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

H.A.J. Russell and E.H. Priebe

(Compilers)

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Canada

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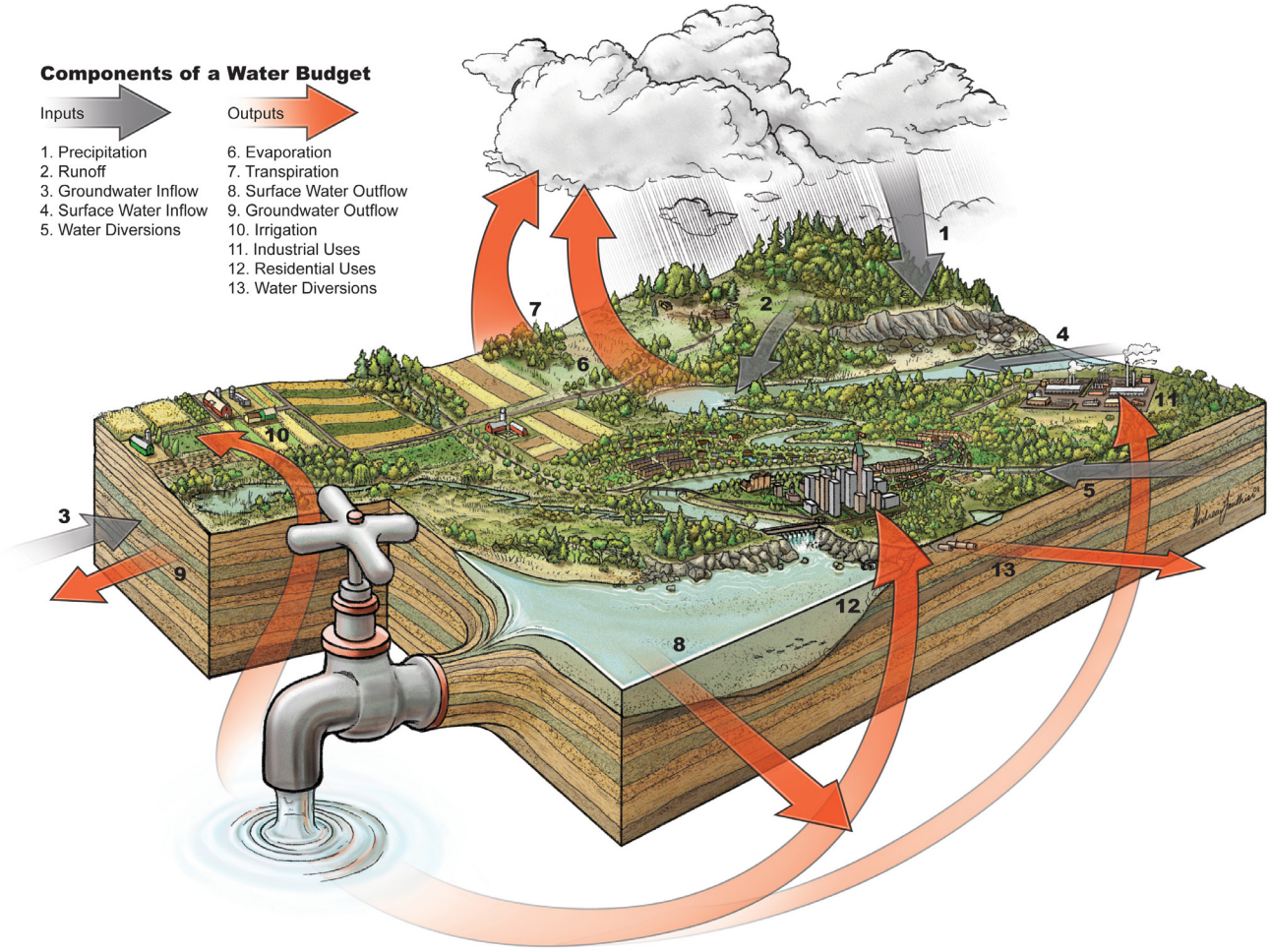
Regional-Scale Groundwater Geoscience in Southern Ontario:

An Ontario Geological Survey and Geological Survey of Canada Groundwater Geoscience Open House

March 10th 2016 | Delta Hotel, Guelph



(Compilers)
H.A.J. Russell and
E.H. Priebe
Geological Survey of Canada and the
Ontario Geological Survey

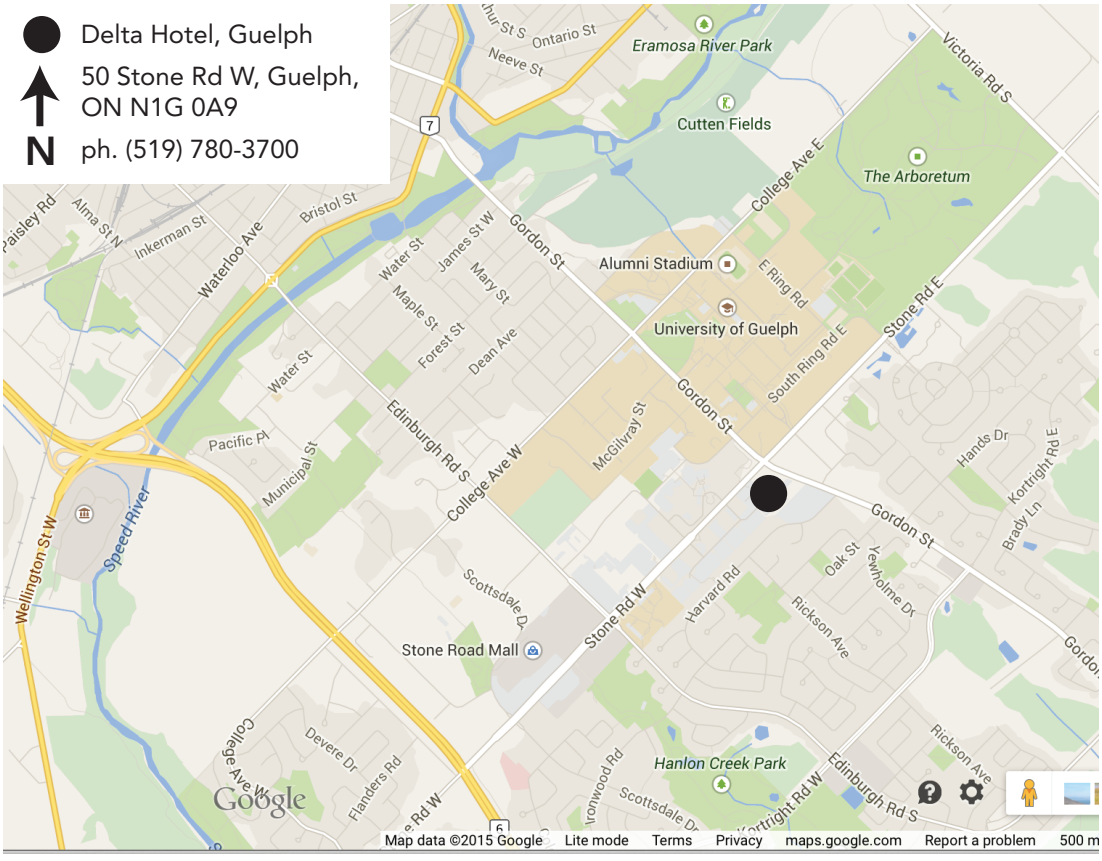
A collaborative initiative of the
Geological Survey of Canada and the
Ontario Geological Survey

Canada

Ontario

Location Map

Delta Hotel, Guelph
50 Stone Rd W, Guelph, ON N1G 0A9
ph. (519) 780-3700



Context

This Ontario Geological Survey – Geological Survey of Canada open house is for the Southern Ontario Groundwater Community. The day comprises a series of presentations by Federal, Provincial, Conservation Authority and Academic collaborators involved in groundwater studies in southern Ontario. Talks will address issues pertaining to:

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

This one-day open house is a response to the outreach and communication issues identified in the 2012 and 2015 OGS Gaps analyses[1]. It is the first 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. This year's one-day format is orientated around a series of 20-minute presentations. Feed back and suggestions on how to improve the open house delivery are greatly appreciated.

Acknowledgements

The time and effort of the workshop presenters and their respective agencies is much appreciated. Jean Francois Bureau helped with a variety of planning issues. An internal review at the GSC by B. Kjarsgaard 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.

Cover image courtesy of Conservation Ontario.

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.

Program

9:00:00	9:10:00	Introduction	
9:10:00	9:25:00	Ontario Geological Survey Response to the 2015 Groundwater Geoscience Knowledge GAP Analysis	Priebe
9:25:00	9:45:00	An Overview of the Ontario Geological Survey's Groundwater Initiative	Bajc
9:45:00	10:05:00	Highlights of OGS – GSC Collaboration on Regional Groundwater Studies: 2015–2016	Russell
10:05:00	**10:20:00**	**Break**	
10:20:00	10:40:00	Information Gaps and Science Needs for Groundwater Science in the Great Lakes Basin	Grannemann
10:40:00	11:00:00	3-D Hydrostratigraphic Modelling of the Paleozoic Bedrock of Southern Ontario	Carter
11:00:00	11:20:00	A Three Dimensional Surficial Stratigraphic Model for Southern Ontario	Russell
11:20:00	11:40:00	Merits and Development Strategies for a Regional Water Resources Modelling Platform for Southern Ontario – Great Lakes Basin	Sudicky
11:40:00	12:00:00	Remote Sensing Activities in Southern Ontario in NRCan/ ESS Groundwater Geoscience Program	Wang
12:00:00	**13:00:00**	**Lunch**	
13:00:00	13:20:00	Regional Geochemical Survey of Soil and Sediment in Southern Ontario	Sharpe
13:20:00	13:40:00	High-Density, High Quality Regional Sampling of Water Supply Wells: Ontario's Ambient Groundwater Geochemical Program	Hamilton
13:40:00	14:00:00	Hydro-Stratigraphic Correlation by Portable X-ray Fluorescence Spectrometry Based Chemostratigraphy	Knight
14:00:00	14:20:00	Integration of 'Golden Spike' Geologic and Hydrogeological Data Sets	Parker
14:20:00	14:40:00	Geophysical Data Acquisition for Hydro-Stratigraphic Mapping in Southern Ontario	Pugin
14:40:00	**14:55:00**	**BREAK**	
14:55:00	15:15:00	3-D Mapping of Quaternary Deposits in the Southern Part of Simcoe County	Bajc
14:55:00	15:15:00	Relating Sequence Stratigraphic and Karstic Controls of Regional Groundwater Flow Zones and Hydrochemistry within the Early Silurian Lockport Group of the Niagara Escarpment, Ontario	Brunton
15:15:00	15:35:00	Conservation Authority Geoscience Programs	Millar
15:15:00	15:35:00	Understanding Ontario's Capital Investment in Numerical Modelling under the Source Protection Program: 2005–2015	Bates
15:35:00	15:55:00	Near Real-Time Water Quantity Monitoring Data Assets Collected, Managed, Analyzed and Disseminated by the MNRF and MOECC	Kenny
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Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, ON, P3E6B5

Since the commencement of the Ontario Geological Survey's groundwater initiative in 2001, a wealth of geoscience information that can assist in an improved understanding of the provincial groundwater resources has been collected, analyzed and reported on. The initiative consists of 5 main activities, which produce intimately related data sets, including.

1) A series of digital, fully-attributed, seamless maps including bedrock geology, karst, physiography, surficial geology, surficial sediment thickness and bedrock topography that serve as a foundation for most hydrogeological investigations.

2) 3-D maps of key Paleozoic bedrock units that host important groundwater resources in southern Ontario paying particular attention to 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. Detailed hydrogeological studies were undertaken in the City of Guelph to better understand the lateral continuity of flow zones by integrating the geological dataset with discrete hydraulic tests over short vertical intervals believed to represent flow zones. Reporting on the Niagara Escarpment Silurian projects is nearing completion and a project focussing on Devonian units to the southwest is currently underway.

3) 3-D models of Quaternary sediment in southern Ontario focussing initially on areas either within or adjacent to the Greater Golden Horseshoe. To date, projects have been completed in the Waterloo (GRS03), Barrie-Oro (GRS11), Brantford-Woodstock (GRS10) and Orangeville-Fergus (GRS15) areas. Work in Southern Simcoe County is nearing completion and projects in the Niagara and Central Simcoe County areas are well underway. The 3-D sediment mapping program uses a basin analysis approach similar to that used by the GSC in the Oak Ridges Moraine. Ground and airborne geophysical surveys coupled with surficial sediment mapping and continuous-coring have enabled the development and refinement of conceptual geologic models, critical for the successful construction of 3-D geologic models. Projects in the Ottawa-St. Lawrence and Norfolk areas are scheduled to begin following completion of ongoing projects.

4) The ambient groundwater geochemistry project, which was initiated in 2007, has collected untreated bedrock- and surficial sediment-derived groundwaters at more than 2100 stations across all of southern Ontario, with the aim of understanding relationships between aquifer composition and groundwater quality, as well as understanding the flow history, residence time and vulnerability of individual and regional groundwater sources. The sampling density is approximately 2 stations per 10X10 km block (100 square kilometers). Each record contains 134 fields, 27 of which describe the station and 107 that describe the water and its chemical constituents. Digital datasets and maps were released for all of southern Ontario in 2015 (MRD283-REV) and an accompanying Groundwater Resource Study is currently in preparation. Meanwhile, a similar study is about to begin in the Sudbury region in 2016.

5) Parallel thematic projects including a study of the geology and hydrogeology of the Dundas buried bedrock valley (GRS12) and an assessment of the subsurface sediments in the central Norfolk sand plain (GRS14) were conducted in partnership with the Grand River Conservation Authority.

3-D Mapping of Quaternary Deposits in the Southern Part of Simcoe County

Bajc, A.F., Mulligan, R.P.M., and Rainsford, D.R.B.
Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, ON, P3E6B5

A Three-dimensional (3-D) Quaternary sediment mapping project in the southern part of Simcoe County is one of several investigations being undertaken as part of a broader groundwater geoscience initiative in the Greater Golden Horseshoe region. Outputs of the project are designed to provide the basic geologic foundation for groundwater studies in a part of the province that is expected to experience significant population growth over the next few decades. A basin analysis approach similar to that used by the GSC in the Oak Ridges Moraine to the south was undertaken in southern Simcoe County to construct the 3-D model. Following the capture and standardization of all available subsurface information (much of which was provided by the Conservation Authorities Moraine Coalition), a series of geophysical surveys (ground gravity, airborne TDEM, downhole logging and reflection seismic profiling) were undertaken to assist with the refinement of bedrock topography and the characterization of the geometry and contact relationships of overlying units. Continuous-coring of Quaternary sediments down to bedrock was undertaken at 25 sites, guided by the results of the geophysical surveys, to establish the regional Quaternary stratigraphic framework and support the subsequent modelling exercise.

The southern part of Simcoe County overlies the Laurentian Valley, a broad, bedrock depression extending from Georgian Bay southward to Lake Ontario. The maximum depth to bedrock encountered in the OGS boreholes exceeded 175 m. Surficial sediment thickness increase to the south of the study area, over the Oak Ridges Moraine, and diminish to the west as one approaches the Niagara Escarpment. Much of the study area is characterized as a till-capped upland incised by a network of deep valleys that are partially infilled with postglacial sediments. Uplands consist of an upper, Late Wisconsin till (Newmarket Till) overlying a thick sequence of glaciolacustrine deposits correlative with the Thorncliffe Formation (Middle Wisconsin). An unconformity characterized by deep subaerial weathering and organic-bearing alluvial deposits at the base of the Thorncliffe Formation is AMS dated at 37.9 to >52.8 ^{14}C ka BP. The unconformity, which possibly spans Middle Wisconsin through to Sangamon time (based on fossil evidence) is developed on an older sequence of tills and stratified deposits overlying bedrock and presumed to be Illinoian in age. The valleys, which are in some cases incised completely through regional upland strata, have been previously interpreted to be tunnel channels. They are partially infilled with fine-textured glaciolacustrine deposits capping variable thicknesses of coarse glaciofluvial sand and gravel either resting on, or incised through, Newmarket Till. Streamlined till has been observed on the upland surfaces as well as on the flanks and bottoms of several valleys suggesting continued deposition by active ice following erosion of the valleys.

Significant groundwater resources are restricted primarily to the highly permeable aquifers at the base of tunnel valleys. Thick, productive aquifers are rare within most of the uplands with the exception of the extreme northern part of the study area where the Thorncliffe Formation coarsens and sandy and gravelly facies are common. Waters from deeply buried aquifers often contain extremely high dissolved solids and some may contain methane limiting their use for municipal water supply.

Understanding Ontario's Capital Investment in Numerical Modelling under the Source Protection Program: 2005–2015

Bates, S.

Surface Water Monitoring Centre, Ontario Ministry of Natural Resources and Forestry, K9J8M5

The tragic contamination of Walkerton's water supply in May 2000, and the resulting inquiry by Justice Dennis O'Connor, saw the Province of Ontario begin the long process of properly addressing drinking water security and sustainable water resources management. In May 2002, exactly two years after the Walkerton tragedy, Justice O'Connor released his second, and final, inquiry report making 22 recommendations to the province for Source Water Protection. The intervening years from 2002 to 2005 saw intense activity from hundreds of people in the coordination of an Advisory Committee on Watershed-Based Source Protection Planning, a White Paper on Watershed-Based Source Protection Planning, a Technical Experts Committee and an Implementation Committee. These high-level committees within the province, and their resulting reports, became the foundation on which the Source Water Protection Program and Clean Water Act were designed. In early 2005, the first in a series of multi-million dollar agreements was signed to begin building and implementing the Source Water Protection Program. This presentation will highlight the first ten years of numerical model development within Ontario's Water Budget Program under the provinces' Clean Water Act. Over this decade approximate $25 million has been allocated to conservation authority and municipal partners for the development of sophisticated water quantity assessments that identified stresses and risks to Ontario's source water. In order to ensure continued value from this provincial investment a team of conservation authority, municipal, academic and private sector experts has been assembled to define guidance for Numerical Model Management for the Source Water Protection Program. This presentation will discuss the key aspects of model management including Governance, Legal and Technical considerations that need to be addressed for a robust model management culture to be established in the province. Early accomplishments within the model management project and critical review from the expert advisory team are showing great promise for defining a framework for model management. These guidelines will prove useful to model developers, users and managers alike, and serve as the basis for future advances in Source Water Protection and more broad application for initiatives like the Southern Ontario Groundwater Science program from the GSC and OGS.

Relating Sequence Stratigraphic and Karstic Controls of Regional Groundwater Flow Zones and Hydrochemistry within the Early Silurian Lockport Group of the Niagara Escarpment, Southern Ontario

Brunton, F.R.B., Priebe, E.H., and Yeung, K.
Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, ON, P3E6B5

The Ontario Geological Survey has been mapping regional bedrock potable groundwater flow zones across the Niagara Escarpment region of Southern Ontario and Manitoulin Island. The sedimentary rocks that comprise the Niagara Escarpment are Early Silurian in age and display a complex but predictable stratigraphic architecture that has been identified through detailed logging/sampling of cores and outcrops both within and away from the "Arch" or forebulge region. This study has developed a new paleogeographic / paleoenvironmental perspective, which provides important insights into the controls on various carbonate bedrock fluid pathways and supports a predictive framework. Intermittent responses to far-field tectonics along the Appalachian Foreland basin influenced local carbonate ramp geometries and relative sea level fluctuations and differential erosion regionally. Findings show that the more significant the time breaks within the stratigraphic architecture, the more regional and significant the extent of the flow zones. It also highlights the economic importance of characterizing forebulge-tectonic zones, and the value of geologic mapping and acquisition of geologic data to successfully explore, characterize, and define bedrock flow zones in a cost-effective manner.

Due to regional stress fields and differential erosion of the Paleozoic strata, rock strata presently dip gently in a SW direction away from the topographic high of the erosional Niagara scarp face. The Cabot Head Fm shales of the Clinton Group form the regional aquitard to the potable water supplies that reside in the overlying Lockport Group carbonates north of Hamilton; the slightly younger Rochester Fm shales of the Clinton Group form the regional aquitard between Hamilton and Niagara Falls.

Delineation of preferred bedrock groundwater flow zones required regional outcrop mapping, combined with examination of > 100 bedrock/overburden cores and geophysical-logs. The cores were logged and sampled for whole rock, trace element, and select REEs and isotopes (C, O, Sr), and conodont biostratigraphy over a five year period (2009 through 2014). Key cored holes across the study area also had video logs, variable duration packer pumping tests, FLUTe™ K-profiling, select Heat Pulse and optical-acoustic televiewer profiling, and select dye tracer tests. Many of the key cores integrated in this study were collected in collaboration with municipalities and other partners that both rely on bedrock ground waters and/or are exploring for new resources to meet future population and industry pressures.

The position and continuity of groundwater flow zones identified with the geological sequence stratigraphic model are currently being corroborated with hydrochemical, geochemical and isotopic tracers (natural, non-injected) and hydrogeochemical modelling. Isotopic and hydrochemical results provide new insight into recharge timing and chemical distinctions between groundwater flow zones. A comparison of Oxygen-18 and deuterium values for pre-freshet composite snow columns, collected along a north-south transect of the study area, show distinct differences between the isotopic-signature of groundwater in the carbonates versus the isotopic composition of the snow – the groundwater isotopic signature resembles that of the local fall season precipitation. Tritium isotopes, redox sensitive parameters and vertical gradient information have assisted in the identification of some areas of deep (~100 m) and rapid recharge. Hydrochemistry results suggest formation- level variability in major and trace elements, which are being used to trace flow zones.

3-D Hydrostratigraphic Modelling of the Paleozoic Bedrock of Southern Ontario

Carter, T.R[1]., Brunton, F.R.B[2]., Clark, J[3]., De Kemp, E.A[6]., Fortner, L[4]., Hamblin, A[5]., Logan, C.L[6]., and Russell, H.A.J[6].

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[2] Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, ON, P3E6B5

[3]Ontario Oil, Gas and Salt Resources Library, London, ON, N6E1L3

[4]Ministry of Natural Resources and Forestry, London, ON, N6E1L3

[5]Geological Survey of Canada, Natural Resources Canada, Calgary, AB, T2L2A7

[6]Geological Survey of Canada, Natural Resources Canada, Ottawa, ON, K1A0E8

The Geological Survey of Canada, the Ontario Geological Survey, the Ministry of Natural Resources and Forestry and the Ontario Oil, Gas and Salt Resources (OGSR) Library have initiated a cooperative project to create a regional 3-D model of the layered Paleozoic bedrock strata of southern Ontario, and the occurrence of water within these strata.

A wealth of data are available, including digital records from 400,000 water wells that penetrate the bedrock, nearly 27,000 petroleum wells records, and approximately 300 stratigraphic boreholes in shallow bedrock formations completed by the Ontario Geological Survey. Petroleum well records are the key data source for the model, with data already coded in an Oracle relational database with geographic coordinates and elevation data for all wells. There are depth and elevation values for nearly 600,000 formation tops and over 35,000 water interval records with information on water type, depth interval and static level. A significant number of QC edits has greatly improved accuracy and reliability of this data set since 2001, with further improvements to be funded by the GSC as part of this project. Also available are compositional analyses for over 1000 samples of produced water from petroleum wells, isotopic and compositional analyses for 130 samples of deep to intermediate groundwater, 89 water type maps and 17 static level maps for deep groundwater aquifers, and field observations from springs, quarries, road cuts, outcrops, well testing, and drill core examinations.

The model will incorporate and build on a published regional 2-D conceptual model of groundwater systems in the bedrock of southern Ontario, documenting a hydrochemical zonation of water by depth into a shallow fresh water system, an intermediate sulphur water system and a deep brine system.

Hydrostratigraphic units in the southern Ontario bedrock are known to cross formational boundaries. Hydrostratigraphic units also change character laterally, within the same formation, due to facies changes, diagenetic modification, faulting and, of particular significance in southern Ontario, karstification of carbonate or evaporite strata at unconformities. Paleokarst horizons are known to be a key geological control on aquifers in the bedrock. Modelling of this inhomogeneity is a complex technical and conceptual task and will comprise an iterative process of modelling, QA/QC data review and editing, and critical geological appraisal.

Final products will be co-released by GSC and the OGS with access via the OGSR Library website, and will include a 3-D model in both Leapfrog and ESRI ArcGIS formats, a 2-D conceptual hydrostratigraphic model, and improvements in data quality and accuracy in the petroleum well database. Numeric groundwater flow modelling is beyond the scope of this project but the static model will support dynamic modelling. Target date for project completion is mid to late 2018.

Information Gaps and Science Needs for Groundwater Science in the Great Lakes Basin

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Traditionally, groundwater science in the Great Lakes Basin was focused on finding and protecting drinking water for inland communities, private supplies, and irrigation. In the last several decades, however, a larger scientific effort has been devoted to understanding the role of groundwater as part of the overall water budget and ecosystems in the Great Lakes Basin. Annex 8 of the Great Lakes Water Quality Agreement is focused on the groundwater resources of the Basin and how they affect the quality of water in the Great Lakes. As part of a binational commitment of the Agreement, a team of about 30 geoscientists prepared a report that outlines the status of groundwater science relevant to the Great Lakes Water Quality Agreement. The report identifies major groundwater information gaps and science needs that are summarized as the following major areas:

1: Advance assessment of regional-scale groundwater discharge (quantity) to surface water in the Basin.
2: Establish science-based priorities to advance the assessment of the geographic distribution of known and potential sources of groundwater contaminants relevant to Great Lakes water quality, and the efficacy of mitigation efforts.
3: Advance monitoring and surveillance of groundwater quality in the Great Lakes Basin.
4: Advance research on local-scale assessment of interaction between groundwater and surface water.
5: Develop better tools for monitoring, surveillance and local-scale assessment of groundwater – surface water interaction.
6: Advance research on the role of groundwater in aquatic habitats.
7: Develop scaled-up models of the regional effects of groundwater on Great Lakes water quality.

A review of these seven science needs will be discussed as they relate to regional-scale groundwater studies.

High-Density, High Quality Regional Sampling of Water Supply Wells: Ontario's Ambient Groundwater Geochemical Program

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The Ambient Groundwater Geochemistry (AGG) initiative of the Ontario Geological Survey is a regional high density groundwater sampling program, the purpose of which is to map and understand the existing groundwater geochemical conditions in Ontario's major rock and surficial sediment aquifers. Throughout the last decade, the study has amassed data for 2664 samples from 2095 stations across 96,000 km^2 representing all of southern Ontario.

This one-time sampling program relies on existing well infrastructure sampled in a 10x10 km grid pattern. Monitoring and farm wells are used but the majority are domestic water supply wells with purging and sampling protocols adapted to the well type. Sites are randomly selected such that three criteria are met: (1) the water source must be determined, (2) the full, untreated geochemical matrix must be characterized, (3) data quality must be assured; i.e. it must be demonstrated that what was intended to be measured has been correctly measured. A combination of field protocols, laboratory methods and a post acquisition QC auditing process, which collectively last for 6 months beyond a typical field season.

Wells are selected only if their well construction details can be ascertained and cross-checked. The sources, and therefore reliability, of this information are recorded in the database and used later in an audit of all station information collected in the field. The audit, which uses well logs, field notes, well owner comments, continuous logs of field parameters (temperature, pH, etc) and field photos, typically lasts several months and scrutinizes well construction details, well-head security, plumbing details, integrity of water source and the geological origin of the water. In most years, based on the audit, a small number of sampled waters do not meet one of the three criteria and are rejected for inclusion in the AGG database.

Analytical QA/QC procedures are rigorous. At least two analytical techniques are used to analyze many of the important parameters including the major ions, nitrate, iodide and many metals and these redundant analyses are checked against each other. Blind field duplicates, blanks and multiple reference standards are inserted at regular intervals in lab submissions and amount to 15% of all samples submitted and are used to confirm precision and accuracy for all parameters. Where data are found to fail the quality assurance tests, mitigation action is taken that may include re-analysis, resampling, or at worst, removal of the problem samples from the database.

These techniques provide the quality assurance required for publication of the database. All blind quality control data are published, along with 27 station attributes, which allows end-users many options in the way they use the data, including creating subsets of the data for particular uses. The breadth of analysis, uniformity of coverage, areal extent and data quality of this dataset together far exceeds that of any previously existing groundwater geochemical databases in the province of Ontario.

Near Real-Time Water Quantity Monitoring Data Assets Collected, Managed, Analyzed and Disseminated by the MNRF and MOECC

Kenny, F[1]., Conrod, D[2]., Gallant, G[1]., Smith, B[1]., MacRitchie. S[2]., and Grgic, D[2].

[1]*Surface Water Monitoring Centre, Ontario Ministry of Natural Resources and Forestry, Peterborough, ON, K9J8M5*

[2]*Environmental Monitoring and Reporting Branch, Ontario Ministry of Environment and Climate Change, Toronto, ON, M9P3V6*

Based within the Ontario Ministry of Natural Resources and Forestry (MNRF), the Surface Water Monitoring Centre (SWMC) is the primary Ontario government office tasked with Emergency Management responsibilities for flood forecasting and drought monitoring. To fulfil these mandates, the SWMC polls and ingests water monitoring data in near real-time, from approximately 2000 monitoring sites from 11 different sensor networks spanning the province, and adjacent jurisdictions.

Central to the SWMC's operational near real-time data stream are 600 strategically located hydrometric stream gauge sites that are cost-shared with Environment Canada –Water Survey of Canada (EC-WSC). The SWMC ingests data from an additional 1400 monitoring stations through an array of partnerships with agencies such as the Meteorological Service of Canada (MSC), Parks Canada (PC), all 36 Conservation Authorities (CA), the International Joint Commission (IJC), NOAA, Ontario Power Generation (OPG), the Ontario Ministry of Transportation (MTO) and a Citizen Weather Science initiative called CoCoRaHS. Along with hydrometric level and flow data, the SWMC captures, archives and disseminates precipitation, wind, temperature (water and air), air pressure, wave buoy, soil moisture, snow-depth and snow water equivalent data from across Ontario.

Beginning in 2014 the SWMC, in cooperation with the MOECC began ingesting groundwater level data from 100 MOECC Provincial Groundwater Monitoring Network (PGMN) wells in near real-time via GOES satellite telemetry. As well beginning in 2015, the MOECC has initiated the migration of the Provincial Groundwater Monitoring Information System (PGMIS) period-of-record into what is becoming a shared MNRF/MOECC water quantity monitoring data environment.

To accommodate this large and ever increasing near real-time data stream and the entire period-of-record associated with each gauge/site (in some cases >100 years), this shared data environment requires robust IT infrastructure and software. Further, because the SWMC provides critical Emergency Management services, we are obligated to operate 24/7 in a restrictive and secure IT environment with numerous hardware and software redundancies. In common with the majority of Ontario's 36 Conservation Authorities (our central local flood forecasting, drought monitoring and groundwater monitoring partners in Ontario) our primary water monitoring data management software solution is a KISTERS product, WISKI (Water Information Systems KISTERS).

This presentation will highlight the MNRF/MOECC's near real-time water quantity monitoring data assets, data flows, polling and telemetry systems/ability, core IT KISTERS data management infrastructure, spatial/temporal (ESRI/Kisters) integration, integrated data linkages to operational models/reports/maps, automated alarm systems, the various sensor networks utilized, the network partnerships that have

developed , current web-based near-real-time data reporting services (WISKI WebPro) and the array of flood forecasting and drought monitoring products and services provided to Conservation Authorities and Ontario based water resource partner agencies.

Lastly we are currently halfway through a major KISTERS version upgrade (WISKI 7). With this latest version we will have the ability to both consume and publish real-time hydrological data over the Internet using OGC (Open Geospatial Consortium) standards like WaterML2.0. This development, consistent with the Ontario Government's commitment to Open Data, will allow us to expose our entire data stream and period-of-record archive globally via a simple web browser.

Hydro-Stratigraphic Correlation by Portable X-ray Fluorescence Spectrometry Based Chemostratigraphy

Knight, R.D., Kjarsgaard, B.A., Russell, H.A.J., and Sharpe, D.R.
Geological Survey of Canada, Natural Resources Canada, Ottawa, ON, K1A0E8

In glacial basins stratigraphic correlation is commonly based on lithostratigraphic methods. Correlation can be significantly improved through the use of geophysical and geochemical properties; however widespread subsurface geophysical data is often limited. For groundwater studies, the collection of sediment geochemistry data is often beyond the scope and budget of many programs and is generally not included as a part of routine data collection. Portable X-ray fluorescent (pXRF) spectrometry has proven to be a successful, cost effective tool to characterize the chemostratigraphy of glacially derived sediments and to improve the interpretation of downhole geophysics, micropaleontology results, and pore water geochemistry. Data collected from this method has now become a routine part of borehole studies within the Groundwater Program at the GSC.

Analytical protocols have been developed to utilize portable X-ray fluorescence spectrometry (pXRF) to obtain precise and accurate data for a suit of up to 14 elements detected in the <63 microns grain size fraction (Ba, Ca, Cu, Fe, K, Mn, Ni, Rb, S, Sr, Ti, V, Zn, Zr). This protocol was developed through the analyses of over 10,000 samples obtained from multiple glacial basins across Canada, and verified against traditional laboratory methods (fusion, four acid, aqua regia digestions) using >500 samples.

The introduction of chemostratigraphic techniques to samples collected from boreholes establishes chemical and related mineralogical variations within sediments and contributes to information collected by sediment description, grain size data, downhole geophysical and stratigraphic correlations. Geochemical data also provides an opportunity to establish a chemostratigraphic framework that complements other stratigraphic correlation techniques, for example lithostratigraphy and biostratigraphy.

Results have demonstrated the ability of chemical analyses obtained from pXRF spectrometry to identify stratigraphic units, refine sedimentological interpretations, and correlate within glacial basins. The addition of geochemical analyses has refined paleogeographic interpretations; provenance studies, and provides information to support 3-D geological models with increased confidence in stratigraphic correlations.

A pilot study in the Greater Toronto Area (GTA) of 10 borehole cores, sampled at approximately one metre interval (1057 sample analysis), has provided a proof of concept for planning of a series of chemostratigraphic transects across southern Ontario. Samples will be collected from OGS and GSC archival material for 18-20 boreholes for approximately 2000 samples. Additionally reanalysis of a suite of samples from the NATMAP (< 50 samples) orientation sample transect in the GTA will provide a link with surface geochemical sampling and the subsurface chemostratigraphic data.

Conservation Authority Geoscience Programs

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Geoscience is a relatively new program area for many Conservation Authorities (CA); it wasn't until about 2001 that CAs started to employ Geoscientists. Initial CA geoscience programs consisted of the newly formed Provincial Groundwater Monitoring Network (PGMN) and the Source Water Protection (SWP) Program. The Geoscience services offered by CAs has evolved and is now more integrated into regular CA business and has opened up additional opportunities for collaborations with municipal, provincial, and federal partners. In 2008 the CA Geosciences Group was formed to ensure consistency between CAs for the application of geoscience among CAs. Of the 36 CAs approximately 14 CAs currently employ qualified geoscientists, the remaining 22 contract out geosciences work as required.

This presentation will look at how geoscience has been integrated into the core CA business, which includes

1. Aspects of planning and development review; review and commenting on public policy and regulations;
2. Watershed Plans, including the watershed Report Cards;
3. Monitoring programs including the PGMN, soil moisture, and climate change;
4. The SWP program that helped to advance groundwater information in Ontario through the water budgets and modeling exercises;
5. Other modeling including the Conservation Authorities Moraine Coalition's YPDT 3-D model;
6. Participation in special projects for the development of a Low Water Response groundwater indicator and soil moisture;
7. Participation in the development of the annex 8 groundwater report under the Great Lakes Water Quality Agreement; and
8. Partnerships with the Ontario Geological Survey investigating locally important geologic features that have an impact on water quantity and quality.

Integration of 'Golden Spike' Geologic and Hydrogeological Data Sets

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High resolution geological data sets have increasingly been collected and used in the context of groundwater mapping programs in Ontario. This has provided much more robust geological conceptual models for key areas in the province. At the same time, many advances have been made in hydrogeology to enable acquisition of high-resolution hydraulic data in vertical profile. Here we present a few examples from Ontario to demonstrate how the collection of these two types of datasets in tandem can provide a hydraulically-calibrated, geologic framework to generate a robust, 3-D hydrogeologic model. While the geological framework remains the key to extrapolation between boreholes, the hydraulic significance of the various stratigraphic (sub)units and sedimentary features are identified and quantified with the direct measurement of hydraulic conditions at multiple depths and locations. These data sets are very much complementary and provide corroborating evidence and robustness to define the geometry, thickness and position of key 3-D hydrogeological units that control the groundwater flow system and contaminant pathways and transport rates.

Ontario Geological Survey Response to the 2015 Groundwater Geoscience Knowledge GAP Analysis

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In March 2015, the Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC) hosted a Groundwater Geoscience Knowledge GAP Analysis session for southern Ontario clients. The session objectives were to solicit input at the planning phase of several large OGS/GSC collaborative mapping initiatives, and to discuss the future of provincial government data management and the potential for accessing data via an "open data" initiative. Session participants identified 30 individual groundwater geoscience knowledge gaps, which fall into 7 categories comprising: i) communications, ii) standards and protocols, iii) hydro and geochemistry, iv) surface and groundwater interaction, v) geology and hydrogeology, vi) climate change and vii) data management and dissemination. In the past year, the OGS has taken significant steps to address many of the knowledge gaps that were brought forward at the March 2015 session.

Communication issues represented the first, and most prominent, category of identified gaps. Session participants agreed that better communication between government ministries and agencies, that hold various land resource and science based mandates, would break down barriers between disciplines and create opportunities for multi-disciplinary collaboration. To address communication issues, the OGS has taken several positive steps to engage with partner land-based ministries. Some highlights of the activities emerging from these new connections include; the OGS providing geoscience mapping products and offering expertise to MOECC Land and Water Policy Branch as they evaluate land-use planning in the Greater Golden Horseshoe region; the development of a new OGS project, in collaboration with MOECC, to map shallow karst using geochemical indicators of rapid recharge; opening communication and information sharing to discuss the inclusion of OGS continuously cored boreholes with monitors into the MOECC Provincial Groundwater Monitoring Network; the creation of a working group to write a White Paper supporting a modern provincial government data strategy; and providing groundwater hydrochemistry mapping and expertise to support policy development for homeowner and public health unit notification when domestic well sampling results exceed drinking water guidelines from natural/geological sources. Each of the new projects and collaborations represents an improvement to inter-government communication. This list also demonstrates the OGS's commitment to create geoscience mapping products that meet the needs of clients, including those making science based policy decisions regarding groundwater.

The OGS will continue to engage with clients and stakeholders as we continue our groundwater mapping initiative in southern Ontario in collaboration with the Geological Survey of Canada.

Geophysical Data Acquisition for Hydro-Stratigraphic Mapping in Southern Ontario

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In two collaborative projects with the OGS in the Southern Ontario, Canada, the GSC has acquired high-resolution reflection seismic and passive seismic data combined with downhole geophysics data. We have acquired innovative high-resolution compressional (P-) and shear (S-) wave reflection sections using a vibratory source and 3-component (3-C) landstreamer system during field programs carried out in 2013 and 2015. The work was part of a strategy to improve the knowledge and understanding of groundwater resources within the glacial and post-glacial sediments in Southern Ontario. The >80 line-km of seismic profiling is an excellent example of an hydrogeophysics data set, providing detailed information on the depth to bedrock, the architecture and stratigraphy, and physical properties of the overlying sediments on both the regional and local scales. Complex sedimentary features observed include deep bedrock valleys, deltaic and till deposits interconnected by erosive metre to multi-kilometre size structures for which observation and measurements are essential for hydro-stratigraphic mapping. Geophysical logging in deep boreholes was undertaken to assist with the calibration of the seismic sections. We also made an attempt to compare shear wave seismic reflection with passive resonance H/V analysis, the first results are encouraging but need further calibration and modeling over existing borehole data to be conclusive.

The seismic surveys were performed using an IVI "Minivib 1" source with a "landstreamer" three-component geophone array built by the GSC. The landstreamer consists of 72 or 48 - 3 kg metal sleds spaced at 1.5 m towed using low-stretch belts. The source vibrates in in-line (H1 or H2) horizontal mode, using a 7 second nonlinear logarithmic sweep of -2 DB/Oct from 20 to 300 Hz to increase the time spent in the low end of the sweep to enhance shear body wave energy. Data were recorded using six to nine 24-channel Geometrics Geode engineering seismographs operated in the cab of the Minivib. Uncorrelated records are collected to allow pre-whitening of the data and careful choice of the correlating function is the first step in the data processing sequence. P-wave sections are derived from data acquired on the vertical geophones, while S-wave sections are produced using the in-line, H1 or the cross-line, H2, component. Seismic sections are then correlated with borehole geophysical data. Interpretation of the equivalent compressional (P-) wave section permits delineation of seismic facies sequences. The shear wave data produce remarkably detailed sections over buried valleys from the surface down to 150 m or more. In the Niagara region, near the seismic lines 6 boreholes have been logged for natural gamma, apparent conductivity, density and fluid temperature, P-wave and S-wave velocities were measured. One hole is situated on a seismic line and was successfully used for seismic depth calibration.

Highlights of OGS – GSC Collaboration on Regional Groundwater Studies: 2015 – 2016

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Following the first year of the Ontario Geological Survey and Geological Survey of Canada collaborative project an update on work completed under four principal themes is provided. To support a Framework for Sustainable Groundwater Use, a multiagency workshop was held on November 24th 2015 to address the need for a provincial groundwater data framework to support sustainable groundwater management. Project contributions to this embryonic framework involve development of a 3-D geological model of the Paleozoic and Surficial Geology. This initiative is also being advanced by development of an index stratigraphic framework of continuous core for the surficial geology of southern Ontario and online access via the Groundwater Information Network (GIN). Collaborative work has been initiated on development of a conceptual landscape framework on groundwater – surface water which will provide a foundation for issues identified in Annex 8 of the Great Lakes Water Quality Agreement.

Methods Development for Regional Groundwater Studies are being advanced through analysis of seismic reflection, downhole geophysics and geochemistry data. Passive seismic techniques are being explored to permit enhanced depth to bedrock mapping and characterization of high velocity contrast units in the surficial stratigraphy. Activity development is ongoing on how to further advance data integration and analysis from a hydrogeophysics perspective. Regional methods for measurement of water storage and soil moisture using inferometry, RadarSat II and SMOS and SMAP are ongoing.

In the past year, specific Case Studies have involved seismic reflection data collection in the Wasaga Beach and Niagara area. Results of previously collected downhole geophysics in the South Simcoe area were published by the GSC and additional downhole data collection commenced in the Niagara area with additional work planned for the Wasaga Beach area in 2016. Documentation of a legacy 300 site surficial geochemical dataset for Southern Ontario has been completed. This regional coverage is being complemented with pXRF analysis of continuous core to develop a subsurface chemostratigraphic framework. Eight cores collected across the Greater Toronto Area (GTA) have been analyzed and analysis will be extended to OGS cores from the Oro, Wasaga Beach, South Simcoe, Orangeville, Waterloo, Brantford-Woodstock, Niagara and London areas. Work is ongoing in the search for collaborative partnerships for an additional geochemical dataset in the GTA. Continuous core, geological modelling, and hydrogeological paraters (K) in the South Simcoe area are being used in a Ph.D. The study involves a stochastic facies simulation (geostatistics) of hydrostratigraphic heterogeneity with the objective to provide regionuncertainty assessment for groundwater flow modelling.

Following up on the March 6th 2015 GAPS analysis workshop, Science & Technology Exchange has been initiated through an annual OGS-GSC open house. Manuscript submissions are underway for a special issue of Canadian Journal of Earth Sciences on the theme of Quaternary Geology and Applications to Groundwater Understanding. Project results are available via OGS – GSC publication streams, conference proceedings, and journal publications.

A Three Dimensional Surficial Stratigraphic Model for Southern Ontario

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Over the past ten years, the Ontario Geological Survey has completed extensive subsurface investigations in and beyond the Greater Golden Horseshoe region of southern Ontario to support development of regional 3-D surficial geological models (e.g., Waterloo, Oro). The combined efforts of this work and that of the Geological Survey of Canada over the Oak Ridges Moraine Area, has resulted in close to 50% of the total area of southern Ontario being modelled. Following the extensive work associated with the development of Source Water Protection Plans, there is now a need, and value, in developing a regional surficial geological framework for all of Southern Ontario. To develop a framework for a regional 3-D model, multiple components are being worked on that include, i) development of a simplified legend of hydrostratigraphic units, ii) identification of a conceptual model to ensure appropriate reconciliation of legend items both stratigraphically and architecturally, iii) compilation of an index stratigraphic framework of continuously cored boreholes, including borehole geophysics and seismic data, iv) quality control of the MOECC water well data, v) stratigraphic coding of the water well records, and vi) interpolation of an integrated, fully attributed 3-D model of regionally significant aquifer and aquitard units. This multiyear initiative is anticipating a preliminary model in 2018 with full documentation and final products available by 2019.

Regional Geochemical Survey of Soil and Sediment in Southern Ontario

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The interplay of geological, biological, and chemical factors controls the natural distribution of elements in the environment. Superimposed on this natural pattern is the effect of human activity, e.g., urban, agriculture, and industrial. Thus, knowledge of natural background levels and cycling processes are required to interpret a geochemical baseline for environmental and human health protection in southern Ontario.

Geochemical sample distribution of the southern Ontario landscape consists of 300 randomly selected sites that provide statistically representative sampling, independent of geological, pedological, and ecological distributions. Paired A and C soil horizon samples (296), and nearby till samples (300), were collected based on funding from a National Geoscience Mapping Program (GSC-OGS partnership). Analysis, using established analytical methods (X-Ray Fluoresence (XRF), Atomic Absorption Spectroscopy (AAS), Instrumental Neutron Activation (INA), Chittick Analysis and Specific Ion Electrode) and reference standards, was completed for 33 elements. This analytical work was funded by the former Ontario Ministry of Environment and Energy (Phytotoxicology section) and the Atomic Energy of Canada Limited.

Many elements display systematic variation in concentration linked to major geological domains, e.g., Superior and Grenville provinces of Precambrian Shield, Paleozoic rocks of eastern Ontario and Paleozoic carbonate and shale rocks of southwestern Ontario, overprinted by patterns in transported glacial sediment of variable thickness. For example, contour maps of Ca, Mg, and As concentrations in A and C horizon samples show pronounced spatial relationship between soil values and bedrock source areas. Regional elemental patterns near Windsor (Sb, Mo, & Ni; low Zr) and near the Niagara Escarpment (Zn, Cd, and Pb) are also apparent. Some elements show local-scale variation rather than regional variation (e.g. Hg, Cu, Ni) patterns which may be due to local geology, textural variation, human activity, or soil formation. For instance, a number of elements display enrichment in the organic A horizon compared to parent material, C horizon, particularly for Hg, Pb and transitional elements, apparently reflecting the influence of biogeochemical cycling by soil forming processes.

Detailed analysis (geochemical tracing or "finger-printing") is often required to distinguish anthropogenic influences, such as Pb from leaded gasoline; As from herbicides, and impurities derived from agricultural fertilizers. Alternatively, anomalously high A/C ratios found southeast from Sudbury (Cu, Ni, As, Se, Cd, Pb) may be due to combined atmospheric fallout from smelting operations and/or mineralization. The radius of significant influence of potential fallout, skewed southeast, is within 100 km of smelting operations.

Merits and Development Strategies for a Regional Water Resources Modelling Platform for Southern Ontario – Great Lakes Basin

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Water resources within Southern Ontario and the Great Lakes Basin (GLB) are a focal point for a wide range of stakeholders who are faced with addressing climate change impacts and resiliency, surface water and groundwater sustainability, and Great Lakes water quality. Because of the complexity of these challenges, modern science-based decision support tools are required. As demonstrated by water resources management projects underway in the Canadian Prairies and Europe, fully-integrated groundwater-surface water models are increasingly being used as multi-stakeholder decision support tools for demanding hydrologic problems. The centralized high-performance modelling platforms and associated databases are being developed through a collaboration of platform end users and requisite specialists. The multi-stakeholder functionality of this next generation of water resource simulation tools is primarily possible because fully-integrated hydrologic models seamlessly couple surface water (SW) and groundwater (GW) flow systems, including the unsaturated zone, and are driven by spatio-temporal precipitation events that are either derived from observational data or climate system projections. As such, traditional groundwater-only and surface-water-only models are replaced by a single simulation platform that employs a holistic physics-based approach emulating the entire terrestrial water cycle with full accounting of water balances within and between the various hydrological compartments. Furthermore, fully-integrated physics-based modeling provides additional benefit when simulating hydrologically complex settings such as the GLB because crucial GW-SW interaction processes are inherently captured. While fully-integrated models have been commonly employed on local-scale academic problems (10's to 100's of km^2) for more than 10 years, their application to 3-D water resources problems at the scale of Southern Ontario or the GLB has only been recently demonstrated. This increase in model scale, as well as complexity and spatial resolution has evolved because of a number of factors, including the mainstream accessibility to high-performance computing resources, improved numerical techniques, and the increasing availability of the large spatially-distributed datasets required to construct these models. While the movement towards open data is recognized as a major impetus for basin-scale model development, some of the datasets required to construct large-scale integrated models are still not widely available. Based on a preliminary investigation of data availability for the GLB and Southern Ontario, it is apparent that the principle data gap relates to the lack of spatially extensive and vertically resolved hydrostratigraphic characterization within the Phanerozoic and Quaternary sedimentary units. Accordingly, a GLB or Southern Ontario focused integrated hydrologic modeling initiative would need strong collaborative support from specialists familiar with the regional geology.

Remote Sensing Activities in Southern Ontario in NRCan/ESS Groundwater Geoscience Program

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Water resources and their sustainability/vulnerability are determined by climate, physiography conditions of land surface and aquifers, and human activities. Satellite remote sensing can contribute to a better understanding of water resources in various ways. In this talk, three activities associated with remote sensing in the NRCan/ESS Groundwater Geoscience Program will be discussed. The first activity (1) is water cycle modelling and water budget assessment. This activity involves modelling the various water fluxes and storages in the atmosphere-vegetation-soil-aquifer system. It relies on the ESS land surface model EALCO and remote sensing products, as well as a number of other datasets for climate, soil and aquifers. Major outputs include evapotranspiration, surface runoff, snow cover, soil water, diffuse recharge and discharge of groundwater, etc. The model provides a platform to integrate the physical water processes with satellite observations, and to study water sustainability/vulnerability issues associated with climate change and human disturbances. The second activity (2) is soil moisture mapping. This activity aims at downscaling SMOS/SMAP soil moisture products (40-50km) using Radarsat-2 data to produce soil moisture map at a higher resolution (5-10km). The method includes removing the effect of vegetation using the water-cloud model and the effect of soil surface roughness using multi-temporal Radarsat-2 data. The wavelet transform is combined with the water-cloud model in soil moisture downscaling. The third activity (3) is characterising water storage variations using Radarsat-2 InSAR data and microgravity measurements. InSAR has been proven to be an efficient technique for measuring surface deformation. This activity investigates the potential of using an inversion model of surface deformation to characterise water storage variations. Field microgravity and GPS measurements over the Waterloo Moraine were also conducted to investigate the potential for using gravity signal to characterise water storage. Activity (1) aims at modelling the water cycle through integrating multiple remote sensing products that are available. Activities (2) and (3) are expected to generate new/improved water-related variables from remote sensing, which can be used in Activity (1) to further constrain the water modelling so that our understanding of the water can be improved.

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