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Regional-Scale Groundwater Geoscience in Southern Ontario: The 2022 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House

2022

ONTARIO GEOLOGICAL SURVEY

Open File Report 6379

Regional-Scale Groundwater Geoscience in Southern Ontario: The 2022 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House

Compiled by

A.K. Burt, D. Ford, S. Holysh, K.J.J. Kalmo and H.A.J. Russell

2022

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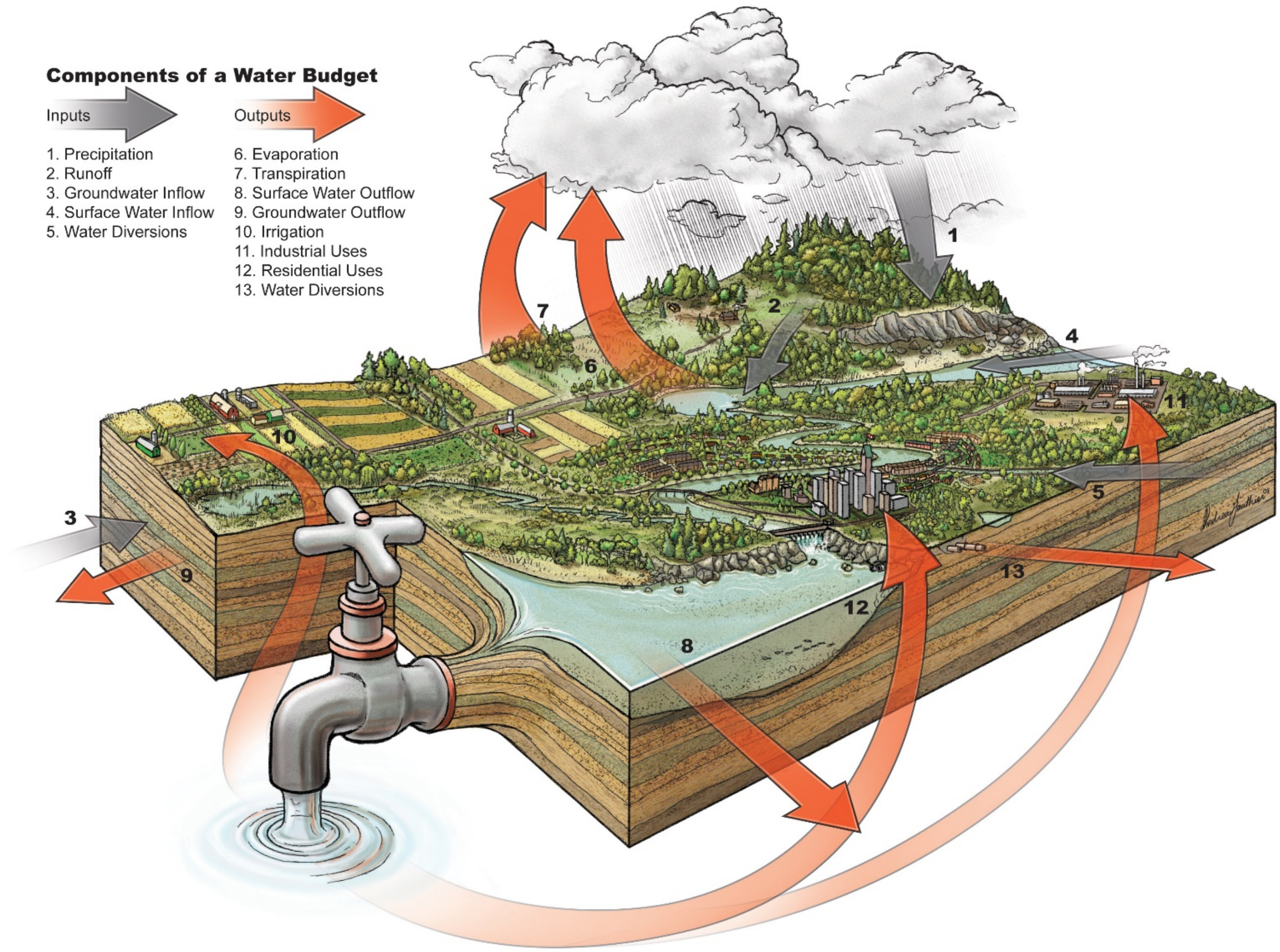
Regional-Scale Groundwater Geoscience in Southern Ontario: The 2022 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House

February 15 and 17, 2022 | Virtual Meeting



Compiled by

Abigail K. Burt	Ontario Geological Survey
Don Ford	Toronto and Region Conservation Authority
Steve Holysh	Oak Ridges Moraine Groundwater Program
Kayla J.J. Kalmo	Ontario Geological Survey
Hazen A.J. Russell	Geological Survey of Canada

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Program

February 15 Presentations

START	END	TITLE	PRESENTER	AFFILIATION	SESSION
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1:30	1:45	Highlights of Update Report of Groundwater Science Relevant to Great Lakes Water Quality	Mohamed	Environment Canada	
1:45	2:00	Canada 1 Water: A Collaborative Approach to an Integrated Groundwater–Surface Water Modelling Framework for Climate Change Adaption	Russell	GSC	
2:00	2:15	Ministry of the Environment, Conservation and Parks – Groundwater Activities Update	Zhang	MECP	
2:15	2:30	Groundwater Discharge to Lake Ontario – A Preliminary Assessment	Marchildon	ORMGP	Groundwater and Surface Water Modelling
2:30	2:35	Monthly Trends and Climate Predictors of Baseflow Across Canada	Murray	University of Waterloo	
2:35	2:55	Break			
2:55	3:10	Groundwater and Surface Water Forecast Evaluation in Two Contrasting Hydrostratigraphic Settings within Southern Ontario	Frey	Aquanty	
3:10	3:15	Assessing Source Water Contributions to Streamflow in a Precambrian Shield Watershed in the Sudbury Region: The Whitson River Watershed	Montgomery	Nipissing University	
3:15	3:20	Identifying Significant Groundwater Recharge Areas and Modelling of Surface–Subsurface Water Balance of the Neebing River	Vehling	Lakehead University	
3:20	3:40	Evidence for Upward Migration of Deep Fluids to Shallow Aquifers on the North Shore of Lake Erie and Pelee Island	Hamilton	OGS	Aqueous Geochemistry, Isotopes and Contaminants
3:40	3:45	Impact of Seasonality on Nutrient Transport Pathways Under Temperate Climate Conditions in an Agriculturally Intense Great Lakes Clay Plain Basin	May / Rixon	University of Guelph	
3:45	4:00	Estimating Groundwater Age in the Subcropping Bedrock Aquifers of Southern Ontario with Tritium	Priebe	OGS	
4:00	4:15	Road Salt Infiltration as Recorded in Provincial Groundwater Monitoring Wells Within the Toronto and Region Conservation Authority	Anderson	TRCA	
4:15	4:20	Groundwater as a Source and Pathway for Road Salt Contamination of Surface Water and Aquatic Ecosystems in the Great Lakes Basin	Mackie / Lackey	University of Guelph	
4:20	4:25	Approaches for Evaluating Septic System Effluent Inputs to Tributaries and Distinguishing Contributing Pathways	Tamang	University of Western Ontario	
4:25	4:30	Estimating the Number of Industrial Facilities Acting as PFAS Point Sources Based upon their Current and Past Activities	Roberts	Royal Military College	
4:30	4:35	Closing Remarks			

Program (continued)

February 17 Presentations

START	END	TITLE	PRESENTER	AFFILIATION	SESSION
1:00	1:10	Opening Remarks	Gavine	CO	Paleozoic and Surficial Geology Modelling, Characterization and Applications
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1:25	1:40	Using Computed Tomography to Unravel the Depositional History of a Late Quaternary Glacigenic Succession, Ottawa, Ontario	Al-Mufti	GSC	
1:40	1:55	Using Ontario Geological Survey's Aggregate Resource Data in Groundwater Applications	Handley	OGS	
1:55	2:00	Understanding the Hydrogeologic Characteristics of a Buried Bedrock Valley Through its Geologic History	Brown	University of Guelph	
2:00	2:15	A 3-D Bedrock Hydrostratigraphic Model of Southern Ontario	Carter	Carter Geologic / GSC	
2:15	2:30	A Semi-Quantitative Representation of Uncertainty for the 3-D Paleozoic Bedrock Model of Southern Ontario	Bunn	GSC	
2:30	2:35	3-D Printing for Geologists and Subsurface Explorers – Turning the Abstract into Reality	Clark	OGSRL	
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2:55	3:10	Geologic Controls on Porosity and Permeability in the Silurian Lockport Group to A-1 Carbonate, Southwestern Ontario	Sun	OGS	
3:10	3:25	Comparing Porosity Development Using Medical CT Scanning in Two Paleokarst Horizons in Silurian Carbonates, Southern Ontario	Larmagnat	GSC	
3:25	3:30	Visualizing and Interacting with 3-D Geology Data in Virtual Reality	Clark	OGSRL	
3:30	3:45	Changes in Southern Ontario Water Storage from the GRACE Gravity Satellite Mission	Crowley	GSC	Geophysics, Remote Sensing, Methods and Techniques
3:45	4:00	Advances in Borehole Porosity Investigations Using NMR Logs in Fractured Sedimentary Rock, Ontario, Canada	Crow	GSC	
4:00	4:15	Can a Passive Seismic Survey Delineate an Esker Aquifer in Lacustrine–Marine Sediments?	Dietiker	GSC	
4:15	4:30	GeologyOntario and OGSEarth Demonstration	Evers / Dodge	OGS	
4:30	**4:45**	**Wrap-up and Thank you**			

Context

The 2022 Ontario Geological Survey (OGS), Geological Survey of Canada (GSC) and Conservation Ontario (CO) groundwater open house represents the 7th annual event. Previous open houses focussed on sharing the results of a collaborative OGS and GSC groundwater mapping and research program that ended in 2019. The annual open house was a key deliverable of this collaboration, and an important opportunity to keep the groundwater community apprised of new mapping, research and publications.

The annual groundwater geoscience open house has been extremely well received by clients, with attendee numbers increasing annually, from 95 in 2016 to 289 in 2020. Because of the COVID-19 pandemic, the 2021 event was delivered virtually as 2 half-day sessions via the Zoom Video Webinars platform (Zoom Video Communications Inc.). The virtual format allowed a wider audience to access the event. A total of 587 people registered for the event, and we saw 400 attendees in sessions on Tuesday, February 16, and 330 attendees in sessions on Thursday, February 18, with an average viewing time of 110 minutes. Registrants from the United Kingdom, Peru, Netherlands and the United States equaled approximately 1%. Attendance was made up of stakeholders and clients from the consulting industry (41%), provincial and federal governments (23%), academic institutions (17%), municipalities (6%), Conservation Authorities (6%), non-governmental organizations (1%), and a remaining 7% who remained anonymous. Survey results indicate that attendees missed the opportunity for networking, discussion and collaboration that an in-person event offers; however, the overall satisfaction rate was still high.

The enduring popularity of the geoscience open house has prompted a second event in virtual space. New for 2022 are a series of shorter “lightning” talks designed to allow students from Ontario universities and colleges to present their exciting research projects. We hope that you will enjoy both the presentations and the opportunity to meet up and coming groundwater professionals.

The program offers presentations on a wide variety of topics grouped into themes. Day 1 opens with groundwater programs and policies, with speakers from the United States Geological Survey, Environment Canada, the GSC and the Ontario Ministry of the Environment, Conservation and Parks and offers the opportunity to learn about jurisdictional differences in approaching groundwater monitoring and management. Presenters from the Oak Ridges Moraine Groundwater Program, Consultants and Universities will address advancements in groundwater–surface water modelling. The day will wrap up with an exciting session on aqueous geochemistry, isotopes and contaminants from experts at the OGS, Conservation Authorities and academia. Day 2 focusses on Paleozoic and surficial geology modelling, characterization and applications. Our speakers represent the OGS, the GSC, the Ontario Oil Gas and Salt Resources Library, consultants and academia. The final session on geophysics, remote sensing, methods and techniques draws on experts from the GSC and the OGS.

We trust that the 2022 open house will remain a valuable forum for sharing groundwater information and networking with peers in southern Ontario and beyond. Contact information for speakers is provided in this compilation to support future connections.

Associated publications of previous gap analysis, workshop(s) and open houses between 2015 and 2022.

2015

Russell, H.A.J., Priebe, E.H. and Parker, J.R. 2015. Workshop summary and gap analysis report: Unifying groundwater science in southern Ontario; Ontario Geological Survey, Open File Report 6310, 64p. www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=OFR6310

Russell, H.A.J. compiler. 2015. Workshop on Groundwater Data Framework and Hydrogeology Model, Southern Ontario; Geological Survey of Canada. (no formal publication, *see* **Groundwater Information Network**)

2016

Russell, H.A.J. and Priebe, E.H. compilers. 2016. Regional-scale groundwater geoscience in southern Ontario: An Ontario Geological Survey and Geological Survey of Canada Groundwater Geoscience Open House; Geological Survey of Canada, Open File 8022, 34p. doi.org/10.4095/297722

2017

Russell, H.A.J., Ford, D. and Priebe, E.H. compilers. 2017. Regional-scale groundwater geoscience in southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House; Geological Survey of Canada, Open File 8212, 56p. doi.org/10.4095/299750

2018

Russell, H.A.J., Ford, D., Priebe, E.H. and Holysh, S. compilers. 2018. Regional-scale groundwater geoscience in southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House; Geological Survey of Canada, Open File 8363, 62p. doi.org/10.4095/306472

2019

Russell, H.A.J., Ford, D., Holysh, S. and Priebe, E.H. compilers. 2019. Regional-scale groundwater geoscience in southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House; Ontario Geological Survey, Open File Report 6349 / Geological Survey of Canada, Open File 8528 (doi.org/10.4095/313529), 32p. www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=OFR6349

2020

Priebe, E.H., Ford, D., Holysh, S., Russell, H.A.J. and Nadeau, J.E. compilers. 2020. Regional-scale groundwater geoscience in southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House; Ontario Geological Survey, Open File Report 6361, 46p. www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=OFR6361

2021

Priebe, E.H., Ford, D., Holysh, S., Nadeau, J.E. and Russell, H.A.J. compilers. 2022. Regional-scale groundwater geoscience in southern Ontario: The 2021 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House; Ontario Geological Survey, Open File Report 6378, 24p. www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=OFR6378

2022

Burt, A.K., Ford, D., Holysh, S., Kalmo, K.J.J. and Russell, H.A.J. compilers. 2022. Regional-scale groundwater geoscience in southern Ontario: The 2022 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House; Ontario Geological Survey, Open File Report 6379, 38p. www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=OFR6379

Presentations from previous years can be found on the Groundwater Information Network (GIN) (http://gin.gw-info.net/service/api_ngwds:gin2/en/gin.html, under “News”). Presentations from 2021 are available on the GSC Groundwater Geoscience Program YouTube channel under Playlists (www.youtube.com/channel/UCHIc7ff3vEdIl708VhgsLsg/playlists). Some presentations may be missing and, in those cases, permission was not granted by the respective organization of the author(s).

Contents

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Using Computed Tomography to Unravel the Depositional History of a Late Quaternary Glacigenic Succession, Ottawa, Ontario

Al-Mufti, Omar N.[1]; R. William C. Arnott[1], Marc J. Hinton[2], Sam Alpay[2], and Hazen A.J. Russell[2]

[1] Department of Earth and Environmental Sciences, University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5

[2] Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8

Late Quaternary glacigenic deposits of the Champlain Sea basin are of great societal interest because of their susceptibility to retrogressive landslides and their integrity as an aquitard in the hydrogeologic system of Ottawa. In the Ottawa and St. Lawrence River valleys, surficial and shallow subsurface deposits consist mostly of fine-grained sediment. Although these deposits are regionally-extensive, their fine grain size and unlithified condition makes them challenging to study in core and in outcrop. In this study, we show how medical-grade computed tomography (CT) can be used to accurately resolve sedimentary structures, textures, and bedding contacts – requisite features for reconstructing the deglaciation and depositional history of sedimentary successions. In east Ottawa, CT-scans and Hounsfield Unit (HU) profiles of two continuous drill cores were used to identify lithologically distinct, mud-dominated stratal units. Beds in all units show a rhythmic pattern of increase followed by decrease in HU, which reflects a waxing (increasing) followed by waning (decreasing) period of glacigenic meltwater discharge. In the lowermost unit (Unit 1), beds consist of parallel-stratified silt overlain gradationally by finer sediment showing a reduction of ~250–350 HU. The silt-rich part of each bed was deposited by meltwater hyperpycnal flows that because of the freshwater composition of the basin fluid, were able to plunge to the bed and effectively sort and segregate particles along the bed surface, followed by suspension fallout. In comparison, the narrower range of ~50–120 HU that characterizes beds of bioturbated mud (Unit 2), banded mud (Unit 3), and diffusely stratified or structureless mud (Unit 4), indicates poorer particle segregation. These differences in bed characteristics and narrower range in HU indicates a change to a saltwater basin fluid that caused meltwater inflows to instead form buoyant hypopycnal plumes. Sediment settling from the plume formed dilute, low-energy density currents that less efficiently sorted bed-surface sediment. Notably also, within each sharply bounded unit, beds vary little in their thickness, contain a distinctive assemblage of sedimentary structures and textures, and are characterized by consistent bed-scale HU values. This suggests that each unit represents a unique suite of depositional processes related to sediment supply and basin fluid conditions, and that significantly, changes in these conditions were abrupt, necessitating sudden rather than progressive changes in basin dynamics. Future work will use micro-textural analyses (<0.1 mm resolution) to determine grain composition, texture, and fabric of these fine-grained sediments in order to assess the nature of pore-fluid diffusion and the physical influence of these sediments on geotechnical properties.

Road Salt Infiltration as Recorded in Provincial Groundwater Monitoring Wells Within the Toronto and Region Conservation Authority

Anderson, Kristina E.

Toronto and Region Conservation Authority, 101 Exchange Avenue, Vaughan, ON L4K 5R6

Health Canada's drinking water guidelines list the recommended limits for sodium at 200 mg/L and chloride at 250 mg/L. Both criteria were published in 1979 and, for chloride, reaffirmed in 2005. The basis for these criteria was aesthetic (taste) and, in the case of chloride, potential for corrosion. Where a sodium-based water softener is used, a separate unsoftened supply for cooking and drinking purposes is recommended (Health Canada 2020). To comply with these guidelines, additional water quality monitoring may be advisable as the public health consequences and ecological impact of de-icing salt application become better understood. Excessive intake of sodium may lead to hypertension, which is a major risk factor for heart disease and stroke (WHO 1996). Persons on a low-sodium diet are recommended to consume water with <20 mg Na/L, which may require distillation and reverse osmosis treatment (Jackson and Avis 2021).

The molar ratio *m*Na/*m*Cl can be used to understand how cation exchange modifies saline snowmelt pulses within aquifers across the Greater Toronto Area. When sodium is measured with chloride, its retardation by cation exchange delays its appearance in water supply aquifers. Molecular ratios around 0.6 indicate sodium retardation; whereas molecular ratios approaching 1.0 indicate end state of groundwater annually recharging saline snowmelt. Once the end state occurs, higher sodium concentrations are likely to be measured. All subbasins within the Toronto and Region Conservation Authority (TRCA) show some impact of road-salt infiltration and continued cation exchange.

The Mimico and Etobicoke watersheds have particularly high chloride levels and low molecular ratios. Bedrock geology and overburden thickness could also be contributing some chloride to surface and ground waters in these watersheds. The bedrock within these watersheds consists of Georgian Bay and Queenston Shale formations which can have chloride concentrations approaching saline (as high as 30,000 mg/L). Consideration should be given to looking at chlorine isotope fractions within these two subbasins to determine if chloride is a result of natural or anthropogenic functions.

We used groundwater quality data collected through TRCA's Hydrogeology Group for the analysis. The Hydrogeology Group currently monitors groundwater quality monthly at 44 stations across the jurisdiction and 21 of these stations are monitored in partnership with the Provincial Groundwater Monitoring Network (PGMN) administered by the Ministry of the Environment Conservation and Parks (MECP). Data from 2003–2021 were used for the assessment.

Reference

Jackson, R.E. and Avis, J.D. 2021. Road-salt infiltration and the evolution of *m*Na/*m*Cl as recorded in monitoring and municipal wells; abstract *in* Canadian Geotechnical Society–International Association of Hydrogeologists (Canadian National Chapter) (CGS–IAH-CNC), GeoNiagara 2021, September 26–29, 2021, abstract 178_AbstractFile_0126035711.

A National-Extent Hydrogeological Framework for the United States: First Steps

Belitz, Kenneth

Earth Systems Processes Division, Water Mission Area, United States Geological Survey

The United States Geological Survey (USGS) Integrated Water Availability Assessments (IWAAs) Program is designed to deliver nationally consistent assessments of water supplies for human and ecological needs, and to identify factors that influence water availability. The IWAAs studies are being conducted at regional and national scales. In support of these studies, a National-Extent Hydrogeologic Framework (NEHF) is under development.

The NEHF will provide a nationally consistent and flexible approach for characterizing groundwater resources in three dimensions and at multiple scales. The NEHF will 1) identify and organize existing relevant data, tools, and approaches (catalog); 2) develop a strategy for implementation of a three-dimensional national extent hydrogeologic framework (strategic plan), and 3) demonstrate the applicability of the proposed strategy by developing three-dimensional hydrogeologic frameworks at national and regional scales.

A wide range of existing data and tools are relevant to the development of the NEHF. Relevant types of data can include lithologic, structural, stratigraphic, mineralogic, geochemical, and hydraulic properties. Relevant tools can include general purpose geographic information systems and special-purpose three-dimensional visualization and data-manipulation software. The cataloging of data and tools is currently underway and is expected to take about one year. The development of a strategic plan is also underway and is also expected to take about one year. The strategic plan will account for existing information, identify gaps in that information, and propose approaches for addressing those gaps.

The spatial resolution (lateral and vertical) of the NEHF is intended to be flexible. The framework needed for predicting groundwater contributions to streams (both quantity and quality) needs to focus on shallow depths and account for properties near the water table and in proximity to streams. The framework associated with the human use of groundwater needs to: identify the depth zones tapped by wells for various purposes; account for regional properties relevant to extraction of groundwater by wells; and account for regional properties that affect the suitability of groundwater (water quality) for the intended purpose. The framework related to the potential development of, or impacts from, brackish/saline water needs to focus on deeper groundwater, generally below the depth of most existing water wells. The spatial resolution required would likely be highest for the first example and lowest for the third. The strategic plan will address issues related to spatial resolution.

Upon completion of the catalog and strategic plan, a three-dimensional hydrogeologic framework will be developed. It is anticipated that a broad-brush approach will be implemented at a national-scale and that a comprehensive, detailed approach will be applied in selected regions. It is anticipated that the NEHF will be a "living model" and that approaches and methods developed for assimilating data into selected regions will be useful for future efforts. The NEHF will also include links to sources of information upon which the NEHF is based and to information that could be relevant to future refinements. The NEHF project is currently planned as a four-year effort.

Understanding the Hydrogeologic Characteristics of a Buried Bedrock Valley Through its Geologic History

Brown, Jesse[1,2]; Emmanuelle Arnaud[1,2], Connor Gorrie[2,3], Oliver Conway-White[2,3], Colby Steelman[2,4], and Beth L. Parker[2,3]

[1] School of Environmental Sciences, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1
[2] Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1
[3] School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1
[4] Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1

Understanding the depositional and erosional history of buried bedrock valleys is crucial to identifying valley impacts on subregional groundwater flow-paths and contaminant pathways, from recharge to discharge. Four bedrock boreholes were drilled along two transects (3.5 km apart) to investigate a buried bedrock valley near Elora, Ontario (388 m total core length, two on the valley flank and two in the thalweg). A previous surface geophysical study identified contrasting valley morphologies (w-shaped in the southwest transect and u-shaped in the northeast transect); boreholes confirmed the estimated depths to bedrock and revealed a 100–120 m succession of Silurian sedimentary rocks from the Cabot Head to the Guelph Formations. In addition, two Quaternary sediment boreholes (129 m total length) were drilled in the valley thalweg of each transect. These data are being used to relate the geologic history of the valley to the groundwater flow system.

Variability in carbonate depositional environment, dissolution, and bedrock stratigraphy is present between the two transects, reflecting the complex geological history of the Silurian seaway and post-depositional processes that affected these rocks. The most variable bedrock unit is the Goat Island Formation, which separates aquifers found in the near-surface Guelph Formation and the deeper Gasport Formation. The Goat Island Formation varies in thickness and facies, with 80 m of off-mound dolomicrite and algal-skeletal wackestone in the southwest, and 30 m of reef mound algal-skeletal packstone/grainstone and coral-stromatoporoid framestone in the northeast.

The buried bedrock valley cuts through these varying depositional environments, presenting an opportunity to explore how geological conditions may influence valley incision, valley morphology, and the evolution of drainage through the valley and its underlying bedrock aquifers over time. Bedrock porosity is derived from fractures, vugs, and macro-scale dissolution conduits, and the relative abundance of each is highly variable across all boreholes. Identifying the stratigraphic distribution of primary and secondary porosity reveals geological factors that are impactful in developing features important to the hydrogeological system. Evidence of relative sea-level change drawn from fossil composition, stratigraphic surfaces, and karstified horizons enables integration with the regional sequence stratigraphic framework. This will aid in correlating stratigraphically controlled hydraulic features and discussing the relationship between local bedrock drainage and stratigraphy through time.

Recovered Quaternary core is consistent with previous geophysical and geological study and confirmed the nature of the sediment bedrock interface that had previously not been cored. Of note, the valley fill varied little between transects, with ~5 m of gravel at the base, ~30 m of sand, and ~20–30 m of interbedded diamict and mud units. The sand fill contains trough, tabular, and planar stratification, fining upwards units, and thin interbeds of deformed or laminated silt and clay. Reconstructing the history of these deposits helps reveal how glaciation may have overprinted the local hydrogeology and how the valley was used as part of the glacial drainage system over time. This study integrates multiple lines of geologic evidence to provide a framework for connecting the evolution of geology around a buried valley to potential hydraulic impacts.

A Semi-Quantitative Representation of Uncertainty for the 3-D Paleozoic Bedrock Model of Southern Ontario

Bunn, Melissa I.[1]; Terry R. Carter[2], Hazen A.J. Russell[1], and Charles E. Logan[1]

[1] *Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8*

[2] *Geological Consultant, 35 Parks Edge Crescent, London, ON N6K 3P4*

Geological modelling, as in all modelling of the natural environment, is imprecise because of the limitations in inferring a continually varying surface based on spatially distributed point data of varying density and accuracy. The Southern Ontario bedrock model was developed through significant efforts combining expert geological guidance and historical data that have undergone an extensive quality control and quality assurance (QA/QC) process. These processes, while yielding a model with high utility, infer some degree of uncertainty in the final model results. The assessment and documentation of this uncertainty is required to support fully informed application of the model.

Because of the nature of the data and the model development process, a semi-quantitative approach was taken to quantify error where data was available, along with an assessment of potential uncertainty where data support was absent. Potential sources of error within the data and the model building process include vertical assignment of the formation contact in borehole logs; topographic error; and interpolation error.

The error in the vertical assignment of the formation contacts was developed through the QA/QC process completed by geologists at the Oil, Salt and Gas Resources Library. The average of this error for each model layer ranges from 0.5 m to 22.5 m, with 42 out of the 54 layers having average errors less than 2 m. Topographic error is the difference between the surveyed and modelled ground surface elevation. This error ranges from 0 m to 90 m, with an absolute mean of 2.5 m. Interpolation error is the difference between the assigned contact depth and the corresponding interpolated surface depth. This error ranges from less than 0.5 m to 18 m, with 42 layers having an average error of less than 2 m.

The total error was calculated by summing each of the sources of error. To visualize results, data were averaged over 100 km^2 grid blocks. Where data were not present within a grid block, uncertainty was approximated as 50% of the range in formation top variation within the block. This value ranged from 10 m to 40 m with an average of 27.5 m. This approximation approach, as intended, highlights the lack of data as the largest source of uncertainty in the model. Data density decreases with depth, causing a corresponding increase in uncertainty for the oldest formations. Exceptions to this dependence on data density occurs for units such as Sherman Fall Formation and Georgian Bay–Blue Mountain formations, for which the error in the vertical assignment of the formation contact is of similar order to the uncertainty assigned in the absence of data. Similarly, interpolation error for the Gull River Formation is of similar order to the uncertainty assigned in the absence of data. Results of this assessment are compiled as a series for maps for each formation, presented as a resource to guide model application, and to focus future data validation efforts.

OGS Sediment Mapping Products and Services – A 20-Year Retrospective

Burt, Abigail K.; and Riley P.M. Mulligan

Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5

The Ontario Geological Survey (OGS) sustains and supports Ontario's quality of life, economic prosperity, environmental quality and public safety by providing public geoscience data and expert knowledge to inform decision making. This year marks the 20th anniversary of three-dimensional (3-D) Quaternary sediment mapping in southern Ontario, with models completed for the Barrie–Oro Moraine, South Simcoe, Fergus–Orangeville Moraine, Waterloo Region and Brantford–Woodstock areas, whereas the Central Simcoe and Niagara Peninsula projects are nearing completion.

These 3-D mapping projects have served the needs of, and fostered enhanced collaborations with, a diverse client group. Conservation authorities and geoscience consultants have guided project goals through routine gap analysis, formal project proposals developed with OGS geoscientists and ongoing communication following project inception. The OGS and the Geological Survey of Canada have collaborated on shallow seismic and downhole geophysical surveys, sedimentological and geochemical studies, and the development of an eight-layer provincial-scale sediment model. Conservation authorities, municipalities and colleges have partnered with the OGS to install a growing network of groundwater monitoring wells in a large proportion of our >300 continuously cored borehole locations, designed to answer watershed- and subwatershed-scale questions. Students from local universities have undertaken projects ranging from Quaternary geologic maps, glacial reconstructions, stratigraphic analysis and dune migration to micromorphology of glacial deposits and groundwater geochemistry.

For each project area, we follow a standardized, well-established workflow from project inception to final products while maintaining flexibility to address the specific needs and issues related to each geographic area. The goals of each project are to reconstruct the regional Quaternary histories, assemble standardized subsurface databases of new and legacy geological and geophysical information, develop 3-D models of regional-scale sediment packages, and generate technical and non-technical products. Our core products, available as free downloads or for purchase on digital media (i.e., CD or DVD) at a nominal fee, include the following:

- annual field summary reports (report of field activities, simplified borehole logs and cross sections, and preliminary interpretations)
- geophysical data sets
- borehole data releases (graphic and written logs, analytical data, core photos)
- interactive maps
- Groundwater Resources Studies (3-D sediment model, report, plates, analytical data)
- journal papers (available through open access on journal web sites or by request to OGS staff)
- conference presentations and posters (uploaded on conference web sites where available)

As the OGS enters the next decade of 3-D sediment mapping, we are focussed on starting new projects designed to fill in gaps (Guelph area) and expand our horizons (Ottawa area). Addressing the need for a new model cross-section viewer and the development of new derivative maps are some of the ways we are striving to improve product delivery. We are also entering a new phase of collaborative efforts aimed at building on some of our previous successes in developing seamless thematic products. Future products and projects include mapping groundwater geochemical baseline and trends within modelled stratigraphic units, establishing monitoring well stratigraphy and developing a standardized and simplified water-well geological nomenclature.

A 3-D Bedrock Hydrostratigraphic Model of Southern Ontario

Carter, Terry R.[1]; Charles E. Logan[2], Hazen A.J. Russell[2], Jordan K. Clark[3], Elizabeth H. Priebe[4], and Shuo Sun[5]

[1] *Geological Consultant, 35 Parks Edge Crescent, London, ON N6K 3P4*
[2] *Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8*
[3] *Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3*
[4] *Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5*
[5] *Department of Earth Sciences, University of Western Ontario, 1151 Richmond Street, London, ON N6A 3K7*

Large volumes of groundwater occur in the Paleozoic bedrock of southern Ontario. At shallow depths, this groundwater is fresh and is an important source of potable water for domestic, agricultural and industrial supply, a ground-source heat pump storage–exchange resource, as well as supporting aquatic habitats by groundwater discharge to streams and wetlands. At greater depths, groundwater is increasingly saline, yet still has a variety of practical uses. Deep saline aquifers are utilized for disposal of saline oilfield water produced as a by-product of petroleum production operations and, in the past, for disposal of liquid industrial wastes. In some parts of southern Ontario, saline aquifers are being considered for CO_2 sequestration. Hydrochemical and isotopic zonation of groundwater also provides supporting scientific knowledge to develop a safety case for long-term isolation of nuclear wastes in low-permeability geological repositories. At intermediate depths, groundwater aquifers in southern Ontario contain dissolved H_2S generated by a diverse but poorly understood microbial ecosystem dominated by sulphur proteobacteria. This "sulphur water" is a known corrosion hazard for unprotected steel and concrete in subsurface infrastructure, such as tunnels, mine shafts, petroleum wells and foundations, especially in the Lucas–Dundee aquifer. In parts of southern Ontario, this aquifer is artesian and is a drilling hazard where it contains H_2S.

A hydrostratigraphic model has been developed based on grouping lithostratigraphic model layers from a previously developed 3-D geologic model into 14 hydrostratigraphic layers. Layers are expressed as either aquifer or aquitard based principally on hydrogeologic characteristics in the intermediate to deep groundwater regimes below the influence of modern meteoric water. Hydrostratigraphic aquifer units are subdivided into up to three distinct hydrochemical regimes: brines (deep), brackish-saline sulphur water (intermediate), and fresh (shallow). The hydrostratigraphic unit assignment provides a standard nomenclature and definition for regional flow modelling of potable water and deeper fluids. Included in the model are 3-D representations of oil and natural gas reservoirs that form an integral part of the intermediate to deep groundwater regimes; 3-D water level surfaces for deep Cambrian brines and the fresh to sulphurous groundwater of the Lucas–Dundee regional aquifer; inferred shallow karst; base of fresh water; Lockport Group total dissolved solids (TDS); and the 3-D lithostratigraphy. Similar to the lithostratigraphic model, the hydrostratigraphic model is constructed using Leapfrog® Works at 400 m grid scale and will be distributed in a proprietary format with free viewer software, as well as industry standard formats.

3-D Printing for Geologists and Subsurface Explorers – Turning the Abstract into Reality

Clark, Jordan K.[1]; Matthew A. Dupont[1], Maryrose N. D'Arienzo[1], Charles E. Logan[2], and Hazen A.J. Russell[2]

[1] Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3

[2] Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8

Tactile three-dimensional (3-D) printed models of subsurface geological formations offer a way to hold and view modelled geology naturally. The ability to hold and rotate a physical model allows the viewer to focus on analyzing the geometry from a geological perspective in a situation where the shape is intuitive. As an introduction to the geology of southern Ontario, a four-layer model was printed from the new lithostratigraphic model of southern Ontario (Carter et al. 2021).

Two types of 3-D printers are available for desktop manufacturing at an affordable price point. The most common and affordable type of printing is fused deposition modeling (FDM). In FDM printing, a model is built on a platform from a spool of filament fused layer-by-layer with heat. The second type of common desktop printer uses stereolithography (SLA). In SLA printing, a model is built on a platform lowered into a tray of resin that is cured in layers using ultraviolet light. Both types of printing were found to produce good results with each having noteworthy advantages. The FDM printers offer the largest size and lowest cost for most projects. The models are durable and do not require post processing; however, printing can be inconsistent and fine details may not be reproduced with accuracy. The SLA printers can offer the highest quality, most consistent prints, with preservation of fine details on the model surface. Models require washing, curing, and post processing.

Objects from the lithostratigraphic model of southern Ontario were created using Leapfrog® Works and exported as Wavefront object (OBJ) files. Any geographic information system (GIS) or computer-assisted design (CAD) software that can export an OBJ or Standard Triangle Language (STL) file format will be compatible with most 3-D printing software. Some 3-D printing software, like Cura® for FDM printers, will also support PNG or JPG formats, enabling the printing of digital terrain models using pixel brightness as the model height.

Model objects were edited for printing using Blender®, a common and powerful 3-D modelling software. Title text, scales, and model features were created as 3-D objects and combined with existing model layers to form a solid 3-D geometry that can be printed as one solid part. Edited objects must then be passed to print slicing software to prepare printer specific instructions. For SLA prints, PreForm™ software from Formlabs Inc. was used. For FDM prints, Cura® was used.

A detailed four-layer model of southern Ontario's geology was printed on a Formlabs Inc. Form 3 printer (SLA). This model consists of Precambrian, Ordovician–Cambrian, Silurian, and Devonian layers that snap together. Each layer was printed with label text as a single part, using a coloured resin corresponding to the geological age. Holding and rotating the geology of southern Ontario immediately reveals regional features, such as the Chatham Sag, Algonquin Arch, and major faults.

Reference

Carter, T.R., Logan, C.E., Clark, J.K., Russell, H.A.J., Brunton, F.R., Cachunjua, A., D'Arienzo, M., Freckelton, C., Rzyszczak, H., Sun, S. and Yeung, K.H. 2021. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Geological Survey of Canada, Open File 8795. doi.org/10.4095/328297

Visualizing and Interacting with 3-D Geology Data in Virtual Reality

Clark, Jordan K.[1]**; Matthew Dupont**[1]**, Kyra Hinnegan**[1]**, Ninava Sibo**[1]**, Charles E. Logan**[2]**, and Hazen A.J. Russell**[2]

[1] Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3

[2] Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8

A stereoscopic three-dimensional (3-D) model is a powerful tool for understanding the geometry of a set of geological data. The Oil, Gas and Salt Resources Library's millions of individually labelled rock samples and hundreds of thousands of geological formation top picks are challenging to analyze and comprehend. Mapping in two-dimensions (2-D) has long been a useful tool for aggregating and summarizing large numbers of spatial data points. Now, 3-D mapping gives us more tools for visualizing this myriad data in powerful and intuitive ways. The stereoscopic viewing experience adds back the missing dimension that hobbles viewing of 3-D models on 2-D screens and, when these models are placed in motion, comprehension becomes even more intuitive. Virtual reality (VR), augmented reality (AR), and mixed reality (MR), collectively known as XR, can all be used to produce similar but slightly different outcomes depending on communication objectives. To accompany the second release of the three-dimensional geological model of southern Ontario (Carter et al. 2021), three VR experiences were created in two different formats.

As a foundation for creating communication assets in XR, all geological formations modelled in the second model released by Carter et al. (2021) were exported from Leapfrog® Works in Wavefront object (OBJ) format, a common 3-D interchange format. These object assets are the basis for all types of XR experiences. Blender® was used to open and edit OBJ files. All OBJ files had textures applied with colours corresponding to the geological age of the formation. Other edits were made as required depending on the publication objective.

Two VR video tours of the model, created using Blender® and Adobe® Premiere® Pro, guide the viewer along a set track with narrations focussing on the lithostratigraphy and hydrostratigraphy. Video in VR allows the viewer to turn in any orientation while their location remains fixed, which is known as a three-degrees of freedom (3dof) experience, this creates a strong sense of immersion. The final product created using the foundational model assets is a VR geology laboratory application. In the application experience, the user controls their view and location guiding themselves through the scene with some help from cues. This is a six-degrees of freedom experience (6dof) and is highly immersive. This experience was developed using Unity® software and published on a Meta (formerly Oculus®) Quest 2 VR headset. Users can handle 3-D rock cores, learn about subsurface fluids, subsurface storage, view rock chips for each formation, inspect the geometry of each formation, and walk virtually on all formations.

The VR videos can be played back on almost any hardware, but are best experienced on a stereoscopic VR headset; they will be available on the OGSR Library YouTube channel (youtube.com/c/ogsrlibrary). The VR application requires a headset and is available for use in the OGSR Library or one of our project partner locations.

Reference

Carter, T.R., Logan, C.E., Clark, J.K., Russell, H.A.J., Brunton, F.R., Cachunjua, A., D'Arienzo, M., Freckelton, C., Rzyszczak, H., Sun, S. and Yeung, K.H. 2021. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Geological Survey of Canada, Open File 8795. doi.org/10.4095/328297

Advances in Borehole Porosity Investigations Using NMR Logs in Fractured Sedimentary Rock, Ontario, Canada

Crow, Heather[1]; Peeter Pehme[2], Stephanie Larmagnat[3], Jonathan Munn[2], Beth Parker[2], and Hazen A.J. Russell[1]

[1] *Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8*
[2] *Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1*
[3] *Geological Survey of Canada, 490 rue de la Couronne, Québec City, QC G1K 9A9*

Porosity is a key parameter in predicting both groundwater flow and the migration of contaminants. Quantifying *in situ* porosity can be challenging and expensive, particularly where extensive laboratory analysis is required in heterogeneous sedimentary rock. Borehole nuclear magnetic resonance (NMR) logging technology provides a continuous downhole measurement of volumetric water content (porosity in saturated materials) and an estimate of the pore size distribution in the formation surrounding the borehole. The evolution of slim-hole NMR tools, with the ability to estimate hydraulic conductivity (*K*) from NMR parameters (KNMR), has generated significant interest among the hydrogeological community in recent years.

The Geological Survey of Canada (GSC) and the Morwick G360 Institute for Groundwater Research (G360) are collaborating in a multiyear campaign of data collection at their respective bedrock borehole test facilities in Ottawa (the Bells Corners Borehole Calibration Facility) and Guelph (the Fractured Rock Observatory) to assess the performance and limitations of slim-hole NMR technology from a hydrogeologic perspective. NMR logging was carried out in fractured Silurian dolomitic (Guelph) and Cambrian sandstone (Ottawa) bedrock boreholes where aquifer and aquitard units provide a range of clay contents, and primary and secondary porosity types (e.g., fractures, reefal structures, vugs, karstic features).

The first phase of the study involved assessing indicators of instrument performance, including the tool's vertical response curve, repeatability of porosity measurements, resolution at various fracture apertures, and how motion during logging affects tool response and acquisition time. Overall, NMR was found to provide a robust measurement of matrix porosity and pore size distribution throughout the borehole, and NMR porosity estimates were found to agree with core measurements to within ±0.04 porosity in both the dolostone and sandstone (Pehme et al. in press). It was observed, however, that the correlation deteriorated in finely bedded lithologies, and where fracturing is present. Much of the discrepancy is attributed to differences in scale between small core samples and the larger volume measured by NMR probes.

To investigate the importance of scale when comparing core and field measurements, the next phase of the study integrates medical-grade computed tomography (CT) scans of the cores in dry and saturated conditions following the protocols developed by Larmagnat et al. (2019). These data are anticipated to provide insight into the pore shape, connectivity, and vertical variability of the heterogeneous pore network at the sub-millimetre to centimetre scale over a range of carbonate rock depositional conditions (e.g., reef mounds, deeper and shallow water conditions, and dissolution). These data, in turn, will provide insight into the prediction of KNMR in these rock types.

References

Larmagnat, S., Des Roches, M., Daigle, L.-F., Francus, P., Lavoie, D., Raymond, J., Malo, M. and Aubiès-Trouil, A. 2019. Continuous porosity characterization: Metric-scale intervals in heterogeneous sedimentary rocks using medical CT-scanner; Journal of Marine and Petroleum Geology, v.109, p.361-380.

Pehme, P.E., Crow, H.L., Parker, B.L. and Russell, H.A.J. in press. Evaluation of slim-hole NMR logging for hydrogeologic insights into dolostone and sandstone aquifers; Journal of Hydrology.

Changes in Southern Ontario Water Storage from the GRACE Gravity Satellite Mission

Crowley, John W.[1,2]; Melissa Bunn[3], Stephen Frey[4], Jianliang Huang[1], Marc Véronneau[1], and Hazen A.J. Russell[3]

[1] Canadian Geodetic Survey, Natural Resources Canada, 615 Booth Street, Ottawa, ON K1A 0E9
[2] Department of Earth and Environmental Sciences, University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5
[3] Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8
[4] Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6

Changing water levels create agricultural and industrial limitations or opportunities, and can lead to significant changes in land surface and water availability. These changes have been pronounced in recent years with floods, droughts, and wildfires increasing in both severity and frequency. A need to better understand the impact of natural variability and climate change on Canada's water resources is paramount. However, most of Canada is remote and observations are few and far between. In Canada, information is limited on the recent and current state of national water change. Satellite gravity observations from the NASA Gravity Recovery and Climate Experiment (GRACE) mission provide this valuable information and can identify regions exhibiting significant water storage changes. We present a case study for southern Ontario that demonstrates our ability to accurately capture changes in regional water storage using GRACE satellite data. We focus on southern Ontario because there are abundant hydrological observations and models that can be used to validate the GRACE estimates. We show that GRACE effectively captures and quantifies both extreme events and regular seasonal behaviour. Furthermore, the GRACE results demonstrate that the large and recent changes in the Great Lakes water levels have little impact on seasonal changes in total water storage for southern Ontario. We conclude with a brief discussion of how our method will be incorporated into the Canada 1 Water project, which aims to produce a comprehensive physically based platform to model the integrated climate–groundwater–surface-water system for Canada. This platform will include decision-support tools to inform on droughts, floods, carbon sequestration, wildfire risk, permafrost changes, ecosystem services, and surface and groundwater quantity.

Can a Passive Seismic Survey Delineate an Esker Aquifer in Lacustrine–Marine Sediments?

Dietiker, Barbara; Andre J.-M. Pugin, Tim Cartwright, and Kevin Brewer

Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8

One aspect of groundwater investigation, evaluation, and management is an expert understanding of the subsurface as many aquifers do not have a surface expression. For example, the delineation of buried eskers or gravel-filled buried valleys is a challenge. Shear-wave reflection seismology is a proven, but rather expensive method which delivers high-resolution profiles outlining potential aquifer geometries.

The passive seismic, micro-tremor survey also known as Horizontal-to-Vertical Spectral Ratio (HVSR) method is routinely used to map bedrock depth, for example to outline bedrock basins, valleys or faulted bedrock blocks. HVSR surveys are much less costly and need less processing than reflection surveys, but the resulting data show less subsurface details. In groundwater applications, this tool might be ideal as a reconnaissance tool, not only for identifying depth to bedrock, but also distinct units within the surficial sediment stratigraphy.

The Geological Survey of Canada has a field laboratory site along the Vars–Winchester esker in eastern Ontario. There is an abundance of geophysical, sedimentological and hydrogeological data, particularly along the 3 km esker segment north of Embrun. Multiple seismic reflection transects delineate the bedrock surface and esker stratigraphy of sand and gravel overlain by Champlain Sea sediments. Almost 200 HVSR sites are co-located with these seismic reflection profiles. It is thus an ideal testing ground to explore the capabilities of the passive seismic method in differentiating unconsolidated sediments units present in the sediment stratigraphy.

The passive seismic method utilizes minuscule ground movements created by earthquakes, ocean waves, traffic, etc. to calculate ratios of horizontal and vertical movements at different frequencies. Processed results are presented as curves of Horizontal to Vertical (H/V) ratios (amplitudes) versus frequency. The highest amplitude (peak) occurs at the fundamental frequency that is related to the resonator depth and the average shear-wave velocity. The difference in density and shear-wave speed between bedrock and soft lacustrine–marine sediments creates a high H/V amplitude and a symmetrical H/V peak when sediments directly overly bedrock. The H/V curves differ where esker sediments are present. For example, when a sand layer overlies bedrock, the resonance peak is asymmetrical. Where the stratigraphy is even more complex, e.g., over the core of the esker, where gravel and sand are present, H/V signals can have two resonance peaks. Based on the co-location of HVSR and seismic reflection data, HSVR curves can be correlated with esker sediment material and geometry. After assessing the correlations, esker structure might be inferred solely from HVSR. Signal response is described for a number of bedrock and esker geometries and contrasting sediment textures of the stratigraphy. The successful application of the technique is reviewed relative to both of these attributes and limitations of the method are identified.

Some esker geometries, such as the distinctive dome shape of the gravel esker core, create HVSR signals that are easy to interpret and map on a transect of HVSR signals. When the esker sediments fill an incised bedrock valley, the HVSR results are more difficult to interpret.

GeologyOntario and OGSEarth Demonstration

Dodge, John; and Alphons Evers

Information & Digital Services, Information & Lands Branch, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5

The GeologyOntario search tool will be demonstrated along with an explanation of the information available within the search page and the search results pages: www.geologyontario.mndm.gov.on.ca/index.html

The OGSEarth page will be explained: how to bookmark sections, what you can view and download.

A demonstration of available data from our OGSEarth web page will be provided using the Google Earth™ mapping service: www.geologyontario.mndm.gov.on.ca/ogsearth.html

Groundwater and Surface Water Forecast Evaluation in Two Contrasting Hydrostratigraphic Settings Within Southern Ontario

Frey, Steven K.[1,2]; Graham Stonebridge[1,3], Helen Zhang[4], Omar Khader[1], Andre R. Erler[1,5], Najmi Shamalisham[1], David Hah[1,6], and Ed A. Sudicky[1,2]

[1] Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6
[2] Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1
[3] Department of Systems Design Engineering, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1
[4] Ontario Ministry of the Environment, Conservation and Parks, 125 Resources Road, Toronto, ON M9P 3V6
[5] Department of Geography and Environmental Management, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1
[6] Department of Civil and Environmental Engineering, University of Waterloo 200 University Avenue West, Waterloo, ON N2L 3G1

Over the course of the 2014–2019 Southern Ontario Groundwater Project, a regional-scale HydroGeoSphere (HGS) fully integrated groundwater–surface water model was developed and tested. From the regional model, a derivative set of watershed-scale HGS models were constructed with much higher levels of spatial resolution. The watershed-scale models have been incorporated into a hydrologic forecasting system that provides coverage across southern Ontario. In 2019, a project was initiated to evaluate the ability of the forecasting system to predict future groundwater levels in the Long Point and Quinte regions, which are both prone to groundwater stress during drought conditions. As the hydrostratigraphic settings of Long Point and Quinte are considerably different, comparison of simulation results between the two regions provides insight on structural factors that influence forecast skill. The forecast evaluation spans the summer and fall of 2021 and includes 7-day and 32-day forward-looking forecasts that were generated at respective daily and weekly frequencies. The skill metrics are calculated for both surface water flow rates and groundwater levels, based on comparison between forecasts and subsequent observed conditions at Water Survey of Canada hydrometric stations and Provincial Groundwater Monitoring Network real-time monitoring wells.

Results from the skill analysis indicate that groundwater levels tend to be much more predictable than surface water flow rates. Based on Kling-Gupta efficiency (KGE) scores, root mean square error (RMSE), and bias, surface water forecasts tend to exhibit a notable degradation of skill between 3 and 5 days, with seasonality playing a role. In contrast, groundwater forecast evaluation based on linear correlation between simulated and observed groundwater levels, RMSE, and bias, indicates that skill extends beyond 20 days at most PGMN well locations utilized for the analysis and beyond 30 days at others, with less influence from seasonality. Groundwater forecast skill also tends to extend longer for the Long Point region compared to Quinte, although the lower number of real-time PGMN wells in Long Point may be influencing this interpretation. The work presented here demonstrates that groundwater forecasting in southern Ontario is a viable tool to help anticipate and manage groundwater resources.

Evidence for Upward Migration of Deep Fluids to Shallow Aquifers on the North Shore of Lake Erie and Pelee Island

Hamilton, Stewart M.

Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5

The north shore of Lake Erie in southwestern Ontario extends for 350 km between the Niagara River in the east and the Detroit River in the west and has mostly low-lying topography. Pelee Island, in the west-central portion of Lake Erie is also very flat with an average elevation across its 40 km^2 extent that is less than 3 m above the lake level of 174 m ASL. Potentiometric heads in bedrock wells over much of the Island are artesian with respect to ground surface and several metres above lake level, which is perplexing considering the lack of local relief – and that the island is more than 20 km from mainland relief. Along the north shore of Lake Erie, water wells and abandoned petroleum wells can be artesian, discharging fluids at surface, as do numerous springs, some of which may be man-made.

The OGS Ambient Groundwater Geochemistry Project collected groundwater samples on a uniform grid throughout this area between 2007 and 2018. Groundwater chemistry in shallow aquifers on Pelee Island and parts of the north shore of Lake Erie exhibit a number of indicators of deep fluid migration including low tritium and extremely low Cl to Br ratios consistent with deep brine influence. On the Niagara Peninsula, recent studies have shown a ~1000 km^2 swath where shallow bedrock groundwaters have high dissolved sulphate with an unusual isotopic character similar to that of the Queenston Formation, which occurs more than 200 m below surface.

The evidence for upward movement of deep fluids and the upward hydraulic gradients observed on Pelee Island and parts of the north shore of Lake Erie, may have their origins on the south shore. The Allegheny Plateau borders Lake Erie to the south in parts of New York, Pennsylvania and Ohio. It has much higher relief than anywhere in southwestern Ontario with elevations that commonly exceed 500 m ASL. Lake Erie and adjacent areas have thick accumulations of glaciolacustrine clays that act as an aquitard, capping hydraulic pressure north of the plateau's margin under both land and lake. Pelee Island, with its wave-winnowed epikarst limestone would represent a "window" through the aquitard. The next closest windows would be on the Canadian mainland, particularly on the Niagara Peninsula, which is in fact an isthmus, between Lake Erie and Lake Ontario. Lake Ontario, with a surface elevation of only 74 m, is the lowest natural hydraulic elevation within several hundred kilometres of Lake Erie and, therefore, would represent the terminal hydraulic boundary for deep fluid migration in the whole region.

Using Ontario Geological Survey’s Aggregate Resource Data in Groundwater Applications

Handley, Laura A.

Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5

Aggregate is a construction product made from sand and gravel or by crushing bedrock. It is fundamentally important to modern-day society because it is used for the construction of our roads and highways, buildings, and infrastructure. Land containing aggregate, particularly around large urban centres, is often under immense pressure to be used for a wide variety of competing uses.

As a result of rising competing market pressures, the Ontario Geological Survey introduced Aggregate Resources Inventory mapping in the early 1980s. The purpose of this ongoing work is to identify areas of potential aggregate resources within the province by delineating and characterizing the quantity and quality of both sand and gravel and bedrock-derived deposits to assist in planning strategies. Aggregate Resource Inventory Papers (ARIP) are technical background documents based on geological information and interpretation of historical geological and/or aggregate data, field observations, water-well records and geotechnical borehole logs that are integrated in attempt to evaluate both the quantity and quality of aggregate resources. Each ARIP document includes a main report providing information on aggregate quality and deposit information, as well as separate 1:50 000 scale geographic information system (GIS)-based maps that delineate a) sand and gravel and b) bedrock-derived aggregate deposits. ARIPs are freely available for download on our web site and OGSEarth.

In 2015, the OGS launched the Aggregate Resources of Ontario (ARO). The ARO is a GIS-based compilation based on data from ARIP mapping conducted by the OGS from 1980 to 2022. The purpose of the ARO is to have a single source for both sand and gravel and bedrock mapping data that can be updated annually for quick dissemination of data to our clients in various user-friendly formats, such as ESRI® ArcGIS®, KML, etc.).

Although ARIPs have been traditionally designed as an aggregate inventory exercise and key component of supporting and balancing the land-use planning process, it could also be a useful tool in other applications such as identifying possible groundwater recharge areas and vulnerable aquifers. The goal of this presentation is to discuss the main mapping methodology involved in creating an ARIP, our provincial aggregate resource coverage to date, main client groups, data reliability and potential applications for groundwater use.

Comparing Porosity Development Using Medical CT Scanning in Two Paleokarst Horizons in Silurian Carbonates, Southern Ontario

Larmagnat, Stéphanie[1]; Terry R. Carter[2], Shuo Sun[3], Hazen A.J. Russell[4], Philippe Letellier[5], and Mathieu Des Roches[5]

[1] *Geological Survey of Canada, 490 rue de la Couronne, Québec City, QC G1K 9A9*
[2] *Geological Consultant, 35 Parks Edge Crescent, London, ON N6K 3P4*
[3] *Department of Earth Sciences, University of Western Ontario, 1151 Richmond Street, London, ON N6A 3K7*
[4] *Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8*
[5] *Institut national de la recherche scientifique (INRS), Centre ÉTÉ, 490 rue de la Couronne, Québec City, QC G1K 9A9*

Porosity and permeability and correspondingly hydraulic conductivity data can be costly and difficult to collect. Additionally, each approach has inherent methodological and scale issues associated with the measurements. Medical computed tomography (CT) scanners provide a nondestructive approach that can be completed on whole cores, and provide three-dimensional quantitative data on the size, shape, and distribution of the macroporosity. Imagery can document macropores and mesopore geometry and connectivity at the centimetric and millimetric scale, provide continuous porosity profile visualization at the millimetric scale, and compare apparent macro porosity versus effective porosity contributions.

Two water-bearing paleokarst horizons were intersected by diamond drilling at the Bruce Nuclear Generating Station in southern Ontario. The Lower Silurian Guelph Formation dolostone occurs at 375–385 m depth, and the Upper Silurian A-1 Carbonate Unit (limestone) of the Salina Group at 325–335 m. The Guelph Formation paleokarst interval forms part of a regional deep brine aquifer underlying a large part of southern Ontario. The A-1 Carbonate paleokarst forms a subregional brackish sulphur water aquifer immediately east of the Bruce site.

Porosity analysis has been completed using a Siemens SOMATOM® medical CT-scanner on both dry and fully saturated cores. Core saturation was achieved using an in-house core-flooding system. Analyses were completed on 15 whole core samples, with core diameter of 75 mm and length varying from 10 to 55 cm. Samples were first scanned in a dry state in a sealed chamber. Subsequently, a vacuum is applied for 24 hours, degassing distilled water and samples simultaneously. The samples are maintained fully immersed for up to 78 hours and are scanned in a saturated state. The dry and saturated scan data can be coregistered and processed to derive effective porosity.

A-1 Carbonate limestone samples have an average matrix porosity along depth of up to 4%. Beds 3–4 cm thick formed predominantly of rounded to elliptic macropores have much greater porosity. In Guelph Formation dolostone samples, the average matrix porosity along depth is around 5%. Locally samples display large vuggy macropores with rapid variation in porosity (e.g., from 3 to 9% in 3 cm thick interval). The largest macropores appear to be connected through a network of fractures and micropores unresolved at the medical CT–scanner scale.

A subset of 4 full-diameter core samples were analyzed with conventional gas porosimetry (discrete sampling) to directly compare porosity evaluation from med-CT (continuous sampling). Conventional gas porosimetry applied to Guelph Formation dolostones gives 13% and 14% porosity over 12 to 16 cm intervals with large vugs, but is not representative of the average matrix porosity along depth, illustrating how the location of the subsampling interval for conventional gas porosimetry can lead to overestimating or underestimating porosity. Data analysis is still underway and petrographic and SEM studies are in progress.

Groundwater as a Source and Pathway for Road Salt Contamination of Surface Water and Aquatic Ecosystems in the Great Lakes Basin

Mackie, Ceilidh[1]; Rachel Lackey[1], Jana Levison[1], and Luciana Rodrigues[2]

[1] School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1

[2] Technical Assessment and Standards Development Branch, Ministry of the Environment, Conservation and Parks, 40 St. Clair Avenue West, Toronto, ON M4V 1M2

Over the past century in the Great Lakes Basin, increases in chloride concentrations in groundwater and surface water have occurred and are projected to continue until steady state is achieved. This increase in chloride corresponds with an intensification in urban areas within the basin since more road salt is being applied in winter as a de-icer to roadways, sidewalks, and parking lots to ensure the safety of motorists and pedestrians. At high concentrations, chloride is toxic to aquatic organisms and has contributed to the degradation of the Great Lakes. The delivery of chloride to the Great Lakes via groundwater pathways is currently not well understood. Thus, the objective of this research is to evaluate the contribution of groundwater as a source and pathway for chloride loading to the Great Lakes, specifically from within the western Lake Ontario Basin. This research is being carried out in several stages including 1) investigating the current state of knowledge regarding groundwater chloride in southern Ontario; 2) compilation of existing data sets and geospatial analysis to determine groundwater chloride hotspots; 3) collection of discrete and continuous groundwater, surface water, and precipitation samples over two years from the Credit Valley watershed; and 4) analyses of groundwater, surface water, and precipitation samples to better understand where chloride is entering the basin and the primary groundwater-surface water pathways of transport. This analysis will be used to interpret seasonal groundwater–surface water interactions for the study watershed, to conduct a comprehensive chloride mass balance, and to develop a method to estimate chloride flux. The literature review (Mackie et al. 2021) concluded that there is a lack of holistic surface water and groundwater monitoring and called for a regional-scale assessment that evaluates chloride in groundwater and surface water over the long term. The geospatial analysis is underway, and the field operations will commence in spring 2022. This research will evaluate chloride concentrations in areas of varying land uses and geology to better understand the spatial distribution of chloride contamination in the basin and the primary pathways that chloride is entering the Great Lakes. The results will be useful to develop sustainable road salting policies and best management practices in the Great Lakes Basin and other cold climates.

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Groundwater Discharge to Lake Ontario – A Preliminary Assessment

Marchildon, Mason; Steve Holysh, Rick Gerber, Mike Doughty, Steve Shikaze, and Britt Smith
Oak Ridges Moraine Groundwater Program (ORMGP), 101 Exchange Avenue, Vaughan, ON L4K 5R6

In Ontario, the topic of groundwater–surface water interaction has been one of considerable research and discussion over the past few decades resulting from the recognition that riverine-based aquatic ecosystems are often dependent on direct groundwater discharge. However, there has been significantly less work directed at quantifying and understanding direct interactions between the groundwater flow system and Lake Ontario. The present study provides a preliminary quantitative exploration of the flux between the groundwater system and Lake Ontario.

The Oak Ridges Moraine Groundwater Program, the study area of which stretches some 250 km along the north shore of Lake Ontario from Hamilton in the west to the Trent River in the east, houses some 80 numerical groundwater flow models. Eleven of these models either abut or incorporate portions of the shoreline of Lake Ontario and, as such, these models present a unique opportunity to investigate linkages between the groundwater flow system and Lake Ontario. How much groundwater moves directly into the lakes? Are there dissolved parameters in the groundwater discharging directly to the lakes that are having an impact on water quality along the shorelines and in the nearshore areas?.

Although the models used in this study were not specifically constructed to investigate the flux between the groundwater system and Lake Ontario, they do reflect a considerable body of groundwater knowledge. In building these numerical models, and using them to investigate groundwater dynamics, teams of hydrogeological practitioners (consultants and or technical government agency staff) have spent considerable resources. The numerical models synthesize subsurface geological (e.g., deposition of glacial and Paleozoic units) and hydrogeological (e.g., permeability distribution) conditions. The models process and summarize climate (i.e., precipitation and evapotranspiration estimation) and streamflow (i.e., baseflow/groundwater discharge) data. All of this is aimed at understanding i) the location and magnitude of water entering the groundwater system; ii) how and where groundwater flows in the subsurface; and iii) the location and magnitude of discharge from the groundwater system. Given the comprehensiveness of the existing modelling work, making use of these models to quantitatively estimate groundwater fluxes to Lake Ontario is certainly justified and likely to provide reasonable initial groundwater–lake flux estimates.

All models were run to completion and the discharge to the Lake Ontario north shore was tabulated. For the steady state models, the fluxes exiting in the groundwater system were assumed to be long-term averages. For the one transient model (monthly Southern Ontario fine model) exchange rates reported at 12 consecutive monthly snapshots (i.e., model states) were aggregated to an annual sum. Simulated total volumetric flux to the lake was divided by the total land surface area in the model that is contributing to the lake. This yields an annual average in millimetres per year (mm/year); allowing for easier comparisons with annual precipitation, recharge, etc.

Figure 1 summarizes the model results and shows that indirect discharge (i.e., discharge to Lake Ontario via streams is shown in green) accounts for the greatest groundwater source (>90%) arriving at Lake Ontario's north shore.

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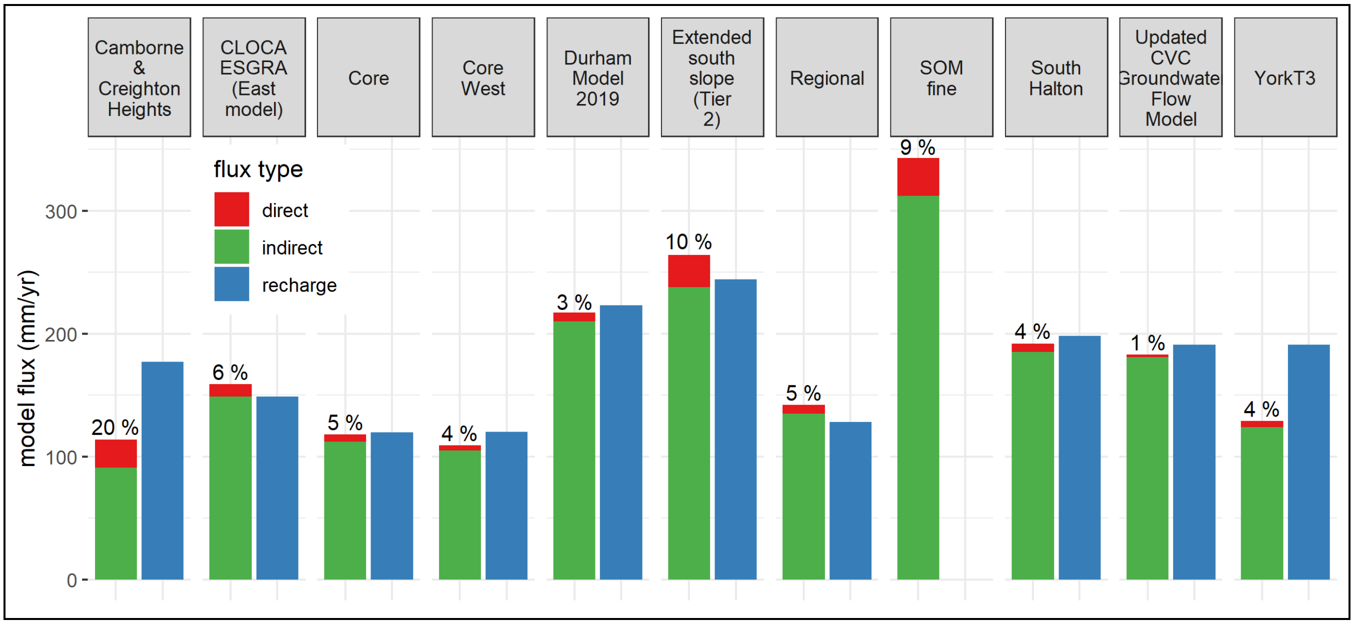

Figure 1. Summary of flux in (recharge, shown in blue) and out (direct (shown in red) and indirect (shown in green) discharge) of the modelled groundwater domain (within the Lake Ontario catchment area for each model). Percentages indicate proportion of total groundwater discharge contributing to the lake.

Highlights of Update Report of Groundwater Science Relevant to Great Lakes Water Quality

Mohamed, Mohamed N.[1]**; and Howard Reeves**[2]

[1] *Environment and Climate Change Canada, Canada Centre for Inland Waters, 867 Lakeshore Road, Burlington, ON L7S 4A1*

[2] *United States Geological Survey*

As part of Annex 8 of the Great Lakes Water Quality Agreement, a binational report entitled, *Groundwater Science Relevant to the Great Lakes Water Quality Agreement: A Status Report*, was published in 2016. This comprehensive report encompassed a wide range of topics where groundwater is relevant to the water quality of the Great Lakes, including contaminants, urban areas, and climate change. The report also identified several priority science needs to advance key issues related to groundwater science in the Great Lakes basin. As part of the current priorities under Annex 8, an update to this report is being developed. This report will update advances, as well as continuing gaps, against the priority science needs identified in the 2016 report, as well as identify emerging issues. Some highlights from the update report, which is in late draft stage, will be presented.

Assessing Source Water Contributions to Streamflow in a Precambrian Shield Watershed in the Sudbury Region: The Whitson River Watershed

Montgomery, Kimberly[1]; April L. James[1], Merrin Macrae[2], and Arghavan Tafvizi[3]

[1] Department of Geography, Nipissing University, 100 College Drive, North Bay, ON P1B 8L7
[2] Department of Geography, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1
[3] Department of Biology, Laurentian University, 935 Ramsey Lake Road, Sudbury, ON P3E 2C6

Stable water isotope ratios are commonly used to assess source water contributions (e.g., groundwater, snowmelt, precipitation, surface water) to streamflow. These types of analysis are important for water management practices, watershed conservation, and water quality assessments. The Whiton River project is focussed on improving understanding of hydrologic function and groundwater–surface water interactions in the Whitson River subwatershed, located withing the Greater Sudbury region. The objective of this study is to understand how different endmembers are contributing to streamflow over space and time using stable water isotopes $\delta^{18}O$ and $\delta^{2}H$ and additional water chemistry parameters.

The Whitson River subwatershed is located in the Vermilion River watershed, a tertiary watershed that delivers water downstream to the Spanish River and onward to Georgian Bay and includes most of the Greater Sudbury municipal area. The Whitson River subwatershed (defined by the outflow to the Vermilion River) is approximately 328 km^2 in size and the main stem has a total length of 71 km. Management of flooding is a concern for this subwatershed. Landcover across the Whitson River subwatershed is about half (49%) forested, with an additional third covered by agriculture (21%) and urban (13%). In addition, 9% of the watershed is exposed bedrock, 5% open water and/or wetland, and 1.6% sand, gravel and mine tailings. Biweekly sampling of streamflow and other surface waters (15 locations) and precipitation (2 rain gauges) was conducted within the watershed from June to November 2021.

A preliminary survey was conducted in October 2020. Sampling locations span the watershed, from headwater tributaries with varying landcover, to sites along the main stem of the river and including Water Survey of Canada gauging stations in Val Caron and Chelmsford. Surveys were scheduled to coincide with regular discharge monitoring conducted by Conservation Sudbury along the main stem of the river, with additional measurements made at headwater sites where and when conditions allowed. Working with Conservation Sudbury, groundwater was sampled from two Provincial Groundwater Monitoring Network wells and from additional municipal wells within the watershed. Surface water and groundwater sampling included field measurement of temperature, specific conductance, pH, and dissolved oxygen. Water samples were analyzed for stable isotope ratios of $\delta^{18}O$ and $\delta^{2}H$ using a Picarro Inc. L2120-*i* Liquid Water Isotope Analyzer in the Department of Geography at Nipissing University. Cation and anion concentrations are being analyzed in the Biogeochemistry Lab at the University of Waterloo.

This presentation focusses on reporting of the preliminary analysis of stable isotopes ratios. Statistical analysis is presented evaluating variation of streamflow and endmember isotope values. Streamflow isotope values are evaluated as a function of distance along the river and by headwater tributary. Bivariate plots of $\delta^{18}O$ and $\delta^{2}H$ are generated to assess streamflow in relation to endmembers of groundwater, precipitation, and lake or wetland samples, exploring variation in space and time. A two-component mixing model is used to estimate percent contributions of endmembers to streamflow and its variation. Assessment of source water contributions to streamflow across the Whitson River subwatershed will provide new insight into hydrologic function and groundwater–surface water interactions in this Precambrian Shield watershed.

Monthly Trends and Climate Predictors of Baseflow Across Canada

Murray, Julian[1]; Jessi Ayers[2], and Andrea Brookfield[1]

[1] Department of Earth & Environmental Sciences, 200 University Avenue West, Waterloo, ON N2L 3G1
[2] Department of Environmental Science, Policy, and Management, University of California–Berkeley, 130 Mulford Hall, Berkeley, California 94720-3114

Baseflow, the groundwater contribution to streamflow, sustains surface water bodies during periods of drought and is an important indicator of groundwater availability. Baseflow is difficult to measure and quantify, and while many site-specific studies have been completed, there have been few studies of long-term Canada-wide trends of baseflow. The studies that have been done have examined annual or seasonal trends, which obscures subtle shifts in climate, such as earlier onsets of thaw and snowmelt. In this work, monthly baseflow trends across Canada will be identified and related to changes to climatic parameters (precipitation, temperature, and antecedent wetness) using data from 1275 hydrometer stations gathered from 1989 to 2019. The hydrographic data are processed using Lyne and Hollick's one-parameter digital filter method and then monotonic trends were identified using the Mann-Kendall Trend Test. Historical baseflow is related to climate parameters by means of GAMLSS statistical analysis. Available data were limited in certain regions, especially in northern Canada. Results vary by region and by calendar month. Although no trends were observed for most stations, significant seasonal trends were observed in many regions, including the southern half of Ontario from January until May. Conversely, significant negative trends were detected for the summer months in Alberta and British Columbia and around Yellowknife, Northwest Territories. The results of this work can identify what streams may become intermittent and what groundwater resources may be declining. In addition, the relationship with climate indicators can help determine the cause of changing baseflow, which can contribute to the development of mitigation strategies.

Estimating Groundwater Age in the Subcropping Bedrock Aquifers of Southern Ontario with Tritium

Priebe, Elizabeth H.[1]; Stewart M. Hamilton[1], Alex Lemieux[2], David Rowan[3], and Ian D. Clark[4]

[1] *Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5*

[2] *Canadian Nuclear Safety Commission, 280 Slater Street, Ottawa, ON K1P 5S9*

[3] *Canadian Nuclear Laboratories, 286 Plant Road, Chalk River, ON K0J 1J0*

[4] *University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5*

In previous decades, tritium was one of the simplest tracers used for estimating groundwater age in the Northern Hemisphere because the 1963 thermonuclear peak offered a ubiquitous and easily identifiable time marker. Today, loss of the 1963 tritium peak from fallout decay means that tritium concentrations in precipitation are lower and more spatially varied as they are influenced locally by point source nuclear generating stations and generally by latitude, weather trends and distance from the oceans. In this investigation, we establish a tritium input function (T0) by interpolating tritium concentrations in shallow, modern groundwater throughout southern Ontario. Groundwater samples representing shallow, modern conditions were carefully selected from the OGS Ambient Groundwater Geochemical data set, using criteria related to aquifer type, well depth and probabilities of encountering tritium concentrations resembling background precipitation levels. The shallow groundwater T0 is established as a proxy for precipitation data, the actual data for which are too sparsely distributed to capture the observed spatial variability in tritium concentrations. Use of this proxy for a precipitation T0 is supported by the good spatial and temporal agreement between shallow groundwater tritium concentrations and sparser data sets in precipitation, tributaries and the Great Lakes. The shallow groundwater tritium interpolation at specific locations can then be used as T0 to estimate groundwater ages where tritium data are available from the deep, subcropping bedrock aquifers throughout the study area. Groundwater ages in these deep aquifers are controlled by geological characteristics such that the youngest waters, recharged in the past 10 years, occur in areas of known or inferred karst underlying thin sediments. The oldest (pre-1950s) waters occur in aquifers underlying the thickest sediment packages. The relative groundwater ages mapped here offer insights into resource renewability by distinguishing recently recharged groundwaters from older groundwaters that may not be connected to the meteoric system.

Impact of Seasonality on Nutrient Transport Pathways Under Temperate Climate Conditions in an Agriculturally Intense Great Lakes Clay Plain Basin

Rixon, Sarah[1]; Hannah May[1], Andrew Binns[1], Jana Levison[1], Pradeep Goel[2], Elisha Persaud[1], Scott Gardner[1], and Ahmed Elsayed[1]

[1] *School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1*
[2] *Ministry of the Environment, Conservation and Parks, Etobicoke, ON*

Water quality continues to degrade within the Great Lakes basin as a result of inadequate nutrient and stormwater management practices. Excessive nutrient and sediment loss from agricultural land to water bodies have severe consequences on human and aquatic life, such as perpetual algal blooms and contaminated drinking water systems. It is understood that nutrient loadings from agricultural land to receiving water bodies can occur all year and can be exacerbated in the non-growing season (NGS) (November–April). An often-overlooked piece of the transport puzzle is groundwater discharge as a potential source of nutrients from land to water bodies, contributing to eutrophication concerns.

Research is conducted in a small southwestern Ontario watershed within the jurisdiction of the Ausable Bayfield Conservation Authority. Land use is predominantly agricultural, consisting of mainly low permeability soils. The Ontario Ministry of the Environment, Conservation and Parks (MECP) established an Integrated Climate and Water Monitoring Station at the outlet of the watershed along the main channel in 2012. Year-round watershed-scale groundwater and surface water quality and quantity monitoring began in 2017. Completed work includes integrated modelling of groundwater–surface water interactions (Persaud et al. 2020), a groundwater vulnerability assessment (Persaud and Levison 2021), identification of spatial and seasonal nutrient (N, P) dynamics in groundwater and surface water (Rixon et al. 2020; Mackie et al. 2021), and determination of the effect of land use changes on the morphology of the creek (Gardner et al., in preparation). Additional research commenced in May 2020 with the objective to further investigate the various nutrient transport pathways, including groundwater–surface water interactions, tile drains, and sediment transport.

In the present study, there are six surface water sites in the watershed that are monitored for quality and flow (including a tile drainage outlet); and eight wells and nine drive-point piezometers from which groundwater elevation and quality are monitored. Six suction lysimeters are used to monitor pore water quality in the unsaturated zone. Discrete sampling methods are used to monitor surface water and groundwater concentrations of P, N and stable isotopes of water ($\delta^{18}O$ and $\delta^{2}H$). Surface water and groundwater quality samples are collected monthly and during storm events; and elevations are continually monitored. Data indicate that from January 2020 to November 2021, concentrations of total phosphorous (TP) in the surface water have ranged from 0.01 to 1.18 mg/L. Shallow groundwater (<6 m BGS) concentrations of TP range from <0.03 to 3.06 mg/L. Nitrate-N concentrations range from 0.15 to 31.8 mg/L in the surface water and from <0.06 to 13.2 mg/L in the shallow groundwater. Preliminary analysis indicates surface water and groundwater nutrient concentrations are elevated during the NGS, aligning with rising water levels, and smaller increases of nutrients occurred in late summer in 2020 and 2021. Data suggest a seasonal and event-based connection between a shallow water table and tile drainage, which may influence surface water quality. Additional work includes land surface and integrated nutrient transport modelling, and sediment transport modelling. Methods developed in this study are relevant to policy makers, scientists and landowners to understand current and future climate impacts on watershed health.

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Estimating the Number of Industrial Facilities Acting as PFAS Point Sources Based Upon Their Current and Past Activities

Roberts, Dylan M.; Kela P. Weber, and Iris Koch

Environmental Sciences Group, Department of Chemistry and Chemical Engineering, Royal Military College of Canada, Kingston, ON K7K 7B4

Since their inception, perfluoroalkyl and polyfluoroalkyl substances (PFAS) have been used in a wide breadth of industrial processes from niche applications to more ubiquitous usage cases. Despite the well-known nature of PFAS usage within specific industrial sectors, little is known about the number of facilities that may be point sources of PFAS releases. This project describes efforts to estimate the number of PFAS point sources in Ontario.

The research consisted of four parts. First, industrial sectors incidentally contaminated with PFAS containing materials were identified. Second, the individual sites pertaining to each identified industrial sector were both detailed and catalogued. Third, the sites were evaluated using decision-making frameworks specially tailored to their respective industrial sector. Fourth, using geographic information system (GIS) software, these facilities were plotted across Ontario.

Over 40 industrial sectors were identified; however, the following five have been evaluated:

- wastewater treatment
- landfills
- paper manufacturing
- fabricated metal product manufacturing, and
- automotive manufacturing

A database was populated with details for over 3200 unique sites using information gathered from informational resources, such as the National Pollutant Release Inventory (NPRI), small landfill data set, and municipal treated wastewater effluent database. To evaluate these facilities and provide estimates for the likelihood of PFAS contamination and being a point source, decision-making frameworks were developed and informed using information available regarding both the individual sites and entire industrial sectors. Throughout the course of the project, information was sourced from a plethora of publicly accessible resources such as governmental reports, scientific publications, technical support documents, company web sites, and others. Once evaluated, a unique site was assigned one of three outcomes in descending likelihood of being a PFAS point source: likely, possible, and unlikely. Afterward, the sites were then plotted across Ontario using GIS to inform prospective end-users of their likelihood of contamination, industrial sector, and the corresponding decision-making process.

Upon the evaluation of the identified industrial sectors, 1482 individual sites were concluded to be likely point sources PFAS and a further 1734 sites were considered as possible point sources. The nature of the informational resources used precluded the assessment of historic facilities and, therefore, no facilities were identified whose closure predates the usage of PFAS within their respective industrial sector. Despite this shortcoming, we anticipate that the work has provided a reliable and accurate methodology for developing the resources needed to identify additional industries of concern and the subsequent evaluation of their facilities.

Canada 1 Water: A Collaborative Approach to an Integrated Groundwater–Surface Water Modelling Framework for Climate Change Adaption

Russell, Hazen A.J.[1]**; and Steven K. Frey**[2]

[1] Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8
[2] Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6

Canada 1 Water is a three-year governmental multi-department–private-sector–academic collaboration to model the groundwater–surface water of Canada coupled with historic climate and climate scenario input. To address this challenge, continental Canada has been subdivided into 6 large watershed basins of approximately two million km^2. Ontario forms part of three of these watershed basins: Nelson, Hudson, and Atlantic. The Great Lakes–St. Lawrence River system forms the western part of the Atlantic watershed. The inclusion of the transboundary watersheds will provide further assessment of water resources in this critical international domain. In year one (2021–2022), data assembly and validation of some 20 data sets (layers) is the focus of work along with conceptual model development. To support analysis of the complete water balance under current and future climate, the modelling framework consists of three distinct components and modelling software. Land Surface modelling with the Community Land Model will provide information needed for both the regional climate modelling using the Weather Research and Forecasting model (WRF), and input to HydroGeoSphere for groundwater–surface water modelling. Modelling is also being integrated with Remote Sensing data sets, notably the Gravity Recovery and Climate Experiment (GRACE). GRACE supports regional-scale watershed analysis of total water flux. GRACE along with terrestrial time-series data will provide validation data sets for model results to ensure that the final project outputs are representative and reliable. The project has an active engagement and collaborative effort underway to try and maximize the long-term benefit of the data and modelling framework. Much of the supporting model data sets will be published under the Government of Canada open access licence to support broad usage and integration.

Geologic Controls on Porosity and Permeability in the Silurian Lockport Group to A-1 Carbonate, Southwestern Ontario

Sun, Shuo[1,2]; Frank R. Brunton[1,3], Terry Carter[4], and Jisuo Jin[1]

[1] *Department of Earth Sciences, University of Western Ontario, 1151 Richmond Street, London, ON N6A 5B7*
[2] *Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3*
[3] *Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Northern Development, Mines, Natural Resources and Forestry, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5*
[4] *Geological Consultant, 35 Parks Edge Crescent, London, ON N6K 3P4*

The Lockport Group comprises stacked dolostones in ascending order: Gasport, Goat Island, Eramosa, and Guelph formations. These dolostones, which form the prominent Niagara Escarpment and cuesta, are amongst the most economically significant sedimentary rocks in southern Ontario because they host bedrock potable groundwater resources, building stone and aggregate resources and, in the deeper subsurface, are significant oil or gas plays and natural gas storage reservoirs. This succession is overlain by the evaporitic carbonate Salina Group strata that comprise, in ascending order: A-1 Unit (A-0 Carbonate, A-1 Evaporite, A-1 Carbonate), and overlying A-2 Carbonate, forming a self-sourcing hydrocarbon play together with the Lockport Group. New mapping results indicate that pinnacle structures and inner-pinnacle karst in this carbonate succession developed in a broad inner ramp transitioned eastward and southeastward into mid-ramp and more open marine environments.

Porosity and permeability analyses are examined from 150 cored petroleum wells stored in the Oil, Gas and Salt Resources Library (OGSRL), including three located in the subsurface of inter-pinnacle karst zone, 54 within the pinnacle structures in carbonate ramp and 93 in the restricted to open marine, inner-middle carbonate ramp. Analyses from 4 additional cored wells at the Bruce nuclear site provide a data comparison of the Lockport to A-1 Carbonate inter-pinnacle karst zone. The data sets comprise 11,765 validated porosity and vertical and/or horizontal permeability analyses, derived primarily from the dolostones of Guelph Formation and dolostones and/or limestones of A-1 Carbonate. Dolomitization is interpreted to have been caused by circulation of hyper-saline marine water prior to the deposition of A-2 Anhydrite. Dedolomitization took place in the A-1 Carbonate within pinnacle structures, likely during subaerial episodes prior to the deposition of A-2 Anhydrite.

Regional porosity and permeability distribution trends indicate strong correlation with lithofacies, paleo-karstic zones and dolomitization. Dolostones in the inter-pinnacle karst have relatively high porosity and permeability with pore systems dominated by irregular, karstic vugs and interparticle and intercrystalline microporosity resulting from fabric-preserving dolomitization and/or paleo-karstification. Calcite-cemented dolostone as karst rubbles are very common in the Guelph Formation with sharp and irregular contact with the highly dolomitized mudstone matrix. Although dolostones have non-fabric selective vugs, pores appear to be effective for fluid flow by the enclosing microporosity systems, as indicated by their relatively high permeability. Within pinnacle structures, the dolostones in Guelph and A-1 Carbonate formations show wide variation in porosity and permeability possibly a result, in part, of the heterogeneity of lithofacies and diagenetic fabrics. Porosity types include irregular, centimetre-sized vugs along karstic conduits and interparticle and intercrystalline micro-porosity enhanced by dolomitization. These dolostones show good porosity–permeability correlation. In the variably karstic carbonate bank settings, porosity–permeability in Guelph to A-1 Carbonate formations show a general decrease from southwest to northeast. In oil and gas pools in western Lake Erie, the higher porosity is controlled by biohermal facies and dolomitization of the Guelph and Goat Island formations. Cavities, vugs and intercrystalline porosity dominate the system. The fabric-preserving dolomitization may have been controlled by diagenetic fluids (modified marine water). Northeastward, the relatively lower porosity may indicate fabric destruction during early diagenesis under open-marine conditions.

Approaches for Evaluating Septic System Effluent Inputs to Tributaries and Distinguishing Contributing Pathways

Tamang, Archana[1]; James W. Roy[1,2], Christopher Jobity[1], and Clare E. Robinson[1]

[1] Department of Civil and Environmental Engineering, University of Western Ontario, London, ON N6A 5B9
[2] Water Science and Technology Directorate, Environment and Climate Change Canada, Burlington, ON L7S 1A1

Quantifying the amount of septic system effluent that reaches streams including the associated contaminant, including nutrient, loads is needed in many watersheds to inform water quality management programs. This quantification is challenging because of the distributed locations of septic systems across watersheds and uncertainties regarding the pathways delivering effluent from septic systems (functioning and failing) to a stream. Recent studies have shown that the artificial sweetener acesulfame can be a useful tracer for quantifying upstream inputs of septic effluent to streams. However, there is a lack of detailed study on this application including its ability to identify septic effluent inputs to streams from failing septic systems. Septic systems can fail in various ways and understanding the types and rates of septic system failures is critical for predicting the pathways via which septic effluent is delivered to streams and, thus, the associated contaminant, including nutrient, loads.
In this study, we conducted artificial sweetener and nutrient stream measurements in twelve subwatersheds in southern Ontario, with no other identified sources of acesulfame (e.g., no wastewater treatment plants, landfills) and with varying surficial geology, septic system density, watershed area, and mean septic system age. The fraction of septic effluent reaching the subwatershed outlets was found to vary between the subwatersheds with no clear relationships observed with the surficial geology, subwatershed area, or septic system density. Positive acesulfame concentration–stream discharge (C–Q) relationships were observed for five of the subwatersheds indicating that pathways, such as surface runoff, may deliver septic effluent from failing septic systems to streams during wet weather conditions (i.e., caused by effluent breakout to surface from septic drain field). Intra-event concentration–stream discharge relationships were examined in five subwatersheds where the changes (hysteresis) in the acesulfame concentrations over individual events were used to disentangle the pathways delivering septic effluent to the subwatersheds. These relationships show that different pathways may dominate for different subwatersheds and at different times of year. For example, groundwater pathways dominate in some subwatersheds and more rapid pathways associated with failing septic systems (e.g., overland runoff) may dominate in others. This research study is ongoing with further work, which will be conducted in the Lake Erie Basin and Lake Simcoe Basin, aiming to better identify the factors (spatial and temporal) contributing to the amounts and pathways by which septic effluent reaches streams. The findings of this research are needed to guide investigations aiming to quantify and manage water quality impairment from septic systems in watersheds.

Identifying Significant Groundwater Recharge Areas and Modelling of Surface–Subsurface Water Balance of the Neebing River

Vehling, Tim; Adam Cornwell, Kamil Zaniewski, and Robert Stewart
Department of Geography and the Environment, Lakehead University, Thunder Bay, ON P7B 5E1

The hydrological function assessment of the Neebing River is part of a greater provincial project to better understand our watersheds, streams, and groundwater–surface water interactions. Hydrological function assessments have been conducted in other parts of Ontario; however, there is limited information on northern watersheds. These previous assessments provide a useful example for the ongoing work with the Neebing River. This project will consist of three components: thematic mapping, surface water, and groundwater interactions modelling and isotope sampling. Thematic mapping of the significant groundwater recharge areas will identify the areas that have an above average contribution to the groundwater within the watershed. Infiltration rates will be developed from the thematic maps which are modelled from topographic, soil and land use data. From this information, surface and subsurface water interactions, and seasonal and annual water balance patterns will be used to develop a model to indicate whether there is a relationship between the climatic and hydrologic variables. Stable isotope sampling will also be used to validate the statistical analysis and the derivation of baseflow from streamflow to ensure accurate conclusions. Expected results include a relationship between the distribution of significant groundwater recharge areas and groundwater contribution to streamflow and a temporal relationship between climatic and hydrologic variables. Gaining a better understanding of the Neebing River watershed and establishing baselines for the hydrologic function of groundwater and surface water interactions will help with future studies of the impacts of climate change on this watershed.

Ministry of the Environment, Conservation and Parks – Groundwater Activities Update

Zhang, Helen; and Luciana Rodrigues

Ministry of the Environment, Conservation and Parks, North Wing, 2nd Floor, 125 Resources Road, Toronto, ON M9P 3V6

The Ontario government is committed to protecting our lakes, waterways and groundwater supply, now and for future generations. Our lakes, waterways and groundwater are a vital resource and the foundation of Ontario's economic prosperity and well being – supplying water to our communities, sustaining traditional activities of Indigenous peoples, supporting Ontario's economy, and providing healthy ecosystems for recreation and tourism.

The ministry is moving forward with enhancements to the province's water taking program as part of its commitment to ensure our water resources are protected and used sustainably. After years of public consultations and an extensive review of the province's water taking policies, programs and science tools, the ministry has finalized enhancements to Ontario's water taking program, and the associated regulatory amendments to the *Water Taking and Transfer* Regulation (*O. Reg. 387/04*) under the *Ontario Water Resources Act, R.S.O. 1990* and the *Registrations under Part II.2 of the Act - Water Taking* Regulation (*O. Reg. 63/16*) under the *Environmental Protection Act, R.S.O. 1990*.

The ministry has continued to maintain the Provincial Groundwater Monitoring Network (PGMN) program and has made progress on several initiatives including improving timely data sharing techniques and the understanding of chloride concentration status and trend across the province using PGMN wells.

In support of the commitments of the renewed *Canada–Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2021*, the ministry has funded a number of groundwater quality and quantity studies related to groundwater–surface water interaction, climate change effects and groundwater contaminant and/or pollutant transport.

This talk will focus on providing updates on Ministry groundwater–related activities such as these.

Presenters, Authors and Key Participants

LAST NAME	FIRST NAME	AFFILIATION/ADDRESS	EMAIL
Al-Mufti	Omar	Department of Earth and Environmental Sciences, University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5	onalmufti@gmail.com
Alpay	Sam	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	sam.alpay@NRCan-RNCan.gc.ca
Anderson	Kristina	Toronto Region Conservation Authority, 101 Exchange Avenue, Vaughan, ON L4K 5R6	Kristina.Anderson@trca.ca
Arnaud	Emmanuelle	School of Environmental Sciences, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	earnaud@uoguelph.ca
Arnott	William	Department of Earth and Environmental Sciences, University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5	warnott@uottawa.ca
Ayers	Jessi	Department of Environmental Science, Policy, and Management, University of California–Berkeley, 130 Mulford Hall, Berkeley, California 94720-3114	jessiayers@berkeley.edu
Belitz	Kenneth	Earth Systems Processes Division, Water Mission Area, United States Geological Survey	kbelitz@usgs.gov
Beneteau	Steve	Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	steve.beneteau@ontario.ca
Binns	Andrew	School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	binns@uoguelph.ca
Boisvert	Eric	Geological Survey of Canada, 490 rue de la Couronne, Québec City, QC G1K 9A9	eric.boisvert@NRCan-RNCan.gc.ca
Brewer	Kevin	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	kevin.brewer@NRCan-RNCan.gc.ca
Brookfield	Andrea	Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	andrea.brookfield@uwaterloo.ca
Brown	Jesse	School of Environmental Sciences, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	jbrown72@uoguelph.ca
Brunton	Frank	Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	frank.brunton@ontario.ca
Bunn	Melissa	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	melissa.bunn@NRCan-RNCan.gc.ca
Burt	Abigail	Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	abigail.burt@ontario.ca
Carter	Terry	Geological Consultant, 35 Parks Edge Crescent, London, ON N6K 3P4	terry.carter@cartergeologic.com
Cartwright	Tim	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	tim.cartwright@NRCan-RNCan.gc.ca
Clark	Ian	University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5	idclark@uOttawa.ca
Clark	Jordan	Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3	jordan@ogsrlibrary.com

Presenters, Authors and Key Participants (continued)

LAST NAME	FIRST NAME	AFFILIATION/ADDRESS	EMAIL
Conway-White	Oliver	School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	oliver.conway-white@g360group.org
Cornwall	Adam	Department of Geography and the Environment, Lakehead University, Thunder Bay, ON P7B 5E1	acornwel@lakeheadu.ca
Crow	Heather	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	heather.crow@NRCan-RNCan.gc.ca
Crowley	John	Canadian Geodetic Survey, Natural Resources Canada, 588 Booth Street, Ottawa, ON K1A 0Y7 Department of Earth and Environmental Sciences, University of Ottawa, 150 Louis-Pasteur Private, Ottawa, ON K1N 6N5	john.Crowley@NRCan-RNCan.gc.ca
D'Arienzo	Maryrose	Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3	maryrose@ogsrlibrary.com
Des Roches	Mathieu	Institut national de la recherche scientifique (INRS), Centre ÉTÉ, 490 rue de la Couronne, Québec City, QC G1K 9A9	mathieu.des_roches@ete.inrs.ca
Dietiker	Barbara	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	barbara.dietiker@NRCan-RNCan.gc.ca
Dodge	John	Information & Digital Services, Information & Lands Branch, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	john.dodge@ontario.ca
Doughty	Mike	Oak Ridges Moraine Groundwater Program, 101 Exchange Avenue, Vaughn, ON L4K 5R6	mdoughty@owrc.ca
Dupont	Matthew	Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3	matt@ogsrlibrary.com
Elsayed	Ahmed	School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	aelsay03@uoguelph.ca
Erler	Andre	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6 Department of Geography and Environmental Management, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	AErler@aquanty.com
Evers	Alphons	Information & Digital Services, Information & Lands Branch, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	alphons.evers@ontario.ca
Ford	Don	Toronto Region Conservation Authority, 101 Exchange Avenue, Vaughan, ON L4K 5R6	don.ford@trca.ca
Frey	Steven	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6 Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	sfrey@aquanty.com
Gardner	Scott	School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	sgardner@uoguelph.ca
Gavine	Kim	Conservation Ontario, 120 Bayview Parkway, Newmarket, ON L3Y 3W3	kgavine@conservationontario.ca
Gerber	Richard	Oak Ridges Moraine Groundwater Program, 101 Exchange Avenue, Vaughn, ON L4K 5R6	rgerber@owrc.ca
Goel	Pradeep	Ministry of the Environment, Conservation and Parks, Etobicoke, ON	Pradeep.Goel@ontario.ca

Presenters, Authors and Key Participants (continued)

LAST NAME	FIRST NAME	AFFILIATION/ADDRESS	EMAIL
Gorrie	Conner	School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	connor.gorrie@g360group.org
Hah	David	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6 Department of Civil and Environmental Engineering, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	kwhah@uwaterloo.ca
Hamilton	Stew	Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	stew.hamilton@ontario.ca
Handley	Laura	Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	laura.handley@ontario.ca
Hinnegan	Kyra	Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3	info@ogsrlibrary.com
Hinton	Mark	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	mark.hinton@nrcan-rncan.gc.ca
Holysh	Steve	Oak Ridges Moraine Groundwater Program, 101 Exchange Avenue, Vaughan, ON L4K 5R6	sholysh@owrc.ca
Huang	Jianliang	Canadian Geodetic Survey, Natural Resources Canada, 588 Booth Street, Ottawa, ON K1A 0Y7	jianliang.huang@NRCan-RNCan.gc.ca
James	April	Department of Geography, Nipissing University, 100 College Drive, North Bay, ON P1B 8L7	aprilj@nipissingu.ca
Jin	Jisuo	Department of Earth Sciences, University of Western Ontario, 1151 Richmond Street, London, ON N6A 5B7	jjin@uwo.ca
Jobity	Christopher	Department of Civil and Environmental Engineering, University of Western Ontario, London, ON N6A 5B9	cjobity@uwo.ca
Khader	Omar	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6	okhader@aquanty.com
Koch	Iris	Environmental Sciences Group, Department of Chemistry and Chemical Engineering, Royal Military College of Canada, Kingston, ON K7K 7B4	koch-i@rmc.ca
Lackey	Rachel	School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	rlackey@uoguelph.ca 15rjl6@queensu.ca
Larmagnat	Stephanie	Geological Survey of Canada, 490 rue de la Couronne, Québec City, QC G1K 9A9	stephanie.larmagnat@NRCan-RNCan.gc.ca
Lemieux	Alex	Canadian Nuclear Safety Commission, 280 Slater Street, Ottawa, ON K1P 5S9	alexander.lemieux@cnsc-ccsn.gc.ca
Letellier	Philippe	Institut national de la recherche scientifique (INRS), Centre ÉTÉ, 490 rue de la Couronne, Québec City, QC G1K 9A9	Philippe.Letellier@inrs.ca
Levison	Jana	School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	jlevison@uoguelph.ca
Logan	Charles	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	charles.logan@NRCan-RNCan.gc.ca
Mackie	Ceilidh	School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	mackiec@uoguelph.ca

Presenters, Authors and Key Participants (continued)

LAST NAME	FIRST NAME	AFFILIATION/ADDRESS	EMAIL
Macrae	Merrin	Department of Geography, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	mmacrae@uwaterloo.ca
Marchildon	Mason	Oak Ridges Moraine Groundwater Program, 101 Exchange Avenue, Vaughan, ON L4K 5R6	mmarchildon@owrc.ca
May	Hannah	School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	hmay@uoguelph.ca
Montgomery	Kimberly	Department of Geography, Nipissing University, 100 College Drive, North Bay, ON P1B 8L7	kmontgomery345@my.nipissingu.ca
Mohamed	Mohamed	Environment and Climate Change Canada, Canada Centre for Inland Waters (CCIW), 867 Lakeshore Road, Burlington, ON L7S 4A1	mohamed.mohamed3@canada.ca
Mulligan	Riley	Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	riley.mulligan@ontario.ca
Munn	Jonathan	Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	jmunn@g360group.org
Murray	Julian	Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	julian.murray@uwaterloo.ca
Parker	Beth	School of Engineering, Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	bparker@g360group.org
Pehme	Peeter	Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	ppehme@waterloogeophysics.com
Persaud	Elisha	School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	epersaud@uoguelph.ca
Priebe	Elizabeth	Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, NDMNRF, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5	elizabeth.priebe@ontario.ca
Pugin	Andre	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	andre.pugin@NRCan-RNCan.gc.ca
Reeves	Howard	United States Geological Survey	hwreeves@usgs.gov
Rixon	Sarah	School of Engineering, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	srixon@uoguelph.ca
Roberts	Dylan	Environmental Sciences Group, Department of Chemistry and Chemical Engineering, Royal Military College of Canada, Kingston, ON K7K 7B4	Dylan.Roberts@rmc-cmr.ca
Robinson	Clare	Department of Civil and Environmental Engineering, University of Western Ontario, London, ON N6A 5B9	crobinson@eng.uwo.ca
Rodrigues	Luciana	Technical Assessment and Standards Development Branch, Ministry of the Environment, Conservation and Parks, 40 St. Clair Avenue West, Toronto, ON M4V 1M2	Luciana.Rodrigues@ontario.ca
Rowan	David	Canadian Nuclear Laboratories, 286 Plant Road, Chalk River, ON K0J 1J0	david.rowan@cnl.ca
Roy	James	Department of Civil and Environmental Engineering, University of Western Ontario, London, ON N6A 5B9 Water Science and Technology Directorate, Environment and Climate Change Canada, Burlington, ON L7S 1A1	Jim.Roy@ec.gc.ca

Presenters, Authors and Key Participants (continued)

LAST NAME	FIRST NAME	AFFILIATION/ADDRESS	EMAIL
Russell	Hazen	Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa, ON K1A 0E8	hazen.russell@NRCan-RNCan.gc.ca
Shamalisham	Najmi	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6	NShamalisham@aquanty.com
Shikaze	Steve	Oak Ridges Moraine Groundwater Program, 101 Exchange Avenue, Vaughn, ON L4K 5R6	sshikaze@owrc.ca
Sibo	Ninava	Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3	info@ogsrlibrary.com
Smith	Britt	Oak Ridges Moraine Groundwater Program, 101 Exchange Avenue, Vaughn, ON L4K 5R6	bsmith@owrc.ca
Steelman	Colby	Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1 Morwick G360 Groundwater Research Institute, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1	cmsteelman@uwaterloo.ca
Stewart	Robert	Department of Geography and the Environment, Lakehead University, Thunder Bay, ON P7B 5E1	rob.stewart@lakeheadu.ca
Stonebridge	Graham	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6 Department of Systems Design Engineering University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	gStonebridge@aquanty.com
Sudicky	Ed	Aquanty Inc., 564 Weber Street North, Waterloo, ON N2L 5C6 Department of Earth and Environmental Sciences, University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1	sudicky@uwaterloo.ca
Sun	Shuo	Department of Earth Sciences, University of Western Ontario, 1151 Richmond Street, London, ON N6A 5B7 Oil, Gas and Salt Resources Library, 669 Exeter Road, London, ON N6E 1L3	ssun224@uwo.ca
Tafvizi	Arghavan	Department of Biology, Laurentian University, 935 Ramsey Lake Road, Sudbury, ON P3E 2C6	atafvizi@laurentian.ca
Tamang	Archana	Department of Civil and Environmental Engineering, University of Western Ontario, London, ON N6A 5B9	archanatamang94@gmail.com
Vehling	Tim	Department of Geography and the Environment, Lakehead University, Thunder Bay, ON P7B 5E1	tvehling@lakeheadu.ca
Veronneau	Marc	Canadian Geodetic Survey, Natural Resources Canada, 588 Booth Street, Ottawa, ON K1A 0Y7	marc.veronneau@NRCan-RNCan.gc.ca
Weber	Kela	Environmental Sciences Group, Department of Chemistry and Chemical Engineering, Royal Military College of Canada, Kingston, ON K7K 7B4	Kela.weber@rmc-cmr.ca
Zaniewski	Kamil	Department of Geography and the Environment, Lakehead University, Thunder Bay, ON P7B 5E1	kzaniews@lakeheadu.ca
Zhang	Helen	Ministry of the Environment, Conservation and Parks, North Wing, 2nd Floor, 125 Resources Road, Toronto, ON M9P 3V6	helen.zhang@ontario.ca

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton(short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 9**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy) / ton (short)	1 ounce (troy) / ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights / ton (short)	1 pennyweight / ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

*Note: Conversion factors in **bold** type are exact. The conversion factors have been taken from or have been derived from factors given in the* Metric Practice Guide for the Canadian Mining and Metallurgical Industries*, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.*

Notes

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