE and MESH.

mizuRoute is a vector-based routing model that can be coupled with any land surface, or hydrological model runoff field. The work in the water management theme focused on integrating range of lake and reservoirs models into mizuRoute, namely, Doll, Hanasaki and HYPE. The user can easily switch between models within a given setup with minimal changes to the setup and test the impact of each lake or reservoir scheme. Additionally, users have the capability to assign different lake and reservoir models across a river network topology based on the available knowledge and the modeling application.

mizuRoute also has the capability to be run in a data driven mode, making it possible for the model to be forced by historical observed data at stations for streamflow or reservoir elevation, and hence storage.

In addition to the developments in mizuRoute, efforts have been made to improve the reservoir representation in large-domain models. For the MESH model, a scheme called the Dynamically Zoned Target Release (DZTR) discretizes a reservoir storage level into various zones and applies different rules for each zone. For the HYPE model, a new formulation for reservoir operations is developed by varying parameters on a monthly basis. The new parameterization increases the flexibility to simulate more complex reservoir operations. The new reservoir scheme will be part of HYPE source code and is already tested for the Arctic region with satisfactory results.

Forecasting: Forecasting elements within core have advanced substantially over the duration of the GWF core modelling program. The forecasting team has focused on diverse and important topics ranging from seasonal data-driven forecasting approaches, operational model evaluation, ice-jam forecasting advancements, and implementation of new systems and tools. The work has also included substantial efforts derived from the current and next generation model developments including the model agnostic framework which is being applied to the forecasting systems, and some of the data assimilation efforts in the CHM system.

The data-driven seasonal forecasting system uses a sophisticated workflow that produces ensemble hindcasts of flow volumes on seasonal timescales, derived from SWE initial conditions. The workflow is structured as a series of Jupyter Notebooks and organized in five consecutive steps:

- Basins regime classification: identify river basins with a nival/glacial regime.
- Discharge pre-processing: calculate volumes of interest to water users from daily discharge observations (WSC HYDAT).
- SWE (snow water equivalent) pre-processing: fill gaps in the SWE stations observations (CanSWE 1928-2021; Vionnet et al., 2022) from neighboring SWE and precipitation stations (SCDNA; Tang et al., 2020), and calculate principal components from the gap filled SWE dataset.
- Forecasting: generate ensemble hindcasts of flow volumes from the SWE principal components for each nival/glacial basin, based on an ordinary least squares regression model.
- Hindcast verification: analyze the quality of the generated hindcasts against the observations using a variety of deterministic and probabilistic performance metrics.

This workflow was run for nival/glacial basins across Canada and will soon be applied to nival/glacial basins in the USA.

Another project has been focused on operationalizing and developing modeling techniques for ice-jam forecasting. The work is at various levels of maturity and has been applied in a number of domains across Canada. This includes validating the spring breakup ice-jam flood forecasting methodology, established for the Athabasca River, for the upper reach of the Saint John River. It also includes extending the ice-jam flood forecasting methodology to include forecasting ice-jam severity of mid-winter breakup events along the Saint John River. Other applications include complementing the stochastic modelling framework with machine-learning algorithms to forecast ice-jam flood highly in regulated rivers (e.g. Yellow River, China, and will be tested for the Peace River, Canada starting January 2023) ; while improvements to an existing ice-jam flood forecasting system used operationally by the Government of Newfoundland and Labrador for the lower Churchill River, Labrador have also been carried out.

As part of the nextGen modelling group, there has been substantial effort in the CHM developments. An offshoot of that work has been the development and quasi-operationalization of the SnowCast system. The importance of high-mountain snow in both flood forecasting and water supply operations is critical. It is well known that blowing snow and avalanche redistribution are key processes that move snow from high to low elevations, or to shaded, north aspects, where snow melts more slowly. The deep snow drifts and avalanche deposits have an inordinately important role in summer streamflow, sustaining glaciers and perennial snowfields; and supplying water for treeline forests and valley bottom wetlands. The Canadian Hydrological Model (CHM) described in the NextGEN modelling sections forms the basis for the SnowCast system since there is an important and timely need to forecast potential changes to mountain snow covers for water supply prediction and forecasting needs downstream. To do so requires advanced, next-generation numerical models like CHM that

are coupled with expert in situ knowledge and observations. A strength of CHM is its ability to calculate wind loading on slopes in complex terrain, which is critical for mountain blowing snow and avalanche calculations. CHM snow cover predictions are being made now over an area from the Saskatchewan border to the Pacific Ocean and from north-central British Columbia into Washington State, Idaho and Montana, and covering all of the Canadian Rockies and foothills headwaters of the Saskatchewan, Missouri, Columbia and Athabasca Rivers. This is now output as SnowCast (www.snowcast.ca), where CHM is run in a forecast mode and is coupled with Environment and Climate Change Canada's weather forecast system. SnowCast produces snow depth and snow water equivalent predictions at resolutions down to 50 metres. It is an example of a system to forecast the spatial development of mountain snow cover with high resolution and high fidelity. The quasi-operational deployment of CHM, "SnowCast" (www.snowcast.ca), provides snow forecasts for the Canadian Rockies has been developed, operationalized and recently improved within the last year. New advances in CHM's ability to exploit high performance computing resources has enabled the SnowCast domain to extend from ~100,000 km^2 to ~1.3M km^2, covering as far west as the Coast mountains in British Columbia as well as extending south into parts of Washington state, Idaho, and Montana. Due to CHM's new resume-from-checkpoint functionality, model run times now remain constant throughout the year. In addition, checkpointing allows for seamless switching between the 2 and 7 day forecasts (near release). The snow model in SnowCast has been updated to the Factorial Snow Model (FSM 2.0). Snow water equivalent outputs from SnowCast are made available to Alberta Environment and Parks at a 2.5km resolution for use in their FEWS deployment.

Another focal point for the forecasting team has been within data assimilation (DA) research on assimilation of ground observed snow data to the CRHM model. The focus of this research has been on the Marmot Creek Research Experimental Basin and has recently been completed. Further to the CRHM efforts, new efforts focused on the next generation CHM model have recently been formulated. A point data assimilation test in Marmot Creek with the high-resolution CHM modelling system was conducted and the results are promising. An areal DA experiment in Fortress Mountain that assimilating snow depth from ground stations and drone-based lidar sensor, and high-resolution snow cover information from satellites is ongoing. The hope is to apply the algorithm to the SnowCast for snow forecasts in Western Canada and the US.

There has been much effort on using the MESH model in a forecasting model to evaluate its capability as a current generation system for large-domain forecasting. The MESH model has been tied to the operational FEWS system being used by many operational agencies. Efforts around calibrating MESH for using the CaSPAr database, to compare the FEWS-MESH model performance by different numerical weather predictions: the Global Deterministic Prediction System (GDPS), the Regional Deterministic Prediction System (RDPS), and the High-Resolution Deterministic Prediction System (HRDPS). The Canadian Precipitation Analysis (CaPA) is also used as a reference forcing. This work is being carried out in the Grand River in Southern Ontario.

Another MESH forecasting application is for the Yukon River Basin (YRB). The Yukon River Basin is one of the most important river networks shared between Canada and USA and is one of the largest river basins in the subarctic region of North America. The Canadian part of the YRB is characterized by steeply sloped, partly glaciated mountain headwaters that generate considerable runoff during melt of glaciers and seasonal snow cover. Snow redistribution, snowmelt, glacier melt and freezing-thawing soil processes in winter and spring along with summertime rainfall-runoff and evapotranspiration processes are thus key components of streamflow generation in the basin, making conceptual rainfall-runoff models unsuitable for this cold region. Due to the remote high latitudes and high altitudes of the basin, there is a paucity of observational data, making heavily calibrated conceptual modelling approaches infeasible. At the request of the Yukon Government, GWF developed and operationalized a streamflow forecasting system for the Yukon River and several of its tributary rivers using a distributed land surface modelling approach developed for large-scale implementation in cold regions. This represents a substantial advance in bringing operational hydrological forecasting to the Canadian subarctic for the first time. This experience is informing research directions to improve operations as Canada develops a nationally coordinated flood forecast system.

Lastly throughout the history of the GWF forecasting project, the project has worked with provincial and federal partners to help develop a community of practice to ensure advancements are made in national forecasting development, and within the bespoke modelling systems developed and currently implemented by the provinces and territories. We supported two very successful national workshops in flood forecasting and have successfully encouraged the development of a national community of practice focused on this topic. The forecasting team continues to make advancements in research and implementation, focusing on both developing state-of-the art models and sciences, and also ensuring that what is developed is disseminated to partners and agencies, through a strategic knowledge mobilization approach.

Water quality modeling:

Hydro-economic modelling: Canada's economic development and long-term sustainability depends on access to water in sufficient quantity and adequate quality. The core hydro-economic modelling group has worked on estimating the social and economic implications of water supply or quality changes at regional and national level. The aim has been to provide policy relevant insights in the relationship between Canada's water resources and economy and identify directions of interventions that improve Canada's ability to respond efficiently to these water challenges. Being able to assess the effect of current and future water challenges such as climate change and water pollution on the economy is crucial to design efficient adaptation and mitigation strategies, and ultimately spark the necessary behavioral changes to sustainably manage water resources for the benefit of the economy, society and environment.

The work has focused on the integration of different data sources and modelling tools and has allowed identification of key sectors and regions that significantly impact Canada's economic growth. For example, the Great Lakes generate 35% of Canada's Gross Domestic Product (GDP). This highlights the relevance and importance of sustainably managing the water resources in the Great Lakes. Another example is the work in the Saskatchewan River basin where the building of multiregional and multisectoral hydro-economic models has highlighted their economic interdependence, and therefore the relevance of addressing transboundary water challenges in an integrated manner. These examples demonstrate the usefulness and need for integrated hydro-economic modelling tools for Canada's main drainage basins and the country as a whole in view of the significant economic spillover effects of global environmental change, regional socioeconomic developments and water policies.

Decision-support tools such as the multiregional input-output models for the Great Lakes and the Saskatchewan River and more recently a computable general equilibrium model for the Canadian economy have been among the key outputs from the core hydro-economic modelling group. These tools have been co-developed and implemented in GWF projects like IMPC and Lake Futures.

Human dimensions of water: This theme was formed in the last year of GWF, 2022, to study the inter-related ways that societies and people are impacted directly by water resources. Water is the key driver of food security and green water through which the water can be distributed, and floods and droughts have a direct impact on people, their communities, and health. In short, the human dimensions of water focuses on four major aspects (1) Infectious disease: Adapting and developing extensions to current GWF models to understand the ability of these models to assess future incidence of waterborne diseases. (2) Vector-borne disease: Adapting and developing extensions to current GWF to understand the ability of GWF models to assess future incidence of mosquito- and aquatic vector-borne diseases (3) Flood and Drought Resilience: Assessing social dimensions of vulnerability and resilience to flood and drought events to inform development of current and future scenario hydrological model outputs in forms that are more practical for local decision-makers. (4) Governance Metrics: Developing a benchmarking system based on core governance and social learning indicators to assess current status and evaluate future policy interventions to inform and be informed by current and future scenario hydrological model outputs.

Link to Publications List

Knowledge Mobilization (KM)

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

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

Professional Development and Technology Transfer

N/A

Transformative Sensor Technologies and Smart Watersheds for Canadian Water Futures (TTSW)

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

Region: Canada

Total GWF funding support: $1,081,341; $500,000

Project dates: June 2017-May 2020; September 2020-August 2023

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The Image Processing Laboratory, University of Valencia -- Antonio Ruiz Verdú
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Spire -- Philip Jales
Fortress Mountain Holdings Ltd. 2012-2022 -- Chris Chevalier
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DraganFly -- Zenon Dragan
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Skaha Remote Sensing -- Maik Wolleben
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Western Economic Diversification -- Abdul Jalil
Canada's Chief Scientific Officer -- Mona Nemer
Statistics Canada -- Francois Soulard
Sustainable Development Goals Unit -- Ugo Therien
Canada Foundation for Innovation (John R. Evans Leaders Fund) 2018-2020
Western Economic Diversification Canada 2017-2021 -- Jennifer Stelzer

Science Advances

Decision makers facing water management challenges across Canada must rely on an unprecedented amount of data and are dependent on highly diverse data streams and data analysis methods. This project focuses on the development, testing and pilot implementation of a 'Big Data' platform that will be pan-Canadian in scale and targeted to support the emerging spectrum of water futures issues throughout cold regions. Advances include improving measurements of environmental parameters in cold regions by developing new sensors and improving existing sensors. Development and deployment of ultrasonic sensors for multiple environmental measurements was delayed by COVID as project researchers could not work with ECCC technicians to test this device. Plans are to catch up in the coming year. Development, deployment, and, and commercialization of drone-based CHIONE for acoustic observations of snow to non-invasively measure snowpack depth, density, snow water equivalent, liquid water content and temperature has progressed through synthetic data and field observations from the Chione electronic system which sends audible sound waves into a snowpack and receives their reflections are being used., and limitations of the forward and inverse models using examples of snowpack observations taken from different seasonal snowpack environments in Canada are being analyzed and documented.

The presence of microplastics in the food chain and drinking water has raised major concerns about human health. Microwave sensors are proposed to achieve reliable online microplastics monitoring with much less complexity measurement setup and comparably less time than the optical spectroscopic method.

Small microwave sensors to measure multiple water quality parameters have been studied: a coupled microwave reader-tag design is proposed as the sensor where a chipless RF tag is the main sensing element integrated with the microfluidic device. Using the chipless tag as the sensing element not only enhances the electric fringing fields and the sensitivity of the structure but combining it with a microfluidic device create a user-friendly, low-cost, contamination-free microfluidic sensory device. Integration of the tag with a microfluidic device enables robust wireless sensing performance, making this a strong candidate for harsh environment sensing. The investigation of novel microwave sensor has been extended to the applications for microplastics sensing.

Pan-Canadian cold regions environmental sensor network testbeds have been evaluated, and the process of developing 'Smart' sensor networks and further deploying transmitters for communication from observatories to satellites /across Canada continues following the departure of a key satellite-based data communications partner, Myriota. Work on this topic has focused on further development of smart data collection utilizing trigger-based data logging systems and data analysis utilizing machine learning (ML) and aspects of artificial intelligence (AI) with terrestrial hydrologic applications. This has been a focus of a PhD student in collaboration with Dr. Jimmy Lin, School of Computer Science at UW. Time series datasets from the Alder Creek observatory have been utilized to develop an AI predictive model for groundwater recharge and the initial manuscript on these results is under development. The work is now being expanded to focus on smart data collection and AI modeling of transient tile drainage phenomena.

Optimization of data transfer through "smart" modems: with the satellite data transfer component of the project ending with the Myriota leaving as an active partner, efforts within this task have been redirected to the integration of low elevation geophysical surveys for permafrost and groundwater discharge mapping, based on electromagnetic induction and infrared imagery, with new modeling tools. Working with a new partner, Xcalibur Multiphysics, the GNWT and First Nations partners within the Sahtú Renewable Resources Board, a feasibility study to conduct an airborne EM survey of the Bogg Creek watershed, NWT was completed during this year. The survey is planned to fly May 2022. In addition, significant advancement in a new generation of numerical modeling tools based on thermal, mechanical, hydraulic, and solute transport processes as applied to permafrost thaw dynamics has occurred during the last year. It is anticipated that the low-level geophysical surveys will provide unique and previously unavailable data to inform predictive groundwater models in discontinuous permafrost terrain.

Vegetation structure is one of the most important factors shaping amount and spatial variation of snow accumulation within forests. However, it is often unclear what regions of canopy around a given ground point of snowfall are important, l there, leading to uncertainty in the effects of climate and vegetation changes on spatial distributions of snow. As snowpack distributions play an important role in determining melt rates and contributing areas during melt periods, a stronger understanding of the snow-vegetation interactions that shape forest snowpacks will inform more robust snowmelt runoff

models, with ramifications for land and forest management decisions. The research team has been assessing and improving drone technology (platforms and sensors) to operate in cold weather conditions and to provide intermediary scale of environmental measurements for monitoring by deploying ACRO drones over large areas for Hyperspectral and LiDAR studies. Observations over two mid-winter storms at a Rocky Mountain field site in Canada were analyzed to identify the angular and spatial footprints of vegetation found in spatial patterns of snow accumulation. Results showed significant vertical asymmetry and angular spread in relationships between snow accumulation and surrounding vegetation which coincided with local wind regimes. Evidence of preferential deposition of snow was seen within the forest due to funneling from downwind vegetation. Over 50% of the spatial variance in snow accumulation seen across the forest was found between points within 2.0 m of horizontal distance. These findings demonstrate how small-scale snow-vegetation interactions result in emergent processes at larger scales including sensitivity of forest snow distributions to wind regimes, with important implications for snowpack modelling in forest stands and hydrological basins. Similar studies over a broader range of environmental conditions and forests will help to further quantify the effects observed.

Spatially distributed measurements of snow water equivalent (SWE) and near-surface soil moisture/freeze-thaw state continue through installation and deployment of the CryoSAR instrument suite (Ku and X-band SAR). In conjunction with the CSA project an airborne campaign and correlative field season in Ontario were anticipated (adjusted due to COVID from Manitoba). In the end, the project installation progress has been longer than expected and at the end of this FY, the instrument supplemental type certificate (STC) should be completed. This will provide an opportunity for a 2022-2023 intensive field campaign in Ontario and in Alberta. In addition, the project is attempting to deploy the CryoSAR system to Saskatchewan for the SMAPVex campaign in the summer of 2022 that will be led by A. Berg (U. Guelph). Despite the delays in deployment of the aircraft (two test flights in hand now), the next 12 months will have active deployments of the instrument for SWE and soil moisture applications. Aaron Thompson, the CryoSAR systems and operations manager under the CFI project, completed his PhD. He is also assisting with the deployment of the system for the CSA and GWF project. Wei Wang, directly funded under GWF, completed his MSc thesis on novel wideband radar observations of snow over Trail Valley Creek. He has now transitioned into the PhD program and is working on the CryoSAR project. In partnership with the Jet Propulsion Laboratory researchers will be participating in a field experiment for improved retrieval of soil moisture in the boreal forest. The experiment, planned for spring/summer 2022 will involve deployment of numerous in situ soil moisture probes and field-based teams to monitor and record vegetation properties.

A prototype for drone-based L-band passive microwave radiometer for soil moisture retrieval is in development by collaborator Skaha Remote Sensing. Plans to deploy and operate this sensor are currently underway for summer 2022. Use of UAV hyperspectral remote sensing for evapotranspiration monitoring to map vegetation growth over a weighing lysimeter facility near Elora Ontario has been explored. Over the summer 2020/2021 weekly flights were conducted to monitor vegetation using the UAV and hyperspectral signature. Optimal vegetation indices were identified using a random forest approach to identify vegetation indices most closely associated with measure evaporation from the lysimeters. Work in 2021 expanded the flights to monitor corn, soybeans and winter wheat grown on the lysimeter network. The results are anticipated to identify optimal vegetation indices for scaling evapotranspiration estimates in numerical models.

Work on developing sensors and design concept of Microsatellite Water Mission continued with a field campaign organized in August 2019 in collaboration with NRC and ~15 Canadian and American organizations to collect water samples from Lake Erie Western basin and concurrently fly NASA, NOAA, and NRC airborne hyperspectral instruments. NRC finalized processing of this data only at the end of 2021 and applied geometric, and radiometric corrections on WISE-collected hyperspectral dataset. These data are currently being analysed. and a publication is in preparation with scientists from NRC. Researchers have collaborated with Professor Simon Bélanger from Université du Québec à Rimouski and other contributors in submitting a FAST (Flights and Fieldwork for the Advancement of Science and Technology) proposal to the CSA (Canadian Space Agency) and extend the collection of such dataset to other regions. The objectives are to develop atmospheric correction algorithm and water quality retrieval models from hyperspectral data. Results from this study contribute to development of the microsatellite mission concept design proposed in Phase I as well as the WaterSat hyperspectral mission proposed by CSA (currently delayed). A new collaboration with company Spire which operates a constellation of nanosatellites (over 100) providing GNSS data over the globe to develop algorithms for the monitoring of lake ice phenology, and plans are being made for the monitoring of inundation and soil moisture.

The project's national (ECCC; Environment and Climate Change Canada) and international (NOAA; National Oceanic and Atmospheric Administration) collaborators provided field-measured hyperspectral reflectance data and water quality parameters (Chlorophyll-a and Phycocyanin; indicators of algal bloom and Cyanobacteria) collected from the western basin

of Lake Erie. The Sea PRISM sensor, a buoy station on Lake Erie as part of the NASA (National Aeronautics and Space Administration) AERONET (AErosol RObotic NETwork) project, is collecting multispectral reflectance data that have been used to evaluate three different atmospheric correction algorithms applied to Sentinel-3 imagery and to investigate the propagation of errors into the estimation of water quality. Results in this study will be used in the next stage of the project to understand the importance of combining satellite-derived multispectral data with airborne hyperspectral data to understand algal bloom distribution. Such studies that take advantage of benefits from fusing multispectral and hyperspectral data are highly encouraged due to increasing availability of hyperspectral missions.

Researchers obtained satellite GNSS-R data through a collaboration with Spire, a private remote sensing company, to explore the ability of reflected GNSS signals in lake ice phenology dates determination. The study areas include mid- and high-latitude lakes in Canada as well as on the Tibetan Plateau. In addition, a GNSS-R tower has been designed for a land-based study near a mid-latitude lake to study lake ice thickness and lake ice phenology dates during the winter 2021-2022; however, due to a system failure, the experiment has been postponed to next winter. It will provide a complementary set up for another GNSS-R installation to further investigate GNSS-R capability for lake ice in in Churchill, Manitoba, in collaboration with GNSS-R specialists working at the German Research Centre for Geosciences (GFZ). Final tests for monitoring the near-surface soil moisture using a UAV-based GNSS-R sensor, which had passed initial tests through the summer of 2019, was conducted in October 2021 near Columbia Lake, University of Waterloo campus, and the data are now in the preparation phase for analysis.

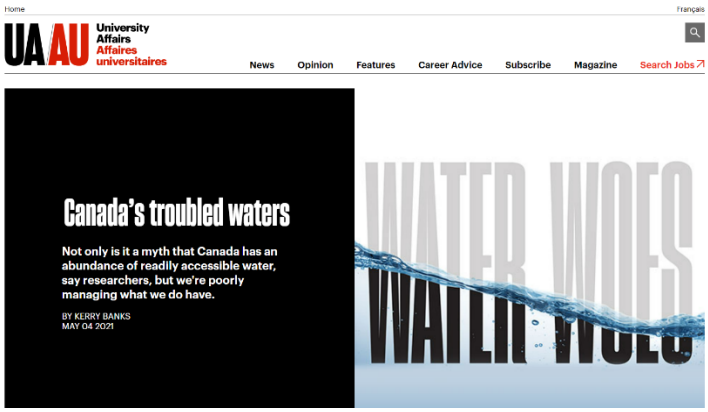
Link to Publications List

Knowledge Mobilization (KM)

The TTSW project is working toward providing water research solutions to those who need them, including the research community. Over the past year the team has worked with several GWF projects, governments, and partners, as well as disseminated research through meetings, workshops, and publications. Researchers continued to collaborate 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), although in a more limited way this year due to COVID-19. Collaboration with FORMBLOOM, the Canada Centre for Inland Waters (CCIW), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) on the collection and processing of multi-scale hyperspectral/multi-spectral data over Lake Erie, Buffalo Pound Lake, and other lake regions of the world is ongoing. Machine learning algorithms developed by GWF research scientist Dr. Kiana Zolfaghari in collaboration with CCIW, NASA and NOAA are now being considered for the 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). 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. Finally, Pomeroy informed the parliamentary speech for House of Commons Debates; Official Report (Hansard), 151 (020), Mr. Francis Scarpaleggia (Lac-Saint-Louis, Liberal) speech, January 2022.

Post about launch of microsatellites in Twitter, 12 June 2019

Outreach:



- Pomeroy, J.W., Ivanov, G. & Davies, T.D. (November 2021) Cold Regions Warming – A Transitions Exhibition: Global Water Futures [Artistic Exhibition]. Cryosphere Pavilion COP26 United Nations (UN) Climate Change Conference, Glasgow, United Kingdom.

Canad's trourbled wtares university affairs

Meetings with governments, decision makers, practitioners

Article in University Affairs, 4 May 2021

- Panel Witness, House of Commons' Standing Committee on Science and Research on its successes, challenges and opportunities for science in Canada, Virtual, February 2022
- Global Water Futures Summary, GEWEX Hydroclimatology Panel (GHP) Annual Meeting, Virtual, November 8, 2021, to November 9, 2021.
- Guest Panelist for Green Party of Canada Leader Annamie Paul roundtable discussion on Climate Change Series: Extreme heat, wildfires, and the IPCC report, Virtual, August 12, 2021,
- Opening presentation of Global Water Futures program and key water science and management goals of importance to Manitoba's water challenges. Global Water Futures Regional Science Exchange with Manitoba – virtual online, June 22, 2021.
- KEYNOTE. Global Water Futures – a transdisciplinary water research program providing solutions to water threats in an era of global change. World Environmental & Water Resources Congress (EWRI) – virtual event, June 7, 2021, to June 11, 2021.

23 articles in popular media

Public workshops and presentations

- Rudolph: developed and lead a special virtual panel discussion entitled: A Cross Country Checkup on Canada's Groundwater: Perspectives on the Future of One of Canada's Most Valuable Resources, for World Water Day on March 22, 2022. Approximately 200 people attended from across Canada.
- Pomeroy: Webinar – Clean & Reliable Water Matters. Creative Solutions for a New World - Climate Series, May 5, 2021.

Promotional videos

- Rudolph: A YouTube video with contents from the World Water Day panel is available for general viewing at https://uwaterloo.ca/world-water-day/
- Pomeroy: CRC Brazil emergency video, Last Warning Campaign, July 2021 https://lastwarning.org/research-video
- Ph.D. candidate Yusof Ghiasi: Animated video to provide a geometrical proof for the SNR formula in GNSS Interferometric Reflectometry, https://www.youtube.com/watch?v=V22Wxbk4jAY

Professional Development and Technology Transfer

As a result of commercial development delays throughout the pandemic, Solinst Canada has had limited scope for direct collaboration on the project but have expressed significant interest in completion of their novel commercial data logging systems, partially created through this project, within the next few years.

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-May 2020; September 2020-August 2023

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Saskatchewan Irrigation Projects Association -- Sandra Bathgate
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OMAFRA -- Kathryn Carter, Rebecca Shortt, Kevin McKague
Lower Thames Valley Conservation Authority -- Colin Little, Ryan Carlow
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Statistics Canada -- Francois Soulard
Canada's Chief Scientific Officer -- Mona Nemer
Sustainable Development Goals Unit -- Ugo Therien
National Sciences and Engineering Research Council (NSERC) Discovery 2019-2024
Western Economic Diversification Canada 2017-2021 -- Jennifer Stelzer
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Canada Foundation for Innovation (John R. Evans Leaders Fund) 2018-2020
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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: A substantial portion of Canadian agricultural production occurs in the sub-humid continental climate of the Canadian Prairies where there are unique challenges to crop production and complex crop-water interactions. In the more humid Great Lakes region, crop production is challenged by variable temperatures (frosts) early and late in the growing season, as well as hydrologic extremes in summer water supply (e.g., dry or flooding). To improve capacity to accurately calculate water use and water productivity for crop and livestock production systems throughout Canada, a combination of field data collection (ON, SK) and modelling approaches are being used. Unique datasets, encompassing 16 site-years, characterizing water use, biophysical characteristics, and energy balance of Prairie agricultural crops (forages, pulses, cereals, canola) have been used to validate and calibrate the AquaCropOS, a water limited crop growth model, for use in the semi-arid Prairies to characterize future changes in crop water use and yield patterns.

Researchers have also used high-resolution Weather Research and Forecasting Model (WRF) simulation output to quantify future changes in several selected agroclimatic indices over the croplands of western Canada under future climate conditions. They have investigated local water availability and water balance within the growing season, and have been working on development of the crop wheat option in the land surface model.

The Cold Regions Hydrological Model (CRHM) platform has been coupled with AquaCropOS to create the Cold Regions Agricultural Hydrology Model (CRAHM) framework to address unique Canadian Prairie agricultural practices and hydrological processes. CRAHM can simulate and evaluate the efficacy of agricultural management practices to improve water use efficiency. CRAHM provides a tool kit with which agricultural stakeholders can test strategies to maximize water for crops to improve production and reduce risks.

A unique dataset has been developed at the University of Saskatchewan Livestock and Forage Centre of Excellence, capturing the dynamics of crop growth and beef cattle production including water use and the impacts of climate and land management on water quality and quantity. Researchers are studying how water quality responds to climate changes and animal production at the same time as establishing best management practices that are cost-effective for producers but ensure sustainable production by the preservation and protection of surface and groundwater resources.

New flux measurement sites were established at two vineyards along the Niagara Beamsville Bench Appellation in June 2020. Over the past year, the project has co-developed and deployed TT-Wine sensors with industry partner Nature 4.0 and the University of Tuscia to monitor sapflow and microclimate of four vines in three different grape varieties: chardonnay, riesling and pinot noir (dominant and most common varieties in the area). These measurements will complement and add to the monitoring of water and carbon fluxes and associated meteorology at the sites. EC and meteorological measurements at the two Niagara vine sites and also at a corn-alfalfa field site near Maryhill, Ontario continued. In partnership with collaborators at USDA-Ohio branch, two new EC-met stations in agricultural fields were deployed in Chatham, Ontario. Data storage for the USDA's Ohio sites at UWaterloo was set up and, over the next year, work will continue in the implementation of Aquacrop-OS and its potential integration with the C3C4 photosynthesis model developed.

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. The work has focused on an improved understanding of the impacts of climate and management practices on both crop water use efficiency and on water quality, allowing better predictions of how Canadian agriculture will be impacted by climate change, and how food producers can respond to these changes to mitigate risks.

One project team has been working on better management of soil phosphorus to help address water quality issues in the Prairies. The team hosted a workshop on this topic and developed a new grant geared towards answering some of the key questions emerging from the workshop, which will contribute to the legacy of the AWF project. The team has recently published work on priorities for Best Management Practices (BMP) implementation, and were told this work was used to help prioritize actions under Canadian Agricultural Partnership (CAP) funding, and was in the hands of influential decision makers (e.g., former MP Goodale). Recommendations were highly promoted by watershed partners and used by them to also help guide funding efforts for further research and implementation efforts.

Implementation of CRHM continued with inclusion of a water quality module. The team made significant progress on improving understanding of the role of rural point sources (agricultural livestock) in watershed phosphorus losses in runoff, or from soils and riparian vegetation grown in wetlands with considerable legacy phosphorus. The combined roles of climate and landscape drivers and management practices has been a central theme of this work, developing and promoting the targeting of conservation practices. Based on conversations with decision-makers in Ontario and the U.S., the team made recommendations for targeted BMPs for regions within the Lake Erie watershed.

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 was carried out.

CHRM has been expanded to simulate biogeochemical and transport processes for nitrogen and phosphorus so that agricultural practices such as tillage and fertilizer application, which strongly impact the availability and release of soil nutrients, can be explicitly represented in the model. A test case in an agricultural basin draining towards Lake Winnipeg showed that the model can capture the extreme hydrology and nutrient load variability of small agricultural basins at hourly time steps. The new nutrient modules are critical tools for predicting nutrient export from small agricultural drainage basins in cold climates via better representation of key hydrological processes, and a temporal resolution more suited to capture dynamics of ephemeral and intermittent streams.

Strengthening capacity for adaptation in agricultural water decision-making: The goal of this work is to strengthen the foundation for adaptation in agricultural water decision-making in Canada, focusing on water quality in the Great Lakes region. A study exploring the effectiveness of four different techniques for identifying potential locations for grassed waterways implementation in the Middle Thames River watershed will inform the development and implementation of best management practices in southwestern Ontario watersheds. The project is also studying the potential for phosphorus losses in agricultural watersheds in Ontario under contemporary and future climates, in coupled human and natural systems (CHANS).

A meta-analysis of water quality trading programs across North America analyzed a farmer survey that looked at the drivers of BMP adoption in Ontario. Also developed was an economic optimization tool that identifies the spatially-optimal design of BMPs in agricultural watersheds, with the Grand River watershed as a case study. An integrated hydro-economic model at higher aggregated drainage basin scale was developed to estimate the impacts of climate change on the Great Lakes basin economy through total 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 such as industry and wastewater treatment, and non-point sources such as agriculture. The work on the SWAT analysis in the Grand River watershed has concluded, and parameterizing SWAT for analysis in another major agricultural watershed of Ontario, Thames River watershed, in collaboration with the Upper Thames Conservation Authority, begun.

Link to Publications List

Knowledge Mobilization (KM)

Extensive within- and cross-team communications have occurred over the year to further project activities. This 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 end user needs, team members continued to engage with project partners, collaborators and stakeholders, however, the pandemic resulted in lower levels than in previous years. A collaboration with CropPro Consulting, the developers of SWATmaps, a precision ag management system focused on soil-water topography interactions was developed and options explored to transfer knowledge of the spatial variability of crop growth and crop water. A

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, mobilizing knowledge of ag and Prairie hydrology is developing. Collaborations with Agriculture and Agri-Food Canada (AAFC) on modelling continue. Ongoing and new collaborations with industry end users include Clavet Livestock and Forage Centre of Excellence, Saskatchewan Irrigation Projects Association; Croptimistic Technology, and SaskWater Strategic Planning, Risk and Policy. Team members worked extensively with partner Rosewood Estates Winery as well as partners from Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) to further develop education about the impacts of climate on viticulture in Ontario. Outputs from this include establishing AWF signage at the winery, maintaining a blog-post, and weather data posted in real-time online. Meetings were held with stakeholders and partners, including with an extension group within SK Agriculture.

Poster by the UW Hydrometeorology Research Group describing the research station at Rosewood Estate Winery, Niagara Falls

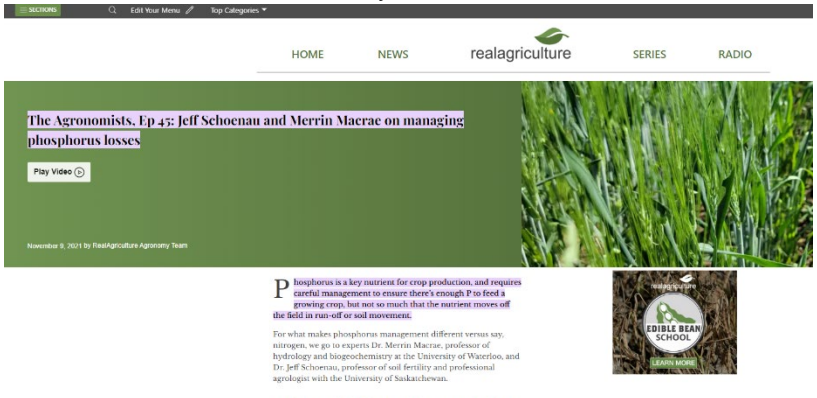
The team continued working on developing extension materials related to agricultural nutrients and water quality in the Prairies. These are hosted on a University of Saskatchewan site that provides research-based recommendations to crop and livestock producers in sustainable nutrient management. Macrae 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. Notably, with KM specialist Goucher, she hosted two targeted webinars in partnership with local conservation authorities where she provided regionally-based recommendations for conservation practices, based on work done through AWF. This work has also been captured in CSA News, and popular media (podcast in 2021, will also be published in Better Farming in May 2022). Brouwer continued his collaboration with researcher Wanhong Yang at the University of Guelph for model development, and the Grand River Conservation Authority, and has recently commenced a new collaboration with the Upper Thames Region Conservation Authority. Bigas (Project Manager prior to 2021), Macrae and Goucher developed a circular brochure to present highlights and key messages that emerged from Phase I of the project (2017-2020) that was disseminated to partners, stakeholders and end users in 2021. The UW Hydrometeorology Research Group has created a project-post that is permanently and prominently hanging at the Rosewood main vineyard sites, which have visitor centres. This poster describes the project in layperson terms and how it fits into the context of the larger aims of AWF and GWF programs as well as helping the viticulture industry. A blog-post was also written up for one of the partner vineyards, at their request, to put on their website, but this has been delayed due to Covid-19.

KM efforts were affected to some degree by the COVID-19 pandemic, but also the departure of Project Manager Harriet Bigas. The impacts from lockdowns (researchers at home with young kids; additional administrative burden; switching to remote learning) and continuing restrictions across the country (no gatherings, no in-person meetings) meant that cross-team collaborations did not happen as easily as they normally would have, and the same is true for opportunities to meet and connect with partners and external stakeholders. However, the switch to a virtual setting offered the opportunity to host and participate in online events that may have reached a broader audience than in-person meetings.

Access of tools by users: Petrone, R. UW Hydromet (website). http://uwhydromet.uwaterloo.ca/ This is a publicly accessible website that displays live weather data at the research team's vineyard sites, which will be expanded to include all of its agricultural sites. This information directly helps the vineyard managers and farmers to observe real-time flux and weather data at their sites to aid in planning fieldscale operations (e.g., frost protection in spring, tilling and pruning in summer). Citizens living in areas around the research sites have also taken an interest in viewing this data and are very receptive to the project's presence in their neighbourhoods.

Meetings with governments, decision makers, practitioners

- Harder, P. 2022. Snow and soil moisture recharge 2022. Western Ag, Saskatoon Saskatchewan, Mar 29, 2022.
- Harder, P. 2022. Hydrology of dryland agriculture: Spring soil moisture recharge. Richardson-Pioneer: Growing for Success 2022, Online, Feb 24, 2022. (Keynote)
- Harder, P. 2021. Dryland agriculture from a water balance perspective. Crop Intelligence Annual Summit 2021, Regina, SK, Nov 30-Dec 1, 2021. (Keynote)
- Macrae, M.L. 2022. One-size does not fit all: Regional conservation practice guidance to reduce phosphorus loss risk in Ontario. Innovative Farmers Association of Ontario. Presentation. Virtual, Jan. 24, 2022.
- Macrae, M.L., and Daigh, A. 2021. Soil Water 101: Too wet or too dry? Getting water into and through the soil for crop availability, nutrient management and weather proofing your soils. Ontario Agricultural Conference, Dec. 10, 2021.
- Macrae, M.L. 2021. Avoiding one-size fits all solutions for the reduction of phosphorus in agricultural runoff in the Lake Erie watershed. Livestock and Poultry Environmental Learning Community (LPELC). Presentation. Virtual, Oct. 15, 2021
- Macrae, M.L. and Goucher, N. 2021. Select conservation practices for managing phosphorus loss depending on where you farm: Best conservation practices for farming on clay soils, Nov. 29, 2021. (Webinar)
- Macrae, M.L. and Goucher, N. 2021. Select conservation practices for managing phosphorus loss depending on where you farm: Best conservation practices for farming on undulating and sloping soils. Nov. 30, 2021. (Webinar)
- Macrae, M.L. 2021. Avoiding one-size fits all solutions for the reduction of phosphorus in agricultural runoff in the Lake Erie watershed. Presentation to Agricultural Soil and Water Group (ASWG). Virtual, Sept. 20, 2021.
- Macrae, M.L. 2021. Is right time-right place enough for phosphorus management? Summarizing what's been learned from field research. Manure Expo. Presentation and Meeting. Virtual, Aug 26, 2021.
- Macrae, M.L. 2021. Avoiding one-size fits all solutions for the reduction of phosphorus in agricultural runoff in the Lake Erie watershed. OMAFRA Policy Branch. Presentation and Meeting. Virtual, July 8, 2021.
- Macrae, M.L. 2021. Agricultural Water Futures. Global Water Futures Regional Science Exchange. June 22, 2021. (Webinar)
- Petrone, R.M. 2021. Meeting with Grape Growers Association of Ontario (GGAO) Nick Lemeux, June 3, 2021.
- Petrone, R.M. 2021. Introductory meeting with OMAFRA (Kathryn Carter and Rebecca Shortt) to establish future research collaborations in Niagara, June 7, 2021.
- Petrone, R.M. 2021. Reconnaissance trip to Essex County to meet with Thames River Conservation (Colin Little and Ryan Carlow) and farmers (Bill and Blake) to discuss installation of EC towers at their sites for collecting carbon and water fluxes and supporting variables. Installations took place in August. June 9, 2021.
- Petrone, R.M. 2021. Meeting with Kathryn Carter and others (OMAFRA) and Andrew Reynolds at Rosewood to highlight current work at the site and discuss future plans for collaborations, November 10, 2021.
- Petrone, R.M. 2021. Meeting with Rosewood vinemaker (Ryan Corrigan) and owner/manager (William Roman) re extending collaborations and their participation in the VineNet project. Preliminary data from the first year of water and carbon measurements at Rosewood was presented and discussed. December 8, 2021.
- Petrone, R.M. 2021. VineNet project concept meeting with all potential partners: OMAFRA (Kathryn Carter and Rebecca Shortt), Grape Growers of Ontario, U of Guelph (A. Reynolds), U of Tuscia in Italy (Valentini Lab), Nature 4.0, Rosewood Estate winery. December 16, 2021.
- Pomeroy, J. 2022. Panel Witness, House of Commons' Standing Committee on Science and Research on its successes, challenges and opportunities for science in Canada, Virtual, February 2022.
- Pomeroy, J. 2021. Global Water Futures Summary, GEWEX Hydroclimatology Panel (GHP) Annual Meeting, Virtual, November 8 - 9, 2021.
- Pomeroy, J. 2021. Guest Panelist for Green Party of Canada Leader Annamie Paul roundtable discussion on Climate Change Series: Extreme heat, wildfires, and the IPCC report. Virtual, August 12, 2021.
- Pomeroy, J. 2021. Opening presentation of Global Water Futures program and key water science and management goals of



The Agronomist broadcast episode about phosphorus losses

importance to Manitoba's water challenges. Global Water Futures Regional Science Exchange with Manitoba – Virtual, June 22, 2021.

- Pomeroy, J. 2021. Global Water Futures – a transdisciplinary water research program providing solutions to water threats in an era of global change. World Environmental & Water Resources Congress (EWRI) – Virtual, June 7 to June 11, 2021. (keynote)

Four articles in popular media

Forty-four Interviews (broadcast or text)

Public workshops and presentations:

- Pomeroy, J. 2021. Webinar – Clean & Reliable Water Matters. Creative Solutions for a New World – Climate Series, May 5, 2021.

Promotional videos:

- Pomeroy, J. 2021. CRC Brazil emergency video, Last Warning Campaign, July 2021, https://lastwarning.org/research-video

Social media

Phillip Harder Twitter (@harder_water): ongoing presence communicating knowledge about prairie hydrology and agriculture. Current follower count: 1155. Impressions in past year: 613K

Merrin Macrae Twitter (@merrinm): ongoing presence communicating knowledge about agricultural water quality. Current follower count: 1927.

Professional Development and Technology Transfer

N/A

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

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

Region: Canada

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

Project dates: June 2017-May 2020; September 2020-August 2023

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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.

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

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.

Understanding, monitoring and adapting to risks:

Risks of cyanobacterial blooms and needs to support adaptation to current bloom conditions are highly variable. We have advanced understanding of toxin risk in key water bodies (Larsen et al. 2020 doi: 10.1139/facets-2020-0022; Painter et al. doi: https://doi.org/10.1039/D2EM00078D), including understanding seasonal change, and weather-related drivers of

cyanobacterial blooms. We have supported new more accurate methods to measure specific toxins sometimes present in high concentrations (Abbes et al. 2022; doi: 10.3390/toxins14040251), and highlighted variation in the way bloom risk is handled regionally across Canada, including key gaps in risk management and risk communication (Bradford et al. 2021 doi: 10.1177/11786302211014401).

Using indicator-species analysis, the team identified temporal groupings in cyanobacteria in a key drinking water resource, finding that the algal community shifts from a diazotrophic bloom in summer to an autumn Planktothrix bloom (Painter et al. 2022 doi: 10.1039/D2EM00078D). Cyanobacterial metabolites differed across the two bloom phases, indicating that taxa can be used to inform toxin risk, supporting improved adaptation and management of water-related risks. Importantly, sensor-based chlorophyll measurements and lab-derived chlorophyll measurements did not detect the substantive fall Planktothrix bloom, potentially indicative of a phenotype with different pigmentation. The fall bloom had important impacts upon water treatment, mitigated in subsequent years by initiation of pre-chlorination, a result informed by ongoing conversations, collaborations and extensive knowledge mobilization work.

Partnerships with the group Algal Blooms, Treatment, Risk Assessment, Prediction and Prevention Through Genomics Status Active Competition (ATRAPP) have yielded large-scale synthesis work, including on the neurotoxic alkaloid β-N-methyl-amino-l-alanine (BMAA). The work produced improved methods for sample handling, yielding higher detection rates, and increased concentrations. BMAA isomers were found across a range of inland lakes across Brazil, Canada, France, Mexico, and the United Kingdom, sometimes at concerningly high concentrations. This work helps broaden our understanding of water-related risks, and improve monitoring and management.

Remote sensing methods have been advanced to combine insights from instrumented buoys and direct measurements, showing the value of phycocyanin measurements in addition to chlorophyll in helping improve model fits within eutrophic waters, and yielding results with good accuracy and reliability (Chegoonian et al 2022; doi: 10.1002/lom3.10480) . Spatial maps for a key water resource were generated and new partnerships with the Government of Saskatchewan have expanded this work to allow extension of the time series of spatial assessment of bloom intensity. There is strong interest in continuing, and broadening this work to develop and implement new tools. FORMBLOOM work, including government partnerships built from it, could have the opportunity to help transform monitoring via some next steps now under discussion.

Bloom drivers to understand key interventions:

Extensive work is underway at the Experimental Lakes Area, including analysis and modelling of existing data, and a new whole-lake experiment. Using a long-term dataset from the experimentally eutrophied Lake 227, and the process-oriented model, MyLake (updated for nutrient uptake kinetics and impacts of changing N:P) researchers were able to test for the effects of temperature and changing nutrient loading regimes on bloom dynamics. The model was effective at simulating lake physics (48 years) and key bloom dynamics. Scenario analyses indicated that spring increases in water temperature worsened bloom conditions, leading to earlier and larger blooms (Salk et al. 2022 doi: 10.1002/lno.11982).

A new whole-lake experiment shows that phosphorus inputs can induce cyanobacterial blooms weeks after inputs begin (Molot et al. 2021 doi: 10.1088/1748-9326/ac0564). And, dense, nitrogen-fixing blooms can be sustained over long periods, doubling nitrogen content in parts of the experimental lakes without a direct anthropogenic nitrogen input. Whole lake fertilization shows, very clearly, that phosphorus alone can lead to rapid induction of cyanobacterial blooms, and that those blooms can have major impacts on other elemental cycles. The next phase of experimentation will assess nitrogen inputs, aiming to understand whether maintaining oxidized sediments via nitrate addition can prevent ferrous iron release, and whether this can mitigate blooms – a direct test of the redox-ferrous iron-cyanobacterial bloom hypothesis. Project work on the redox-bloom hypothesis, outlined in the recent award-winning paper (Molot et al. 2021; doi: 10.1080/10402381.2020.1854400), helps outline potential mitigation strategies for diverse lakes.

Modelling-based work has identified another potential intervention to help mitigate blooms. Floating solar deployments used in a renewable energy transition, are being deployed across more ecosystems globally each year. Work within FORMBLOOM shows these deployments can impact phytoplankton communities via effects including reduced water temperatures, and deteriorating light conditions for phytoplankton growth, which can ultimately impact both species composition, and biomass. The location and size of deployments will mediate key changes within lakes (Exley et al. 2022, doi: 10.1016/j.jenvman.2022.116410).

Helping meet the need for undergraduate training in a challenging time, researchers decided to proceed with the proposed LUGNUTS (linked undergraduate experiments on nutrients) experiments, and conducted experiments on two topics related to FORMBLOOM work. First, undergraduate students tested the effects of nitrogen addition on bloom toxicity, finding an important role of nitrogen in mediating toxin risk. In a second contribution, students addressed the importance of atmospheric phosphorus deposition across four varied regions in Canada and the US. Interestingly, at the Lake Winnipeg research forum in 2022, atmospheric deposition of phosphorus was identified as a critical data gap. Work to date suggests that atmospheric deposition is likely to be a small input into lake phosphorus budgets; however, it may be important in key periods, when in-lake phosphorus concentrations are drawn down.

Towards interventions to address bloom risk:

Understanding interventions that can help mitigate bloom risk across the diverse lakes of Canada includes both biophysical work – such as the team's efforts to characterize interventions based on redox (Molot et al. 2021; doi: 10.1080/10402381.2020.1854400), and emergent areas, including (energy-generating treatment methods), which can have multiple sustainability benefits. In all cases, there are societal costs to living with blooms and managing risk and risk communications. There are also substantive costs to biophysical interventions to help prevent blooms. A PhD student has engaged local partners on Vancouver Island to discuss goals and preferences for managing the bloom-affected Elk-Beaver Lake. This lake, with very high usage, suffers extensive and long-lasting blooms. Her ongoing work suggests a high willingness to pay to mitigate water quality issues, suggesting that, despite the often high cost of lake treatment and watershed mitigation activities, public willingness to support such programs is strong. Through her research, she has worked to develop new, transdisciplinary approaches to limnology and the economics of limnological interventions.

Link to Publications List

Knowledge Mobilization (KM)

Project work on Elk/Beaver Lake has progressed very well with ongoing engagement of the Vancouver Island Capital Regional District (CRD), through focus groups, and then a survey, which received very high response rates. A PhD student is currently analyzing the choice experiment to understand preferences and willingness to pay associated with lake treatment. This work is co-designed, aiming to meet needs of both the CRD and academic interests and is focused on understanding adaptation and management goals, and willingness to pay for mitigation of bloom-related impacts. This work will be presented to the CRD, and others, as it advances.

Ongoing work with Buffalo Pound Lake Water Treatment Plant is formalizing efforts to diagnose and manage bloom upset conditions, with ongoing communications with Baulch and support of Painter, Venkiteswaran, and others. They were able to diagnose issues within the plant of buoyant scum formation, and link in-plant issues to the taxonomic data. Further, they have adopted processes during this period to help manage scum formation (creating a new approach to prechlorination of pragmatic prechlorination in these periods where buoyant taxa are present). Project researchers continue to support and advise the plant as it navigates upgrade decisions, including about data management and integration. Late in 2021, the plant announced the commitment of up to $250K to support replacement of the project's buoy infrastructure on Buffalo Pound Lake, both due to its integration in plant operations, and the value of GWF and GIWS research for the plant. This partnership has had immediate impacts on operations, reducing risks of major supply disruption events (having helped avoid events akin to a 2015 treatment upset), and informing design of an upgraded treatment system based on the ecology of the lake, and hydrochemistry of the catchment.

Ongoing work with IISD-ELA is underway to seek additional funding and help mitigate Covid-delays on the whole-ecosystem experiment. IISD-ELA have partnered on a new Alliance grant that includes commitment of their policy and communications staff at IISD to FORMBLOOM efforts, and extensive work on a two-phase bloom mitigation-recurrence experiment. They have also dedicated considerable staff time to data analysis, design, and planning of the project's whole ecosystem experiment, and agreed to restart the experiment in 2022. IISD-ELA is contributing substantial scientific support to the work, and helping codesign the program, with further KM and communications support anticipated. Advances made on an operating model are a major benefit to the partner, with applicability for forthcoming lake experimentation and other ongoing scientific work. As well, FORMBLOOM is engaged with Blue Leaf on analysis of long-term bloom and hydrochemical data for a shallow lake in an agricultural region of Quebec, and the team is also engaged with Lake Bromont catchment conservation authority (Action

Conservation du Bassin Versant du lac Bromont) supporting knowledge transfer on longevity and efficacy of lanthanum-based internal load treatment and onset and timing of anoxia.

Broader visibility of the project's work has been facilitated via extensive coverage of 'superbuoy' and presentations at multiple venues. The Buffalo Pound Water Treatment Plant invested $250,000 in renewing instrumentation that has been fundamental to the partnership, and hired a media consultant to help promote benefits of this ongoing partnership. The instrumentation streams data during the open water season, which is important to plant operations, and with codesigned decision-support tools, has helped avoid treatment upsets driven by thermal conditions and blooms. Instrumentation now includes photographs, which the team plans to use in communications efforts moving forward. We now also have enhanced capacity for under-ice monitoring, supporting key ongoing needs of the plant and research to address new user-led questions. Presentations have reached key audiences including scientists and managers in the Lake Winnipeg Basin (Lake Winnipeg Basin Program Virtual Symposium), the Interdisciplinary Freshwater Harmful Algal Blooms Workshop, and other venues.

Meetings with governments, decision makers, practitioners: Water Security Agency hired recently defended Dr Cheegonian for a short-term project and has now recruited him as a PDF (with Leavitt, Duguay). 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.

Articles in popular media: Extensive coverage of 'superbuoy' and plant partnership (December 2021 - multiple media outlets).

Public workshops and presentations: Bradford, L. 2022. Invited Speaker. Lake Winnipeg Basin Program Virtual Symposium, Jan 18-20th 2022. DAY 3 - JANUARY 20, 2022. Actions Throughout the Basin - Indigenous Engagement on Nutrient Issues in Treaty 4, 5, 6. https://www.lwbpsymposium2022.com.

Professional Development and Technology Transfer

Access of tools by users: Continued use of buoy and data, co-development of decision-support systems for Buffalo Pound Water Treatment Plant. Investment of up to $250,000 in new instrumentation ("superbuoy") announced by the plant and promoted via their media contractor.

FORMBLOOM has provided expertise to the Center for Ecology and Hydrology (Lancaster, UK) and Thames Water Research (Hanworth, UK) for development of a model to simulate the effect of floating solar panels on algal bloom development.

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

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Six Nations Confederacy Council -- Rod Whitlow
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Six Nations Health Services -- Nicole Bilodeau
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SHAD Canada -- Melissa Bruno
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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.

- The 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 center 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 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.

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:

Article in Guelph Today, 19 August 2020

- 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

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Partners, Collaborators, and Users

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

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 develops and validates 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. The 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 oilspill, characterization of oilsands 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.

Professional Development and Technology Transfer

N/A

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 2020 COMPLETED

Investigators

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Partners, Collaborators, and Users

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

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 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 additional spatiotemporal information 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

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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

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Partners, Collaborators, and Users

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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

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 attempts 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 were presented, and these data are now disseminated for use in the hydrologic community, and 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 land cover 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, 5 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 contributes toward 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

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Bhaleka Persaud, University of Waterloo

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 barriers faced by GWF researchers.

Significant contributions and relationship building include:

- Fostering RDM community relationship building: The DM team has representation within the Network of Experts to continue support and involvement in national RDM initiatives including the Digital Research Alliance of Canada, which brings together CARL Portage, Compute Canada, and others. Nationally, the University of Waterloo data manager (UW DM) and McMaster University data manager (MU DM) continued to engage with the Canadian RDM community.2021 UW DM served as Co-Chair, on the Alliance Data Management Planning Assistant Steering Community.
- MU DM serves on the Data Management Plan Expert Group.

This work has brought knowledge about 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.

- 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.
    - o UW DM - Data and Information team
    - o 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 Allocations: Compute Canada provides high performance computing resources and temporary long-term storage for very large volumes of data. The GWF allocation, available to all GWF researchers, was awarded almost 4PB of storage and 3000 core years of computing resources for the period between 2020 and 2023, and it is expected that this will be renewed and increased in the next period and continue to be a source of high-performance computing and storage for years to come.

Compute Canada Management Committee: A Quota Policy for GWF users of Compute Canada was created and approved by the GWF's Senior Management Committee. Monthly reports on usage by GWF users 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).

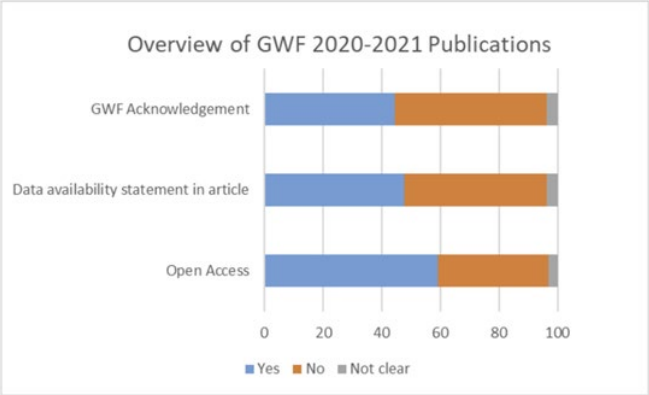
WISKI: In the GWF data portal, Water Information System Kisters (WISKI) is used for accessing hydrometeorological, hydrometric, soil moisture, snowpack, water quality, and groundwater raw data. Work has been ongoing to ensure the Web interface is kept up to date with the latest visualization and web 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). Hence GWF DM has begun some preliminary scoping work by indexing some metrics and some initial review of articles from GWF Annual 2020-2021 report to determine how well GWF Program is progressing with data management. See the following chart.



Graph showing three types of compliance with GWF data management requirements

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. 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

N/A

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

Investigators

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Partners, Collaborators, and Users

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Alain Pietroniro, University of Calgary
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Grant Ferguson, University of Saskatchewan
Helen Baulch, University of Saskatchewan
Chris Marsh, University of Saskatchewan
Ali Bahrami, University of Saskatchewan
Wouter Knoben, University of Saskatchewan

Science Advances

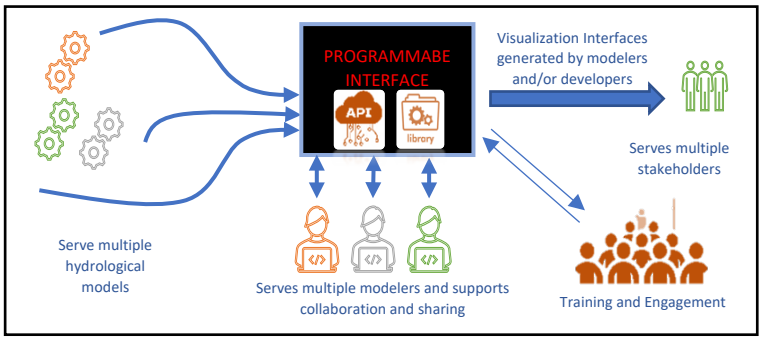
The Core Computer Science team was established to deliver software platforms and tools for integrating hydrological, water quality and economic models, and developing decision-support systems and scientific processing pipelines for these integrated models. In collaboration with other GWF projects and core technology teams, the core computer science team delivers core computing functionality and expertise, provides high performance computing, software, visualization, 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: CRHM was migrated from Borland C++ to a modern C++ environment guided by state-of-the-art software engineering principles, including source code version control and automated testing. Improvements were made to the core simulation code as well as to both the command line and graphical user interfaces. The core simulation code benefited from two major improvements that makes the code much easier to maintain, strengthens type checking for container types, and decreases the memory footprint of the application. To renovate CRHM, the team analysed different versions of CRHM, extracted its architectural structure, reverse engineered CRHM to a set of technical requirements, and elicited use scenarios from multiple stakeholders. Based on the team's analysis, a new architecture for Next-Gen CRHM was designed, and the Borland version was migrated to the new environment. The latest version is available at https://research-groups.usask.ca/hydrology/modelling/crhm.php. As well, APIs and a map application for GWF's Nutrient App was developed and is hosted at USask (https://gwf.usask.ca/projects-facilities/nutrient-app.php).

Hydrological Model Acceleration and Coupling: The Canadian Hydrological Model (CHM) received significant refinement of its distributed processing capabilities that are critical for simulating demanding spatial configurations such as large and high-resolution spatial extents, and for enabling timely forecasts via the SnowCast product (http://snowcast.ca). A new pre-processing tool was created to allow for creating the distributed high performance HDF5 mesh format required for CHM parallel computing, enabling fully parallel partial mesh loading into CHM, and ensuring fewer user-caused errors to be introduced into the mesh generation. This is dramatically lowering memory requirements. Also, CHM can now interact with the hydrological sub-components of the Structure for Unification of Multiple Modelling Alternatives (SUMMA). SummaX modifications include SummaSundials, error-controlled adaptive time integration, and SummaActors, better management of computational resources and better fault detection and recomputation strategies.

Applying AI Techniques to the Management of Textual Data and Metadata: In response to the CFREF Midterm report in July 2021 that called for the additional application of AI techniques in the GWF project, and the programme's continual quest to leverage synergies between core Computer Science and core Data Management at the University of Waterloo, the focus this past year has been on applying natural language processing (NLP) and information retrieval (IR) techniques to the automated analysis of textual metadata associated with GWF publications and datasets. These efforts are enabled by machine-learning approaches based on neural networks, a central component in modern AI. To enable data rescue of legacy solar radiation records, the team prototyped and evaluated a digitization pipeline combining different image pre-processing techniques, semantic segmentation, and an open-source optical character recognition (OCR) for extracting data and metadata recorded in the scanned documents. The team is also applying the latest AI-based techniques from NLP and IR to build a portal for accessing textual data and metadata output from GWF projects. Current efforts focus on the intersection of geospatial and textual analytics, where researchers are developing AI-based algorithms to automatically "link" text with geographic features (e.g., rivers and streams) to support cross modal geo-textual search.

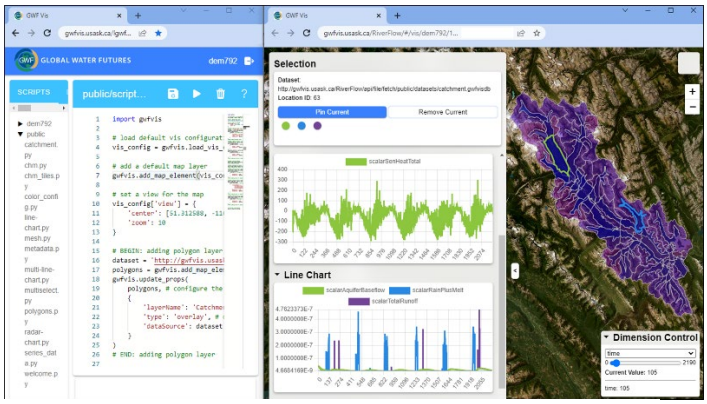
GWF Visualization Platform: In collaboration with the GWF Core Modelling team, researchers investigated the concept of a programmable interface to interactively build context-specific visualizations. The aim is to create a model-agnostic visualization platform to be used by modelers and to provide resources to train end-users and modelers beyond GWF.



The model-agnostic platform

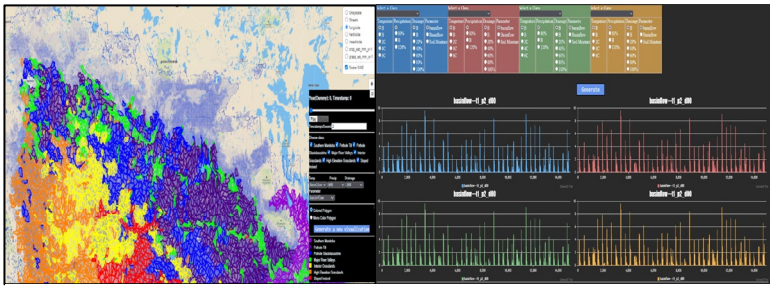
Major accomplishments to date are: (1) a proof-of-concept programmable visualization platform; (2) a scalable server-based architecture with web-browser front-end; (3) APIs and library routines for data import, analysis, and visualization; and, (4) documentation and code samples.

The visualization platform's primary users are GWF core modelers. The visualization platform currently consists of two key components: a programming interface and an interactive visual analytics dashboard, generated by a program. A brief demo of the platform is available at https://github.com/river-flow-vis/docs. The platform allows modelers to use data processing libraries and APIs to create programs to generate a 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 configuring the dashboard to best suit their needs. The interactive visual analytics dashboard can be shared as a web link so that end users can access it directly without knowledge of the programming interface. In the long run, the platform should support scientists to better understand their models through visualization, inspire multi-disciplinary team collaboration, and improve the dissemination of scientific knowledge to a broader audience for better water risk management and decision-support.



Programmable visualization platform

In collaboration with Prairie Water investigators a proof-of-concept visualization was developed to see whether the platform could be generalized to support use cases beyond those of the core modeling team. There are some key differences and commonalities among the needs of the various user groups. The similarities are mainly the high-level visualization needs, including support for creating charts for temporal dimensions, rendering geospatial features on different layers, scenario comparisons, data filtering, and selection. The differences are in the ways different user groups structure their data, interact with the data, and interpret the data at different granularities with different goals in mind. This has created some valuable insights and a knowledge base of visualization, interaction, dashboard components and potential features that should be integrated into the system over time as the platform matures to support more and more scientific teams and stakeholders.



Prototype created for Prairie Water data to assess platform flexibility

To support sustainability, the team envisions the programmable visualization platform to improve based on user feedback and hope to engage a community of developers who continue the open-source development and create a forum around the platform to sustain its development. To achieve this goal, the team integrated key backend components that such a system should have such as user management to manage user specific programs and visualizations, security checks to prevent unexpected server attacks or computational loads, and scalable visualizations both during interaction and when rendering. In the next phase, structured interviews with modelers are planned to evaluate the system and to help test the functionalities of the current system. Plans also include creating a pipeline for making video tutorials and training materials, which is the first step towards organizing webinars and workshops that would allow us to introduce the platform to a broader community of modelers.

Link to Publications

Knowledge Mobilization (KM)

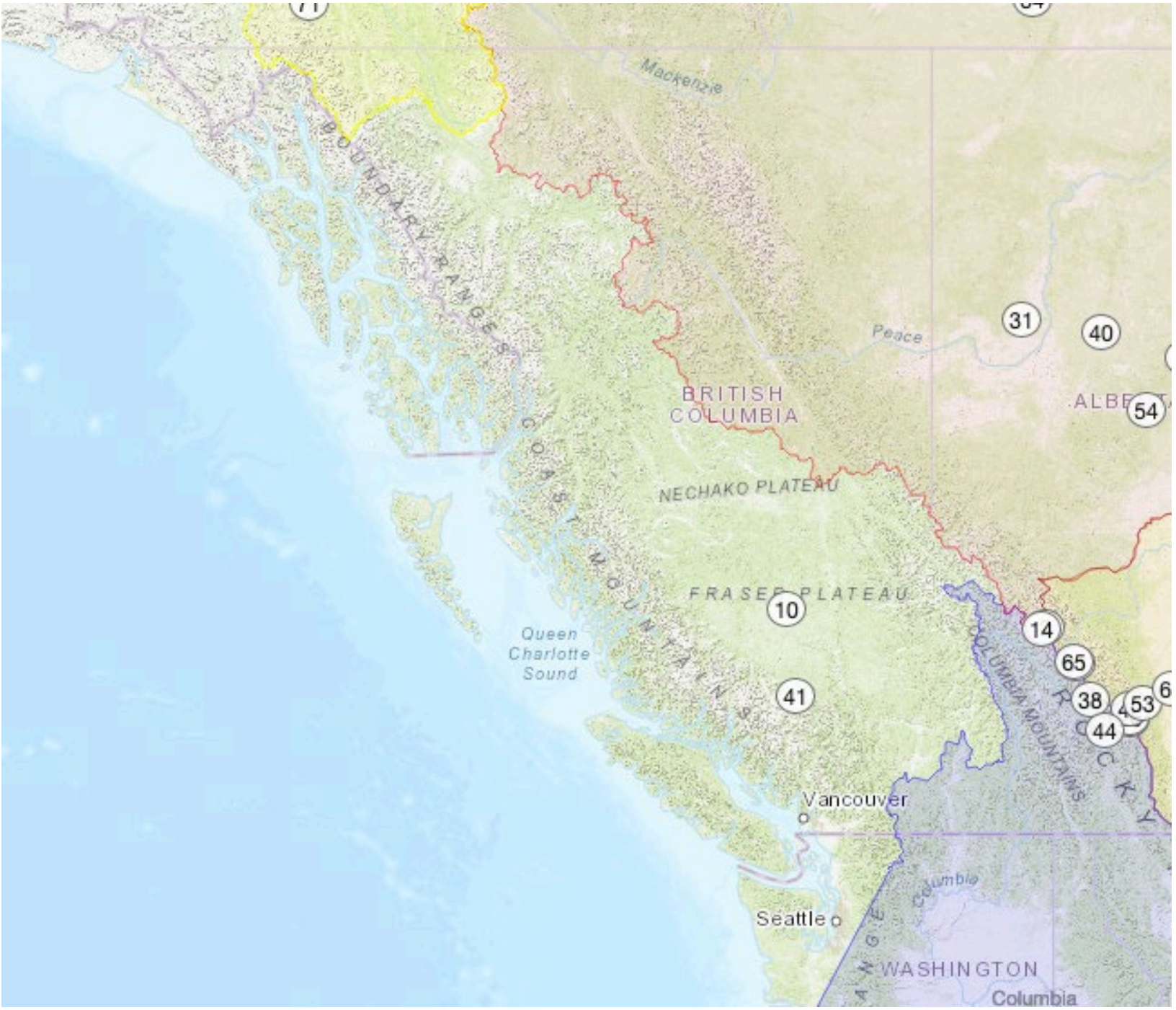
The team's work was featured as part of the Star Phoenix's young innovators series in the article https://www.cs.usask.ca/news/2022/building-a-tool-for-more-efficient-software-coding-usask-research.php.

Professional Development and Technology Transfer

A brief demo of the visualization 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.

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 - Investigators

Region: Pacific

Total GWF funding support: $280,000

Project dates: December 2017-November 2020

Investigators

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University of Saskatchewan 2017-2020 (GIWS CFI match) -- John Pomeroy
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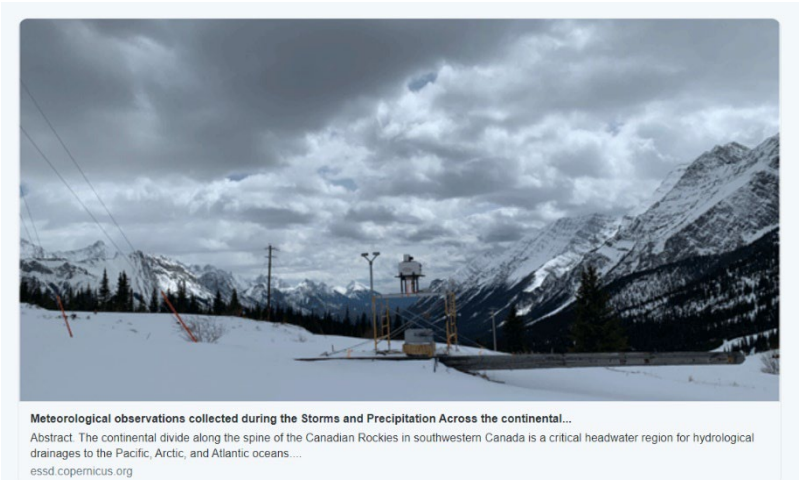
Environment and Climate Change Canada -- Peter Rodriguez, Zen Mariani, Stella Melo (2019 – 2024)
Western Economic Diversification -- Abdul Jalil
Canada's Chief Scientific Officer -- Mona Nemer
Statistics Canada -- Francois Soulard
Canada Sustainable Development Goals Unit -- Ugo Therien
Canada Research Chairs, Tri -- Agency Institutional Programs Secretariat 2017 - 2024 -- John Pomeroy
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

Link to Publications List

Science Advances

This project studied cold region processes related to storms and their precipitation at the top of the western Cordillera. The precipitation in this region provides the primary source of water for North American rivers going to the Pacific, Atlantic and Arctic Oceans, can trigger catastrophic flooding, and maintains glaciers. The objective of the April-June 2019 SPADE work was to determine the atmospheric processes producing precipitation on the eastern and western sides of the Canadian Rockies during springtime, a period when upslope events of variable phases dominate precipitation on the eastern slopes. To do so, three observing sites across the divide were instrumented with advanced meteorological sensors. The scientific analysis was conducted using a multi-scale approach with field measurements collected during the experiment, reanalysis datasets, as well as theoretical calculations.



Mountain storm observation station

During the observed events, the western side was nearly 6°C warmer, received rainfall rather than snowfall on the eastern side, and recorded only 25% of the eastern side's precipitation accumulation. Moisture sources and amounts varied markedly between events. Given the role of the microphysical processes producing clouds and precipitation near the continental divide, high-resolution Global Environmental Multiscale (GEM) model simulations were conducted. Simulations of two westward moving storms suggested that the incoming moisture at elevations below the continental divide was blocked due to stable atmospheric conditions, leading to dry conditions on the western side. In contrast, the moisture above the continental divide was converted to ice condensate and transported to the western side of the divide, leading to precipitation, during the second storm. This process did not occur during the first storm due to limited moisture available at elevations above the continental divide.

To place the precipitation distribution measured during SPADE into perspective, the precipitation gradient was investigated at up to 60 stations between 2011 and 2019. It suggested that elevation explains only half ($R^2 = 0.51$) of the total annual precipitation accumulation, which increases at a rate of 0.39 mm m^{-1} of elevation. This precipitation–elevation relationship is not observed on the western side of the continental divide.

Wind-flow during SPADE was analyzed using two scanning Doppler lidars installed at two elevations on the east side. We found that most precipitation events were associated with a northerly wind component at the surface whereas only two were associated with a southerly component. The turbulence in the valley was attributed to surface heating leading to updrafts prior to most precipitation events and cooling aloft due to the development of clouds, precipitation layers, and mechanical mixing by wind shear at the boundary layer top.

Two main mechanisms impacting the preferential deposition on topographic features of different widths and heights were identified. First, hills blocking particle trajectories increased preferential deposition on the windward slopes. Second, the fluid-particle interaction resulted in lower deposition on both slopes compared to flat terrain.

Overall, the water distribution across the continental divide in North America is a multi-scale challenge associated with moisture and condensate transport. It will be impacted by climate change in that warmer storms would produce more rain that is less impacted by the wind than snow but the precipitation layer within warmer conditions would be higher, which would allow condensate to farther cross the divide. Additional analysis and research are needed to better understand these atmosphere processes.

Knowledge Mobilization (KM)

Meetings with governments, decision makers, practitioners:

- World Water Day, 22 March 2022, Château Laurier, Ottawa, Ontario (J. Pomeroy and J. M. Thériault). Science in Canada, Virtual, February 2022.
- Global Water Futures Summary, GEWEX Hydroclimatology Panel (GHP) Annual Meeting, Virtual, November 8, 2021 to November 9, 2021.
- Guest Panelist for Green Party of Canada Leader Annamie Paul roundtable discussion on Climate Change Series: Extreme heat, wildfires, and the IPCC report, Virtual, August 12, 2021.
- Opening presentation of Global Water Futures program and key water science and management goals of importance to Manitoba's water challenges. Global Water Futures Regional Science Exchange with Manitoba – virtual online, June 22, 2021.
- KEYNOTE. Global Water Futures – a transdisciplinary water research program providing solutions to water threats in an era of global change.


The Future of Flooding in Canada

We've left ourselves exposed by transforming our landscapes. Here's why we can expect more catastrophes like BC's.

Ed Struzik / 19 Nov 2021 / TheTyee.ca

Edward Struzik is a fellow at Queen's Institute for Energy and Environmental Policy at Queen's University in Kingston. His latest book is *Swamplands: Tundra Beavers, Quaking Bogs and the Improbable World of Peat.*

73 Comments

Article about flooding in Canada in The Tyee

International Exchanges: Julie Thériault (May, 2021), was invited to give a training course on rain-snow transitions for the China Meteorological Administration in preparation of the Beijing Winter Olympics 2022. This course was organized by COMET© (Cooperative Program for Operational Meteorology, Education and Training), Boulder, Colorado (Approximately 20 students from China attended the class).

Professional Development and Technology Transfer

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

Mountain Water Futures

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

Region: Pacific

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

Project dates: June 2017-May 2020; September 2020-August 2023

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Brian Menounos, University of Northern British Columbia
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Joseph Shea, University of Northern British Columbia
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Cherie Westbrook, University of Saskatchewan
Francis Zwiers, University of Victoria

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Université du Québec à Montréal -- Julie Theriault
University of Alberta -- Augustana -- Hood, Glynnis
UWaterloo/Alberta Innovates 2020-22 -- Richard Petrone
Pacific Institute for the Mathematical Sciences (PIMS) 2018-21 -- Ruth Situma
University of Saskatchewan 2017 -24 (CRC Support)
University of Saskatchewan 2017-20 (GIWS CFI match)
Connect Charter School -- Cherie Westbrook
Spanish National Research Council -- Juan Ignacio Lopez Moreno
Water Security Alliance -- Andrew Schofield
Fortress Mountain Holdings Ltd. 2016-22 -- Chris Chevalier
Strategic Planning, Risk and Policy at SaskWater, Board of Directors -- Ingrid Newton
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Yukon Environment Water Resources Branch -- Heather Jirousek, Director
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Alberta Innovates -- Brett Purdy
CFI Adaptable Earth Observing System -- Julie Thériault
National Sciences and Engineering Research Council (NSERC) Discovery 2019-24
Statistics Canada -- Francois Soulard
Western Economic Diversification -- Abdul Jalil
Canada's Chief Scientific Officer -- Mona Nemer
Sustainable Development Goals Unit -- Ugo Therien
Natural Resources Canada (NRCan) 2018-20 -- Elaine Dehamel, Carolyn Mann, Monica Harvey, Mary-Ann Wilson
Western Economic Diversification Canada 2017-21 -- Jennifer Stelzer
Environment Canada and Climate Change 2019-24 -- Stella Melo
Canada Foundation for Innovation (John R. Evans Leaders Fund) 2018-21
Canada Research Chairs, Tri-Agency Institutional Programs Secretariat 2017-24
National Sciences and Engineering Research Council (NSERC) Discovery 2019-24
Stoney Nakoda First Nation -- Bill Snow
Trond'ëk Hwëch'in FN -- Alice McCulley
Miistakis Institute -- Danah Duke
Cows and Fish -- Norine Ambrose
Ann and Sandy Cross Conservation Area -- Greg Shyba
Canadian Mountain Network -- Matt Berry

Science Advances

Mountains source water for over 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.

Surface groundwater interactions: Recent studies in the Canadian Rockies, Andes, and elsewhere have demonstrated the importance of alpine aquifers in regulating streamflow and providing buffering mechanisms against climate change. In the north, the presence of permafrost further complicates the groundwater system and how groundwater exchanges with surface water. The goals of this research are to 1) identify unique aquifer systems which represent common conditions 2) quantify hydrogeological response to glacial melt, snowmelt, and rainfall inputs 3) characterize effects of stream-groundwater exchange processes distribution and extent of thermal refugia 4) incorporate understanding of these processes into models and 5) develop tools to estimate groundwater contribution and its sensitivity to climate change and land-use practices.

Watersheds along the Dempster Highway were instrumented in association with the Yukon Government and Tr'ondëk Hwëch'in (TH) First Nation. In Year 3, monitoring continued but most measurements were scaled back for logistical reasons. These watersheds are providing foundational information for a region that has, as of yet, not had hydrological information as related to surface-groundwater interaction and streamflow generation processes.

Streams exist in a number of physiographic and permafrost settings and include intermittent streams in continuous permafrost, which are rarely documented features. While researchers continued to measure long-term fluxes from several sub-basins, new work on diel streamflow parameters, spatial attribution of sources of water using extensive repeat aerial sampling, and the role perched and valley-bottom wetlands in the hydrology of Wolf Creek was begun. Two new students began in 2021 to explore the role of wetlands and lakes in biogeochemical cycling and the role of environmental change (warming, permafrost thaw, vegetation change) on stream temperature across the Yukon. The unique data set from the study of how a seasonal lake at the headwater of a mountain stream controls the thermal regime of the stream is being used to develop methods to evaluate the sensitivity of stream energy balance model and improve its performance.

Wetlands -- advancing nature-based stream restoration science and practice: A ubiquitous ecosystem engineer, the beaver, changes key ecosystem-forming processes that regulate water storage and the downstream flow of water. Beaver-inspired stream restoration science has high importance for restoration practice. In 2021, a working group was struck that includes several of the Mountain Water Futures research partners (Miistakis Institute, Cows and Fish), new research partners (Trout Unlimited) and new Indigenous partners (Blood Tribe) to use an ecohydrological model (BRAT) to identify the capacity of streams in select sub-watersheds of the Bow River and Oldman River watersheds to support beaver dams. The working group will be able to use this modelling to identify places to target beaver reintroduction and places where the stream is too degraded to support beavers. This has led to securing new research funding from Alberta Conservation Association, in partnership with Trout Unlimited, to expand the beaver dam capacity modelling work started with the Mountain Water Futures funding.

Project researchers improved the knowledge of hydrological functioning of mountain peatlands and lakes, vital ecosystems for biodiversity, habitat, and carbon and water cycling, by studying the mechanisms by which mountain peatlands supply baseflow during drought conditions, and the importance of frozen ground and rainfall in

regulating their hydrological functioning. One outcome has been a conceptual framework to explain water storage in mountain lakes. The findings about the ecohydrological functioning of mountain wetlands are part of the research being used to inform the development of the Yukon Wetlands Policy (ongoing), with project investigator Westbrook serving as a technical reviewer of the draft policy.

This past year an MSc Student has worked extensively on applying CRHM for a catchment in the Peruvian Andes (in collaboration with John Pomeroy). Due to COVID, fieldwork for this project has been on hold.

Forest and vegetation change: Vegetation structure and dynamics exert a profound control on the hydrological cycle through their influence on evapotranspiration (the dominant hydrological flux) and on sublimation, which controls the amount of water available as snowmelt runoff. Nowhere is this more significant than in alpine headwater catchments. Associated with climate warming, there are widespread shifts in vegetation type, most notably treeline advance and the encroachment of shrubs at high elevation. The objective of studying vegetation change is to improve capacity to predict changes in water yield from headwater basins by understanding and numerically representing the role of vegetation on water storage and cycling in alpine watersheds.

An MSc student has identified rapid shrub expansion in Wolf Creek through repeat LiDAR measurements with field validation. A PhD student is using eddy covariance, direct sap-flux measurements, and stable isotopes to understand how shifts in vegetation will impact catchment hydrology. Findings suggest that advances in treeline will increase overall evapotranspiration and lower interannual variability. 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. Quantified subalpine forest water use for three growing seasons, gaining an understanding of evapotranspiration and transpiration contributions to the seasonal water budget. A stable water isotope investigation found that soil moisture is the most important source, with younger trees placing more reliance on this source. Forest health could be compromised if successive years of summer drought occur, and growing seasons lengthen. Large scale eddy flux analysis has shed light on the sensitivity of mountain ET to variability and strength of mountains winds, influenced by complex topography, and canopy variation. The researchers have looked at tree islands, finding higher rates of potential evapotranspiration in open areas -- these islands also held the snowpack for longer, providing insulative properties prolonging melt. Work has also been done with John Pomeroy's MWF team and the Transformative Sensor Technologies and Smart Watersheds group to map the Fortress Mountainarea using drones equipped with lidar and multispectral sensors, the data collected used to scale up vegetation fluxes from community to ecosystem and catchment scales.

The Cryosphere: Updating the area and mass change of glaciers in western Canada continued with quantification of mass change of Earth's glaciers and accelerated mass loss, primarily in western North America, an update of western Canada's glacier inventory, and the response of western Canadian glaciers to the influence of wildfire activity. Data from this work are now used by the Government of Canada to update its digital data products for policy makers and data users. The 2021 Heat Dome was responsible for extreme flooding in Robson Provincial Park and land sliding in northwest British Columbia. The project's geodetic data was used to quantify record glacier mass loss during 2021. Researchers are working with Natural Resources Canada on sharing geodetic data for mass change of Peyto, Place and Helm glaciers. This includes biannual geodetic surveys of key glaciers, including the Columbia Icefield. The project projected response of Earth's glaciers, taking into account the IPCC 6th Assessment emission scenarios. Another study considers the combined impacts of climate and glacier changes due to recession on the hydrology and water balance of the Peyto and Athabasca glacier basins in the Canadian Rockies. The CRHM model was used to calculate the water balance of glacierized basins, influenced by the surface energy and mass balance, and considering redistribution of snow by wind and avalanches. Observations of glacier mass balance, snow and glacier ice surface elevation changes at glacier and alpine tundra meteorological stations and streamflow discharge at the glacier outlets were used to evaluate the model's performance. The results suggest that increased exposure of glacier ice and lower surface elevation due to glacier thinning were less influential than climate warming in increasing streamflow. Streamflow from these glaciers continues to increase. The understanding gained here provides insight on how future climate and increased meteorological variability will impact glacier meltwater contributions to streamflow, downstream water availability and sea level rise. Smoke from upwind wildfires was

found to increase glacier melt through both a decrease in the surface albedo from deposition of soot and ash on the glacier and through the impact of smoke on atmospheric conditions above the glacier.

Mountain climate and extremes: The climate of the Mountain West region has been rapidly changing over the past 50 years, and model projections indicate continued warming, but they differ widely with regards to precipitation. All regions of the Mountain West are prone to extreme precipitation, which often leads to record streamflows, high snowpack variability, and avalanche risk. Given the region's complex topography, flooding can be rapid, elevating hazards for communities and industry. Abnormally warm conditions can lead to thin snowpacks resulting in low streamflows required for hydroelectricity, ecosystem functioning and snow-based recreation.

Research focused on precipitation and surface temperature features at Terrace, BC, and surrounding areas. This region is prone to surface temperatures lasting for long periods near 0°C and accompanied with 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 atmospheric rivers which 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. Another component of this project involves placing into a climatological context the mid-November 2021 floods in southwestern BC. This study included more than 20 extreme flood events over the last 21 years in BC, inclusive of the mid-November 2021 flood event. Findings suggest that spring annual peak flow may be triggered by substantial snowmelt while either intense or prolonged rainfall increases flow rates to nearby streams. Several flood events showed that the discharge rates varied with the cutblock area, suggesting that land disturbance may influence the discharge rate within related watersheds. A special focus on the mid-November 2021 flood event showed that a rise in air temperature interlinked with rapid snowmelt and intense precipitation at higher elevations led to the extreme flooding.

Model development and testing: In collaboration with Dr. Francis Zwiers (PCIC) and Dr. Brian Menounos (UNBC), Dr. Siraj ul Islam has implemented the VIC-GL model to the 51,600 km2 Stikine Watershed of northwestern BC. Along with the more southerly Nass and Skeena rivers, the Stikine River begins its descent to the Pacific Ocean in the Sacred Headwaters of BC. The interior sections of the basin are relatively dry, sheltered by the west coast mountains. Vast glaciers and icefields dominate the coastal mountains and combined with landfalling atmospheric rivers and other storms lead to high river runoff to the Pacific Ocean. Implementation of the VIC-GL model to the Tuya (glacier-free) and Iskut (glacier-covered) sub-basins provides contrasting responses of the watersheds to recent climate change. While the Tuya River exhibited no trend in mean annual runoff between 1976-2015, the Iskut River showed a positive trend. Ongoing VIC-GL simulations in the two sub-basins with its dynamic glacier routine will allow partitioning the recent runoff changes from rainfall, snow and glacier melt contributions.

A comprehensive glacier hydrology model was developed within the Cold Regions Hydrological Modelling platform (CRHM) to include modules representing wind flow over complex terrain, blowing snow redistribution and sublimation by wind, snow redistribution by avalanches, solar irradiance to sloping surfaces, surface sublimation, glacier mass balance and runoff, meltwater and streamflow routing. The model developed was applied to simulate the hydrology of the instrumented, glacierized and rapidly deglaciating Peyto and Athabasca glacier research basins in the Canadian Rockies. Long term modelling results indicate that the increases in discharge from the 1960s to the present are due to increased glacier ice melt contributions, despite declining precipitation and snow melt.

A set of algorithms representing permafrost and frozen ground dynamics, coupled into a physically based, modular, cold regions hydrological model at two mountain tundra sites in northern Yukon Territory successfully represented observed ground surface temperature, ground thaw and snow accumulation at the two sites without calibration. Results showed great sensitivity of snow regime and soil thaw to warming, even in the cold continental climate of the northwestern Canadian Arctic. The results are pertinent to transportation infrastructure and water management

in this remote, cold, sparsely gauged region where traditional approaches to hydrological prediction are not possible.

The HRDPS-CHM was applied to simulate snow conditions down to 50-m resolution during winter 2017/2018 in a domain around the Kananaskis Valley (~1000 km^2) in the Canadian Rockies: results highlight the need for further improvements of snowdrift-permitting models for large-scale applications, in particular the representation of sub-grid topographic effects on snow transport.

Interaction with other GWF projects: A linkage with Climate-Related Precipitation Extremes is mountain precipitation, especially occurring near 0°C. Some of the techniques developed to examine such temperatures and their associated precipitation over New Brunswick and Manitoba are being applied to Terrace and surrounding areas. Studies within these two eastern regions have been conducted because of the havoc caused by the accretion of their precipitation onto infrastructure and vegetation. Mountain Water Futures has linked with the Geogenic Contaminants project of Dr. Matt Lindsay for work in the Tombstone Range in Alberta.

Link to Publications List

Knowledge Mobilization (KM)

In Yukon the project team liaises with Yukon Government hydrologists and also with the Tr'ondëk Hwëch'in First Nation. As McMaster has an office co-located with Yukon Government, continuous interaction and sharing of knowledge allows for results to be rapidly translated and shared. While outreach activities have been limited in the past few years because of the COVID-19 pandemic, researchers were able in July/August 2021 to work with Yukon Government Parks to host two evening 'fireside chats' at the Tombstone campground. Research tours of the local area were well attended by park visitors. In Wolf Creek, an interpretive sign was installed and the team liaised with Parks about a permanent installation of professional signs in the campground. Two public talks were delivered about Yukon research, one to the Yukon Science Community of Practice (SCOPe) and another to McMaster University Alumni (Lager Lecture series). A PhD student, as part of an NSERC CREATE internship, interned with Water Resources Branch at Yukon Environment to advance Wolf Creek as a knowledge resource for all Yukoners.

Hayshi gave a full-semester course on surface water - groundwater interaction in Fall 2021 for graduate students, attended by seven employees from Alberta and BC government agencies, and, with Sara Lilley, an invited seminar on alpine hydrogeology for the Bow Valley Naturalists in October 2021 to transfer the knowledge gained from the project's alpine hydrogeology studies. This seminar was attended by a member of Alberta Speleological Society, who invited Sara to give another seminar focusing on her work on alpine karst hydrogeology in November 2021.

Petrone and members of his team have been meeting at least annually with end-users at workshops organized by Alberta Innovates, Bow River Basin Council and Alberta Environment and Parks.

Stewart made contact with BC Hydro to determine outages occurring in the Terrace area for 2020. Further interactions will provide feedback to BC Hydro on the meteorological factors contributing to these.

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 are made to transfer knowledge to communities including First Nations, stakeholders, and end users including industry partners. Primary users of findings from this research are Rio Tinto who are especially concerned about the impacts of climate change on precipitation in the mountainous, upper portion of the Nechako Watershed they regulate. 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 and 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 who have facilitated the installation of hydrometeorological equipment on their property to track hydrometeorological extremes in the upper Nechako Watershed.

Cherie Westbrook (@ecohydro_gal) tweets regularly about her team's research. A PhD student is the Youth Engaged in Wetlands (YEW; https://www.youthengagedinwetlands.com/) Americas representative. YEW is a non-profit organization consisting of an international youth team committed to the conservation, protection, and wise-use of wetlands. Ms Sánchez is involved with Girls on Ice, an organization about empowering young women. though science, art, and wilderness exploration. She was selected to be an Expeditions at Home Instructor for summer 2021. Field photos of beavers were used in a new children's book (Frances Backhouse, Radical Rodents and Ecosystem Engineers, Orca Book Publishers, released May 2021: https://www.netgalley.com/catalog/book/219225). Appearance in film, "Finding Water: Healthy Land, Healthy Stream", commissioned by the Livingstone Landowners Group, available at: https://www.youtube.com/watch?v=E2wYNZJ-tC4 (2198 views as of April 15, 2022).


News / Local News

Landslide on central B.C. coast caused lake tsunami more than 100 metres high: UNBC study

'Imagine a landslide with a mass equal to all of the automobiles in Canada, travelling with a velocity of about 140 kilometres an hour when it runs into a large lake,' says UNBC's Dr. Marten Geertsema.

Tiffany Crawford
Mar 30, 2022 • March 30, 2022 • 3 minute read • 5 Comments

Article about BC landslide from Vancouver Sun, March 2022

A landslide in a rural part of the central B.C. coast two years ago displaced enough water to cause a tsunami more than 100 metres high, according to a study by the University of Northern B.C.

John Pomeroy's work was reported in House of Commons Debates, Official Report (Hansard), 151 (020), Mr. Francis Scarpaleggia (Lac-Saint-Louis, Liberal) speech, January 2022.

Meetings with governments, decision makers, practitioners: Menounos on April, 2021 – 30 Minute zoom call with Premier Hogan (BC) on BC's glaciers. On 24 February 2022 Prof. Dery delivered a presentation titled "Climate change and water security research at UNBC" to the BC Hydro Board of Directors. Westbrook participated in scientific review of Yukon Wetlands Policy (October 2020; March 2021), as Scientific advisor, Saskatoon Wildlife Monitoring Network (ongoing), as Scientific Advisor, Tr'ondëk Hwëch'in First Nation (ongoing), and provided expert testimonial at Yukon Water Board hearing, October 27-29, 2020.

20 articles in popular media

44 interviews

4 public workshops and presentations

One promotional video

Theriault, J. What are atmospheric rivers? https://youtu.be/Pq6zda71Zp0

Professional Development and Technology Transfer

In October-November 2021, MWF researchers Pomeroy, Petrone, and Carey shared project learning in an intensive course on the physical principles of hydrology with particular relevance to Canadian conditions at the University of Saskatchewan Centre for Hydrology with the assistance of the Canadian Society for Hydrological Sciences. Erin Nicholls hosted/moderated the UofS GWF Women and Water Lecture Series: Transborder Collaboration: Women and High Mountain Water on January 13, 2022. Petrone delivered "Alpine Watershed Management: Are Wetlands the Tap on the World's Water Towers?" at Mountain Royal University-COSIA World Wetlands Day, February 2, 2021, Calgary, Alberta, Canada. Langs hosted/moderated the UofS GWF Women in Water Lecture Series by April 2021.

In Phase 1 of Mountain Water Futures, Dr. Siraj ul Islam had the opportunity to visit the Pacific Climate Impacts Consortium (PCIC) on several occasions. This allowed Dr. Islam to interact with the team of hydrologists at PCIC led by Markus Schnorbus to learn how to set up and run the VIC-GL model to glacier-covered watersheds. The VIC-GL model was then implemented on a high-performance computer at UNBC through the support of PCIC. During the COVID-19 pandemic, conversations continued via phone calls and online meeting platforms.

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

Investigators

Corinne Schuster-Wallace, University of Saskatchewan
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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

Water Quality Branch, Saskatchewan
Water Security Agency -- Lorelei Ford
Hydrology and Groundwater Services, Saskatchewan Water Security Agency -- Kei Lo
Saskatchewan Ministry of Health

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

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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

Investigators

Grant Ferguson, University of Saskatchewan
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University of Waterloo
University of Saskatchewan
University of Waterloo
Laura Smith, University of Saskatchewan

Partners, Collaborators, and Users

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

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 improves understanding of how typical hydrogeological settings in the Canadian Prairies will respond to both groundwater pumping and climate change. Progress continues on development of an integrated hydrologic model of an alluvial aquifer system characteristic of the Canadian Prairies. Initial conceptual model development, site delineation and mesh generation are complete, and work is ongoing towards model spin-up and further calibration. A monthly baseflow trend analysis across Canada, including the Prairies, is complete. 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. Project researchers been granted access to collect samples from monitoring wells maintained by SWSA and the City of Saskatoon. Sampling plans were delayed due to COVID-19 restrictions, notably the inability of collaborators from the US to enter Canada to support noble gas sampling. Ferguson, McIntosh and Lindsay are currently organizing a field campaign with students that will take place in June 2022.

Link to Publications List

Knowledge Mobilization (KM)

Brookfield and Ferguson co-chaired the session “Groundwater as a cause and cure of water insecurity” at the 2021 GWF Annual Science Meeting. This brought together groundwater researchers from across GWF. This was the first knowledge engagement effort from this project that commenced in 2020.

Professional Development and Technology Transfer

N/A

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

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

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

Science Advances

Over the past century, profound changes have occurred upstream of the Saskatchewan River Delta, the largest inland delta in North America and home of Swampy Cree and Métis people. These include major alterations to natural flow patterns, with less water reaching the delta during summer months and erratic flow pulses occurring on a daily basis. Importantly, changes also include trapping of sediment in upstream reservoirs – sediment that was once headed for the delta. To date, sediment starvation in the delta has led to erosion of the channel bed and banks, leaving once-productive off-channel wetlands high and dry. This project is examining whether sediment restoration may be feasible for this once vibrant delta ecosystem. Despite challenges in gathering data due to COVID, there was progress.

The sediment transport model is now operational and has generated considerable discussion within the team. This 2-dimensional model is based in HEC-RAS and can provide spatially-explicit water velocities from EB Campbell Dam to the outlet of Cumberland Lake in the delta, which, when combined with sediment texture characteristics, can predict erosion and deposition. It will therefore be used in testing different flow scenarios such as climate change and weir construction, to know if erosion will be accelerated or reduced as flows change. It will also allow modeling of any scenario that involves deliberate addition of sediment to the system from upstream.

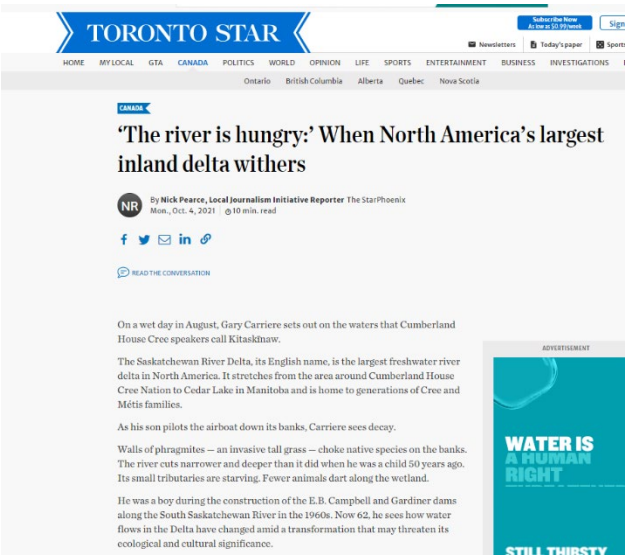
Testing of sediments has been completed. Some sediments had unexpectedly high dioxin-like activity, suggesting past industrial operations (e.g., the pulp and paper mill at Prince Albert) have led to legacy contamination of sediment. Additional funding was received from the Saskatchewan government to test fish for dioxins after finding these compounds above potential effect levels in some sediments. Concentrations in fish were low, suggesting limited bioavailability or rapid metabolism of these compounds, and point to limited negative human health effects of consuming fish.

Link to Publications List

Knowledge Mobilization (KM)

Project researchers held an in-person meeting with the Delta Stewardship Committee to discuss results, with a follow-up meeting online to provide additional presentations. Sediment restoration is on many people's minds as a result of the work (see quotes in the media article by Pearce). As more is learned, it becomes apparent that fixing problems in the delta will

require changes to both the flow and sediment regimes, something stated explicitly by land users to Azza Mohammadiazar in her Master's thesis research.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CANADA

'The river is hungry:' When North America's largest inland delta withers

By Nick Pearce, Local Journalism Initiative Reporter The StarPhoenix
Mon., Oct. 4, 2021 | 10 min. read

READ THE CONVERSATION

On a wet day in August, Gary Carriere sets out on the waters that Cumberland House Cree speakers call Kitaskinaw.

The Saskatchewan River Delta, its English name, is the largest freshwater river delta in North America. It stretches from the area around Cumberland House Cree Nation to Cedar Lake in Manitoba and is home to generations of Cree and Métis families.

As his son pilots the airboat down its banks, Carriere sees decay.

Walls of phragmites — an invasive tall grass — choke native species on the banks. The river cuts narrower and deeper than it did when he was a child 50 years ago. Its small tributaries are starving. Fewer animals dart along the wetland.

He was a boy during the construction of the E.B. Campbell and Gardiner dams along the South Saskatchewan River in the 1960s. Now 62, he sees how water flows in the Delta have changed amid a transformation that may threaten its ecological and cultural significance.

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STILL THIRSTY

Article about Saskatchewan River Delta in the Toronto Star

Presentations to Cumberland House community members and partners at Delta Stewardship meetings. Mohammadiazar, Petersen and Sabokruhie presented to this group, which included a follow-up one-to-one session with the mayor and council from the northern village of Cumberland House to explore possible scenarios for future flows through the delta and implications for sediment transport. Researchers also responded to inquiry from a council member from Nipawin regarding contamination in sediments and fish.

Regular updates have been made to government agencies and NGOs via Delta Dialogue meetings in collaboration with IMPC. Petersen and Sabokruhie have both presented to this group, which includes representatives from Saskatchewan Water Security Agency, SaskPower, Ducks Unlimited, CPAWS Saskatchewan, Saskatchewan Environment, and Fisheries and Oceans Canada.

Interviews (broadcast or text)

G. Carriere, Jardine, Strickert, R. Carriere, S. Carriere, Smith and Crane interview with Nick Pierce of the Saskatoon Star Phoenix on the state of the Saskatchewan River Delta. Article later appeared in the Toronto Star, https://www.thestar.com/news/canada/2021/10/04/the-river-is-hungry-when-north-americas-largest-inland-delta-withers.html, October 4, 2021.

Professional Development and Technology Transfer

N/A

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-May 2020; September 2020-August 2023

Investigators

Colin Whitfield, University of Saskatchewan
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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

Alberta Biodiversity Monitoring Institute -- Stephen Lougheed
University of Calgary Alberta -- Paul Galpern
University of Waterloo Jeremy -- Pittman
University of Alberta -- Scott Jeffry
Arrell Food Institute (Guelph) -- Phil Loring
University of McGill (ResNet project) -- Elena Bennett
University of Saskatchewan, Andrew Watson
Red River Basin Commission -- Steve Strang
International Institute for Sustainable Development -- Dimple Roy
Assiniboine River Basin Initiative -- Wanda McFadyen
Water Security Alliance -- Andrew Schofield
Winnipeg Metropolitan Region -- Michael Miltenberger
Agricultural Producers Association of Saskatchewan -- Todd Lewis, Duane Haave
Sask. Farmer -- Dwight Odelein
Clavet Livestock and Forage Centre of Excellence -- Ernie Barber
Strategic Planning, Risk and Policy at SaskWater, Board of Directors -- Ingrid Newton
Saskatchewan Security Agency -- John Fahlman, John-Mark Davies
Saskatchewan Water Security Agency (Water quality) -- Etienne Shupena- Soulodre
Saskatchewan Water Security Agency (Hydrology) -- Kei Lo
Saskatchewan Water Security Agency -- Heather Davies, Corie White, Doug Johnson
Saskatchewan Ministry of Agriculture -- Ron Eley
Saskatchewan Ministry of Environment -- Shawn Francis
Alberta Geological Survey -- Jessica Liggett
Alberta Agriculture and Forestry -- Jacqueline Kohn, Virginia Nelson, Daniel Itenfisu
Alberta Agriculture and Forestry - Water Quality Section, Alberta Shaun Cook & Greg Piorowski/ Madison Kobryn, Barry Olson
Alberta Environment and Parks -- Thorsten Hebben, Cynthia McClain, John Orwin
Alberta Land Use -- Ken Calbick
Manitoba Sustainable Development -- Elaine Page
Agriculture and Agri-Food Canada SK -- Allan Howard, Aston Chipanshi, Kim Hodge, Henry Wilson
Agriculture and Agri-Food Canada -- AB Claudia Sheedy
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

Canadian Wildlife Service, Alberta and Saskatchewan -- Mike Watmough, Blake Bartzen
Federation of Sovereign Indigenous Nations -- Kyle Prettyshield
Geological Survey of Canada -- Steve Grasby
Statistics Canada -- Francois Soulard
Western Economic Diversification -- Abdul Jalil
Canada's Chief Scientific Officer -- Mona Nemer
Sustainable Development Goals Unit -- Ugo Therien
Western Economic Diversification Canada2017-2021 -- Jennifer Stelzer
Environment Canada and Climate Change (LWBP) 2018-2020 -- Michelle Duval
Lake Winnipeg Basin Stewardship Foundation
Environment and Climate Change Canada -- Ram Yerubandi
Mistawasis Nêhiyawak -- Anthony Johnston
Muskeg First Nation (Beardy's and Okemasis First Nation) -- Alfred Gamble
Sturgeon Lake First Nation -- Jeff McLeod
Ducks Unlimited Canada (SK, AB, IWWR) -- Pascal Badiou, Jim Devries, Lauren Bortolotti
North Saskatchewan River Basin Council -- Katherine Finn
Bow River Watershed Council -- Mike Murray
Souris River Watershed District -- Dean Brooker
Upper Assiniboine River Conservation District -- Ryan Canart
Red Deer River Watershed Association -- Josee Methot
Redberry Lake Biosphere Reserve-- John Kindrachuk
Saskatchewan Association of Watersheds-- Bridget Andrews
Wascana Upper Qu'Appelle Watershed Association -- Joe Ralko
Moose Jaw River Basin Stewards -- Janine Heinrich (past)
Prince Alberta Model Forest Association Inc. -- Sarah Schmid
South Saskatchewan River Watershed Stewards Inc. -- Juliane Schultz
Lower Qu'Appelle Watershed Stewards -- Alice Davis
Lower Souris Watershed Committee --Tyler Fewings
Alternative Land Use Services -- Rhonda King
Prairie Habitat Joint Venture -- Deanna Dixon
Manitoba Association of Watersheds -- Lynda Nicol
Canadian Rural Revitalization Foundation -- Laurie Brinklow

Science Advances

This project prioritizes scientific research on water to address pressing concerns of water security and management in the Canadian Prairies. Its objectives are informed by partners' questions, and its goal is to direct research to help inform water-related management and decision-making with the vision to enhance the resilience of Prairie communities in a changing world. The project is organized under three, inter-related research teams focused on key water challenges: water availability, aquatic ecosystem health, and water management practices and governance. Entering the final two years of the Prairie Water project, activities increasingly reflect a move towards integration and application of the knowledge produced during the project's early stages. Synthesizing what the teams have learned and applying this to key operational issues experienced by partners remains a focus: exploring opportunities with partners to understand how research outputs can be crafted and shared in useful, and usable ways.

Water availability: The Water Availability team has made significant progress in several areas. Groundwater hydrology studies in Alberta have shown the importance of topographic depressions for groundwater recharge. This is significant as researchers also found that deep groundwater in the prairies is not well connected to surface hydrology. A prairie basin classification system has allowed assessment of potential impacts of drainage and climate change on streamflow regimes, improved

existing hydrological modelling techniques, and produced data to support better hydraulic design. 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 by the oil and gas industry.

Aquatic ecosystem health: To date, the work on wetlands and aquatic ecosystem health has brought the project a long way towards initial goals. Many of these efforts are summarized in this report, and some new work (e.g., on pothole salinity) is now beginning. In the remaining stages of the project, researchers will work to connect the virtual modelling scenarios of surface hydrology with emerging information on aquatic ecosystems. This will allow exploration of how anticipated changes in hydrology associated with climate change and wetland drainage can affect, for example, aquatic ecosystem services. This will include refining and advancing integrated modelling work completed to date, working closely with the other teams, and including these outputs as part of a data visualization tool.

Water management practices and governance: To better understand decisions involving water resources on the prairies, researchers have been developing participatory models, conducting economic analyses, implementing large-scale surveys, coordinating experimental decision labs, and conducting interviews. They are currently working on integrating their analyses with the other Prairie Water teams.

Link to Publications List

Knowledge Mobilization (KM)

Knowledge mobilization remains a foundational part of Prairie Water, involving applying an 'evidence informed decision making' approach to stakeholder engagement activities. The 'evidence informed' approach is based on the concept that facilitating the integration of new knowledge into decision making processes requires first understanding what the knowledge is to be used for, how best to present knowledge to decision makers, and understanding institutional challenges to integrating new knowledge into existing governance processes and structures. This approach has informed the design of meetings with individuals, small groups, and larger workshops and meetings. In the past year the project has held a workshop introducing the Prairie Hydrology and Design and Analysis Product (PHyDAP), three meetings with partner organizations to discuss potential pilot applications for PHyDAP, and the Annual Partners Meeting.

Prairie Water is represented on the SK Water Security Agency's BRACE project Steering Committee. Dr. Chris Spence and Dr. Colin Whitfield contribute their expertise and experience at regular committee meetings, and provide technical assistance to the Water Security Agency (WSA) in adapting research outputs for WSA's needs. In this way, Prairie Water contributes to the WSA's AgH20nwards education program, and their Community Hydrological Drought Planning project.

Eric Asare, under the supervision of Dr. Patrick Lloyd-Smith and Dr. Ken Belcher developed a webtool for assessing the financial implications of draining wetlands on cropland. A test version of the tool was demonstrated at the Prairie Water Brown Bag Lunch talks series. This presentation has stimulated discussions on how data from Prairie Water's hydrological and biogeochemical research might be integrated into the tool. A workshop is planned for fall 2022 to introduce the webtool to external partners and explore how it might be further developed to meet user needs.

In February 2022 the fifth Annual Partner's Meeting was held to listen to partners to find out what they have used, and what they may use Prairie Water research outputs for. Findings have been used to develop a targeted communications strategy to help mobilize knowledge in the most efficient way possible. For example, several partners act as intermediaries, sharing Prairie Water knowledge with their own internal and external clients and tailoring it to their needs. By working more closely with partners on these intermediary activities it is possible to learn more about how best to present research outputs for these audiences. And by working more closely with partners in these activities, researchers can take advantage of pre-existing knowledge-sharing networks, increasing project reach.

There has also been extensive interest in a synthesis statement published in the Canadian Water Resources Journal: it has been received and considered within government. The project was asked by the Prairie Habitat Joint Venture (PHJV) to develop a series of webinars for fall 2022, along with requests to participate in videos (Trever Herriott), and numerous other requests that will further help enhance dialogue and awareness of Prairie Water work.

Citizen Science: Ditch monitoring project supported by watershed groups, and in-kind contributions (contract support) of WSA (Leveraged ECCC funds).

Access of tools by users: Prairie Water provided an introductory workshop for the PHyDAP data product. This workshop presented the modelling approach used to create PHyDAP data and potential ways the research team envisioned it being utilized. 35 participants from provincial governments, municipal associations, Ducks Unlimited and watershed associations were in attendance. The workshop intended to demonstrate that Prairie Water can produce valuable data through the virtual basin modelling approach, to hear how this data might be used, and to engage partners for pilot tests of applications of the PHyDAP product. Researchers are actively engaged in one pilot project with the Souris River Watershed District, and in discussions for further potential pilot applications with IISD and Ducks Unlimited Canada. It is also being tested with the Saskatchewan Ministry of Transportation.

- A data visualization dashboard is under development in collaboration with VisForce. A test version containing hydrology data for selected climate scenarios will be ready in late spring 2022.
- A tool for economic assessment of wetland drainage has been developed.This tool will be developed further to include data from other Prairie Water research themes. A workshop is planned for fall 2022 to introduce the tool to external partners.

Meetings with governments, decision makers, practitioners:

- Numerous meetings with the Water Security Agency on water quality, wetlands, drainage policy.
- Ongoing discussions with Ducks Unlimited Canada on wetlands, drainage policy, integrated modelling.
- Meetings and data sharing with Souris River Watershed District and Upper Assiniboine River Conservation District.

Six articles in popular media

Multiple interviews (broadcast or text)

Public workshops and presentations:

- PHyDAP tool. Workshop hosted by Prairie Water. Oct 13th 2021.
- Prairie Water Annual Partners' Meeting. February 2022: Canadian Water Resources Association SK Branch; Provincial Association of Resort Communities of SK; Bow River Basin Council; Red River Basin Commission; GWF AgWater Expo; Saskatchewan Association of Watersheds.

Article about prairie potholes in the Manitoba Co-Operator, 29 October 2021

Other

- Co-development with WSA on BRACE and AgH2Onward program. Participation on steering committees, and contribution to education materials, webinars and videos. Ongoing.
- Supported WSA with "Building Capacity for Community Hydrological Response" project with hydrological sensitivity to climate data. Ongoing.
- Numerous art pieces through the Virtual Water Gallery and others.
-

Professional Development and Technology Transfer

Principles of Hydrology (Jan 10–21, 2021): The University of Saskatchewan Centre for Hydrology with the assistance of the Canadian Society for Hydrological Sciences offered an intensive short course on the physical principles of hydrology with particular relevance to Canadian conditions. This course was offered online for 2021 due to restrictions related to the Covid-19 pandemic and was attended by 22 researchers.

Prairie Water HQP are jointly engaged in Resnet workshops.

Leveraged funding was used to develop a ‘water quality toolbox’ and website that supports some Prairie Water objectives (e.g., noting considerations around drainage).

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

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

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, Sheri Andrews-Key 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

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

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

Science Advances

This project is using agent-based modelling (ABM) to assess and investigate comprehensive impacts on Indigenous communities from flooding and demonstrate its capability as an operational tool for evaluating and supporting health services, emergency planning and management measures. This should contribute to the sustainability of Indigenous communities and their environments by providing a tool to investigate complex interactions and feedbacks between human and natural systems and to communicate understanding of flooding impacts and improvements to mitigation measures. The model framework in future will be applied towards other unresolved public health and water issues including Canada's most pressing public health issue- drinking water in Indigenous nations.

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.

Link to Publications List

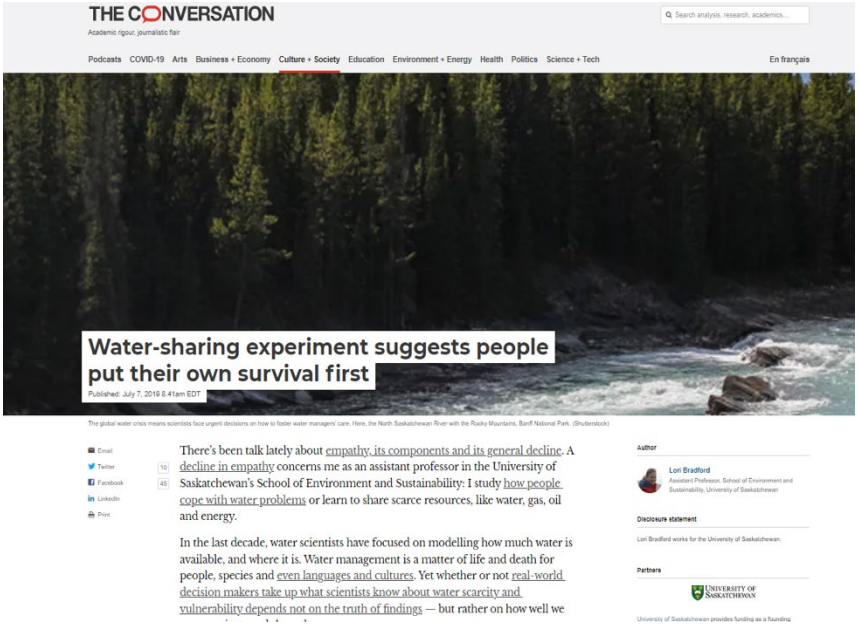
Knowledge Mobilization (KM)

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 which occurred throughout the year.

This year focused on finalizing proof of concept models. 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 the 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.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Water-sharing experiment suggests people put their own survival first

Published: July 7, 2019 8.41am EDT

The global water crisis means scientists face urgent decisions on how to foster water managers' care. Here, the North Saskatchewan River with the Rocky Mountains, Banff National Park. (Shutterstock)

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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

Assistant Professor, School of Environment and Sustainability, University of Saskatchewan

Disclosure statement

Lori Bradford works for the University of Saskatchewan.

Partners

University of Saskatchewan

University of Saskatchewan provides funding as a founding

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.

Professional Development and Technology Transfer

N/A

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

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

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

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 over 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. Blake Woroniuk 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 by an M.Sc. student working with Ferguson on 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 by Blake Woroniuk as part of his MSc. project.

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.

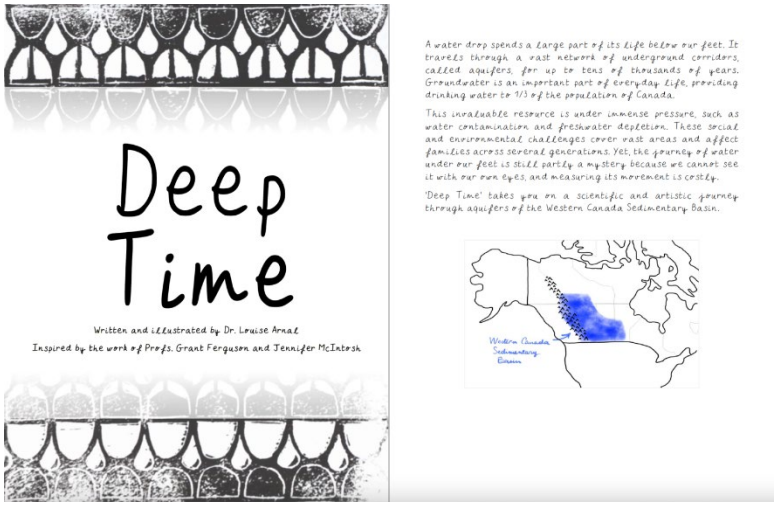
Statistical analyses of permeability have been conducted. Conventional statistics have been calculated for nearly 100 different hydrostratigraphic units in Western Canada. These statistics will be used as model input later in this project. Blake Woroniuk has constructed several models using different approaches to assess migration of fluids between deep and shallow aquifers.

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 Chris Perra as part of his M.Sc. thesis. 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 jurisdictions, including the United Kingdom and Texas.



Graphic from Deep Time artwork

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.

Professional Development and Technology Transfer

N/A

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

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Simon Lambert, University of Saskatchewan

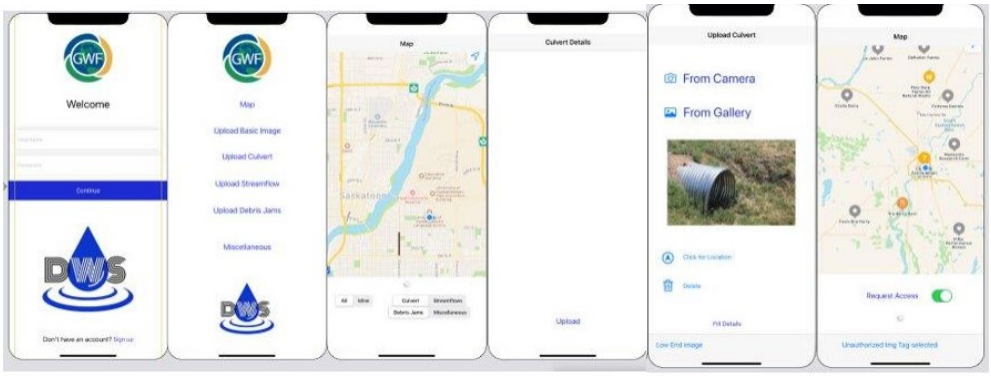
Partners, Collaborators, and Users

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

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 platforms are 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.



Mobile phone screens for citizen science data collection app

Link to Publications List

Knowledge Mobilization (KM)

Working with partners in Saskatchewan River Delta and Redberry Lake Biosphere Region, citizen science was on hold due to COVID. Application testing may resume in 2022.

Professional Development and Technology Transfer

N/A

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

Investigators

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Partners, Collaborators, and Users

Joe Melton, ECCC

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 was 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

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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

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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

N/A

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 is engaging with 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 off 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). 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 have been invited to different events put on by all 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 the ResNet research project.

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, Saskatchewan in 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, 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 17,000 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

Professional Development and Technology Transfer

N/A

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: COMPLETED

Investigators

Warren Helgason, University of Saskatchewan
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Partners, Collaborators, and Users

Science Advances

The issue of dynamic water storage in prairie wetlands has received considerable attention in recent years. Accordingly, we have 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

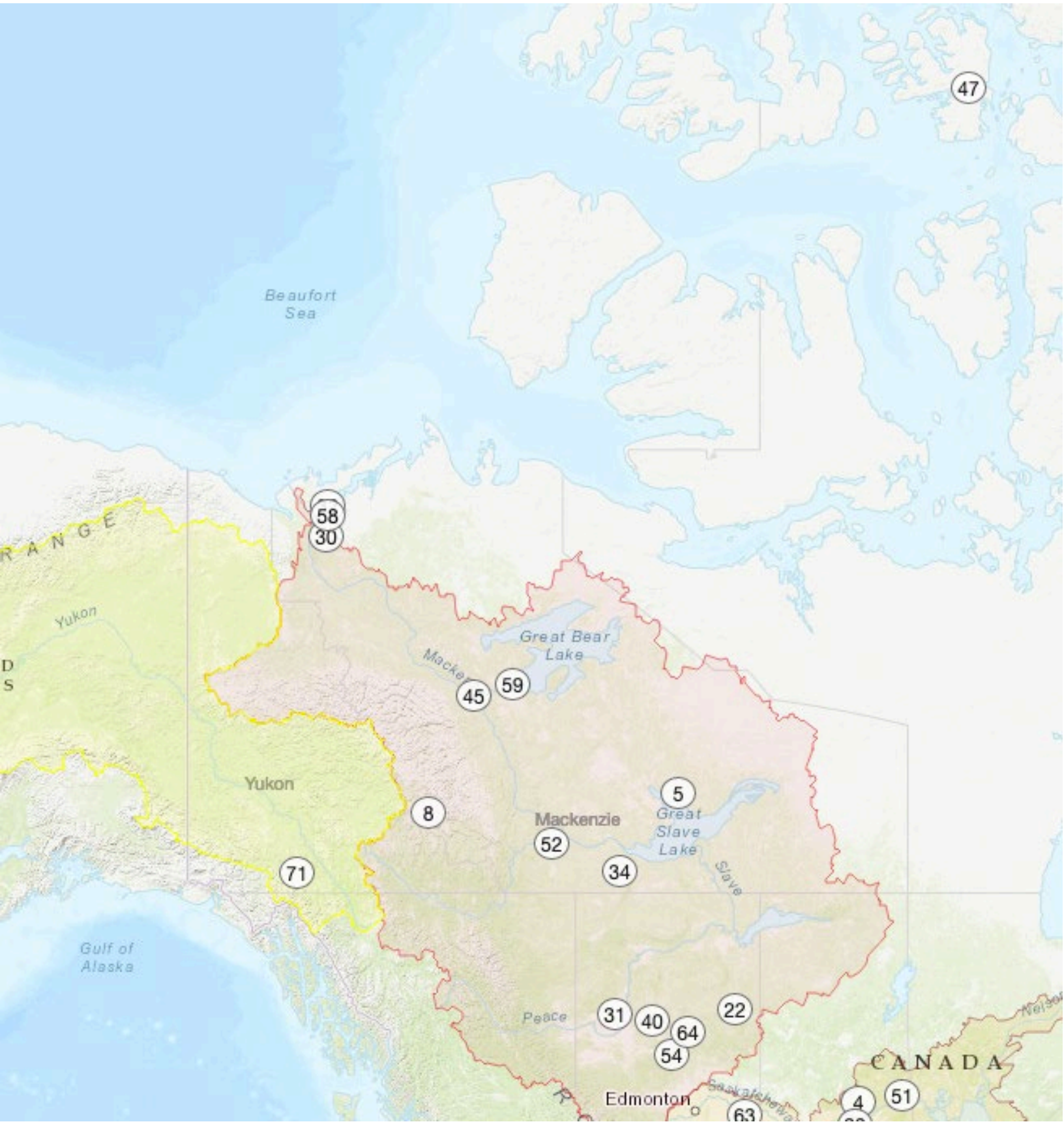
Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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

Investigators

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Grant Ferguson, University of Saskatchewan
Matthew Lindsay, University of Saskatchewan
Sean Carey, McMaster University

Partners, Collaborators, and Users

University of Ottawa -- Clément Bataille
University of Saskatchewan -- MatthewLindsay
University of Saskatchewan -- Elliott Skierszkan
Global Water Futures (GWF) -- Phani Adapa
Newmont Corp. -- Jennie Gjertsen
Casino Mining Corp. -- Mary Mioska
Yukon Gov't (YG) -- Brendan Mulligan
Banting Postdoctoral Fellowships -- Julie Conrad

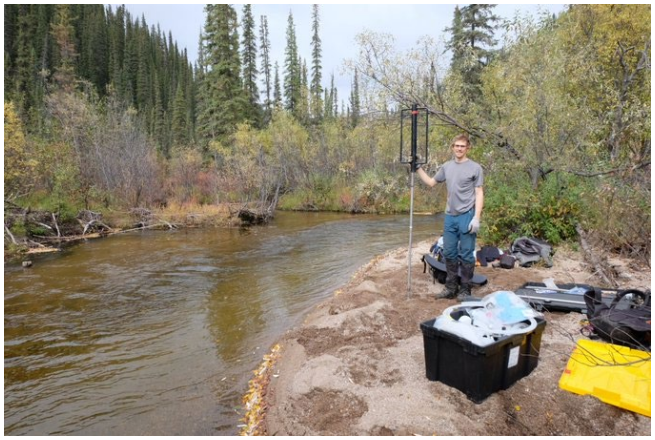
Science Advances

This work provides critical information on the age of groundwater found beneath permafrost in western Yukon, and the mechanisms that explain why there are elevated uranium concentrations in this groundwater. The elevated uranium and arsenic concentrations observed at field sites over a wide range in geomorphic environments from southern to west-Central Yukon pose concern for water quality under a changing climate. Laboratory permafrost thaw experiments are under way to assess risks to water quality under warming conditions. This work will provide important insight into potential transport pathways of nefarious elements into surface water under warming conditions.

Link to Publications List

Knowledge Mobilization (KM)

Within the territorial government, the research team has held quarterly research meetings with Yukon Government's (YG) Environment division. YG has directly participated in field activities and project researchers have made presented to the ations for YG's Water Resources Branch (WRB) to discuss project goals and results to date. Ongoing regular communications occur with YG as well as part of this research project. YG is highly motivated to understand impacts of permafrost thaw on groundwater in YT, where 97 % of the population uses groundwater as a drinking water source., and therefore is a highly engaged collaborator in the research. YG has also been in communication with the research team as their findings on the chemical composition of shallow permafrost may have important ramifications for regulation of the placer-mine industry of Yukon that extracts ore found within this material.



FDr Skierszkan installing drive-point piezometers for groundwater sampling on traditional territory of the Tr'ondëk Hwëch'in First Nation (Dawson Range, Yukon, Canada

Within First Nations governments, Skierszkan participated in an in-person meeting with Tr'ondëk Hwëch'in's (TH) Natural Resources Department. The meeting served as an opportunity for TH to discuss how this research project intersects with community concerns. It was also an opportunity for the research team to present findings to TH and identify possible future areas of cooperation.

Partnership from the Yukon mining industry is critical to this project. Numerous meetings were held over the last year with environmental management teams at Newmont Corp and Casino Mining Corp to secure commitments of in-kind support and sharing of historical data from remote exploration sites, which are a major contribution to this project. Both companies plan to create open-pit mines in permafrost regions of west-Central Yukon and recognize the importance of understanding changes to baseline water quality either through their operations or indirectly due to climate change. These meetings have resulted in substantial in-kind support (est. ~$20,000 value) which enabled Skierszkan, Fellwock, and partners to access remote field sites for field sampling activities. Extensive baseline monitoring data that was obtained at significant cost by these companies is also being used in the research.

Numerous outreach events have taken place in the last year to ensure KM with research is shared with the public. In July 2022, MSc Grunsky participated in a public outreach water workshop co-hosted by Yukon Government WRB and Yukon Territorial Parks. Grunsky participated in fireside chats to talk to park visitors about climate change, Yukon hydrology, and research projects. Grunsky also participated in hosted interpretive drives through the various landscapes and ecosystems along the Dempster Highway and operated a booth at the park's interpretive centre. In September 2021, the research was featured on CBC radio's popular science show Quirks and Quarks, where Skierszkan discussed fieldwork and possible considerations of permafrost thaw on water quality. As part of World Water Day in March 2022, Skierszkan participated in a public presentation on permafrost, groundwater, and northern water quality, hosted by the Whitehorse Beringia Centre's Science Talks series and was introduced by the Yukon Minister of the Environment, Nils Clarke.

Professional Development and Technology Transfer

A workshop at the Canadian Permafrost Association Annual General Meeting, in Whitehorse, is planned for August 2022. This will be an opportunity to learn about Canadian permafrost and engage with other Canadian permafrost researchers. In Through cross-institutional placements or internships, MSc Grunsky spent May to September 2021 hosted by collaborators at Yukon Government's Water Resources Branch (WRB), trained by WRB staff on groundwater sampling and worked with the WRB team collecting groundwater samples across southern Yukon. Under user training and tech transfer opportunities, Grunsky completed EQW in data management software training with the WtRB 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.

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

Investigators

Martyn Clark,	University of Saskatchewan Contact: 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

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

Science Advances

Climate warming is accelerating disturbance processes in northern ecosystems, including thermokarst, boreal and tundra wildfire. In tandem, more gradual processes relating to warming-induced species range shifts are occurring, most notably at the taiga-tundra ecotone. These changes are resulting in dramatic land cover changes across the terrestrial arctic drainages, with profound implications for hydrological and land surface-atmosphere interactions. Despite their importance, these changes and associated feedbacks have been poorly represented in Earth Systems Models. This project synthesizes understanding of dominant hydrological-ecological interactions and their feedbacks, identifies shortcomings in the current generation of modelling approaches, and is working on a hierarchy of model simulations.

A Post-Doctoral Fellow has begun development of a conceptual model of ecohydrological response to tundra shrub expansion. In April 2022 an initial project meeting discussed the scope and direction of this conceptual model and accompanying review and meta-analysis of the literature. Also discussed was the potential of collecting ecophysiological measurements from shrubs across several tundra sites. These data would be used to address current knowledge gaps regarding model parameterization of plant traits.

Link to Publications List

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

Professor Martyn P. Clark completed the course “Gender-based Analysis Plus” offered by the Government of Canada.

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

Investigators

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Grant Gunn, University of Waterloo
Homa Kheyrollah Pour, Wilfrid Laurier University (WLU)

Partners, Collaborators, and Users

NWT and Nunavut Chamber of Mines -- Tom Hoefer
NWT Centre for Geomatics -- Mélanie Desjardins
Environmental Impact Screening Committee, NWT -- David Livingston
Environment and Natural Resources, NWT -- Bruce Hanna and Andrew Applejohn
Environment and Climate Change Canada -- Steve Howell
The Wek'èezhìi Land and Water Board -- Ryan Fequet
North Slave Métis Alliance -- Cat Fauvelle

Science Advances

The timing of lake ice freeze-up, break-up, and the duration of ice cover in winter are indicators of the annual temperature regime in cold temperate lakes. Estimation of ice phenology and thickness are vital for safe winter travel for Northern community members and transportation companies, who use ice roads to move both people and goods into areas that would otherwise not be accessible. Under current climate change and winter warming, northern lakes are experiencing significant shifts in ice cover duration and water temperature. Knowledge of the thickness of the lake ice and of the overlaying snow cover are important requirements when determining how much weight an ice cover can safely sustain. This project is developing tools to further develop Big Data applications in the realm of cryosphere studies, evaluating novel lake ice monitoring approaches, and contributing to scientific study of lake ice phenology and thickness retrievals.

Achievements so far include confirming the usefulness of microwave scattering mechanisms in determining lake ice thickness. Techniques were tested using three regions of interest (Alaskan North Slope, Tibbit to Contwoyo Ice Road, NWT, and Churchill, MB) where the team successfully retrieved ice thickness parameters. Results will be incorporated into a high-impact publication to demonstrate the utility of synthetic aperture radar (SAR) in identifying changes in ice thickness for Canadian northern lakes. This project also spurred the development of a supplementary study exploring the maximum length of the 2022 ice season for Arctic and sub-Arctic regions with high density of small ponds and lakes.

Fieldwork on NWT lakes

working with sensor technology alongside, Homa Kheyrollah Pour (Co-PI), Gifty Attiah (PhD Student), Alicia Pouw (MSc Student), and Arash Rafat (MSc Student) on Landing Lake, N.W.T. (photo credit: ReSEC Lab)

The first field campaign was conducted from November – March 2002. It collected ice thickness and other lake ice parameters (snow and temperature) on 10 small lakes

in the Northwest Territories using Ground Penetrating Radar (GPR) and other traditional ice thickness measurements instruments. Data will be used for further calibration of model parameters and to validate model outputs.

Link to Publications List

Knowledge Mobilization (KM)

Contact has been established with two additional local indigenous communities, the Wek'èezhìi Land and Water Board (WLWB) as well as North Slave Métis Alliance. Both communities are supporting project research activities in terms of detailed assessment of the effects of rapidly accelerating climate warming on lake ice coverage. These findings may be relevant to winter water withdrawal limits set in their water licenses. The Fisheries and Oceans Canada (DFO) Protocol for Winter Water Withdrawal from Ice-covered Waterbodies in NWT and Nunavut outlined various water withdrawal limits for lakes depending on physical lake characteristics such as maximum depth and maximum expected ice cover that required bathymetric surveys. It recognized that maximum expected ice thickness varies throughout the NWT; therefore, ice thickness data from lakes were estimated using long term data from Environment Canada, Water Survey of Canada and Canadian Ice Services. The project research may also be useful for the Mackenzie Valley Land and Water Board, which is currently leading the development of a Guideline for the Determination of Water Source Capacity in the Mackenzie Valley -without bathymetric data. Using remote sensing to determine more accurate maximum expected ice cover for remote lakes is supporting the WLWB and other regulators to better assess which lakes are appropriate for water sources and suitable winter water withdrawal limits.

Data workshops are planned with GWF data management team members to review data policies policy rundown, implications, and moving forward with project data with project HQP.

Shared in popular media

- NNSL Media: https://www.nnsl.com/news/duo-hope-to-use-research-data-to-make-ice-travel-safer/
- CBC North: https://www.cbc.ca/news/canada/north/simba-ice-thickness-nwt-1.6329022
- Cabin Radio: https://cabinradio.ca/85155/news/yellowknife/sensors-on-yellowknife-lakes-could-be-start-of-larger-ice-network
- CBC News Northbeat: https://www.cbc.ca/player/play/1998210115722/
- Satellite Measurements of Lake Ice from Space, Gifty Attiah, Geography and Environmental Studies: https://www.wlu.ca/academics/faculties/graduate-and-postdoctoral-studies/research-chat-podcast/index.html

Professional Development and Technology Transfer

N/A

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

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
Yellowknives Dene First Nation
Lutsel K'e Dene First Nation

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. 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 to summer/autumn 2022.

Link to Publications List

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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

Investigators

Sarah Cockerton, Matawa First Nations Management
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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

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

Science Advances

MFN's homelands and traditional territories 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 km2 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 water 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.

In 2020/21 MWF shifted to online interviews, increased use of social media, and remote field work conducted by Indigenous students within their own communities with permission to engage in water sampling that respected social distancing and public health concerns.

Link to Publications List

Knowledge Mobilization (KM)

Matawa Water Futures (MWF) has been active in community engagement during a period of restricted travel and public health guidelines arising from the global pandemic. While co-investigators have been unable to travel the project's Co-PI Sarah Cockerton and Matawa's Four Rivers Environmental Services Group have been creative, persistent, and successful in advancing two-row water science with Matawa First Nations in terms of community engagement, training and capacity building, knowledge mobilization, and transfer of knowledge to First Nation users (leaders, decision makers and community members).

Community engagement: Four Rivers creatively responded to the pandemic with technical work-arounds and successfully developed and launched a webinar series for Matawa communities. They continued to provide GIS and water monitoring internships to Matawa Members who with the support of MWF funding and faculty mentorship have advanced in both undergraduate and graduate water science degree programs. The project has supported drone and GIS trainings for community members to advance community led field work and mapping in compliance with Covid-19 restrictions. Social media is also being employed to promote community engagement. Facebook has been a vehicle for engaging communities in reflecting upon the importance and value of water in their communities through Facebook photo contests.

Products built/used to exchange/transfer knowledge: Enhanced data access is a priority for Matawa member First Nations. Four Rivers designed and procured new technology packages for each of the nine Matawa communities, including tablets and mobile internet hubs, as well as equipment to support group setting engagement (i.e., speakers, microphones, projectors). With leveraged funding Four Rivers also procured a quadcopter and a fixed-wing drone to support aerial drone surveys in communities to develop advanced mapping/imagery products (including 3D community maps) that can be used for community planning, watershed monitoring, and climate change preparedness work, as desired.

Poster for Four Rivers webinar series, January 2021

How research is being used for Informed decision making, policies, programs, and planning: Briefing notes, data graphs, and maps, e.g., depth contour map of Tidy Lake and community reports e.g., algae and benthic reports have been prepared and shared with participating First Nation communities as work progresses in each community. Reports are also provided to the Chiefs at regional Chiefs' meetings and the Matawa AGM to advance environmental goals and water monitoring in Matawa. The framework of an accessible Geodatabase HUB site that supports community connectivity and engagement has been drafted. This HUB site, featuring both a public Matawa wide page, as well as private individual community pages, hosts public and sensitive data for the Matawa members to browse, analyze and download for further use. The site also features a survey application that will be used to collect traditional knowledge and technical data as the project continues.

In March 2020, Four Rivers organized a week-long trip to Yellowknife, NWT with community representatives MFNM representatives, Four Rivers staff and RA from the project. The purpose of the trip was to build capacity in Matawa member First Nations to participate in impact assessment and environmental/natural resources programs (monitoring, economic development) through information and knowledge exchange with NWT groups (First Nations, gov'ts, boards/committees, development corporation). They met with Deton Cho Yellowknives Dene Land Development Corporation, Tlicho Nation Government, NWT Government Cumulative Impact Monitoring Program Co-Management Steering Committee, NWT Government Lands Department Land Use Planning, Mackenzie Valley Environmental Impact Review Board, Mackenzie Valley Land and Water Board, Wek'èezhìi Land and Water Board, and NWT Government Lands Department.

Popular media and outreach

- Matawa Radio Show, December 9th, Climate Change Adaptation, guest speaker from Four Rivers
- Matawa Radio Show, February 13th, Climate Change in the North co-guest speakers from Four Rivers, MFNM and from Laurentian University

- Four Rivers Webinars
- Matawa Messenger Climate Change Adaptation Tip series (2) Dec 2020/March 2021. Series intended to teach Matawa Members ways they can help reduce the impacts of climate change
- Photo contest on World Rivers Day 2020 and for Thanksgiving 2020
- Matawa Messenger, Living With Us articles (4): “Blue Green Algae”, “Balsam Fir”, “Dragon Fly” and “Lichen” by Four Rivers. Living With Us articles provide information and photos on plants, animals and other critters living in the Matawa homelands. The articles also makes connections to relevant programming and opportunities within Four Rivers. It also offers further resources and opportunities to connect with Four Rivers for more discussion.
- Social Media Water Values Art Campaign: Engagement on water values, water relationships, water health, water connection, water security and other water themes was conducted through artwork, photography and videography

Public workshops and presentations: Ongoing outreach and engagement to all member First Nations through the Four Rivers Webinar Series (13 episodes delivered as of March 2021). This webinar series is a broadcast of environmental information relevant to Northern Ontario to Matawa First Nation Members.

Professional Development and Technology Transfer

N/A

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

Investigators

Kelly Skinner, University of Waterloo Contact: kskinner@uwaterloo.ca
Barb Duffin, Mushkegowuk Council
Brian Laird, University of Waterloo
Heidi Swanson, University of Waterloo
Vern Cheechoo, Mushkegowuk Council
Jim Wallace, University of Waterloo
Glenn Ferguson, University of Waterloo

Partners, Collaborators, and Users

FEHNCY University of Ottawa -- Dr. Laurie Chan
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
Biotron, Western University -- Brian Branfireun
Laurentian University -- Gretchen Lescord
Intrinsik, Mississauga -- Glenn Ferguson
MRIS Early Researcher Award -- Heidi Swanson
SSHRC Insight Grant -- Kelly Skinner
Northern Scientific Training Program (NSTP) -- Skinner/Laird
NSERC -- Laird
Mushkegowuk Council (MC) -- Vern Cheechoo, Barbara Duffin
Fort Albany First Nation -- Robert Nakogee, Leo Metatawabin

Science Advances

The project received ethics approval from the University of Waterloo Office of Research Ethics and worked with Fort Albany First Nation and Mushkegowuk Council to develop Community Research Agreements, working closely with these community investigators and collaborators to plan for data collection in Fort Albany in Year 2. Hearing that 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, discussions about collaboration took place and a data sharing agreement with the FEHNCY team developed. Plans to travel and conduct field research with hair sampling and survey data collection in Fort Albany in 2020 were postponed because of Covid. In preparation for 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, a survey on food behaviour and perceptions of adults living in Fort Albany, Ontario was developed.

In 2021-2022, existing archived fish tissue samples provided by Dr. Alex Litvinov have been analyzed for mercury, trace metals, and arsenic speciation. A community report was prepared and shared with Mushkegowuk Council in May 2022. The level of total arsenic, total mercury and arsenic speciation in fish and mollusca samples (n=50) from the Albany River located in the Mushkegowuk Region was measured, with levels for the most part below maximum limits. Collection of fish samples from this region will continue, and samples will be analyzed for concentrations of nutrients and contaminants.

Since 2017, the FIShNET team has worked with the collaborators within the Northern Water Futures (NWF) project. Progress under NWF has included important scientific and knowledge mobilization achievements. This work has characterized levels and determinants of several priority biomarkers (e.g., mercury, cadmium, and polycyclic aromatic hydrocarbons) in the Mackenzie Valley Biomonitoring Project. Results from the Health Messages Survey (and complementary key-informant interviews) describing contaminant awareness and perceptions as well as preferences for communication strategies have been shared. By pairing the Health Messages Survey results with human biomarker data, it has been 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 written within research manuscripts and incorporated into Arctic Monitoring and

Assessment Programme 2021 reports. FIShNET will generate complementary information for Fort Albany First Nation and Mushkegowuk Council.

Link to Publications List

Knowledge Mobilization (KM)

If Mushkegwouk Council and Fort Albany First Nation wish to continue this project, then training of HQP and work with the Council and community partners will be carried out. 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 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.

Professional Development and Technology Transfer

N/A

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-May 2020; September 2020-August 2023

Investigators

Jennifer Baltzer, Wilfrid Laurier University Contact: jbaltzer@wlu.ca
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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
Heidi Swanson, University of Waterloo
Jason Venkiteswaran, Wilfrid Laurier University
Brent Wolfe, Wilfrid Laurier University

Partners, Collaborators, and Users

Alfred Wegner Institute -- Julia Boike
Canadian Wildlife Service -- Mark Bidwell, John Conkin
Cenovus Energy -- Chris Salewich
Crown – Indigenous Relations and Northern Affairs Canada
Service Canada -- Not provided
Dehcho 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 Derksen, Chris Spence, 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
GNWT – Geological Survey -- Steve Kokelj
Government of the Northwest Territories (GNWT) -- Anna Coles; Michael Palmer, Lorraine Brekke
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
Inuvialuit Fisheries Joint Management Committee -- Herb Nakimayak
Ka'a'gee Tu First Nation, NT -- Chief Lloyd Chicot
Northumbria University -- Nick Rutter
NWT Power Corp -- Matthew Miller
Parks Canada -- Paul Zorn (and Sophie Fillion, Queenie Gray, Rhona Kindopp, Lori Parer)
Sahtú Renewable Resources Board -- Alyssa Bougie
Solinst Canada -- Jim Pianosi
Tlicho Government -- Michael Birlea
University of Guelph -- Ben DeVries
University of Waterloo -- Bob Lemieux (Dean of Science), Richard Kelly, Richard Elgood
Wek'èezhìi Land and Water Board -- Shawne Kokelj; Ryan Fequet
Wekweeti (Community) -- Adeline Football (Chief)
Wilfrid Laurier University -- Rod Melnik
Xcalibur Multiphysics -- Adam Smiarowski

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 seeks to expand the capacity for research and monitoring in the NWT and improve the understanding of the long-term sustainability in water resources, predicting future changes in the health of streams, rivers, and lakes, including key waterways used for hydropower, water supplies and transportation.

- Baltzer's team leveraged support from the Environmental Studies Research Fund to sample 20 sites established in the Mackenzie River valley by the Geological Survey of Canada. Those sites have long-term, continuous records (up to 40 years) of ground temperature and active layer thickness, providing an unprecedented dataset to evaluate ecological responses to permafrost thaw. Initial results demonstrate the importance of permafrost thaw for predicting remotely sensed measures of forest productivity changes. Together these studies will inform terrestrial and aquatic ecosystem responses to ongoing thaw.

Permafrost degradation evidence in arctic tundra (Trail Valley Creek research station). Photo courtesy of Vincent Graveline

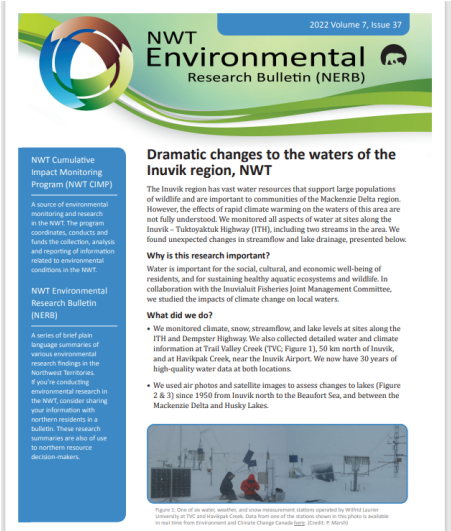
- Baltzer et al. reported on a North America wide synthesis of post-fire compositional changes in boreal forests. They showed widespread decline in black spruce, the dominant North American boreal tree species, and regional differences in alternate successional trajectories. Western North America is currently more vulnerable to post-fire compositional changes due to the drier climate and more complete combustion of organic soils.
- Baltzer and NWF Project Coordinator, Savage, have been developing a synthetic diagram for NWF that illustrates the interdisciplinary research within the program. They have collaborated with the NWF co-Is to categorize research themes and end-users/stakeholders for each of their team's NWF-affiliated works. This will be developed in the coming months into a paper involving case studies of cross-cutting subarctic research.
- Chang et al. provided a method for estimating the leaf area index and biomass of arctic shrubs using L-band synthetic aperture radar remote sensing. Berg's team anticipates that the launch of the NISAR (2023) will allow shrub biomass monitoring across broad areas.
- Merchant and colleagues mapped the hydro-ecological classification of the Mackenzie Delta (and surrounding area). These maps, developed using a time series approach and synthetic aperture radar (C-band), allow for the classification of flooded vegetation and inundation time frames for large regions independent of cloud cover.
- English's NWF-funded project was on hold throughout most of the pandemic. However, in recent months, he has re-engaged the NT Power Corp. English is collecting eddy covariance data for use in hydrological models of the Snare River basin upon which over 50% of the NWT population depends for electricity. A significant issue related to hydroelectric power generation on the Snare is that it is prone to drought as the storage potential in the basin is very limited. At present there is little in the way of instrumentation in the basin to parameterize models predicting river flow under future climate scenarios.
- Garcia-Barrios used chemical analyses of biobanked samples to document elevated exposures of PFNA (perfluorononanoic acid) in Dene/Métis communities in the Dehcho, NWT. This study reported baseline levels for nine PFAS in the Dehcho, facilitating future studies of temporal trends and exposure pathways.

- Hair-to-blood ratios among participating regions of the NWT were on average 2-5 times higher than typically reported in the literature. As such using the 250:1 ratio described by the WHO to estimate blood mercury concentrations would substantially overestimate mercury risks in the regions. Peak seasonal mercury exposures were aligned with September/October, appearing to follow a similar pattern to fish consumption in the territory. This work will inform the timing of future blood sampling efforts to describe mercury exposures. Packull-McCormick used segmental hair mercury analysis to study the seasonality of mercury exposures in the Dehcho and Sahtu regions, NWT.
- PDF Thorn, has reviewed state-of-the-art permafrost, suprapermafrost, surface water modelling, showing that the Geotop hydrological model has an excellent 3D subsurface heat and moisture flow component appropriate for use in continuous permafrost regions and will be used to examine the interactions between permafrost, suprapermafrost groundwater, and surface water under a rapidly changing climate.
- During the summer of 2021, MSc Dakin measured active layer, suprapermafrost water, and streamflow at Trail Valley Creek, NWT. This field work developed a unique high-resolution data set as needed for testing and developing Geotop. Building on this review and data collection, Thorne, Dakin, and Tutton have focused on testing Geotop. to consider the appropriateness for use in other GWF models (legacy and future) as outlined in the NWF proposal.
- Rudolph's team developed analytical modeling tools to validate numerical models designed to simulate non-linear soil freeze-thaw processes. The group has also developed a series of modeling tools to simulate various completed permafrost and annual freeze-thaw scenarios incorporating soil deformation and partially saturated conditions. These tools are available to investigate a wide range of critical conditions in cold climate environments. Rudolph's team also developed and demonstrated use of portable and remote monitoring methods to quantify groundwater flow processes in discontinuous permafrost terrain. These methods are now being considered for use in other similar cold region locations.
- Development and dissemination of models that link catchment composition and water quality to fish mercury concentrations and help predict which catchments and lakes are at greatest risk of climate-induced increases in fish mercury concentrations.
- Neary and Savage and colleagues advanced a state-of-the-art Parks Canada led aquatic ecosystem monitoring program for lakes in the Peace-Athabasca Delta (PAD).

Link to Publications List

Knowledge Mobilization (KM)

- NWF hosted a Virtual Webinar Series throughout the Fall 2021 term (Figure 11). There was great enthusiasm among the NWF community to participate in the event by presenting their work (5-7 speakers at each of 5 sessions) or by attending sessions and engaging in meaningful discussion (average of 46 participants). Positive feedback came from NWF partners, especially those affiliated with the Government of the Northwest Territories.
- Collaboration with artists Megan Leung, Rhian Brynjolson, and Louise Arnal as part of the Virtual Water Gallery, https://www.virtualwatergallery.ca/arctic-polarity.
- Advisors for Smithsonian Institute Boreal Forest and Climate Change travelling exhibit.
- Liaised with Government of the Northwest Territories, Dehcho AAROM, and Sahtú Renewable Resources Board on statistical models examining the effect of fish harvest location on mercury exposure and risk. This work informs responses to site-specific fish mercury data generated through current and future environmental monitoring projects.
- Engagement with the Inuvialuit Joint Secretariat-Fisheries Joint Management Committee through Zoom meetings and presentations to the FJMC Management Committee. This effort builds upon the Laurier-JS-FJMC Memorandum of Understanding,



Article in NWT Environmental Research Bulletin

and has led to a successful application to the Canada-Inuit-UK Arctic Research Program. JS-FJMC is a funded Co-Investigator in this program (Marsh).

- NWT Environmental Research Bulletin publications (Marsh, Sonnentag, Baltzer, Spring)
  https://www.enr.gov.nt.ca/sites/enr/files/resources/128-cimp_bulletin_37_en_proof.pdf
  https://www.enr.gov.nt.ca/sites/enr/files/resources/128-cimp_bulletin_34_en_proof.pdf
  https://www.enr.gov.nt.ca/sites/enr/files/resources/128-cimp_bulletin_35_en_proof.pdf
  https://www.enr.gov.nt.ca/sites/enr/files/resources/cimp_bulletin_24_en.pdf
- Funded through the Future Skills Centre, Sonnentag leads a training network to build local capacity for the community-based operation of the tower network. With strong support from the GNWT, university, and industry partners, the training network builds local capacity by training ten northern HQP through virtual lectures, site visits, and a hands-on workshop (scheduled for 02 to 13 May 2022). The goal is to bring to life the collective desire to engage community members in knowledge co-creation and co-management to improve understanding of climate change impacts and support ecosystem resilience. For example, a strong relationship has been developed with the Inuvik Community Corporation (ICC). Coordinated through a Yellowknife-based research professional, Emma Riley, two ICC members have received training through virtual lectures and site visits and are now actively involved in tower maintenance and operation. The training network aims to continuously expand the skills of northern HQP (e.g., snowpack sampling).
- Ecology North with support from NWF hosted the 2021 Young Leaders' Summit on Northern Climate Change, bringing young leaders together from across the North to learn about northern climate change. The Summit provided an opportunity for youth, aged 18 to 30, to come together and learn about the effects of climate change in northern Canada – a region that is experiencing some of the fastest and most extreme changes. At the Summit, the youth learned about the effects of climate change from Elders, researchers, land-users, policy makers, and other climate leaders, as well as learned some of the steps being taken to mitigate and adapt to these changes. A Photovoice project with the youth at the Summit to their learning and experiences.
- Ecology North and Ka'a'gee Tu FN with support from NWF hosted the Water Stewardship Gathering as an on-the-land camp. This brought together NWT youth (ages 18-30) to discuss, share and identify solutions to water stewardship issues impacting their communities while developing leadership skills. Knowledge holders, researchers, community monitors, and scientists led activities related to water stewardship and local water-related issues. A Photovoice project with the young leaders shared what they learned and experienced during the camp.
- Co-developed literature-based conceptual models with GNWT that illustrate conceptual linkages between stressors and water quality for each NWT ecoregion (briefing note). Results are helping to guide community-based research and monitoring prioritization.
- Worked with GNWT to test a site selection tool for water quality monitoring (technical report). Results are being used to develop a targeted, evidence-based monitoring program for water quality throughout the NWT. (Swanson)
- Worked with GNWT to consolidate 15 years of monitoring and industry data on water quality, and tested methods for quantifying natural baselines (technical report). Results are helping to develop regional baselines for comparison to future stressor-induced effects.
- Worked with NWT Power Corp to review literature on walleye spawning locations in the Little Buffalo and Slave rivers. Used to guide conversations with Indigenous stakeholders re: habitat offsetting.
- Summer 2021 marked Year 2 of Parks Canada adopting Wolfe and Hall's recommended aquatic ecosystem monitoring framework for lakes of the Peace-Athabasca Delta, which builds upon university-led research from 2015-2019 (partially supported by NWF). Parks Canada continued to collect water samples from multiple lakes and rivers for measurement of water isotope composition. A 7-year record of water isotope data for the delta now exists, which provides an exceptional perspective on the spatial and temporal variability of hydrological processes that influence lake water balances. Other hydrological and limnological components of the monitoring program were executed in the field by Parks Canada staff including deployment and retrieval of depth loggers and sampling for measurement of water chemistry, respectively. The project continued to provide Parks Canada staff with remote training in field sampling methods. MSc Imran is leading preparation of a report for Parks Canada on the 2021 monitoring data.
- The success of Wolfe and Hall's long-standing hydrological and paleohydrological research in the Peace-Athabasca Delta generated a new opportunity to characterize water resource vulnerability to climate change in the Whooping Crane Nesting Region in the northern sector of Wood Buffalo National Park. Using contemporary methods (water isotope tracers, depth loggers, water quality surveys) and paleolimnological analyses of sediment cores, NWF supported research will contribute directly to recommendations by UNESCO for increased monitoring in this

wetland-rich landscape and implementation of the Wood Buffalo National Park Action Plan. During the past two and a half years, researchers have been actively planning and collaborating with staff from the Canadian Wildlife Service and Parks Canada. This strong partnership enabled the research to be initiated in 2021, despite Covid-related travel restrictions. Remote field sampling training was provided to local Parks Canada staff, who then sampled 50 ponds in June and September for water isotope composition and water chemistry (major nutrients, major ions, DIC, DOC) and installed and retrieved depth loggers from each pond. A PhD student is leading preparation of a report on these data for Parks Canada. Agency-led field sampling in 2021 is serving as the foundation for a more ambitious and expanded collaborative field sampling campaign in 2022, when both contemporary and paleolimnological components of the research program will be executed by members of the team and Parks Canada staff.

Professional Development and Technology Transfer

Special Seminars

- GWF women + water lecture series (attended by Ogden)
- NWF virtual webinar series (many NWF HQP presenters and attendees)
- Special Topics in Kinesiology (KPE416H), Title: "You can clean the river, but the mercury is in the people": A case study of Grassy Narrows and White Dog First Nations, Faculty of Kinesiology & Physical Education, University of Toronto, 2021 (Woodworth invited as guest lecturer)

Workshops

- Academic Freedom and Antiracism: Panel between Cornel West and Myrna Lashley, University of Ottawa, 2022 (attended by Woodworth)
- Cultural Safety in Indigenous Community-Based Research, Community-based Research Canada, 2021 (attended by Woodworth)
- Graphic design workshop (attended by Ogden)
- Isotope Tracers in Catchment Hydrology, Global Institute for Water Security (attended by Lyons)
- Land-Atmosphere Interactions Workshop, 2021 (attended by Graveline)
- Mental health workshop (attended by Ogden)
- Science communication (attended by Ogden)
- Synthetic aperture radar workshop (attended by Ogden)

Cross-institutional placements or internships

- Health Canada Research Affiliate Program (Health Canada MIREC Team): Prenatal and concurrent blood mercury concentrations and associations with IQ in Canadian preschool children, September 2021-August 2022 (Packull-McCormick)
- Research stay at Dalhousie University, Halifax, April 2022 (completed by Graveline)
- User training or tech transfer opportunities
- Knowledge Mobilization Scholarship Training: Developed knowledge mobilization skills and strategies through training workshops and co-created a knowledge mobilization plan with community research partner, 2021, https://research.uottawa.ca/rms/news/nine-exceptional-doctoral-students-receive-uottawa-graduate-student-knowledge-mobilization , 2021, (Woodworth)
- ROM Introductory Identification Course for Ontario Fish Species (completed by Dixon)
- The Collaborative: A graduate student mentor for elementary and secondary schools as part of a multi-institutional network dedicated to education, social innovation, and knowledge policy, 2021-2022, http://www.yourcollaborative.org/?s=woodworth
- Virtual training course as part of the Future Skills Centre training network (12/2021 – ongoing; in completion by Sonnentag)

Others

- Aukes, P., Guo, T., Atkins, J., Venkiteswaran, J., Elgood, R., English, M., et al.: How do different species of Disinfection By-Products compare to water quality guidelines? figshare. Poster. https://doi.org/10.6084/m9.figshare.14582946.v1 , 2021 (Venkiteswaran)

- Free Grassy: Regional poster lead. Coordinated and organized local volunteers to poster around Ottawa/Gatineau to raise awareness of the mercury poisoning in Grassy Narrows First Nation, 2021, https://freegrassy.net/ (Woodworth)
- Twitter thread and visualization about climate change and river water quality in NWT: https://twitter.com/pieteraukes/status/1357569593313611777 (Venkiteswaran).

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

Investigators

Jennifer Baltzer, Wilfrid Laurier University Contact: jbaltzer@wlu.ca
Leon Andrew, ʔehdzo Got'ıę Gots'éˌNákedı -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'ıę Gots'éˌNákedı -Sahtú Renewable Resources Board
Kelly Skinner, University of Waterloo
Andrew Spring, Wilfrid Laurier University
Gordon Yakeleya, Tulita Renewable Resource Council

Partners, Collaborators, and Users

Wilfrid Laurier University
University of Waterloo
On the Land Unit, Environment and Natural Resources, Government of the NWT
Nę K'ə Dene Ts'ılˌıˌForum
ʔehdzo Got'ıę Gots'étę Nákedı
Fort Good Hope, Tulita and Norman Wells Renewable Resources Councils

Science Advances

ommunities 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 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 Dǝ́ (Great Bear River) at Tek'áícho Dǝ́ (Marten River) Tulít'a, NT. Advancements include reviewing transcribed interviews and focus groups to identify key concepts and themes for a manuscript in preparation.

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. Please note that this has been again postponed to 2023 due to COVID-related

concerns by 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.

Professional Development and Technology Transfer

N/A

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

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

Swedish University of Agricultural Sciences – Martyn Futter
Giant Mine Oversight Board -- Kathy Racher
Environment and Natural Resources, Government of Northwest Territories -- Melanie Williams
Environment and Climate Change Canada -- Chris Spence
Tłı̨chǫ Government -- Jessica Hum
Yellowknives Dene First Nation -- Alex Power
Wek'èezhìi Land and Water Board -- Ryan Fequet
North Slave Métis Alliance -- Nicole Goodman
GWF: Sensors and Sensing Systems for Water Quality Monitoring -- Scott Smith

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 aims to understand how legacy pollutants from mining activity move through the landscape, with potential negative effects on drinking water and aquatic organisms. The researchers are tracing 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 antimonywere 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 have held annual meetings with Environment and Climate Change Canada (ECCC). The meetings include ECCC staff as well as academic partners from Laurier, Montreal, Quebec, Lethbridge and Guelph. These meetings have been regular between the government and this group of researchers since the NSERC-sponsored Metals in the Environment Research Network (MITE-RN) starting in 1999. These meetings include student presentations and discussion with other academic partners as well as ECCC staff Meetings are usually in-person in Ottawa (Gatineau) but since COVID they have been 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.

Professional Development and Technology Transfer

N/A

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-May 2020; August 2020-July 2023

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
Magnetawan First Nation -- Alanna Smolarz
Shawanaga First Nation -- Steven Kell
Institute for Catastrophic Loss Reduction -- Glenn McGillivary
Ducks Unlimited -- Kristyn Mayner
Global Peatlands Initiative -- Dianna Kopansky
Canadian Sphagnum Peat Moss Association -- Paul Short
Fire Smart -- Ray Ault

Science Advances

Canada's boreal biome, a critically important global freshwater resource and carbon reserve, is undergoing extraordinary 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, prpoviding 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.

Earlier project work included establishing networks of eddy covariance towers and sap flow sensors. Data from current and historical LiDAR were being used to detect ecosystem change. A report delivered to the Canadian Oil Sands Innovation Alliance summarised more than 70 years of boreal flux data. Snow water equivalent data were also analysed. A database of field data covering more than 10 years was used to investigate the long-term changes to peatlands surrounding the De Beers Group of Companies Victor mine pit, with new data provided by the company and government (MOECC). Water sampling for isotope analysis iwas included in this. The project also looked at the impact of winter roads on hydroconnectivity and peatland function, and long term CRHM hydrological process and water balance simulations of Whitegull Creek using BERMS data. A study of Pelican Mountain fuel treatment laid the foundation for more recent work on wildlfires.

With Covid restrictions and a delay in receiving funds researchers were unable to conduct extensive field work in the first year and a half but pivoted the work by moving remote sensing mapping analysis forward. Through evaluation of a novel dataset that utilizes high-resolution ecosystem mapping from partner Ducks Unlimited, emerging fuels of concern on the boreal landscape have been delineated: black spruce treed peatlands. By incorporating expert-opinion and the most current research, an initial assessment of smoldering fire risk was carried out. 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. A peat fire hazard map was published and project researchers will investigate the potential to generalize this approach for other peatland dominated regions across Canada and work with collaborators (e.g., FireSmart, Alberta Wildfire, Ducks Unlimited) to incorporate this knowledge into local-regional fire management planning and operations.

While fieldwork was delayed due to Covid-19 there was significant progress with hydrological modelling. Following several planning meetings with wildfire partners, integration of the Peatland Hydrological Impact model with development of a Peat

Moisture Code (PMC), was initiated. The PMC will operate 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. Researchers also initiated modelling on the potential for sustained, deep smoldering in peatlands. The model will soon incorporate (categorical) measures of peat bulk density, which 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 by Patrick Deane in work to evaluate peat smoldering potential following peat compression as a fuel treatment, in collaboration with FireSmart.

A side project was initiated during a 2021 lockdown to examine the management implications of peat extraction sites (CSPMA as a stakeholder). McCarter et al. applied the project's hydrological model to investigate ecohydrological trade-offs induced by multiple disturbances in peatlands. The study highlighted the urgent need to understand complex interactions multiple disturbances have on peatland ecohydrology 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, Abigail Shingler was able to instrument a recently burned section of peatland to monitor Greenhouse Gas (GHG) exchange in August – September 2021. She measured CO2 and CH4 exchange in the field at both the burned site and an unburned control area and collected cores for an incubation study on methane production and oxidation and role of charcoal. This will be compared to 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. These results support understanding of how wildfire impacts will affect peatland GHG exchange and can be linked to coupled peatland carbon-hydrology-wildfire models for improved peatland management.

In March 2022, Marissa Davies started her PDF position to integrate information on peatland fuel management and carbon cycling into models of peatland GHG exchange. She is, in collaboration with Dr. Kelly Bona at ECCC, currently exploring the use of the Canadian Model for Peatlands (CaMP) to evaluate the potential for various fuel management strategies to reduce peatland GHG emissions.

Given field travel constraints during Covid, post-doc Wilkinson formed a working group 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 development and implementation of new elements of the operational fire management system across Canada and internationally.

Link to Publications List

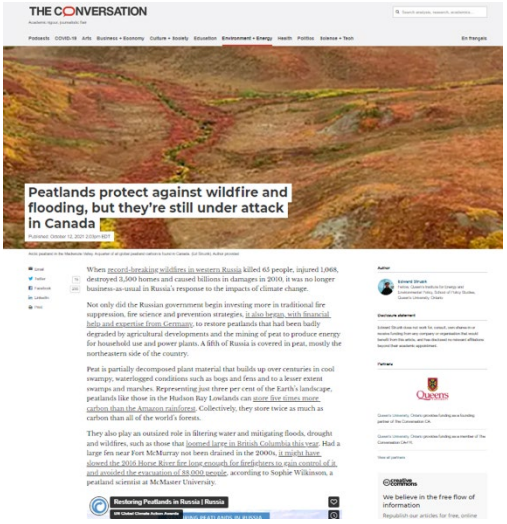
Knowledge Mobilization (KM)

Despite Covid restrictions, project researchers continue to work with FireSmart, CILR, and Alberta Wildfire to develop fuel modification treatments that are appropriate for implementation at the wildland-human interface in the Boreal. A network of 3 eddy covariance towers and 10 micro-met towers (used in Boreal Water Futures 1) to examine water futures for Boreal wetlands was maintained, where some instrumentation now covers recently burned areas of the Boreal Shield landscape. One tower is in collaboration with Magnetawan First Nation who are collaborating in climate change monitoring. Results of this program were presented at an Indigenous Knowledge and Species at Risk workshop in conjunction with Magnetawan First Nation in early March, 2022. A 1-minute YouTube video with Magnetawan First Nation (MFN) partners summarized Boreal Water Futures research for community members. Given the success of the partnership with MFN, the project was approached by Shawanaga First Nation (SFN) to expand water observatory work onto their lands. MFN and SFN are now partners and supporters of the Nibi Observatory for Barren and Bog Ecohydrological Landscapes (NOBEL). NOBEL was 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 Mnidoo Gamii Biosphere , 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.

In May, 2021 a 2,000+ ha wildfire burned through the Tomahawk, Alberta region including several drained peatlands. We received a request from Parkland Co. to assist and the result is a new partnership allowing the project to parameterize its

hydrological model in very dry peatlands (using drainage as a control on moisture status). The fire also burned a portion of one of the CSPMA stakeholder's member companies: researchers will communicate the results to the company through the CSPMA and expand this work in 2022.

Researcher Strack is a member of the Nature Based Climate Solutions Advisory Committee,, providing expert advice to NRCan, ECCC and AAFC about 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.



Article about peatlands in The Conversation, 28 October 2021

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 code (and potentially a peatland spread sustainability index) has been presented to operational fire managers as part of the early outreach to Canadian fire management agencies. This early outreach activity was designed to stimulate 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. Researcher Wotton leads this outreach activity in Canada.

Citizen Science: iWetland: A citizen science platform for monitoring wetland water levels. Expansion to Alberta though partner, Ducks Unlimited.

Meetings with governments, decision makers, practitioners: Canada Wildfire 2021 Fire Season Lessons Learned Meetings (March, 2022) with Canada Wildfire practitioners. Parkland County Fire Safety. Meetings regarding overwintering smoldering fire.

Articles in popular media: Peatlands post complex, poorly understood wildfire risk (May 18, 2021, Creative Commons, Eureka Alert, Science Daily).

Eight interviews (broadcast or text)

Professional Development and Technology Transfer

N/A

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

Investigators

Jeffrey McKenzie, McGill University Contact: jeffrey.mckenzie@mcgill.ca
David Rudolph, Waterloo University

Partners, Collaborators, and Users

Yukon -- Brendan Mulligan
NWT Government -- Isabelle de Grandpré

Science Advances

The reliance on groundwater resources in northern Canada is rapidly increasing, yet the understanding of its occurrence and vulnerability is very poorly understood. The unique characteristics of both the climatic and subsurface conditions in the north (e.g., extreme cold, permafrost, etc.) significantly influences groundwater systems and their vulnerability. This project directly engages 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). Two pilot locations were selected for implementation and evaluation of the selected/developed vulnerability assessment methods: Riverdale Aquifer in the Yukon Territory, which provides water for Whitehorse (pop. 32,000), and the Community of Whatì, NWT (pop. 500), a member community of the Tłı chǫ government. Both rely completely on groundwater for their drinking water supplies.

Given the flooding last summer, and the potential for more flooding this summer, the research in the Yukon has evolved to also include assessing the impact of flooding on groundwater vulnerability, a critical issue for the Yukon. MSc Yin now has a working operational model of the Carmacks groundwater well capture zone using the HGS model. The project is now using the model to evaluate the impact of flooding on solute transport and contaminant processes. MSc Stribling has developed a model using FlexPDE to simulate dynamic freezing and thawing, groundwater flow, and solute transport. This model is being used to understand how thawing permafrost may affect solute/contaminant breakthrough for a variety of settings and boundary conditions. PDF Wiebe has worked extensively on finalizing a groundwater vulnerability report for Whatì and is working on developing a probabilistic method for assessing vulnerability.

Link to Publications List

Knowledge Mobilization (KM)

Monthly meetings were held with northern partners, Brendan Mulligan, Yukon, and Isabelle de Grandpre, NWT. Researchers have developed a new KM program for the summer of 2022 called “Under the Land”, a series of in-community co-designed knowledge sharing sessions that help foster discussion and learning around groundwater in Yukon communities across knowledge systems. Project researchers have met with the communities in May to organize the content for the Under the Land events. These 2-day events are scheduled for July and August in the Yukon: Little Salmon Carmacks First Nation (Carmacks), Tr’ondëk Hwëch’in (Dawson), and in NWT: Whatì. The project team will also attend the Tombstone Water Weekend from July 22-24.

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.

Professional Development and Technology Transfer

N/A

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

Tsá Tué Biosphere Reserve
Canada Department of Fisheries and Oceans
Gordon Foundation

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. We expect a data inventory and access tool for this project to be in place by late Fall 2019.

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 radiation 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.

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

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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-May 2020; September 2020-August 2023

Investigators

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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
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Partners, Collaborators, and Users

University of Windsor Great Lakes Institute for Environmental Research (GLIER) -- Jan Ciborowski, Douglas Haffner
University of Guelph, CFREF Food from Thought -- Wanhong Yang
University of Laval -- Raoul-Marie Couture
Intact Centre on Climate Adaptation; University of Waterloo -- Blair Feltmate
Cold Regions and Water Initiatives at Laurier University -- Kelly Munkittrick
Lawrence Berkeley National Laboratory -- Haruko Murakami Wainwright
University of Michigan, Water Centre -- Jennifer Read
Helmholtz Centre for Environmental Research -- Sabine Attinger; Jan Fleckenstein
Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany -- Georgiy Kirillin
Institute of Surface-Earth System Science, Tianjin University -- Siliang Li
China University of Geosciences -- Yanxin Wang
Ontario Ministry of Agriculture, Food and Rural Affairs -- Dorienne Cushman
Ontario Ministry of Natural Resources and Forestry – LEMU -- Tom MacDougall
Grand River Fisheries Management Plan Implementation Committee -- Crystal Allan (GRCA), Al Murray (MNRF)
Ministry of the Environment, Conservation and Parks -- Ryan Sorichetti; Chris Jones; Ling Mark
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
Agriculture and Agri-Food Canada (AAFC) -- Tiequan Zhang, Natalie Feisthauer, Pamela Joosse
Parks Canada -- Trevor Swerdfager
Six Nations of the Grand River-- Weylin Bomberry (Paul General)
Council of the Great Lakes Region -- Mark Fisher
International Institute for Sustainable Development (IISD) Experimental Lakes Area -- Scott Higgins, Matthew McCandless
Toronto and Region Conservation Authority -- Gary Bowen, Michael Tolensky
Grand River Conservation Authority -- Robert Messier; Janet Ivey; Crystal Allan; Ryan Hamelin; Mark Anderson
Lake Simcoe Region Conservation Authority -- Steve Auger
Conservation Halton -- Barb Veale

Muskoka Watershed Council -- Christy Doyle
Haldimand County -- Zach Gable
Great Art for Great Lakes event, Waterlution -- Christopher McLeod

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 to 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.

Ecosystem impacts: Not continued in Phase II

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 over 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 Lakes Futures 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, IPNIOMAFRA, 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. A link to 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 organized together with postdoctoral fellows 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 2-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

Investigators

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Nandita Basu, University of Waterloo
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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

Water Institute, University of Waterloo -- Kevin Boehmer
Ontario Ministry of the Environment, Conservation, and Parks -- Pradeep Goel
Toronto and Region Conservation Authority -- Krista Chomicki
Grand River Conservation Authority -- Mark Anderson
The Regional Municipality of Durham -- Tavis Nimmo
City of Kitchener -- Bu Lam

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.

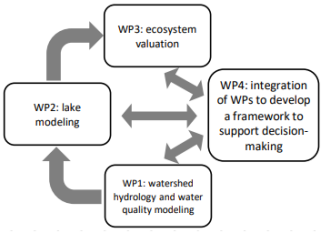


Figure 1. Inter-linkages among work packages

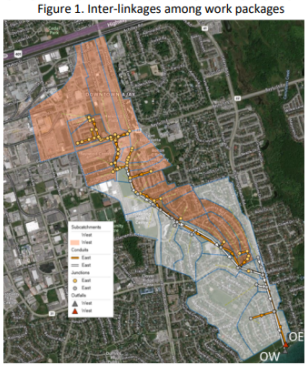


Figure 2. Layout of two modeled Ajax sewersheds where the blue lines identify the sub-basin boundaries, orange and gray circles are stormwater collection nodes, orange and white lines are the main sewers, red and gray triangles (OW and OE) are the stormwater outfalls of the two sewersheds.

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.

Professional Development and Technology Transfer

N/A

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-November 2021; September 2020-August 2023

Investigators

Dawn Martin-Hill, McMaster University Contact: dawnm@mcmaster.ca
Christine Wekerle, McMaster University
Beverly Jacobs, Senior Advisor to the President on Indigenous Relations and Outreach University of Windsor
Bonnie Freeman, 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

Partners, Collaborators, and Users

Cheyenne River Reservation (South Dakota) -- Chief Arvol Looking Horse
Grassy Narrows First Nation -- Judy Da Silva
Digital Democracy -- Rudo
Envision -- Summer Leigh
First Nations Youth Warrior Program (Warrior Park Athletics) -- John Williams
Haudenosaunee Confederacy Council -- Allen McNaughton, Cleveland Thomas
Haudenosaunee Resource Centre -- Jock Leroy Hill, Howard Thompson, Roger Silversmith, Jock Leroy Hill
Indigenous Elders and Youth Council-- James Knibb-Lamouche, Clanmother Mary Sandy
Juddah's Place -- Elva Jamieson
Kawenní:io|Gaweni: yo Private School -- Jeremy Green, Artie Martin, Brian Hill
Kayanase Kerdo Deer -- Clanmother Norma Beverly

McMaster University -- Lorraine Carter, Nancy Mcquigge, Shylo Elmayan, Adrianne Xavier, Kari Hill
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 Health Services -- Kelly Gordon, Amber Skye
Six Nations Polytechnic STEAM Academy -- Kali Anevich, Nathan Rowbottom
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

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 the project produces.

As the nature of the research is community-led and community-driven, Ohneganos team had to adapt and modify research activities and timelines when the COVID-19 pandemic hit. While finding innovative ways to circumvent the obstacles put in

place in response to the continuing changes of COVID-19 (i.e., physical distancing and public health measures) it has been difficult to find recourse for everything. However, the team successfully made progress through the following activities.

Indigenous knowledge training: The Ohneganos Digital Mapping Team is utilizing a participatory mapping software application, to conduct a community-led digitized Indigenous Map of Haudenosaunee knowledge, history and stories (shared with GWF Co-Creation and Sensors), led by Chris Martin, with the guidance and facilitation of Rudo Kemper from Digital Democracy. Following a 2021 workshop, the team has been trained in Terrastories and has begun preliminary data collection and mapping through interviews and archival research. In the spring of 2022, under the guidance of Co-Investigator Bonnie Freeman, the Ohneganos team initiated conversation with the organizers of Two Row on Grand, an annual, Indigenous-led, 10-day event in July, in which participants, paddle down the Grand River to learn about the river and engage with Haudensoaunee culture. Ohneganos water researchers plan to provide information sessions along the route. Youth participants will document the experience through photo, video and digital mapping.

Turtle tagging and monitoring, compilation of information on water geographies, ecosystem health, and turtle nesting was initially halted due to the pandemic. The project was able to focus on team building and forming community connections, having necessary partnerships and resources ready to move forward in spring/summer of 2022.

Accredited training programs for youth: Training in Traditional Ecological Knowledge (TEK)/Western Science (WS) environmental monitoring; new pathways into post-secondary science education; and the creation of new TEK/WS programs were developed through formation of the TEK Education Committee. Youth training and certification were facilitated by finalizing CE credits for STEAM Academy students to translate 90 hours for a university credit. The TEK Education Committee is developing accreditation for current, ongoing and future mixed methods, forward reach, diploma and water management training. A Haudenosaunee Science Guidebook is underway with the Kawenni:io (Six Nations) Private School, who completed a bilingual textbook building on existing Haudenosaunee sciences and ecological sciences with Indigenous stories, interactive maps and other educational re-sources with apps and governance materials.

Bilingual educational materials for IK/WS; IEYC website were prepared to make mixed-method materials accessible globally/locally, and the Virtual Reality project. Ohneganos established a Virtual Reality (VR) development script, gaming prototypes, and committee of mothers, speakers, and Indigenous knowledge holders for Haudenosaunee cultural engagement and learning/continued development of Haudenosaunee VR scripts and game interfaces. The team has developed the Skyworld story water teachings script in Mohawk, and has hired actors and artists to facilitate this work. In the fall of 2021, Ohneganos was awarded the Princeton University Press Supporting Diverse Voices Book Development Grant. A team of writers has been gathered under Dawn Martin-Hill, Bonnie Freeman and collaborator Adrianne Xavier. In March of 2022, Dawn Martin-Hill attended a two-day virtual writing workshop sponsored by the award. Plans are in place for further workshop sessions in May and writing retreats to prepare a prospectus for submission in late spring of 2022.

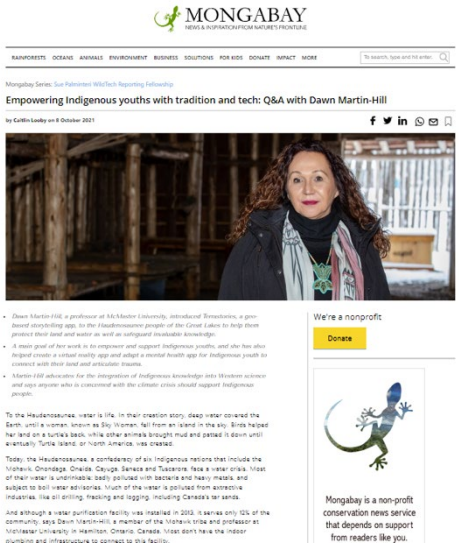
Creation of digital stories demonstrating how water quality shapes and informs mental wellbeing; and interactive learning workshops on water sensors, health, and anxiety were enabled through the Ohneganos vodcast, Let's Talk Water, which completed its fourth season in 2021 and won the David Suzuki People's Choice Award. Several collaborators worked with Ohneganos to build seven new digital stories posted to the Ohneganos YouTube channel in April of 2021.

Knowledge exchange was facilitated in the spring of 2022, under the guidance of Co-Investigator Nicholas Reo, when the Ohneganos team began planning to host a knowledge exchange at Six Nations, welcoming members from the Grand Traverse Band of Ottawa & Chippewa Indians to focus on practical strategies for ecological dam remediation, community capacity building, and exchange of Traditional Ecological Knowledge. The TEK team has also begun work in collaboration with Mohawk College on accreditation for VR Water Treatment Plant Operator training for Indigenous people at Six Nations and Treaty 8, with potential for widespread, national application.

The team is adapting a mental wellness mobile application to provide tools for youth struggling with water/ecosystem anxiety/stress by integrating digital stories, day planning, etc. This work is guided by the Six Nations Youth Mental Wellness Advisory and Research Development Committee. A mental health survey to determine the impact of boil water advisories/water insecurity on youth and a guidebook for adults in water- anxieties/resilience captured water security was contextualized using semi-structured individual and group interviews. The team conducted a survey on the impacts of water insecurity on maternal health.The Six Nations Birthing Centre co-developed and conducted a survey for new mothers on water access. McMaster students, under the supervision of Dr. Christine Wekerle, created 'resilience curriculums' on various topics for middle school students from Six Nations. These involved a TED-Ed video, quiz, and activity/infographic for students

to complete. Students created a draft that was presented and approved by Indigenous consultants from the Six Nations Youth Mental Wellness Advisory Committee. Resilience curriculums were revised for Cayuga & Mohawk language inclusion, presented to school teacher meetings, and finalized for upload on the school website as open access material.

COVID-19 continued to delay the progress of the water governance team over the past year. The work is heavily dependent on guidance from, and leadership of, Elders on the Six Nations Grandmother's Council and the Water Committee, in addition to consultation with other First Nations communities. The transition to virtual meetings has been difficult due to technology, internet, and geographical barriers. Additionally, the water governance team lead has suffered an overwhelming amount of personal loss in relation to COVID-19 which has impacted the ability of the team to conduct this work. Despite these, some important steps have been made relating to water and governance at Six Nations. The team engaged in knowledge mobilization within Six Nations about Nestle/Blue Triton and in November of 2021, Ohneganos youth lead Makasa Looking Horse was successful in securing a cease-and-desist order from the Haudenosaunee Confederacy Council against the company, forbidding their extraction of groundwater from Haudenosaunee land. Also, in conjunction with the Indigenous Knowledge Training team, the Ohneganos TEK committee secured a network between SHAD Academy, Indigenous Studies at McMaster, and SNP STEAM academy to host youth awards and promote Indigenous futurisms. Finally, Ohneganos lead Dawn Martin-Hill has been meeting with members of the International Water Association to plan a high-level panel presentation as part of the OZWater conference in Australia coming up in May of 2022. Through this work she has been participating in building an international network of Indigenous water experts to support water governance for Indigenous peoples in the long term, with plans for another major conference in Toronto in 2024. The governance team also developed a Six Nations response for the Canada Water Agency. The governance team has also developed a network of scientists and university senior administration into a working group with Six Nations Elected Council, to advance Indigenous management of waters.


MONGABAY

Empowering Indigenous youths with tradition and tech: Q&A with Dawn Martin-Hill

Article about the work of Dawn-Martyn Hill

A grant writer will facilitate two large grant applications that would continue the work of Ohneganos in the future: the New Frontiers in Research Fund (NFRF) Transformations grant and a Canada Skills for Success Research & Training grant to build pathways for education and employment for Indigenous people in STEM fields. Planning is underway for a symposium on health to be hosted by Six Nations and Ohneganos in August of 2022.

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

Professional Development and Technology Transfer

N/A

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

Investigators

Walter Illman, University of Waterloo Contact: willman@uwaterloo.ca

Partners, Collaborators, and Users

Aquanty, Inc. -- Steven J. Berg

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.

Professional Development and Technology Transfer

N/A.

Winter Soil Processes in Transition

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

Region: Great Lakes

Total GWF funding support: $300,000

Project dates: December 2017-November 2020 COMPLETED

Investigators

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Chris Parsons (Collaborator), Environment and Climate Change Canada
Colin McCarter (Collaborator), University of Waterloo & University of Toronto
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Chris Spence (Collaborator), University of Saskatchewan
Jennifer Baltzer, Wilfrid Laurier University
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Partners, Collaborators, and Users

Canadian Forest Service Great Lakes Forestry Centre (CFS -- GLFC)
Natural Resources Canada -- Kara Webster
RARE Charitable Research Reserve -- Jenna Quinn

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 ability to evaluate the impact of different potential climatic scenarios on C and nutrient export and speciation along the aquatic continuum.

In 2022 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 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 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/arctic-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

Professional Development and Technology Transfer

N/A

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

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Partners, Collaborators, and Users

Wilfrid Laurier University -- Homa Kheyrollah-Pour

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

Knowledge Mobilization (KM)

N/A

Professional Development and Technology Transfer

N/A

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 COMPLETED

Investigators

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Partners, Collaborators, and Users

Ontario Forestry Research Institute, Ministry of Natural Resources and Forestry -- Dr. Bill Parker
Environment and Climate Change Canada -- Dr. Paul Bartlett, Dr. Joe Melton, Dr. Luis Leon, Canada Centre for Inland Waters
Canada Centre for Remote Sensing, Natural Resources Canada -- Dr. Shusen Wang
University of Waterloo -- Dr. Myroslava Khomik
Climate Research Division, Environment and Climate Change Canada (ECCC)
Centre for Inland Waters (CCIW), Environment and Climate Change Canada (ECCC)
Canada Centre for Remote Sensing (CCRS), Natural Resources Canada (NRCan)
Ontario Ministry of Environment and Climate Change (OMECC)
Ontario Ministry of Natural Resources and Forestry (OMNRF)
Long Point Region Conservation Authority (LPRCA)
Ontario Climate Consortium (OCC) & Toronto and Region Conservation Authority (TRCA)
St. Williams Conservation Reserve Community Council (SWCRCC)
The James Hutton Institute, Aberdeen, Scotland, United Kingdom
United Nations University - Institute for Water Environment and Health (UNU-INWEH)
Ameriflux and Global Fluxnet initiatives

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. These data are archived at the GWF Central Data System with the help from GWF Core Data Management team at McMaster University.

Michael Pisaric and his student collected >1200 tree cores from ~600 trees in the VRH treatment plots at the Turkey Point study site. The tree cores were processed using standard dendrochronologicalechniques, and analysed, the results suggesting that dispersed harvesting treatments are a more effective management technique to promote carbon sequestration in afforestation settings.

Shawn McKenzie, Michael Pisaric, and Altaf Arain completed a study that integrated dendrochronological and long-term eddy covariance (EC) data to investigate the relationships between tree ring growths and gross and net ecosystem productivities (GEP and NEP) in different age (15-, 42- and 78-year-old) pine plantation forests from 2003 to 2017. GEP estimates for years prior to 2003 reconstructed from tree ring data showed low GEP during the late 1960s and late 1990s, concomitant with increased drought during these periods.

Results 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 converse water resources.

Link to Publications List

Knowledge Mobilization (KM)

Project researchers worked closely with the GWF Knowledge Mobilization Team for dissemination of project results to end users and policy makers, also collaborating with members of McMaster Centre for Climate Change (MCCC, https://climate.mcmaster.ca/) for various activities such as Twitter feeds, sponsored public and academic lectures, conference sponsorship including the Mapping the Global Dimensions of Policy, and student engagement and communication activities. Team members also collaborated with the United Nations University - Institute for Water Environment and Health (UNU-INWEH) for knowledge dissemination to the public and engagement with the global sustainable development and policy processes, including participation in the Water and Climate Dialogue – a lecture series organized by Dr. Nidhi Nagabhatla at the United Nations University – Institute for Water Environment and Health (UNU-INWEH) along with SEES.

Dr. Altaf Arain collaborated with the McMaster Indigenous Studies Program in the Faculty of Social Science. Work on the co-creation of indigenous water quality tools and ecosystem health is being conducted to investigate the impacts of climate change on hydrological processes, water resources, and ecosystems in the Six Nations community at McKenzie Creek. This work helped to understand how climate change will affect the social fabric of the Six Nations community. Through development of a physical and social indicators framework. Dr. Arain also collaborated with Northern Water Futures (Drs. Baltzer, Sonnentag) for sapflow measurements, and sapflow synthesis work across GWF SFWF forest sites was planned with Drs. Baltzer, Sonnentag, Carey and Petrone.

Dr. Arain collaborated with the Ministry of Environment and Climate Change Canada to continuously measure trace gas (CO_2, CO, CH_4, N_2O) measurements at the Turkey Point Deciduous (TPD) site. These fluxes are used for tracking cross-border transport of air pollution trace gases, and estimate Canada's carbon emissions using atmospheric observations and models. The project also 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 land cover 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. 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. With MCCC, the project co-sponsored the Water and Climate Dialogue with SGES during 2020. Lunchtime lectures were held at the UNU-INWEH, McMaster Innovation Park, Hamilton, Ontario. The McMaster High School Weather Network has facilitated data collection across high schools in Hamilton, collecting 10 different weather variables on an hourly basis. Southern Water Futures also collaborated with Learning for a Sustainable Future (LSF) to support the Decide, Design, and Discover workshop at the LSF's Youth Climate Change Forum.

Professional Development and Technology Transfer

N/A

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

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Partners, Collaborators, and Users

Region of Waterloo -- Dominika Celmer-Repin

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 growth) in 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.

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

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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

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
Bereket Isaac, University of Waterloo

Partners, Collaborators, and Users

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

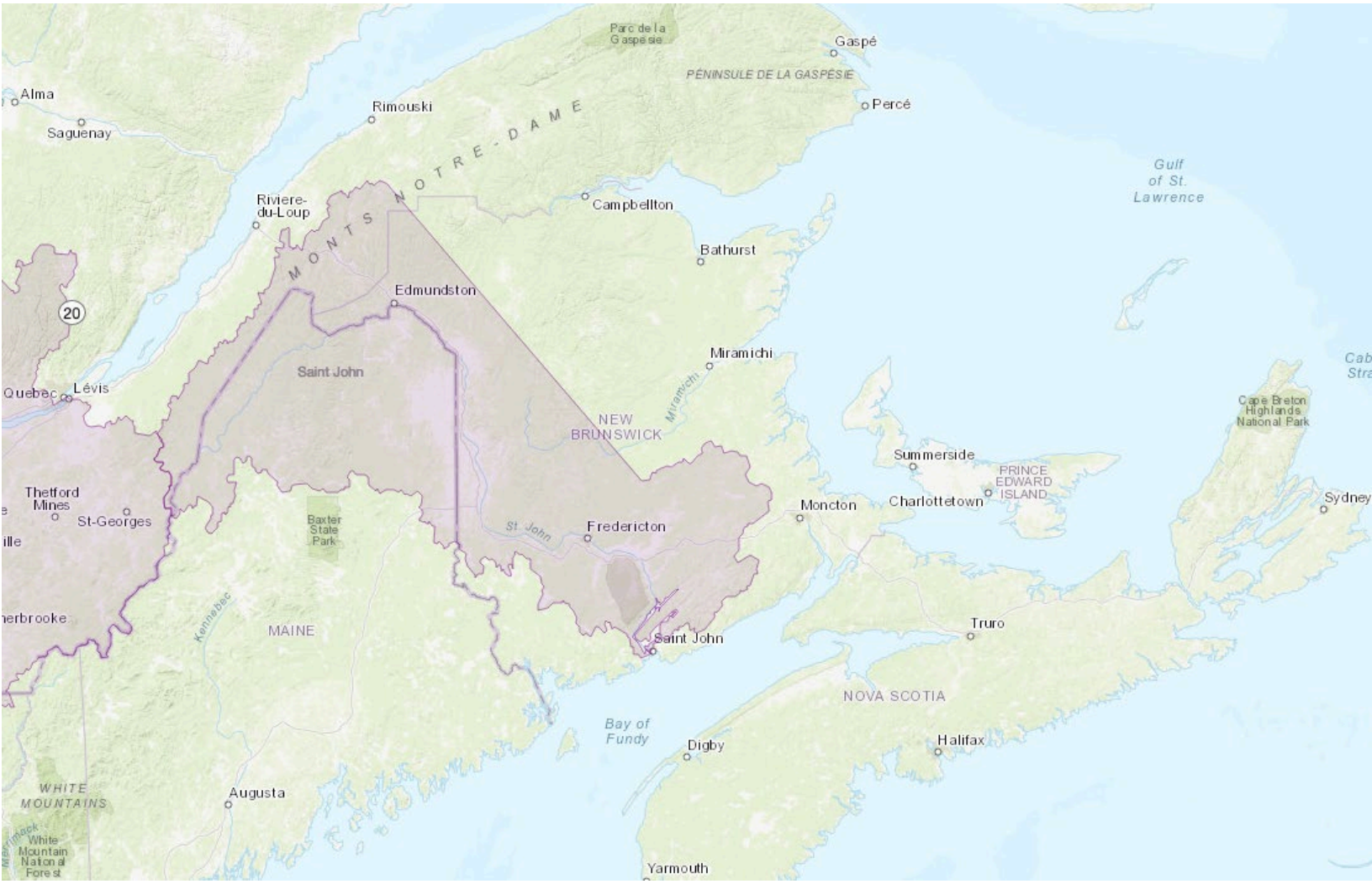
Knowledge Mobilization (KM)

Erin Murphy-Mills 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

Bereket Isaac 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

Investigators

Julie Thériault, Université du Québec à Montréal
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Stephen Déry, University of Northern British Columbia
Ronald Stewart, University of Manitoba

Partners, Collaborators and Users

University of Saskatchewan -- Karl-Erich Linderschmidt
University of Northern British Columbia -- Stephen Déry
Université du Québec à Montréal -- Julie Thériault
University of Manitoba -- Ronald Stewart
Artys -- Matteo Colli
Météo Suisse -- Yves-Alain Roulet
École Polytechnique Fédérale de Lausanne -- Alexis Berne
NB Power -- Jim Samms
NB Environment -- Darryl Pupek
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
University of Manitoba, Ronald Stewart
CFI Innovation, Adaptable Earth Observation System -- Julie Thériault
Canada Research Chair Tier 2 -- Julie Thériault
NSERC Discovery Grant -- Julie Thériault
Société d'aménagement de la rivière Madawaska -- Charles-Oneil Crites
Brilliant Labs -- Kathleen Rice

Science Advances

This project focuses on cold region processes related to winter and spring storms and the resulting precipitation over the transboundary upper Saint John River Basin. Although this area experienced catastrophic flooding in 2008, 2018, and 2019, no studies of storms and precipitation and their impact on snowpack evolution had been conducted in this region. SAJESS contributes 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, critical information for water managers to support emergency responses to flooding and ice jam. A field experiment conducted in March-April 2021 showed that the distribution, amount, and phase of the precipitation varied across the upper Saint John River Basin. Precipitation upstream tended to fall as a solid (e.g., snow and freezing rain), whereas it was mostly rain closer to Edmundston. A climatology study of the Saint-John River Basin was conducted for use as a reference for conditions during the SAJESS field campaign. The team is currently analyzing recent major spring flood events in the Saint John River basin (2008, 2018, and 2019), and comparing them with 2021 conditions that did not include major flooding. Preliminary findings over the upper Saint John River basin show that the three flooding periods all exhibited positive winter (December, January, February) and spring (March, April, May) precipitation anomalies, but temperature anomalies differed. The phase of precipitation impacts the snowpack accumulation and melt. During SAJESS, most of the storms contributing to the snowpack occurred at 2-metre temperatures above -20 degrees C. At these temperatures, estimating precipitation phase at the surface is difficult and the dataset collected provides an opportunity to analyze the impact of various precipitation phase partitioning methods on snowpack evolution.

Link to Publications List

Knowledge Mobilization (KM)

SAJESS recruited volunteer observers of all ages, from school-aged children to retirees. They 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. 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.

Students measuring snow depth near Edmundston, New Brunswick

A student prepares to release a sounding balloon during the Saint John River experiment on cold season storms (SAJESS), in Edmundston, New Brunswick

Interviews (broadcast or text):

- Des stations de collecte de données météorologiques installées au Nord-Ouest, Info Weekend, Edmundston, N.-B.
- Une étude sur les tempêtes hivernales pour mieux comprendre la fonte des neiges au printemps. Text interview. Infoweekend.ca, March 2021.
- Comprendre les effets de la neige sur les inondations au printemps. Video interview. Téléjournal Acadie, Radio-Canada, March 2021.
- Une chercheuse tente de mieux comprendre les causes des inondations au N.-B. Text interview. Radio-Canada New Brunswick, March 2021.
- Madawaska: une étude pour mieux prédire l'évolution de la fonte des neiges. Video interview. TVA CIMT-CHAU, March 2021.

- Projet scientifique au Nouveau-Brunswick. Text article. Actualités UQAM, UQAM Communications department, March 2021.

Promotional videos: Immersion dans l'univers du déneigement à Montréal, avec Stéphane Bellavance, full article: https://montreal.ca/articles/immersion-dans-lunivers-du-deneigement-montreal-avec-stephane-bellavance-22600

Interview with Julie Thériault: https://www.youtube.com/watch?v=9udC88k-0A8&t=31sVille de Montréal, 31 December 2021

Public workshops and presentations:

- Thériault, J. M., M. Lachapelle, D. Boisvert and H. Thompson, Mesures météorologiques à la surface de la Terre et en altitude, Portes Ouvertes Virtuelles UQAM (9 Feb 2021), The instruments used during SPADE were presented to students interested in atmospheric sciences and a live weather-balloon launched. The weather balloon measures temperature, humidity and wind speed in the atmosphere.

Special Seminars:

- Thériault, J. M. (2020), Avancement des connaissances sur la mesure de la précipitation solide, Centr'Eau Webinar
- Thériault, J. M. (2020) Advances in spatial meteorological forcing data, Global Water Futures, Core modelling seminar series

Professional Development and Technology Transfer

Julie Thériault (May, 2021), was invited to give a training course on rain-snow transitions for the China Meteorological Administration in preparation of the Beijing Winter Olympics 2022. This course was organized by COMET© (Cooperative Program for Operational Meteorology, Education and Training), Boulder, Colorado (Approximately 20 students from China attended the class)

International

Planetary Water Prediction Initiative (PWPI)

Photo: Wolf Creek Research Basin, Yukon Territory. Photo by Mark Ferguson

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
Raymond Spiteri, University of Saskatchewan
Chris DeBeer, University of Saskatchewan

Partners, Collaborators, and Users

United Nations Educational, Scientific, and Cultural Organization Intergovernmental Hydrological Programme (UNESCO-IHP)
World Meteorological Organization (WMO)
Water and Climate Coalition (WCC)
World Climate Research Programme (WCRP)
International Network for Alpine Research Catchment Hydrology (INARCH)

Future Earth Sustainable Water Future Programme (SWFP)
Arctic Council
Chinese Academy of Sciences and the Third Pole Environment Initiative (TPE)
Indian Institute of Science, Bangalore (IIS)
Spanish National Research Council (CSIC)
Government of Tajikistan
Tribhuvan University, Nepal
University of Chile, Santiago

Overview and Vision

Global Water Futures (GWF) and its institutional partners are committed to international leadership in water science for cold regions. We are 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 has 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 the recognized strengths of GWF.

Science Advances

Model Development

GWF's PWPI is built around several modelling platforms that have been developed and refined by GWF and its predecessor research networks, assembling process-level understanding and model parameterizations from cold regions around the world from many decades of field research.

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

Cold Regions Hydrological Modelling (CRHM) platform. CRHM is a flexible modelling system originally developed in Environment Canada that can be used to generate a process hydrology model, specific to the needs of the user. A functioning model is built by selecting various process modules from a library based on several decades of hydrological research. CRHM can be applied at point scales and over small to medium sized river basins to simulate system behavior and response to climate and other changes and is particularly useful for disentangling complex process interactions between climate, vegetation, snow, glaciers, permafrost, land management, surface–atmosphere fluxes, and runoff. CRHM description and download

Canadian Hydrological Model (CHM). CHM is a multi-scale and multi-resolution hydrological model. It uses a variable resolution mesh to capture fine-scale variability where it exists, while reducing computational demands by reducing resolution in other parts of the domain. It has the design goals of i) multi-scale, multi-physics, variable complexity and

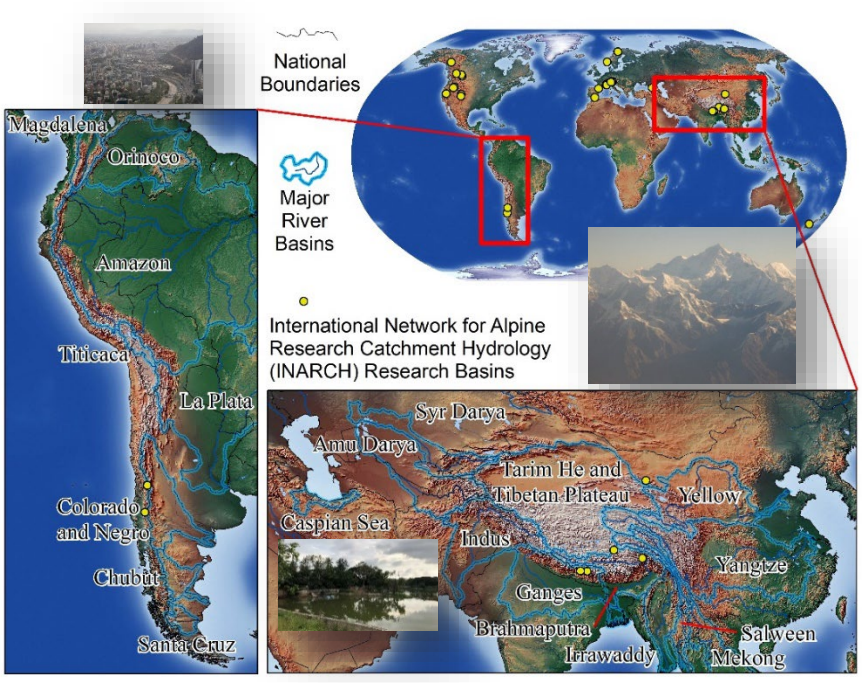
domain, ii) assessment of model structural, parameter, and data uncertainty, iii) ability to test multiple hypotheses, avoid rigid model structures, iv) incorporating existing code, and v) contributing to decision support systems. Many existing process algorithms from CRHM and the modular, physics-based continental-capable SUMMA model have been ported into CHM, and given its flexibility and robustness, CHM represents the next generation in cold regions hydrological prediction with the capability to bridge scales for prediction and forecasts from local to large areas. https://github.com/Chrismarsh/CHM

GWF is also utilizing other models, developed and/or applied within its core modelling efforts (https://gwf.usask.ca/core-modelling/), to support PWPI. Of note is the project's strong collaboration with the US National Center for Atmospheric Research, which is providing high-resolution, convection-permitting state-of-the-art Weather Research and Forecasting (WRF) atmospheric forecasting and land-surface model driving data for continental domains, driven by RCMS nested within GCMs under future atmospheric conditions.

Global Model Implementation

PWPI is comprised of both global-domain projects to be implemented using available global data products and covering all regions across the world, and regionally nested and more focused applications in select areas where collaborations exist or are being developed, and where targeted goals and questions will be addressed. First, the team is building the computational infrastructure (models, data) to enable state-of-the-art hydrological simulations anywhere on the planet. This involves assembling and improving global datasets on climate forcing, digital elevation models, vegetation, and soils, for example, and using these datasets to configure hydrological models for the global domain. Second, the project is developing regional models in key regions where there are already strong collaborations (Himalaya, Andes, central Asia) to address pressing societal needs. The regional models are constructed as cut-outs from the global-scale fabric, and the global instantiations are used as a baseline to systematically evaluate the benefits of specific regional information (e.g., regional DEMs). he activities include regional forecasting, diagnostic and predictive modelling of hydrological systems, and climate sensitivity analyses for the purpose of informing local management, decision making, and policy development, and strengthening local resilience to anticipated changes.

PWPI is now well underway with ongoing projects and collaborations in many focal regions, and working with regional partners on specific activities, including the application of CHM in the Pyrenees Mountains of Spain, CRHM in Andes (Chile) and Himalayas (Nepal), MESH in Central Asia, India, Iran, and the Andes, and CHM extension from the Bow River Basin in Canada to larger domains over the Canadian Rocky Mountains and soon, North America. In due course this work aims to extend CHM to the world for global water assessment and water resources mapping.



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 was 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 Environmentale 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.

Link to Publications List

https://inarch.usask.ca/datasets-outputs/key-publications.php

Knowledge Mobilisation

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.

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 marketplace. 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 are informing the 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

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