Three Case Studies:
In-Situ Remediation of PHCs in Bedrock

October 14, 2015
Bruce Tunnicliffe
Agenda

- Bedrock Background
- Case Study 1: LNAPL in House
- Case Study 2: Gas Station
- Case Study 3: Heating Oil
- Questions
Vertex

Contracting Firm
Vertex Services:
  ▪ Remediation:
    ▪ ISCO, ISCR, enhanced bio
    ▪ In-Situ and Ex-Situ treatment
  ▪ Treatment Systems
  ▪ High-Resolution Characterization
    ▪ LIF, MIP, HPT
Bedrock

vs.

Porous Media
Contaminant **Migration & Remediation** in Bedrock is Affected By:
- Groundwater & NAPL **Advection**
- Groundwater & NAPL **Diffusion / Adsorption**
Groundwater Advection

Flow Through Porous Media

Flow Through Fractured Media

Flow governed by Darcy’s Law:

\[ Q = K \ i \ A \]

- **Q** = Flow rate (m³/s)
- **K** = Hydraulic Conductivity (m/s)
- **i** = Hydraulic Gradient (unitless)
- **A** = Area (m²)
Groundwater Advection

Porous Media Flow (by Darcy’s Law):

\[ v = -\frac{K i}{n} \]

- \( v \) = Groundwater Velocity (m/s)
- \( K \) = Hydraulic Conductivity (m/s)
- \( i \) = Hydraulic Gradient (unitless)
- \( n \) = Porosity (unitless)
Groundwater Advection

Bedrock Fracture Flow (by Darcy’s Law & the Cubic Law):

\[ v = -\frac{\rho g (2b)^2}{12 \mu} i \]

- \( v \) = Velocity Through Fracture (m/s)
- \( \rho \) = Density of Fluid (kg/m\(^3\))
- \( g \) = Acceleration of Gravity (m/s\(^2\))
- \( \mu \) = Viscosity of Fluid (Pa s)
- \( 2b \) = Fracture Thickness (m)
- \( i \) = Hydraulic Gradient (unitless)
Groundwater Advection

Porous Media

\[ v = - \frac{K i}{n} \]

<table>
<thead>
<tr>
<th>Sand</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>10^{-4} m/s</td>
</tr>
<tr>
<td>i</td>
<td>0.001</td>
</tr>
<tr>
<td>n</td>
<td>0.30</td>
</tr>
<tr>
<td>Velocity</td>
<td>10 m/yr</td>
</tr>
</tbody>
</table>

Bedrock Fracture

\[ v = - \frac{\rho g}{12 \mu} (2b)^2 i \]

<table>
<thead>
<tr>
<th>Bedrock</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>0.001</td>
</tr>
<tr>
<td>Velocity</td>
<td>10 m/yr</td>
</tr>
<tr>
<td>Fracture Ht (2b)</td>
<td>19 um</td>
</tr>
</tbody>
</table>
Groundwater Advection

Bedrock Fracture Aperture $K$ vs Porous Media $K$:

$K = \text{Hydraulic Conductivity}$
Contaminant Diffusion into Bedrock

Rule of Thumb: “It takes 20 times longer to get contamination out of a matrix than it takes to diffuse into a matrix.”

Source: Beth Parker
Case Studies
Case Study #1
LNAPL In House
Case Study – LNAPL in House

• Heating oil release
  – Home owner woke up to oil pooling in his garage
  – Under the crawl space
  – Into the backyard
  – Around the foundation of his home

• Insurance Claim

• Quick action undertaken
  – Vacuum truck and booms to remove LNAPL
  – Excavation of shallow soils

• Install Bedrock Monitoring Wells
  – Vacuum LNAPL (Vac Truck)
  – LNAPL consistently returned to MWs
  – More aggressive approach required
### Case Study – LNAPL in House

#### Borehole Log for MW11-08

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Layer Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.21</td>
<td>TOPSOIL</td>
</tr>
<tr>
<td></td>
<td>FILL, Brown medium sand, trace gravel, moist.</td>
</tr>
<tr>
<td>98.3</td>
<td>SANDSTONE BEDROCK</td>
</tr>
<tr>
<td>95.1</td>
<td>END OF BOREHOLE at approximately 4.11 metres below grade.</td>
</tr>
</tbody>
</table>

- **31 mm, Schedule 40, PVC Casing, with Bentonite Seal**
- **31 mm, Schedule 40, PVC Casing, with Sandpack**
- **31 mm, Schedule 40, slot #10, PVC Screen with Sandpack**
At start:
- 14 wells clean
- 25 wells contaminated
Case Study – LNAPL in House

- In-Situ Chemical Oxidation (ISCO) Approach
  - Persulphate
  - Alkaline activation
  - Inject small volume (2,000 L)
    - Injection = 1 day
  - Inject frequently (~ every 2 months)
    - Inject for 1 year (5 events)
  - Reassess the plume
Prior to ISCO

At start:
- 14 wells clean
- 25 wells contaminated
After 5 one-day ISCO Injections

After 5 one-day injections:
• 33 wells clean
• 6 wells contaminated
Case Study – LNAPL in House

• Enhanced ISCO
  – Focused persulphate injections
  – Use of enhanced gradient
    • Vacuum on wells
    • Enhanced gradient during injection
    • Influence unsaturated zone
  – Use of surfactant
At start:
- 14 wells clean
- 25 wells contaminated
After 5 one-day ISCO Injections:
- 33 wells clean
- 6 wells contaminated
After 10 one-day ISCO & Surfactant Injections

After 10 one-day injections:
- 38 wells clean
- 1 well contaminated
After 12 one-day injections:
- 39 wells clean
- 0 well contaminated
Total PHC Concentration (µg/L)

PHC Spill
Start of ISCO


Spill Response  In-Situ Chemical Oxidation (ISCO)  ISCO with Vacuum  ISCO with Surfactant

MW11-25
MW11-08
MW11-29
PHC Site Criteria
Case Study – LNAPL in House

• Conclusions
  – Remediated LNAPL & GW to MOECC Standards
  – Shallow soils excavation
  – Vacuum removal of LNAPL from wells
  – Bedrock remediation accomplished through intelligent use of:
    • ISCO
    • Enhanced Delivery using Vacuum
    • Surfactant
  – Result: LNAPL & dissolved PHCs removed from bedrock
Case Study #2
Gas Station
Case Study – Gas Station

• Historical gas station and auto body shop
  – Operated for many decades
  – Bedrock blasted to place 4 Underground Storage Tanks (USTs) in north-east corner of Site
  – USTs removed in 1996
    • No soil was excavated
    • PIDS were low, assumed Site was clean

• Bedrock at 0.5 m to 1.0 m bgs
  – Except where USTs dug, bedrock at 4.5 m to 5.5 m bgs

• Groundwater at 6 to 7 m below ground surface (bgs)

• LNAPL found in well at edge of former UST area
Grade Surface

ASPHALT (125 mm)

Brown SAND (FILL), some gravel, (broken apparent bedrock), moist
- some silt

Grey, LIMESTONE (BEDROCK)

95.9

92.3

End of Borehole

Monitoring well installed to approximately 8.0 m bgs

1 40
2 10
3 5

PHCs, VOCs

<5

Silica Sand

Flush Mount Casing

Bentonite Seal

February 21, 2013

2' x 10' #10 Slot Screen
Pre-Remediation Concentrations

<table>
<thead>
<tr>
<th>Parameter (ug/L)</th>
<th>MOECC Table 7</th>
<th>BH101 Source Area</th>
<th>% Reduction</th>
<th>BH202 Down-gradient</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.50</td>
<td>400</td>
<td>99.9%</td>
<td>&lt;0.20</td>
<td>0%</td>
</tr>
<tr>
<td>Toluene</td>
<td>320</td>
<td>71</td>
<td>0%</td>
<td>&lt;0.20</td>
<td>0%</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>54</td>
<td>1,400</td>
<td>96%</td>
<td>&lt;0.20</td>
<td>0%</td>
</tr>
<tr>
<td>Xylenes</td>
<td>72</td>
<td>9,000</td>
<td>99.2%</td>
<td>&lt;0.40</td>
<td>0%</td>
</tr>
<tr>
<td>PHC(F1)</td>
<td>420</td>
<td>68,000</td>
<td>99.4%</td>
<td>120</td>
<td>0%</td>
</tr>
<tr>
<td>PHC(F2)</td>
<td>150</td>
<td>100,000</td>
<td>99.9%</td>
<td>430</td>
<td>65%</td>
</tr>
<tr>
<td>PHC(F3)</td>
<td>500</td>
<td>3,400</td>
<td>85%</td>
<td>920</td>
<td>45%</td>
</tr>
</tbody>
</table>
Case Study – Gas Station

• Install Injection Wells
  – In the “Source Area”

• Surfactant Injection & Extraction
  – Dissolve as much LNAPL as possible
  – Add tracer, understand groundwater flow regime
  – Extract surfactant and tracer from subsurface
    • In total 15,000 L of tracer / surfactant injected
    • In total 25,000 L of gw / surfactant removed

• In-Situ Chemical Oxidation
  – Persulphate, base activated
    • In total 6,500 kg of persulphate injected

• Quarterly Injections
  – To date: 6 injections completed
Hint: Use Injection Wells to look for LNAPL
Case Study – Gas Station

• Conclusions
  – Remediated LNAPL
  – Tracer helped to understand distribution
  – Tracer helped to extract surfactant
    • And the dissolved PHCs
  – Exceedances of MOECC Standards, but only marginally, anticipate only a limited number of additional quarterly injections
  – Bedrock remediation using:
    • ISCO
    • Enhanced Delivery using Vacuum
    • Surfactant
  – Result: LNAPL removed from bedrock
Case Study #3
Heating Oil
Case Study – Heating Oil

- Heating oil release
  - Estimated 800 L from 2 side-by-side ASTs
- Mobile home park
- Insurance Claim
- Relatively quick action required
  - Fractured rock aquifer, drinking water wells
- 47 wells (between 4.5 m to 9 m bgs)
- Plume: 60 m long, 1,300 m²
- Time to Impact DW Wells = 245 to 750 days
## Case Study – Heating Oil

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Clean-up Standard (μg/L)</th>
<th>Maximum Groundwater Concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>5.0</td>
<td>280</td>
</tr>
<tr>
<td>Toluene</td>
<td>24</td>
<td>630</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>2.4</td>
<td>230</td>
</tr>
<tr>
<td>Xylene</td>
<td>300</td>
<td>780</td>
</tr>
<tr>
<td>PHC(F1)</td>
<td>F1 &amp; F2 ≤ 1000</td>
<td>50,000</td>
</tr>
<tr>
<td>PHC(F2)</td>
<td>F1 &amp; F2 ≤ 1000</td>
<td>8,400</td>
</tr>
<tr>
<td>PHC(F3)</td>
<td>F3 &amp; F4 ≤ 1000</td>
<td>1,300</td>
</tr>
<tr>
<td>PHC(F4)</td>
<td>F3 &amp; F4 ≤ 1000</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>
Case Study – Heating Oil

- **Shallow Excavation**
  - Removal of heavily impacted soils

- **Monitoring Wells & Injection Wells Installed**
  - Plume was constantly changing (quick moving)

- **In-Situ Chemical Oxidation**
  - Sodium Percarbonate ($2\text{Na}_2\text{CO}_33\text{H}_2\text{O}_2$)
    - In total 2,500 kg of percarbonate injected

- **In-Situ Bioremediation**
  - ORC (oxygen release compound)
    - In total 100 kg of ORC used
Case Study: Pre-Injection
Case Study: Post Injection 2
Case Study: Post Injection 3
Case Study: Post Injection 4
Case Study – Heating Oil

PHC F1 to F4 (ug/L)

Jan 07  Aug 07  Nov 07  April 08  July 08  Oct 08
Case Study – Heating Oil

• Conclusions
  – Remediated LNAPL & GW to MOECC Standards
  – Shallow soils excavation
  – Vacuum removal of LNAPL from wells
  – Bedrock remediation accomplished through intelligent use of:
    • ISCO
    • Enhanced Bioremediation
  – Result: LNAPL & dissolved PHCs removed from bedrock
Closing Thoughts

Bedrock LNAPL & Dissolved Phase Movement
- Contaminant mobility mainly through fractures
- Fractures comprise a low volume
- Porosity of rock matrix is important
- Bulk of contamination may end up in rock matrix

Bedrock Remediation
- Vac Trucking LNAPL alone isn’t a remedial solution
- Excavation of overburden soils is important
- Quick response to bedrock spills is very important
  - Due to adsorption into rock matrix (remember Rule of Thumb)
- Keep volumes low and use regular injection frequency
  - To combat matrix back-diffusion
- Oxidation and surfactant flushing are effective
Questions?

Thank You for Your Time

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