



Geological Survey of Canada Scientific Presentation 164

**Public presentations of November 16th, 2022: Groundwater Geoscience Program,
current status of research projects for the 2019–2024 program cycle**

**J. Aubut Bernard, D. Paradis, E. Boisvert, H.A.J. Russell, D.R. Sharpe, C. Rivard, N. Benoit,
and B. Brodaric**

2025

Presented at: Public presentations of November 16th, 2022: Groundwater Geoscience Program, current status of research projects for the 2019–2024 program cycle

Date presented: November 2022

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Programme géoscientifique des eaux souterraines (PGES) de la Commission Géologique du Canada (CGC) à Ressources naturelles Canada (RNCa)

L'objectif du PGES est de mieux comprendre la distribution, la quantité et la dynamique de l'écoulement des eaux souterraines dans des modèles d'eau intégrés pour une gestion durable de l'eau.

Au cours de la phase 2019-2024, le PGES se concentre sur cinq projets : (1) Aquifères archétypaux (dont *Canada One Water* ou C1W) ; (2) les systèmes aquifères de Fox Creek ; (3) Caractérisation et modélisation des ressources en eau (CMRE); (4) Réseau d'information sur les eaux souterraines (RIES); et (5) Évaluation régionale pour le Cercle de feu. Ces projets sont associés à des thèmes de recherche définis comme les inventaires des eaux souterraines, les effets cumulatifs, les méthodes d'évaluation des eaux souterraines, la modélisation des données et la diffusion.

À court terme, l'objectif du PGES est de fournir des connaissances, des outils et des informations géoscientifiques pour comprendre les systèmes aquifères et encourager les gouvernements et les clients à utiliser ces outils. Le résultat à moyen terme est d'incorporer des réglementations et une surveillance plus efficace, et le résultat ultime est une meilleure gestion des ressources en eaux souterraines par les juridictions responsables.

En raison de la pandémie, l'avancement des recherches a parfois été retardé par la fermeture des laboratoires et le manque d'accès au travail sur le terrain. Néanmoins, l'avancement des projets est documenté dans le présent document et sur le compte YouTube du PGES. Les exposés sur ces travaux ont été enregistrés lors des présentations publiques via Zoom le 16 novembre 2022 et sont disponibles via le lien suivant:

<https://www.youtube.com/channel/UChIc7ff3vEdII708VhgsLsg>

Mots-clés : classification des eaux souterraines, développement de méthodes, portail des eaux souterraines, caractérisation, aquifères peu profonds, Fox Creek, ressource en eau, modélisation, Cercle de feu, évaluation régionale, Canada 1 Water et cadre de modélisation

Groundwater Geoscience Program (GGP) of Natural Resource Canada's (NRCan) Geological Survey of Canada (GSC)

The goal of the Groundwater Geoscience Program (GGP) is to better understand groundwater distribution, quantity, and flow dynamics within integrated water models for sustainable water management.

During the 2019-2024 phase, GGP is focused on five projects: (1) Archetypal aquifers (including Canada One Water or C1W); (2) Fox Creek aquifer systems; (3) Water resources characterization and modeling (WRCM); (4) Groundwater Information Network (GIN); and, (5) Regional assessment for the Ring of Fire. These projects are associated with research themes defined as groundwater inventories, cumulative effects, methods for assessing groundwater, data modelling, and dissemination.

In the short term, GGP's goal is to provide geoscience knowledge, tools and information to understand aquifer systems, and to encourage governments and clients to use these tools. The medium-term outcome is to incorporate more effective/efficient regulations and oversight, and the ultimate outcome is better management of groundwater resources by responsible jurisdictions.

Due to the pandemic, research advancement occasionally faced delay due to laboratory closure and lack of fieldwork access. Nevertheless, the advancement of projects is documented herein and via the EGP YouTube account. The talks on this work were recorded during the public presentations via Zoom on November 16, 2022, are available via the following link:

<https://www.youtube.com/channel/UCH1c7ff3vEdII708VhgsLsg>

Key words: groundwater classification, methods development, groundwater portal, characterization, shallow aquifers, Fox Creek, water resource, modelling, Ring of Fire, regional assessment, Canada 1 Water and modelling framework

Presentations // Présentations:

Slide 6-22: Daniel Paradis

Characterization and Modeling of Water Resources (CMWR) // Caractérisation et modélisation des ressources en eaux (CMRE)

Slide 23-35: Boyan Brodaric | Eric Boisvert

Groundwater Information Network (GIN) // Réseau d'information sur les eaux souterraines (RIES)

Slide 36-61: Hazen Russell

Canada1Water: A new framework for understanding Canada's water budget // Canada1Water: Un nouveau cadre pour comprendre le bilan hydrique du Canada

Slide 62-92: David Sharpe

Archetypal Aquifers: From case studies to regional hydrogeological terrain conceptualization // Aquifères archétypaux : la transition vers la conceptualisation de terrain hydrogéologique régional à partir des études de cas

Slide 93-108: Christine Rivard

Characterization of shallow aquifers and assessment of potential impacts of oil and gas development activities on these aquifers in the Fox Creek area (Alberta) // Caractérisation des aquifères superficiels et évaluation des impacts potentiels liés aux activités pétrolières et gazières sur ces aquifères dans la région de Fox Creek (Alberta)

Slide 109-122: Nicolas Benoit

Ring of Fire (RoF): Reconstructing long-term environmental dynamics to support regional assessment // Cercle de Feu: Reconstruire la dynamique environnementale à long terme pour soutenir l'évaluation régionale





NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

Update: Characterization and Modeling of Water Resources Project

Daniel Paradis

November 16, 2022



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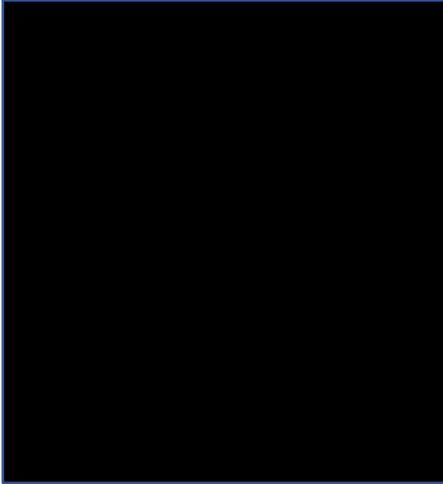
Project Goal

- **Goal:** to develop methods/approaches to improve hydrogeological modeling and characterization;
- **End users:** professionals, scientists involved in hydrogeological assessments

Activities Underway

- **This project consists of 3 main activities carried out by PhD students:**
 1. Understanding environmental flows (Lemuel Arzola)
 2. Modeling groundwater flow through artificial intelligence (Xia Xiao Liang)
 3. High-resolution aquifer testing (Aymen Nefzi)

A1 Understanding environmental flows



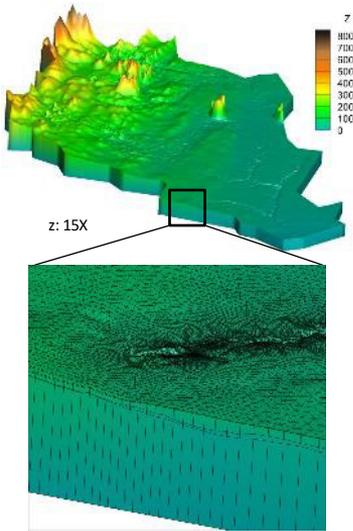
Lemuel Arzola

- **Goal:** Better understanding of environmental flows (volume and temperature of water) during recession periods (winter and summer)
- **Application:** for a sensitive watershed (Yamaska River, QC 6800 km²)
 - Frequent water shortages (extreme low river water levels)
 - Fish habitats in danger (>30°C)

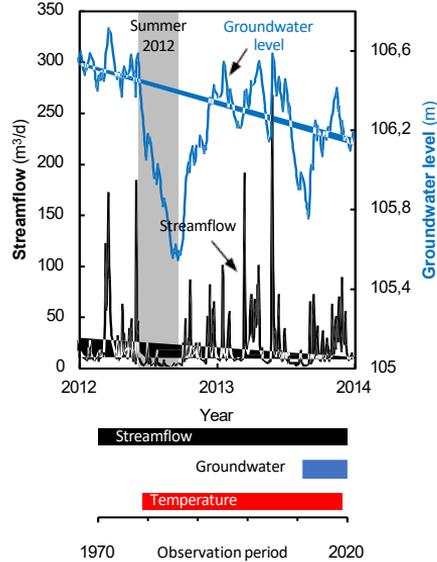
A1 Methodology



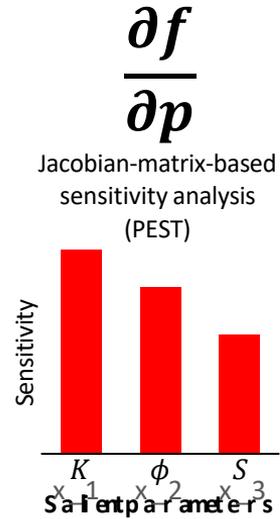
Represent GW-SW interactions –
HGS model



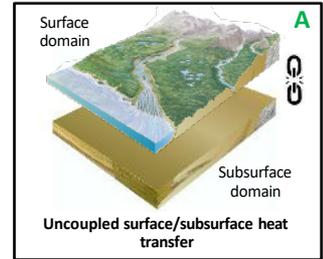
Capture the system
dynamics – calibration procedure



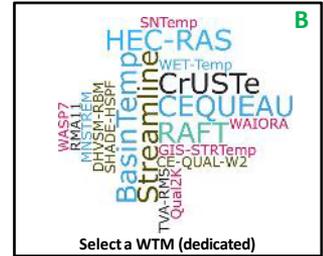
Extract the most salient features
– sensitivity analysis



Model river water
temperature – flow/heat module

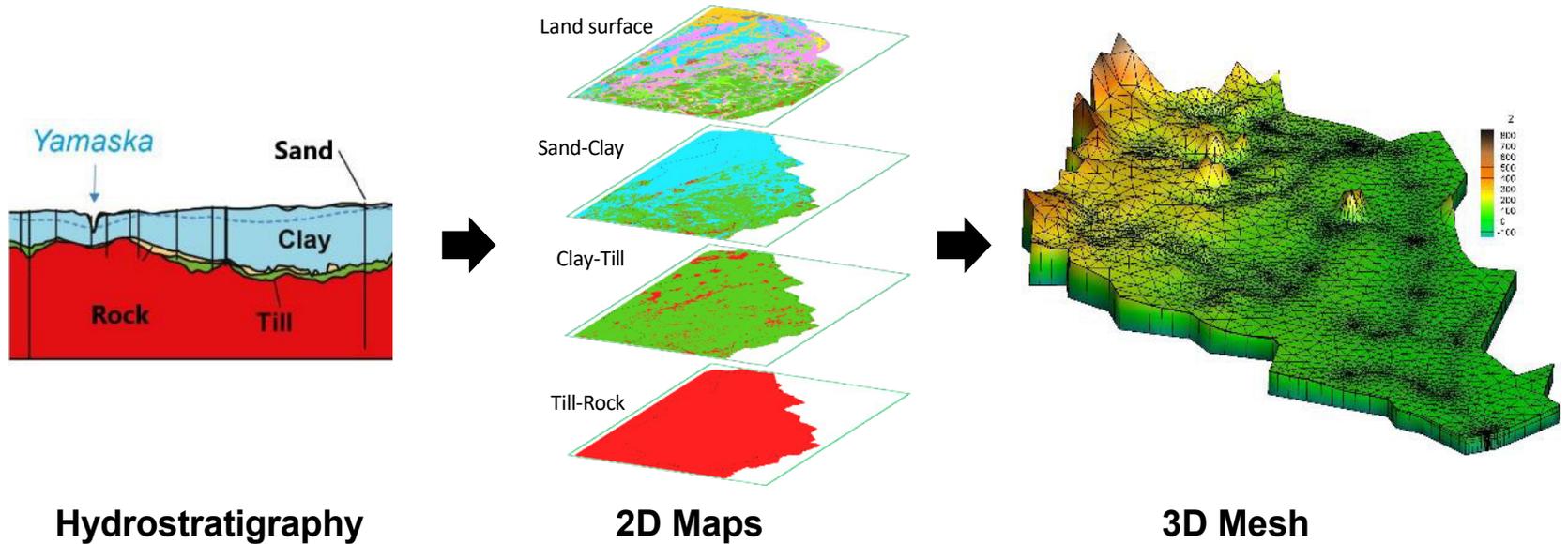


Select A or B



A1 Current Status

Integration of hydrostratigraphy into a 3D model:



A1 Collaborations

- D. Paradis (CGC)
- R. Lefebvre, E. Gloaguen, A. St-Hilaire (INRS)
- M. Ouellet, N. Roy: Ministère de l'environnement et de la lutte contre les changements climatiques du Québec (MELCC)
- Jean-François Cyr: Centre expertise hydrique du Québec (CEHQ)

A1 Publications

Congrès RHQ22 | La recherche hydrologique au Québec – 4e édition | « Imaginer l'hydrologie de demain » | Mai 2022

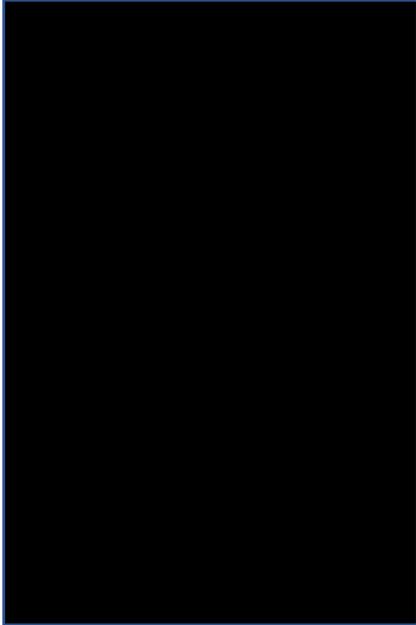
Surface-subsurface flow and temperature modelling during low-flow periods
in the Yamaska River watershed, Québec, Canada

Lemuel Ramos-Arzola¹, Daniel Paradis², René Lefebvre¹, André St-Hilaire¹, Erwan Gloaguen¹

1: Institut national de la recherche scientifique, Centre Eau Terre Environnement, Québec, Canada. email: lemuelcarlosra@gmail.com

2: Geological Survey of Canada, Québec, Canada

A2 AI flow modelling



Xia Xiao Liang

**Can we replace
conventional
groundwater flow
models with artificial
intelligence
?**

A2 Objectives

- **Objective 1: Develop a Deep Neural Network (DNN) model framework** that is capable of 3D spatial and temporal GW forecasting
- **Objective 2: Train and optimized the DNN** model framework for forecasting using physical model simulation data with multiple realizations from a validated physical watershed model
- **Objective 3: Develop a method to transfer learnings** to other watersheds with similar hydrogeological settings for forecasting

A2 Collaborations

- D. Paradis (CGC)
- E. Gloaguen, M. Claprood (INRS)

A2 Highlights

- IVADO scholarship (summer 2022)
- 2nd place (oral presentation) at the Digital Conference in Montreal (hosted by MILA)

A3 High-resolution aquifer testing



Aymen Nefzi

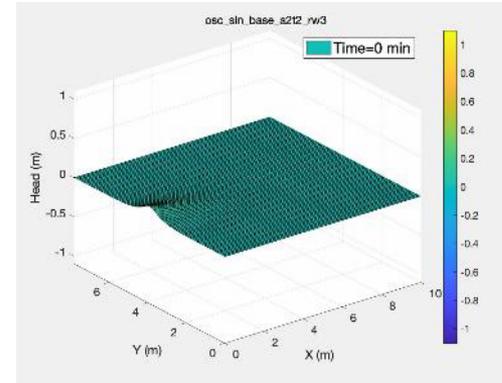
Motivation: need for a better characterization of the heterogeneity of the aquifer (e.g., aquifer remediation)

Objective: evaluation of hydraulic multifrequency tests as a new characterization method

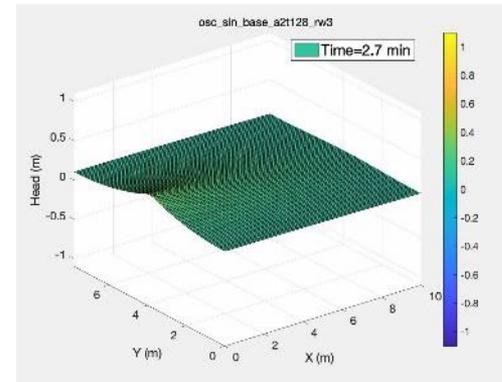
A3 General idea

- Generate various hydraulic stresses (e.g., $\sin(\omega t)$) in the aquifer and measure the associated aquifer response at different locations :
 - **Each response** to a particular period **contains different information** about the structure of the aquifer
 - The analysis of the combined responses gives a better picture

Short period: 2 min



Long period: 128 min



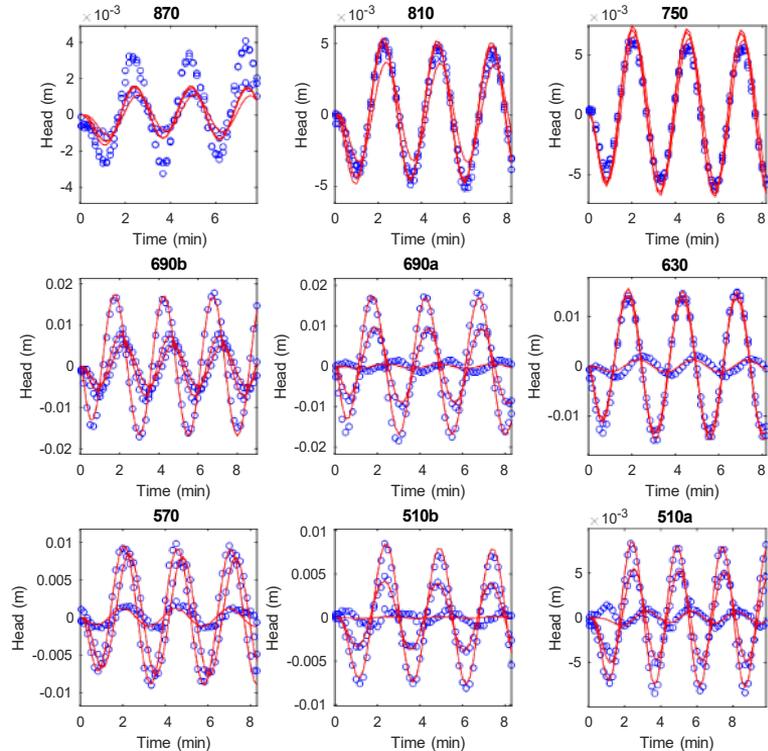
A3 Contribution #1

First demonstration of the feasibility of periodic testing under real field conditions:

Field acquisition

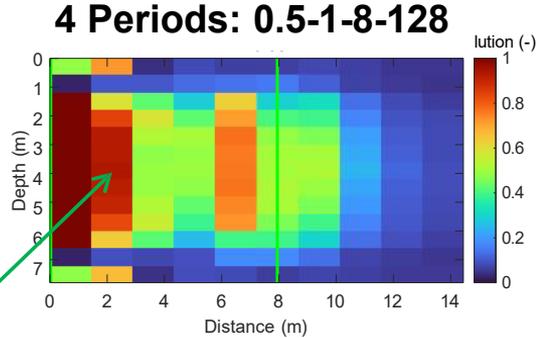
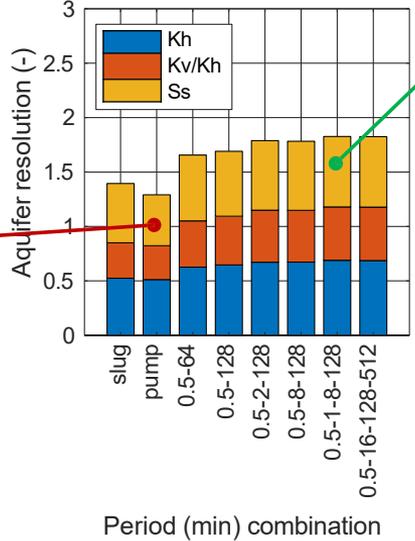
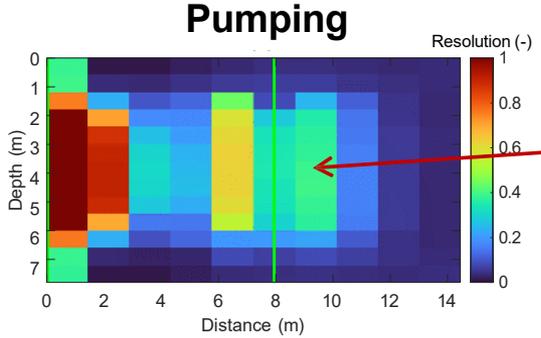


Modeled vs. observed heads



A3 Contribution #2

First quantitative demonstration that the multiperiod approach is far superior to conventional slug and pump tests:



A3 Collaborations

- D. Paradis (CGC)
- R. Lefebvre (INRS)
- O. Bourg, N. Lavenant (Université Rennes I, France)

A3 Publications

- Nefzi *et al.* (to be sub.) **Field proof-of-concept of periodic hydraulic tomography in an unconsolidated anisotropic aquifer.** *Journal of Hydrology*
- Paradis *et al.* (to be sub.) **Review of the principles of periodic hydraulic testing in aquifers.** *Journal of Hydrology*

For information...

Daniel Paradis, PhD

Research Scientist

Geological Survey of Canada (Quebec City)

daniel.paradis@nrcan-rncan.gc.ca



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Groundwater Information Network

Réseau d'information sur les eaux souterraines

Boyan Brodaric, Simon Gagnon, François Létourneau,
Joost Van Ulden, Eric Boisvert

Groundwater Geosciences Program
Geological Survey of Canada

Présentations scientifiques PGES 2022 GGP Scientific presentations



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Motivations



Findings

1. Data is hard to find & use
2. Data gaps & poor quality

Recommendations

1. **More online access**
Consolidate data
2. **More data** (use, monitoring)
Better data quality

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Still an (wider) issue

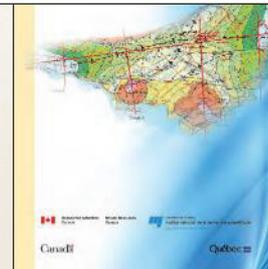
Toward the Creation of a Canada Water Agency

Stakeholder and Public Engagement What We Heard

A significant number of participants highlighted the need for a strategy to support a more integrated, coordinated and standardized approach to data collection, management and sharing. Several suggested national standards, consistent methodologies, and defined operating procedures and protocols are needed to increase the reliability of freshwater data, and to enable interoperability of datasets collected by different organizations. Others suggested data standardization could help advance community-based monitoring by ensuring data quality, compatibility, harmonization and interoperability. A number of participants also stressed that appropriate and respectful inclusion of Indigenous Knowledge should be given special consideration in development of a data strategy.

GIN two main activities

- **Standard development**
 - WaterML2 Part 1 (Timeseries)
 - WaterML2 Part 4 (GroundwaterML)
 - Methodological guides influenced GIN products
- **Infrastructure (GIN)**
 - Technology
 - Data



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Standards

info@opengeospatial.org



About ▾ Standards

OGC Geoscience Markup Language (GML)

OGC® WaterML

- 1) Overview
- 2) Documents and Downloads
- 3) Official Schemas
- 4) Related News

1) Overview

WaterML 2.0 is a standard information model for the representation of water with the intent of allowing the exchange of such data sets across information systems. By re-using existing OGC standards, it aims at being an interoperable exchange model. To address a range of exchange requirements, some of which are described in this document.

2) Documents and Downloads

Version	Document Title
2.0.1	OGC® WaterML 2.0: Part 1- Timeseries
1.0	OGC® WaterML2.0: Part 2 - Ratings, Gaugings and Sections
2.2	OGC WaterML 2: Part 4 – GroundWaterML2
	WaterML-WQ – an O&M and WaterML 2.0 profile for water quality data (1.0)

CHy-15 Pre-Session



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Standardized Data Sharing

Introduction

At its fourteenth session in 2012, the Commission Working Group "to commence a process, including WaterML 2.0 become a WMO standard for information exchange (CHy-14, Res. 3). This request put in motion an effort to address data-sharing activities that need to be addressed and decisions that will need to be made on three items:

1. Whether or not to endorse the WMO HydroML 2.0 standard.
2. Whether or not to recommend to the WMO that WaterML 2.0: [Part 1](#) and [part 2](#) be adopted as information exchange for use by National Hydrological Information Systems.
3. Whether or not to support ongoing adoption of [2.0 standards](#).

WaterML 2: Part 4 – GroundWaterML2
Groundwater Features



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WMO-OGC Workshop "GroundWaterML2 standard"



10 March 2022, 12:00 – 16:00 (UTC), Online

The workshop introduced the GroundWaterML2 (GWML2) standard and demonstrated its recent implementations. Presenters included core developers of the standard as well as developers of related implementations from their respective organizations.

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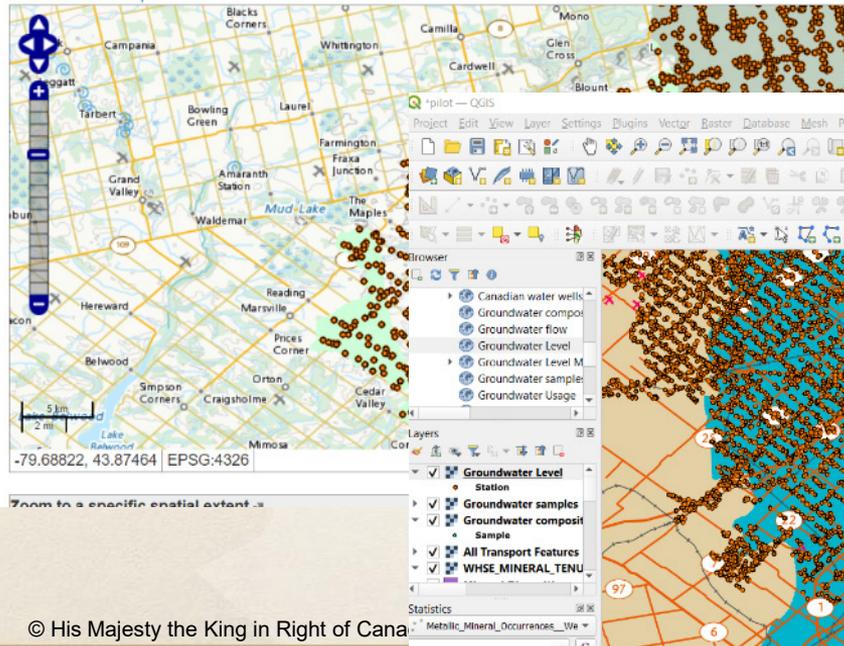
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Infrastructure / architecture

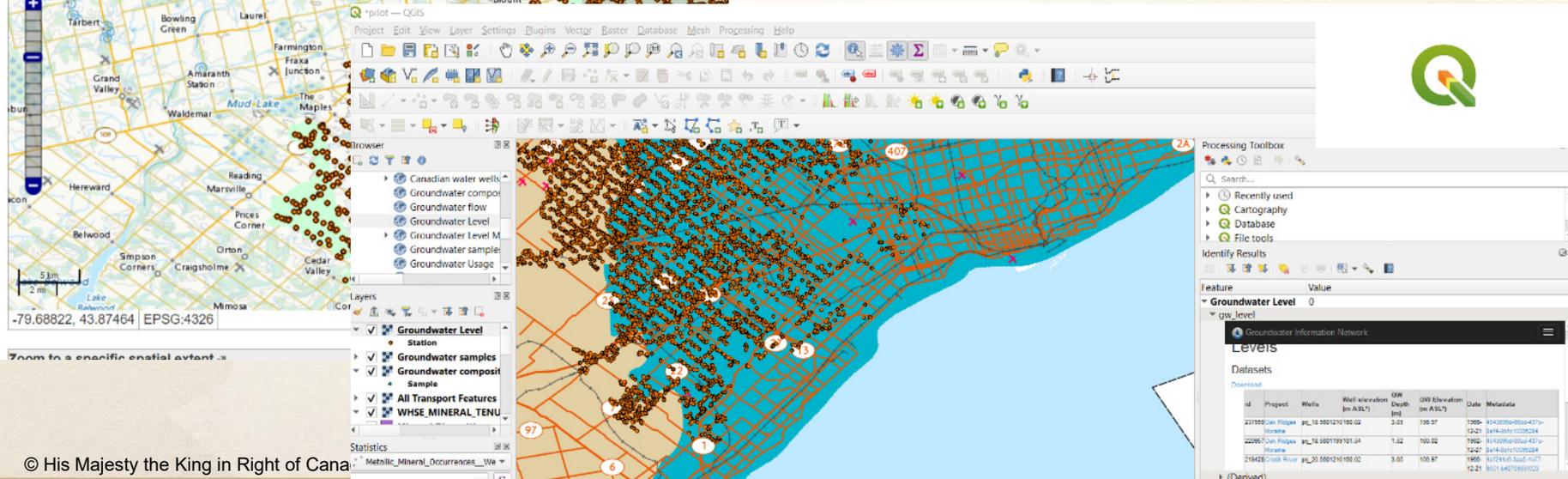
Groundwater Information Network

GIN Basic Map Viewer

How to use this map



- Portal
- Data Services



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Challenges

- Standards
 - They keep evolving ! Some standards used by GIN will be deprecated
- Ability to address new requirements
 - New use cases, move to new technologies
- Aging infrastructure
 - Maintenance, security



Canada One Water Use Case

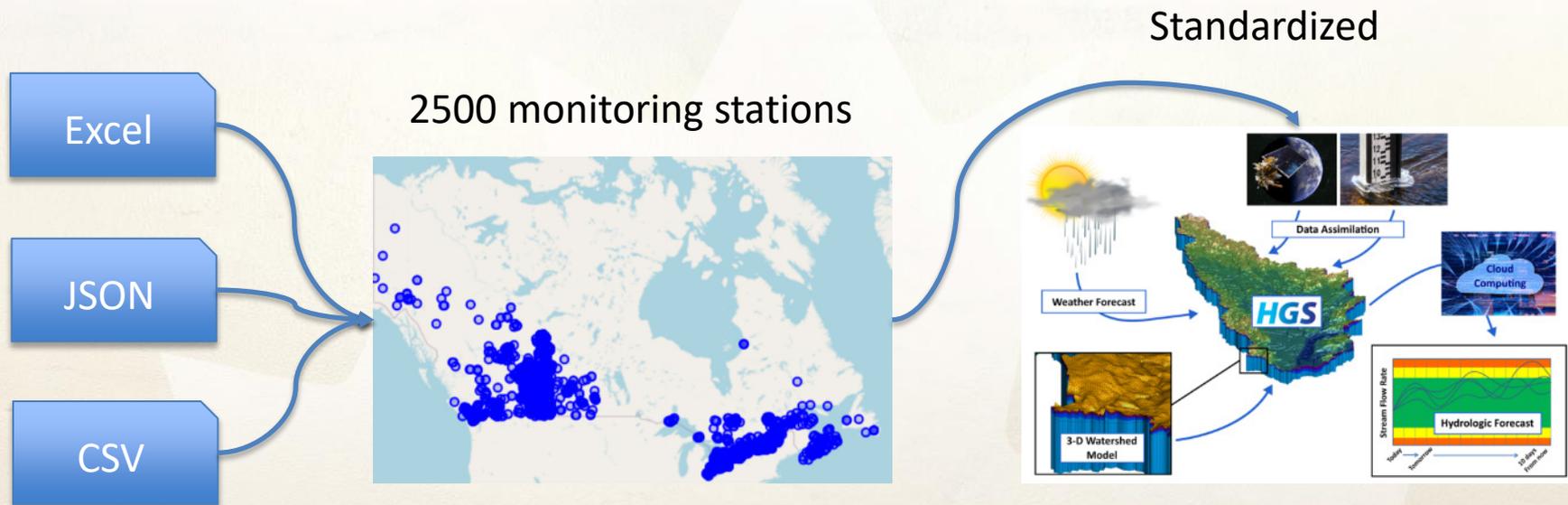


Figure from <https://www.aquanty.com/>

Deliver national size datasets

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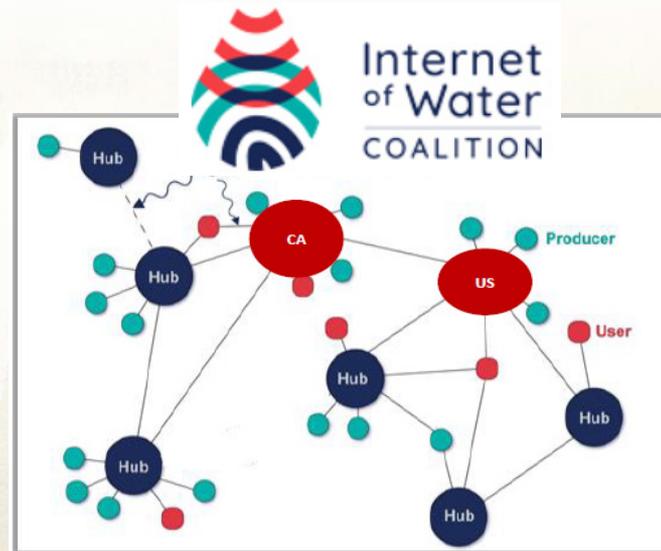
Full water cycle support: Linked data

“...effective land and water management requires a clear understanding of the **linkages** between ground water and surface water as it applies to any given hydrologic setting.”

Robert M. Hirsch, Chief Hydrologist, USGS
From USGS Circular 1139

“...**losing streams** could become common in future decades, ... highlighting the importance of **coordinating groundwater and surface water** policy [and data].”

Nature 591:391–395, 17 Mar 2021



<https://internetofwater.org/>

<https://internetofwater.org/internet-of-water-principles/>

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Progress

- Modernisation of infrastructure (cloud)
- Modernisation of architecture
- Adapting to new standards
- Progress is slow due to resources issues

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Conclusion

- GIN is in transition
- Infrastructure + architecture evolution
- Hampered by resources issues



Thank You



<https://gin.gw-info.net>

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Canada1Water:

A new framework for understanding Canada's water budget

Hazen A.J. Russell¹ and Steven Frey²

¹ Geological Survey of Canada

² Aquanty Inc.

Collaborative – Multidisciplinary Team

Government – Private Sector – Academia



Aquanty



Dr. Steve Frey



Dr. Andre R Erler



Dr. Ed Sudicky



Dr. Omar Khader



Mr. Eric Kessel



Mr. Tyler Herrington



Ms. Amanda Taylor



Mr. Matthew Tsui



Mr. Brayden McNeill



Dr. Tariq Aziz

Government of Canada



Dr. Hazen Russell



Dr. Boyan Brodaric



Dr. Melissa Bunn



Dr. John Crowley



Dr. Heather MacDonald



Dr. Dan McKenney



Dr. Hugh Brendan O'Neill



Dr. Shusen Wang



Dr. Susan Preston



Dr. Xiaoyuan Geng



Dr. David Lapen



Dr. Daniel Paradis



Mr. Eric Boisvert

Academic



Dr. Mani Mahdinia



Dr. David Rudolph



Dr. Chris Fletcher

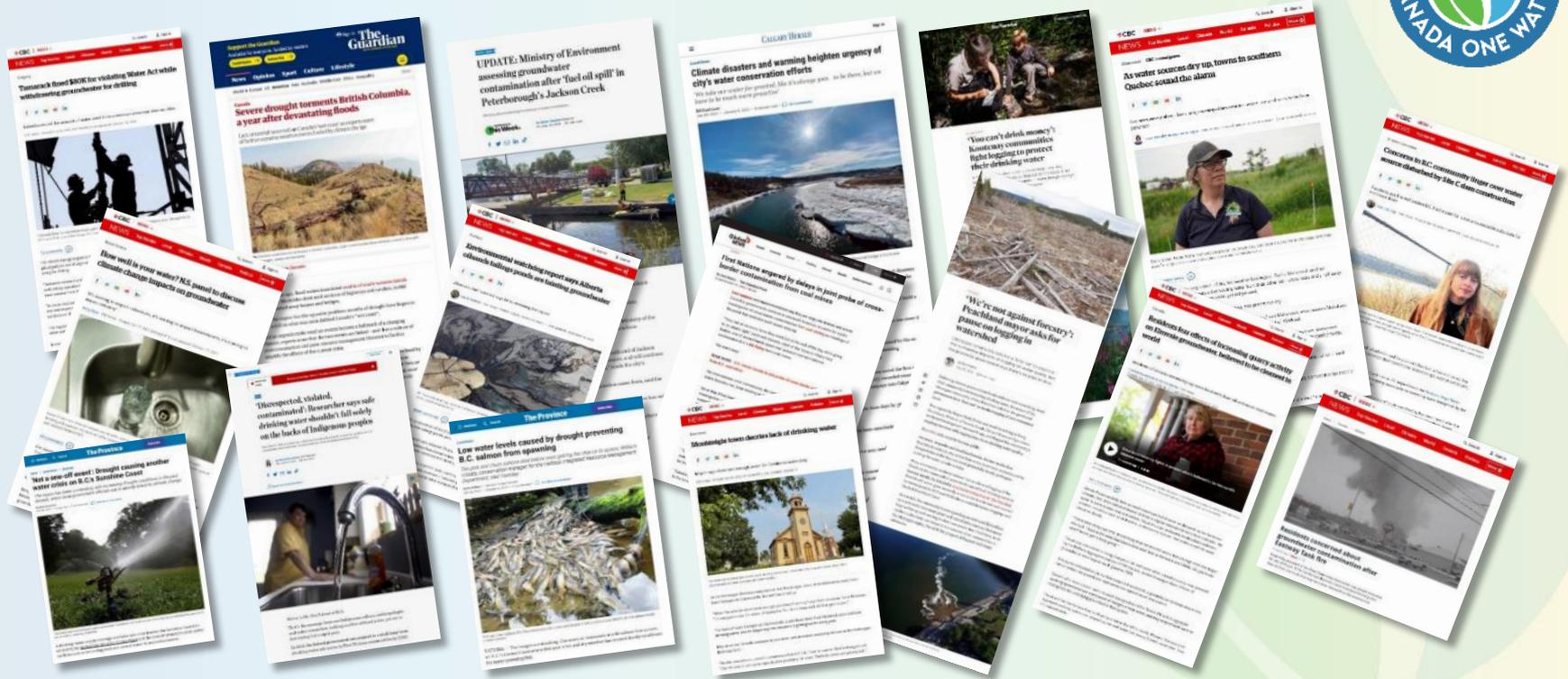


Dr. Richard Peltier



Dr. Xiaoyong Xu

Groundwater in the News



DROUGHT SALTWATER INTRUSION FLOODING CONTAMINATION FIRST NATIONS POTABLE WATER WATER ACT VIOLATIONS WATER SHORTAGES

Groundwater Usage in Canada



Why do we need Canada1Water?

- Creating and mobilizing the knowledge needed to predict and respond to water problems –
- Strengthening transboundary water management ...–

From. Water Security for Canadians 2021

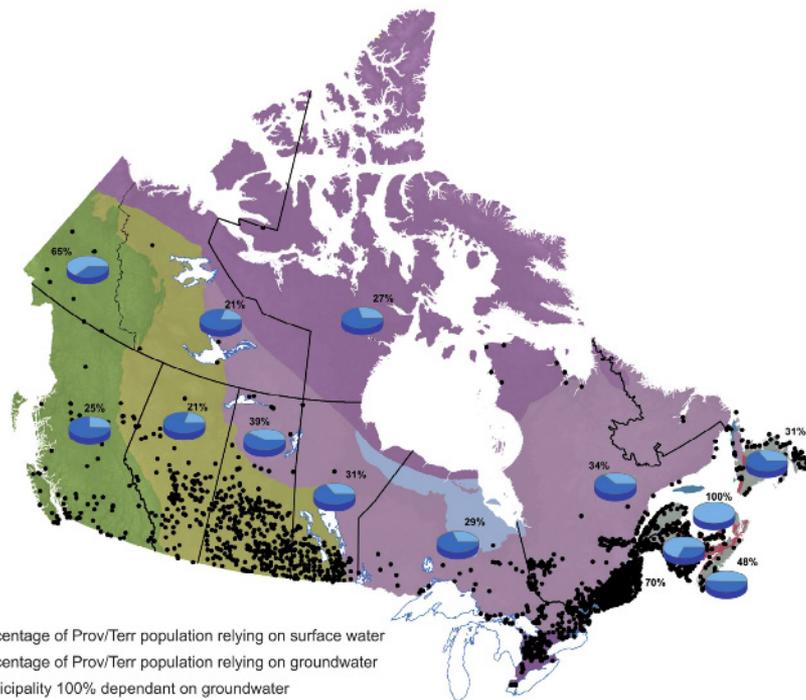
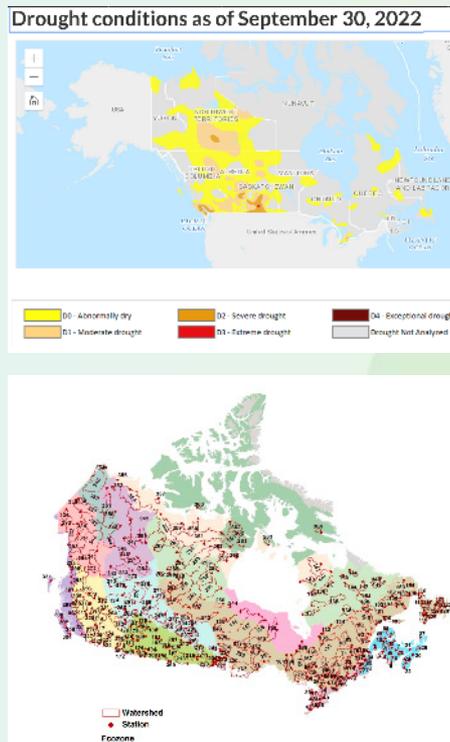


Figure 16.1 Groundwater use in each province and territory. Also shown are the hydrogeological regions in Canada.

Continental Scale Modelling in Canada



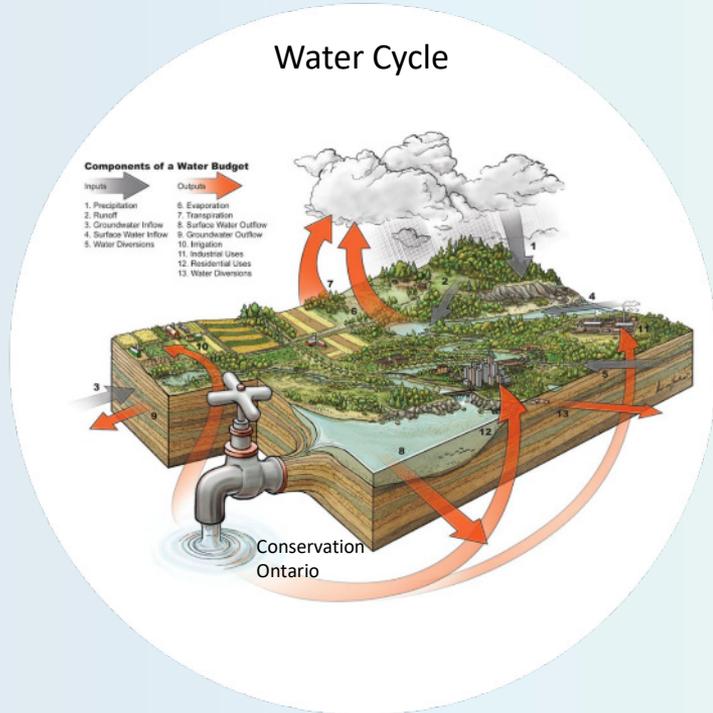
- Earth Observation
- Land Surface Modelling
- Surface Water Modelling
- Integrated Modelling
- Physically Based Integrated Modelling



Project Objectives

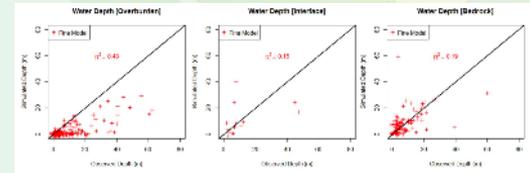
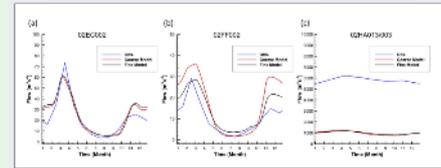
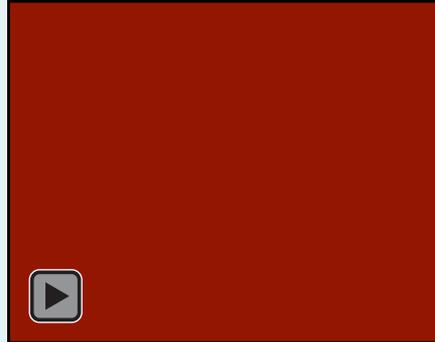
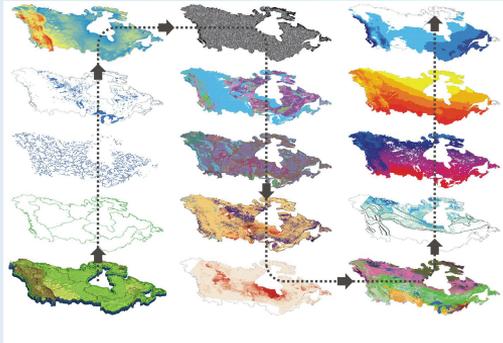
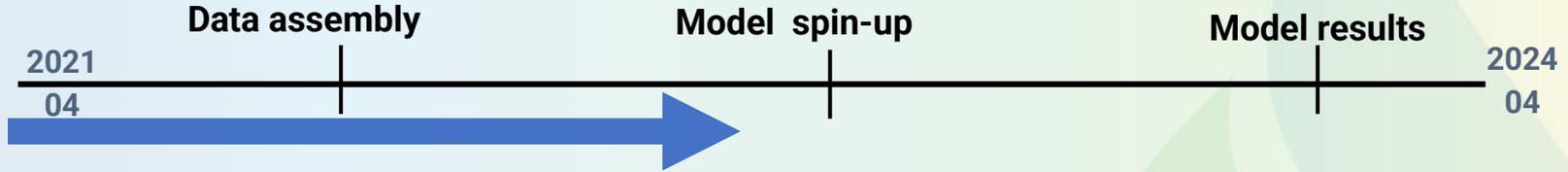


Water Cycle

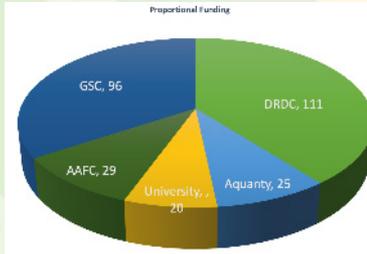
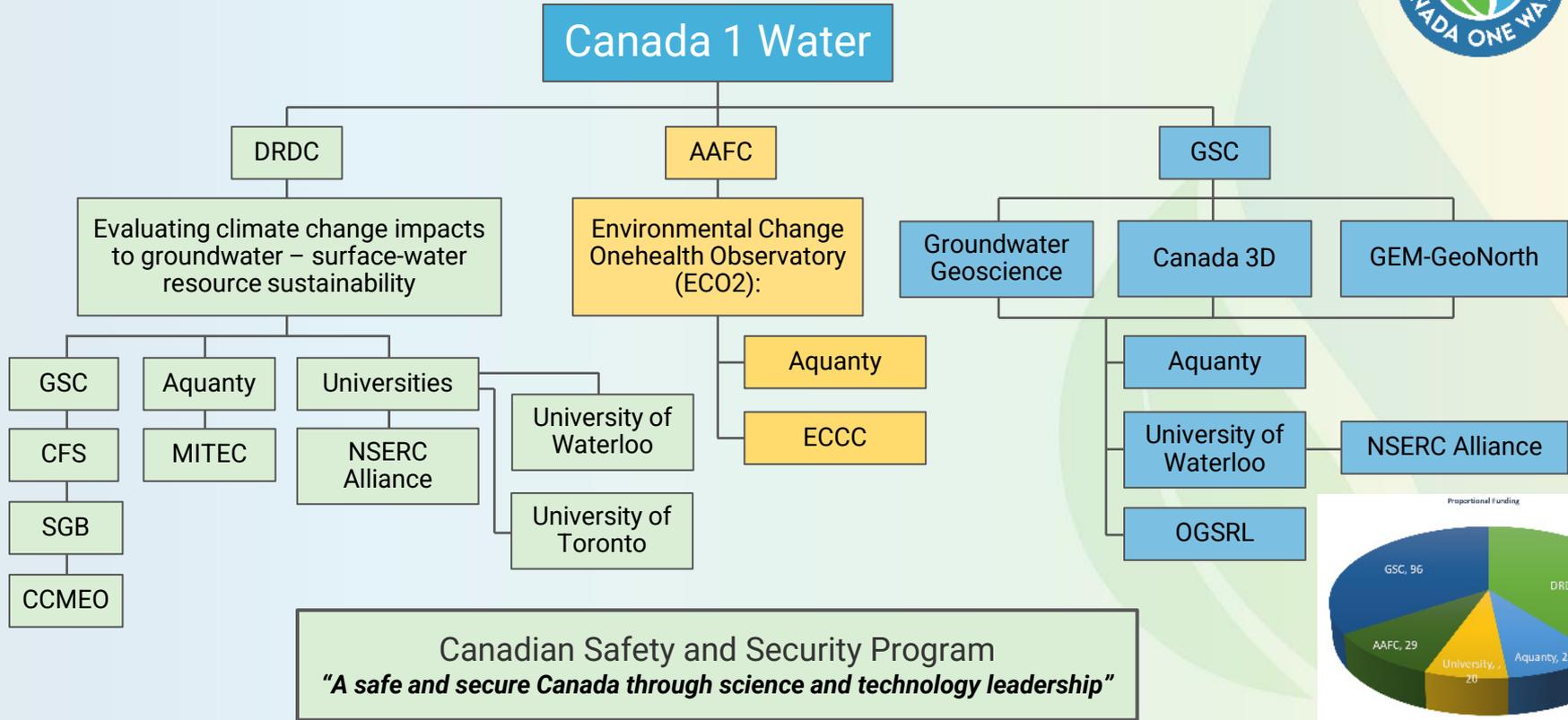


- Model the complete water cycle
- Develop fully-integrated groundwater – surface-water model(s) for Canada
- Evaluate the potential influence of Climate Change on water resources (large scale)
- Translate model output into societal-relevant metrics

Project Time lines



Collaboration / Funding

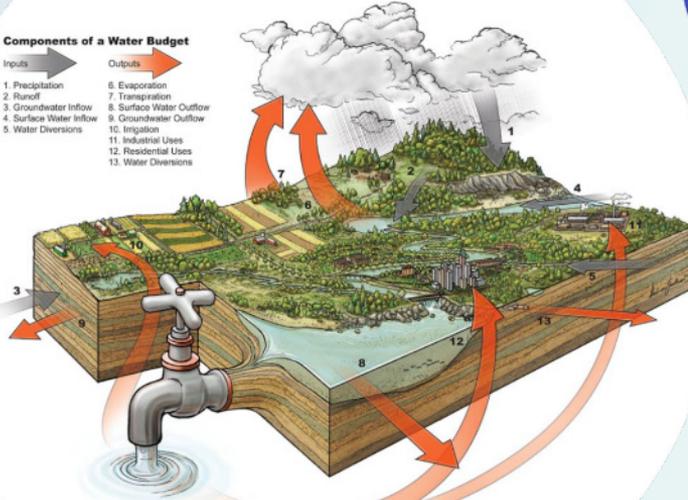


Integrated Modelling Framework



Complete Water Budget

- Components of a Water Budget**
- | | |
|-------------------------|--------------------------|
| Inputs | Outputs |
| 1. Precipitation | 6. Evaporation |
| 2. Runoff | 7. Transpiration |
| 3. Groundwater Inflow | 8. Surface Water Outflow |
| 4. Surface Water Inflow | 9. Groundwater Outflow |
| 5. Water Diversions | 10. Irrigation |
| | 11. Industrial Uses |
| | 12. Residential Uses |
| | 13. Water Diversions |

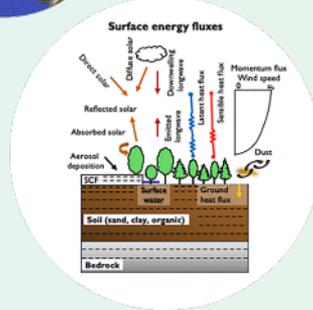


Conservation Ontario



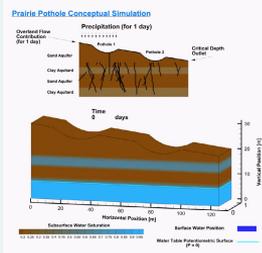
Regional climate modelling
12.5 km resolution

Historic: 1979-2020 • Projections 2050, 2100
Weather Research Forecast Model



Land surface modelling
5 km resolution

Subsurface parameterization • Re-analysis products
Community Land Model



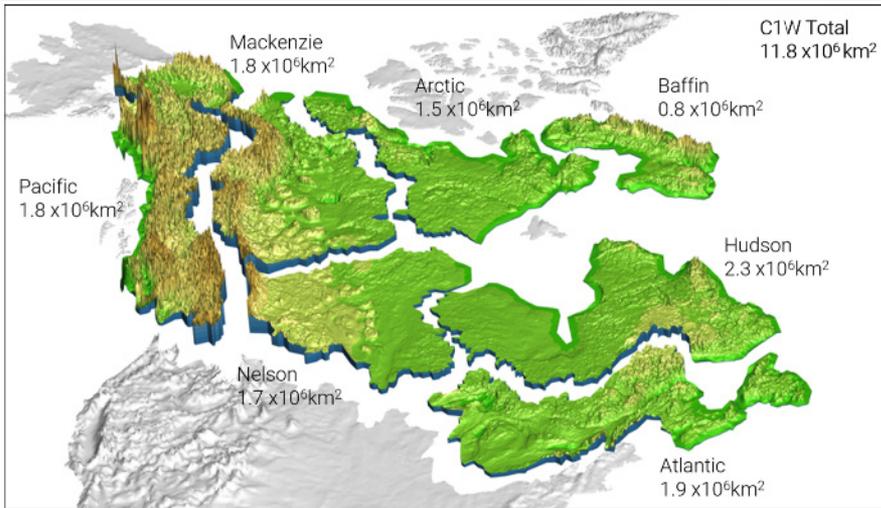
Groundwater – Surface-water modelling
1 to 5 km resolution

Integrated groundwater • Surface water
HydroGeoSphere

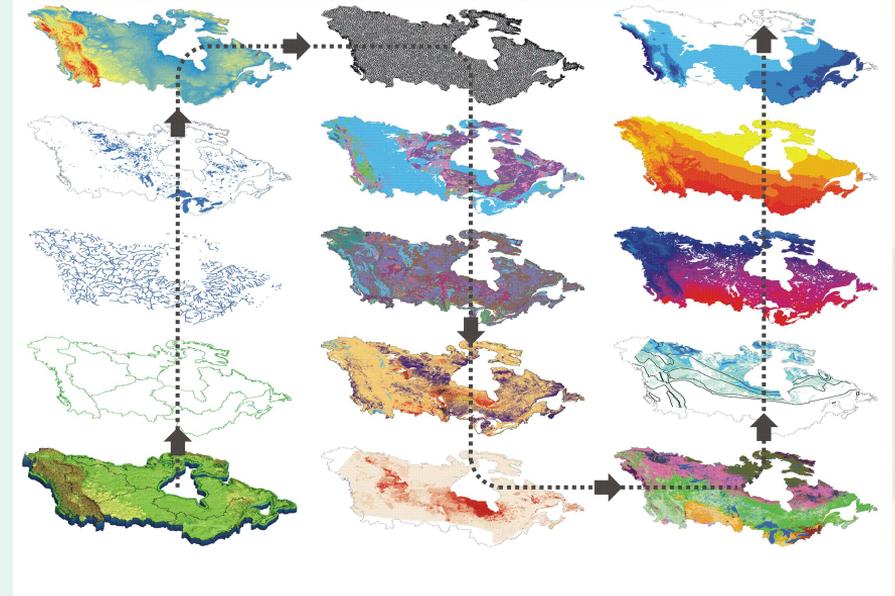
Building Canada 1 Water



7 Model Domains



Illustrative Data Layers



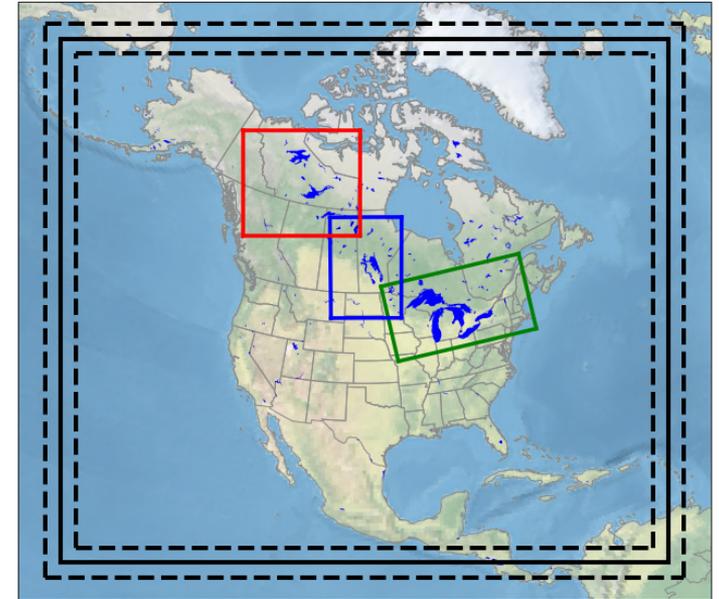
Data Assembly across multiple themes

The Major NA Lakes and Lake Model Design to Support Regional Climate Modelling



- **Lakes have an effect on neighbouring NA precipitation & surface temperatures (up to 20% or more)**
- 3 NA lake regions: 1) GSBLA 2) LWW 3) GL
- 3 different physical/empirical lake models:
 - A) **The default model (DM)**
 - > **Overly-simple** Performs poorly compared to other models
 - B) **More recent models**
 - > This study uses **GLERL25** (Xiao et al. 2016); like DM based on CLM, but has **better solar diffuse radiation & lake surface ice/snow/water albedo representations**
 - C) **A widely-used and tested empirical model, FLAKE**
 - > D. V. Mironov 2008, German Weather Service, Tech. Report # 11
 - > Performed well in Gula & Peltier 2012 and d'Orgeville et al. 2014

Major Lake Regions Within NA Domain



Data Assembly Challenges



- National plus USA transboundary
- Data integration across jurisdictional domains (provincial-territorial, national)
- Data normalization
- Data classification and parameterization

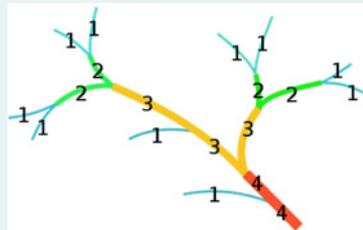
Data integration across jurisdictional



Data normalization



classification



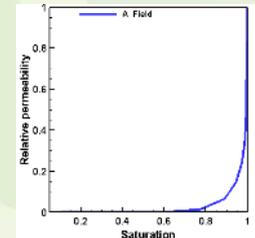
parameterization

From DSS

Sand %
Silt %
Clay %
BD
KP33
KP1500

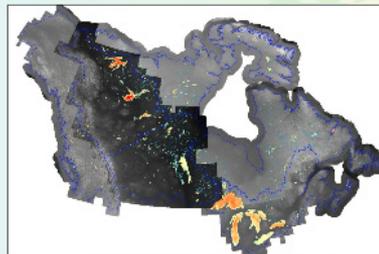
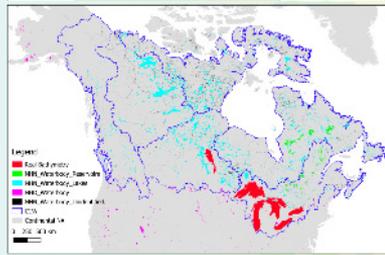
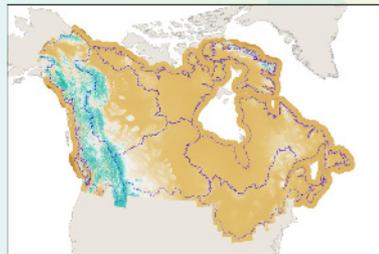


Rosetta
Pedotransfer
Functions



Illustrative Data challenges: DEM

- Land surface
- DEM for Canada
 - Arctic DEM
 - SRTM DEM
- Seamless stitch at 60 degrees north
- Infill of data voids
- Integration of lake depths
 - navigational lakes
 - Lakes > 10 km²
- Marine bathymetric buffer
- Seamless interpolation
- Removal of perhiperal landmass (islands)

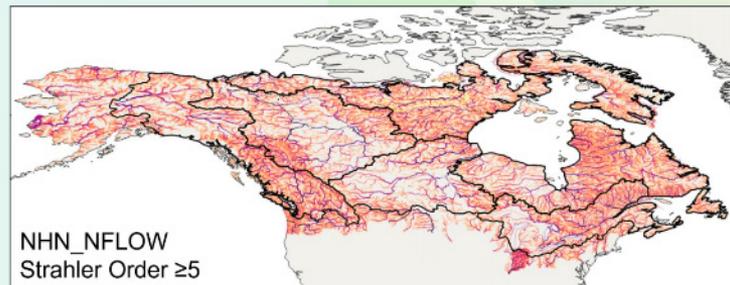
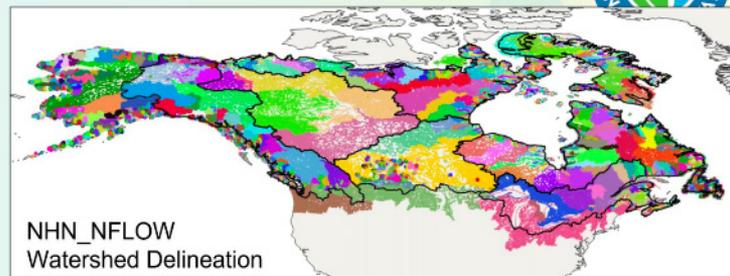


- Arctic DEM
- SRTM DEM
- Seamless stitch at 60 degrees north
- Infill of data voids
- Water bodies > 10 km²
- Navigational lakes vs non navigational
- > 4500 lakes with depth integrated
- Seamless interpolation of DEM sources

Illustrative Data challenges: Drainage



- Drainage System
- NHN
- Unclassified spaghetti vector network
- Numerous artifacts
- Need to classify
- Jurisdictional and geographic discontinuities





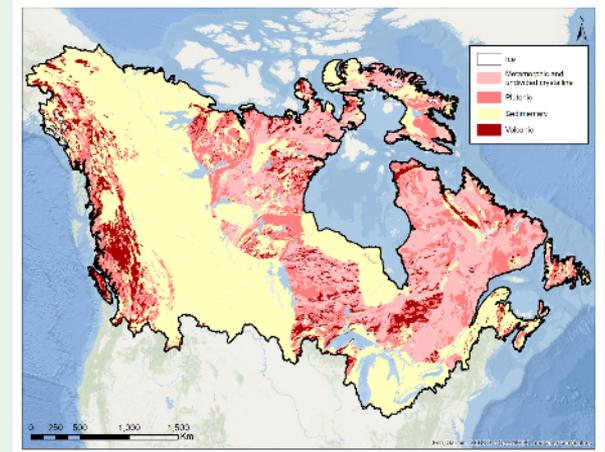
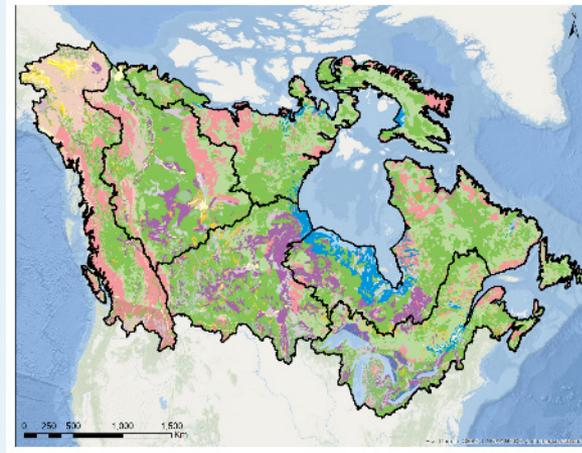
Illustrative Data challenges: Drainage

- Drainage System
- NHN
- Unclassified spaghetti vector network
- Numerous artifacts
- Need to classify
- Jurisdictional and geographic discontinuities



Illustrative Data challenges: Geology

- Geological Coverage
- National scale
1:5,000,000
- Provincial scale
1:1,000,000
- Stratigraphic
nomenclature
- Parametrization



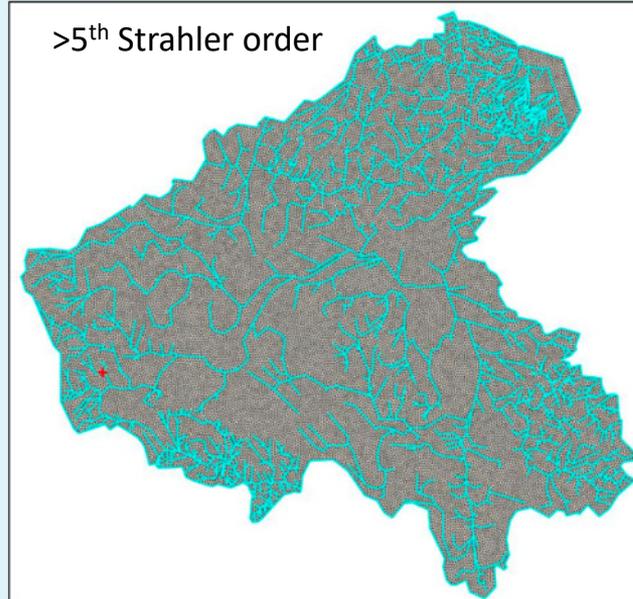
2022- Summer/Autumn: Model Discretization



Nelson River example

- Coarse Resolution

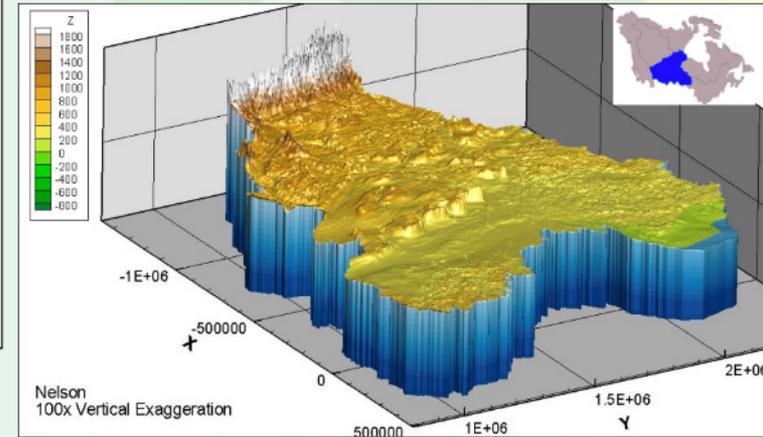
- >5th Strahler order
- < 500K nodes
- ~60K nodes per sheet



- Fine Resolution

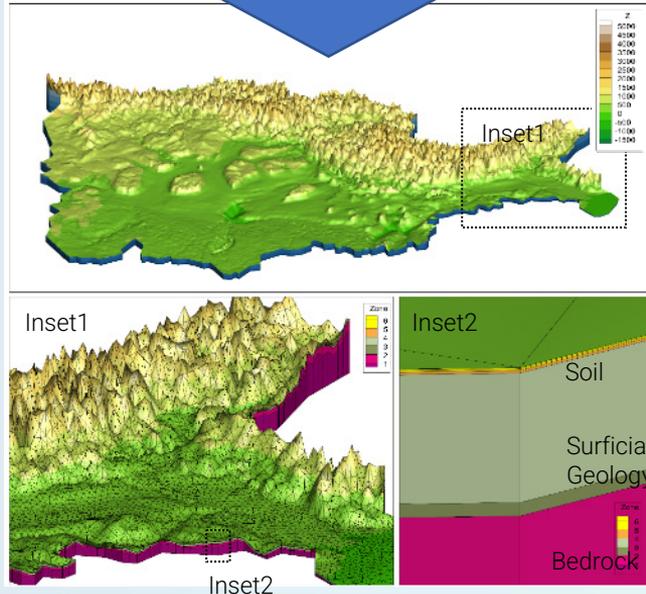
- > 4th Strahler order
- <2M nodes
- ~250 nodes per sheet

Model	Area (x10 ⁶ km ²)	Nodes per sheet	Sheets	Total Nodes
Nelson	1.6	38,000	8	304,000



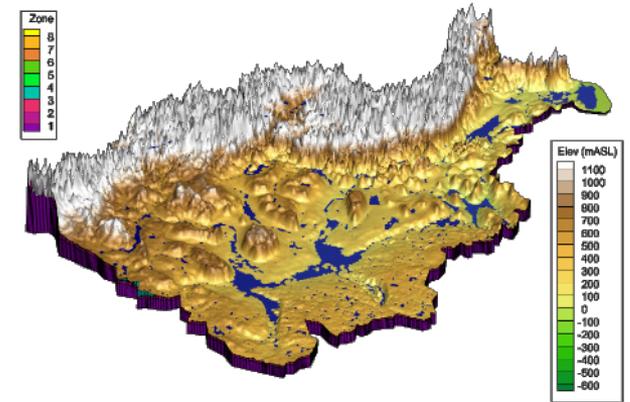
1. Conceptual model
2. HGS domains
3. river network
4. lake bathymetry
5. DTMs
6. FEMs
7. Bedrock Geology
8. Surficial Geology
9. Soil Maps
10. Peatland Map
11. Landcover

3D
Model

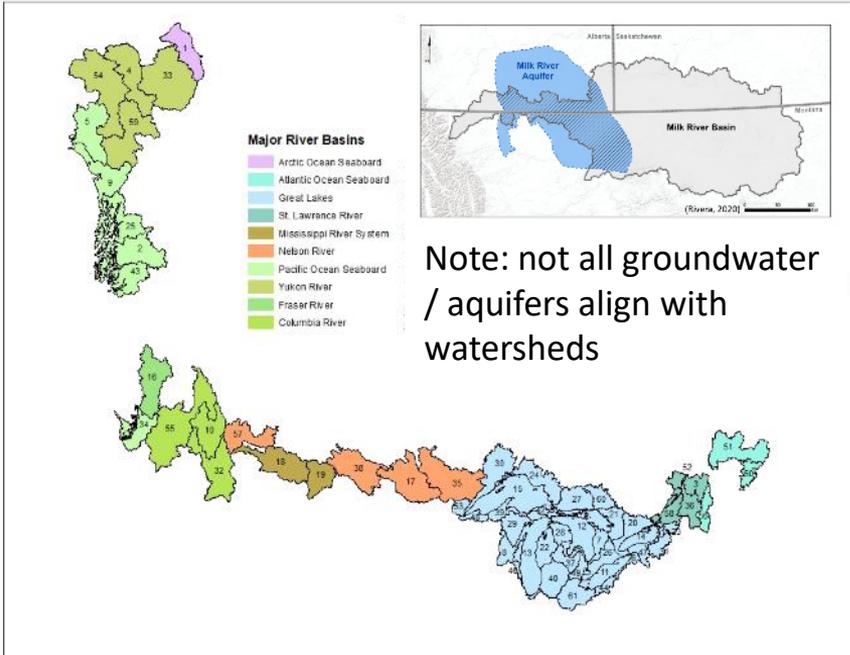


Model
Calibration
and
Validation

Model spin-up before transient simulations



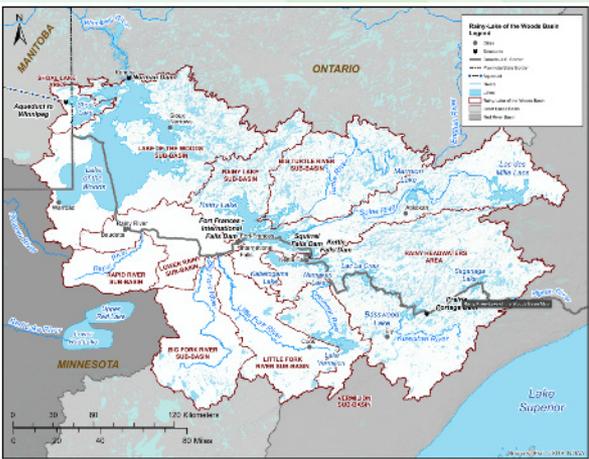
Canada-USA Watersheds



Note: not all groundwater / aquifers align with watersheds

- order: 4th
- number: 61
- Area: 2,350,443.30 km²

Rainey River



Collaboration
IJC
USGS

Cumulative
Effects

- population: 60,000,000
 - Per watershed: min: <200. max >6 million

Community Support

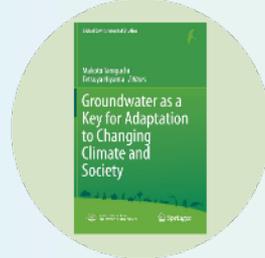
Decision support for sustainable water resource management
Addressing ESG – Environment, Society, and Governance



First Nations



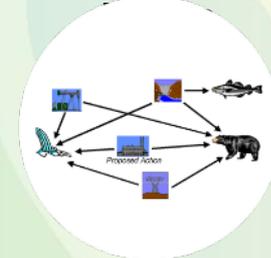
Society



Sustainable



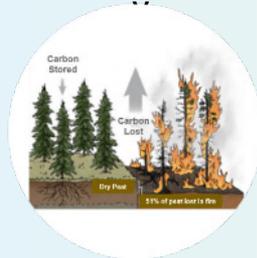
Cumulative



Mining



Forestr



Economic
Agriculture



Fisherie

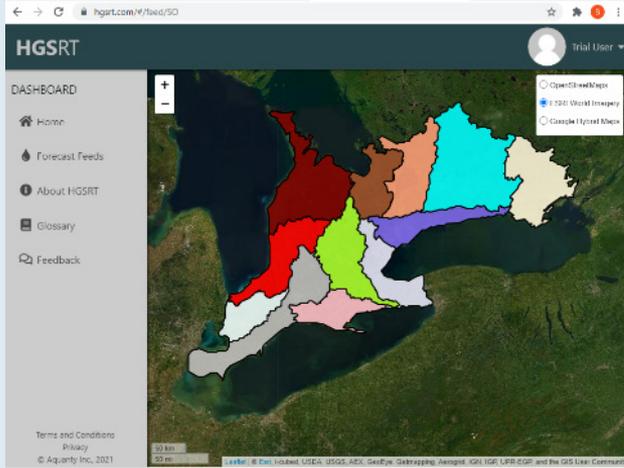


Environmental Flows

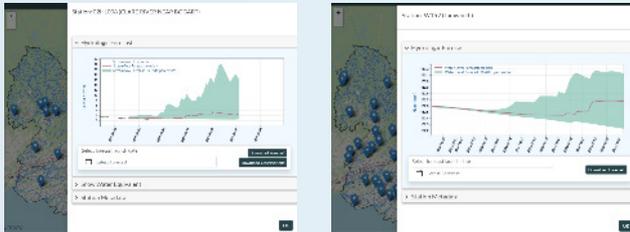
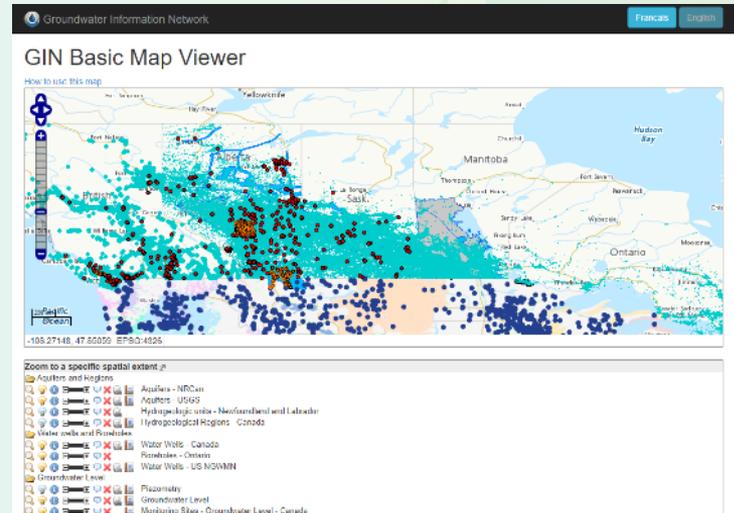


Decision Support Framework

HGSRT Proof-of-concept



Groundwater Information Network

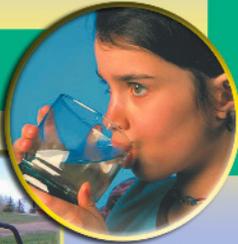


Engagement



 Government of Canada
Gouvernement du Canada

Canadian Framework for Collaboration on Groundwater



2003

Canada 

- National Dialogue on Groundwater
 - 2021-06-02; 2021-09-08; 2022-01-19
- One-on-one contacts with provinces
- Connecting with individual researchers
- Outreach to NGO organizations, Conservation Authorities, etc.
- First Nations engagement via GEM, CFS, etc.,



Summary

- 3 year project
- Physically based GW-SW models with CC scenarios
- Monthly historic transient model
- Decision support pilot tests
- Supporting Communities – Geographic, Social, and Economic
- Open access data and results

Acknowledgements



Funding:

- Defence Research Development Canada (DRDC)
- Agriculture and Agri-Food Canada (AAFC)
- Geological Survey of Canada

Partners

NRCan:

- Canadian Forest Service (CFS)
- Canadian Centre for Mapping and Earth Observation (CCMEO)
- Surveyor General Branch (SGB)

Aquanty:

Agriculture and Agri-Food Canada (AAFC):

University of Toronto

- Earth Atmospheric and Planetary Physics

University of Waterloo

- Earth and Environmental Sciences
- Department of Geography

Additional Information

- Canada1Water Website: <https://www.canada1water.ca>



<https://www.canada1water.ca/news>

2021- December volume 1-1.

2022- April volume 1-2

2022- September volume 1-3



Archetypal Aquifer Project: 2022 Update

Groundwater Geoscience Program 2019-2024

David Sharpe and Hazen A.J. Russell

Geological Survey of Canada hazen.russell@canada.ca

GSC contributors

Alpay, S., Bunn, M., Crow, H.L., Dietiker, B., Hinton, M., Knight, R.D., Larmagnat, S., Logan, C.E., Pugin, A.,

GGP: 2022-11-16



Colleagues

GSC Collaborators

Brewer, K.
 Cartwright, T.
 Enkins, R.
 Grenier, A.
 Madore, S.
 Moore, C.
 Paradis, D.
 Wygergangs, M.

Al, T.
 Al-Mufti, O.
 Arnott, W.R.C.
 Brunton, F.
 Carter, T.
 Celejewski, M.
 Clarke J.
 Francus, M.
 Kearney, M.
 Milloy, C.
 Parker, B.
 Phelme, P.
 Priebe, E.

Collaborating Agencies

Funding

City of Ottawa, AAFC

Collaborators

Agriculture and AgriFoods Canada (AAFC)
 City of Ottawa
 Environment Climate Change Canada
 Institut national de recherche scientifique (INRS)
 Public Safety Geoscience Program (GSC)
 Rideau Conservation Authority
 South Nation Conservation Authority
 University of Guelph
 University of Ottawa
 Western University



Content

1. Communications
2. Field Laboratories
 1. Regional (seismic reflection and passive seismic)
 2. Embrun esker hydrogeophysical
 3. Bells Corners bedrock downhole
3. Geophysics / Geochemistry
4. Aquitard hydrogeology (Bilberry Creek)
5. Spiritwood modeling
6. Presentation: Hydrogeological Terrains, Southern Ontario

Strong list of publications and pending products



Communications



- Changed during COVID
- Reduced travel
- Virtual Presentations

- GSC Groundwater Program YouTube channel
- Southern Ontario open house - online talks on YouTube

<https://alumni.uga.edu/2020/04/10/cdc-bulldogs-bring-the-covid19-coronavirus-to-life/>

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New Tools

- GSC Groundwater Program YouTube channel
- Southern Ontario open house online - talks on YouTube
- Talks supporting Archetypal Aquifer Project

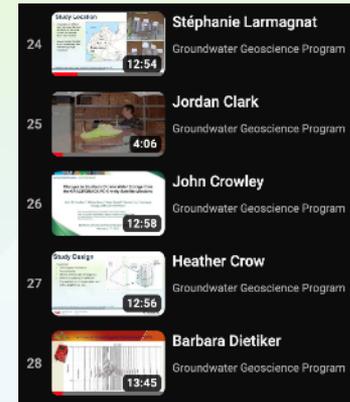
2021: 6 talks

2022: 8 talks



Search Groundwater Geoscience GSC

<https://www.youtube.com/channel/UChIc7ff3vEdII708VhgsLsg>



<https://alumni.uga.edu/2020/04/10/cdc-bulldogs-bring-the-covid19-coronavirus-to-life/>

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Near Surface Geophysics collaboration

1. Buried valley studies & test sites, Guelph:

- 3 km of microvibe high-res seismic surveys
- 113 passive seismic recordings (Tromino) along seismic profiles

Morwick G360 Groundwater Research Institute (Univ. Guelph)

2. Surveys in support of field labs

- ### 3. New geophysical logging tool—NMR
- Measures porosity in rock & sediment
 - Interprets **K** along borehole wall



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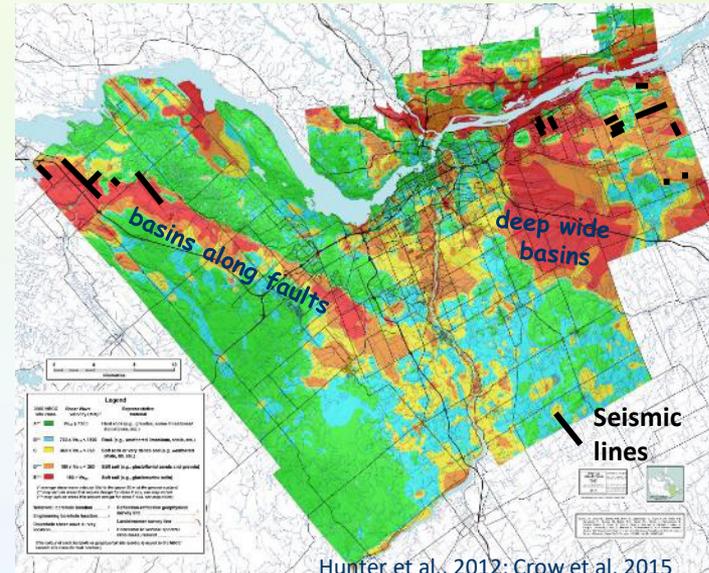
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Contact: Barbara Dietiker

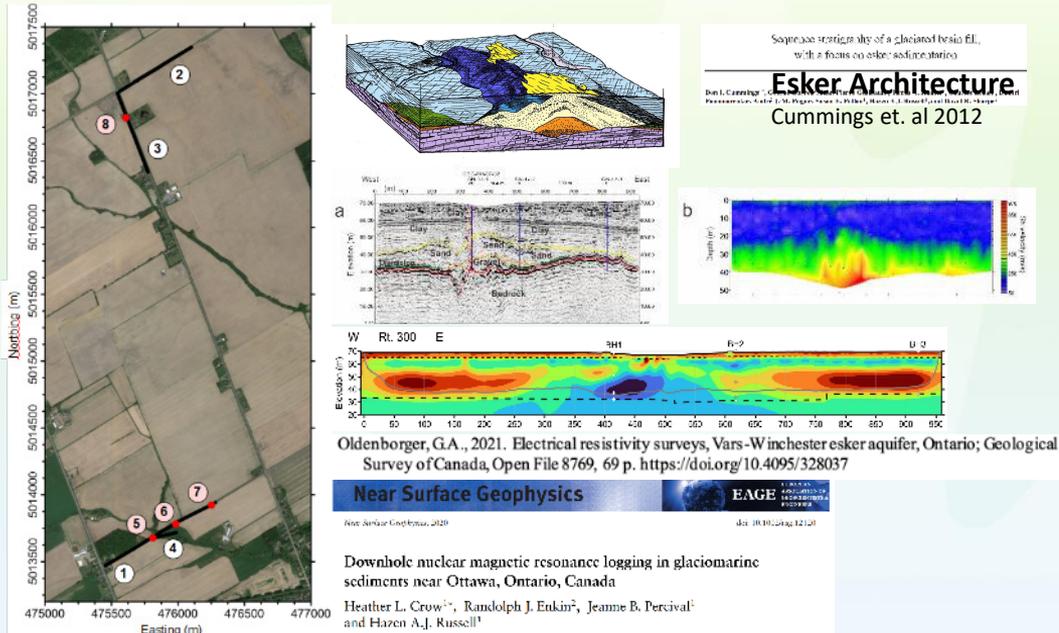
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Field Laboratories

- Methods development
- Aquifer characterization
- Regional
 - Seismic profiling; BH logging
- Bells Corners
 - Downhole tools in fractured Precambrian Paleozoic rock
- Embrun
 - esker and Champlain Sea muds



Embrun Esker Site

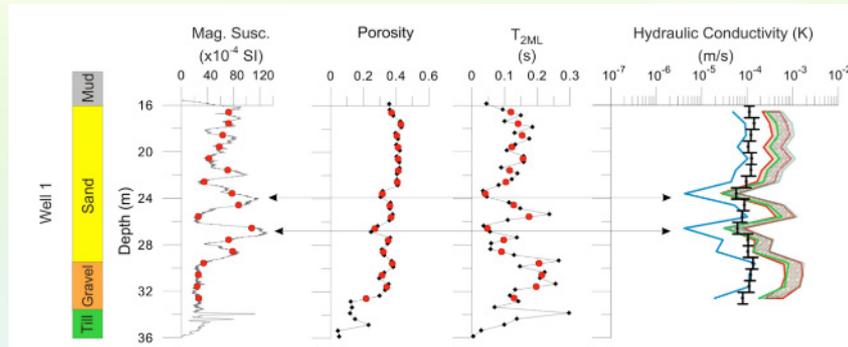


Datasets

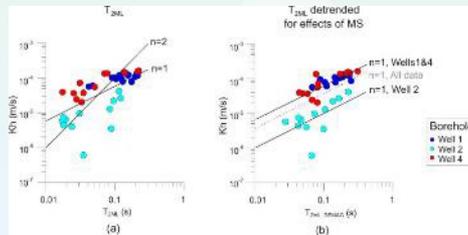
- hydraulic
- geophysical
 - seismic
 - reflection
 - seismic
 - passive
 - resistivity
 - borehole
 - litho logs
 - NMR

Crow et al. Hydraulic conductivity from NMR logs

Embrun NMR and Magnetic Susceptibility



- unconsolidated aquifer
- hydraulic conductivity
- magnetic susceptibilities – moderate to elevated (10^{-4} to 10^{-2} SI)



Groundwater

Hydraulic Conductivity from Nuclear Magnetic Resonance Logs in Sediments with Elevated Magnetic Susceptibilities

by Heather Crow^{1,2}, Daniel Paradis³, Elliot Grunewald⁴, Xiao Xia Liang³, and Hazen A.J. Russell¹

Bells Corners Deep Borehole Research Site

Nuclear Magnetic Resonance

- Collaboration - G360 University Guelph
- Target: fractured sandstone & limestone-dolostone

- Assessment/ refinement of NMR
 - void volume estimation
 - repeatability measurements
 - hrs-days
 - logging speed
 - threshold response
 - evaluation against lithology



Contact: Heather Crow

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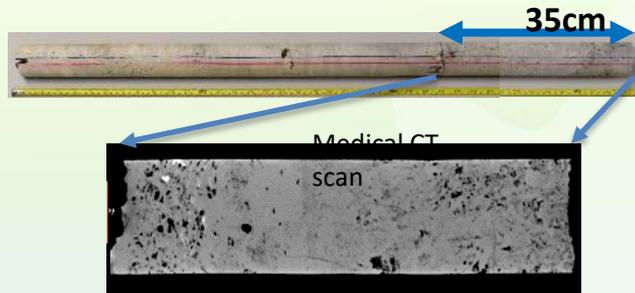


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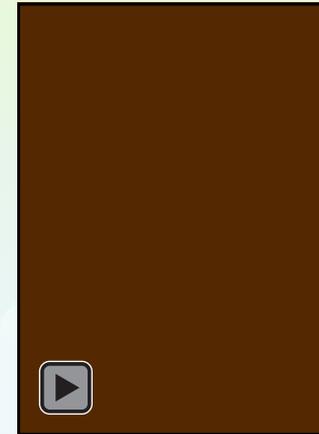
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CT Scan porosity analysis



Three thematic study areas
Paleo-karst of Guelph Formation



Contact: Heather Crow

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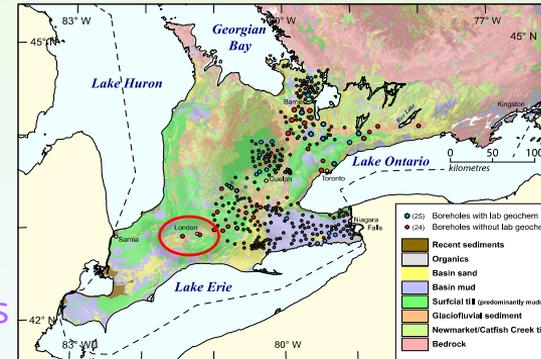
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Geochemistry

Publications in progress

- borehole geochemistry southern Ontario
- London area
- Ottawa area bedrock

Olson, L.C, Knight, R.D, Crow, H.L., and Russell, H.A.j 2022. Chemostratigraphic logging of the Lower Ordovician and Precambrian, Bells Corners borehole calibration facility, Ottawa, Ontario Geological Survey of Canada, Open File 8913, 22 pages, <https://doi.org/10.4095/330519>



Hydrogeology & hydrogeochemistry of Champlain Sea Aquitard

GSC : *Alpay, Hinton, Crow, Enkin, Dietiker, Grenier*
 Partner(s): UOttawa, UQAM, RVCA, City of Ottawa

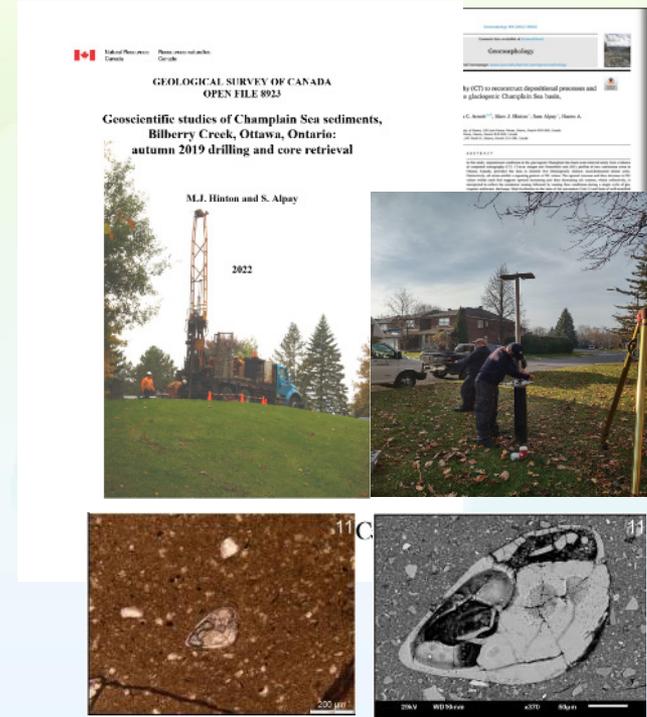
Mud sediment -CT scan ms published, Uottawa/GSC
 Open File 8923 -final proof, GSC Northern
 Ph.D. thesis defence (1 ms- pore water), U Ottawa
 B.Sc. Thesis (diffusion), U Ottawa
 UQAM collaboration: pollen, micropaleo & isotopes,

Additional studies completed:

NMR downhole logging, GSC Central
 Thin section optical/ SEM imaging, U Ottawa
 GSC Sediment lab analyses, GSC Northern
 Mineral magnetism progress, GSC Pacific
Ongoing: GW monitoring; drone imagery

-HG / geochemical influences of Champlain Sea deposits on GW flow system
 -Any implications on landslide hazard

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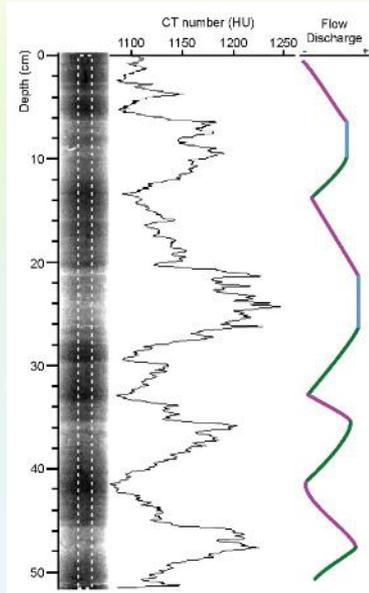
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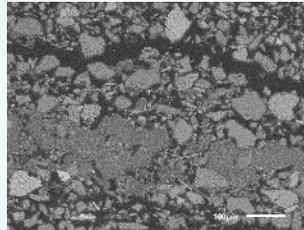
Contact Marc Hinton and Sam Alpay

Canada

Champlain Sea Sedimentology



Unit 4a: well-stratified mud
 Unit 4a: diffusely stratified
 or structureless mud
 Unit 3: banded mud
 Unit 2: bioturbated mud
 Unit 1: mud rhythmites



Hounsfield Units*

~ 250-300
 ~ 50
 ~ 80-120
 ~ 50-100
 ~ 300
 * spread



Future Work

Microfabric analysis

Improved understanding of porosity –
 permeability distribution within muds
 -understanding mud desalinization

Hydrostratigraphic Model: S-Ontario

Publication (in press)

Carter, T.R., Logan, C.E., Clark, J.K., Russell, H.A.J., Priebe, E.H., and Sun, S. 2022. A 3-D bedrock hydrostratigraphic model of southern Ontario. Geological Survey of Canada, Open File ##### doi

Confidence modelling (in review)

Bunn, M., Carter, T.R., Russell, H.A.J., and Logan, C.E. in review. A Semi-Quantitative Representation of Uncertainty for the 3D Paleozoic Bedrock Model of Southern Ontario; Geological Survey of Canada, Open File xxxx, xxx p. <https://doi.org/10.4095/xxxxxxx>

Robust HS framework for addressing a host of water resources issues across southern Ontario, ie., deeper flow system issues and storage potential

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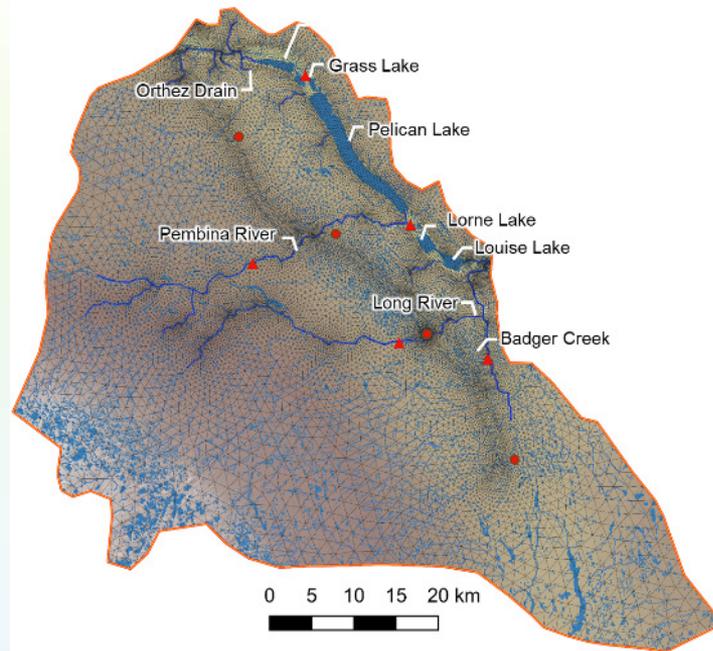
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Integrated groundwater- surface water modelling of Spiritwood Aquifer

- Duplicate Groundwater (FEFLOW) and Integrated Groundwater-Surface Water (HGS) models constructed / calibrated based on 3D Geological Model of Spiritwood buried valley aquifer.
- Low hydraulic conductivity surface limits GW recharge. Most recharged water discharges to proximal surface water. Buried valley aquifer is unlikely to be replenished.
- Ongoing work to publish comparative modelling approaches
- Contributes to conceptual model of prairie water balances.



This well framed HG model allows for progress on water balances in buried valley aquifers common across the prairie region

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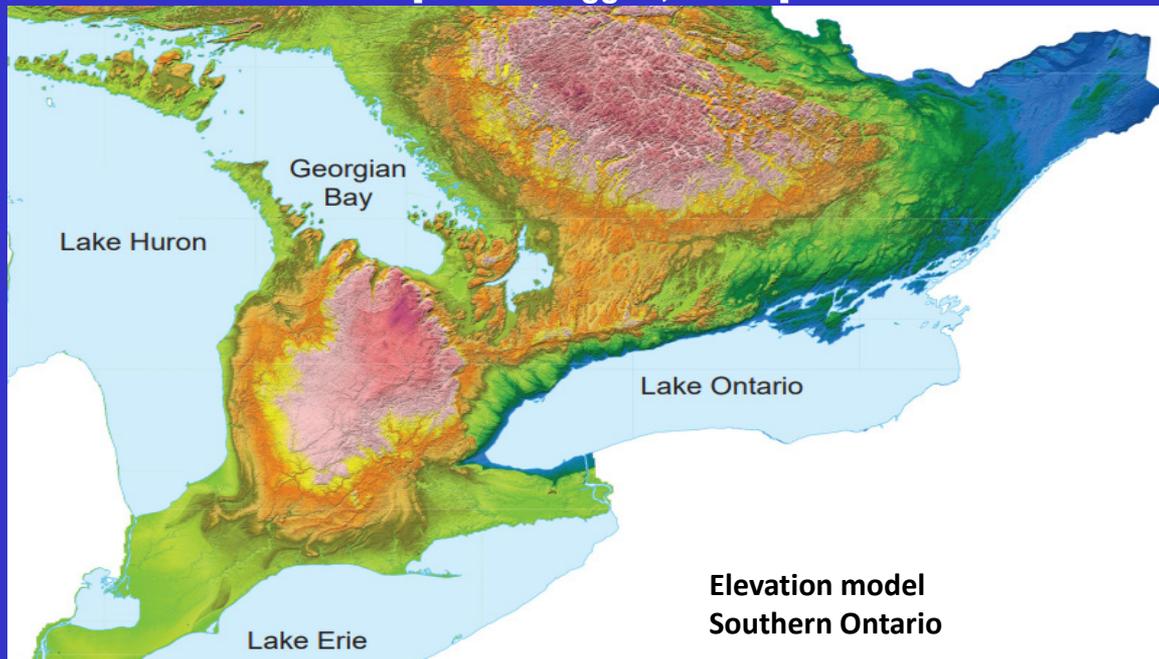
Contact: Melissa Bunn

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Hydrogeological terrains of Southern Ontario

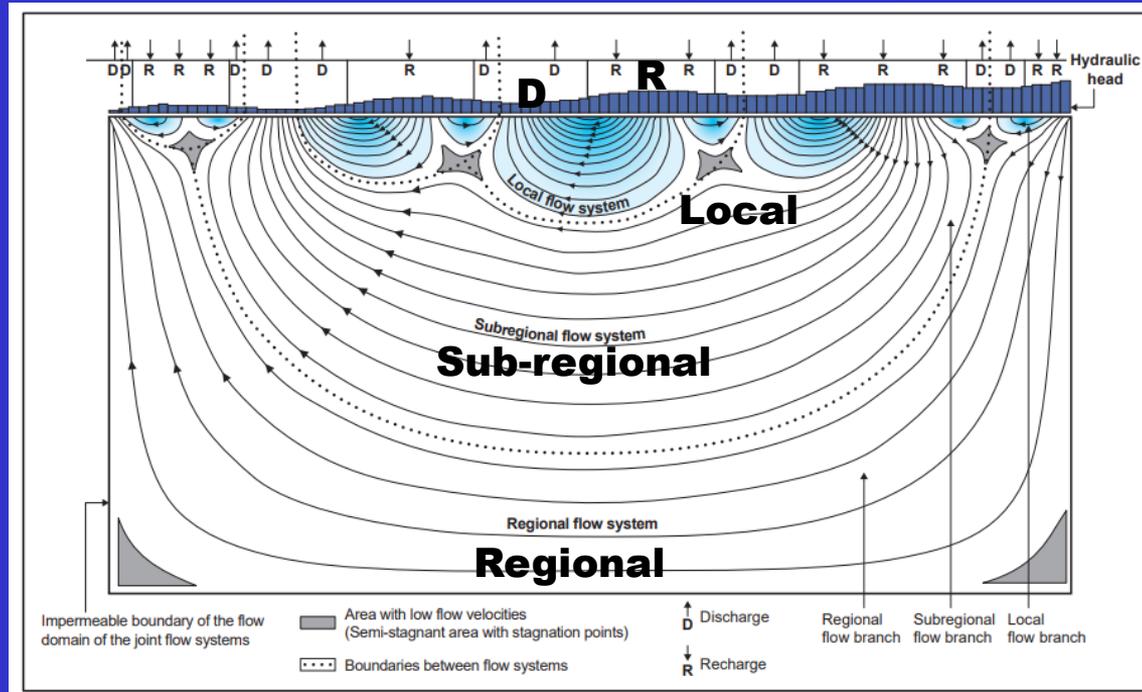
David Sharpe
Geological Survey of Canada
[Andrew Piggott, retired]



Developing HG archetypes characteristic of southern Ontario

0

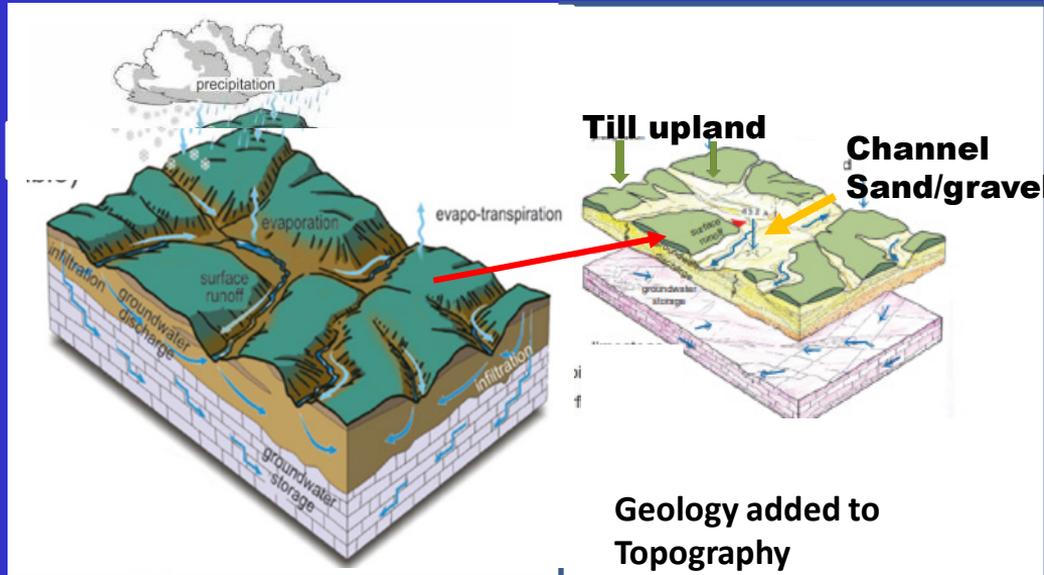
Classic Archetype (Toth flow system)



Nested, hierarchical groundwater flow system

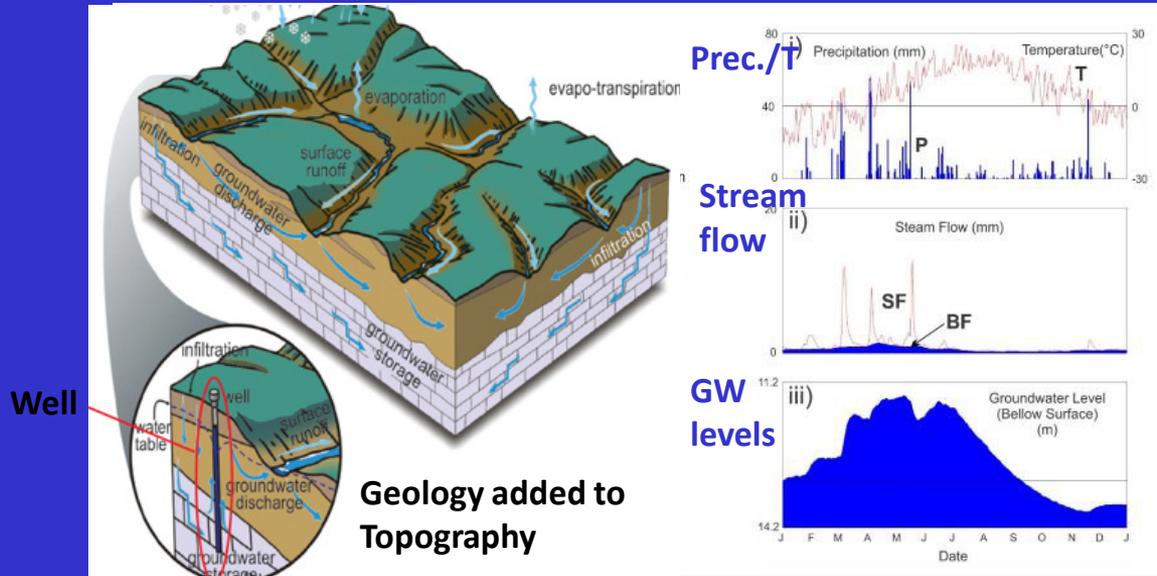
-assumes homogenous geology

TERRAIN GEOLOGY



Geology provides regional data on infiltration and permeability

TERRAIN GEOLOGY & HYDROLOGY

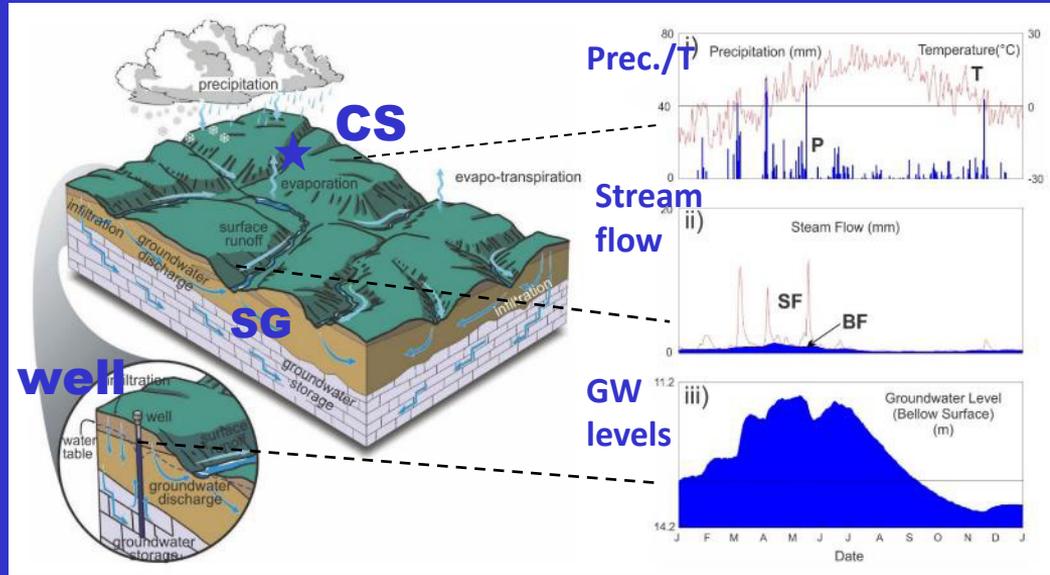


Terrain geology

Hydrology

Link terrain geology to readily-available hydrologic monitoring

TERRAIN SETTING & HYDROLOGY

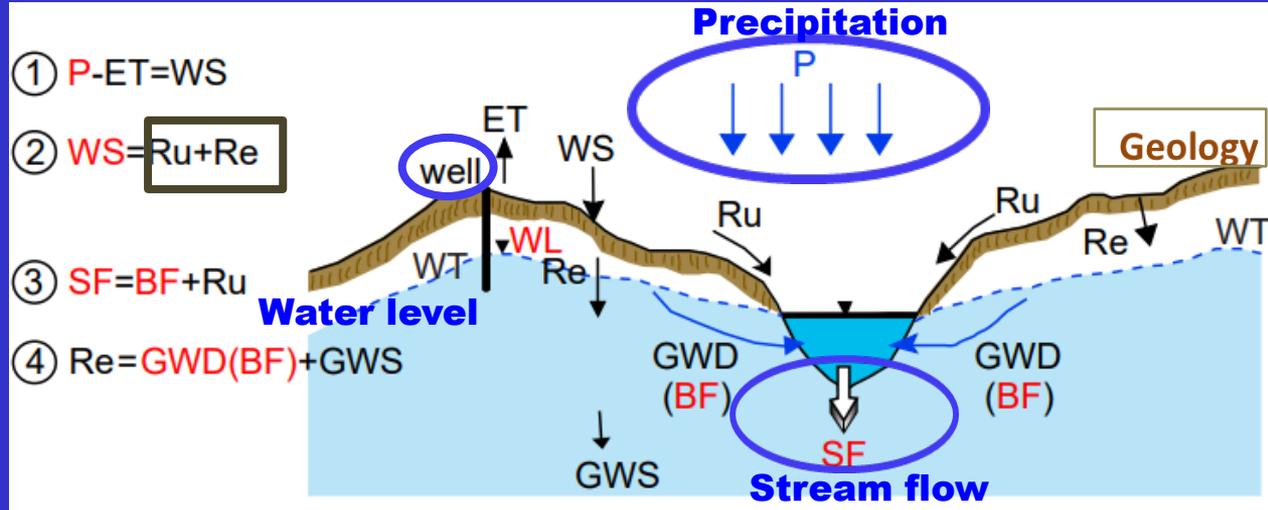


Terrain geology

Hydrology

Combined these data describe how water moves through southern Ontario landscape

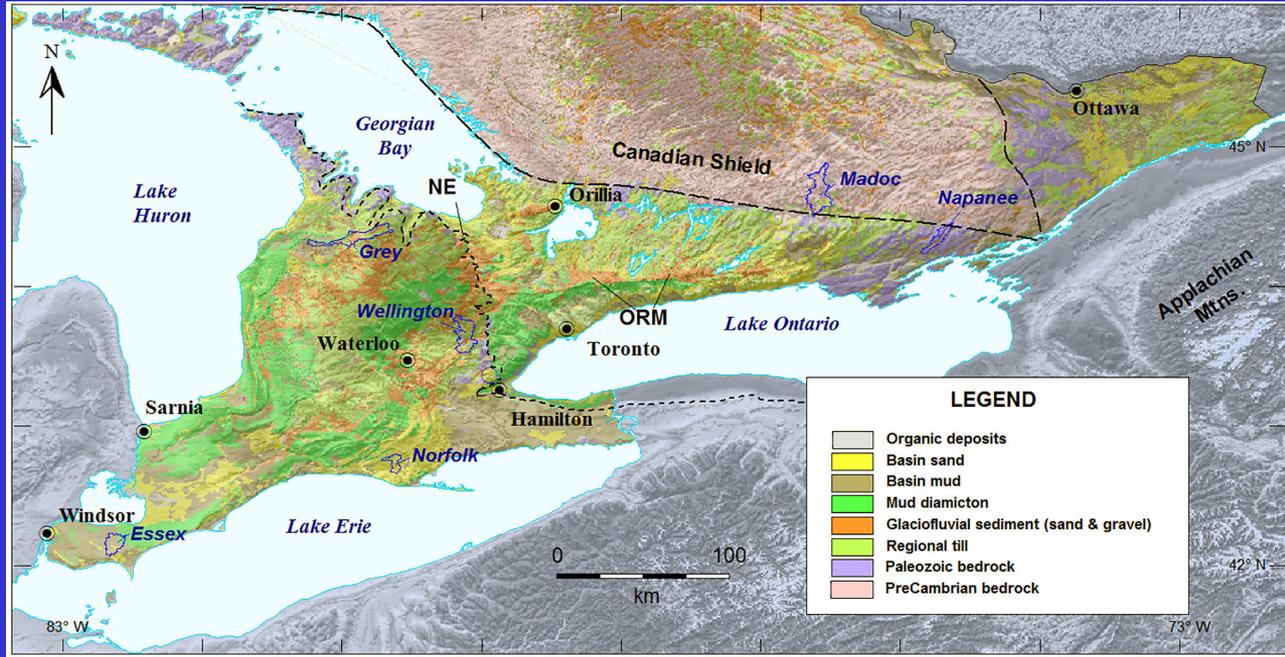
WATER CYCLE



Precipitation, stream flow & water level

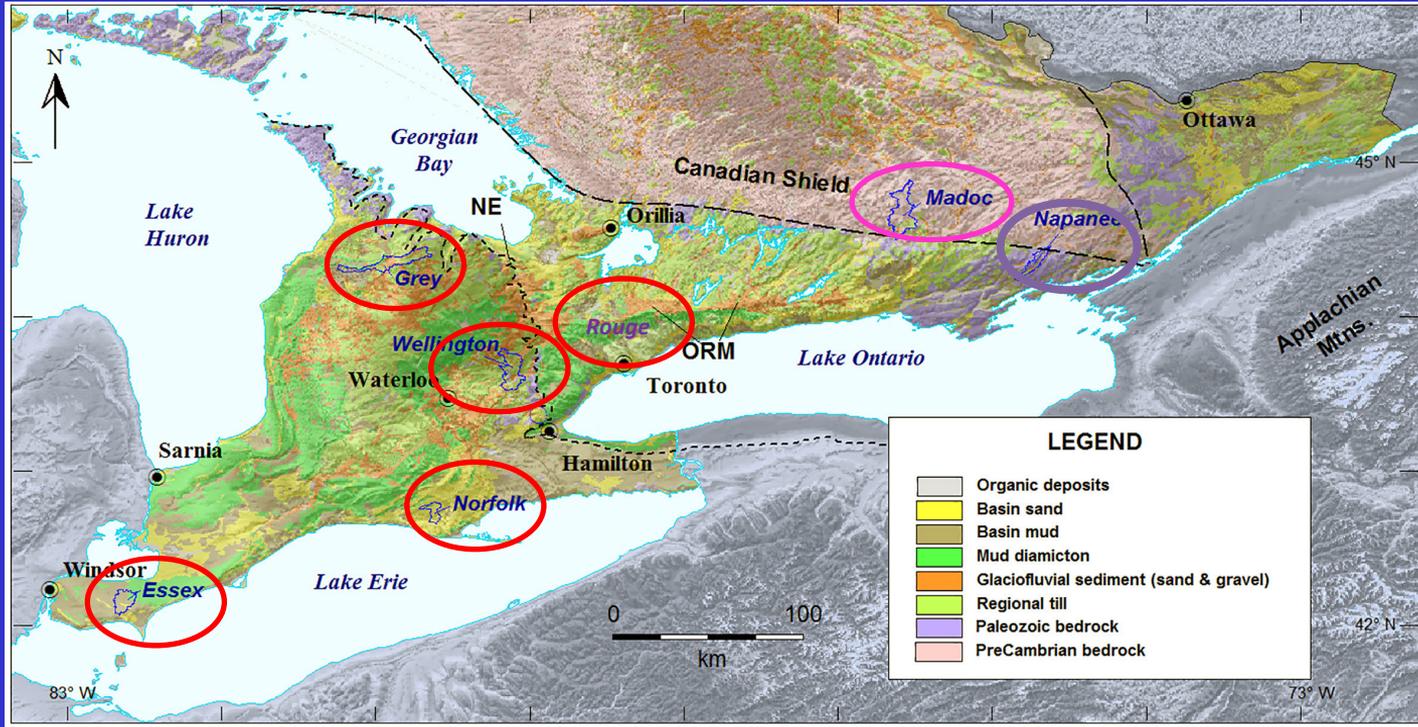
Geology allows water surplus (WS) to be partitioned into runoff (Ru) and recharge (Re) based on infiltration & permeability properties of geological units

Surface geology southern Ontario



- 8 units simplify geological landscapes (draped on DEM)
- they help define terrains based on their inherent hydraulic properties

SELECTED TERRAINS

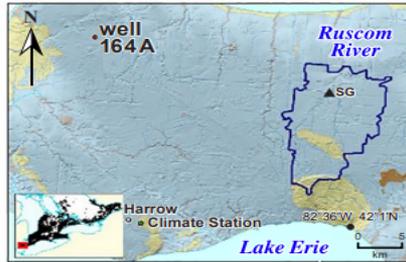


**Windsor/ Essex
clay plain**

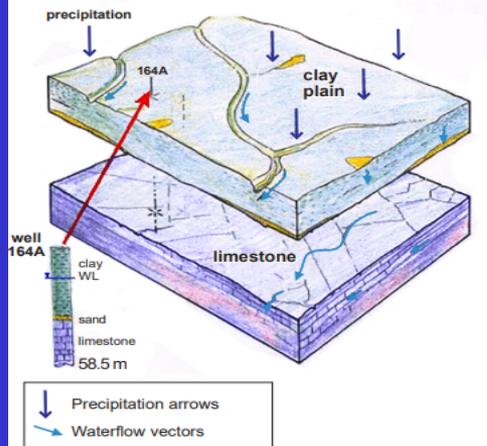
**Norfolk
sand plain**

CLAY PLAIN SETTING

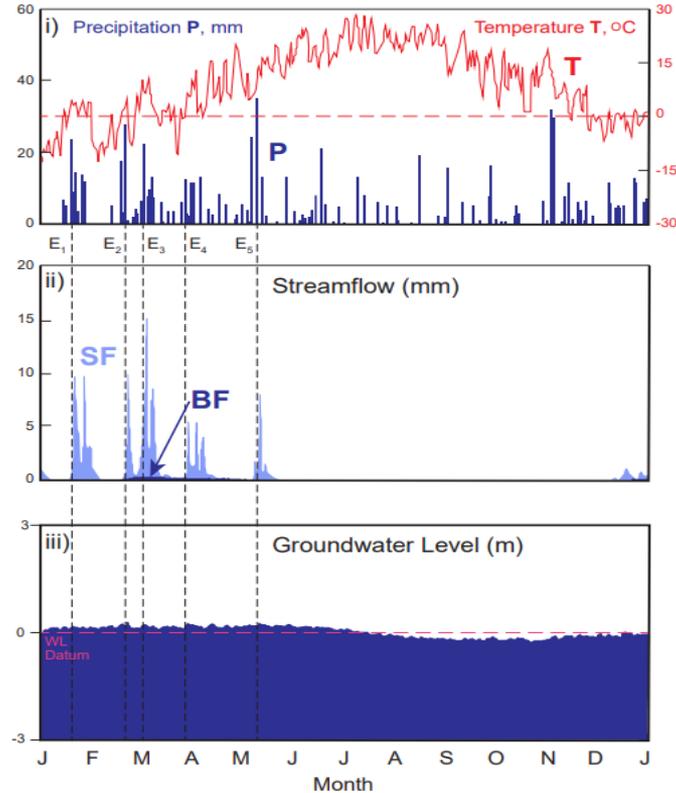
a) Terrain Setting



b) Hydrogeology with 3-D Block Model



c) Hydrology

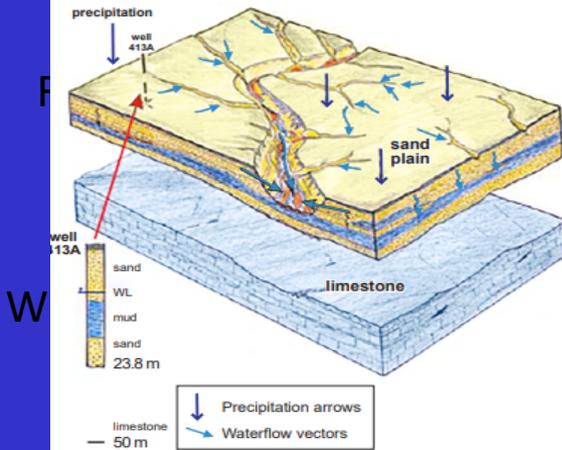


SAND PLAIN SETTING

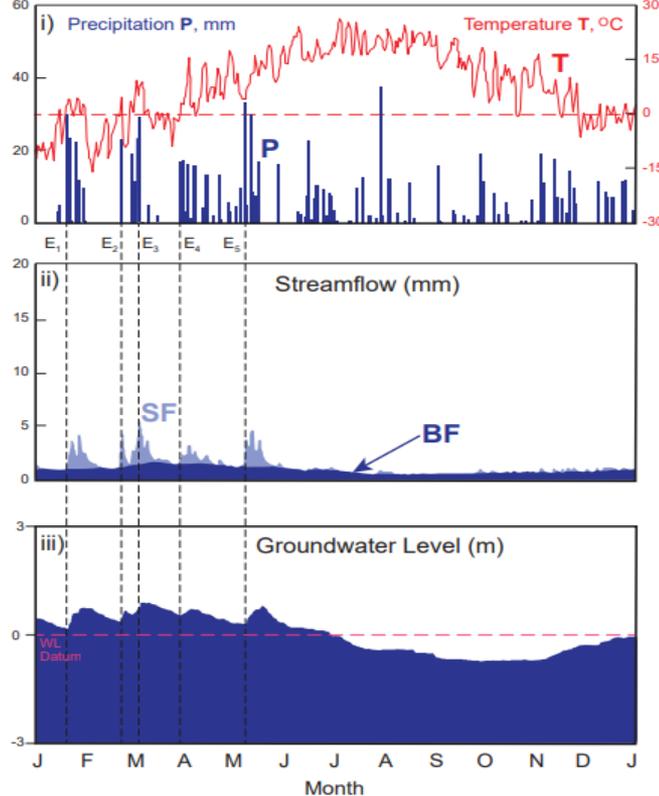
a) Terrain Setting



b) Hydrogeology with 3-D Block Model



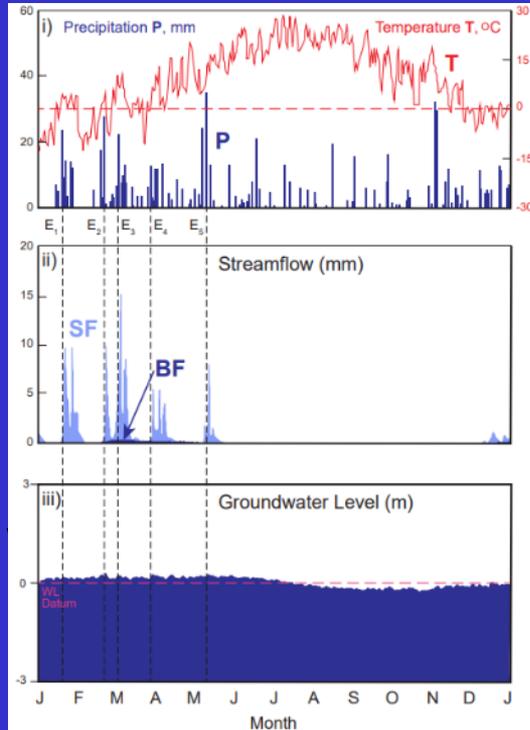
c) Hydrology



NORFOLK SAND BASIN

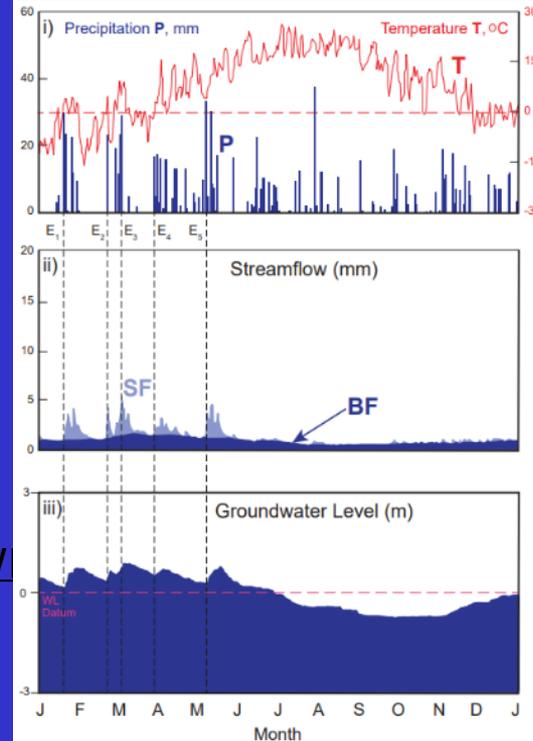
END-MEMBER HYDROLOGY

CLAY BASIN



Windsor

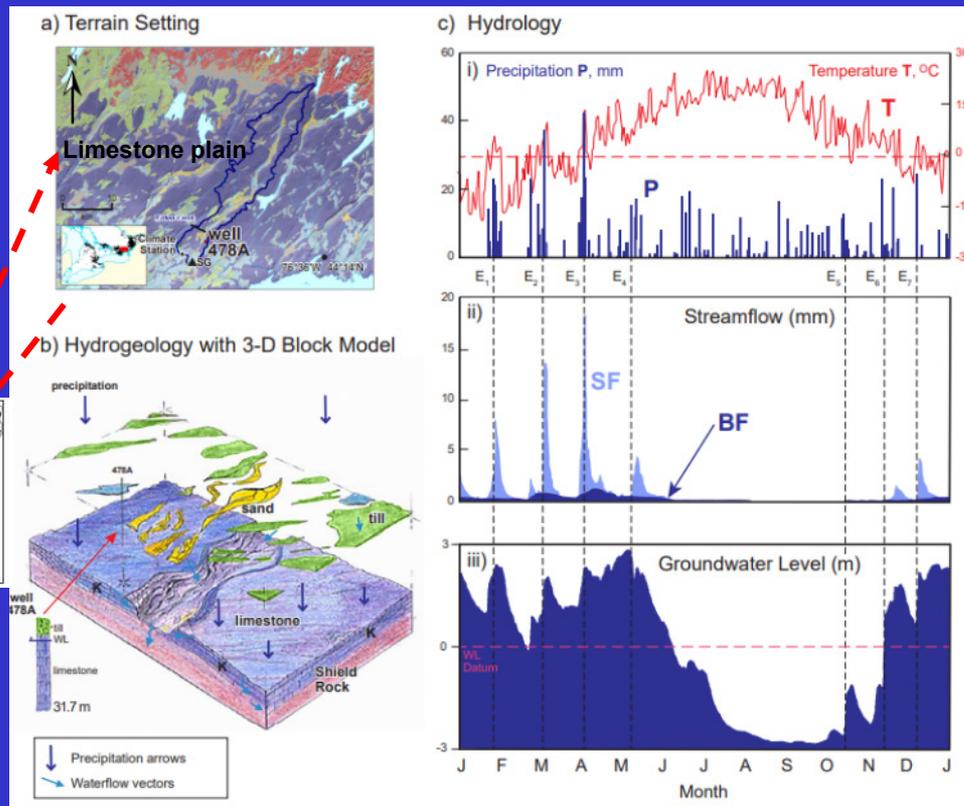
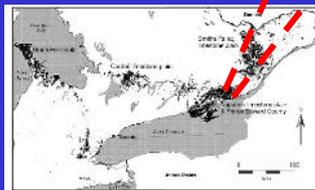
SAND BASIN



W

Norfolk

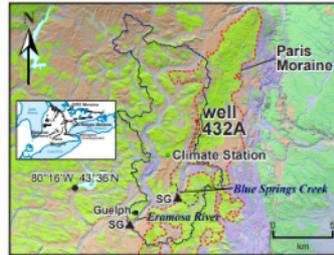
NAPANEE LIMESTONE KARST HYDROLOGY



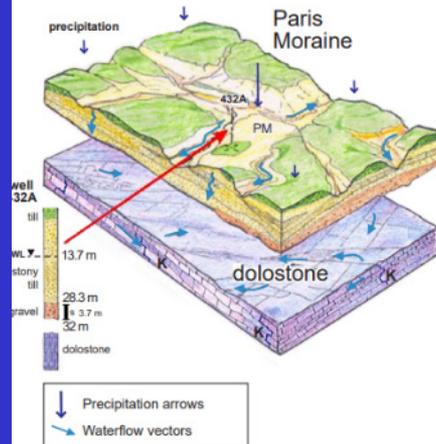
Karst & water-enhanced fractured rock system in 20 m bedrock valley

PARIS MORaine SETTING

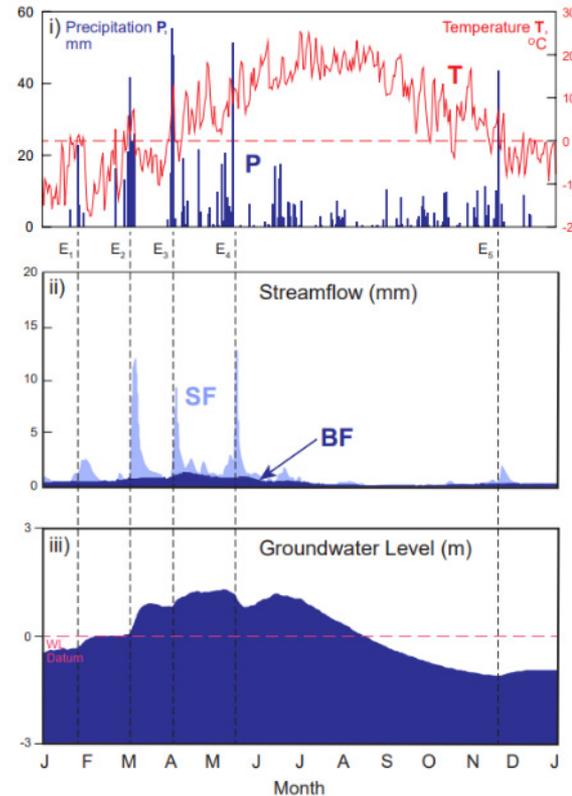
a) Terrain Setting



b) Hydrogeology with 3-D Block Model



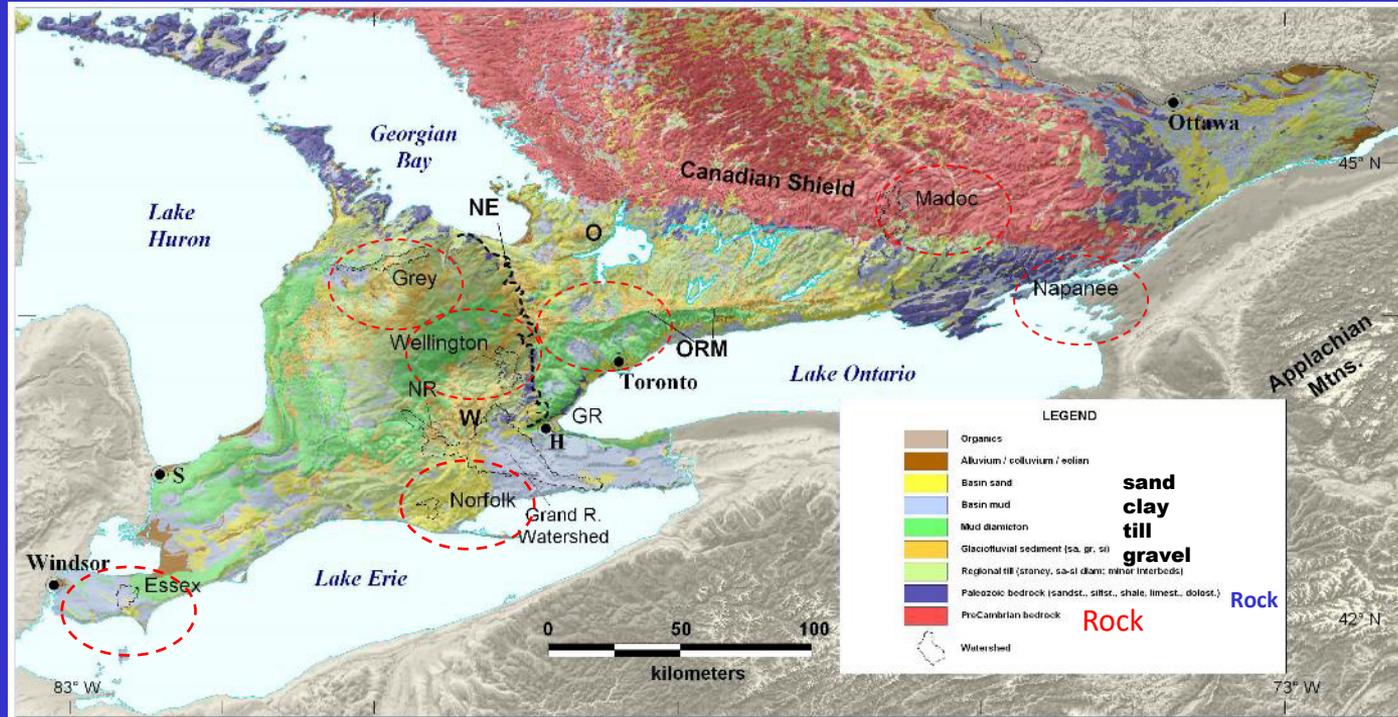
c) Hydrology



Added geological complexity

HG TERRAIN /ARCHETYPE SUMMARY

Surface geology



Selected terrains =90%; credible conceptual models SW-GW flow (ref)

-archetypes cost effective & provide HG knowledge to wide user base /accessible data

HG TERRAIN /ARCHETYPE Publication

Seven hydrogeological terrains characteristic of southern Ontario

D.R. Sharpe 

Geological Survey of Canada, 601 Booth St., Ottawa, ON K1A 0E8, Canada

Corresponding author: D.R. Sharpe (email: david.sharpe@canada.ca)

Abstract

Groundwater is an important component of the hydrological cycle of southern Ontario, significant to water supply and discharge to surface water. To improve overall understanding of key hydrological mechanisms, a proof-of-concept framework is presented that consists of seven typical terrains or hydrogeological settings. Geologic and topographic controls influence each setting as recorded by climate, streamflow, and groundwater level data, which trace how water moves through various parts of the southern Ontario landscape. This hydrogeological framework considers the geology of surface sediment and bedrock, permeability and porosity (inferred), physiography, and topographic gradients to define seven distinctive hydrogeological terrains. The data and watershed selection process allow for concentration on patterns of hydrologic response across the landscape, with less focus on hydrologic accounting of the terrain. The analysis identifies events in climate, stream, and well-monitoring data indicative of influxes and temporal patterns of hydrological and hydrogeological response to local geology and topography, thus differentiating styles of groundwater movement in sediment/bedrock landscapes of the Paleozoic basin and Shield margin. A case study is provided for each setting: five in sediment (clay, sand, gravel, till upland, and thick till); and two in bedrock (crystalline and carbonate). The selected hydrogeological terrains characterize ~90% of the landscape based on a simplified geological map of southern Ontario. The main hydrogeological characteristics and behaviour of these terrains are proposed as a set of conceptual models representative of near-surface groundwater regimes. Such models can inform water and land resource management as future climates change.

Key words: hydrogeology, southern Ontario, base flow, terrain geology, hydrological monitoring



Caractérisation des aquifères superficiels et évaluation des impacts potentiels liés aux activités pétrolières et gazières sur ces aquifères dans la région de Fox Creek (AB) – mise à jour de novembre 2022

Characterization of shallow aquifers and assessment of potential impacts of oil and gas development activities on these aquifers in the Fox Creek area (AB) - November 2022 update

Christine Rivard



ABSTRACT

A multidisciplinary and multi-institutional project was initiated in the **Fox Creek** area (west-central Alberta) in April 2019 to study environmental impacts of hydrocarbon development activities. **The initial objective** was to specifically **study potential impacts on shallow groundwater**. However, different Sectors within NRCan later identified the Fox Creek area as a region of interest for developing regional **cumulative effects evaluation methods** in support of new impact assessment legislation. As a result, the **scope is now much broader** and the project includes studies of **vegetation, forest, snow cover, wetlands**, and contributes to a **woodland caribou habitat** study. The project involves many collaborators from the federal and provincial governments, as well as from the academic community. This project is supported by the GGP and EGP programs.

Project members

(including EGP, GGP and cumulative effects)

C. Rivard¹, C. Paniconi², E. Konstantinovskaya³, G. Bordeleau², H. Crow¹, O. Haeri Ardakani¹, L.I. Guarin-Martinez^{2,1}, B.J. Meneses-Vega^{1,2}, D. Kononovs^{3,4,1}, D. Alessi³, D. Degenhardt⁴, B. Xu.⁵, P. Leblanc-Rochette^{6,1}, R. Lavoie⁶, D. Lavoie⁷, B. Smerdon^{3,8}, D. Palombi⁸, J. Lovitt⁹, W. Chen⁹, S. Heckbert⁸, H.M. Cole^{10,4,1}, A. McIntosh¹⁰, I. Aubin⁴

¹ *Geological Survey of Canada, Natural Resources Canada, Québec, QC; Ottawa, ON; Calgary, AB; and Victoria, BC;*

² *Institut national de la recherche scientifique – Eau Terre Environnement (INRS-ETE), Québec, QC*

³ *University of Alberta, Department of Earth and Atmospheric Sciences, Edmonton, AB*

⁴ *Canadian Forest Service, Natural Resources Canada, Edmonton, AB and Sault-Sainte-Marie, ON*

⁵ *Northern Alberta Institute of Technology (NAIT), Edmonton, AB*

⁶ *Université Laval, École supérieure d'aménagement du territoire et de développement régional, Québec, QC*

⁷ *Consultant, geologist, Quebec, QC*

⁸ *Alberta Energy Regulator and Alberta Geological Survey, Edmonton, AB*

⁹ *CCMEO, Natural Resources Canada, Ottawa, ON*

¹⁰ *University of Alberta, Department of Science, Augustana Campus, Camrose, AB*

≈22 people

4 MSc students

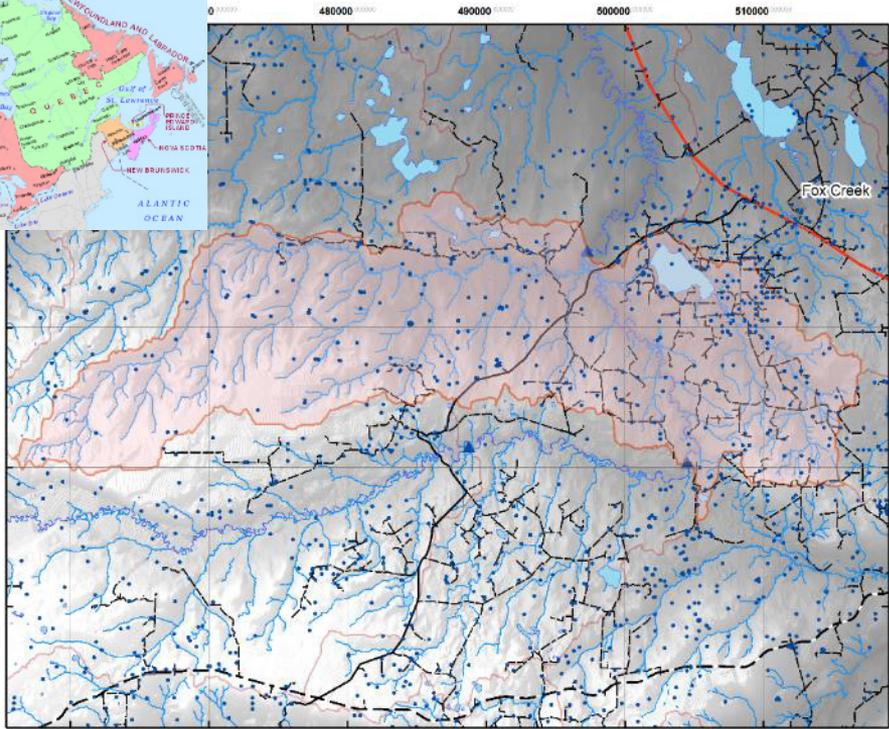
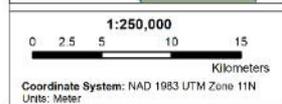
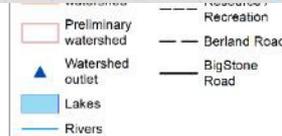
1 PhD student

Description of the study area

Alberta: one of the most active regions for O&G production in the last 50 years



Fox Creek



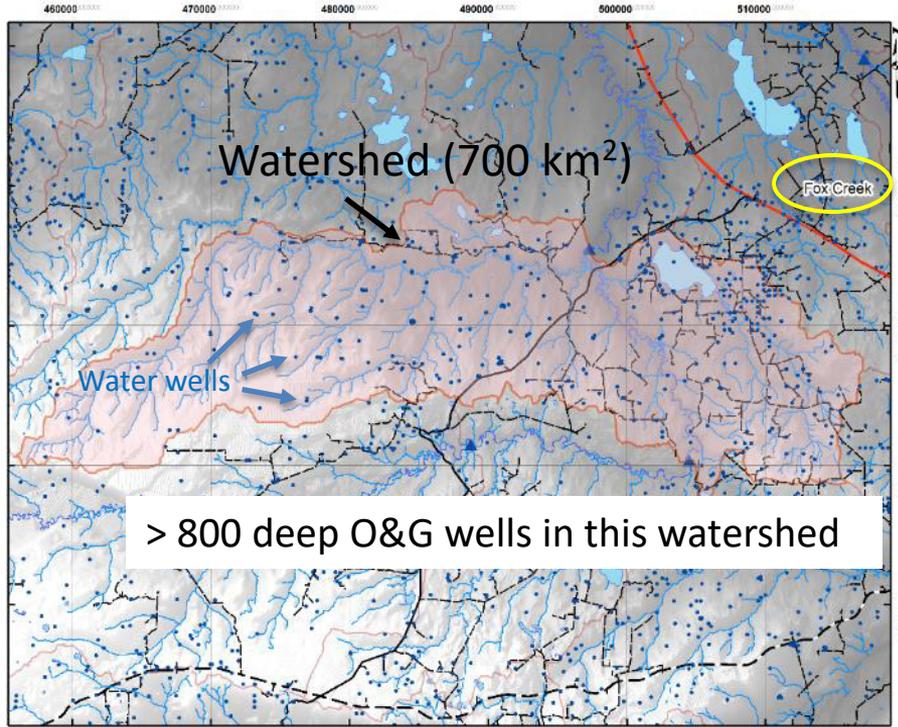
The study area is mainly
forested and unpopulated

Elevations range from
785 to 1180 m

The regional aquifer is located in
the **Paskapoo Fm.**: a complex
succession of interbedded
mudstone and siltstone with
sandstone channels

Description of the study area

Fox Creek, west-central Alberta: one of the most active regions for O&G production in the last 50 years



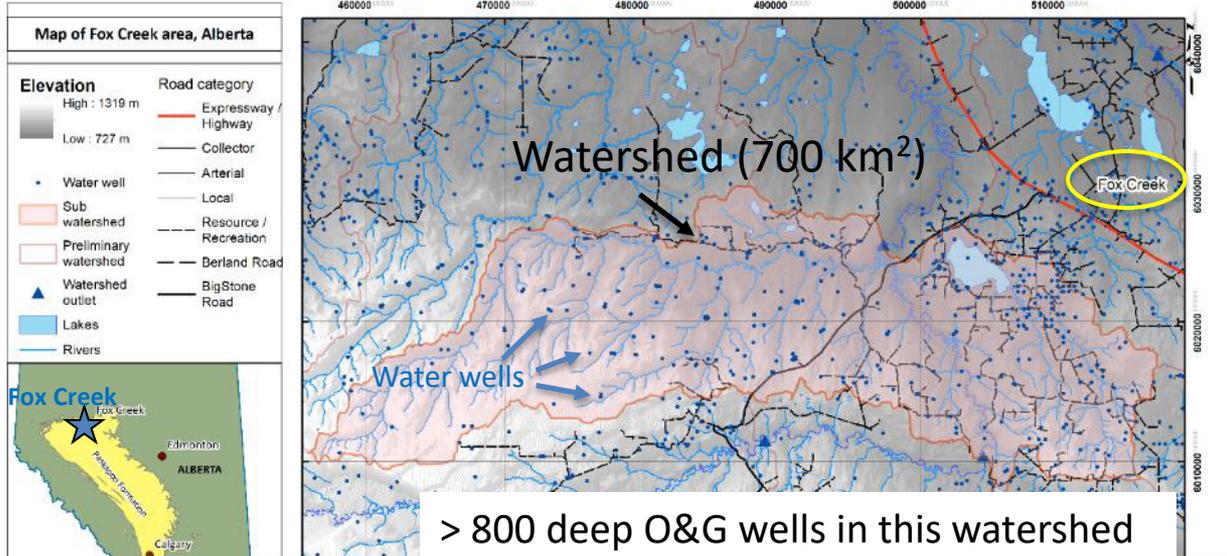
The study area is mainly **forested** and unpopulated

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Description of the study area

Fox Creek, west-central Alberta: one of the most active regions for O&G production in the last 50 years



The study area is mainly forested and unpopulated

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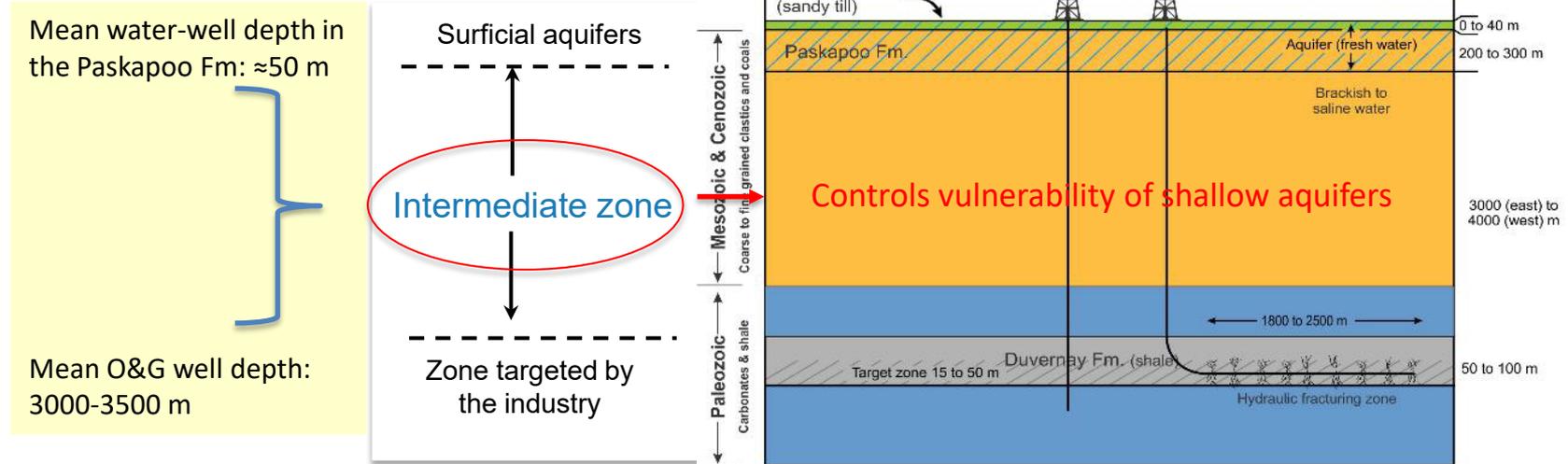
The regional aquifer is located in the Paskapoo Fm.: a complex succession of interbedded mudstone and siltstone with sandstone channels



Coordinate System
Units: Meter

Project objectives

- 1) Characterize the regional shallow aquifer (GGP)
- 2) Study the intermediate zone integrity (EGP)



- 3) Assess cumulative effects (CE initiative)

Fieldwork 2022

- 3 monitoring wells drilled in October:
 - Cores: 2 x 32 m and 1 x 100 m
 - Wells: 3 x 32 m
 - Groundwater sampling (to come: winter 2023)
 - Permeability (slug) tests (to come: winter 2023)



Coal



Gouge



Fossils in limestone

- Initial identification of vegetation on former well pads
- Collection of data or samples from lysimeters, soil moisture sensors, rain gauges, rain collectors and weather stations at 5 sites in undisturbed and disturbed areas
- Snow density and thickness

} monthly sampling



Results

(some are preliminary)

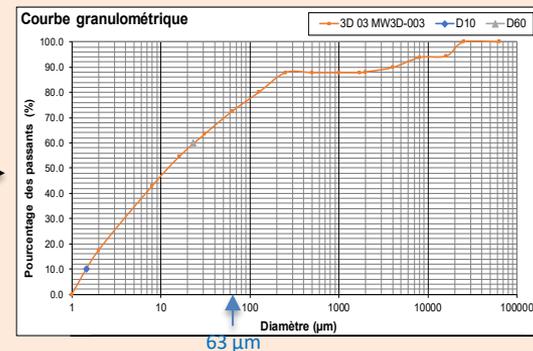
Interpretation of hydrogeological properties and flow

Hydraulic conductivity (K) values in surficial deposits:

Using Guelph permeameters at the monitoring well sites

Using grain-size analysis (70% of fine particles) and the Kozeny-Carman formula

$$3 \times 10^{-8} < K > 6 \times 10^{-7} \text{ m/s}$$



Recharge (assessed using various methods):

From literature, water budget and 2D and 3D modeling: 0-70 mm/y

Estimation of baseflow from a provincial gauging station (3000 km²): 80 mm/y



Borehole geophysical data:

- Fluid pathways → mainly along discontinuous fractures and, to a lesser extent, through the sandstone matrix.
- The poorly consolidated rock caused wall roughness, thus affecting geomechanical property estimates.

Geochemistry – Groundwater and surface water

Map of water types

For GW:
mostly NaHCO_3

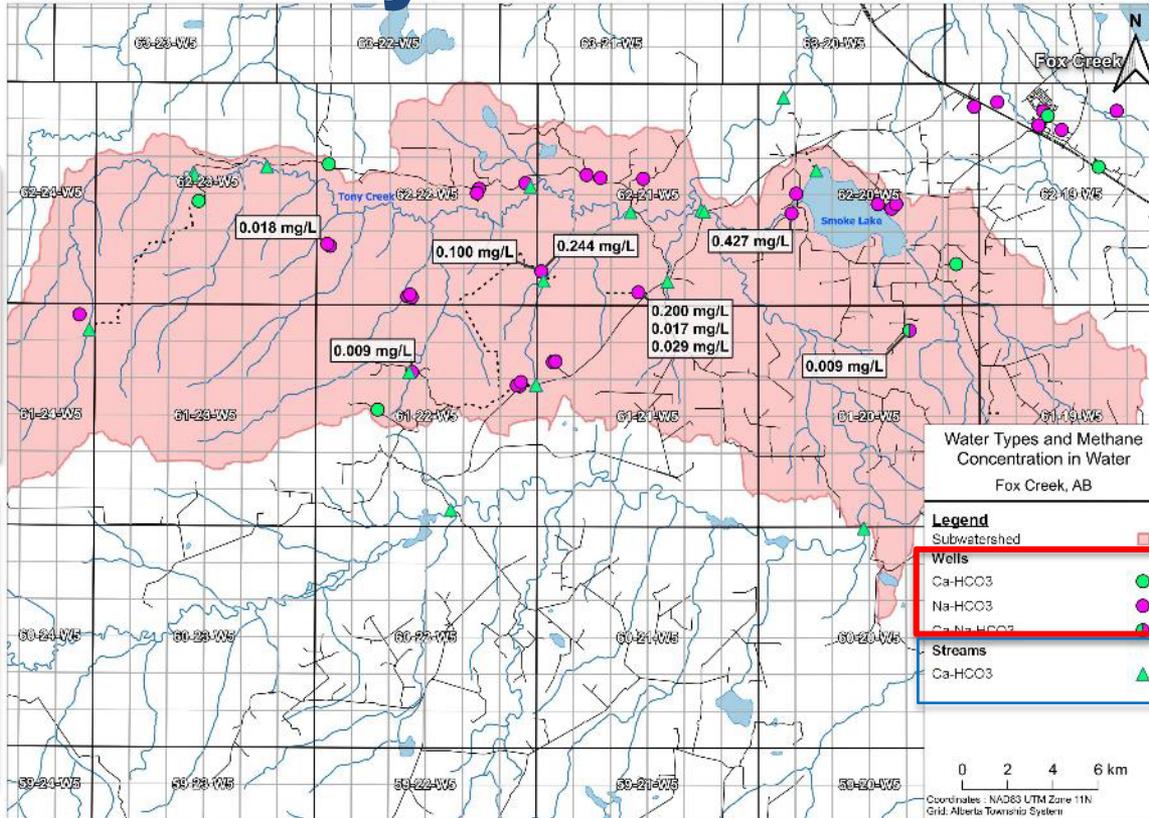


moderately
evolved

For SW:
 CaHCO_3



little evolved



Private wells (screened
in sandstone) and
monitoring wells
(screened in shale)



same water type

Well depth (m)	Mean SWL (m)	Mean Elev. (m)
0 - 30	10.5	936.7
0 - 50	20.3	913.7
50 - 100	33.5	857.6
100 - 150	67.3	827.7

Geochemistry – Groundwater and surface water

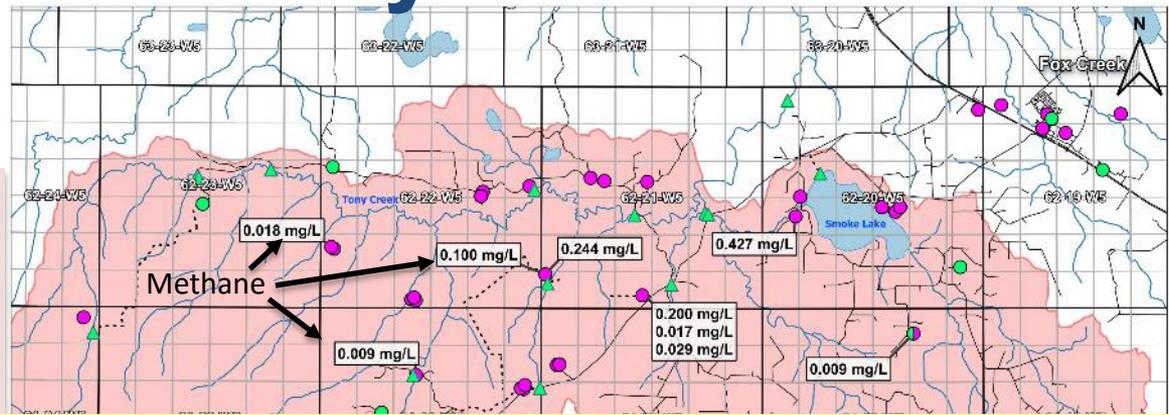
Map of water types

For GW:
mostly NaHCO_3

moderately evolved

For SW:
 CaHCO_3

little evolved



Private wells (screened in sandstone) and monitoring wells (screened in shale)

same water type

- 1) high yields are available
 - 2) vertical recharge is low
 - 3) some sandstone intervals are barely consolidated
 - 4) GW show large uncorrected radiocarbon age values (> 10,000 y)
- significant contribution of water likely comes from the Rocky Mountains

Depth (m)	Mean SWL (m)	Mean Elev. (m)
	10.5	936.7
	20.3	913.7
	33.5	857.6
	67.3	827.7

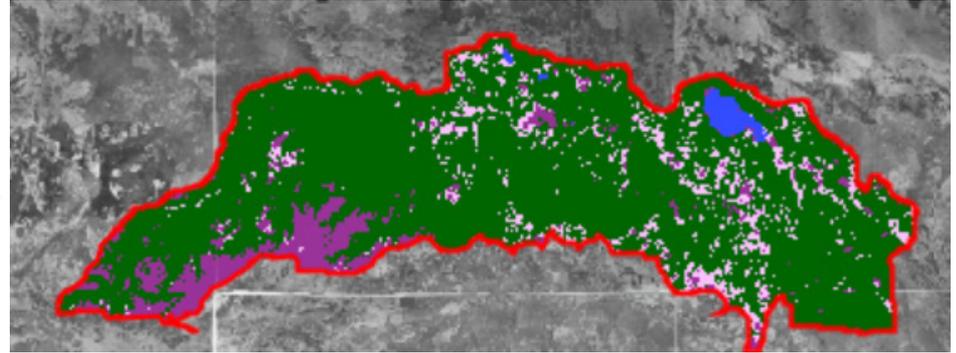
Only 7 wells contained small concentrations of dissolved methane. All of microbial origin.

Landscape change over time (~70 y)

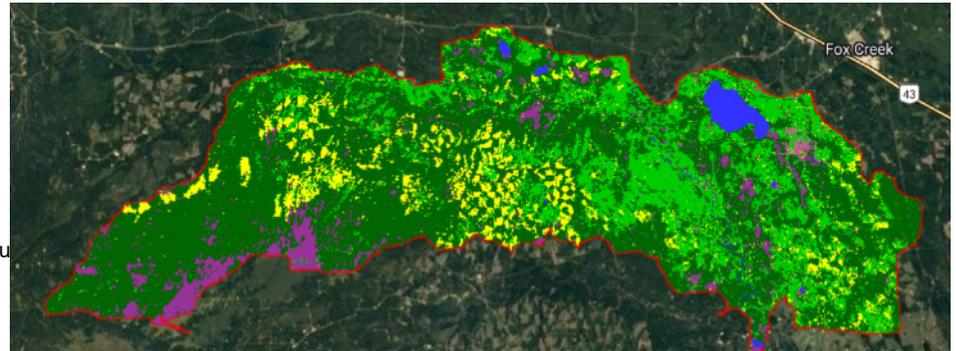
- Today, **broad leaf forest** occupies a much larger area, notably due to human activities and CC.
- The extent of **wetlands** and **bogs** has decreased
- The extent of **cutblocks** has increased (for roads, O&G well pads, seismic lines, and pipelines)

- Blue: open water
- Pink: wetland
- Purple: bogs
- Light green: broad leaf forest
- Dark green: coniferous forest
- Yellow: cutblocks

Pre-development: 1949 LULC map (from air photos)



2020 LULC map (using satellite imagery)



THANK YOU!



CONTACT INFORMATION

- Christine Rivard
- Work phone number: 418-654-3173
Christine.Rivard@nrca-nrcan.gc.ca



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Ring of Fire: Reconstructing long-term environmental records to support regional assessment

Nicolas Benoit - Nicolas.Benoit@NRCan-RNCan.gc.ca

Josué Jautzy - Josue.Jautzy@NRCan-RNCan.gc.ca

November 16th, 2022



Background

Previous works

2020 presentation (post-mining context: Chaudière-Appalache)

<https://www.youtube.com/watch?v=Di3G6FBplpg&list=PLdapv5BeduhXDE4XnjWz6EZjeOEA3DbA3&index=1&t=8s>



2021 presentation (post-mining context: Chaudière-Appalache)

<https://www.youtube.com/watch?v=QjJPd-plw4Y&list=PLdapv5BeduhX3m6Mkn167esKsiQRr6wH1&index=5>



2022 presentation (pre-mining context: Menarik lake)

<https://www.youtube.com/watch?v=QjJPd-plw4Y&list=PLdapv5BeduhX3m6Mkn167esKsiQRr6wH1&index=5>



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Project main objective

Improve knowledge on the evolution of the wetlands baseline conditions in response to climate and anthropogenic stresses and their effects on metal(loid)s mobility.

Why chromium?

- Gap knowledge about the fate of chromium species
- Total Cr in water: mix of Cr(III) and Cr(VI) concentrations
- Cr(III) essential for health, involved in various body processes
- Cr(VI) is highly toxic
- Cr species difficult to measure: affected by field, sampling and analytical conditions

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Activity objectives

- Propose efficient Cr speciation methodology for water sampling and analysis
- Define the Cr(III) and Cr(VI) species occurrence in post-mining context of chromite deposits (Reed-Bélanger and Montreal mines)

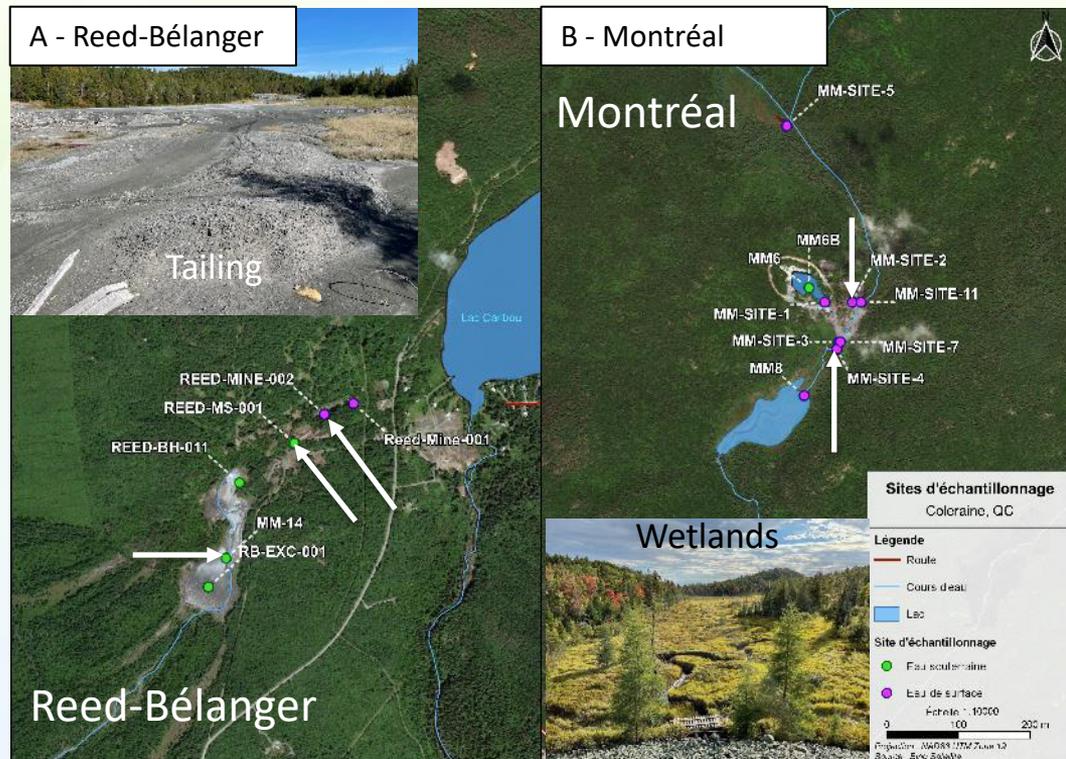
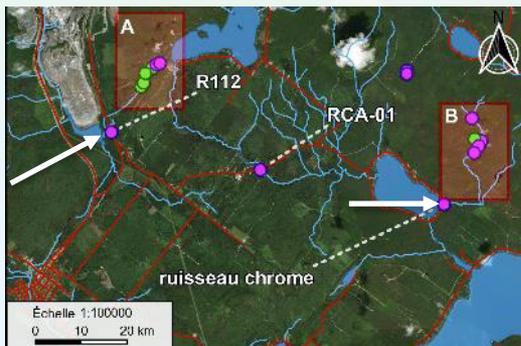
Activity Team

N. Benoit, J. Jautzy, P. Pelchat, P. Gammon, J. Marion, M. Parsons, V. Tremblay, A. Desbarats, J. Galloway



Study areas

- Ophiolitic complex of Thetford (ultramafic rock)
- Reed-Bélanger: vast tailing area
- Montréal mines: open pit and wetlands
- Surface water and GW sampling

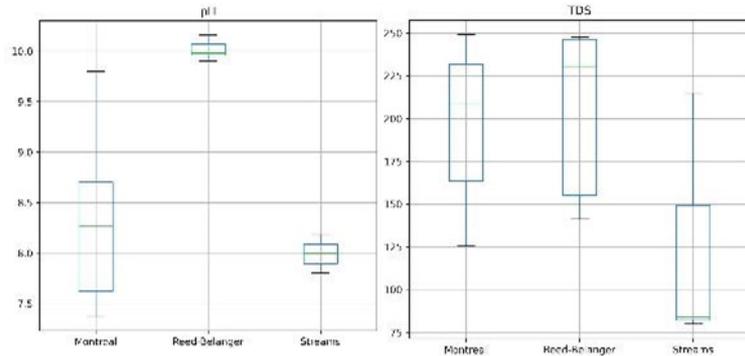


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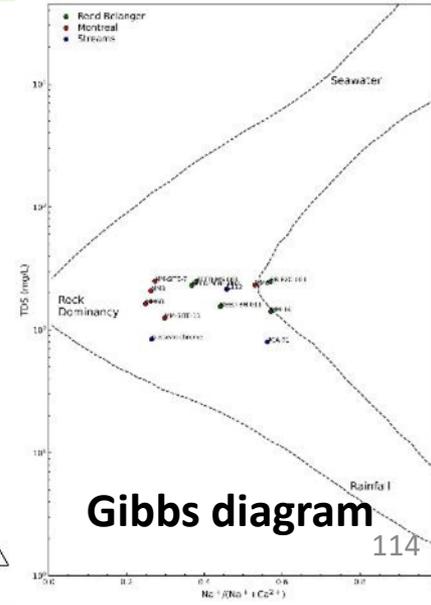
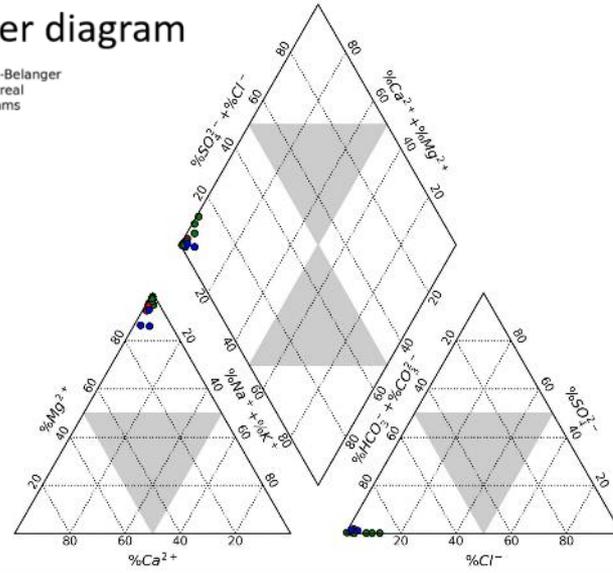
Major ions and more

- **pH:** mostly alkaline everywhere over the study area (7.4 to 10.3)
- **TDS:** moderately to hard water for streams and hard to very hard water for mines
- **Piper diagram:** absolute dominance of the Mg-HCO₃ water type (recent recharge and ultramafic rock interaction)
- **Gibbs diagram:** water-rock interactions (mines); more precipitation influence (streams)



Piper diagram

- Reed-Belanger
- Montreal
- Streams



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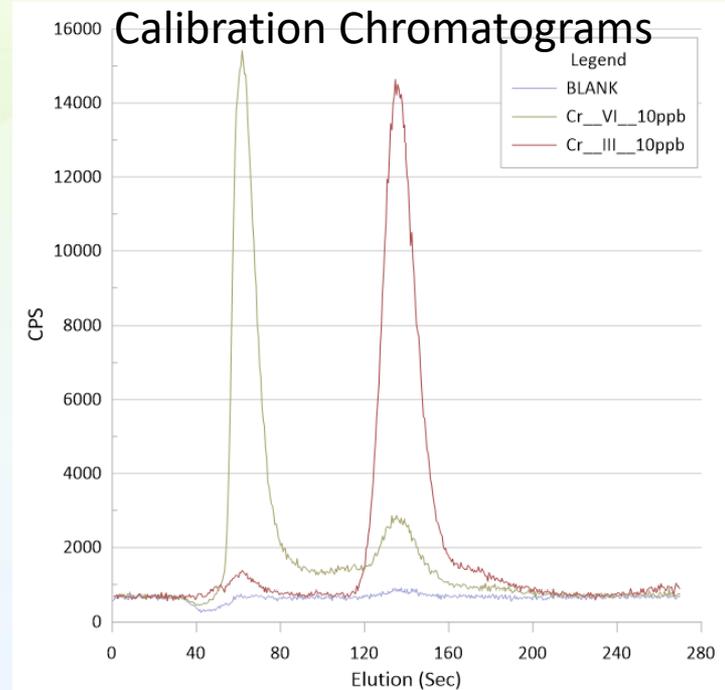


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Cr (III) and Cr(VI) determination

- Frontal Chromatography (FC) to isolate Cr(VI) from Cr(III)
- In theory: FC retains Cr(III) and let Cr(VI) through the cartridge
- $\text{Cr(III)} = \text{Total Cr} - \text{Cr(VI)}$
- Measured by ICP-MS: standards shows good separation between the two Cr species
- Samples analysed at Brooks Applied Labs for development validation



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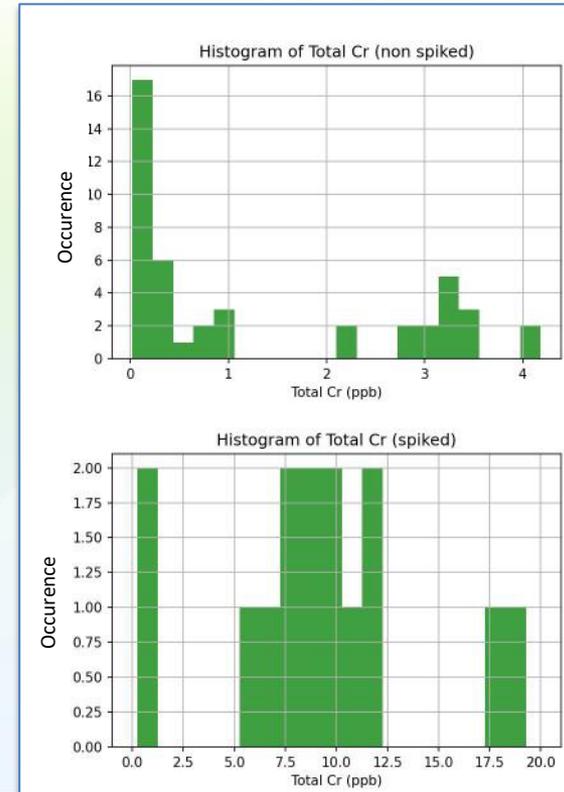
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Total Cr

- Total Cr : non-spiked and spiked (add 10 ppb)
- Spikes: measure species evolution
- Total Cr detection limit is 0.02 ppb
- Non-spiked max concentration 4.18 ppb
- Spiked: low concentration (mean 8.99 ppb)
- Recovery issues: expected spiked values ≥ 10 ppb



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Cr spikes recovery

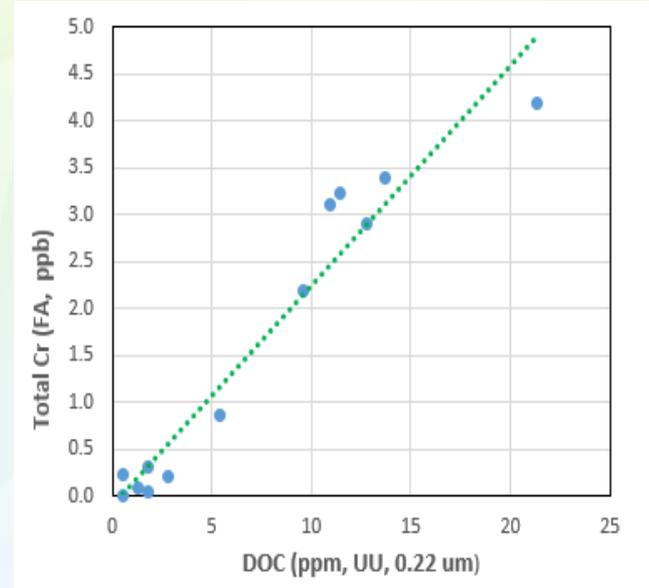
Site	Sample only	Sample +	Spike alone	10ppb Cr+3 Spike	Sample +	Spike alone	10ppb Cr+6 Spike	ph
	Sample only	10ppb Cr+3 spike	10ppb Cr+3 spike	%RECOVERY	10ppb Cr+6 spike	10ppb Cr+6 spike	%RECOVERY	
MM6	0.2	8.6	8.4	84	9.25	9.05	91	9.7
MM6B	0.82	100.47	99.64	996	10.29	9.46	95	8.7
MM7	3.14	11.59	8.46	85	12.2	9.06	91	7.9
MM12	0.04	7.88	7.84	78	7.31	7.27	73	9.9
MM13	0.29	6.3	6.02	60	9.64	9.36	94	10.1
MM14	0	5.92	5.92	59	9.95	9.95	100	10.1
RB15	0.07	18.74	18.67	187	18.02	17.95	180	9.9
RB16	0.31	0.26	-0.06	-1	0.24	-0.07	-1	10

- Issues - MM6B: Cr+3 spiked at 100ppb instead of 10; RB15: spiked twice; RB16: not spiked
- Good recoveries for Cr(VI) >90%; a little less good for Cr(III)
- High pH favoring Cr(VI) stability and getting Cr+3 unstable (Spanu et al., 2021)
- Possible co-precipitation of Cr(III) oxides/hydroxides and accumulation bottle inner wall (low recoveries)?
- 2022 sampling: spike before FC to test the efficiency of the frontal chromatography



Organic matter effect

- Linear correlation Total Cr and DOC
- For high DOC (12 ppm), FC show a false positive, possible Cr(III)-Organic enrichment?
- Some forms of Cr(III) can combine with organic matter and behave as an anion, pass through the cartridge and give false positives for Cr(VI)
- Similar results for FC and FC-Cr(VI) spiked for DOC<2ppm
- 2022 sampling: make new experiment better understand organic matter effect



2022 sampling and analysis

- Field campaign last September: adapted the field methodology to resolve 2021 issues (spike before FC)
- Spikes concentrations reduced (10 to 2 or 5 ppb): more representative
- Faster shipping and analysis to reduce interspecies conversion impact
- New in-house experiments and inter-laboratory comparison continue
- Sample isotopes (^2H , ^{18}O , $^{13}\Delta\text{C}_{\text{dic}}$, ^{14}C) : to better understand water origin and ultimately the mobility of the chromium



CONTACT INFORMATION

Project co-leaders:

- Nicolas.Benoit@NRCan-RNCan.gc.ca
- Josue.Jautzy@NRCan-RNCan.gc.ca

Thank you / Merci!



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Steve Shikaze	14:40	Steve Shikaze	250 views	1 year ago
Background: Under-performing septic systems	4:05	Archana Tamang	179 views	8 months ago
Archetypal Aquifer Project Consolidating 25 years of GSC groundwater work Groundwater Geoscience Program 2019-2024 Hazen A.J. Russell Managerial Services of Canada (Government of Canada)	9:58	Hazen A.J. Russell	145 views	2 years ago
Model Performance - Long Point	13:03	SK Frey	130 views	1 year ago
Canada 1 Water Team	11:52	Hazen Russell	117 views	8 months ago

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Thank you ! Merci !

For additional information about the GGP, please contact //
Pour plus de détails sur le PGES, veuillez contacter :

Eric Boisvert (Program Manager) eric.boisvert@nrcan-rncan.gc.ca OR/OU
Joby Aubut Bernard (Program Planning & Coordination) joby.aubutbernard@nrcan-rncan.gc.ca
Réjean Couture (Division Director): rejean.couture@canada.ca

