ISSN 1916-6117 (online)
ISBN 978-1-4868-4214-8 (PDF)
(for entire OFR 6361)

ISSN 0826-9580 (print)
ISBN 978-1-4868-4213-1 (print)
(for entire OFR 6361)

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or, for partial Content

Eberts, S.M. 2020. U.S. Geological Survey Water Resources Mission Area priority programs; abstract *in* 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, p.13.

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Ontario Geological Survey
Open File Report 6361

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

2020

ONTARIO GEOLOGICAL SURVEY

Open File Report 6361

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

Compiled by

E.H. Priebe, S. Holysh, D. Ford, H.A.J. Russell and J.E. Nadeau

2020

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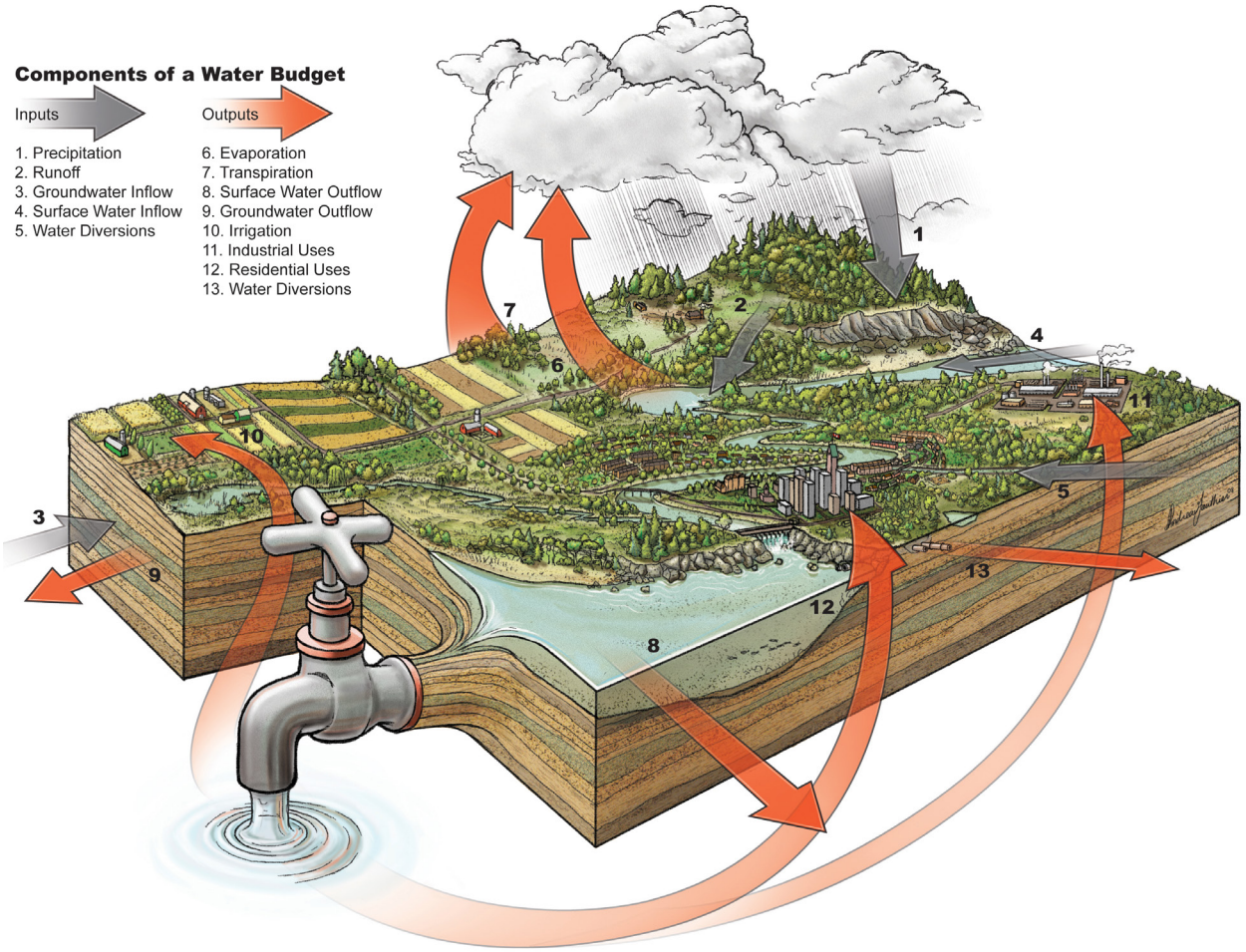
Regional-Scale Groundwater Geoscience in Southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House

February 19th and 20th, 2020 | Federation Hall, Waterloo, Ontario



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Ontario Geological Survey, Open File Report 6361

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ISBN 978-1-4868-4213-1 (print)
ISBN 978-1-4868-4214-8 (PDF)

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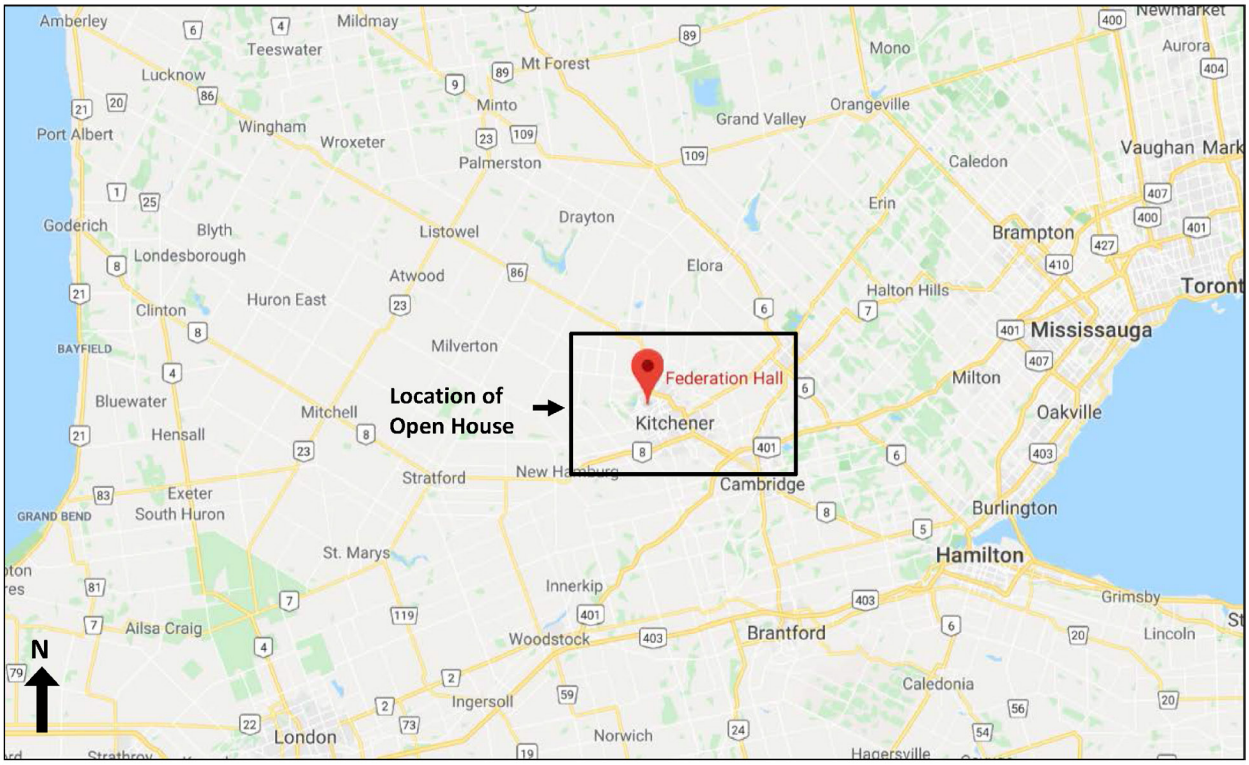
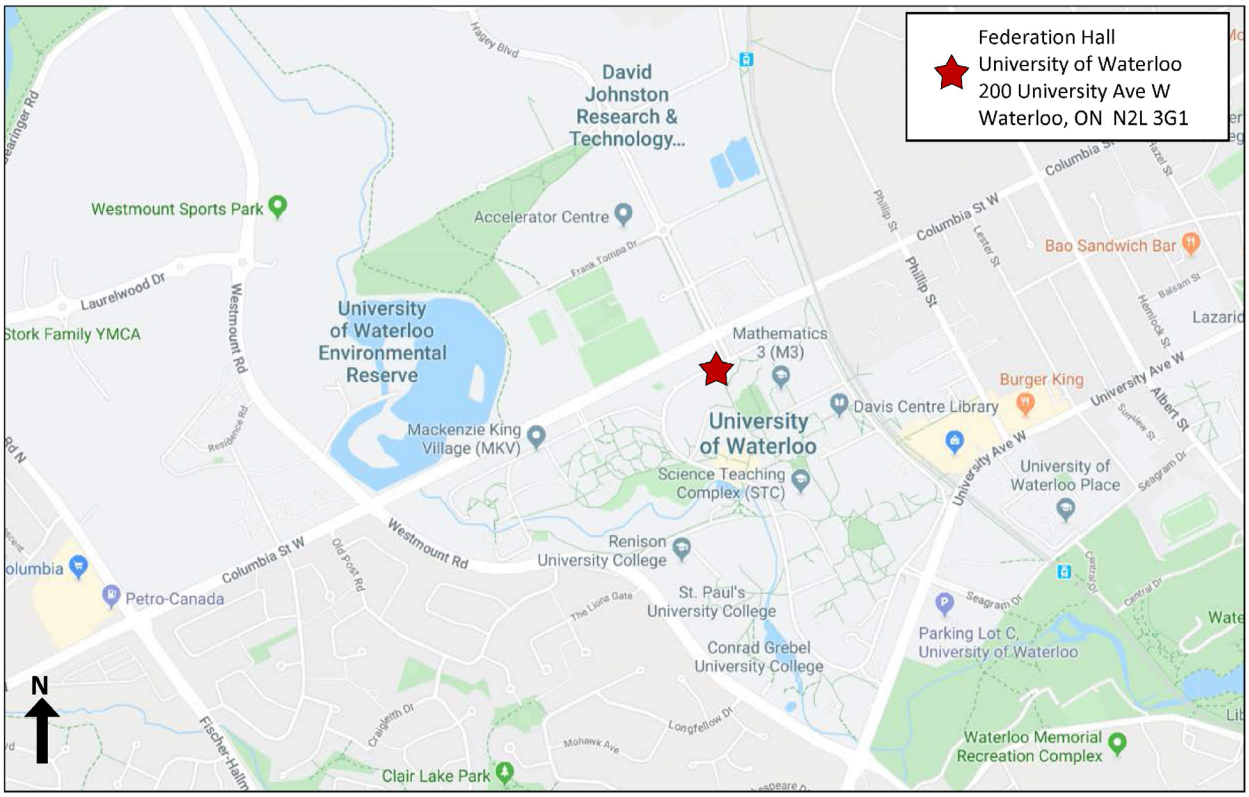
Location Map





Program

February 19th Oral Presentations

START	END	TITLE	PRESENTER	AFFILIATION
8:00	8:45	Registration and Networking		
8:45	8:55	Welcome to Day 1 / Logistical Details	Priebe / Russell	OGS / GSC
8:55	9:10	Opening Ceremony	Kelly F. Davis	Six Nations of the Grand River Territory
9:10	9:20	Introduction	Michaud / Beneteau	GSC / OGS
9:20	9:40	GSC Activity in Southern Ontario for 2019–2024	Hazen Russell	GSC
9:40	10:00	Ministry of Environment, Conservation and Parks Groundwater Activities Update	Heather Brodie-Brown	MECP
10:00	10:20	U.S. Geological Survey Water Resources Mission Area Priority Programs	Sandra Eberts	USGS
10:20	**10:45**	**Break**		
10:45	11:05	Canada–3D: Toward a National Geological Model with Groundwater Applications	Boyan Brodaric	GSC
11:05	11:25	Investigating the Controls on Groundwater Chemistry in Crystalline Silicate Rock Terrain in Northeastern Ontario	Kayla Dell	OGS
11:25	11:45	Sulphur Isotopic Evidence of Terrestrial Evaporites in the Queenston Formation, and the Implications for Groundwater Quality on the Niagara Peninsula	Stew Hamilton	OGS
11:45	12:05	Characterization of Groundwater Geochemistry in Eastern Ontario	Shane Foubister	University of Ottawa
12:05	**13:00**	**Lunch**		
13:00	13:20	A Regional Stratigraphic Framework for Hydrogeologic Studies Above the Niagara Escarpment in Southern Ontario	Abigail Burt	OGS
13:20	13:40	Geologic Controls on Groundwater Flow in Surficial Sediments in Simcoe County, Southern Ontario	Riley Mulligan	OGS
13:40	14:00	Regional Groundwater Systems Mapping in Simcoe County, Southern Ontario	Elizabeth Priebe	OGS
14:00	14:20	Introducing the New Electronic Permit to Take Water Application and Reporting System	Stuart Miller	MECP
14:20	**14:40**	**Break**		
14:40	15:00	A Proposed Hydrostratigraphic Chart for Southern Ontario	Terry Carter	Independent
15:00	15:20	Geographic Analysis of the Porosity and Permeability Variations in the Silurian Lockport Group, Southern Ontario	Shuo Sun	University of Western Ontario / OGSRL
15:20	15:40	Characterizing Regional- and Watershed-Scale Groundwater–Surface Water Interactions with a Fully Integrated Groundwater–Surface Water Model	Steven Frey	Aquanty
15:40	16:00	Using Porewater Chemistry in Champlain Sea Muds to Constrain Groundwater Flow	Mark Hinton	GSC
16:00	**16:20**	**Wrap-up**		

Program (cont.)

February 20th Oral Presentations

START	END	TITLE	PRESENTER	AFFILIATION
8:00	8:45	Registration and Networking		
8:45	8:55	Welcome to Day 2 Conservation Authorities Geoscience	Ford / Holysh	TRCA / Oak Ridges Water
8:55	9:10	Opening Ceremony	Kelly F. Davis	Six Nations of the Grand River Territory
9:10	10:20	**Approaching the 50th Anniversary of the GLWQA** A Panel Discussion focussed on groundwater science in the Great Lakes **Panelists** Mohamed Mohamed, Heather Brodie-Brown, Sandra Eberts and Lizhu Wang	Yves Michaud	GSC
10:20	**10:40**	**Break**		
10:40	12:00	**Approaching the 50th Anniversary of the GLWQA** (Panel Discussion cont.)		
12:00	**13:15**	**Lunch**		
13:15	13:40	The Information of Data	Mason Marchildon	Oak Ridges Water
13:40	14:05	Groundwater "Areas of Concern" Mapping, South-Central Ontario	Richard Gerber	Oak Ridges Water
14:05	14:30	Reclassifying an Existing GUDI System Under the New Draft GUDI Terms of Reference	Erin Wilson	Regional Municipality of York
14:30	14:55	Utilizing Source Protection Knowledge to Improve Groundwater Management While Encouraging Urban Development in the City of Barrie	Paul Martin	Aqua Insight Inc.
14:55	**15:25**	**Break**		
15:25	15:50	A New Don – Build Me a River	Don Ford	TRCA
15:50	16:15	Integration of Frequency-Domain Airborne Electromagnetics, Surface Geophysics and High-Resolution Boreholes to Support Groundwater Resource Assessments	Colby Steelman	University of Waterloo / G360
16:15	**16:25**	**Wrap-up**		

Program (cont.)

February 19th and 20th Poster Presentations

	TITLE	AUTHOR / PRESENTER	AFFILIATION
1	3-Dimensional Mapping of Surficial Deposits in the Southern Part of the County of Simcoe, South-Central Ontario	Andy Bajc	OGS
2	The Niagara Peninsula 3-D Sediment Mapping Project: From Data Acquisition to Modelling	Abigail Burt	OGS
3	Karst Map of Southern Ontario: An Update	Frank Brunton	OGS
4	QA/QC Examination of Archived Drill Cuttings, Core and Geophysical Logs to Improve Bedrock Geological Data Quality in Southern Ontario	Alexandre Cachunjua	OGSRL
5	Investigating the Controls on Groundwater Chemistry in Crystalline Silicate Rock Terrain in Northeastern Ontario	Kayla Dell	OGS
6	Sulphur Isotopic Evidence of Terrestrial Evaporites in the Queenston Formation, and the Implications for Groundwater Quality on the Niagara Peninsula	Stew Hamilton	OGS
7	Assessing the Hydrogeological Properties Influencing Nitrate Distribution in a Shallow Unconfined Fractured Bedrock Aquifer	James Hommersen	G^{360}
8	Fate of Land Applied Waste Greenhouse Nutrient Feed Water During Controlled Field Infiltration Experiments	Jiangyue Ju	University of Waterloo
9	Using the New 3-D Digital Model of Ontario's Paleozoic Geology to Bridge Gaps in the Traditional Education Framework	Jeremy Kamutzki	University of Waterloo
10	Determination of the Source of Salt Contamination Using a Combination of Novel Stable Isotopic Parameters (^{37}Cl, ^{81}Br, ^{18}O, ^{2}H) and Tritium to Assess the Impact on Regional Groundwater Supplies in Southern Ontario, Canada	Lori Labelle	University of Waterloo
11	Quaternary Stratigraphy and Hydrogeology in Central Simcoe County	Riley Mulligan	OGS
12	Geological Controls on Hydraulic Conductivity in the Karst-Influenced, Carbonate Groundwater Systems of the Lockport Group, Guelph Region	Elizabeth Priebe	OGS
13	Learning About Ontario's Paleozoic Geology with Virtual Reality Google Expedition Tours	Henry Visneskie	University of Waterloo

Context

The 2020 Ontario Geological Survey (OGS), Geological Survey of Canada (GSC) and Conservation Ontario (CO) groundwater open house represents the 5th annual event of its kind. 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. Survey results from the 2019 open house demonstrated the importance of such an event to continue.

The aim of the 2020 open house is to share OGS, GSC and CO groundwater mapping results and products with a wide range of client groups and to advance groundwater geoscience knowledge across southern Ontario. Oral presentations on the first day will be delivered by OGS and GSC geoscientists, government partners and collaborators. The OGS presentations will provide a comprehensive overview of the results and ongoing activities of current projects related to 3-D sediment mapping, hydrogeology and hydrochemistry. Presentations from the GSC will highlight many products from the large collaborative investigations conducted in the past five years, as well as a discussion of plans for future groundwater work in southern Ontario. The first day of the open house will also feature an invited presentation by the United States Geological Survey, offering the opportunity to learn about jurisdictional differences in approaching groundwater monitoring and management. The second day of the open house comprises presentations from Conservation Authorities and collaborators, as well as a discussion panel focussed on groundwater in the Great Lakes and the organizations committed to improving understanding and management of these water resources.

The poster session will span two days and will highlight the work of the hosting agencies as well as many graduate students from local universities who are conducting groundwater research in southern Ontario.

As in previous years, we trust that the 2020 open house will remain a valuable forum for sharing groundwater information and networking with peers in southern Ontario. Contact information for speakers and poster presenters is provided in this compilation to support future connections.

Acknowledgements

Day 2 has been sponsored by a contribution to Conservation Ontario Geoscientists Group by the International Association of Hydrogeologists Canadian National Chapter (IAH–CNC). The time and effort of the workshop presenters and their respective agencies is much appreciated. An internal review at the OGS by A.F. Bajc, F.R. Brunton, R.D. Dyer, S.M. Hamilton and D.R.B. Rainsford is much appreciated.

Associated publications of previous gap analysis, workshop(s) and open houses between 2015 and 2020.

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.

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. https://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. https://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. https://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 (https://doi.org/10.4095/313529), 32p.

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"). Some presentations may be missing and, in those cases, permission was not granted by the respective organization of the author(s).

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3-Dimensional Mapping of Surficial Deposits in the Southern Part of the County of Simcoe, South-Central Ontario

Bajc, Andy F.; Riley P.M. Mulligan and John E.P. Dodge

Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Ministry of Energy, Northern Development and Mines, 933 Ramsey Lake Rd, Sudbury, ON P3E 6B5, andy.bajc@ontario.ca

The Ontario Geological Survey (OGS) recently released the results of a multi-year project in south Simcoe County focussed on the subsurface geology of Quaternary deposits and their hydrogeologic applications. The results of this study build on a recently updated conceptual geologic model developed for the region based on observations acquired as part of extensive field programs that include detailed surficial mapping, both airborne and ground-based geophysical surveys and continuous sediment coring. The conceptual stratigraphic framework consists of 15 hydrostratigraphic units overlying Paleozoic bedrock. New OGS drilling within this area of thick drift has resulted in revisions to bedrock geology and refinements to bedrock topography.

The Quaternary sequence is grouped into 3 main sediment packages that include 1) an Illinois Episode (or older) drift sequence, consisting primarily of diamicton, overlain by non-glacial sediments spanning the Sangamon Interglacial and earliest part of the Wisconsin Episode; 2) a thick (up to 125 m), Early–Middle Wisconsin glaciolacustrine sequence (Scarborough Fm. and Thorncliffe Fm. equivalents) deposited largely within a high-level proglacial lake bordered by the advancing Georgian Bay and Lake Ontario ice lobes of the Laurentide Ice Sheet (LIS). Subsequent overriding of the lake deposits by the LIS initiated deposition of the Late Wisconsin Newmarket Till which continued during and after multiple phases of tunnel valley erosion; and 3) a mixed package of late-glacial stratified deposits laid down in interlobate, ice-marginal, deltaic and glaciolacustrine settings.

The 3-D model and accompanying report (OGS Groundwater Resources Study 18) supplements previously released data sets, including results of geophysical surveys and continuously cored boreholes. Collectively, these data provide an improved understanding of the distribution, architecture and facies variability of sediments comprising the Quaternary succession for future hydrogeologic modelling exercises. Outputs include an abbreviated version of the subsurface database (including stratigraphic picks) used for the creation of the 3-D model, a series of both continuous and discontinuous surfaces for hydrogeologic modelling (available as both ArcGIS® and ASCII grids), structural contour and isopach plots with accompanying maps showing the distribution and quality of data used for their generation, and N-S and E-W cross sections plotted at 2 km intervals using both a hydrostratigraphic legend and a simplified aquifer–aquitard–bedrock scheme. The model has also allowed for the generation of derivative products including aquifer recharge and vulnerability maps. Much of this information is viewable in a Google Earth® platform for enhanced interactive viewing and interpretation. Groundwater Resources Study 18 is available for download at http://www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=GRS018.

Canada–3D: Toward a National Geological Model with Groundwater Applications

Brodaric, Boyan; Hazen A.J. Russell, Dave Snyder and Marc St-Onge

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National geological compilations are essential to any geoscience framework underpinning a wide variety of societal applications, such as management of mineral, groundwater and other resources. While previous national compilations document the distribution of geological units on surfaces of either exposed bedrock or unconsolidated cover, recent advances in geological understanding, information technology and geological modelling, enable three-dimensional (3-D) modelling of the whole of the Canadian subsurface. Such a model would be a critical foundation for groundwater science in particular, aiding the identification, classification and characterization of aquifers, national and regional flow modelling, integrated groundwater–surface water modelling, as well as the measure of groundwater indicators for national water accounting.

To achieve this vision, the Canada–3D project is developing a new 3-D geological model for Canada, in addition to new national bedrock and surficial geology maps. Canada–3D is a national collaboration of Canada's geological surveys, with project principles including a commitment to open and accessible data and to the ongoing assimilation of data at variable resolutions to ensure an authoritative and current synthesis. Presented will be an overview of the project, including new scientific and technological results, as well as challenges and lessons learned. A new web portal will be demonstrated, highlighting the state of the bedrock and surficial map compilations, as well as progress on the national 3-D model, including integration of the recently developed Paleozoic bedrock and surficial geology models for southern Ontario. Expected beneficiaries of Canada–3D are all users of geoscience information and knowledge, including industry, other federal and provincial government departments, educational institutions and non-governmental organizations.

Ministry of Environment, Conservation and Parks Groundwater Activities Update

Brodie-Brown, Heather

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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. Through our draft environment plan, we have committed to thoroughly reviewing the province's water-taking policies, programs and science tools to ensure that vital water resources are adequately protected and sustainably used. To further these goals, the Ministry of Environment, Conservation and Parks is currently undertaking a number of groundwater-related activities including a review of its water quantity management framework and proposing to enhance how groundwater is addressed under the Canada–Ontario Agreement on the Great Lakes. This talk will focus on providing updates on Ministry groundwater-related activities such as these.

Karst Map of Southern Ontario: An Update

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The mandate of the Ontario Geological Survey (OGS) is to provide citizens and institutions of Ontario with accurate and objective earth science knowledge, in order to sustain and support quality of life, economic prosperity, environmental quality, and public health and safety. The Ontario Geological Survey updates maps of varying scales on a 10- to 25-year cycle, depending upon demand from clients and staff availability. It has been 11 years since the first karst map for southern Ontario and Manitoulin Island was published (Brunton and Dodge 2008).

Publication of the initial two-dimensional (2-D) karst map by the OGS coincided with the creation of a potable groundwater mapping initiative of Paleozoic bedrock groundwaters. The official establishment of the OGS groundwater mapping initiative in 2007, in part a response to the Walkerton tragedy in May 2000, is an outgrowth of geoscience activities that have been ongoing by the OGS for more than half a century. This initiative is an expanded geoscience mandate comprising three-dimensional (3-D) surficial and Paleozoic bedrock mapping, and ambient groundwater geochemistry.

Field-based protocols and methods have been developed since the publication of the first karst map to address the character of karstic groundwater flow zones in the potable water zones (upper 250–300 m) of the Early Silurian Niagara Escarpment cuesta and select areas in the Devonian and Ordovician cuestas. The protocols and methods coincide with the establishment of regional Paleozoic bedrock drilling programs by the OGS in the potable water zones (Devonian, Silurian and Ordovician cuestas), and have allowed for the character of deeper karst features and controls on sequence stratigraphic, karst-controlled bedrock groundwater flow zones to be outlined.

The key objectives of this update of the regional southern Ontario karst map are to 1) investigate the distributions and occurrences of karst features brought to our attention over the past decade, including cave types, sinkholes, disappearing streams and various forms of karren; 2) place the variety of karst landforms within a regional stratigraphic–sedimentologic, geomorphologic and hydrogeologic context that enables the nature of key karstic bedrock aquifers to be examined; and 3) provide a 3-D perspective to the karstic groundwater flow zones in the various cuestas across southern Ontario. Understanding where and how speleogenic (karst) processes have affected the uppermost 250 to 300 m of sedimentary bedrock in a given area is fundamental to bedrock aquifer mapping, water budget estimates within subwatershed- and/or municipal-scale to regional scales, the generation of groundwater models, and the development of vulnerability and/or susceptibility maps.

Reference

Brunton, F.R. and Dodge, J.E.P. 2008. Karst of southern Ontario and Manitoulin Island; Ontario Geological Survey, Groundwater Resources Study 5.

The Niagara Peninsula 3-D Sediment Mapping Project: From Data Acquisition to Modelling

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The Ontario Geological Survey Niagara Peninsula project encompasses 5000 km^2 extending from the Niagara River westward to Port Dover and Brantford. With the upcoming publication of a Miscellaneous Release—Data (MRD) containing detailed sediment descriptions, graphic borehole logs, photographs, analytical data and reference maps tied to recent OGS drilling, work is now focussed on producing a three-dimensional (3-D) block model of regional-scale Quaternary sediment packages. A total of 99 continuously cored boreholes, 29 of which have been converted to monitoring wells by conservation authority and municipal partners, a ground gravity survey, Geological Survey of Canada downhole geophysical logging and shallow seismic surveys coupled with the results of completed 3-D sediment mapping projects to the northwest (Orangeville–Fergus, Waterloo Region and Brantford–Woodstock) have been used to establish a conceptual geological and hydrostratigraphic framework to guide future modelling efforts.

The traditional view that the Quaternary sediment package within the project area is dominated by thin and featureless clay overlooks considerable geologic complexity resulting from a bedrock surface characterized by two escarpments and numerous buried- and partially buried-bedrock valleys that range from broad and shallow to narrow and deep, as well as ice marginal fluctuations following the last glacial maximum. The thickest sediments are found within the bedrock valleys, whereas the thinnest are found at the escarpments. Thicker sediment accumulations occur at recessional moraines, subaqueous fans, deltas and drumlins.

The physical properties of hydrostratigraphic units vary considerably across the project area. Dominantly coarse-grained and often water-bearing pre-Catfish Creek Till deposits appear to have been preferentially preserved in the deep and narrow bedrock valleys. Diamicton, glaciolacustrine and glaciofluvial deposits in the southwestern part of the area are correlated with the Nissouri to Mackinaw phases Catfish Creek Till, Erie Phase, Port Stanley Till, Grand River Outwash and Wentworth aquifers and aquitards modelled in adjoining project areas. Meanwhile, a continuous ice cover in the central and eastern portions of the peninsula during most of this interval resulted in deposition of a Catfish Creek Till to Wentworth Till continuum. Glaciofluvial and glaciolacustrine gravel and sand that forms the Whittlesey Aquifer was deposited contemporaneously with and following ice retreat. Higher level, ancestral Erie basin water bodies fronted the retreating ice margin resulting in the deposition of thick, fine-grained glaciolacustrine sediments (Whittlesey glaciolacustrine aquitard) blanketing the area. In the north-central and eastern portions of the area, a wedge of typically localized sandy aquifers and more widespread silty to clayey Halton Till and glaciolacustrine sediments, deposited during the Port Huron advance out of the Lake Ontario basin, separates the Whittlesey glaciolacustrine aquitard into older (lower) and younger (upper) units. The sequence is capped by a thin and patchy aquifer deposited in early post-glacial to modern nearshore to shoreface, eolian and fluvial settings. This complexity has resulted in a conceptual stratigraphic framework containing 18 hydrostratigraphic units overlying bedrock.

A Regional Stratigraphic Framework for Hydrogeologic Studies Above the Niagara Escarpment in Southern Ontario

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The Ontario Geological Survey (OGS) has been conducting three-dimensional (3-D) sediment mapping in southern Ontario since 2002 as part of its groundwater initiative. These projects are aimed at better understanding the architecture and inherent properties of the Quaternary sediment sequence for groundwater applications. To date, 181 continuously cored boreholes, many of which were located to test features identified as part of supporting geophysical surveys, have been drilled by the OGS within an area of roughly 10,000 km^2 above the Niagara Escarpment to infill gaps in legacy data sets. Three models, centred over the Late Wisconsin interlobate zone along which the Orangeville, Waterloo and Dorchester moraines were constructed, have been released (Orangeville–Fergus, Waterloo Region and Brantford–Woodstock), and the Niagara Peninsula project is underway. The completed projects revealed similar stratigraphic successions that could be traced from one area to the next, whereas drilling on the Niagara Peninsula highlights both similarities and differences.

Tills and coarse- to fine-grained stratified deposits in the completed model areas range in age from pre-Michigan Subepisode to late glacial (Erie, Port Bruce and Mackinaw phases) separated by Nissouri Phase Catfish Creek Till, an important marker bed and regional aquitard in southwestern Ontario. In contrast, on the Niagara Peninsula pre-Catfish deposits are confined to deep and narrow buried-bedrock valleys (BBVs). A continuous cover of ice spanning the Nissouri to Mackinaw phases resulted in a Catfish–Wentworth till continuum that forms the basal sediment unit in boreholes beyond the BBV margins. Fine-grained glaciolacustrine deposits and silty to clayey Halton Till dominate the sediment record.

Aquifers have been observed in several stratigraphic settings. Pre- and post-Catfish aquifers have been identified within both narrow and broad BBVs in all project areas. The aquifers are variable in thickness and may occur at multiple stratigraphic positions within a single valley. A complementary investigation of the Dundas BBV suggests the presence of discrete and fragmented aquifers rather than one continuous aquifer along the valley length. Thick, sandy moraines deposited in the interlobate zone between retreating Erie–Ontario and Huron–Georgian Bay ice lobes, form the primary sediment aquifers in the completed model areas. Fluctuating ice margins partly over-rode these moraines burying them in places. Gravelly outwash deposited during ice retreat and sands laid down in ancestral high-level Erie basin lakes cap the sediment sequence and serve as important, but vulnerable, local and regional aquifers. Sandy ice-marginal fan–delta complexes are the most prevalent sediment aquifers on the Niagara Peninsula and appear to have been preferentially deposited in close proximity to BBVs. The presence of underlying thick, fine-grained glaciolacustrine deposits may prevent local groundwater recharge of bedrock and at least some buried-bedrock valley sediment aquifers.

The completed projects collectively provide valuable insights into the Quaternary history of a large portion of the Greater Golden Horseshoe highlighting the distribution and characteristics of important sediment aquifers. The knowledge gained from each project can be transferred to surrounding areas and used to guide the ongoing search for safe and sustainable water supplies.

QA/QC of Bedrock Formation-Top Picks Using Archived Geophysical Logs, Drill Cuttings and Core in Southern Ontario

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Geological maps and models are only as good as the data used to generate them. Fortunately, Ontario has a strong tradition and long history of data collection from the drilling and operation of petroleum wells. The data are recorded and actively managed in a relational database made publicly accessible by the Oil, Gas and Salt Resources Library (OGSRL) in London. Geologists and GIS specialists at OGSRL regularly perform quality assurance and quality control (QA/QC) reviews to ensure access to the highest quality and most up-to-date subsurface geological data. The revised formation-top data can be used for various purposes, including exploration for and development of hydrocarbon and mineral resources, hydrocarbon and compressed air storage, studies related to deep geological disposal of nuclear wastes and liquid wastes, mapping intermediate and deep groundwater systems, geological education, and 3-D geological and hydrogeological modelling.

The QA/QC process involves the revision of formation-top depths recorded in the petroleum well database for consistency and accuracy. OGSRL geoscientists use geophysical logs (gamma ray, neutron and density), drill cuttings and drill core to review formation tops, and to confirm well location co-ordinates from well records. Consistency of formation-top picks is maintained by reference to standards published in Ontario Geological Survey Special Volume 7.

From 2015 to 2018, OGSRL geologists completed edits to 30,320 formation tops from a total of 7,812 wells in support of the construction of a 3-D geological model of southern Ontario, resulting in improvements to the petroleum well database. Further opportunities for improvement have been identified and a new QA/QC review is in progress to support subsequent 3-D model development. As of December 31, 2019, a total of 426 wells in Bruce, Essex, Huron, Kent, Lambton counties and 155 cored wells with analyses covering the Lockport Group in southwestern Ontario have been reviewed and updated.

Challenges come from the various carbonate lithofacies in the Lockport Group. Top-pick criteria of each formation in the Lockport Group has been complemented by summarizing the updated lithological and geophysical descriptions. QA codes have been assigned accordingly to reflect the geologists' confidence in a formation-top pick, which is dependent on the geologist's ability to make a reliable pick based on the quality of drill cuttings and/or logs. Other QA issues that have been encountered and fixed in the database include inconsistent, missing and/or incorrect unit top picks for geological formations, and data entry errors.

Future work will include revisions of formation-top picks within the Lockport Group, the Decew Formation, the Collingwood Formation, and other economically significant or water-bearing formations, for better quality controlled subsurface stratigraphic models of southern Ontario.

A Proposed Hydrostratigraphic Chart for Southern Ontario

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In 2019, a revised lithostratigraphic chart for the Paleozoic bedrock of southern Ontario was developed in conjunction with the creation of a 3-D geologic model of the bedrock by the Geological Survey of Canada, the Ontario Geological Survey (OGS) and the Ontario Ministry of Natural Resources and Forestry (MNRF). A new study has been initiated to model 3-D hydrogeologic relationships in the Paleozoic bedrock. A necessary component of this work is identification of regional aquifers and aquitards and assignment of lithostratigraphic units as hydrostratigraphic units.

Hydrostratigraphic unit assignments are based on a compilation, summary and assessment of published and newly acquired geoscientific data on the bedrock geology and hydrogeology of southern Ontario. Water interval records (~35,000) from the MNRF petroleum well database are an often overlooked resource, but are a key source of information for hydrostratigraphic unit assignments, especially for the intermediate to deep saline groundwater regimes. In southern Ontario, most petroleum wells were drilled with cable tool drilling technology that allows groundwater to flow freely into the borehole. Drillers record the depth at which the water enters the well, the water type, and eventual static level, before the zone is sealed off by casing. These data have enabled the delineation of regional aquifers and aquitards in southern Ontario west of the Niagara Escarpment, hydrochemical depth zonation of groundwater, and regional groundwater flow directions.

Other sources of information for the hydrostratigraphy include chemical analyses and stable isotope characterization of groundwater, field observations in outcrops and quarries, published hydraulic conductivity data from test wells and field studies, observations and interpretations of faults and fractures, and published geological, hydrochemical, karst and groundwater studies by the Ontario Geological Survey.

A preliminary hydrostratigraphic chart for the Paleozoic bedrock of southern Ontario is proposed as a work-in-progress. Comments and discussion are invited. Principal regional aquifers that occur in the intermediate and deep subsurface, from shallowest to deepest are Detroit River–Dundee Aquifer, Bass Islands Aquifer, Guelph Aquifer and the Cambrian Aquifer. Except for the Cambrian Aquifer, these aquifers all have a near-surface freshwater component in southern Ontario. Principal regional shallow aquifers, dominated by freshwater, are Overburden Aquifer/Aquitard System, Contact Aquifer, Karst Aquifer System, and the Gasport Aquifer. Most bedrock strata in the intermediate to deep subsurface are aquitards.

Extrapolation of hydrostratigraphic units from the deep and intermediate regimes to the shallow freshwater regime can be problematic and complicated. Near-surface karst in areas of exposed bedrock or thin overburden host shallow aquifers in some bedrock units, which in the intermediate to deep subsurface lack solution-enhanced permeability and form aquitards.

Integration of Frequency-Domain Airborne Electromagnetics, Surface Geophysics and High-Resolution Boreholes to Support Groundwater Resource Assessments

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The generation of a data-constrained geological conceptual model represents a foundational step in the creation of a numerical groundwater flow model. This requires detailed knowledge of an area's hydrostratigraphy—how does the geologic environment control the hydrologic properties and conditions across a region? The non-invasive nature of airborne geophysical surveys offers a method to rapidly image the subsurface. However, its usefulness for resolving complex metre- to decametre-scale vertical and lateral variability remains to be fully realized. A survey was completed using a helicopter-borne frequency-domain electromagnetic (FDEM) RESOLVE system over a 50 km^2 area of farmland adjacent to Elora–Fergus in southern Wellington County, Ontario. This region has recently undergone a water budget and local area risk assessment. The goal of the airborne survey was to assess local stratigraphic and structural controls on groundwater flow through the Quaternary–bedrock system with a focus on characterizing a buried-bedrock valley feature. The Ontario Geological Survey recently completed a 3-D Quaternary model that includes a portion of the airborne electromagnetic (AEM) study area. However, it is likely that sediment heterogeneity, particularly within the buried valley, was not fully resolved considering the limited borehole data within the valley. Our initial study objective is to explore the capacity of the AEM to identify and delineate the bedrock surface and the various Quaternary and/or bedrock lithofacies that exist across the study area. The results of the airborne survey are compared against an existing hydrostratigraphic conceptualization, together with multiple surface-based geophysical surveys completed along two transects centred over a buried-bedrock valley. Surface geophysical surveys included gravity, electrical resistivity and seismic refraction, and were used to assess the spatial resolution of the AEM instrument over a complex buried-bedrock feature. These transects were jointly interpreted with historical geophysical data sets and the existing regional Quaternary model to evaluate the capacity of the airborne survey to ultimately generate a more refined 3-D spatial interpretation of the local geologic environment. High-resolution boreholes, together with downhole hydraulic and geophysical testing at strategic locations within the study region, will be used to assess the relationship between lithology and hydrogeologic properties. Data

integration will ultimately support geologic and hydrogeologic interpretation of the AEM data over the full study area. This project was funded in part by a Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant to members of the G^{360} Institute for Groundwater Research at the University of Guelph in partnership with Wellington County.

Investigating the Controls on Groundwater Chemistry in Crystalline Silicate Rock Terrain in Northeastern Ontario

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In 2016, a study was initiated to determine if the methods employed in the Ambient Groundwater Geochemistry Project (AGGP) in southern Ontario could successfully delineate the effect of Precambrian host lithology on groundwater chemistry in northern Ontario. Field work during 3 seasons involved collection of groundwater in a broad band extending across north-central Ontario from Blind River in the west to Mattawa in the east, and included Manitoulin Island. The whole study area encompasses approximately 37,000 km^2 and a total of 402 samples were collected: 125 samples from overburden-completed wells and 277 samples from wells finished in bedrock. Samples were analyzed for metals, anions, bacteria, nitrogen parameters, δ^2H and $\delta^{18}O$, tritium and several other radionuclides.

An initial interpretation suggested that groundwater geochemistry was influenced by different factors including host lithology (on a geologic province-scale), hydrogeological flow conditions, drift thickness and drift composition. Principal components analysis (PCA) has since been completed to characterize these controls of geochemistry on groundwater. Samples collected from the Grenville Province Central Metasedimentary Belt in southern Ontario between 2008 and 2014 were included in the PCA. Here we report the preliminary observations from the PCA and other data exploration regarding observed regional trends.

The first principal component has a geochemical signature that suggests a deep brine–meteoric groundwater interaction and accounts for approximately 20% of the total variance in the data set. This interpreted "brine component" is characterized by high concentrations of Sr, B, Li, Mo, F^- and elevated concentrations of many parameters including Br^-, SO_4^{2-} and Rb. Many samples collected from wells in the Grenville Province have high positive scores in the brine component and a discrete zone of brine influence forms a northeast to southwest linear trend to the west of Lake Nipissing. Another group of samples that load positively in the brine component was collected from bedrock wells near the centre of the Sudbury Basin over the Onwatin Formation slates and the Chelmsford Formation greywacke. The brine component in this distinct group may result from lengthy flow systems and residence times because groundwater recharged at the elevated margins of the Sudbury Basin migrates towards the centre of the basin under confining glaciolacustrine clays. The second and third principal components are interpreted to represent recharge through surficial material and account for approximately a quarter of the variability in the data. These components appear to be most influenced by several factors, such as the thickness of glacial sedimentary drift cover (where present), the composition of drift and recharge timing. Insight into elevated concentrations of uranium across the study area is offered by several minor principal components, which suggest uranium mobility in the groundwater is controlled by multiple factors including pH, redox, the presence of complexing agents such as Ca^{2+} and SO_4^{2-} and a uranium source in the aquifer. Ongoing work is employing tools, such as strontium and sulphur isotope analysis, as well as other multivariate statistical methods, such as hierarchical cluster analysis, to further characterize the controls on groundwater chemistry in Ontario's north.

U.S. Geological Survey Water Resources Mission Area Priority Programs

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The U.S. Geological Survey (USGS), Water Mission Area (WMA), has identified several priorities for targeted effort and investment. These include a Next Generation Water Observing System (NGWOS) that will utilize fixed and mobile monitoring assets in the ground, water and air to provide high-fidelity, real-time data on water quantity, quality, and use to support improved water prediction through modern models and decision support systems for water emergencies and daily water operations. When fully implemented, NGWOS monitoring networks will deliver integrated high temporal- and spatial-resolution data on streamflow, evapotranspiration, snowpack, soil moisture, groundwater–surface water connections, stream-velocity distribution, sediment transport, water quality, and water use. The NGWOS aims to foster monitoring innovation; each selected basin will include monitoring innovation testing sites. The first two NGWOS basins are the Delaware River Basin and the Headwaters of the Colorado River and Gunnison River Basin. The USGS WMA also is engaged in an ambitious federal partnership to develop a new national, interagency capacity for Integrated Water Prediction (IWP). A central element of this partnership is the National Oceanic and Atmospheric Administration's (NOAA's) Office of Water Prediction's National Water Model (NWM)—a hydrologic model that simulates observed and forecast streamflow over the entire continental United States. USGS science (observations, process understanding, and models) and the NWM together will drive prediction of stream temperature; erosion and sediment/constituent entrainment; and in-stream constituent transport. A third priority program, the Integrated Water Availability Assessments (IWAAs) program, is building on the work of the NGWOS and IWP to produce a national water budget, or water census, that describes the amount and quality of water available for a range of uses, including domestic and municipal water supply, agriculture, energy production, transportation, ecosystem and habitat management, and recreation. Complementing these programs is an effort to modernize the USGS National Water Information System (NWIS), which serves as the repository and public-facing interface for USGS water data. Through its NWIS modernization, the USGS hopes to realize a streamlined online presence that can leverage the latest technology for data telemetry, storage and delivery to accommodate anticipated data needs of stakeholders.

Reclassifying an Existing GUDI Well System Under the New Draft Ministry GUDI Terms of Reference

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Two municipal supply wells, Stouffville Well 5 and Well 6, were previously assessed as Groundwater Under the Direct Influence of surface water (GUDI) with effective filtration based on a hydrogeological study completed in 2002. The results of this investigation were based on the *Terms of Reference for Hydrogeological Studies of Groundwater Sources Potentially Under Direct Influence of Surface Water* prepared by the Ministry of Environment and Climate Change in 2001.

York Region is currently undertaking projects to review the supply and storage solutions in Stouffville including assessment of water treatment operations at this wellfield. In support of these studies, York Region assessed the GUDI status of the wells under new draft Terms of Reference to ensure the system is properly classified and appropriate treatment is provided. This presentation presents the findings of the GUDI reclassification work undertaken by York Region. Work included a review of hydrogeological conditions, baseline monitoring for turbidity, fecal indicators and sampling for *Cryptosporidium* spp., *Giardia* spp. and photosynthetic pigment bearing algae and/or diatoms, and enhanced water level monitoring of groundwater and surface water features.

A New Don – Build Me a River

Ford, Don

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The Don Mouth Naturalization Project (DMNP) in downtown Toronto is one of the most significant active brownfield redevelopment projects in Canada. The overall goal is to transform 356 hectares of flood-prone, under-utilized commercial and/or industrial land into a vibrant mixed-use community. The overall scope of the project involves the construction of a new, naturalized mouth for the Don River, along with associated flood-protection infrastructure to allow for redevelopment of the study area. Preliminary estimates suggest the need for excavation of 1,494,000 m^3 of soil and placement of 1,068,000 m^3 of fill.

Three key challenges for this transformative project are the following:

1. an abundance of contaminated soil and groundwater from over 150 years of fill placement and industrial activity within the project area;
2. excavation of a new river valley through the relatively low strength native soils and fill; and
3. treatment and management of large volumes of groundwater extracted from the excavated area.

To minimize the environmental and social impacts of the Don Mouth Project, innovative remedial and/or treatment technologies were considered to minimize the volumes of contaminated and geotechnically inadequate soil needed to be exported from the site. This will of course also minimize the volume of clean, geotechnically suitable materials that need to be imported to the mouth of the Don site. In addition, innovative technologies for the treatment of pumped groundwater were also considered.

Several teams were retained to undertake bench-scale tests on limited samples of soil, groundwater and hydrocarbon products obtained from the site. Eleven different technologies ranging from chemical stabilization, physical stabilization, biodegradation and thermal treatment were considered in the bench-scale testing.

Following this testing, Waterfront Toronto evaluated the probability of success of each method given the site-specific technical constraints, anticipated project schedule and project budget. Six technologies were selected for follow up pilot-scale testing.

The pilot-scale testing was done at the Don Mouth site, with each team assigned a specific test area based on the results of earlier soil and groundwater testing. As with the bench-scale testing, each project team produced a report detailing i) the pilot test methodology and results; ii) the estimated costs to implement the technology at the site; and iii) a feasibility assessment for application of the technology at the site scale. Documentation included laboratory tests for soil and groundwater quality and/or the geotechnical properties of the final remediated soils.

This talk will provide a brief overview of program to date and the anticipated direction for moving forward for this key Canadian environmental undertaking.

Characterization of Groundwater Geochemistry in Eastern Ontario

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Geochemical data for 369 bedrock wells collected across four field-seasons have been used to characterize the controls on groundwater chemistry in a 2700 km^2 area of eastern Ontario between the City of Ottawa and Champlain Township (located approximately 90 km east of Ottawa). Bedrock topographic and overburden thickness mapping was completed, using carefully selected, publicly available water well records and known bedrock outcrops. Extensive quality-control protocols were developed and implemented to improve the spatial and stratigraphic reliability of over 9,000 wells in the study area. Anomalous geochemical patterns are observed in groundwater across the region including elevated levels of methane, sodium and various halogens (e.g., I, Fl, Cl). Multivariate statistics (principle components analysis) were used to interpret dominant geochemical processes that result in these patterns, most of which appear to be related to a large buried-bedrock valley that modulates recharge and groundwater flow. Investigating the inter-relationships between groundwater geochemistry, bedrock topography and overburden thickness enhances our understanding of groundwater resources across the region and assists municipal officials with development reviews and land-use planning decisions. This project is supported by the Ontario Geological Survey and involves data from collaborative studies involving local municipal authorities (City of Ottawa, United Counties of Prescott and Russell, and South Nation Conservation Authority).

Characterizing Regional- and Watershed-Scale Groundwater–Surface Water Interactions with a Fully Integrated Groundwater–Surface Water Model

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A prototype groundwater–surface water model for the southern Ontario Phanerozoic Basin region has been developed with HydroGeoSphere (HGS) in order to provide a three-dimensional (3-D), physics-based simulation of fully integrated groundwater–surface water (GW–SW) flow. To date, the model has been tested for its ability to reproduce average monthly surface water flow rates and groundwater levels, and its sensitivity to spatial and temporal resolution. The full model domain encompasses 109,565 km^2, with approximately 79,000 km^2 being land area and the remainder being surface water area within the Great Lakes. To facilitate evaluation of spatial sensitivities, low- and high-resolution versions of the model have been constructed, with surface water features resolved down to Strahler order 4 and Strahler order 3, respectively. The hydrostratigraphy in the model is constructed using recently released 3-D Paleozoic and Quaternary geological models, along with mapping that depicts depth to the base of high-sulphur content groundwater. In total, the respective low- and high-resolution models consist of 21 and 16 layers, and 874,398 and 2,127,760 3-D finite-element mesh nodes. Both models incorporate spatially distributed soil and landcover, and spatially and temporally distributed evapotranspiration.

This presentation will describe application of the regional model towards the study of spatially and temporally distributed GW–SW interactions, and baseflow contribution to surface water flows. Considerable work has been conducted previously in order to characterize the baseflow component of surface water flow within the Great Lakes Basin; however, there remain many unanswered questions pertaining to spatial variability, as well as the variability associated with seasonality and climate factors. Given that GW–SW interactions are widely regarded as a core component of the southern Ontario hydrologic cycle, and that groundwater discharge to surface water often sustains river and stream flow during mid to late summer in southern Ontario, it is important to gain a better understanding of the dynamic interplay between groundwater and surface water so that we can better predict the impact of climate change and anthropogenic factors on water resource sustainability.

Although the southern Ontario model is well suited for the task of characterizing large-scale GW–SW behavior, there remain many unknowns related to the interpretation of model output, and the influence of model structural uncertainty as it relates to quantitative estimation of GW–SW interaction. In this study, the role of model spatial resolution, as a component of structural uncertainty, is specifically addressed through a comparison of simulated GW–SW exchange

generated by both the low- and high- resolution versions of the southern Ontario model, and by a high-resolution model for the Grand River watershed that resolves the surface water network down to Strahler order 2 streams. The results of this study provide insight on 1) how fully integrated models can be applied towards the study of large-scale GW–SW interactions, 2) the potential influence that model spatial resolution can have on simulated GW–SW exchange, and 3) the direct and indirect contribution of groundwater to the Laurentian Great Lakes.

Groundwater "Areas of Concern" Mapping, South-Central Ontario

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In Ontario, it has been historically perceived that there exists a paucity of groundwater information readily available to make responsible resource management and planning decisions. In 2001, this perception gave birth to the Oak Ridges Moraine Groundwater Program (ORMGP; www.oakridgeswater.ca), a collaboration between municipal and conservation authority partners whose mandate is to collect and interpret water-related information and apply this knowledge to various water resource management initiatives. Despite the mountain of information that has been collected for the study area, perceptions of data deficiencies relating to groundwater information still exist. An alternate possibility is that the amount of information and analysis tools (e.g., groundwater flow models) that currently exist are simply too overwhelming for some to easily digest. Within the study area, one attempt to facilitate increased utilization of water-related information into the decision-making process is to provide mapping that outlines areas where groundwater issues are known to, and/or may, occur, herein termed groundwater "Areas of Concern" mapping. The "Areas of Concern" mapping visualized here aims to outline areas, where, during and/or after construction, groundwater control may pose problems (and potentially financial burdens) beyond those typically encountered in other locations.

The ORMGP study area covers much of south-central Ontario. A working hypothesis is that the "Areas of Concern" mapping for the study area generally relate to four types of regional hydrogeologic settings as follows:

1. confined shallow regional aquifers, for example where the Oak Ridges Aquifer Complex pinches out on the southern flank of the Oak Ridges Moraine;
2. areas of regional aquifer outcrop/subcrop along steep topographic slopes. Examples include along deep river valleys and along the Lake Iroquois shoreline;
3. coarse-grained sand and gravel deposits (i.e., channels). An example would be the 'Yonge Street Aquifer' situated beneath and north of Aurora; and
4. extensive gravel zones within bedrock valleys (e.g., western part of Toronto).

It is acknowledged that there may be other areas with less extensive thinner aquifers that may be under confined conditions. It is also acknowledged that much of the study area may contain shallow water table conditions that will need to be controlled during, and perhaps following, any excavation. Also, locations situated near large lakes (e.g., Lake Ontario) may need groundwater control in perpetuity.

This talk will look at the technical information and factors (e.g., groundwater levels, geologic interpretation, groundwater use, etc.) that are considered in compiling groundwater "Areas of Concern" mapping for the study area. Mapping has been initiated on a 'local' (i.e., Township or Lower-Tier Municipality) scale in order to better collect and synthesize groundwater knowledge and experience, this being a key input to the mapping. It is anticipated that these 'local' studies

can eventually be assembled to build up a 'regional' understanding of groundwater "Areas of Concern". This exercise is seen as an excellent way to test the collected data and the developed conceptual model (understanding) for the study area and to allow for better utilization of this information by project managers and planners.

Sulphur Isotopic Evidence of Terrestrial Evaporites in the Queenston Formation, and the Implications for Groundwater Quality on the Niagara Peninsula

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The Queenston Formation is a shallow marine to terrestrial red shale unit of Ordovician age that crops out along the base of the Niagara Escarpment in southern Ontario and northern New York State. Groundwater from wells finished in the Queenston Formation was sampled as part of the Ontario Geological Survey's (OGS) Ambient Groundwater Geochemistry Program (AGGP). In contrast to groundwater from other shale units in Ontario, Queenston Formation groundwater exhibits elevated sulphate (SO_4^{2-}) concentrations and a characteristic lack of dissolved methane. Both of these are the result of the common occurrence of soluble gypsum in beds, nodules and fractures within the Queenston Formation.

As part of a related project, archived groundwater samples, for almost all AGGP groundwater collected across southern Ontario with sulphate concentrations above 300 mg/L, were analyzed for sulphur isotopes ($\delta^{34}S_{SO4}$) to help identify the source of the solutes and to investigate the mineralogical character of the host aquifer. A serendipitous outcome was the discovery of a strongly gradational signature in $\delta^{34}S_{SO4}$ in groundwater from wells finished in the Queenston Formation: with values, on the Bruce Peninsula in the north, indicative of full marine conditions (> +30‰ CDT) ranging to full terrestrial conditions (−5 to +5 ‰ CDT) on the Niagara Peninsula in the south. The $\delta^{34}S_{SO4}$ signature at the lower end of this range could result from pyrite oxidation, but the extremely high SO_4^{2-} concentrations (>1000 mg/L) in some of these waters makes this unlikely. A more probable explanation is the presence of terrestrial evaporitic gypsum, which had not been previously identified in the Queenston Formation.

To determine the sulphur isotopic composition of the host aquifer, gypsum samples were obtained from the Queenston Formation and younger strata from drill samples archived at the Oil, Gas and Salt Resources Library in London, Ontario, and the OGS core repository in Sudbury. Samples were analyzed for $\delta^{34}S_{gypsum}$ and the results showed a similar south to north trend, which was also observed stratigraphically within the Queenston Formation from shallow to deep in the core samples. None of the gypsum from younger Ordovician or Silurian strata showed a similarly depleted sulphur isotopic response. These data confirm the previous geological interpretation that the character of the Queenston shale changed over time as a result of a marine regression; from marine to fully terrestrial facies. The south-north gradation in sulphur isotopes could result from either a syndepositional lateral facies change or differential post-depositional erosion to the north, resulting in older marine beds being exposed at the top of the formation. These results help to account for an isotopically depleted "exogenic sulphate" trend observed in groundwater in a recent OGS-supported, McMaster University MSc thesis (by Caitlin Smal) and support its conclusion that large-scale upward migration of deep fluids to surface is occurring across the Niagara Peninsula.

Using Porewater Chemistry in Champlain Sea Muds to Constrain Groundwater Flow

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Champlain Sea deposits of post-glacial fine-grained silts and clays (muds) form a regionally extensive aquitard in the St. Lawrence Lowlands and the Ottawa Valley. Investigations of porewater chemistry, borehole geophysics, and geotechnical parameters within a thick sequence of Champlain Sea muds provide insights into groundwater flow across the aquitard, original salinity, and development of landslide susceptibility. Typically, the assumption is that diffusion alone controls solute transport through Champlain Sea muds. However, this study uses one-dimensional (1-D) groundwater modelling to demonstrate that both advection (Darcy flux of approx. 1-4 mm/a) and diffusion contribute to solute transport at two sites located in thicker (>75 m) Champlain Sea mud deposits near Ottawa. Previous hydrogeological studies estimate Champlain Sea salinity to be approximately 33% of contemporaneous ocean salinity. However, in this study, where the Champlain Sea mud sequence is thicker, the peak measured ionic concentrations in porewater represent up to 88% of relic seawater salinity. Geophysical logs of bulk apparent conductivity were representative of porewater salinity and provided continuous downhole estimates of salinity where porewater samples could not be taken. Additionally, 1-D transport modelling can constrain the rate of groundwater advection and the concentration of seawater ions (e.g., [Cl^-]), and hence, the original salinity of the Champlain Sea. Although the concentrations of seawater ions (Cl^-, Br^-, Na^+) allow an estimate of the seawater fraction, when combined with isotopic signatures (e.g., $\delta^{18}O$), these multiple tracers form the basis to estimate relative proportions of seawater, meteoric freshwater, and fresh glacial meltwater of the Champlain Sea episode. Champlain Sea salinity, along with the combined effects of advection, diffusion, and thickness of the muds, controls the current porewater chemistry, which, in turn, influences sensitivity development of the muds and susceptibility to landslides. For two additional deep boreholes, drilled in residential areas during the autumn of 2019, a multidisciplinary approach incorporates geological, geotechnical, hydrogeological, geochemical and geophysical investigations to unravel the key factors contributing to the development of sensitivity in Champlain Sea deposits. Results will represent the most complete suite of multidisciplinary measurements within Champlain Sea muds to date.

Assessing the Hydrogeological Properties Influencing Nitrate Distribution in a Shallow Unconfined Fractured Bedrock Aquifer

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The Davidson Wellfield is located downslope of the Paris moraine in Acton, Ontario, and this well pair is designated with 'Groundwater Under Direct Influence (GUDI) of surface water' status. These two water supply wells, near each other in a single wellhouse, are completed to 14 m below ground surface (bgs) in an unconfined fractured bedrock aquifer. A thin, 2 m layer of glacier-derived sediment overlies dolostone bedrock of the Silurian Gasport Formation and the water table resides at the overburden–bedrock interface. The supply wells are surrounded by active agricultural land in which pastures and soybeans dominate and the Regional Municipality of Halton staff implement Source Protection Plan policies under the *Clean Water Act, 2006* in the vicinity of the supply wells. Downgradient of the Davidson wells, a creek flows adjacent to the wellhouse. The two wells operate individually, but show similar water quality and, in the past 15 years, have exhibited fluctuating concentrations of nitrate between a minimum concentration of 2.15 mg/L and a maximum concentration of 7.45 mg/L NO_3-N, exceeding half the drinking water standard of 10 mg/L NO_3-N for nitrate on several occasions. The goal for this project is to determine the vertical distribution of nitrate concentrations within the context of the groundwater flow paths captured by these pumping wells. Hence, understanding the position and thickness of aquifer–aquitard layering within the bedrock flow system is a primary objective and is based on data collected using high resolution vertical profiles of stratigraphy, hydraulic head and vertical components of gradient, and hydrochemistry. These data-informed hydrologic units will refine the conceptual model for groundwater flow and improve the assessment of nitrate inputs and attenuation along groundwater flow paths highly dependent on hydrochemical conditions and residence times, providing process-based insights on the spatial and temporal variability of nitrate within the capture zone of the supply wells.

A removable, G[360] multilevel system (MLS) with water-inflated rubber packers for isolating nine monitoring zones was installed to gain insight on the vertical and temporal variability of nitrate concentrations and isotopic composition. Observations made during logging and sampling of continuous core and resultant porewater analyses, along with borehole geophysical/hydrophysical logging, helped inform monitoring port and packer positions. Most notable of this investigation is the use of several temporarily deployed RBR*duet*[3] loggers for monitoring hydraulic head transients at 24 depth intervals that was preceded by active-distributed temperature sensing (A-DTS) using fiber optic cables to identify the location of hydraulically active fractures based on preferential zones of cooling, both deployed behind FLUTe™ liners. These characterization methods were followed by the installation of a removable G[360] MLS with nine ports designed to target active flow paths where elevated levels of nitrate were observed in the matrix based on core porewater analysis. Pneumatic rising and falling head slug tests

were conducted on each MLS port to obtain values of transmissivity and identify where vertical connectivity exists. The findings from this research aims to differentiate nitrate sources and pathways to determine major contributors, improve pumping and mitigation strategies, and inform agricultural best management and wellhead protection practices.

Fate of Land Applied Waste Greenhouse Nutrient Feed Water During Controlled Field Infiltration Experiments

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Because of the high concentration of greenhouses in Essex County, greenhouse discharges are considered as a potential contributor to nuisance and harmful algal blooms (HABs) and hypoxia in Lake Erie. Nutrient feed waters from greenhouses are comparable to other nutrient sources used in agriculture. Land application of greenhouse nutrient feed water to adjacent crop land is regarded as a potentially suitable alternative to in-house wastewater treatment systems both in cost and ease of adoption. Therefore, the land application of the feed water can be an appropriate management response to the nutrient load issues in such water courses. In an effort to assess the potential environmental impacts of this land application option, a collaborative monitoring program was established at partner greenhouse operations near Leamington, Ontario. We hypothesized that the nutrients in feed water applied to active crop lands would be absorbed and attenuated to an acceptable level within the soil profile before reaching the local water table. Four field trial sites were established and characterized for controlled plot-size experiments. Field installations included porous cup lysimeters at 30 cm, 60 cm and 90 cm for the collection of soil water samples, groundwater wells above and below water table to monitor groundwater quality and water table fluctuations, and composite soil cores at random locations for soil analysis. Feed waters from the greenhouses was applied to the monitored plots at the maximum allowed rate in the spring as common practice when crops are growing and late fall as worst-case scenario when plant take-up is minimized. Composite soil samples and water samples including soil water from lysimeters, shallow groundwater from monitor wells and surface water from tile outlets were collected both before and after the land application events. Laboratory analysis focussed on nutrients and heavy metals. The field data sets will be compared in this presentation to illustrate the performance of the land application process relative to environmental impacts, and initial observations regarding the utility of this approach to managing the waste greenhouse feed waters will be discussed. Initial evidence indicates that land application of greenhouse feed waters may represent a promising nutrient management strategy.

Using the New 3-D Digital Model of Ontario's Paleozoic Geology to Bridge Gaps in the Traditional Education Framework

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The demand for competent geoscientists and engineers is high, and the development of a new resource has addressed a gap in the traditional education framework. Spatial understanding is a key component of geoscience competency, but it has proven to be difficult for students to grasp three-dimensional (3-D) concepts using two-dimensional (2-D) teaching media. A new 3-D digital model of Ontario's Paleozoic geology, created in partnership by the Geological Survey of Canada, Ontario Geological Survey, Ministry of Natural Resources and Forestry, Oil, Gas and Salt Resources Library, and Carter Geologic (Carter et al., 2019), has the potential to effectively complement the existing teaching resources and vastly improve an education framework for geoscientists and engineers. The Department of Earth and Environmental Sciences at the University of Waterloo has been developing a teaching framework for this revolutionary new resource in two undergraduate theses. Applying this new 3-D digital geological model in the class "Earth 235: Stratigraphic approaches to understanding Earth History" has helped bridge the dimensional and interactive gaps that exist with the traditional education framework. To interpret the detail shown in the 3-D geological model, the new Paleozoic lithostratigraphic chart for southern Ontario, developed by the Ontario Geological Survey, was used in conjunction with the 3-D model. By examining the 3-D model and lithostratigraphic chart, as well as enlisting the help of students and professionals, a list of the 'Top 10 Important Aspects of Ontario's Paleozoic Geology' is being compiled to help guide development of a new education framework. This list is helping to define educational learning objectives that connect to professional competencies, provide a focus on certain features and resources that are hidden in the wealth of information in the 3-D model, and link key features to core geologic concepts that could be transferred to other sedimentary basins.

Reference

Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Freckelton, C.N., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2019. Three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Ontario Geological Survey, Groundwater Resources Study 19 / Geological Survey of Canada, Open File 8618 (https://doi.org/10.4095/315045), 45p.

Determination of the Source of Salt Contamination Using a Combination of Novel Stable Isotopic Parameters (^{37}Cl, ^{81}Br, ^{18}O and ^{2}H) and Tritium to Assess the Impact on Regional Groundwater Supplies in Southern Ontario, Canada

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The application of road salt or de-icing chemicals to southern Ontario roadways has been the standard practice for the past 70 years. Approximately 100,000 tonnes of road salt are used on southern Ontario roadways, and 5 million tonnes is applied to roads across Canada annually. Groundwater protection and management are vital in southern Ontario and are a topic with increased interest as the impacts of road salt application are becoming more widely known and understood. The Oak Ridges Moraine (ORM) is recognized as a regional groundwater recharge area and has an extensive history of groundwater use, with records of approximately 150,000 private and public wells drilled in the region's watershed. Samples of salts and bedrock brines, in addition to suspected anthropogenic contributors, are compared with groundwater and porewater samples from some regional and municipal wells across the ORM.

Stable chlorine and possibly bromine isotope analyses can aid in the identification of anthropogenic salt contamination in groundwater and, along with other geochemical methods such as Cl–Br mass ratio, help to identify additional sources of salt contamination. This study attempts to determine what contributes to the presence of chloride in groundwaters of the ORM. The ^{37}Cl isotopic signature of road salt is ±0.2 per mil (‰) SMOC and the ^{81}Br isotopic signature ranges from +0.8 to −0.2‰ SMOB. The standard mass ratio of chloride to bromide (Cl/Br ratio) in the ocean is about 300 and the value of Cl/Br ratios of deep formation water from under the ORM is lower than 300, whereas the value of Cl/Br ratio of shallow groundwater affected by road salt is greater than 300. In this study, the isotopic value of bromine (Br) ranged from −1.9‰ to +2.8‰, which may be the result of several processes, such as road salt dissolution and recharge into groundwater, saline sedimentary formation fluid upward advection from the bedrock and/or organic and microbial release of organically bound bromide from subsurface sedimentary reservoirs. The highest chloride concentrations (800–1400 mg/L) are found at shallow depths and carry the localized isotopic signature for road salt. High concentrations (>200 mg/L) are also found in both older and recently recharged waters in deeper aquifers within the ORM. Some of these waters based on other parameters such tritium, ^{18}O, and Cl/Br ratios appear be recent recharge of anthropogenic fluids at depth. Additional high concentrations of salt contaminated groundwaters appear to be sourced from the upper migration of high salinity bedrock formation fluids based on novel isotopic tools and a lack of tritium.

The Information of Data

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While advancing our capacity to store and share data, it appears that simply providing public access to a database limits information transfer. For instance, collectively analyzing data from a pool of disparate monitoring stations (e.g., climate, streamflow, groundwater), allows for enhanced understanding through interpolation. Much of this interpolation can be automated using intelligent systems to deliver on-the-fly data interpolation products. This presentation describes the "information content" of data and how the Oak Ridges Moraine Groundwater Program (ORMGP) is using accessible technologies to enrich the information shared with our users.

Utilizing Source Protection Knowledge to Improve Groundwater Management While Encouraging Urban Development in the City of Barrie

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Similar to many municipalities within the Province, the City of Barrie is working to balance the need to protect the City's municipal infrastructure (e.g., groundwater supply, stormwater capacity), as well as to support growth and brownfield redevelopment. Construction associated with development, particularly high-density development, can enhance hazards that could threaten water quality and quantity of municipal production wells. Water quality hazards include existing contamination areas, which could be mobilized through new preferential pathways as deep construction works (e.g., caissons) are extended through naturally protective aquitards to bedrock. Water quantity hazards include reduced groundwater flow and enhanced surface water discharge due to perpetual dewatering, and reduction of groundwater recharge.

To foster economic development within Barrie, the City wished to limit development hurdles resulting from source protection initiatives (i.e., risk management requirements) to conditions that are expected create an issue, either for the City or for the developer. In concert, the City desires to provide developers with insights regarding potential development hazards (e.g., areas of flowing wells or known contamination) to help developers avoid "surprise" issues during development.

The goals of the City included developing a strategy and tool-kit that would

1. document what is known about potential water quality and quantity hazards (and factors that contribute to those hazards);
2. evaluate the **likelihood** of potential hazards, spatially, and in three-dimensions;
3. provide a strategy and tools to help the City and prospective developers interpret how planned site activities may lead to **exposures** of those hazards;
4. evaluate the groundwater management **risks** resulting from the hazard exposure level to City infrastructure and the developer; and
5. determine development requirements to further assess and manage and/or mitigate identified risks.

The strategy and tool-kit developed brings together the local experience of City staff and the knowledge developed through source protection work (vulnerability and Tier 3 WQRA) into an interactive decision-support system for the City. The tool-kit allows City staff to confidently and transparently request a scope of work from the developer; it also allows prospective developers to evaluate potential risks for a given site and scale of development before investing heavily into planning. Where significant risks are identified through this screening-level assessment, site-specific field work requirements are identified to refine risk understanding and determine mitigative initiatives required to reduce or circumvent risks. The tool-kit was provided to the City in the summer of 2019 and is currently being used to guide and support technical discussions and decision-making regarding new developments in Barrie.

Utilizing Source Protection Knowledge to Improve Groundwater Management While Encouraging Urban Development in the City of Barrie (cont.)

The data assessment and interpretation completed through source protection initiatives provides a wealth of hydrogeological knowledge that can be leveraged to help with many decisions throughout a municipality. This presentation will demonstrate yet another example of how municipalities can capitalize on the Province's investment in source protection to make informed groundwater management decisions.

Approaching the 50th Anniversary of the GLWQA: A Panel Discussion Focussed on Groundwater Science in the Great Lakes

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After a scientific study conducted by the International Joint Commission (IJC) in the early 1970s, both Canada and the United States agreed on actions they would take to clean up the waters of the Great Lakes and meet their Treaty commitment regarding pollution. In 1972, this action became the **Great Lakes Water Quality Agreement**. The Great Lakes are shared by Canada and the United States and are vital to the well being of millions of people. Among other things, these lakes

- contain almost 20% of world's surface freshwater,
- sustain 4,000 species of plants and animals,
- are the basis for billions of dollars in economic activity, and
- provide drinking water for tens of millions of Canadians and Americans.

The Great Lakes Water Quality Agreement (GLWQA) identifies shared priorities and actions needed to restore and protect the freshwater resources within them. The Agreement was updated in 2012 to reflect new knowledge and tackle additional issues affecting Great Lakes water quality and ecosystem health. Canada and the United States have established a comprehensive **shared vision**, and **common objectives** and commitments to science, governance and action that will help to restore and protect Great Lakes water quality and ecosystem health in order to make its water: Drinkable, Swimmable and Fishable.

The 2012 GLWQA is organized as a series of Articles and Annexes. The Articles describe the **general and specific objectives** of the Agreement, define **principles and approaches**, and lay out the **structure and process** for its implementation. This includes a commitment for Canada and United States to report on progress every three years to document domestic and binational actions relating to GLWQA. As described in Article 7 of the 2012 GLWQA, the IJC is tasked with reviewing and seeking public input on progress.

Of the ten Annexes that describe commitments on specific environmental issues that can affect the quality of the waters of the Great Lakes basin, there is one (Annex 8) on groundwater. Its objective is to encourage co-ordinated groundwater science and management actions that will contribute to the achievement of the general and specific objectives of the Agreement.

As we approach the 50th anniversary of the GLWQA, the purpose of the panel discussion is to highlight the objectives and actions presented in Annex 8 of the GLWQA, along with the objectives from other complementary agreements and groups, such as the Canada–Ontario agreement on the Great Lakes and the IJC Science Advisory Board.

Introducing the New Electronic "Permit to Take Water" Application and Reporting System

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To promote water conservation and stewardship, section 34 of the *Ontario Water Resources Act* (OWRA) requires anyone taking more than a total of 50,000 litres of water in a day—with some exceptions—to obtain a "Permit to Take Water" (PTTW). In 2019, as part of the Ministry of the Environment, Conservation and Park's commitment to modernizing its environmental permits and approvals processes to create faster, smarter, stream-lined government-to-business services, the ministry launched a new electronic application system for PTTW. The new electronic system will allow improved tracking of applications statuses, one window for permissions and reporting, and improved data analytics.

This presentation will involve a live demonstration of the new electronic Permit to Take Water application system. The demonstration will provide an overview of how applicants and authorized representatives (i.e., consultants) can create their accounts, apply for permits, and report annual water takings through the ministry's Regulatory Self-Reporting System (RSRS).

Quaternary Stratigraphy and Hydrogeology in Central Simcoe County

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A three-dimensional (3-D) sediment mapping investigation is underway in the central part of the County of Simcoe, southern Ontario, designed to produce an improved understanding of bedrock topography and geology, the properties and architecture of Quaternary sediments and potential groundwater flow systems. The investigation was initiated in 2014, beginning with updates to surficial sediment and landform mapping, followed by geophysical investigations and drilling of 33 continuously cored boreholes from surface down to bedrock.

Sediment thickness within the area ranges from 0 to 156 m and consists of four major depositional packages. The oldest package overlies the bedrock in areas of thick drift and is composed of a tripartite succession of two tills with intervening glaciolacustrine deposits that locally serve as useful aquifers. The upper surface of the older drift sequence is deeply weathered, suggesting prolonged non-glacial conditions, likely dating back to the last interglacial. Overlying the lower sediments is a thick package of muds with intervening sands containing organic material ranging in age from >50 ka (beyond the limits of radiocarbon dating) to 30.26 ^{14}C kyr BP, suggesting stratigraphic correlation with the Scarborough–Thorncliffe formations in the Toronto area. In some parts of the study area, much of the fine-grained portion of this package is absent and the entire succession consists of stacked fining-upward sequences of gravel to sand. The Late Wisconsin Newmarket Till is a regional, drumlinized and highly undulating package up to 36 m thick, that forms a leaky aquitard above the two older sediment packages. The appearance and physical properties of the till and associated stratified sediments are highly dependent on the local subglacial environments into which they were deposited. The uppermost package of sediments records deglaciation of the region. Sand and gravel deposited as outwash and/or esker–subaquatic fans locally overlie lows or infill incisions into the Newmarket Till. Successions of laminated glaciolacustrine silts and clays deposited proglacially during ice retreat infill lows on the Newmarket Till sheet, particularly within valleys separating uplands and within the Minesing basin in the southeast corner of the study area. Sandy and gravelly shoreline deposits locally cap the postglacial successions and/or erosional surfaces cut through the Newmarket Till along the flanks of till uplands.

Seventeen of the boreholes were converted into observation wells which permit long-term monitoring of water levels in significant hydrostratigraphic units, as well as pumping tests and detailed hydrochemistry and isotope analyses to enhance delineation of local and regional groundwater flow systems.

Geologic Controls on Groundwater Flow in Surficial Sediments in Simcoe County, Southern Ontario

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The Ontario Geological Survey (OGS) has been conducting three-dimensional (3-D) sediment mapping investigations in southern Ontario since 2002 in order to provide a better understanding of the properties and architecture of Quaternary sediments overlying bedrock and their combined influence on local and regional groundwater flow systems. As part of these investigations, 96 continuously cored boreholes have been drilled by the OGS throughout Simcoe County since 2004. Numerous previously cored boreholes and geophysically logged wells, ground-based and airborne geophysical surveys and over 3700 km2 of recent surficial sediment and landform mapping provide further constraint on sediment characteristics and stratigraphic relationships. Together, these new data sets have guided the development of 3-D hydrostratigraphic models in the Barrie–Oro Moraine area (GRS 11) and in south Simcoe County (GRS 18), with a third underway in central Simcoe County. These models provide an enhanced understanding of sediment architecture east of the Niagara Escarpment. The complex terrain in this region consists of uplands, lowlands and stratified interlobate moraines overlying the deeply buried and poorly defined Laurentian bedrock valley that spans the three study areas between Georgian Bay and Lake Ontario.

Traditionally, a simple layer-cake stratigraphy has been used to provide context for groundwater flow models in the region. Little was known about the bedrock topography and the nature of recharge to, and flow within, deep water-bearing units. The development of the 3-D geologic models has led to an enhanced understanding of geologic complexity in the region, shedding light on several key geomorphic features and their associated sediments that control groundwater flow within the Quaternary sequence. A single, continuous, deep regional aquifer extending from Georgian Bay to Lake Ontario cannot be delineated with the available data. Rather, isolated deeply buried coarse-grained units have been identified and form locally significant aquifers. The prolific 'Alliston aquifer' is now recognized as consisting of several coarse-grained sediment units occurring at multiple stratigraphic intervals spanning nearly 100,000 years of sediment deposition in the Angus–Alliston–Tottenham area. Local hydraulic connection between deep aquifers and recharge–discharge zones highlights the spatial variations in the characteristics and thickness of regional aquitards, including the Late Wisconsin Newmarket Till. Significant topographic variations between moraines, uplands and lowlands in the region create strong hydraulic gradients that drive both local (predominantly shallow) and more regional-scale (deeper) flow systems within the Quaternary sediments. Unconfined, stratified interlobate moraines occur on topographic highs of the undulating and heterogeneous Newmarket Till, creating extensive potential recharge zones. Local incision of the till by tunnel valley systems provides enhanced connection to deeper aquifers. Groundwater is discharged both locally, along the margins of the moraines and uplands, and more distally, likely into large wetland complexes, Lake Simcoe and Georgian Bay. Observations along cut banks of deeply entrenched rivers and streams provide clues to the nature of potential

groundwater flow within shallow stratigraphic units in lowlands and enhances possible exchange between shallow and deep flow systems. These new insights have helped to guide follow-up investigations into hydrogeology and groundwater geochemistry that will test conceptual models of groundwater recharge and flow within the region.

Geological Controls on Hydraulic Conductivity in the Karst-Influenced, Carbonate Groundwater Systems of the Lockport Group, Guelph Region

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A large set of hydraulic conductivity values has been integrated with the sequence stratigraphic framework of the Lockport Group stacked dolostones to assess the relative influence of geologic controls on hydraulic conductivity in the City of Guelph region. The geological features investigated comprise proximity to buried-bedrock valleys, carbonate rock fabrics and sequence stratigraphic surfaces.

The influence of buried-bedrock valleys on hydraulic conductivity (*K*) was assessed by interpolating a bedrock surface, mapping and confirming the presence of valleys with bedrock depth information from water well records, generating stratigraphic cross sections along these valleys and finally, by plotting *K* estimates against distance from each valley thalweg. Although previous researchers in the area have inferred a correlation between well capacity and proximity to buried-bedrock valleys, our results suggest no such correlation. The influence of carbonate rock fabrics was assessed by plotting the cumulative probability (%) of hydraulic conductivity (*K*) for each bedrock formation. The bedrock formations have sufficiently distinctive rock fabrics to make the comparison informative. Results show that the coarsest crystalline dolostones (i.e., Gasport Fm.) have the highest *K* values and that the fine-medium crystalline dolostones (i.e., Eramosa Fm.) have the second highest *K* values. These results suggest that there is no simple correlation between carbonate bedrock fabric and *K*. The influence of karstic sequence stratigraphic surfaces (representing time breaks of variable duration) on *K* was assessed using high-quality *K* estimates made in the Gasport Fm. Two cumulative probability distributions (%) of *K* were plotted, one for the area where karstic sequence breaks occur and a second for the area where karstic sequence breaks do not occur. Results show a significant difference in the two *K* distributions, with the karstic sequence break data set having a geometric mean *K* (1×10^{-4} m/s) an order of magnitude greater than the geometric mean *K* (1×10^{-5} m/s) for the non-karstic sequence break area.

The combined influence of various geological features on *K* in the Gasport Fm. was also assessed within the geomorphological context of the study area. Results of this assessment demonstrate that *K* trends within the Gasport Fm. cannot just be attributed to the presence or absence of a single geological feature. For example, the high *K* trend in the Gasport Fm. occurs in an area where karstic sequence breaks are present, where the Gasport Fm. crops out or subcrops, where bedrock valleys penetrate deeply into the dolostones, and where it is closest

to the stress release zones adjacent to bedrock valleys and the Niagara Escarpment edge. This investigation demonstrates that predicting the spatial distribution of *K* in old dolostones requires a regional understanding of the stratigraphic complexity with a conceptualization of where and when waters have interacted with the rocks to dissolve and enhance porosity through geologic time. The comprehensive approach presented here provides valuable support for groundwater resources exploration and contaminant transport pathways mapping in the complex karst-influenced, carbonate bedrock groundwater systems of the Guelph region.

Regional Groundwater Systems Mapping in Simcoe County, Southern Ontario

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The Ontario Geological Survey (OGS) has been conducting geological and geochemical investigations related to groundwater resources in the County of Simcoe (Simcoe County) since 2003. In the past decade, two separate three-dimensional (3-D) sediment models were created, one for south Simcoe County and one for the Barrie–Oro Moraine area. An additional 3-D sediment model is currently being developed for central Simcoe County. Collectively, these models will create a seamless, 3-D sediment framework for the majority (>4100 km^2) of Simcoe County. Previous OGS work in the area also includes sampling conducted in 2011 as part of the Ambient Groundwater Geochemistry Project. The present investigation will interpret new and previously collected hydrochemical and hydrogeological data within the stratigraphic context provided by the newly developed 3-D sediment framework. The objectives of this investigation are to characterize the hydrochemical and physical properties of the main hydrostratigraphic units (HSU) and to map regional groundwater flow systems. Provincial Source Water Protection studies for the south Georgian Bay and Lake Simcoe areas have determined that the aquifers supplying several local municipalities are under water quantity threat. The present investigation is intended to offer a regional scientific context in which to interpret groundwater quantity and quality issues.

Major ion trends for the main regional HSUs show groundwaters becoming more mineralized with depth of stratigraphic position and increasing groundwater residence time. Evidence of local road salt impacts is observed in younger waters of the unconfined Lake Algonquin sand aquifer. Chloride and bromide ratios identify a natural brine signature in the deepest confined HSUs of south Simcoe County in lowland and valley locations, comprising the lower Thorncliffe Formation and aquifers in the Older Drift that overlies bedrock. Principal component analysis indicates that about a third of the aqueous geochemical variability in the study area is associated with this brine signal. The $\delta^{18}O$ isotopic composition of groundwater ranges from −18.6 ‰ to −10.6 ‰ (VSMOW). At its most depleted, this range comprises waters recharged during cooler conditions than present, likely during the Early Holocene or Late Pleistocene. The enriched end of the $\delta^{18}O$ range indicates modern recharge temperatures. The very depleted $\delta^{18}O$ signatures are found at several locations in the study area, within the Thorncliffe Formation and in the deep buried-bedrock groundwater system; with the most depleted collected from bedrock in the Penetanguishene area. The presence of dissolved methane in groundwater was previously known to occur in the study area. In-situ dissolved methane reaches values of up to 35% saturation in the deep confined aquifers of the lowlands and valleys from Wasaga Beach in the north to the Oak Ridges Moraine in the south. Methanogenic groundwaters are not found in areas to the east-northeast of Wasaga Beach. The stratigraphic distribution of high methane in

groundwater appears to be mainly restricted to the deeper HSUs of the Thorncliffe Formation and the Older Drift, although high methane is also present in younger confined sediment aquifers in the Cookstown Valley, suggesting mixing of older waters in valley-fill sediments. Analysis of δ^2H and $\delta^{13}C$ of methane supports the previously held view that it is biogenic in origin. Data collection for this investigation is complete and future work will include the additional interpretation of hydrochemical and isotopic trends within a groundwater flow systems context. Final products will comprise maps of hydrogeological and hydrochemical parameters for the main HSUs, as well as an assessment of recharge pathways and groundwater evolution.

Geological Survey of Canada Activities in Southern Ontario for 2019–2024

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The Geological Survey of Canada (GSC) groundwater work in southern Ontario will continue for the next five years with activity focussed on i) further development of regional geological and hydrogeological models, ii) Archetypal Aquifer project activity, iii) remote sensing studies, and iv) collaborative support of Ontario Geological Survey (OGS) work in the Ottawa area.

With the publication of the 3-D bedrock geology model in 2019, work is underway on QA/QC for an update and improved resolution of the formations within the Lockport Group. The new model will be a full geocellular model constructed in SKUA-GOCAD™, incorporating faults, oil and gas pools and salt mine footprints. An important part of the modelling initiative underway will be development of confidence measures for each of the model surfaces. The activity is also working toward an updated hydrostratigraphic framework that will support reclassification of the geological model for groundwater modelling applications. With collaborators, the GSC is reviewing how to further enhance and complete additional analysis of the regional hydrogeological model and to examine the applications of the model for various analysis. Public outreach will be improved through model visualization in a virtual reality environment, and 3-D printing of model highlights for improved tactile interaction.

The GSC Groundwater Geoscience Program has a national project for Archetypal Aquifer classification and characterization. The classification component is hoping to provide a systematic approach to aquifer classification of glacial sediment aquifers that advances beyond the sediment–landform approach using the concepts of hydraulics, confining units, and aquifer (reservoir). The classification will provide a basis for synthesis of information from case studies to provide a synthesis for the respective aquifers.

Within the Ottawa valley and particularly the South Nation Conservation Area (SNCA), activities are under way on hydrogeophysics of the Vars–Winchester esker and Champlain Sea mud aquitard. In collaboration with the City of Ottawa, Rideau Valley Conservation Authority, and University of Ottawa, work is focussed on porewater chemistry and modelling of hydrogeological and geotechnical behaviour of the aquitard. Understanding of the aquitard is important for both the protection of underlying aquifers and from a landslide–seismic hazard perspective because of the physical properties of the clays. In collaboration with South Nation, Agriculture and Agrifoods Canada work is proceeding on enhancement of the hydrogeological modelling framework for the SNCA watershed.

The OGS has both bedrock and surficial geology projects underway in the Ottawa region and the GSC is working toward supporting this work through provision of seismic data and downhole geophysics data with the potential update of the regional eastern Ontario framework geological model.

Geographic Analysis of the Porosity and Permeability Variations in the Silurian Lockport Group, Southwestern Ontario

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The Lockport Group, which is a cyclic succession of dolostones reflecting open to restricted marine conditions during the Early Silurian (Wenlock: 433–427 Ma), comprises 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 succession of sedimentary rocks in southern Ontario because they 1) possess significant bedrock aquifer groundwater resources; 2) possess deeper subsurface oil and/or gas resources and natural gas storage reservoirs; 3) possess significant chemical, dimension stone and aggregate resources; and 4) are a major tourist and agricultural attraction (e.g., wineries, agriculture, waterfalls, hiking, climbing, and camping), resulting in millions of investment dollars in Ontario.

The Oil, Gas and Salt Resources Library staff in London, Ontario, have compiled a database of porosity and permeability measurements from 485 cores in 2018, and 155 cover part or all of the Lockport Group interval. The data set comprises 11,543 porosity and vertical and horizontal permeability analyses undertaken at 12 laboratories. This new data set, in combination with outcrop sections, newly drilled rock cores, geophysical well logs, and drill cuttings, will be used to document the regional variations in porosity and permeability in the Lockport Group at the formational rank.

To improve the data quality, data validation has been conducted by summarizing laboratory protocols and standards from the 12 different laboratories and reconciling data fields with auxiliary data, including geophysics and duplicate cores. Data have been validated following the data QA protocols provided by core analysis labs on the parameters of Residual Saturation, Effective Porosity, Grain/Bulk Density and Valid Permeability. Geology QA/QC of the 155 cored wells and 375 wells along the Lockport Group subcrop belt from Niagara area to Bruce County have been performed to delineate formational tops using well logs (gamma-ray, neutron and density), core and drill cuttings, in order to revise the regional lithostratigraphy. A validated core analysis database of the Lockport Group has been created with each porosity/permeability parameter plotted in ESRI® ArcGIS®. The plotted results in ArcGIS® provides a visual distribution of formation isopachs and porosity/permeability changes at the formation rank.

All of the core analysis data are located in the deeper subsurface of southwestern Ontario and represent the intermediate brackish to saline sulphur water, and deep brine regimes. The

plotted porosity/permeability data fill the gap between the shallow potable groundwater zone to the intermediate water zone, improving the representation of the continuity/discontinuity of bedrock permeable zones, relationships to hydrocarbon traps, and isolation of deeper bedrock formations from Ontario Geological Survey potable bedrock aquifer mapping in the Niagara cuesta has demonstrated that both geologic and geomorphologic attributes control the subregional character of confined and unconfined bedrock aquifers. Newly compiled data from this study reveal that in the deeper subsurface, the porosity/permeability values are controlled by variations in carbonate lithofacies, diagenetic destruction/enhancement and existence of paleokarst systems. Within the Lockport Group, the inter-pinnacle facies of the Guelph Formation have high porosity and permeability values because of its paleokarstic nature. Formation within pinnacle structures has formed either oil and natural gas reservoirs or saline water–bearing zones. In the deep regime, from the Algonquin Arch to western Lake Erie, both the karstic top of the Guelph Formation and the overlying A-1 Carbonate appear to be variably/highly permeable, with a second highly permeable zone of the Gasport Formation.

Learning About Ontario's Paleozoic Geology with Virtual Reality Google Expedition Tours

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How well can you interpret or place into context the different geological features or rock types that are exposed along roadways, rivers, coastlines or construction sites? Here in the Department of Earth and Environmental Sciences at the University of Waterloo, we recognize a gap between learning foundational geoscience knowledge (i.e., in traditional classrooms and lab settings) and applying this knowledge during field experiences. To bridge this gap and better prepare students for field experiences we suggest using virtual reality.

The Google Expedition Kit funded by the Dean of Science Undergraduate Teaching Initiative was chosen as the best entry-level system because it is cost effective, self contained, already tested and versatile for teaching up to 20 people. Here we present the perceived advantages and disadvantages of this system to provide immersive learning experiences for improved understanding of Ontario's Paleozoic geology. Initial use of this VR Kit has shown it can be used successfully to investigate Paleozoic rock outcrops across Ontario by using existing and student-created Tours, as well as self-guided and leader-guided Tours. There was increased motivation and engagement among students, improved familiarization and connections among a variety of outcrops in space and time. And there was also enhanced meaning and context for the many Paleozoic rock layers in Ontario, and an increased number of insightful questions. Although field experiences will always play a vital role in university geoscience education, virtual reality can help in improving understanding and compliment field experiences through its uniquely immersive capabilities. We suggest this would also be effective in professional geoscience practice and everyday life.

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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.*

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ISSN 0826-9580 (print)
ISBN 978-1-4868-4213-1 (print)

ISSN 1916-6117 (online)
ISBN 978-1-4868-4214-8 (PDF)