Co-Existence of Industrial-Derived Contaminant Plumes & Municipal Water Supply Wells In Fractured Sedimentary Rock

Beth Parker, J. Olesiuk, C. Maldaner, R. Aravena

G360 Institute for Groundwater Research, University of Guelph

GQ2019 Conference
10 September 2019
How Fast do Contaminants Travel in Fractured Sedimentary Rock Aquifers?

Municipal Supply Well

Aged DNAPL Plume

Time of Arrival?

Future Concentrations at receptors?
Municipal Well & Date Removed from Service due to TCE detection (near/below provincial health standards)

- Sacco well (1991 VOCs)
- Smallfield well (1993 VOCs)
- Edinburgh well (1996 VOCs)
- 5/21 supply wells with detected VOCs
Source Zone Evolution and Plume Stages
Time and Distance Scales are Site Specific

NOTE: Rapid Evolution of Source Condition Effects Plume
Interplay Between Matrix and Fractures Controls Plume Behavior (time of arrival & flux)

Same bulk K but very different mass distributions
This Talk Shows...

- Field research shows solute plume and source zone evolution in the Silurian dolostone aquifer is dominated by diffusion.

- Plumes become stationary in 3-5 decades after contamination began.

- Recent data shows evidence of slow degradation in the rock matrix, causing plume front to retreat back toward source zones.

- Plumes attenuate quicker than expected (back-diffusion) and are no longer threats to down-gradient water supply wells.
Silurian Dolostone Belt
Major Water Supply Aquifer

Grand River Watershed

Guelph
Cambridge

Buffalo

Toronto

Fractured Dolostone
## Two Chlorinated Organic Contaminants with Similar Properties

<table>
<thead>
<tr>
<th></th>
<th>Metolachlor</th>
<th>TCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqueous Solubility</td>
<td>530 mg/L</td>
<td>1,100 mg/L</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.12 g/cm³</td>
<td>1.46 g/cm³</td>
</tr>
<tr>
<td>(NAPL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>110.7 @ 20°C</td>
<td>0.53 @ 25°C</td>
</tr>
<tr>
<td>(mPa.S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koc</td>
<td>~200 mL/g</td>
<td>87-150 mL/g</td>
</tr>
<tr>
<td>MCL</td>
<td>50 ug/L</td>
<td>5 ug/L</td>
</tr>
</tbody>
</table>

Common Herbicide
Plume Appears Stationary or Shrinking

2005

Metolachlor (µg/L) 2005

2011

Metolachlor (µg/L) 2011
Metolachlor Plume Transect Using Multilevels

2005

2011

Metolachlor 2005

Metolachlor 2011

MDL = 0.5 µg/L

MDL = 0.1 µg/L

Kriging, Anisotropy = 8
Temporal Monitoring
Water Supply Well and Multilevels

Rock Core Delineation and MLS Installation

Monitoring Well

vadose zone

groundwater zone
Metolachlor in Sentry Monitoring Wells

Source: Dillon Consulting and Region of Waterloo
2004 TCE Plume and Two Water Supply Wells in Guelph ~ 500m away

Not pumping since early 1990’s due to VOC detects
Conventional Well Network

Conventional Well Network

70% Plume Mass

Ground Surface (341 masl)

Bedrock Surface (337 masl)

Shallow Wells (0-4 m BTOR)
  n = 18 wells

Intermediate Wells (4-10 m BTOR)
  n = 6 wells

Deep Wells (10-16m BTOR)
  n = 2 wells (+ 1 TD)

Cabot Head Shale (240 masl)

Westbay MLS

Westbay MLS

MW - 22

n = number of wells sampled in 2013
BTOR = below top of rock
TD = Temporary deployment
Focus of Investigation

Upper Guelph Formation
From 2003 to 2018:

70% reduction in TCE plume aerial extent, 82% reduction in average concentration, 93% reduction in total mass.
Temporal Trends 2003-2018: cis-DCE Shallow Bedrock

Shallow Bedrock cis-DCE Plume - 2003 to 2008 increase in the aerial extent by 52% and 2013 to 2018 increase by 38%
Overall reduction of 54.7% from 2003 to 2018 sampling event.
Temporal Trends 2003 to 2018: VC Shallow Bedrock

Shallow bedrock vinyl chloride plume
- 2003 maximum concentration is only 4.4 ug/L
- 2013 VC Concentration is increasing at several locations (max at 94 ug/L)
- Reduction in the aerial extent by 63% (2003 – 2018)
**Shallow Bedrock - Approach**

- Plume average concentration, area, and mass calculated using grid nodes generated by Surfer®

- Centre of mass - centroid of the contoured concentration values

- Mass balance - Equivalent TCE Includes cis-DCE, 1,1-DCE, trans-DCE, VC, ethene and ethane

<table>
<thead>
<tr>
<th>Analyte/Year</th>
<th>2003</th>
<th>2008</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCE</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>cis-DCE</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>VC</td>
<td>ND (&lt;1.3 ug/L)</td>
<td></td>
<td>✗</td>
</tr>
<tr>
<td>Ethene</td>
<td>Not Analyzed</td>
<td>ND (&lt;0.5 ug/L)</td>
<td>6 wells</td>
</tr>
<tr>
<td>Ethane</td>
<td>Not Analyzed</td>
<td>3 wells</td>
<td>5 wells</td>
</tr>
<tr>
<td>Total Equivalent TCE</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>
General Conceptual Model
Later Stages of Solvent Plume Evolution in Sedimentary Rock

Plan View

Stage 4

Stage 5

Stage 6
Assimilative Processes
General Order of Importance in Sedimentary Rocks

- Diffusion
- Sorption
- Dispersion in fracture network
- Degradation (both biotic and abiotic)
Slow Degradation in the Matrix Causes Strong Plume Attenuation

(Pierce, Parker et al., JCH 2018)
Guelph & Cambridge Sites: Key Findings

- Detailed spatial and temporal groundwater sampling confirms plumes become stationary then shrink toward the source zone.

- Vulnerability to supply wells is diminishing with time.

- Expected delays in site clean-up due to back-diffusion are off-set by imperceptible degradation rates in the rock matrix!

- City considers turning the Smallfield supply well back on.
Site Conceptual Model (SCM)
if process-based, improves prediction and informs decision-making (risks, costs, time, designs for remediation, etc.)

General Conceptual Model (GCM)
inform our intuition or professional judgement
Our Next ‘Recalcitrant’ Contaminant Challenge: PFAS

PFOS
Perfluorooctane sulfonate
A perfluorosulfonic acid

- Persistent
- Bioaccumulative
- Toxic (EPA advisory level 70 ng/L)
- Nearly ubiquitous globally
### Diversity in Contamination

**Stratigraphy & Hydrogeology**

<table>
<thead>
<tr>
<th>California</th>
<th>Ontario</th>
<th>Wisconsin</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- **California**
  - Semi-arid climate
  - Topographic high 300m above valley
  - Dipping beds
  - Faulted
  - Marine turbidite sandstones-shales
  - TCE, ³H, other

- **Ontario**
  - Temperate climate
  - Flat-lying carbonate stratigraphy
  - Dissolution enhanced porosity
  - TCE, PCE, Metolachlor

- **Wisconsin**
  - Temperate climate
  - Flat-lying stratigraphy carbonates & clastic
  - Very transmissive bedding fractures
  - Mixed organic solvents
Contamination in Fractured Sedimentary Rock requires a Different Approach

Source Zone

Plume Zone

vadose zone

groundwater zone

Plume Front
Thank you