Unifying Groundwater Science in Southern Ontario Workshop
March 6th 2015 | University of Guelph Arboretum

Components of a Water Budget

Inputs
1. Precipitation
2. Runoff
3. Groundwater Inflow
4. Surface Water Inflow
5. Water Diversions

Outputs
6. Evaporation
7. Transpiration
8. Surface Water Outflow
9. Groundwater Outflow
10. Irrigation
11. Industrial Uses
12. Residential Uses
13. Water Diversions

A collaborative initiative of the
Ontario Geological Survey,
Geological Survey of Canada, and
University of Guelph
with support from the Ministry of
Environment and Climate Change,
and Conservation Ontario

Compiled by
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ACKNOWLEDGEMENTS

The help of Amanda Buttenham at the University of Guelph is much appreciated for administrative assistance with Eventbrite and general organization. The Ministry of Environment and Climate Change; Ontario Geological Survey; Centre for Applied Groundwater Research, University of Guelph; and Geological Survey of Canada assisted with workshop costs and hospitality.

Cover image provided by Conservation Ontario.
HOW TO GET TO THE ARBORETUM, UNIVERSITY OF GUELPH

THE ARBORETUM
If travelling from out of town, use the map on the left. From within Guelph use the map on the right. Follow College Avenue to The Arboretum Entrance. The co-ordinates to the entrance are: 43°32'39.06" N 80°12'57.78" W

THE OAC CENTENNIAL ARBORETUM CENTRE
From the Entrance off College Avenue, continue south about 0.3 km to the parking lot on the left. The Arboretum Centre is on the right.

If walking from Campus, take Arboretum Road off East Ring Road to the Kiosk and follow the Ivey Trail or Arboretum Promenade to The Arboretum Centre

BY BUS
Take Guelph city bus route 1a or 1b to the Arboretum Road bus stop on East Ring Road. Follow Arboretum Road to the Information Kiosk and from there walk along the Ivey Trail or Arboretum Promenade.

The workshop is being held at the OAC Centennial Arboretum Centre which is located on the Arboretum road. Entrance is from College Avenue.
# Table of Contents

- **Program: Morning Session:**
  9:00 – 12:00 Engage with Groundwater Practitioners to Inform GSC-OGS Collaborative Work............. 1

- **Afternoon Session:**
  13:00 – 16:00 Unify Data Management and Accessibility within Open Government Initiatives ......... 2

- **Location Figure of Southern Ontario**.................................................................................................. 3

- **Workshop Rational** ......................................................................................................................... 4

- **Morning Session:**
  Engage with Groundwater Practitioners to Inform GSC-OGS Collaborative Work.......................... 5

- **Groundwater Resource Management in Ontario:**
  Current and Future Science Needs....................................................................................................... 6

- **GLWQA and COA Annex 8 on Groundwater:**
  Identifying Groundwater Science Needs and Information Gaps .............................................................. 7

- **Water Budgets in Ontario: Where Do We Go from Here?**................................................................. 9

- **Conservation Authorities – Partners in Groundwater Management**............................................... 10

- **Bedrock Aquifers and Municipal Groundwater Supplies:**
  A Collaborative Research Framework.................................................................................................. 11

- **Ontario Geological Survey (OGS)**
  Project Planning and Review of 2012 Groundwater Geoscience Gap Analysis .................................. 12

- **OGS and GSC Plan for Collaborative Work 2014 – 2019**.................................................................. 14

- **Afternoon Session:**
  Unify Data Management and Accessibility within Open Government Initiatives ......................... 15

- **Provincial Open Government Open Data Strategy** .............................................................................. 16

- **Data Management – Perspectives from The Oak Ridges Moraine Hydrogeology Program**........ 17

- **Municipal Asset Management and the Business Case for a Geoscience Information**
  and Visualization Platform......................................................................................................................... 18

- **The Ontario Oil, Gas and Salt Resources Library:**
  A Model for Groundwater Data Sharing in Ontario?.......................................................................... 20

- **Groundwater Information Network:**
  Regional, National, and International Groundwater Data Integration and Delivery ...................... 21

- **Annex A**
  Ontario Geological Survey, Groundwater Geoscience Gap Analysis
  Client Planning Meeting, November 13, 2012 .................................................................................. 22

- **Annex B**
  Workshop Registrants ................................................................................................................................. 30

- **Notes**.................................................................................................................................................... 32
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 h 00</td>
<td>Registration and Continental Breakfast</td>
</tr>
<tr>
<td>8 h 45</td>
<td>Logistics and Welcome to Workshop</td>
</tr>
<tr>
<td>9 h 00</td>
<td>Introduction</td>
</tr>
<tr>
<td></td>
<td>Jack Parker, Senior Manager, Ontario Geological Survey</td>
</tr>
<tr>
<td>9 h 10</td>
<td>Groundwater Resource Management in Ontario: Current and Future Science Needs</td>
</tr>
<tr>
<td></td>
<td>Katherine Baker / Heather Brodie-Brown: MOECC</td>
</tr>
<tr>
<td>9 h 25</td>
<td>GLWQA and COA Annex 8 on Groundwater: Identifying Groundwater Science Needs and Information Gaps</td>
</tr>
<tr>
<td></td>
<td>Scott MacRitchie, MOECC</td>
</tr>
<tr>
<td>9 h 40</td>
<td>Water Budgets in Ontario: Where Do We Go from Here?</td>
</tr>
<tr>
<td></td>
<td>Scott Bates, MNR</td>
</tr>
<tr>
<td>9 h 55</td>
<td>Conservation Authorities – Partners in Groundwater Management</td>
</tr>
<tr>
<td></td>
<td>Don Ford: TRCA</td>
</tr>
<tr>
<td>10 h 10</td>
<td>Break 15 minutes (Tea and Coffee provided)</td>
</tr>
<tr>
<td>10 h 25</td>
<td>Bedrock Aquifers and Municipal Groundwater Supplies: A Collaborative Research Framework</td>
</tr>
<tr>
<td></td>
<td>Beth Parker, UofG</td>
</tr>
<tr>
<td>10 h 40</td>
<td>Ontario Geological Survey (OGS) Project Planning and Review of 2012 Groundwater Geoscience Gap Analysis</td>
</tr>
<tr>
<td></td>
<td>Jack Parker, OGS</td>
</tr>
<tr>
<td>10 h 45</td>
<td>OGS and GSC Plan for Collaborative Work 2014 – 2019</td>
</tr>
<tr>
<td></td>
<td>Hazen Russell / Andy Bajc, GSC and OGS</td>
</tr>
<tr>
<td>11 h 00</td>
<td>Discussion panel (50 minutes)</td>
</tr>
<tr>
<td></td>
<td>Guidance themes</td>
</tr>
<tr>
<td></td>
<td>1. Gaps</td>
</tr>
<tr>
<td></td>
<td>2. Opportunities for interagency collaborations</td>
</tr>
<tr>
<td></td>
<td>3. Priorities</td>
</tr>
<tr>
<td></td>
<td>Discussion wrap-up: 10 minutes</td>
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<tr>
<td>Lunch: 12 h 00 to 13 h 00</td>
<td>(provided on site)</td>
</tr>
</tbody>
</table>
Afternoon Session: 13:00 – 16:00  
Unify Data Management and Accessibility within Open Government Initiatives

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
</table>
| 13 h 00 | Introduction  
Hazen Russell                                                                 |
| 13 h 10 | Provincial Open Government Open Data Strategy  
Raphael Sussman, MNRF                                                               |
| 13 h 25 | Data Management – Perspectives from The Oak Ridges Moraine Hydrogeology Program  
Steve Hoylsh, CAMC                                                                 |
| 13 h 40 | Municipal Asset Management and the Business Case for a Geoscience Information and Visualization Platform  
Kevin Cover, City of Ottawa                                                      |
| 13 h 55 | The Ontario Oil, Gas and Salt Resources Library: A Model for Groundwater Data Sharing in Ontario?  
Terry Carter, Consulting Geologist                                                             |
| 14 h 10 | Groundwater Information Network: Regional, National, and International Groundwater Data Integration and Delivery  
Boyan Brodaric, GSC                                                                          |
| 14 h 25 | Question Period                                                                           |
| 14 h 45 | Break 15 minutes  (Tea and Coffee provided)                                               |
| 15 h 00 | Discussion: 45 minutes  
Lead Question: Given that groundwater data is collected, stored and managed by many different organizations across Ontario, how might we move toward a collective data care and control strategy?  |
| 15 h 45 | Workshop Wrap-up                                                                         |
Location figure of southern Ontario with delineation of principal study region scope outlined in bold. Inset block diagram is from Sharpe et al. 2014.

Following nearly ten years of minimal activity in southern Ontario the Geological Survey of Canada (GSC) is re-engaging in groundwater work in southern Ontario in collaboration with the Ontario Geological Survey (OGS). The two agencies have a long history of collaboration on supporting geoscience frameworks for groundwater studies, notably through work on the Oak Ridges and Waterloo moraines. Since 2004, the OGS has had an active program of framework geoscience in southern Ontario to support groundwater science, for example through work on the shallow Silurian bedrock aquifers, three dimensional framework modeling of surficial sediments in the Waterloo, Oro, and the Orangeville moraines, and their regional ambient groundwater chemistry mapping. The GSC and OGS aim to focus their collaborative initiative by targeting the groundwater geoscience gaps identified by active practitioners and policy makers in southern Ontario. Movement towards a modern approach to data management and accessibility, in particular as Source Water Protection is ending, is essential to support both this collaboration, as well as all other groundwater activities in southern Ontario.

The GSC activity in groundwater and work in the provinces is governed by the Interprovincial Geoscience Accord between NRCAN and provincial geological survey organizations. GSC provincial relationships on groundwater studies are also strongly influenced by the Framework on Groundwater Collaboration (Rivera et al.1). More specifically Geological Survey of Canada activity is governed by the 2005 Canadian Senate recommendations to the government of Canada in the Fourth Interim Report of the Standing Senate Committee on Energy, the Environment and Natural Resources, “Water in the West: Under Pressure” (http://www.parl.gc.ca/Content/SEN/Committee/381/enrg/rep/rep13nov05-e.htm). Specific to water and the Groundwater Geoscience Program at the Geological Survey of Canada was Recommendation 1, quoted below.

The Government of Canada should take the necessary steps to ensure that all of Canada’s major aquifers are mapped by 2010. This data should be made available in the national groundwater database and supported by a summary document assessing the risks to groundwater quality and quantity.

In southern Ontario, GSC work is also influenced by the International Joint Commission (http://www.ijc.org/en_/Great_Lakes_Water_Quality) and the Great Lakes Water Quality Agreement – 2012 (http://www.ijc.org/en_/Great_Lakes_Water_Quality) for which Environment Canada plays a key role at the federal level. Work on the Great Lakes and water quality is also influenced by the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (http://ec.gc.ca/grandslacs-greatlakes/default.asp?lang=En&n=B903EE0D-1). It is apparent from the above that there is strong institutional framework for collaborative federal – provincial work on groundwater in Southern Ontario.

Morning Session: Engage with Groundwater Practitioners to Inform GSC-OGS Collaborative Work

The Source Water Protection Era of 2005-2015 has witnessed an unprecedented financial expenditure and effort by the groundwater community in Ontario to address the Clean Water Act. Groundwater Management is a distributed responsibility between provincial ministries (MOEEC, MNR) Conservation Authorities, and Municipalities. The Ontario Geological Survey, academia and the private sector provide much of the science and technical work to support this management. There is, consequently, an essential role for collaboration to support ongoing requirements of Source Water Protection and address broader issues of groundwater management in Ontario.

For the scale and complexity of the problems of sustainable groundwater use in Ontario, both human and financial resources are scarce. Sustainable use requires the groundwater community to address not only source water challenges, but also issues of cumulative impact (demand, quality), balancing the rights and needs of multiple user communities, and ensuring sustained ecosystem function. Sustainable groundwater use must be considered within the context of the broader water cycle as an essential component of sustained surface water systems. To maintain momentum following Source Water Protection there is a need for all parties to maximize collaboration and to ensure that data and knowledge is captured using common protocols, and standards. Furthermore it is essential that both data and knowledge is made accessible to future initiatives.

Seven presentations have been coordinated to provide perspectives from key provincial ministries charged with water management and data collection along with perspectives from Conservation Authorities and Academia. Time allocation for the presentation has been restricted to 10 minutes to afford the maximum opportunity for questions and discussion with participants.

It is anticipated that the morning session of the March 6th workshop will help identify science gaps remaining following SWP. We hope that these discussions will contribute to an improved framework on inter-agency collaboration required to continue to support groundwater science that is needed to enhance groundwater management, protection and policy.
Groundwater Resource Management in Ontario: Current and Future Science Needs

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Groundwater management in Ontario is the responsibility of many agencies including provincial ministries (such as Environment and Climate Change, Natural Resources and Forestry), municipalities and conservation authorities.

Groundwater quantity and quality are managed separately through a limited number acts (e.g., Ontario Water Resources Act, Environmental Protection Act and Safe Drinking Water Act) and associated regulations. The current legislative framework only regulates in pieces primary using site-specific instruments. Recently, the province introduced legislation manages water on a broader scale, for example the Clean Water Act, Nutrient Management Act, Great Lakes Strategy, Ontario Drought Response Program. These recent developments allow the province to assess cumulative effects on limited scale such as watershed, receptor or municipal water supply scale.

Ontario has put significant resources towards a better understanding of groundwater resources within the province, in recent years, particularly with respect to municipal water supply. This includes a significant effort the compile and verifies existing data to develop vulnerability mapping, water budgets, and additional field work and mapping by other agencies.

Increasingly a more integrated approach to water management is expected. As a result governments are starting to consider water sustainability and how groundwater fits into the greater ecosystem (i.e., integrated watershed management, cumulative impacts, role of groundwater in sustaining Great Lake waters and ecosystems).

Where are we at with groundwater science in Ontario? What additional science, data and tools do we need to better manage groundwater resources and protect the environment? What additional groundwater science do we need moving forward?
The Great Lakes Water Quality Agreement (GLWQA) is a binational agreement that was first signed by Canada and the United States in 1972, amended in 1987, and amended again in 2012. The most recent version was signed and came into effect in February 2013. In amending the agreement in 2012, the Governments of Canada and the United States have committed to a shared vision of a healthy and prosperous Great Lakes region in which the waters of the Great Lakes, through their sound management, use, and enjoyment, provide benefits to present and future generations.

The current GLWQA contains the following 10 Annexes:

1. Areas of Concern
2. Lakewide Management
3. Chemicals of Mutual Concern
4. Nutrients
5. Discharges from Vessels
6. Aquatic Invasive Species
7. Habitat and Species
8. Groundwater
9. Climate Change Impacts
10. Science

The three basic commitments that have been made under Annex 8, Groundwater are:

1. Within two years of entry into force of this Agreement, publish an initial report on the relevant and available groundwater science, and update this report at least once every six years;
2. Identify priorities for science activities and actions for groundwater management, protection, and remediation; and
3. Coordinate binational activities under this Annex, together with domestic programs, to assess, protect, and manage the quality of groundwater, and to understand and manage groundwater-related stresses affecting the Waters of the Great Lakes.
GLWQA and COA Annex 8 on Groundwater: Identifying Groundwater Science Needs and Information Gaps

(Continued)

The science commitments are:

1. identify groundwater impacts on the chemical, physical and biological integrity of the Waters of the Great Lakes;
2. analyze contaminants, including nutrients in groundwater, derived from both point and non-point sources impacting the Waters of the Great Lakes;
3. assess information gaps and science needs related to groundwater to protect the quality of the Waters of the Great Lakes; and
4. analyze other factors, such as climate change, that individually or cumulatively affect groundwater’s impact on the quality of the Waters of the Great Lakes.

The Canada-Ontario Agreement (COA) on Great Lakes Water Quality and Ecosystem Health is the federal-provincial agreement to help meet Canada’s obligations under the Canada-US Great Lakes Water Quality Agreement (GLWQA). The first goal of COA Annex 8 Groundwater Quality is to enhance understanding of groundwater impacts on ecosystem health and current and future management actions and decisions. This goal includes Ontario and Canada working with the United States to form an Annex 8 team to develop the state of groundwater science report.

The Annex 8 team was directed to summarize and report on groundwater science in support of this Annex, including: impacts of groundwater on waters of the Great Lakes; analysis of contaminants from point and non-point sources, including nutrients; knowledge gaps and science needs that must be resolved to improve protection efforts; and other factors that affect the interaction between groundwater on waters of the Great Lakes such as climate change.

SCIENCE NEEDS:

Areas where there is a lack of understanding about how the system works, such as basic processes or relationships between components of the system.

INFORMATION GAP:

Information gaps are considered to be a lack of data rather than a lack of scientific understanding, meaning it is known how the system works but there is insufficient data or measurements to answer the questions being asked. To resolve science needs, one often needs to fill a variety of information gaps first, but at times the reverse is true where the information gaps exist and science does not have the techniques or ability to measure and collect the information that is needed.
Water Budgets in Ontario: Where Do We Go from Here?

Scott Bates
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escott.bates@ontario.ca

Since 2000 the Province of Ontario has made a substantial investment in the development of Water Budget and Water Quantity assessment tools under the Oak Ridges Moraine Conservation Act, Clean Water Act, Ontario Water Resources Act, Lake Simcoe Protection Act and Emergency Management and Civil Protection Act. We will share a few of our recent successes and ongoing work related to Tier 3 Municipal Water Quantity Risk Assessments, Ecologically Significant Groundwater Recharge Areas, Environmental Flow Regime Design and Drought Management Planning within the province. With a focus on groundwater, this presentation will provide a brief history of Water Budget development within the province and look forward to exciting new initiatives that are leveraging the strong foundation that has been built.
Conservation Authorities – Partners in Groundwater Management

Don Ford
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Toronto and Region Conservation (TRCA) began integrating groundwater data into watershed planning with the Duffins Creek and Carruthers Creek Watershed Plan in 2001. That same year, TRCA joined with eight other conservation authorities to assess the groundwater resources across the Oak Ridges Moraine. The underlying conceptual geologic and hydrogeologic models were based upon mapping and interpretation completed by the Ontario Geologic Survey (OGS) and the Geologic Survey of Canada (GSC). In 2005, TRCA and its partners further refined these models under the drinking water source protection program, culminating in our Approved Assessment Report, issued in January 2012.

Groundwater management is now a component of all our existing watershed plans, and is considered in the more than 1,000 development permits our organization issues annually. We also utilize this information in our land acquisition strategy and the review of environmental assessments conducted by municipalities within our nine watersheds.

This paper summarizes the groundwater management activities conducted by Conservation Authorities in Ontario, with particular emphasis on work completed within the jurisdiction of Toronto and Region Conservation over the past ten years. It proposes a path forward to continue the evolution of our understanding of the available groundwater supplies, and the human and ecological dependencies on those supplies.
Bedrock Aquifers and Municipal Groundwater Supplies: A Collaborative Research Framework

Beth Parker
G360, Engineering University of Guelph, bparker@g360group.org

Bedrock aquifers provide drinking water to more than one million people in southern and eastern Ontario and are inherently complex due to the nature and distribution of the discrete features that govern flow. Groundwater flows quickly through bedrock aquifers (a few to tens of meters per day) relative to granular aquifers such as sand and gravel and fresh groundwater is generally limited to the upper 100m below ground surface. Overlying glacial deposits can provide some protection to the underlying bedrock aquifer from surface contaminants but this cover is not always thick enough, or has a low enough permeability to offer sufficient protection. The combination of high groundwater velocities, and inconsistent protection offered by overburden makes these bedrock aquifers particularly susceptible to surface contaminants. However, field research studies of contaminant plumes in these bedrock aquifers show strong attenuation of contaminants limiting the impacts to wells and surface water. However, after a decade of improved groundwater flow system characterization and well field monitoring, there remains considerable scientific uncertainty in predicting aquifer vulnerability to changes in water quantity and quality given the myriad of potential impacts.

For the past five years, fourteen Principal Investigators from University of Guelph, University of Waterloo and McMaster University developed, tested and applied innovative field and laboratory methodologies and gathered detailed datasets to inform groundwater conceptual and numerical models at several intensive study sites. Using a systems approach, numerous projects were defined under five major themes: 1) Bedrock Contaminant Hydrogeology, 2) Overburden Contaminant Hydrogeology, 3) Groundwater Recharge, 4) Well Field Development in a Sustainable Hydrologic Cycle Context, and 5) Modelling and Uncertainty Analysis of Groundwater Systems and Contaminant Transport. The main goal of the ORF-RE3 is to develop and apply improved methods and approaches for understanding and predicting groundwater contamination in fractured sedimentary bedrock aquifers in the context of entire urban water systems serving communities throughout southern Ontario and internationally. These groundwater systems are naturally complex and the value of this program is enhanced by bringing together expertise from across multiple disciplines and sectors (i.e.: municipalities, governmental agencies, consultants, equipment and technology vendors, and academics). This program serves as an example of multi-sector and multidisciplinary scientific research framework providing opportunities for the training of next generation of groundwater scientists and accelerating knowledge transfer to reduce the gap between state of the practice and state of the science.
OGS provides publicly available, regional geoscience data and mapping products that support land-use decisions by Ontario ministries, Aboriginal and municipal governments, as well as environmental non-government organizations. Through collaborative efforts, the OGS also provides scientific and technical expertise in support of environmental assessments, source water protection and physical infrastructure planning. OGS defines new prospective regions for energy, mineral and groundwater resources and develops new tools and methods to assist in their discovery.

Annual OGS project planning is focussed on identifying geoscience gaps that can be addressed by geoscience disciplines under the OGS mandate. Geoscience gaps, needs and challenges must be aligned with government policy priorities; therefore, the OGS is not able to consider geoscience gaps that do not meet these priorities. A groundwater geoscience gap analysis conducted by OGS in 2012 has assisted in guiding the development of groundwater projects over the next 5 years.

The OGS has also identified 4 key technical mapping commitments for the next 5 years:

- contribute to effective and efficient decisions related to Earth resource exploration (minerals, groundwater and energy), land-use planning, and economic and infrastructure development and provide a geoscience baseline to help assess cumulative impacts of development and climate change;
- assess mineral, aggregate, energy and groundwater Earth resource potential across all of Ontario to support land-use planning, resource and infrastructure development;
- identify and interpret natural and anthropogenic influences on the environment, water-quality issues and geo-hazards;
- identify and inventory groundwater resources for use, protection and planning.

The Groundwater initiative, one of several technical initiatives, is designed to address these key geoscience commitments based on three focussed activities:

- **3D Sediment Mapping** which includes development of 3D models of glacial deposits overlying bedrock and characterization of the geometry and properties of aquifers and aquitards;
- **3D Bedrock Mapping** which includes the development of a testable sequence stratigraphic framework and delineation, characterization and mapping of regional scale groundwater flow systems in bedrock;
- **Ambient Groundwater Geochemistry** which includes characterization and mapping of natural groundwater and evaluation of the relationship between rock and groundwater chemistry.
For the next 5 years, the OGS plans to deliver the Groundwater initiative, in part, through collaboration with the Geological Survey of Canada under the principles of the Intergovernmental Geoscience Accord (IGA) which is a national agreement signed by Federal, Provincial and Territorial Ministers that confirms the roles and responsibilities for government-funded geoscience across Canada. The IGA guides and enables collaboration, communication and cooperation between the geological surveys. Ontario benefits under the IGA from increased geoscience communication, and technical cooperation between Canada and Ontario on addressing Ontario’s geoscience gaps and needs, which in turn, help to address Ontario’s policy priorities.
OGS and GSC Plan for Collaborative Work
2014 – 2019

Hazen Russell¹ and Andy Bajc²
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²Ontario Geological Survey, Ministry of Northern Development and Mines, andy.bajc@ontario.ca

Since 2005 the Geological Survey of Canada (GSC) has been working on increasing understanding of 30 key Canadian aquifers. In southwestern Ontario work was completed on the Oak Ridges Moraine, Waterloo Moraine and in southern Ontario the remaining aquifer complexes on the list are in the Upper Thames, Grand and Credit river watersheds. To honour provincial responsibility in the domain of groundwater management the GSC completes work under the auspices of the Interprovincial Geoscience Accord and collaboration with appropriate provincial agencies. In the Groundwater Geoscience Program cycle 2014-2019 the GSC is initiating a collaborative project with the OGS and other interested government groups and universities.

The collaborative GSC-OGS study will apply a basin analysis approach to investigating the complex interplay of hydrogeological issues of southern Ontario. The study will advance in an iterative approach that works on multiple aspects of the hydrogeological framework in parallel and sequentially. Public domain data sets (water wells, monitoring data, geochemistry, hydrochemistry, surface mapping) will be integrated into appropriate 3-D geodatabases that will be compatible with delivery via GIN and/or the Federal Geospatial Platform. This will ensure that improvements to these datasets will be available for future studies. The project will advance project objectives under 5 key thematic groupings, each of which will focus on a number of core studies to be refined as funding and project planning advances.

1) **Framework for Sustainable Groundwater Use**: will build on the decade of source water protection work, and Ontario and Government of Canada Open Data initiatives, to develop a groundwater geoscience data network, regional conceptual geological framework, and regional geological model construction of the Phanerozoic bedrock succession and Quaternary geology.

2) **Support Great Lakes water accords**: as identified in bilateral Ontario – Canada agreements by contributing to improved understanding on groundwater – surface water interaction and contributions of groundwater to Great Lakes water quality.

3) **Methods Development for Regional Groundwater Studies**: advance the field collection and data processing of shallow high resolution seismic reflection data, airborne electromagnetic data, downhole geophysical data, pXrf analysis for chemostratigraphy and remote sensing in support of hydrogeology.

4) **Case Studies**: complete work on targeted geographic and thematic issues that can contribute to emerging regional understanding. For example possible studies include groundwater – surface water studies and water quality in the Upper Thames River watershed, depression focused recharge, the Niagara groundwater anomaly, petrophysical studies of aquitards, etc.

5) **Science & Technology Exchange**: demonstrate science leadership through collaboration and coordination of geoscience publications, S&T exchange opportunities, etc. Early progress in this regard is underway with a proposed special issue on the contribution of *Quaternary Geology of Southern Ontario and Applications to Groundwater Understanding*. This workshop is an additional early initiative in this regard.
The public launch of Google Earth in 2005 changed the way we saw the earth and consequently the surface geology of the planet. In parallel with the general progress in data processing speed and storage capacity, the past ten years has seen a revolution in digital geoscience data storage, management and accessibility. During the intervening period there has been a host of cyber information initiatives (EarthCube, Digital Crust, Critical Zone, USGIN) that parallel development of government open data initiatives and a suite of emerging academic and private sector interests. These advances have been mirrored by increased delineation and modeling of the subsurface by geoscience organizations and the development of jurisdictional wide three-dimensional mapping programs (e.g. Britain, France, Holland, Denmark). In economically developed countries, and particularly in areas of critical population density, there is a realization that there is a need for, not only improved data quality and coverage, but also improved data storage, management, accessibility, and distribution of data. In a national review on The Sustainable Management Of Groundwater In Canada (Council of Canadians\textsuperscript{1}) it was identified that there is a need for a data-sharing platform. The document suggests the possibility of such a platform being developed through federal-provincial cooperation. The Ontario government funds provincial government ministries, Conservation Authorities, universities, and the private sector to collect new data and to create significant new information – knowledge, on the groundwater of southwestern Ontario. The challenge of managing not only data but this information, and ensuring that the cumulative value is not lost to future workers has been highlighted by Holysh and Gerber\textsuperscript{2}. There is growing interest in not only accessibility to the data but the use of this data to generate knowledge and inform decision makers as illustrated by Sudicky and Rudolph\textsuperscript{3}.

There is a growing interest by provincial agencies, but also municipalities, conservation authorities, and the private sector to manage data more efficiently. In most cases there is an interest to ingest and upgrade data to meet respective institutional priorities. The objective of this afternoon session is to provide a venue for an open discussion regarding a range of issues from multiple stakeholders, technical and data perspectives. This session addresses issues raised by participants at the 2012 OGS GAP analysis, specifically items raised on pages 26 and 28 referring to regional frameworks and the need for improved data management, respectively.


\textsuperscript{3} In SOSCP 2014 Impact Report.
Provincial Open Government
Open Data strategy

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Land Information Ontario (LIO) has long had a data distribution process that allows both selective and excellent public access to hundreds of data sets representing all aspects of Ontario’s geography under the new Ontario Government Open Data licence.

LIO actively promotes and supports good information management practices among geographic information practitioners. This presentation reviews:

• the organization, technology, policy, and data issues that had to be resolved
• the lessons learned during and after implementation

This paper will also address the significant difficulties associated with using internally and making available externally the same, authoritative, version of data sets.

¹ Raphael Sussman is a professional Geographic Information Systems (GIS) Manager, Urban and Regional Planner, Landscape Architect, Project Manager, and Ontario Land Surveyor. He worked for many years in municipal government, specializing in Enterprise Architecture and GIS, and now coordinates Land Information Ontario.⁴
Since 2001, a core component of the Oak Ridges Moraine Hydrogeology Program (YPDT-CAMC) has been the focus on assembling a comprehensive groundwater database. Over the years, program staff has put forward that data management and accessibility, as well as overall groundwater “knowledge management”: i) together are perhaps the most important components that contribute to effective management of Ontario’s groundwater resources; ii) remain the most under-appreciated and under-funded aspects of groundwater resource management; iii) require a very long term vision and an abundance of passion; and iv) can be considered ‘shovel-ready’ infrastructure – this in hopes of attracting funding over the past few years. Although there have, as yet, been no significant federal/provincial database related epiphanies (or funding dollars) resulting from past initiatives, slowly but surely the program’s data infrastructure continues to grow into what must certainly be one of Canada’s most comprehensive, actively managed groundwater related databases. It continues to provide a solid framework for any groundwater related investigation occurring within the geographic area of any of the 13 agencies partnered in the program.
Municipal Asset Management and the Business Case for a Geoscience Information and Visualization Platform

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The City of Ottawa is creating a geoscience information and visualization platform to capture, maintain, and provide access to geoscience information collected through its operations. Geoscience information is a critical gap in the City of Ottawa’s ‘authoritative data sets’ within its asset management approach. Data capture will include data valued at about $3,000,000 annually, the estimated costs of geology investigations for municipal planning, development proposals, designs, and construction. The platform will be developed in coordination with the Ontario Geology Survey, The Geological Survey of Canada, and local Conservation Authorities. All information will be made available to the public.

Geology is the foundation for all things in Ottawa. It defines where our farms, forests, and wetlands are situated; and provides aggregate resources for our roads. It is also the foundation for our homes, buildings, and bridges, and it is the environment for our underground services which include water, sanitary and storm pipes, gas lines, and other utility needs. Geoscience and geology information is essential for municipal planning, design, construction, and environmental protection including source water.

The purpose of the asset management approach is to optimize system function within resource constraints. Components include:

- data collection and review
- data consolidation, storage, and ready access
- synthesis, analyses, and reporting
- system objectives, assessments, and priority setting
- decision making

Asset management starts with a consolidated inventory. Others have created systems to capture and store data including the following:

- The Ministry of the Environment maintains an Ontario-wide water well database
- The Geological Survey of Canada and the Ontario Geological Survey maintain and provide geological data, interpretations, and maps
- geotechnical consultants have well maintained databases of information
- databases developed for Source Water Protection Projects

A consolidated inventory requires information from all available sources, including those listed above with a unifying structure and model for interpretation. The capture of geoscience information will follow processes similar to those followed for City’s infrastructure databases, requiring the provision of the information as part of City project terms of reference, tenders, and development agreements.
(Continued)

Extensive efforts are invested in retrieving, reviewing, and organizing this information for projects. Most notably, significant effort was invested in information development for regional groundwater studies and the Source Water Protection (SWP) projects that provide enhanced understandings derived from this wealth of information. The data, knowledge, and understandings that have been gained through SWP are in danger of being shelved and ultimately lost if a concerted effort in knowledge management is not undertaken. The maintenance of knowledge is the foundation for robust decisions and innovation and without integrating the understanding of information derived from data and the associated lessons learned, the result is a duplication of effort every time a new project is initiated and ongoing data collection is largely inaccessible.

1 An example of such a system is provided by Holysh, S and Greber, R; 2014. Groundwater Knowledge Management For Southern Ontario for the Oak Ridges Moraine, in Friend E., (ed), Waterloo Moraine: Water, Science and Policy, Special Issue, Canadian Water Resources Journal, 39, 2, 240-253.
The Ontario Oil, Gas and Salt Resources Library: A Model for Groundwater Data Sharing in Ontario?

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In a 2009 report on sustainable management of groundwater in Canada, an expert panel of groundwater specialists identified “collection, maintenance, and management of existing and newly collected groundwater-related data, coupled with ready access to these data, be viewed as a priority for action across the country” (Council of Canadian Academies, 20091). Since that time there has been some progress, in particular with respect to access to water well records, but broader and more holistic collection and sharing of groundwater data still is not occurring.

Government agencies are the public source of groundwater data in Canada. Traditionally, provincial governments have been the lead agencies in collecting regional-scale data in the form of water well records and dedicated water level monitoring wells, and providing public access to this data. Municipalities and conservation authorities collect data at local scales and the federal government has generally played a national coordinating role. Access to data, where it is provided, has generally been free. The real cost of collecting, maintaining and improving these datasets is not readily discernible.

In a continuing environment of spending constraints at all levels of government, and in particular at provincial governments, these databases, and supporting source data, are vulnerable. In 1997 the Ontario government withdrew its funding of the Petroleum Resources Laboratory which had provided free public access to well records and drilling samples from petroleum wells since 1971, and declared the staff redundant. There was a very real risk that these records and samples would be destroyed. Fortunately the Ontario petroleum industry recognized the value of maintaining and continuing the data operations of the Laboratory and in its place has emerged the Oil, Gas and Salt Resources Library.

The Library is a unique and innovative approach to data sharing, driven by necessity. The Library business model is based on profit-driven data vendors in western Canada and the United States who package and market access to public petroleum well data, as well as a wide variety of other data and data products. The small size of the industry in Ontario does not support a 100% fees-based model so the Library is a hybrid. Its possible use as an alternative model for funding and managing groundwater data in Ontario is explored in this report.

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Computing environments for scientific data are at present being influenced by major trends that emphasize: (1) operations over massive collections of data (Big Data), that (2) are physically distributed but logically interoperable and meaningfully connected (Linked Data), by (3) leveraging open standards, software, and licenses (Open Data). Groundwater data are no exception, and indeed are a good fit to these trends: as a collection they are voluminous, while being fragmented thematically as well as distributed physically amongst a multitude of providers; they are also the subject of ongoing international data standards efforts, and an emerging target for governmental open access.

The Groundwater Information Network (GIN) is an example of a data environment that realizes many aspects of these trends. It brings together a large amount of federal and provincial groundwater data, connecting it online such that it appears to be a single virtual collection. The distributed and heterogeneous source data are unified and linked on-the-fly, without altering the source databases, facilitating use of the data across the multiple sources. Key datasets delivered by GIN include provincial water well databases and some monitoring networks, as well as aquifer characteristics from NRCan studies. GIN operates at regional, national, and international scales: the aquifer studies exemplify the use of GIN as a data repository and dissemination vehicle for large regional projects, while the Canada-wide integration of water-well data demonstrates its national scope. Internationally, ongoing collaboration with the U.S. National Groundwater Monitoring Network has also led to successful interoperability between networks, resulting in the nascent emergence of a North American groundwater data network.

In the fall of 2012, the Ontario Geological Survey conducted a workshop in Barrie, ON, to acquire insight from clients on Groundwater Geoscience Gaps in southern Ontario. Twenty-seven people from Conservation Authorities, Ontario ministries, the private sector and academia participated in the workshop, providing excellent representation of the range of clients who use OGS products. Clients were given the opportunity to identify and discuss the geoscience gaps that affect their ability to practice hydrogeology, or create groundwater policy. The meeting was considered to be a component of the OGS project planning process, and as such, the emphasis was on identifying gaps that might be addressed by geoscience disciplines. Many geoscience gaps/needs/challenges were identified, and those that align with government policy priorities are now being addressed or considered for future projects. Gaps that fell outside of the OGS mandate were also discussed at the meeting, with a focus on potential areas for inter-agency collaboration. The first deliverable to come out of the workshop was a summary table outlining the details of the identified groundwater geoscience gaps and how these gaps might be addressed. Please find this summary table appended below for your information.
## Annex A

<table>
<thead>
<tr>
<th>Gap Description</th>
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</table>
| Geochemical and hydrogeological data need to be more fully integrated into 3D surficial sediment and bedrock products to provide context for the data and to accomplish groundwater resource characterization. | Conduct 3D mapping in such a way as to provide the most benefit to clients by incorporating the following components:  
- integration of other tools where appropriate (e.g. hydrogeological, physical, geophysical and chemical data) into 3D geologic framework  
- groundwater flow path delineation  
- surface water/groundwater interaction | OGS should continue 3D framework mapping of surficial sediments and bedrock.  
Integration of hydrogeological data with geologic framework where possible by OGS and in collaboration with other organizations where OGS resources aren’t available.  
Integration of OGS mapping projects with MOE (via PGMN) to develop recognized key geographies of enhanced groundwater monitoring centers resulting in enhanced hydrostratigraphy. |
| Lack of knowledge regarding variability in groundwater chemistry, temperature and dissolved gas as they relate to stratigraphy across southern Ontario. | Incorporate OGS ambient groundwater geochemistry data into a 3D geologic framework.  
Maps delineating health-related water quality parameters within a 3D geologic framework would support safe development of groundwater supplies at all levels – from private domestic well to municipal supply. | OGS will consider publishing Groundwater Resource Study (GRS) report where the link between aqueous geochemical data, temperature and shale gas data are discussed and interpreted in relation to bedrock and surficial sediment stratigraphy.  
The OGS will consider integrating the ambient groundwater geochemistry data, as well as discrete groundwater sampling data, with whole rock geochemistry (gathered from bedrock and core sampling, MNR core library) and thin section work where available. This work could result in the development of maps that identify areas of anomalous natural element concentrations. OGS could support thesis work to get this done, partner with academia and possibly GSC. |
### Annex A  (Continued)

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<th>Gap Description</th>
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| There is a lack of 3D bedrock and surficial sediment mapping as well as aquifer mapping across Ontario with groundwater resources largely uncharacterized. Regional-scale aquifer mapping would help to address lack of geoscience data and urgent water needs in several regions of Ontario. All major aquifers need to be characterized to support water use and management policy in the face of increasing demand and stress on the resource. | Incorporate priority areas for 3D mapping into OGS project planning:  
  - City of Guelph  
  - North York  
  - Central Simcoe County  
  - Upper Thames River  
  - Nepean aquifer characterization  
  - Eragin Channel and St. David's Buried Gorge  
  - irrigation areas where surface water is under stress  
  - mapping ‘orphan aquifers’ -- the Nepean and the Norfolk sand plain.  
  - MNR Petroleum Operations needs more detailed information on the Lucas sulphur water aquifer. | OGS to review 5-year mapping plan to re-prioritize and incorporate priority areas where possible. John Warbick, OMAFRA, to supply map showing irrigation areas where groundwater work is needed. |
| Need regional geologic fault characterization to better understand what role specific faults and fault types play in groundwater flow regimes at a regional scale. | Need to account for groundwater flow near and in geologic faults. Products need to characterize regional fault types and groundwater flow in relation to these features and show how to adequately represent these faults in groundwater flow models. | OGS to consider regional bedrock fault studies to address this gap in collaboration with others (academia, GSO). |
| A lack of rock porosity estimates for carbonate rock aquifers across southern Ontario. | Effective porosity estimates are required for contaminant transport models and determining water travel times to well-sites. Rock porosity can be estimated using lab tests, thin section work and some geophysical tools. Example – Bedrock porosity estimates are used in the groundwater models applied by the City of Guelph to develop its wellhead protection areas. Unfortunately, there are few reliable effective porosity estimates available for the bedrock formations in and around Guelph. | Apply mapping and/or core logging of bedrock formations to develop effective rock porosity estimates to be used in groundwater transport models. The OGS to consider incorporating porosity and permeability estimates for significant aquifer units. Map outlining variability in these characteristics could be included in GRS reports on carbonate rock aquifers. Involve other organizations in this work. |
### Annex A  *(Continued)*

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<tr>
<th>Gap Description</th>
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| Don’t have an appropriate understanding of fracture systems in bedrock.        | Need to collect and document stress field data from rocks to produce stress field maps that would support prediction of groundwater flow conduits.  
The evolution of fracture/karst patterns in Silurian bedrock will take some time to determine because we don’t understand the role of stress as a precursor to bedding plane parting that is then acted upon to create karst-like features. | This product could be created in collaboration between OGS, academia and possibly GSC.  
This problem is also being addressed through Frank Brunton and Elizabeth Priebe’s project work.  
Further karst mapping to extend the work of Frank Brunton into the subsurface seems to have been missed. The mapping should focus on “paleokarst” in particular, and the distribution of modern karst in the shallow subsurface where it is not readily observed to supplement existing studies of modern near-surface karst. |
<p>| Need the OGS to apply mapping of bedrock formations to enhance groundwater exploration | Recent mapping of the bedrock formation in the Guelph region by the OGS presents an opportunity for the City of Guelph to benefit from the OGS mapping in identifying exploration targets for new groundwater supply. If the OGS could take the existing mapping and define attributes for enhanced water supply (i.e. increased thickness of the Gasport Formation, enhanced porosity due to karst formation, etc.), the result may be used to identify probable groundwater exploration targets. For example if areas of increased thickness of the Gasport Formation represent reefal formations with good water supply potential, it may be possible to use isopach maps or surface geophysics to identify target areas for exploration wells. | OGS will consider and include this approach in current bedrock mapping projects. |</p>
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<tr>
<td>Need a deep understanding of principal aquifers (Silurian, surficial sediments) of southern Ontario. These aquifers need to be fully described to provide a holistic reference that can be used to support water policy and funding for further aquifer mapping.</td>
<td>Develop a Groundwater Resources Study synthesis report on “The Principal Aquifers and Aquitards of Ontario”. It could be similar to the Armstrong/Carter volume on the Paleozoic of Ontario [SP 7]. It would include a full account of the Quaternary research conducted since Peter Barnett’s account in 1991 [SP 4] and an account of the Silurian carbonate aquifer, the Nepean and the Quaternary aquifers plus the principal aquitards protecting these aquifers. This volume should include the hard hydrogeological data from field, lab and numerical studies compiled from the past ten years in particular. This volume would become the indispensible reference for every Hydrogeologist practicing in the Province.</td>
<td>OGS should consider producing a special volume over the next 5 years that fully describes principal aquifers in southern Ontario. OGS could facilitate working groups involving folks with detailed understanding of groundwater to summarize what we know and our current state of knowledge.</td>
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<tr>
<td>Lack of regional digital elevation models for the eastern Ontario limestone plain.</td>
<td>GSC produced DEMs for the surfaces of the limestone/dolostone and sandstone formations in the immediate Ottawa area. Uncertain whether this work is being supported anymore and it has not been developed for the rest of Eastern Ontario. It would be beneficial for the hydrogeological industry in Eastern Ontario to have the surfaces of all local formations delineated for use in various computer software applications.</td>
<td>OGS to explore this gap with GSC. Cataraqui Conservation Authority indicated that LiDAR information is available across much of eastern Ontario now, and using it to build new surface DEMs is something that each CA is doing. This information could be used to refine the bedrock DEM as well. Some sort of data sharing agreement would be needed, but it’s probably easy enough to accomplish.</td>
</tr>
<tr>
<td>Groundwater age determination</td>
<td>This fits within the groundwater flow path determination piece of the aquifer mapping. This requires enhanced age-dating and isotopic work on municipal supplies to better understand recharge to deeper aquifer systems, etc.</td>
<td>OGS to explore this gap with other collaborators (GSC, academia, etc.)</td>
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### Annex A (Continued)

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<th>Gap Description</th>
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| Improved collaboration and linkages with the GSC aquifer mapping program.     | Need more integration/collaboration with federal counterparts.                                                                            | OGS is project planning in collaboration with GSC to address this gap.  
OGS could incorporate a flux estimate into all aquifer mapping projects conducted adjacent to the Great Lakes where water demand is increasing and anthropogenic inputs are assumed.  
Integrate data from Ontario Stream Sediment Survey work being conducted by OGS and MOE.  
Collaborate on thematic or more local studies by other organizations. |
| Gap in our understanding regarding the interaction between groundwater and water from the Great Lakes. More work needs to be done and incorporated into groundwater mapping to support both international and local water management. | Water budgets have not accounted for interaction with the Great Lakes and as such, water and contaminant fluxes between these connected systems are not understood. |                                                                                                                                                                                   |
| Surface water/Groundwater interaction is not well understood across southern Ontario. | Geophysical tools could be used to help identify groundwater discharge zones, thermal imagery. Hydrologic data could be incorporated into aquifer mapping to facilitate this characterization. | OGS to consider regional geophysical survey types which may address this gap in collaboration with GSC and others.  
Queen's U has been doing some of this, maybe more looking at WG discharge, by tracking Radon in streams, or in wells….it seems promising. This, along with lots of other potential stuff, could be collaborations between universities, CAs, and OGS/GSC. |
### Annex A (Continued)

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<td>There needs to be coordination, better integration and improvement of databases involving borehole and geophysical logs, hydrographs, GW quality information etc. Too much data is “scattered” and in different formats which makes it difficult to access and use. There needs to be one portal for “one-stop shopping” - much of the data clients are looking for exists in some form or another it just needs to be corralled and updated unilaterally.</td>
<td>Data standardization and availability is required for the Province rather than the individual Ministry data offerings. Incorporation of private data into a provincial database would be very beneficial.</td>
<td>It is very important in this environment of different layers of government dealing with groundwater, to have synthesized groundwater GIS-based database accessible to everybody (not just gov’t). This GIS-based system could ideally have all available (and free) information such as well records, obs. Wells, aquifer boundaries, aquifer properties where available, aquifer classification (use, vulnerability) ortho, topo, etc. Water quality from private wells might be problematic because of privacy considerations. I think 3D model would be an ideal part of the database but in the meantime 2D model would be very useful. The challenge here is to have this database assembled from the data of different layers of gov’t. A government Ministry needs to take the lead on an initiative like this but it is expensive to undertake. Some possible solutions: could this initiative be put on a paying basis by incorporation of a Groundwater Library similar to the Oil, Gas &amp; Salt Resources Library in London? Clients would obtain information by purchase which would reflect the true value of the information. A second suggestion was put forward to consider the Oil, Gas and Salt Resources Library as a “Groundwater Library” as well since the OGSR Library business plan already has endorsed the concept of providing one-stop shopping for all Ontario well data, including petroleum wells, water wells, geothermal wells, and others. The Library is exploring the benefits of collaboration with the Ontario Ground Water Association and the Ontario Geothermal Association. If OGS, MOE and the CA’s would endorse this approach and commit to supporting the Library we could build on this existing expertise quickly and cheaply. MOE has made a huge step.</td>
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</table>
in the past year to provide all of its database free to users and also incorporates Google Earth. Improvement in the water well database/info is required....It’s more a province thing, but if the OGS and GSC get behind it, that might be helpful. Require a GPS coordinate for every well that has work done on it, new casing, new pump, deepening, etc. Well drillers do that anyway, but making it a requirement will eventually update the location info for all wells in the province or, some programs to go out to wells to GPS them specifically with a secondary piece to update the depth to GW, the geology, etc., which is a larger scale project, but would be useful all the same.

So much is not known about the overburden and bedrock aquifers in southern Ontario and there is a gap in funding to support government efforts in this regard. Municipal water treatment costs are expected to rise significantly as cities turn to surface water supplies to meet demands, directly impacting the public.

Government needs a bigger budget to conduct aquifer work in southern Ontario to address future pressures on groundwater use.

Develop a strategy for dealing with well legacy issues. Acquire and develop equipment and skills to conduct drilling and hydraulic testing in house. More integration and horizontal collaboration within government.

More outreach to client groups and training is required

Client groups, including drillers and university students, would benefit from training and short courses on logging core and developing 3D models.

OGS could participate in initiatives that might address this gap but other organizations need to be involved.
# Annex B
## Workshop Registrants

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tbody>
<tr>
<td>Aravena, Ramon</td>
<td>University of Waterloo</td>
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<tr>
<td>Arnaud, Emmanuelle</td>
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<td>Gerber, Richard</td>
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<td>Liu, Frank</td>
<td>Credit Valley Conservation, P.Geo</td>
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Annex B
Workshop Registrants

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<td>Sudicky, Edward</td>
<td>University of Waterloo</td>
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<tr>
<td>Sussman, Raphael</td>
<td>MNRF</td>
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<tr>
<td>Trimper, Shawn</td>
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<td>Warbick, John</td>
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<tr>
<td>Zeb, Jehan</td>
<td>Toronto and Region CA, P.Geo</td>
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