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Regional-scale Groundwater Geoscience in Southern Ontario: an Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario open house

H.A.J. Russell, D. Ford, and E.H. Priebe
(Compilers)

2017

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Regional-scale Groundwater Geoscience in Southern Ontario: an Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario open house

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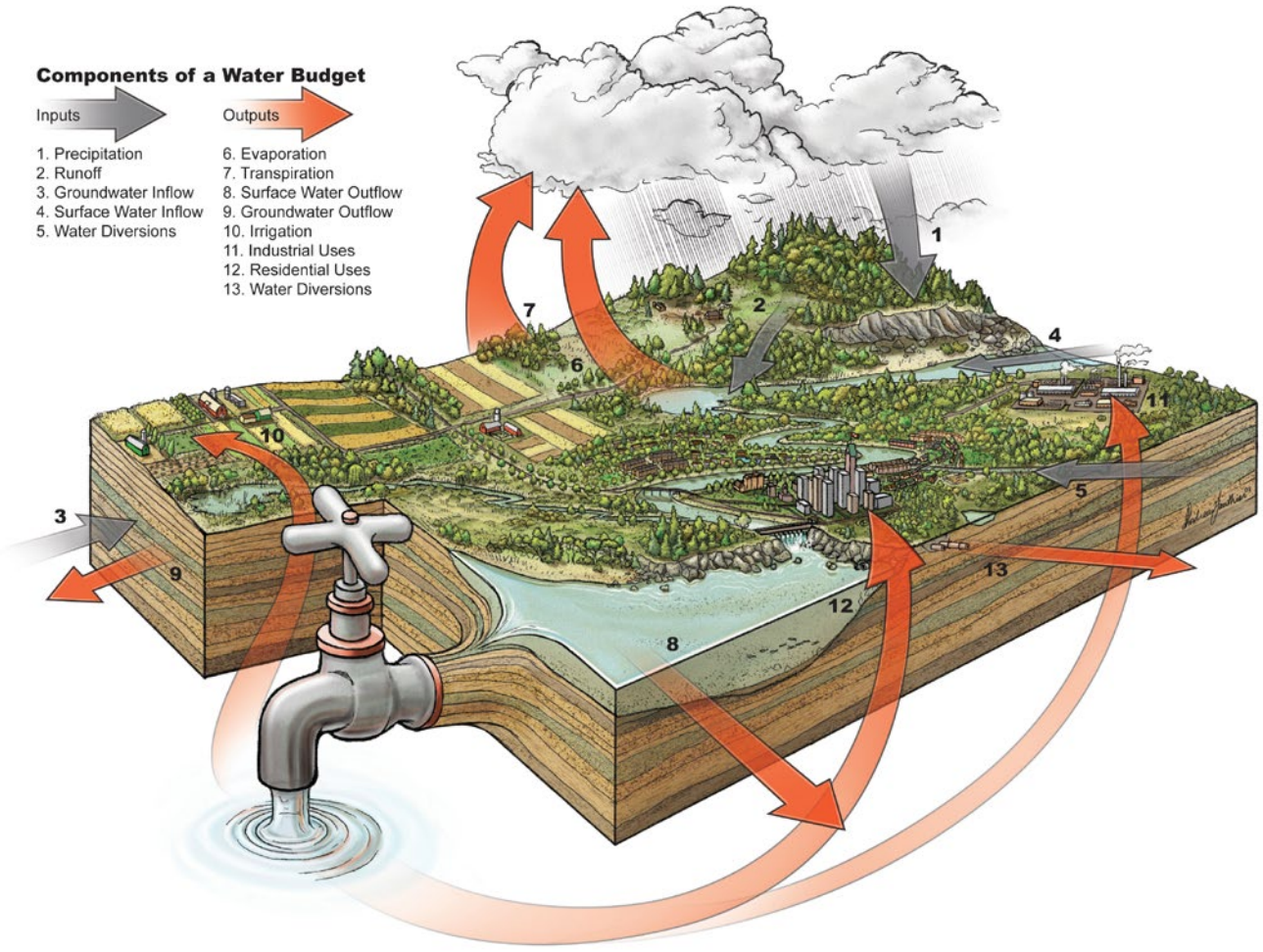
Publications in this series have not been edited; they are released as submitted by the author.

Regional-scale Groundwater Geoscience in Southern Ontario: an Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario open house

March 1st and 2nd, 2017 | Delta Hotel, Guelph



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Geological Survey of Canada, Open File 8212.

Canada

Ontario

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Location Map

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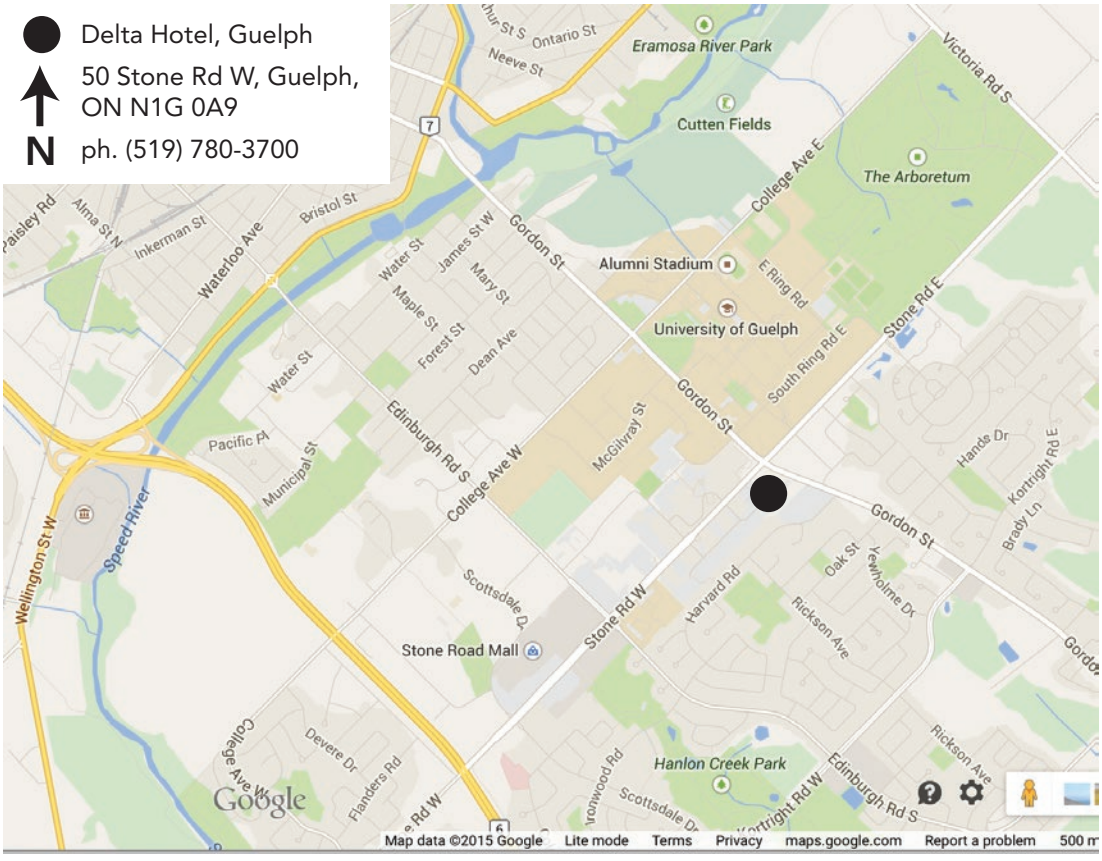

Program

March 1 Oral Presentations

START	END	TOPIC/TITLE	PRESENTER	AFFILIATION
8:30	9:00	Registration/Networking	Russell/Priebe	
9:00	9:10	Welcome/Introduction	Parker/ Michaud	
9:10	9:30	An Overview of the Ontario Geological Survey's Groundwater Initiative	Priebe	Ontario Geological Survey
9:30	9:50	Highlights of OGS – GSC Collaboration on Regional Groundwater Studies: 2016 – 2017	Russell	Geological Survey of Canada
9:50	10:30	Break		
10:30	10:55	U.S. Geological Survey Groundwater Research in the Great Lakes Basin	Eberts	United States Geological Survey
10:55	11:20	Lithostratigraphic Compilation of Phanerozoic Bedrock Units and 3D Geological Model of Southern Ontario	Brunton	Ontario Geological Survey
11:20	11:40	Developments in a Surficial Stratigraphic Framework for 3D Geological Modelling	Sharpe	Geological Survey of Canada
11:40	12:00	Near Surface Hydro-Geophysics in Southern Ontario	Pugin	Geological Survey of Canada
12:00	13:00	Lunch		
13:00	13:20	Niagara 3D Sediment Mapping	Burt	Ontario Geological Survey
13:20	13:40	Geochemical Characterization of Southwestern Ontario's Breathing Well Region	Freckelton	Oil, Gas, Salt Resources Library
13:40	14:00	GW/SW interaction: Development of a Conceptual Framework	Conant	University of Waterloo
14:00	14:20	Mapping of Buried, Surface-Connected, Karstic Groundwater Systems Using Dissolved Gases and Hydrochemical Tracers	Hamilton	Ontario Geological Survey
14:20	14:50	Break		
14:50	15:10	Water Well Record Data Enhancement Project	Carr	Ministry of Environment and Climate Change
15:10	15:30	Directional Geostatistical Simulation for Regional Hydrostratigraphy	Benoit	Geological Survey of Canada
15:30	15:50	Improving the Spatial Density of a Regional Hydraulic Conductivity Dataset with Estimates Made from Domestic Water Well Information	Priebe	Ontario Geological Survey
15:50	16:00	Wrap-up	Priebe/Russell	

Program

March 2 Oral Presentations

START	END	TOPIC/TITLE	PRESENTER	AFFILIATION
8:30	9:00	Registration/Networking		
9:00	9:10	Welcome	Ford	CO Geoscientists
9:10	9:30	Recharge Offsetting – Maintaining Recharge in an Urban Environment	Cuddy	Lake Simcoe Conservation
9:30	9:50	Clarence-Rockland Groundwater Study – Aquifer Capability Screening Tool Pilot Study, Prescott-Russell, Ontario	Di Iorio	City of Ottawa
9:50	10:35	Break		
10:35	10:55	Development of Groundwater Vulnerability Guidelines in Thin-Drift and Paleozoic Bedrock Terrains, Cataraqui Region Conservation Authority, Southeastern Ontario	Evans	Cataraqui Region Conservation Authority
10:55	11:15	Wetland Surface and Groundwater Interactions Monitoring Program	Strakowski	Conservation Halton
11:15	11:35	Wetland Ecohydrology Monitoring at TRCA: Insights and Lessons Learned	Taylor	Toronto and Region Conservation
11:35	12:00	Hydrogeological Tools for Characterizing Groundwater Discharges to Surface Water: Advantages, Disadvantages, and the Importance of Proper Timing	Conant	University of Waterloo
12:00	13:00	Lunch		
13:00	13:20	Insights from a "One Water" Integrated Approach to Tier 3 Water Budget Analysis	Kassenaar	EarthFx
13:20	13:40	Application of the Tracer Radon-222 to Identify Groundwater Discharge Hotspots Along the Lake Simcoe Shoreline	Robinson	Western University
13:40	14:00	Implementing Drinking Water Source Protection – Conservation Authority Perspective	Ford	Toronto and Region Conservation
14:00	14:20	Modelling Advancements from Source Water Protection	Van Vliet	Matrix Environmental
14:20	14:50	Break		
14:50	15:10	Municipal Water Well Efficiency Programs – a Fresh Approach in Peel Region; the Good, the Bad and the Imminent	Lasso	Region of Peel
15:10	15:30	Access to High Quality Groundwater Data – a Geoportal for Central Ontario	Gerber/ Holysh	Oak Ridges Groundwater Program
15:30	15:50	OGS Client Survey Feedback – Presentation on 2015/2016 Survey and Feedback Request	Parker	Ontario Geological Survey
15:30	15:50	Wrap-up	Russell/ Priebe/Ford	

Program

Posters

NUMBER	PRESENTER	TOPIC/TITLE	AFFILIATION
1	Brunton	Karst and Hazards Lands Mitigation: Some Guidelines for Geological and Geotechnical Investigations in Ontario Karst Terrains	Ontario Geological Survey
2	Burt	Results of the Orangeville-Fergus 3D Sediment Mapping Project	Ontario Geological Survey
3	Cushman	Agriculture Actions to Reduce Phosphorus to Lake Erie	Ministry Agriculture, Food, Rural Affairs
4	de Jong	Anticipating Demand for Groundwater Geoscience: Groundwater Risk Information Seeking Behavior Among Stakeholders in Southern Ontario	Laurentian University
5	Ford	How to Build a Living City – Balancing the Needs of Human Development and Ecosystems	Toronto and Region Conservation
6	Kjarsgaard	Newmarket Till Aquitard: Optimum Grain Packing with a Pore-filling Calcite-Rich Cement	Geological Survey of Canada
7	Knight	Chemostratigraphy in Southern Ontario by pXRF Spectrometry	Geological Survey of Canada
8	Milloy	Ottawa Harvested Hydrogeological Information Geodatabase	Rideau Valley Conservation
9	Milloy	Barometric Pressure Responses in Groundwater Level Time Series Data, A Literature Review	Rideau Valley Conservation
10	Mulligan	New Insights on Regional Stratigraphy and Hydrogeology Based on Surficial and Subsurface Sediment Mapping in Simcoe County, Southern Ontario	Ontario Geological Survey
11	Wang	Downscaling SMOS/SMAP Soil Moisture Product Using High Resolution Radarsat-2 SAR Data: A Case Study in Southern Ontario	Geological Survey of Canada

Context

Following the successful 2016 Ontario Geological Survey (OGS) – Geological Survey of Canada (GSC) Open House, and based on feedback from participants, this year has been expanded to two days and incorporates an expanded role for Conservation Authorities. The Conservation Authorities participation has been coordinated by Conservation Ontario's Geoscience Group (COGG). The first day of the open house continues to profile OGS and GSC research with an attempt to integrate perspectives from the USGS and other provincial ministries. Day two focuses on work completed by, and in collaboration with Conservation Authorities in Southern and Eastern Ontario. Talks on the two days continue to be 20 minutes in length; however, there is an expanded time frame during the health breaks and at the end of the day to network and also interact with authors who decided to have poster presentations. Poster presentations will be on display for the complete two days.

In 2016 four key issues were identified as being the focus of presentations. This year we continue to emphasize:

- Outcomes of the OGS-GSC 2012-2015 Groundwater Geoscience Knowledge Gap Analysis
- Canada – USA Great Lakes Water Quality Agreement /Canada – Ontario Great Lakes Agreement
- Provincial Groundwater Data Management.
- Conservation Authority Geoscience

As in 2016, the 2017 open house builds upon the issue of outreach and communications identified in the 2012-2015 OGS Gaps analyses[1]. It is the second in a series of annual open houses planned for March to connect with groundwater practitioners and policy makers in southern Ontario, and share updates on OGS-GSC geoscience activities. Following each open house the organizers will complete an evaluation of the success of the open house and refine the format and content for the following year. The OGS and GSC are committed to developing this open house for a four year period till March 2019 when the exercise will be re-evaluated.

Abstracts in this volume have not been edited. The information presented is the responsibility of the respective authors and agencies.

Acknowledgements

Day two has been sponsored by a contribution to Conservation Ontario Geoscientists Group by the International Association of Hydrogeologists (IAH) Canadian Chapter. The time and effort of the workshop presenters and their respective agencies is much appreciated. Matthew Millar, Claire Milloy, and Jean Francois Bureau helped with a variety of planning issues. An internal review at the GSC by Dan Kerr is much appreciated. Donna Ferguson and Glenn Ferguson completed graphic production of the workshop program. This is a contribution of the Groundwater Geoscience Program of the Geological Survey of Canada, Earth Science Sector, Natural Resources Canada. This work is a contribution of the GSC-OGS Southern Ontario project on groundwater 2014 – 2019.

1 Russell, H.A.J., Priebe, E.H., Parker, J.R., 2015. Workshop Summary and Gap Analysis Report: Unifying Groundwater Science in Southern Ontario. Ontario Geological Survey Open File Report. 6310 64 p.

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Ottawa Harvested Hydrogeological Information Geodatabase

Below (Ramey)[1], Marisa; Cassandra Michel[1], Michel Kearney[2], and Claire Milloy[1]

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Several of the conservation authorities (CA) in eastern Ontario are partnered with the City of Ottawa to provide technical advice about hydrogeological studies that are submitted to the City in support of development applications and about related policy and guidance development. These CA's also facilitate *Source Protection* initiatives for the local *Source Protection Regions* and maintain an ongoing partnership with the Ministry of the Environment and Climate Change (MOECC) to collect data from local *Provincial Groundwater Monitoring Network* (PGMN) wells. In addition, the City also owns information from municipal wells and data from numerous land use monitoring programs.

As a result of the above responsibilities, the CAs and City house a tremendous amount of hydrogeological information in separate paper, pdf, tabular, and various old database formats; all of which has never been catalogued. Moreover, this data cannot currently be accessed, summarized, mapped or analysed together. However, there are on-going demands for the presentation and use of this information during the course of regular municipal and conservation authority business.

To address the above hydrogeological data management gap, in 2016, the City of Ottawa in partnership with the Rideau Valley Conservation Authority implemented a project to develop a hydrogeological geodatabase and data harvesting plan. This presentation will provide an overview of the project context, outcomes and anticipated next-steps.

Directional Geostatistical Simulation for Regional Hydrostratigraphic Units Uncertainty Characterization, Innisfil Creek Sub-watershed, Ontario

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The uncertainty characterization of hydrostratigraphic systems is important for risk assessment in hydrogeology. A complex system is difficult to characterize due to limited sampling. Geostatistical simulation methods aim at representing the underlying modeling uncertainties about hydrostratigraphic units proportions, properties and spatial arrangement through an ensemble of equally probable models. These models control the connectivity and, ultimately, the response of the system under an external stimulus. It is then critical to have geostatistical algorithms that can accurately reproduce the geological controls on the flow, such as the directional ordering of units. The latter is an important and common feature of sedimentary environments. Recent developments in geostatistics have improved the realism of hydrostratigraphic units simulation. In that regard, we revisited the Markovian Categorical Prediction (MCP) simulation method to allow for trends and directional ordering in simulation. The adapted MCP approach was applied to determine the uncertainty at a regional scale within the Innisfil Creek subwatershed with its 18 hydrostratigraphic units. The trend in unit occurrences is accounted for by locally confining the geostatistical algorithm to a deterministic model, without resorting to auxiliary variables. The presented methodology allows characterization of the uncertainty of the hydrostratigraphic model.

The outputs are a suite (ensemble) of models, which provide a variability assessment of the spatial units arrangement and are an alternative to the deterministic one that complies with known data and unit ordering and trends. The alternative models propose a realistic variation for the thicknesses of the different units. Results suggest that the updated MCP methodology is highly flexible and efficient for closely replicating hydrostratigraphic units ordination, even for units occurring with low frequency. These geostatistical models are then appropriate for characterizing the uncertainty of groundwater flow and transport as well as aquifer vulnerability and the delineation of wellhead protection areas.

Lithostratigraphic Compilation of Phanerozoic Bedrock Units and 3D Geological Model of Southern Ontario

Brunton[1], Frank R.; Terry Carter[2], Charles Logan[3], Jordan Clark[4], Kei Yeung[1], Lee Fortner[5], Candace Freckelton[4], Liz Sutherland[4], and Hazen A.J. Russell[3]

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A 3D geological model of the Paleozoic bedrock geology of Southern Ontario is being developed through a collaborative project involving the Ontario Geological Survey (OGS), Geological Survey of Canada (GSC), Ministry of Natural Resources & Forestry (MNRF), and Oil, Gas, Salt, Resources Library (OGSRL). This multi-year initiative involves a number of parallel objectives, including: 1) update of rock unit nomenclature at formation and group levels; 2) characterize criteria for delineating formational contacts; 3) better constrain the bedrock topography surface by integrating data from regional MOECC (water) and OGSRL (oil and gas) wells; 4) develop a revised bedrock topography for Lake Ontario from legacy shallow reflection data; 5) revise formation boundaries to update the Paleozoic bedrock geology maps; and 6) delineate groundwater types (potable vs non-potable) with a focus on potable groundwater within the shallow, karst-influenced, carbonate-dominated and cuesta-forming bedrock successions. The latter two initiatives will extend beyond the scope of the 3D Paleozoic bedrock model project. This project builds upon the OGS mandate to map the potable groundwater resources of Ontario and the GSC mandate to delineate key aquifers across the country.

Preliminary 3D geologic models have been developed using Leapfrog™ Hydro implicit modelling software based on more than 26,700 deep petroleum boreholes and published OGS bedrock geology maps. The model area covers approximately 110,000 km^2, extending across south-central and southwestern Ontario and beneath the Great Lakes to the US border, but not Manitoulin Island. The model currently comprises 61 layers and attempts to render the bedrock topography, the Precambrian- Paleozoic contact, and the regional variability of 58 Paleozoic bedrock formations plus sediment cover. It is a product of an ongoing, iterative process of interim modelling, model review, and QA/QC editing of formation picks. Leapfrog™ modelling software is used to produce 3D models based upon Radial Basis Functions primarily using the formation depth picks. Leapfrog™ lends itself well to iterative data QA/QC because data inputs can be readily reloaded without the need to re-construct the formation contact structure and model chronostratigraphy. The formation model will eventually be reclassified to a hydrostratigraphic model. In 2015 and 2016 project geologists reviewed over 50,000 formation picks by examination of geophysical logs, core and drill cuttings, and more than 100,000 digital water well records. Issues resolved include: well location errors, formation assignment, anomalous data points, and wells with missing or incorrect formation picks and bedrock characterization. The study integrates traditional outcrop/field- and lab-based protocols and petroleum industry subsurface mapping techniques, with GIS, database mining and queries, and 2D and 3D mapping and modelling techniques.

Over the past 12 months, efforts have focused on refining formational contacts and regional distributions of Paleozoic formations, including: 1) stacked Ordovician-, Silurian- and Devonian-age carbonates that form regional karstic escarpments that are variably blanketed by Quaternary sediments; 2) select Devonian and Cambrian siliciclastics; and 3) key regional clay-rich sedimentary rocks and mixed carbonates-siliciclastics that appear to form regional to sub-regional aquitards.

Karst And Hazards Lands Mitigation: Some Guidelines For Geological And Geotechnical Investigations In Ontario Karst Terrains

Brunton, Frank R.

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The mandate of the Ontario Geological Survey is to provide citizens and institutions of Ontario with accurate and objective earth science knowledge about Ontario, in order to sustain and support quality of life, economic prosperity, environmental quality, and public health and safety. The OGS does not comment on best practices or recommended approaches for reviewing and approving changes to landuse or development applications in karst terrains. Various Ontario ministries – the Ontario Geological Survey (MNDM) and the Ministry of Natural Resources & Forestry (MNRF), Municipal Affairs and Housing (MMAH), and Agriculture and Food and Rural Affairs (OMAFRA) have been reviewing existing policies related to land-use and development throughout southern Ontario and Manitoulin Island to update hazard lands guidelines, nutrient management practices and to develop best practices documents for various forms of development in karst terrains.

The main purpose of the Ontario Geological Survey Karst Mitigation field-based research is to provide a more comprehensive summary of the kinds of geoscience field work and data sets that could be integrated into field-based studies in order to address gaps in the current guidelines framework (e.g., Natural Hazards Technical Guidance documents for use with the current Ontario Provincial Policy Statement). A "best practices" approach to addressing karst hazards should be carried out in a staged manner, one that involves a general geologic- and geomorphologic-data-gathering desktop investigation (Phase 1 study) that would progress to a more detailed field-based study (Phase 2) to quantify and qualify identified karst terrain hazards (i.e., progress from Phase 1- to Phase 2-level site investigation depending upon nature of land use or development project being proposed). An overview of proposed best practices for investigating karst hazards in Ontario and an innovative "toolkit" for investigating karst-influenced groundwater flow zones will be reviewed in this presentation.

3D Sediment Mapping on the Niagara Peninsula

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In 2013, the Ontario Geological Survey (OGS) initiated a 3D sediment mapping project encompassing the Niagara Peninsula. As with other sediment mapping projects, the goals are to reconstruct the Quaternary history of the area, build a 3D model of Quaternary deposits that form regional-scale aquifers and aquitards, and to define the internal characteristics of each sediment package. This study represents a multi-agency collaborative effort: a regional ground gravity survey (6828 stations covering 3920 km^2) and sediment logging of hand auger cores, natural sediment exposures, and 95 continuously cored boreholes have been completed by the OGS; the Geological Survey of Canada has completed shallow seismic reflection surveys (48.1 km) and downhole geophysical logging (14 wells); and 28 monitoring wells have been installed and sampled by conservation authority and municipal partners.

This presentation will focus on the results of the 2014-2016 OGS drilling program. The bedrock surface is characterised by southward-dipping strata forming 2 prominent escarpments. Ordovician shale lies below the Niagara Escarpment, Silurian dolostone, shale and gypsum between escarpments and Devonian limestone and cherty limestone above the Onondaga Escarpment. The surface is incised by buried and partially buried bedrock valleys that range from broad and shallow to narrow and deep. Drift thickness is largely controlled by bedrock topography; the thickest sediments are found within the bedrock valleys while the thinnest sediments are found at the escarpments. Drumlins, moraines, deltas and fans form locally thicker sediment accumulations.

In the western part of the area there is a thick older drift package of diamicton, glaciolacustrine silt and clay and sand to gravelly sand that can be correlated with the main Late Wisconsin Catfish Creek Till aquitard, late glacial Port Stanley Till aquitard, Grand River outwash aquifer and Wentworth Till aquitard from adjacent 3D sediment mapping areas. The central and eastern portions of the study area are dominated by younger sediments. Coarse-textured ice-contact stratified drift, glaciofluvial sand and gravel and glaciolacustrine sand that forms the Whittlesey aquifer was deposited during and after ice retreat. Thick glaciolacustrine silt and clay was then deposited in a series of proglacial lakes that ponded against the retreating ice front. In the northern and eastern portions of the area these fine-textured glaciolacustrine deposits are separated into lower and upper Whittlesey aquitards by a 'sandwich' of sandy aquifers and muddy Halton Till, diamicton and glaciolacustrine sediments (Halton aquitard) deposited during the late glacial ice advance out of the Lake Ontario basin. The uppermost unit is typically a thin aquifer composed of post-glacial to modern shoreline, aeolian and river sediments. This high-resolution stratigraphy forms the framework for interpreting monitoring well data collected by conservation authorities and municipalities.

The results of the extensive drilling program mean that the physical properties of aquifer and aquitard sediments can now be defined across the region. This information, as well as seismic velocities obtained by downhole geophysical logging, will allow verification of seismic time sections into depth sections. It is anticipated that combining the results of drilling and geophysics will provide the best possible definition of buried valley geometry and fill; an important objective of the project. The long-term impact of this study will be to provide conservation authority and municipal partners with an improved water resource decision making tool.

Results of the Orangeville-Fergus 3D Sediment Mapping Project

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The Orangeville-Fergus 3D sediment mapping project was undertaken between 2008 and 2015. The 1550 km^2 study area is situated above the Niagara Escarpment between Waterloo Region and the city of Orangeville. The study area is centered on the sand and gravel Orangeville Moraine which forms the headwaters of the Nottawasaga Valley, Grand River and Credit Valley Conservation Authorities. Fortythree new boreholes were drilled and these, together with new geophysical surveying, surface sampling and analysis of a significant volume of legacy data, were the basis for the creation of a 3D model. The model is underpinned by a conceptual geological framework which subdivides the Quaternary sediments into 16 hydrostratigraphic units. The units are identified on the basis of age and sediment characteristics resulting from deposition in different environments. Each unit typically contains a range of sediment textures resulting from depositional facies changes and short-term or localized changes in ice-margins, lake levels, sediment sources and water velocities.

Undifferentiated southward dipping Paleozoic bedrock forms the basal hydrostratigraphic unit across the area. A new bedrock topographic surface significantly refines previous provincial-scale mapping studies. Broad lows and resistant bedrock highs, deeply incised re-entrant bedrock valleys extending back from the Niagara Escarpment and narrow rectilinear buried valleys characterise the surface.

A series of older tills confine the bedrock aquifer and small sediment aquifers in the western portion of the area. Catfish Creek Till, deposited during the last glacial maximum, is mapped across most of the area, thinning then pinching out towards the Niagara Escarpment. The till forms a regionally significant aquitard that can be detected in many low quality records and is considered to be an important stratigraphic marker. As the ice thinned and began to break up, a lake formed within the interlobate zone between the retreating ice fronts. Small sand and gravel fans were buried by up to 20 m of silt and clay in the central part of the lake. The readvanced of lobate ice initiated deposition of the thick centrally located Orangeville Moraine. The moraine is characterised by a hummocky surface and coarse gravel to sand ice-proximal sediments in the northeast. The surface becomes progressively smoother and the sediments shift to fine-textured sand, sandy silt and silt towards the distal flanks. These fine-textured sediments can be expected to complicate local groundwater flow paths through the sediment package. The moraine forms an important groundwater recharge area, particularly in the hummocky and coarse-textured zones. The ice continued to advance, and partially overrode the moraine. A series of tills were deposited and these form the upper aquitard across much of the area. Outwash cobbles and gravels were deposited in channels incised into the till as the ice retreated and these form unconfined aquifers across the area. The final readjustment of the retreating ice lobes resulted in the construction of the hummocky, Paris and Singhampton end moraines in the southeast and northeast corners of the study area, respectively. The moraines are characterised by discontinuous beds of diamicton and course-textured stratified sediment, providing recharge potential despite classification as an aquitard.

The development of an evidenced-based 3D hydrostratigraphic model in the Orangeville-Fergus area has provided the first opportunity for a detailed examination of the lateral extent, thickness and composition of regional-scale sediment packages. Surface and buried sediments forming aquifers have been identified and described. This information is intended to inform source water protection and land use planning.

Well Record Data Enhancement Project

Carr[1], Cynthia and Dajana Grgic[2]

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Ontario's Ministry of the Environment and Climate Change (ministry) has a dataset of over 750,000 well records from 1899 to present with a growth rate of 15,000 to 20,000 records per year. Well records provide information about a well's location, construction, lithology and pumping test, as prescribed by the Wells Regulation. In general, a well record is required to be submitted by the well contractor at the time of construction, major alteration or decommissioning of water supply wells, test holes and dewatering wells.

Since its inception, the provincial well record dataset has been an invaluable resource for geologists, engineers, and other stakeholders across the province as it is the primary source of province wide subsurface geological and groundwater information. It is made available through the ontario.ca website as a Data Catalogue and an Interactive Well Records Map.

Data on the well records are of varied quality with some well records providing a high degree of accuracy and completeness, and others not. During use of the well record data by external stakeholders, professional geoscientists and engineers have assessed and corrected the data, and added new data to produce "value-added" well record datasets for their areas of study. They have checked for and interpreted for regional consistency in nomenclature, location, etc.

In November 2016, the ministry initiated the Well Record Enhancement Project to determine how to create, maintain and present an authoritative provincial well record dataset in which the geoscience community has confidence and can contribute ongoing improvements. WSP Canada Inc. was retained to assist with the delivery of this project.

The objectives of the project are to identify and assess options to 1) enhance the quality of Ontario's well record data, including the integration of existing value-added datasets; 2) identify how to validate/curate corrections and value added data from external sources into a "best available" dataset on an ongoing basis; 3) enhance how well record and value-added data are made available to the public, including improved functionality/presentation and delivery models; and 4) potentially recover the costs of enhancements and delivery. Recommendations are to be based on a solid understanding of the needs and capacity of the MOECC, other existing well record users and creators of existing value added datasets including professional geoscientists, engineers and well contractors.

To this end, the ministry is consulting with key stakeholders to better understand what enhancements they need and want in terms of well record quality, access, presentation and delivery. In addition the ministry is examining what corrected/value added data may be available for a curated authoritative provincial dataset, and what role, if any, stakeholders would like to play in its delivery.

Hydrogeological Tools for Characterizing Groundwater Discharges to Surface Water: Advantages, Disadvantages, and the Importance of Proper Timing

Conant Jr., Brewster
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Many of the water management responsibilities of Conservation Authorities require an understanding of groundwater/surface-water (GW/SW) interactions. GW/SW interactions play a major role in the physical, chemical, and biological integrity of surface water and groundwater systems and are relevant to: source water protection; protection of groundwater dependent ecosystems; protection of wetlands, management of fisheries; assessment of the effects of land use changes on watersheds; and the prediction and management of floods. The type and amount of hydrological data needed to answer specific management questions will vary greatly. If financial or personnel resources are limited, it is a challenge to collect data at a sufficient scale and frequency to ensure a full understanding of the system.

The complexity of GW/SW systems means it can be difficult to collect enough data to put it all into proper hydrological context and develop reliable conceptual models of the GW/SW interactions. Therefore, there is a need for inexpensive and cost effective methods and tools to efficiently characterize groundwater discharges and GW/SW interactions on both large and small scales. To address this problem, a multi-scale, multi-technique characterization approach is proposed, where large-scale large-area reconnaissance methods are used to quickly assess large areas and identify the largest groundwater discharges. This work is then followed by progressively smaller-scale characterization techniques (with successively higher sensitivity) to make point measurements of groundwater discharge and GW/SW interactions and quantify fluxes.

The reconnaissance methods consist primarily of temperature-as-a-tracer methods (i.e., aerial thermal infrared surveys, drag probe surveys, and streambed/lakebed temperature mapping) that are very useful and relatively inexpensive methods for delineating groundwater discharges. The reconnaissance results are used to pick locations for more conventional and/or point measurement techniques (i.e., differential streamflow gauging, monitoring water levels, mini-piezometers, seepage meters, and lakebed/streambed temperature monitoring and modeling) to characterize the groundwater flow directions (discharge versus recharge) and quantify fluxes.

An overview of the overall approach and a brief description of the advantages and disadvantages of each technique will be provided. This approach can obtain good spatial characterization of GW/SW interactions; however, timing of the data collection is critical. All data collected should be put into the context of (and help define) how the hydrological system changes over time, because groundwater discharge and GW/SW interactions are not constant over time. For temperature-as-a-tracer methods, timing of data collection is of paramount importance. Temperature based GW/SW interactions methods are deceptively simple and can provide excellent information; however, collecting data when there is poor or no contrast between surface and groundwater temperatures should be avoided, because it can result in useless or misleading results. If properly applied, the multi-scale, multi-method characterization approach can be a cost effective way of comprehensively characterizing groundwater discharges and GW/SW interactions and help improve decision making with respect to managing natural resources.

A Conceptual Framework for Groundwater/Surface-Water Interactions and Identifying Potential Impacts on Water Quality, Water Quantity and Ecosystems

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Groundwater/surface-water (GW/SW) interactions play an important role in controlling the physical, chemical and biological integrity of surface water and groundwater systems in the Great Lakes Basin (GLB). Increased recognition of their importance is illustrated by the addition of Annex 8 on groundwater to the Great Lakes Water Quality Agreement in 2012. GW/SW interactions in the GLB are complex can impact water quantity, water quality and ecosystem health of streams and lakes including the Great Lakes. Although considerable work has been done to characterize the geology, hydrology, and groundwater resources in Southern Ontario, there are still numerous science gaps with respect to GW/SW processes and no guidance or framework exists for evaluating the importance of GW/SW interactions. Decisions regarding land use and resource development are often made without an adequate understanding of the way in which GW/SW interactions may impact water quantity, water quality and ecosystem health. Therefore, to enhance the ability to make informed science-based decisions, a conceptual framework has been developed to help evaluate GW/SW interactions and identify potential impacts. The purpose of the framework is to provide a comprehensive and logical approach to understanding, evaluating, and identifying the important factors and processes that control GW/SW interactions of both streams and lakes and linking them to impacts on their water quantity, water quality, and ecosystems. The framework consists of five fundamental parts including: 1) the surface water system; 2) the groundwater system; 3) the interface connectivity; 4) GW/SW interactions; and 5) the ultimate impacts on the water quantity, quality and ecosystems associated with the surface water, groundwater and the transition zone. For each of the first four parts, lists of important factors and critical processes have been identified. For ease of use, the framework is presented as a flow chart that highlights the relationship between factors and processes and the potential impacts on the surface water, groundwater, and the transition zone. Processes that are common to both streams and lakes are identified as well as those processes unique to each. A benefit of the framework is that it is flexible and can be adapted to the needs of the end-user to develop scientifically sound understanding of a setting and to help answer key management questions. This flexibility is important in Southern Ontario because there is a range of hydrological landscape settings where the mechanisms controlling GW/SW interactions and resulting impacts are vastly different. To illustrate the application of the framework, case studies will be presented for different GW/SW interaction settings (i.e., riverine and nearshore lake settings) and management questions. The framework presented provides a comprehensive and accessible approach to evaluating GW/SW issues in Southern Ontario.

Recharge Offsetting – Maintaining Recharge in an Urban Environment

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Through the updated Growth Plan for the Greater Golden Horseshoe (2016), the Lake Simcoe Watershed can expect growth of an estimated 9,000 hectares of new development over the next 25 years. The Province of Ontario has increased development density targets which will accordingly increase impervious areas in an already urban environment; making it more difficult to maintain predevelopment recharge rates. Typically, maintaining recharge has focused on the sustainability of natural features such as wetlands and cold water streams; however more recently, it has led to better management of municipal drinking water supplies and stormwater management throughout the Lake Simcoe Watershed. Due to the significant advancement of recharge-based policies within the Lake Simcoe Protection Plan (LSPP) and the South Georgian Bay Lake Simcoe Source Protection Plan, new and innovative development strategies are being implemented within the Lake Simcoe Watershed.

Since 2009, the Lake Simcoe Region Conservation Authority has implemented the LSPP recharge policies on behalf of member municipalities to ensure pre-development water balance targets can be achieved through the development plan. The LSPP requires any major development within the Lake Simcoe Watershed to submit a water balance which demonstrates changes to the pre-development water balance will be minimized. Development within a Significant Groundwater Recharge Area also requires a hydrogeological assessment and water balance demonstrating that the quality and quantity of groundwater in these areas and the function of the recharge areas will be protected, improved or restored.

More recently, the Approved South Georgian Bay Lake Simcoe Source Protection Plan came into effect July 1, 2015, which requires development proponents to complete water balance and hydrogeological assessments for future development activities proposed under the Planning Act or Condominium Act where applications are within the wellhead protection quantity area. The Source Protection Plan also requires that proponents demonstrate that their projects will maintain the pre-development groundwater recharge rates. The Policy is similar to the Lake Simcoe Protection Plan recharge policies, however it goes one step further and requires recharge offsetting should site conditions not allow for the implementation of on-site Low Impact Development measures to promote recharge. As a result, the Lake Simcoe Region Conservation Authority has developed a recharge offsetting program where all new development or redevelopment greater than 0.50 hectares requires recharge to be maintained after development so that there is no net reduction in water supplied to the groundwater system. Any loss in recharge after implementation of on-site measures will be offset through agreement with the Lake Simcoe Region Conservation Authority under the Conservation Authority's Urban Stormwater Retrofits Projects Program.

Agriculture Actions to Reduce Phosphorus to Lake Erie

Cushman, Dorienne; Cale Selby, and Ross Kelly

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For more than a decade, toxic and nuisance algal blooms in Lake Erie have increased in frequency, and the summer of 2015 saw the largest documented algal bloom in the lake's history. Blooms threaten drinking water quality, fish populations, beach quality, coastal recreation and the overall health of the lake. In addition, when algae die and decompose, hypoxic conditions can be created, meaning there is a lack of oxygen in the water. In 2012, hypoxic conditions were responsible for tens of thousands of dead fish washing up on a 40-kilometre stretch of shoreline between the communities of Erieau and Port Stanley in Ontario. The increased occurrence of harmful algal blooms in Lake Erie is influenced by many factors, including nutrients, climate change and invasive species such as zebra mussels. Phosphorus is the primary nutrient driving increased algal blooms in the lake and comes from multiple sources, both urban and rural. After decades of work on major sources, non-point sources are now the majority of phosphorus entering Lake Erie. The challenge is significant, but with coordinated action there is hope for the lake's future.

However, with the recent rise in blooms, Canada and the United States recognized the need for a new approach to action, and in February 2016 agreed to a 40 per cent reduction target for phosphorus entering the Central and Western basins of Lake Erie. Federal and provincial ministries are collaborating to develop an Action Plan for Lake Erie to Achieve Phosphorus Reductions from Canadian Sources. Governments cannot do this alone. Additional actions from all sectors and communities across the Lake Erie basin are going to be needed to achieve our goals. A draft is currently out for consultation soliciting actions from all sectors.

The Ministry of Agriculture, Food and Rural Affairs (OMAFRA) focus is on rural communities and Ontario's agriculture and food systems. Rural and agricultural sources of phosphorus include soil erosion from fields and nutrient runoff from manure, fertilizer and other soil amendments. OMAFRA has been studying the effectiveness of management practices in reducing environmental impacts and promoting environmental planning for decades. To support the work on phosphorus reduction OMAFRA reviewed the available information to determine which practices have the greatest potential for reductions and to identify our scientific gaps. Preliminary conclusions include the need to: improve soil health through practices like crop rotation, reduced tillage, cover crops; carefully manage nutrients including the appropriate timing and application of nutrients; and select practices that are effective in the non-growing season and heavy storm events when the majority of the loss can occur. Current science also indicates that a multi-barrier approach that uses multiple BMPs is most effective at minimizing phosphorus loss from fields through runoff and tile drainage.

Anticipating Demand for Groundwater Geoscience: Groundwater Risk Information Seeking Behaviour Among Stakeholders in Southern Ontario

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This study asks the important question ***What is happening in the digital world of groundwater geoscience?*** This is the first systematic, interdisciplinary study investigating how the Internet is enabling the uptake of geoscience information in Southern Ontario groundwater risk management decisionmaking. It follows on three earlier projects: 1) *Groundwater Resources and Risks in Canada* – presented at the 2016 Annual meeting of the Geological Association of Canada/ Mineralogical Association of Canada. 2) *Canadian Hazard Risk Land Use Plans* – presented at the 2016 World Conference on Disaster Management Research. 3) Desktop research completed for the Ontario Geological Survey *2016 Ontario Geohazards Program Framework* (Reviewed: 22 international principles, guidelines and standards; 35 Reports and Statements on Open Data Interconnectivity; and 21 Canadian Provincial Geoscience Provider's Geohazards Programs and Projects).

Our research identifies that the Internet is a resource available to an increasing number of Southern Ontario citizens. However, a lack of groundwater information seeking research in the Southern Ontario context means that the potential of the Internet as a source of geoscience-based aquifer hazard risk information for land use planning may not be fully understood.

The purpose of this project is to build civil society's capacity and capability in geoscience based hazard risk identification and management. This project is being completed in collaboration with the University of Waterloo, the National Research Council, Health Canada, Indigenous and Northern Affairs Canada and Defence Research and Development Canada. It seeks to develop a concept map for the digital delivery of groundwater geoscience, detailing how to innovate with information and communication technology (ICT) to engage communities in geoscience-based aquifer hazard risk assessments.

In this presentation, we present preliminary research results:

A critical review of user access to online Southern Ontario groundwater geoscience studies (2006 to 2016). Completed through linking the information science literature with the post Walkerton Inquiry policy changes to determine if these websites profile the potential of the Internet as a source of geoscience-based aquifer hazard risk information.

Our community engagement concept map for the digital delivery of groundwater geoscience, developed for the purpose of building capacity in community focused aquifer hazard risk assessments.

New questions raised for further study on stakeholders seeking ICT options for groundwater geoscience research, practice, and uptake. Emphasising that such questions may have implications for future research and practice in groundwater geoscience, especially in the subfields of:

1. New groundwater resource exploration economic cost and benefit analysis
2. Community based groundwater geoscience education and outreach capacity building activities
3. Location specific indicators for community based groundwater hazard risk assessments (i.e. carbonate fissures and conduits, geochemical anomalies and some anthropogenic activities).

Clarence-Rockland Groundwater Study – Aquifer Capability Screening Tool Pilot Study, Prescott-Russell, Ontario

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Natural groundwater quality in exceedance of Ontario provincial drinking water standards is a persistent issue that limits development of private services in Eastern Ontario. Local ambient groundwater quality issues are linked to geological conditions and are predominantly the result of the marine environment that existed in the St. Lawrence lowlands following the most recent glacial retreat. In addition to trapping saline water, the marine clays mask complex Paleozoic bedrock topography and geology, whose interbedded limestone and shale units, along with long groundwater residence times, further contribute to poor water quality.

A study was initiated at the request of the municipality, the United Counties of Prescott and Russell (UCPR), to develop an Aquifer Capability Screening Tool (ACST) to evaluate the development potential of a property where private wells are required to supply drinking water. The ACST consists of maps of expected groundwater quality and quantity in relation to Provincial standards for private wells. The tool is intended to identify potential issues early in the application process, saving time and money for developers and the municipality. The pilot study was undertaken within a single municipality in the UCPR, the City of Clarence-Rockland, to determine the viability of the approach.

The Clarence Rockland Groundwater Study (2013–2015) was completed through a collaborative partnership between the Upper and Lower Tier Municipalities, South Nation Conservation Authority, the Ontario Geological Survey (OGS), the University of Ottawa and Geofirma Engineering Ltd. Development of the ACST was supported by a robust groundwater sampling program to characterize hydrostratigraphy, identify groundwater flow patterns, and develop water quality maps. Well sampling was carried out in accordance with protocols developed by the OGS Ontario Ambient Groundwater Geochemistry Study (Hamilton, Brauneder and Mellor, 2007 and Hamilton and Brauneder, 2008). A 2km sampling grid was used to facilitate even sampling across the municipality; 136 wells were sampled, including 74 bedrock wells and 62 overburden wells.

The study created a new overview of ambient groundwater quality and quantity for the City of Clarence-Rockland. ACST water quality maps were generated from groundwater sampling results, with an emphasis on parameters in exceedance of Provincial standards that could inhibit lot creation or development; including fluoride, barium, selenium, chloride, sodium, total dissolved solids, dissolved organic carbon, methane and colour. ACST water quantity maps were created for shallow overburden aquifers and the contact zone/ shallow bedrock aquifer. Currently, the ACST is being used within the City of Clarence-Rockland to pre-screen development applications.

U.S. Geological Survey Groundwater Research in the Great Lakes Basin

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U.S. Geological Survey (USGS) conducts national and regional-scale investigations with relevance to the Great Lakes Basin as part of its Water Availability and Use Science Program and its National Water Quality Program. USGS also conducts local-scale investigations in the Great Lakes Basin that collectively have regional significance. From a groundwater perspective, major resource issues include finding adequate supplies, understanding the relation between groundwater and surface water, and understanding the effect of water quality on drinking water sources.

At the national scale, USGS recently completed an assessment of brackish groundwater (dissolved-solids concentration between 1,000 and 10,000 milligrams per liter) that provides information on the potential for such groundwater to augment freshwater supplies, including in the Great Lakes Basin. USGS also recently completed a national assessment of the potential corrosivity of untreated groundwater. New York and Pennsylvania were classified as having a high prevalence of potentially corrosive groundwater; however, most Great Lakes states were classified as having a moderate prevalence of such water (**http://water.usgs.gov/nawqa/pubs/gw_corrosivity/**). A recent analysis of decadal-scale changes in groundwater quality at USGS well networks across the U.S. reveals an increase in chloride and total dissolved solids concentrations in groundwater in many areas, including in the Great Lakes Basin (**http://nawqatrends.wim.usgs.gov/decadal/**).

At the regional scale, USGS work on the quantity and quality of groundwater in glacial aquifers has particular relevance to the Great Lakes Basin, because unconsolidated materials deposited at or near land surface as a result of glaciation make up the most productive aquifers in the Basin. USGS is developing an updated geologic framework for glacial deposits across the U.S. that includes the texture and thickness of glacial deposits, the depth to top of bedrock, the number of glacial aquifers beneath a given location, and the depth and degree of aquifer confinement. The distribution of domestic and public supply wells in glacial aquifers is being mapped. Over 15 million driller's logs were compiled and standardized to provide the desired level of spatial heterogeneity for these efforts. Generalized groundwater-flow models are being constructed for each HUC-8 watershed within the U.S. side of the Great Lakes Basin to estimate groundwater age and to provide insight into the time lag between nonpoint source contaminant loading at the water table and arrival at streams. Samples from glacial aquifer wells were collected and analyzed for tracers of groundwater age in support of this effort. Samples also were analyzed for a wide variety of water quality constituents to estimate the percentage of glacial deposits where constituent concentrations are high, moderate and low with respect to human-health benchmarks. Three-dimensional maps of manganese and arsenic are being developed for the glacial deposits by using a statistical modeling approach that incorporates information from the updated geologic framework and the measured and modeled information on groundwater age. Data from state ambient monitoring programs were procured in support of this water quality mapping effort.

At the local scale, one topic of investigation with regional significance is the effect of stormwater management on groundwater beneath urban areas. Study areas include Buffalo, NY; Cleveland, OH; Detroit, MI; and Gary, IN.

Development of Groundwater Vulnerability Guideline in Thin-Drift and Paleozoic Bedrock Terrains, Cataraqui Region Conservation Authority, Southeastern Ontario

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Numerous groundwater studies, including technical work completed under the Clean Water Act to support the Cataraqui Source Protection Plan, have identified the majority of the Cataraqui Source Protection Area (CSPA) in Eastern Ontario as having highly vulnerable aquifers (HVAs). The prevalence of HVAs is due to thin or absent soils, fractured bedrock and a relatively high water table. In addition, bedrock formations in the central and western part of the CSPA are susceptible to the development of karst.

Locally applicable guidance for land use planning authorities to account for aquifer vulnerability and the presence of karst was not available; therefore, the Cataraqui Region Conservation Authority (CRCA) recently developed a Groundwater Vulnerability Guideline. Its intent is to help proponents of development, consultants, planning approval authorities and the CRCA to: a) identify the presence, extent and impact on groundwater vulnerability of karst on or adjacent to a property; and b) assess the vulnerability of the bedrock groundwater in a local area (i.e. property parcel or small group of contiguous parcels) based upon available desktop and field data. Geofirma Engineering Ltd. was retained through an RFP process by CRCA to produce the guideline document. Funding was provided by the Ontario Ministry of Environment and Climate Change.

The guideline is presented in two parts, an aquifer vulnerability assessment and a karst assessment. Results of the aquifer vulnerability assessment are used to determine whether or not a karst assessment is required. An initial desk-top survey is conducted to see if a field-based investigation is warranted. A flow chart was established with checklists to ensure proponents obtain all required information to identify groundwater vulnerability. A supporting document was also prepared, with a glossary and karst field photos, to provide supplementary information about the guideline submissions. The guideline should be read together with the Appendices and Supporting Document.

Implementing Drinking Water Source Protection – Conservation Authority Perspective

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Drinking water source protection began in Ontario in response to the Walkerton tragedy in May 2000, when seven died and thousands became ill from drinking municipal water contaminated with E. Coli and Campylobacter bacteria. The public inquiry that followed recommended a multi-barrier approach to protect drinking water from source to tap. In response, the province passed the Clean Water Act in 2006 as the first barrier. The intent of this new legislation was to protect the sources of drinking water before it enters municipal water systems.

Scientists across the province were tasked with developing Assessment Reports to characterize the quality and quantity of drinking water resources. In addition, these reports documented the human and ecological features, mapped areas vulnerable to impacts from human activities, and enumerated significant drinking water threats. The technical work included integrated mapping of surface and subsurface features, groundwater / surface water modelling, contaminant transport, capture zone analysis for municipal wells, and enumeration of significant drinking water threats.

At Toronto and Region Conservation, 456 significant drinking water threats were identified with respect to municipal wells, and locally developed policies were developed to eliminate or manage these threats. The source protection policies were developed into a Source Protection Plan by scientists, engineers, and planners who worked in partnership with a local Source Protection Committee. Each of the 19 committees across the province included a mix of municipal appointees, industry representatives, and watershed residents.

The policies for the jurisdiction of Toronto and Region Conservation took effect December 31, 2015. These policies are based on science, and yet recognize the existing fabric of land development and the effects of human activities on the landscape. We have met the challenges of implementation of new policy tools by a variety of government agencies by ensuring rigorous public consultation, inter-agency meetings, and provincial oversight.

How to Build a Living City – Balancing the Needs of Human Development and Ecosystems

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Conservation Authorities are unique to the province of Ontario. They are local, non-profit environmental organizations that are empowered to regulate development and activities in or adjacent to river or stream valleys, Great Lakes and inland lakes shorelines, watercourses, hazardous lands and wetlands. The *Conservation Authorities Act*, passed in 1946, provides the legislative backbone for their existence. Funding is provided through a combination of municipal and provincial support, permit and service fees and charitable donations.

Toronto and Region Conservation serves a population of more than 4,000,000 people in a jurisdiction that covers more than 2400 km^2. We receive development applications for over 1000 projects per year. These files include engineering and hydrogeologic reports prepared on behalf of the development proponents that often downplay the potential impacts of their projects to the natural environment. Our role as hydrogeologists is to critically review these reports and determine if reasonable conclusions have been made based on reliable data.

For hydrogeology, we consider both temporary and permanent dewatering, pre- and post-development water budgets, and consumptive groundwater use. We must then communicate our findings in clear, simple language to our in-house planning team, proponents, and sometimes members of the public. All this is done in a framework of limited funding and challenging timelines.

We meet these challenges through the use of conceptual and numerical models developed in partnership with neighbouring conservation authorities and our municipal partners. These regional model results are then shared with development consultants to facilitate continuous improvement from their studies completed at the site scale. To continue to advance our hydrogeologic understanding, we also work with subject matter experts at the provincial and federal levels of government, and are working at integrating climate change into our models. This presentation will summarize some of our successes and failures over the past 15 years and provide insights to similar organizations responsible for protecting and enhancing our natural environment.

A Geochemical Characterization of Southwestern Ontario's Breathing Well Region

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A physical and geochemical characterization has been completed for a 1400 km^2 breathing well zone in a Middle Devonian, karstic carbonate aquifer system in southwestern Ontario. Breathing wells are unusual because they draw in or emit large volumes of air, in response to fluctuations in atmospheric pressure. This behavior causes gas exchange between the atmosphere and the subsurface and quite commonly the expelled gases are depleted in oxygen and enriched in carbon dioxide. To better understand this unique atmosphere-geosphere connection, geochemical, hydraulic, and barometric data were used to investigate the interconnectivity within the breathing well zone. Regionally, 102 sites were sampled for groundwater chemistry characterization, and 10 wells located within the breathing well zone were monitored monthly over one year. Spatial and time series analyses reveal that most wells affected by the breathing well phenomena are drilled through the Dundee Formation and finished in the underlying Lucas Formation. The results suggest that a significant amount of unsaturated void space exists within the Lucas Formation, and that hypoxic, high CO_2 gases are generated by several processes and emitted during low atmospheric pressure periods. Locally, groundwater shows remarkable chemical and isotopic stability over the 1 year monitoring period, which suggests a very large degree of storage in the aquifer. Regional distributions of groundwater facies types are strongly influenced by local hydrogeological conditions and consist dominantly of Na-Ca-HCO_3, Ca-Mg-HCO_3, Ca-Sr-HCO_3, and Ca-Mg- SO_4-types. The groundwater composition includes detectable levels of dissolved oxygen and elevated concentrations of sulphate. Sulphur isotopic data indicate that the sulphate results from two endmember processes: evaporite dissolution and oxidation of metallic sulphides. Evidence for the latter process also includes elevated concentrations of iron and trace metals including Zn, Pb, Cu and Ag. Very high strontium up to 80 mg/L comes from the dissolution of celestite (or celestine; $SrSO_4$) in the absence of gypsum. This provides insight on the solution-karstification process that appears to have formed the breathing well system and may provide a tool for mapping the system in areas to the north where void space is saturated and air exchange is prevented.

Regional-scale Mapping of Buried, Surface-connected, Karstic Groundwater Systems Using Dissolved Gases and Hydrochemical Tracers

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In 2008, the Ontario Geological Survey (OGS) released a map of known and potential karst in southern Ontario. Known karst occurs mostly in areas where glacial overburden is thin (<1m) or absent and in many places the top of bedrock shows evidence of active, ongoing solution-enhancement. Data from deep bedrock boreholes indicate that karst in Ontario's carbonate terrains is much more widespread than can be observed on surface and that it extends into areas covered by thick glacial sediments. Direct evidence for this pre-glacial karst includes: (1) televiewer logs and drill-core showing solution-enhanced bedding planes and sequence boundaries; (2) drill records reporting large cavities in bedrock that are open or filled with glacio-fluvial sediments; (3) epikarst and bedrock conduits in quarries; (4) driftthickness mapping with extensive buried valleys and canyons, some that appear to form natural bridges; and (5) thick glacial sediment-covered areas with extensive interpreted karst rubble at the bedrock surface. Traditional methods for local mapping of subsurface karst and its effects on groundwater cannot be easily adapted for regional-scale studies. Physical techniques include tracer tests and piezometric logging of monitoring wells to detect conduits (by the rapid rise and fall of water levels); chemical techniques include monitoring, at spring vents, of pH, Ca^{2+}, HCO_3 - and saturation indices of carbonate minerals to determine the degree of corrosiveness of groundwater. However, these are all proximal techniques that characterize individual, known systems. To date, there are no well-developed regional techniques that can map areas where groundwater is influenced by buried karst over a wide area.

Here we describe a methodology that uses dissolved CO_2 and O_2 in groundwater to map areas in buried karstic carbonates that have a rapid hydraulic connection to surface. O_2 originates in the atmosphere and has no geological sources. CO_2 in groundwater originates largely in the soil zone and has few other geogenic sources in non-tectonic settings. Because both parameters are attenuated with increasing distance from their sources, a CO_2/O_2 factor allows for an objective description of how well connected these buried karstic groundwater systems are to meteoric and soil zone recharge sources. An empirically derived lower threshold for the CO_2/O_2 factor delineates a number of large regions in southern Ontario where groundwater is elevated in either or both gases; all of these are centred on areas of known karst. Groundwater analysis using tritium, nitrate and bacteria (for samples collected from secure-cap water supply wells) show that these areas have younger, more recently recharged groundwater with a relatively rapid connection to the surface environment. Regional CO_2/O_2 and other chemical, isotopic and bacteriological data were purpose-filtered from the large, publically accessible OGS Ambient Groundwater Geochemistry database. This is an exceptionally well characterized groundwater geochemical dataset for samples collected on a uniform grid from domestic, farm and monitoring wells across southern Ontario. Mapping areas of groundwater vulnerability to surface contamination due to karstic flow systems is another of the many possible uses for this database.

Access To High Quality Groundwater Data – A Geoportal For Central Ontario

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Over the past fifteen years the Oak Ridges Moraine Groundwater Program (ORMGWP) has assembled a comprehensive groundwater-focused database. The assembled data is wide ranging and includes geological, hydrogeological, climatic and surface water related information that has been used by technical staff from the thirteen partnered agencies (municipalities and conservation authorities) to drive improved decision making in central Ontario.

During 2016, a password-protected website was launched that allows for easier access to the information housed in the database by less technical (i.e., non-hydrogeologist) staff. This has led to discussions regarding as to whether the data should be made more widely accessible to the broader consulting community and the general public. One consideration currently being assessed is that of extending a "membership" service to the consulting community in a two-way data exchange program.

A significant advantage of greater accessibility to the program's data would be that more eyes would be looking at the program's data, and with the right mechanisms in place, this could serve to assist staff in improving the overall quality of the data. This presentation will showcase the current web-based data access platform and discuss the future pathways for the program.

Insights from a "One Water" Integrated Approach to Tier 3 Water Budget Analysis

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One of the significant benefits of the tiered Ontario Source Water Protection water budget approach was the opportunity for significant improvement in numerical model analysis at each progressive level. The concurrent improvements in water use data, advances in computing and storage, and the release of a practical, open-source integrated surface water/groundwater model in 2008 (USGS GSFLOW) further supported the technical advancements. Most important, however, was the recognition that a holistic "one water" approach, addressing the entire hydrologic cycle, was necessary to address the cumulative effects of increased water use, drought, storage, and land use change on groundwater levels, streamflow, and wetland viability.

Recognizing this challenge and opportunity, Earthfx strongly advocated conducting fully-integrated surface water and groundwater modelling studies for all the Tier 3 studies. A number of common response patterns and insights emerged from the six fully integrated Tier 3 and Lake Simcoe Protection models that we created. First, we found that groundwater feedback (Dunnian rejected recharge) was the dominant form of interaction, occurring in as much as 30 percent of the watershed areas. Hortonian runoff was found to be relatively rare, due to the infrequency of intense storms, summer ET deficits, and actively-vegetated loose soil conditions.

Fully represented headwater streams and springs, high resolution surface topography, and detailed land cover were needed to represent spatially variable and often highly-focussed recharge. The need for detail extended into the conceptualization of the shallow subsurface, where detailed representations of the soil zone and shallow geology were needed to properly simulate subsurface stormflow and seasonal flow through highly permeable shallow aquifer units (weathered tills, epi-karst, etc.). Detailed representations of reservoir operations, quarry dewatering, irrigation water takings, and return flow were also found to be important to simulate overall watershed functions and, ultimately, producing a defensible risk assessment. Based on this experience and insight gained, we are convinced that the key to successful integrated modelling is in the details.

Perhaps the most significant conclusion is that practical, engineering-scale integrated analysis can be accomplished within a watershed context. At too large a scale, many of the key process details and complex shallow system interactions would be oversimplified and generalized. Similarly, at too small a scale, such as limiting the model to the extended area of influence of a wellfield, would require oversimplification of model boundaries and neglect of the transient nature of surface and groundwater flow in the surrounding area.

In 2010, Refsgaard et al. predicted that by 2020 all modelling in Denmark would consist of fullyintegrated analysis. Perhaps, due to the challenges and opportunities of the Tier 3 process, that future has arrived early in Ontario.

Newmarket Till Aquitard: Optimum Grain Packing with a Pore-filling Calcite-Rich Cement

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Newmarket Till is a stoney, sandy (38%) silty (~47%) diamicton, which is of variable thickness (~1 – 69 m) and of widespread distribution (correlated with Catfish Creek Till) in southern Ontario. The Newmarket Till has unusually high densities (2.2 – 2.4 g/cm^3); elevated seismic velocities (Vp ~2600 m/s) determined by downhole geophysical studies are characteristic and the Till can be traced across the region as a seismostratigraphic marker. As the Till is highly indurated and has low permeability, it forms a regional aquitard that confines underlying aquifers, and is also a basal aquitard for overlying aquifers (e.g. Oak Ridges Moraine). Given the high sand content of this diamicton, the low permeability and indurated nature is surprising, and could be resultant from over-consolidation due to glacial loading, presence of a secondary cement, or both processes. Clasts larger than coarse gravel consist of grantoids and limestone, however clasts smaller than coarse gravel are dominanted by limestone, with rare granitoids. The mineral assemblage (in decreasing abundance) is quartz, calcite, K-feldspar, plagioclase, dolomite, amphibole and clinopyroxene; these grains are comminuted and range in size from ~1000 µm to ~2 µm, leading to optimum packing. The intra-grain matrix is exceptionally fine (<1 µm, typically 0.25 – 0.50 µm) and not resolvable by optical methods. Higher resolution SEM and FE-SEM backscattered electron and secondary electron images of the intra-grain matrix reveals a complex pore filling cement, with a very low percentage (<1%) of open pore space. The minerals comprising the secondary cement are a challenge to analyze due to their very fine grain size and composition. Preliminary semiquantitative EDS analyses suggest they consist of calcite ($CaCO_3$) and portlandite ($Ca[OH]_2$), with minor phyllosilicates, and possibly hydrated calcium-rich silicate minerals (CSH). The Ca-rich minerals cement the silt- to sand-sized mineral grains and larger clasts, and result in the Newmarket Till being highly indurated and of low permeability. The presence of calcite and portlandite in a glaciogenic sediment cement is quite unusual. Additional analytical work is being undertaken to fully characterize the mineralogy of these Late Wisconsin / Holocene cements.

Chemostratigraphy in Southern Ontario by pXRF Spectrometry

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For groundwater studies, the collection of sediment geochemistry is often beyond the scope, and budget of many programs, and is generally not included as part of routine data collection. Portable XRay Fluorescence spectrometer (pXRF) has proven to be a successful tool to characterize the chemostratigraphy of glacial derived materials collected from boreholes in southern Ontario. Portable XRF provides near-total geochemistry results similar to fusion and multi-acid methods for 14 elements with minimal sample preparation and at low cost. An extensive suite of near surface samples provides characterization of the regional geochemistry. In a collaborative project with the OGS and the GSC two transects are being completed (E-W, N-S) to provide a framework of subsurface geochemistry. To eliminate the effects of variability in sample grain-size, sample volume, and to minimize nugget effects, samples are dried and sieved to <0.063 mm (silt + clay) prior to analysis. To ensure quality control, a number of Standard Reference Materials (SRM) and Certified Reference Materials (CRM) are analyzed with each project, and comparisons made with previously published results. For further quality control, a sub-suite of sediment samples are analyzed by ICP-MS/ES using lithium borate fusion, multiacid, and aqua regia digestions.

Bivariate plots comparing pXRF to ICP-MS/ES display a high degree of linearity ($r^2 > 0.8$) for Ca, Fe, K, Mn, Rb, Sr, V, Zn, Zr, and to a lesser degree for Ba, Cu, Cr, Ti, and Pb. These 14 elements return precise and generally accurate results within each borehole; however, continued analyses of CRM's and SRM's has demonstrated display drift in accuracy between projects. Resulting data for meet the US EPA criteria for quantitative data quality based on r^2 values and y=mx+b relationships. Concentration levels play a significant factor in the accuracy of the pXRF data. At low concentration levels near the detection limit of the pXRF, there can be greater scatter in results. At high concentration levels, data needs to be adjusted using post-data calibration to obtain accurate results.

Municipal Water Well Efficiency Programs – A Fresh Approach in Peel Region: The Good, The Bad and The Imminent

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The Region of Peel operates 15 municipal production wells and 4 municipal residential drinking water systems in the Town of Caledon communities of Alton, Caledon East, Caledon Village, Cheltenham, Inglewood, and Palgrave. Historically, well maintenance has been carried out on a regular, as needed, basis to maintain the water supply for the residents of these communities. Typically the water operations group would determine the maintenance schedule in response to either the staff noticing a decline in the well performance and a consultant/contractor would be commissioned to help in addressing the issue or due to a periodical well and pump maintenance program.

Early 2016, the groundwater group recognized the lack of involvement in the Region's well maintenance tasks by technically qualified regional staff from other groups. A new approach was proposed by the groundwater group to management and it was approved to start a pilot project by the end of 2016, whereby cross-functional staff (Operations, hydrogeologists, management and Program Planning and Compliance) took on additional responsibilities for the well efficiency program. Palgrave No. 2 was approved to test the proposed approach. Only after the project team met to discuss and plan for a comprehensive testing of the Palgrave water system was a contractor and consultant retained, albeit with a reduced scope of work.

As a result of the work in Palgrave No. 2, several inconsistencies were found in Peel's approach to maintaining the rural community's water supply systems. These were largely due to poor, or in some cases non-existent, communication between various technical experts in different groups within the region. The new approach has fostered a renewed sense of appreciation for the diverse skills among Peel Region staff and will undoubtedly result in less reliance upon contractors and consultants for this type of work into the future.

Downscaling SMOS/SMAP Soil Moisture Product Using High Resolution Radarsat-2 SAR Data: A Case Study in Southern Ontario

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Soil moisture is a key component in the water cycle. Continuous observations of soil moisture over large spatial scales are important in many earth sciences applications. Current soil moisture products derived from SMOS and SMAP satellites can provide global coverage with 2-3 days cycle but have very coarse resolutions (~40 km), which limits the soil moisture products in many applications where a resolution of 1-10 km is generally needed. SAR imagery is available at high resolution and has high sensitivity to soil moisture. However the soil moisture retrieval from SAR depends on high volume of in-situ soil moisture data and is also complicated by their sensitivity to surface roughness and vegetation. This study proposes an algorithm for retrieving high resolution soil moisture by downscaling SMOS/SMAP soil moisture products using time series dual-polarized (HH and HV) Radarsat-2 data. The approach can overcome the effect of vegetation, surface roughness, and change of scales. Specifically, the effect of vegetation is removed by the water-cloud model, in which the conditions of vegetation are characterized by the backscatter coefficient of Radarsat-2 HV polarization. Time series Radarsat-2 data is used to eliminate the dependence of backscattered signal on soil surface roughness. Different mathematical models including wavelet transform are used for scale change. The algorithm is validated using in-situ soil moisture data collected in Southern Ontario in the spring and summer of 2016. The study shows promising results in soil moisture retrieval over large area.

Barometric Pressure Responses in Groundwater Level Time Series Data, A Literature Review

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Ontario's Ministry of Natural Resources and Forestry (MNRF) oversees Ontario's *Low Water Response* (OLWR) *Program*. As partners with MNRF, conservation authorities across Ontario coordinate responses to local low water conditions, amongst the various levels of government, as conditions arise. In further support of OLWR, conservation authority (CA) geoscientists have, in the past, participated in a technical consultation group with staff from MNRF and from the Ministry of the Environment and Climate Change (MOECC).

The technical geoscience group convenes once or twice annually to discuss amongst other topics, the potential uses of available groundwater level monitoring data from the MOECC's Provincial Groundwater Monitoring Network (PGMN) in the OLWR Program. In support of the use of this data, the staff geoscientist from the Rideau Valley Conservation Authority (RVCA) was asked to review and report on the available literature that explaines the barometric responses, which are known to be recorded in some groundwater level monitoring data-sets.

This presentation will: provide an overview of the information summarized in the literature review; present several examples of barometric pressure responses and earth tide effects in PGMN time-series data; explain the necessary next-steps in the initiative; and summarize the relevance for all groundwater level monitoring projects.

New Insights on Regional Stratigraphy and Hydrogeology Based on Surficial and Subsurface Sediment Mapping in Simcoe County, Southern Ontario

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The integration of detailed field mapping of surficial sediments and landforms with information obtained from 14 continuously-cored boreholes are providing key insights into the character and distribution of major sediment packages that form regionally significant hydrostratigraphic units that control groundwater flow systems within Simcoe County.

Six major sediment packages are observed, forming successions >160 m thick. A dense sandy till (LCT) overlies the bedrock at most locations in the study area. This till is locally overlain by glaciolacustrine deposits (LGL), which are generally fine-grained although sandy facies are encountered and gravel deposits forming units up to 48 m thick have been observed in two boreholes to date. A fine-grained till (LFT) overlies the lower glaciolacustrine deposits forming a continuous, highly undulating marker bed in the subsurface. The upper surface of the till shows evidence of subaerial weathering at higher elevations (> 170m asl). It is overlain by a fining-upward succession of predominantly sand with lesser gravel and local accumulations of silt and clay-rich diamictons (TF), tentatively assigned to the Thorncliffe Formation. These deposits are overlain by a dense silty sand to sand till (NT) ranging from 2 to 30 m thick and correlative with the Newmarket Till. Particle size analysis of this till shows a progressive coarsening northward. Significant topographic variation in the Newmarket Till is observed across the study area – its upper surface ranging from 150 to 310 m asl. This highly undulating unit imparts a strong control on the character of overlying deposits. Where the till is found at lower elevations, laminated silts and clays form the bulk of the deglacial succession (LA). At higher elevations (>230 m asl), sands and gravels dominate.

The lower parts of the succession (LCT, LGL, LFT) do not commonly host significant aquifers. However, the bedrock interface aquifers can meet the demands for rural domestic use, and where the thick gravel deposits are encountered, significant groundwater resources may be present, especially given its occurrence at several tens of meters below modern Georgian Bay. Within the study area, the Thorncliffe Formation deposits form a regionally significant confined aquifer. It occurs regionally beneath both uplands and lowlands and, in many areas, artesian conditions are present. The Newmarket Till forms a regionally significant leaky aquitard, but coarser textures observed in this till in the north appear to significantly decrease its competency as an aquitard. Deglacial sediments generally form thick aquitards in low-lying areas but may form unconfined aquifers at higher elevations. Additionally, erosion of the Newmarket Till during deglaciation has led to preferential groundwater flow path that govern groundwater seepages and create large piping features. Geophysical studies have been carried out to better constrain the architecture of major sediment packages in the subsurface and to characterize the physical properties of the major stratigraphic units. In-situ hydrogeologic tests are planned in order to provide preliminary analysis of aquifer capacities and assess hydraulic connection of aquifers in the region.

An Overview of the Ontario Geological Survey's Groundwater Initiative

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The Ontario Geological Survey (OGS) initiated mapping activities in support of regional hydrogeological characterization in 2001. Concurrent activities included the generation of updated fully-attributed, bedrock geology, karst, physiography, surficial geology, drift thickness and bedrock topography seamless maps. These pan-southern Ontario maps and products serve as a foundation for hydrogeological investigations, and in particular, they have formed an integral part of the watershed characterization portion of the source protection plans. Following the release of these pan-southern Ontario products, the OGS shifted focus to characterizing the subsurface through the development and implementation of three sub-surface mapping activities; 3D Paleozoic bedrock mapping, 3D surficial sediment mapping and ambient groundwater geochemistry mapping. Each of these activities is described below.

1) The primary goal of the 3D Paleozoic bedrock mapping is to delineate the stratigraphic units that host important groundwater resources in southern Ontario. This is done by identifying the main geologic controls on groundwater flow and mapping and delineating regional-scale groundwater flow systems within the context of a sequence stratigraphic framework. The first study area concentrated on the Niagara Escarpment because this region is undergoing significant population pressures and relies heavily on deep bedrock groundwater resources. The next regional-scale 3D Paleozoic bedrock mapping project will focus on Upper Silurian through Middle Devonian carbonate-dominated units located to the southwest.

2) The goals of 3D sediment mapping projects are to reconstruct the Quaternary history of each area, build a regional-scale 3D model of Quaternary deposits that form aquifers and aquitards, and to define the internal characteristics of each sediment package. The initial focus was on areas either within or adjacent to the Greater Golden Horseshoe and to date, projects have been completed in the Waterloo (GRS03), Barrie-Oro (GRS11), Brantford-Woodstock (GRS10) and Orangeville-Fergus (GRS15) areas, South Simcoe is nearing completion and projects in the Niagara and Central Simcoe areas are well underway. The 3D sediment mapping program has taken a basin analysis approach similar to that used by the GSC in the Oak Ridges Moraine. Ground and airborne geophysical surveys coupled with continuous-coring have enabled the development of conceptual geologic models, critical for the successful construction of 3D geologic models.

3) The ambient groundwater geochemistry project which was initiated in 2011 and resulted in the collection of untreated bedrock- and overburden-derived groundwaters at approximately 1850 stations across all of southern Ontario. The main purpose of the study is to understand and predict the effect that aquifer composition has on groundwater quality as well as to understand the flow history, residence time and vulnerability of individual and regional groundwater sources. The sampling density is approximately 1 station per 10 square kilometers. Digital datasets and maps were released for all of southern Ontario in 2015 (MRD283-REV). Moving beyond southern Ontario, a similar study was initiated in the Sudbury region in 2016, with plans to conduct mapping activities on Manitoulin Island in 2017.

Improving the Spatial Density of a Regional Hydraulic Conductivity Dataset with Estimates Made from Domestic Water Well Information

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High-quality hydraulic conductivity data tend to be sparse relative to the large areas under investigation in regional-scale groundwater studies. From the 1960s through the 1990s, the literature is replete with articles discussing the details of augmenting high-quality hydraulic conductivity datasets with values estimated from specific capacity tests. Early publications focused on the development of the fundamental mathematical relation between specific capacity and hydraulic conductivity. Later articles presented approaches claiming improved accuracy of hydraulic conductivity estimates from specific capacity by correcting for additional well losses. However, because the site-specific data required to correct for additional well losses are generally not available, these corrections often led to error. Through the 1990s, many workers abandoned the analytical approach for an empirical one, arguing that correcting for additional well losses introduces significant error into the K estimate. Since the early 2000s, the literature has become largely silent on the topic of augmenting high-quality hydraulic conductivity datasets with K estimates developed from specific capacity.

Despite a pause in the literature, integration of the results of high-quality tests within more approximate but spatially extensive datasets is still desired, particularly to support the identification of groundwater resource exploration targets in complex, heterogeneous geological settings. We present a simple and effective approach to synthesize the results from high-quality hydraulic tests with reconnaissance-level hydraulic conductivity estimates made from domestic water well specific capacity tests. Domestic water wells are ubiquitous across Ontario, and although their associated well records do not contain the information required to support rigorous hydraulic test analyses, they do contain the information required to calculate specific capacity. We use the fundamental Theis relation to make hydraulic conductivity estimates from specific capacity tests, assuming that additional well losses account for a relatively small portion of the total observed drawdown. The utility of this approach is demonstrated with data comparisons at three different spatial scales. Each comparison is conducted to evaluate the suitability of augmenting the high-quality data set with lesser quality estimates to answer specific research questions. The results of the comparisons results show good correlation between both sets of hydraulic conductivity estimates, and provide the information required to support careful data integration for improved hydraulic conductivity data coverage.

Near Surface Hydro-Geophysics in Southern Ontario

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The Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC) have been collaborating on groundwater projects in the southern and central parts of the County of Simcoe, south of Georgian Bay and in the Niagara Peninsula region of Southern Ontario. Geophysical tools used in these projects consisted of geophysical surveys using active and passive seismic, downhole geophysical logging, gravity, airborne EM and magnetic surveys. The main research goal is to better characterise the subsurface by defining geophysical properties of lithological units, defining their spatial distribution, and sedimentary architecture. The ultimate goal is to improve our understanding of regional hydrostratigraphic units, and locally aquifers and aquitards.

More than 100 km of high resolution seismic reflection data have been acquired along public roads. The work was performed using a reconfigured IVI "Minivib 1" source with a "landstreamer" threecomponent geophone array built by the GSC. The landstreamer length is adapted to the depth of imaging using 48 or 72 geophones, mounted on 3 kg metal sleds spaced at 1.5 m towed using lowstretch belts. Data were acquired with shot points every 4.5 m. The Minivib source vibrates a 140 kg mass in cross-line (H2) horizontal mode, using a 7 second nonlinear logarithmic sweep of -2 DB/Oct from 20-280 Hz. This type of sweep increases the sweep time in the low end to increase low frequency energy of shear body waves. Data were recorded using Geometrics Geode engineering seismographs operated in the cab of the Minivib. P-wave sections are processed using the vertical geophones data, while S-wave sections are produced using the cross-line, H2, component data. Seismic sections are then correlated and interpreted with borehole geophysical data. The method has allowed us to measure thicknesses of aquitards and aquifers down to the resolution limits of seismic reflection which is approximately of 1.5 m for s-wave and 3 m for p-wave reflection data. Passive seismic data have been acquired using Tromino Eng-Geo seismographs for further research and comparisons along seismic sections; more research is required to identify the potential use in groundwater exploration of this method. Downhole geophysical logging was collected in 20 OGS boreholes; most of the holes have been logged using natural gamma, apparent conductivity, magnetic susceptibility, gamma-gamma density, fluid temperature and seismic Pand S-velocity. This data set provides a high vertical resolution for characterisation of formation properties, allowing an assessment of discontinuities, variation in grain size and mineral composition, porosities and compaction for further interpretation on geophysical data.

These new geophysical and borehole data sets have led us to identify unknown and potentially significant groundwater resource targets in both areas of investigations. Aquifers have been highlighted in the form of gravel sheets and eskers. Results constrain the extent and architecture of a newly discovered deep gravel groundwater reservoir that may be a supply for municipal use in the Stayner – Wasaga Beach area. Up to 20 km long seismic sections assist in depicting the architecture of regionallysignificant stratigraphic units, as well as the extents of sedimentary lobes associated with meltwater related sand, gravel, and mud and diamicton that are very accurately mapped using shear wave reflection data. The seismic section with the borehole data and local water well analysis demonstrate that in the Georgian Bay area, several erosion surfaces truncate aquifers and aquitards, creating a complex sedimentary architecture. Dome-shaped structures up to several kilometres wide have been profiled by seismic reflection in the Niagara region, near Welland, data is still being processed. Additional features awaiting processing and interpretation are potential buried valleys, notably one north of Port Dover, This project highlights the valuable role geophysics can play for groundwater reservoir exploration.

Application of the Tracer Radon-222 to Identify Groundwater Discharge Hotspots Along the Lake Simcoe Shoreline

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Groundwater discharge can be an important pathway for transporting pollutants, including nutrients, metals, and chloride into large inland lakes. Quantification of groundwater inputs into large lakes is often challenging due to high spatial variability in discharge patterns. While prior studies have identified offshore groundwater discharge locations (submarine hollows and vents) into Lake Simcoe, there is limited understanding of the magnitude of groundwater discharge to the lake including identification of areas that may be hotspots for discharge. The objective of this study was to evaluate the use of the natural tracer radon-222 (222Rn) for evaluating groundwater discharge along the shoreline of Lake Simcoe. 222Rn is a suitable tracer for quantifying groundwater discharge to inland lakes as its concentrations are typically 3-4 orders of magnitude higher in groundwater than in surface water. Regional scale 222Rn boat surveys were conducted along the shoreline of Lake Simcoe in summer 2015 and 2016 to identify potential groundwater discharge hotspots. Measurements were conducted using portable radon instrumentation (RAD 7 and RAD AQUA, Durridge Inc.). Groundwater discharge hotspots were located along the north shore of Kempenfelt Bay and along the south shore of Lake Simcoe. Regional-scale survey results were compared with hydrogeological studies previously conducted for subwatersheds around Lake Simcoe to gain understanding of the hydrogeological controls on the detected groundwater hotspot areas. High spatial resolution 222Rn surveys were also carried out in identified hotspot areas and a steady-state mass balance model which considers the various sources and sinks of 222Rn (e.g., air evasion, offshore mixing) was applied to estimate groundwater discharge rates. The challenge of applying a 222Rn mass balance is minimizing uncertainties associated with 222Rn loss through air evasion, as well as adequately characterizing 222Rn concentrations in the groundwater endmember. High resolution survey results confirmed high groundwater discharge in the hotspot areas with discharge highest near the shore and decreasing offshore. The development of regional-scale methods such as 222Rn for evaluating groundwater discharge to large inland waters including Lake Simcoe is critical for developing effective and targeted management plans aimed reducing the contribution of groundwater pollutants to degrading lake water quality.

Highlights of OGS – GSC Collaboration on Regional Groundwater Studies: 2016 – 2017

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The Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC) groundwater collaboration in Southern Ontario is currently half-way through a five year project cycle ending March 31st 2019. Following earlier updates on work completed this update will be provided under five principal themes.

1. Framework for Sustainable Groundwater Use: The 3D bedrock modelling activity has developed a 57 layer formation working model. This model is being used to guide QA/QC throughout the stratigraphy. Database enhancements are focussed on shallow formation of significance to potable water. A wrap-up document to the November 24th 2015 workshop on a Groundwater Framework was released as a GSC publication. The surficial modelling work is continuing on data capture and development of an authoritative stratigraphic reference framework and online access via the Groundwater Information Network (GIN).

2. Supporting Great Lakes Water Accords: Work has advanced on development of a conceptual framework for evaluating groundwater – surface water interactions and impacts on the quality and quantity of water and ecosystems. This aligns well with issues identified in Annex 8 of the Great Lakes Water Quality Agreement.

3. Methods Development for Regional Groundwater Studies: Methods are being advanced through analysis of seismic reflection, downhole geophysics, geochemistry data and infrared survey data. Passive seismic data was collected in the Wassaga Beach area in the vicinity of OGS boreholes and OGS-GSC seismic data. The objective is to verify the utility of this technique to mapping depth to bedrock surface. The value of collecting down-hole seismic profiles using the mini-vibe was investigated and demonstrated to provide significantly improved results. Regional methods for soil moisture studies using RadarSat II and SMOS are ongoing. Data were captured along 20 km of Lake Simcoe shoreline by an infrared airborne survey to investigate groundwater – surface water interaction and to coordinate with a lake based radon survey.

4. Case Studies: Data collection has been completed in a number of areas. Seismic reflection data were collected in Simcoe central and Niagara area complimented by borehole geophysics. pXRF analysis of continuous core to develop a subsurface chemostratigraphic framework has been expanded to include Simcoe County and Waterloo. A geostatistical approach was applied within the Innisfil Creek subwatershed to determine the uncertainty of 18 hydrostratigraphic units. Characterization of Newmarket Till cementation was initiated and preliminary results are available on carbonate cementation in the matrix. Contract work was initiated on consolidation of information on municipal well information within Source Water Protection documents. Additionally work is ongoing on the hydrostratigraphic classification of wells within the PGWMN.

5. Science and Technology Exchange: Manuscript submissions are in progress for a special issue of Canadian Journal of Earth Sciences with ten manuscripts in various states of review. It is hoped that a 2017 publication remains feasible. Project results are available via OGS – GSC publication streams, conference proceedings, and journal publications. An overview document on the project was published in the Ontario Geological Survey Report of Activities for 2016.

Developments in a Surficial Stratigraphic Framework for 3D Geological Modelling

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Work is ongoing on the development of a framework for a Southern Ontario regional 3D surficial geological model. The focus in 2016-17 has been on data capture and web enabling for online viewing/ download. This work builds on and complements the extensive database of subsurface information acquired over the last 15 years by the Ontario Geological Survey (OGS) as part of its surficial 3D mapping initiative. Recent coring programs in Simcoe County and the Niagara Peninsula have resulted in cores to bedrock being retrieved across much of the 'Golden horseshoe'. Continuous coring provided ground-truthing for over 100 line-kms of reflection seismic data recently collected in these areas. Legacy and archival datasets are also being added to complement the cored-borehole dataset. The 3D model is built on a provincial digital elevation model supplemented for Great Lakes by NOAA bathymetric data and for smaller lakes Canadian hydrographic field sheets (e.g., navigable waterways, Trent – Severn). Geological interpretations have been added from legacy high-resolution reflection seismic profiles in Lake Ontario (bedrock topographic elevation). The stratigraphic framework is additionally being enhanced by the capture of section descriptions and borehole logs from past OGS surficial mapping projects, integrated into a PostgreSQL database. Stratigraphic classification of Provincial Groundwater Monitoring Wells and data-mining from Source Water Protection technical reports will also inform the model as will data from the MOECC Water Well enhancement project.

In addition, downhole geophysical and geochemistry frameworks will assist with stratigraphic classification. Downhole geophysical data can reduce reliance on continuous-core data for stratigraphic studies once adequate work has established an index 'fingerprint' for stratigraphic units.

Consolidation of combined stratigraphic data in a PostgreSQL database supports serving this information online via Groundwater Information Network (GIN). GIN works in concert with parallel MOECC initiatives to support a distributed database framework for groundwater geoscience in Ontario.

Wetland Surface and Groundwater Interactions Monitoring Program

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Wetlands are important elements of the natural environment. More than 63 km^2 of the Conservation Halton watershed is covered with wetlands, 94% of which lie above the Niagara Escarpment, an area which is headwaters to major Conservation Halton creeks. Wetlands have various functions and properties and their understanding draws on multiple disciplines from terrestrial and aquatic ecology, chemistry, hydrology to engineering. From a hydrological point of view, wetlands can store water, lose water through evapotranspiration, recharge underlying aquifers, or collect groundwater discharge and convey it to local streams and rivers. Based on local topographical settings, geology, groundwater levels, climatic conditions the wetland hydrological conditions may differ. To understand the wetland hydrological functions, its hydroperiod and vertical hydraulic gradient need to be understood.

In the fall of 2012 Conservation Halton, in collaboration with the Regional Municipality of Halton, initiated a wetland monitoring project to address a lack of data identified during the development and calibration of an integrated surface and groundwater GSFLOW numerical model for drinking water source protection water budget studies in the Halton-Hamilton Source Protection Region. Specifically, the wetland monitoring program was designed to enhance the understanding of surface and groundwater interactions, their timing and fluxes. Five wetlands within Conservation Halton watershed were selected and instrumented. Wetlands 1 through 4 are located above the Niagara Escarpment and Wetland 5 is located below it. Wetland 1 is located in the Mountsberg Conservation Area, Wetland 2 just north of 5th Concession Road and west of Highway 6 in Hamilton, Wetland 3 in Crawford Lake Conservation Area, Wetland 4 in Hilton Falls Conservation Area, and Wetland 5 on private lands in North Oakville west of Sixth Line. Wetland 1 is classified as a swamp, Wetlands 2 and 5 are marshes, and Wetlands 3 and 4 are vernal pools.

Each wetland was instrumented with two drive point piezometers completed at different depths in close proximity. The shallow piezometers are completed at a maximum depth of 0.1 metres and effectively measure the wetlands' hydroperiod. The deep drive point piezometers were completed at depths between 0.4 and 1.5 meters to monitor shallow groundwater levels underneath wetlands. Each drivepoint piezometer was instrumented with an electronic datalogger measuring absolute pressure and temperature and collecting data at 10 minute or 1 hour intervals. To obtain accurate water height above sensor, the absolute pressure data were then corrected for barometric pressure changes using atmospheric pressure data.

The results show that the wetlands above the Niagara Escarpment are very dynamic and depending on the wetland type and local conditions, they behave differently during precipitation events. The instrumented wetland below the Escarpment is not as dynamic and mostly depends on surface water. In 2015 and 2016 three additional wetlands were added to the network in collaboration with Conservation Halton staff. Together with our neighboring conservation authorities, who have similar monitoring programs, having more instrumented wetlands will allow to develop relationships between wetland type, hydrology and occupying species. Collected data are an invaluable dataset to replicate natural processes in numerical modeling and a critical tool in local decision making, wetland management and watershed planning.

Wetland Ecohydrology Monitoring at TRCA: Insights and Lessons Learned

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The Wetland Water Balance project seeks to develop tools, knowledge, and guidelines to support TRCA's stormwater management criteria for water balance analyses where these are required for the protection of wetlands. This includes tools to better characterize the pre-development hydrology of a wetland and the components of the water balance that may contribute to maintenance of important ecological functions. As part of this project, a number of wetlands across TRCA and Credit Valley Conservation jurisdictions have been instrumented to learn how to: a) efficiently characterize baseline conditions, and; b) over the longer-term, develop a better understanding of wetland hydrological functions in the landscape and how these may relate to ecological functions. This presentation will focus on the preliminary results from the regional monitoring study, as well as physical monitoring techniques for characterizing shallow groundwater dynamics in wetlands. This research will help TRCA achieve its objectives of maintaining and enhancing the existing natural heritage system in the watersheds of greater Toronto by informing stormwater management system design and future water resource management decisions.

Assessing the Hydrologic and Environmental Impacts of Climate Change with an Integrated Groundwater and Surface Water Model

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There has been increased public awareness of the potential impacts of climate change on water resources in the Spencer Creek Watershed in Hamilton. This study, commissioned by Hamilton Conservation Authority and the City of Hamilton was completed as a pilot study to evaluate not only potential impacts to surface water hydrology, but explore how an integrated model can provide a thorough assessment on those groundwater and surface water interactions relating to environmental flows and wetlands.

The team for this project consisted of Matrix Solutions Inc., McMaster University, and the Ontario Climate Consortium (OCC). This pilot project received funding support from the Royal Bank of Canada (RBC) Blue Water Project, the City of Hamilton, Hamilton Conservation Authority, and Mitacs.

1. The study goals included the following:
2. Characterize local future climates and create future climate change scenarios with which to evaluate infrastructure and environmental vulnerabilities in the Hamilton area.
3. Apply possible future climates to an integrated groundwater and surface water model of the Spencer Creek watershed.
4. Compare baseline watershed and hydrologic and hydrogeologic conditions and future conditions against multiple impact indicators to assess vulnerabilities to climate change in the Spencer Creek watershed.
5. Recommend adaptation and monitoring measures to address the risks posed to the watershed by both current and future climate scenarios.

Future projected climate changes include increases in mean annual temperature, maximum temperatures, growing degree-days, and evapotranspiration. In addition, the models predict potential increases in total annual precipitation, more days with substantial rainfall and more long duration events. All of these potential changes may affect the form and function of the environmental features in the watershed. The effect of these changes on environmental features may affect water levels and soil moisture in wetlands and warmer stream temperatures. These hydrologic changes may then result in shifts in wetland species and more habitat for invasive species. For coldwater streams, these changes could mean loss of brook trout habitat; and for forest habitats, vernal pools supporting amphibian reproduction may be lost. Warming and drying of forests may lead to shifts in vegetation and loss of rare species.

GSC/OGS/CO Partnership Workshop 2017
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