Assessing Mass Discharge vs. Aquifer Assimilation at a Complex Fractured Bedrock Site

Ernest C. Ashley, P.G.
Presentation Topics

• Why Listen
  • Mass discharge to manage sites
• Case Study
  • Site Setting, Hydrogeology, Initial CSM
• Overburden and Bedrock Characterization
  • Tools and Techniques
• Mass Discharge & Aquifer Assimilation
  • Quantification Efforts
• Findings and Changes to the Initial CSM
• Conclusions and Paths Forward
Mass Discharge Applications for Site Management

1. Site Characterization
   - Identify hotspots and flux/discharge from them
   - Discharge to receptors
   - Discharge to pumping/supply wells
   - Discharge to surface water
   - Vapor intrusion discharge
   - Develop estimates for attenuation capacity of plume
   - Evaluate stratigraphic units for targeted treatment
   - Develop performance objectives for active treatment based on reductions in risk to receptors

2. Potential Impacts and Exposure Evaluation
   - Evaluate site stratigraphy and flux from low and high-K zones
   - Evaluate plume discharge
   - Evaluate attenuation rates

3. Remediation Selection and Design
How it all started:

- CVOCs discovered in public water supply well
- Search for “The Usual Suspects”
- “It was YOU!”
- Broader search reveals additional potentially responsible parties and additional impacts
Site Setting

Former Tank Farm

Bedrock high

Wetlands overlying buried valley containing 60+’ of stratified outwash sand and gravel

Regional River
Site Setting – Geology

- Eastern Massachusetts – Hard rock and glaciated terrain
- Bedrock surface dips steeply beneath stratified glacial drift overburden
- Groundwater flow towards adjacent wetlands / buried valley and regional river
- Historic Tank Farm installed/excavated into shallow crystalline bedrock
- 3 types of porosity in granite/diorite
  - Primary – intergranular
  - Secondary – fracture
  - Tertiary – microfracture
Initial CSM Cross Section

Impacts indicated down to 300 ft bgs
Well -202R  Mass Flux – Basis of Initial CSM

![Graph showing Total VOCs (μg/L), Average Hydraulic Conductivity (ft/day), and Mass Flux (g/d) vs. depth (ft bgs).]
Initial Conceptual Site Model

• Shallow and deep groundwater flow east towards buried valley
• Bedrock groundwater discharges to overburden deposits to the east
• Transmissivity drops off markedly below ~115’ bgs
• Concentrations drop off markedly in downgradient buried valley
• Significant attenuation likely occurring in buried valley
• Potential to document balance of mass discharge and attenuation
Bedrock Aquifer Characterization Tools and Techniques

• Bedrock drilling by diamond core and sonic coring in transects
• CORE$^{\text{DFN}}$ sampling of bedrock + porosity and permeability testing
• Geophysical Logging Suite
  • Caliper, optical & acoustic televiewers, natural gamma, spontaneous potential, resistivity, fluid temperature, fluid conductivity, heat pulse flowmeter
• FLUTe Transmissivity Profiling
• Active Line Source Temperature Profiling
• Water FLUTe and CMT multi-level monitoring well installations
• Groundwater sampling
  • VOCs, metals, CSIA, dissolved gasses
CORE$^{DFN}$ Rock Core Sampling

- Sub-sampling of rock core
  - adjacent to and at distance from fractures
- Assessment of contaminant mass
  - estimation of pore water concentrations
- Assessment of rock properties
  - porosity, permeability
2019 Design and Construction Issues at Hazardous Waste Sites
FLUTe Lining and Borehole Geophysics
FLUTe Transmissivity Profiling
ALS Temperature Logging
Multi-Level Well Installations

- Multiple nested well screens
- WaterFLUTe Systems
- Continuous Multi-Channel Technology (CMT)

Key Characterization Concept:
Need screens in both high and low conductivity intervals
Transect A – Geologic Cross-Section

Approximate core of the plume
Findings – Updates and Changes to the Initial Conceptual Site Model

- Very low primary porosity, and generally low bedrock transmissivity
- Relatively low CVOC concentrations in the rock matrix
- Concentrations in groundwater fractures higher than in the bedrock matrix
- Significant transmissivity at depths greater than 115’ bgs (up to 250’)
- Extensive glacial till layer controls bedrock to overburden discharge
Aquifer Assimilation Quantification Efforts

• Comparison of mass discharge between transects
• Retardation calculations
• Compound Specific Isotope Analysis (CSIA) results
• Dissolved gasses and biologic/abiotic degradation rates
• Estimated and modeled abiotic degradation rates
Mass Discharge Quantification Efforts

- Mass Discharge evaluated by calculating Mass Flux across two transects using the Mass Flux Toolkit
  - Inputs: hydraulic conductivity, hydraulic gradient and GW concentrations
  - Obtained K from transmissivity profiles

\[ K = \frac{T}{b} \]

\[ T \text{ profile} \]

\[ \text{top of spacer} \]

\[ \text{bottom of spacer} \]
Mass Discharge Comparison (g/d)

\[ M_D = \sum_{i=1}^{n} C_i K_i \theta A_i \]

<table>
<thead>
<tr>
<th>Transect</th>
<th>Formation</th>
<th>Overburden</th>
<th>Bedrock</th>
<th>Total Building 1:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building 1</td>
<td>Overburden</td>
<td>4.73</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bedrock</td>
<td>0.71</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>5.44</td>
<td>1.51</td>
<td>6.95</td>
</tr>
</tbody>
</table>

| Transect A | Overburden | 0.07 | 0.08 | |
|           | Bedrock    | 2.09 | 3.2  | |
|           | Total      | 2.16 | 3.28 | 5.44 |

| Transect B | Overburden | 0.04 | 0.12 | |
|           | Bedrock    | 0.002 | 6.12E-03 | |
|           | Total      | 0.042 | 0.13 | 0.17 |

| Transect C | Overburden | 0.01 | 0.01 | |
|           | Bedrock    | 2.12E-06 | 9.46E-06 | |
|           | Total      | 0.010 | 0.010 | 0.02 |
Retardation Calculations

\[ K_d = (K_{oc}) (f_{oc}); \quad R = 1 + \frac{K_d x b_d}{n_e} \]

<table>
<thead>
<tr>
<th>Compound</th>
<th>Koc</th>
<th>Overburden</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>foc</td>
</tr>
<tr>
<td>PCE</td>
<td>265</td>
<td>0.0019</td>
</tr>
<tr>
<td>TCE</td>
<td>94</td>
<td>0.0019</td>
</tr>
<tr>
<td>cis-1,2-DCE</td>
<td>65</td>
<td>0.0019</td>
</tr>
<tr>
<td>VC</td>
<td>24</td>
<td>0.0019</td>
</tr>
</tbody>
</table>

Retardation is not expected to be an important attenuation mechanism in this bedrock based on lack of organic carbon, porosity and surface area.
Degradation of PCE along flow path appears minimal going from Transect A to Transect B.
Dissolved Gasses

- Biotic degradation indicators: ethene (ethane), methane, hydrogen
- Abiotic degradation indicators: acetylene, propane (ethene and ethane)

Abiotic degradation indications:
- Acetylene: 0.5 to 44 µg/L
- Propane: 0.0041 to 1.1 µg/L

Biologic degradation indications:
- Methane 0.72-3,800 µg/L
- Dissolved H₂ 1.4 nM to 77,000 nM
Abiotic Degradation Processes in Rock Matrix

• Reduced gas generation
• Visual observations of pyrite
• Ferrous minerals present
Estimate of Rock Matrix Diffusion/Adsorption Impacts

CRAFLUSH Modeling

• Site Specific Factors
  • Fracture Spacing – 40 cm
    • Borehole geophysics
  • Fracture Aperture – 0.0007 cm
    • Pumping tests and Cubic Law Calcs.
  • Matrix Porosity – 0.023
    • Rock testing
  • Seepage Velocity – 1873 cm/day
    • Cubic Law Calcs.
  • Diffusion Coefficient – 6.5 × 10^-9 cm²/sec
    • Matrix Diffusion Test
  • Linear Adsorption Coefficient – 0.08 L/kg
    • TOC, density & porosity
Mass Discharge Assessment Applied for Site Management

1. Site Characterization
   - Identified hotspots and flux/discharge from them
   - Evaluated site stratigraphy and flux from low and high-K zones

2. Potential Impacts and Exposure Evaluation
   - Evaluated plume discharge
   - Evaluated attenuation rates

3. Remediation Selection and Design
   - Developed estimate of site-specific attenuation capacity
   - Documented stable or shrinking plume
   - Established condition of no significant risk to receptors under MassDEP
Conclusions and Recommendations to Challenges Mass Discharge & Aquifer Assimilation Quantification Efforts

• Must develop a representative quantification of mass discharge
• Must be confident that transects capture the plume
• Need to account for all degradation and attenuation processes
• Need to bracket degree of uncertainty
Lesson Learned – Path Forward

• Expenditure of significant effort and money is often required to adequately quantify mass discharge and aquifer assimilation

• Additional data can (will) change the CSM
  • Often requiring additional effort and funding to further define nature and extent, mass discharge and aquifer assimilation capacity

• The “Investment in Characterization” is justified by the ability to assess current and future exposures and mitigate risk appropriately
Assessing Mass Discharge vs. Aquifer Assimilation at a Complex Fractured Bedrock Site

Ernest C. Ashley, P.G.