Advancing Groundwater Science: Field Research Stations Creating a Collaborative Framework

Beth Parker

Unifying Groundwater Science in Southern Ontario
GSC OGS Workshop, University of Guelph Arboretum
March 6th, 2015
University Collaborative Potential
Role of Academic Researchers

- Leveraged expertise, expanded network, research capacity, resources,
- HQP – training students as future work force
- Knowledge Transfer & Translation
- Publications in peer-reviewed journals
- Outreach
- Access and advance existing research infrastructure, tools/methods and data – sustaining Field Research Stations
Ontario Research Fund Research Excellence (ORF – RE) Round 7

“Groundwater and Wellhead Protection: Adapting to Change in Large and Small Ontario Communities”

5 Themes
- Changing Contaminants Types and Inputs
- Changing Landscapes and Land Uses
- Changes in Water Balance (Incl. Climate Change)
- Water & Waste Water First Nation Communities
- Changing Capabilities of Monitoring Methods

19 Principal Investigators

4 Universities

- UoG Field research stations & Municipal monitoring networks
- New research sites across Ontario
Silurian Dolostone Belt

Water supply

Grand River Watershed

Fractured Dolostone

Toronto

Buffalo

Waterloo

Guelph

Cambridge
G360 Government Collaborations

Parker Research Group

Institutions:
- Region of Waterloo
- Guelph
- Centre Wellington
- Ontario
- unesp
- USP
- USGS
- SERDP
- University of Wisconsin-Madison
- China Geological Survey
SOWC: A PLATFORM FOR COLLABORATION AND INNOVATION IN THE WATER SECTOR
What is SOWC?

Platform for Water Innovation

- SOWC is a platform for research, development and demonstration of water technologies.
Platform Components

Enhanced by Data Integration Platform (collaboration with IBM)
sowcdata.ca
Develop a network of instrumented “Field Laboratories” for monitoring and investigating integrated hydrologic processes at the watershed scale.

1. Establish instrumented sub-watersheds
2. Enhance bedrock aquifer testing facility at U of Guelph
3. Augment groundwater remediation testing facility at Base Borden

Provide a unique platform for field-based water research

- Flexible infrastructure and equipment
- Integrated wireless data communication
- Generate dense/diverse data streams
- Access to advanced analytics
Who is SOWC?
Post-Secondary Partners

McMaster University
Inspiring Innovation and Discovery

University of Waterloo

Ryerson University
Everyone Makes a Mark

Western University

Wilfrid Laurier University

University of Toronto

University of Guelph
Changing Lives Improving Life

UOIT
University of Ontario Institute of Technology

www.sowc.ca
Who is SOWC?

Funders:

Canada
Ontario

IBM

Strategic Partners:

London
City of Guelph
Grand River Conservation Authority
Major Components

A. Individual Subwatersheds
   1. Fully Urbanized – Mimico Creek *(Carl Mitchell)*
   2. Urbanizing – Alder Creek *(Dave Rudolph)*
   3. Rural – Hopewell Creek *(Rich Petrone)*

B. Grand River *(Sherry Schiff)*

C. Bedrock Research Facility *(Beth Parker)*

D. Groundwater Remediation Facility *(Jim Barker)*
A. Individual Subwatersheds
   1. Fully Urbanized – Mimico Creek
   2. Urbanizing – Alder Creek
   3. Rural – Hopewell Creek

B. Grand River
C. Bedrock Research Facility
D. Groundwater Remediation Facility
Mimico Creek (97% Urban Cover)

Monitoring:
- Flow
- Surface Water Quality
- Groundwater Levels
- Eddy-Covariance
- MET Stations
- Wireless data communication

Especially suitable for in-stream testing of pollution control technologies, sensors, automation technologies, model calibration and validation.
Alder Creek Watershed

Instrumentation
- Groundwater monitoring network
  - *continuous head and temp*
- Soil moisture measurements
- Stream flow and water sampling
- In stream quality and temperature
- Meteorologic Stations
- Wireless data transmission
- Mobile hydraulic testing facility

- Land-use impacts on surface and groundwater
- Seasonal hydrology/climate
- BMP performance
- Data streams for modeling
Hopewell Creek (rural)

- 75 km² in largely agricultural, drains to the Grand River.
- 5 municipal wells, major recharge area
- catchment of great interest in terms of mass flow to the Grand River
- Extensive historical data

- **Hydrologic/hydrometric infrastructure:**
  - (eddy covariance (H2O, CO2), meteorological variables, soil moisture, tension & well network, streamflow, stream chemistry)

  water storage & movement within & between landcover units in multiple land-use catchments

- **Biogeochemical infrastructure:**
  - (meteorological variables, radiation budget, soil moisture, tension & well network, streamflow, stream chemistry)

  water & geochemical movement/storage through Hopewell Creek, from Strawberry Creek to the Grand River
Unique:
• The World’s best characterized aquifer for contaminant hydrogeology. Controlled release of chemicals permitted.

Opportunity:
• Evaluation of chemical fate in groundwater, monitoring tools, and in situ remediation technologies

Partners:
• Chevron, 2 consultant firms in discussion

Model:
• Charges for infrastructure use ($5k - $30k), site restoration, technical assistance with design, operation, interpretation

E95 release into sand aquifer
Plume in Porous Medium
Non-Reactive Contaminant Migration Controlled by Advection and Dispersion

A: DISPERSION ZONE AT FRONT
Borden Landfill Chloride Plume

(Freeze and Cherry, 1979)
Stanford-Waterloo Natural Gradient Tracer Test -- 1982

“THE SAND PIT”

FLOW

Multilevel Samplers

Mackay et al. (1986)

- weak transverse dispersion
- sorption / retardation effects
Borden DNAPL Infiltration [BDI] Experiment - 1999

- 50L of 3-component DNAPL infiltrated 1.8 m bgs
- 45% PCE, 45% TCE, 10% TCM by volume
- Plume monitoring >250 MLS, >3500 sampling points
- Small scale controls on DNAPL distribution and persistence
- Long-term source / plume evolution from multicomponent DNAPL release

Laukonen (2001)
Sampling to Quantify Processes
(Parker, 1996)

DNAPL in Borden Aquitard
B94-7
3.3 years

PCE Diffusion from Micro-beds
(Parker, 1996)

De/R = 2.49 x 10^{-7}
R = 8.6

De/R = 1.44 x 10^{-7}
R = 7.7

De/R = 1.98 x 10^{-7}
R = 10.7

De/R = 2.30 x 10^{-7}
R = 13.6

PCE Diffusion from Micro-beds
(Parker, 1996)
Evidence That Head profiles provide exceptional insights
A single device installed into a borehole that divides the hole into many separated intervals for depth – discrete monitoring.

Available from:

**Westbay, FLUTE, Solinst**
Borden Aquitard: Detailed Vertical Hydraulic Head Profile using a CMT System

Indicates a much higher $K_v$ in the upper part of the aquitard

Why?
Examples of Fractured Porous Media

- Clay
- Sedimentary Rock
BEDROCK GROUNDWATER SYSTEMS (BGS)

High-Resolution Core Logs

Bedrock Drilling & Instrumentation

Borehole Cluster Design
Bedrock Aquifer Field Facility (BAFF)
Static modelling using FracMan
FracMan Static Model
Floodplain and Streambed Exposed Dolostone (Eramosa Fm in Guelph Region)
Old Groundwater is ‘Pristine’
No Human Produced Contaminants

Groundwater Travels much more slowly than surface water.

Old water

Aquifer

Old water

Aquifer

Older Deeper Pristine Water

Old Deep Pristine Water

Young Shallow Water
Not Pristine

Pumped Well

Unconfined Aquifer

Confined Aquifer

Confining Bed

Water Table
Hypothesis

High resolution head profiles identify the position / thickness of $K_v$ contrasts that can be used to delineate HGUs.
City of Guelph “Tier 3” MLS

FLUTE
10-30 Ports

Solinst Waterloo
9-15 Intervals

Westbay
20-45 Intervals

Monitoring Zone

(Single port system shown for clarity)

(Cherry et al., 2007)

(Cherry, 2011)
Head Profiles MLS (Waterloo Solinst, Westbay, FLUTE)  
“Tier 3 Wells”

Guelph Tier 3 - Stratigraphy, Gamma-ray, and Head Profiles (m MASL)

<table>
<thead>
<tr>
<th>Depth 100m</th>
<th>Gamma</th>
<th>Solinst Waterloo</th>
<th>Vertical Gradient</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0 cps</td>
<td>333 (mAMSL)</td>
<td>0.15 m/m</td>
</tr>
<tr>
<td>1</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.06</td>
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</tr>
<tr>
<td>3</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(+) upward 08-Jun-2011

(-) downward 08-Jun-2011

(+) upward 29-Aug-2011

(-) downward 29-Aug-2011

(+) upward 18-Oct-2011

(-) downward 18-Oct-2011

(1) Monitoring Zone

(2) Monitoring Zone

(3) Monitoring Zone

(4) Monitoring Zone

(Unonius MSc Thesis, 2012)
City of Guelph Tier 3 Multilevel Wells
Cross Section A-A’ Conceptual Model For GW Flow

(Unonius MSc Thesis, 2012)
Threats to Ontario Groundwater

• Changes in Water Balance (i.e. climate, over extraction)

• Threats from Above
  – physical changes due land use or resource extractions,
  – various contaminants from waste or operations

• Threats from below (leaky oil/gas wells, gas storage, natural constituents, etc.)
Threats from Below:

Are Intermediate Zone Aquitards Protective or Not?

Kv, chemistry...
What are Aquitards?

Zones causing resistance to vertical flow between aquifers
Data Analysis Pyramid for DFN Approach

DFN datasets used to inform and ground truth dynamic EPM groundwater flow models and DFN transport models.
Regional Scale 3-D FEFLOW EPM Model

~8 km x 8 km domain

3-D domain with 46 layers
~250,000 elements per layer
~11.5M elements total

Average element area ~ 256 m²
Average layer thickness ~10 m
(refinement in key zones)

EPM Model developed by Matrix Solutions
- P. Martin, D. Abbey, C. Gabriel, B. Zhang
Thank You
Geology and Topography of the Bedrock Surface

Field Research Sites

- International Field Research Sites
Vance Tract (GRCA land)

Reforested 1960s; no development

Turfgrass Institute

Agroforestry plots; chemical fertilizer; tile drained

Arkell Research Station

Agriculture; manure & fertilizer

<table>
<thead>
<tr>
<th>Paris Moraine</th>
<th>Drumlin</th>
<th>Outwash plain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reforested 1960s; no development</td>
<td>Agroforestry plots; chemical fertilizer; tile drained</td>
<td>Agriculture; manure &amp; fertilizer</td>
</tr>
</tbody>
</table>
Wellbore Influence on Natural Aquitard Integrity?

- Gas from the thin gas zone migrates into and up the deformed or cracked cement sheath.

- Where the sheath intersects a permeable bed, gas migrates laterally through the permeable bed.

- Gas may reach and contaminate the fresh water zone and the surface via natural fractures in the rock or other pathways.
Contrasts in Fracture Network
Hydraulic Conductivities
Almost always detected decades after initial contamination.