Application of Enhanced Bioremediation Following Thermal Treatment for Remediation of VOCs

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Basis for Thermal-Bio

- Research by Danish Technical University & Geosyntec to evaluate impacts of thermal treatment on follow-on TCE bioremediation
- Site materials from ERH site at Fort Lewis, WA
- Evaluation of thermal treatment impacts on:
  - Dissolved organic carbon (DOC) release
  - Terminal electron acceptor (TEA) usage
  - Microbial diversity & community structure
  - Dechlorination (natural & bioaugmented)

ERH = Electrical Resistance Heating
Basis for Thermal-Bio: Key Findings

1. Soil heating releases organic carbon - potential electron donor

2. Soil heating reduces microbial community composition (methanogens) & dechlorination capability

3. Bioaugmentation quickly re-establishes microbial community – highly efficient (no competition)

4. Optimal dechlorination rate for Dehalococcoides occurs at 30 to 35°C

Basis for Thermal-Bio

Potential exists to reduce cost, footprint & duration using sequenced techniques (thermal-bio)

Temperature Profile During ERH, Fort Lewis

Timing of Post-Thermal EISB Activities

Case Study

- 17 x 17 m lagoon for spent acids, process waste water -> CEs, CAs
- Used in 1970s, in-filled in late 1970s
- ERH application in 2008
- Chlorinated solvents remained in GW
- EISB “polishing” application in 2010
Geology

- Clay/fill overburden - 2 to 13 m deep
- Karst limestone
- Cutter features in bedrock surface
ERH Application

- Surface cap of asphalt / concrete
- >80 electrode wells installed
- Heating started June 2008
- Potassium citrate electrolyte
- Soil sampling confirmed remedial objective met (TCE <400 µg/kg)
- ERH shut down January 2009
Pre-ERH Concentrations & Layout

**soil data (µg/kg)**

- **TCA** 1,700
  - **MC** 13,000
  - **TCE** 9,800
  - 1,1-DCE 830

- **TCA** 870
  - **MC** ND
  - **TCE** 3,500
  - 1,1-DCE 15

- **TCA** 19,000
  - **MC** 1,800
  - **TCE** 73,000
  - 1,1-DCE 4,400

- **TCA** 2,000
  - **MC** 8,300
  - **TCE** 14,000
  - 1,1-DCE 1,700

- **TCA** 760
  - **MC** 43,000
  - **TCE** 12,000
  - 1,1-DCE 440

- **TCA** 2,100
  - **MC** 6,800
  - **TCE** 21,000
  - 1,1-DCE 1,100

- **TCA** 95
  - **MC** 27
  - **TCE** 2,460
  - 1,1-DCE ND

- **TCA** 510
  - **MC** ND
  - **TCE** 2,200
  - 1,1-DCE ND

- **TCA** 760
  - **MC** 1800
  - **TCE** 73000
  - 1,1-DCE 4400

- **TCA** 19000
  - **MC** 1800
  - **TCE** 73000
  - 1,1-DCE 4400

- **TCA** 21000
  - **MC** 6800
  - **TCE** 21000
  - 1,1-DCE 1100

- **TCA** 950
  - **MC** ND
  - **TCE** 2460
  - 1,1-DCE 322

**Thermocouples**

**ERH wells**

**NAP-MW-103**

**NAP-MW-102**

**FORMER LAGOON LOCATION**

**FORMER "NEW" ACID PIT**

**CONC. PAD**

**HW-10**
Post-ERH Soil Concentrations

- TCE in soil below remedial goal (400 µg/kg) at majority of locations
- 2 locations ~700 µg/kg
Post-ERH GW Concentrations

- Residual VOCs (primarily Cl-Ethenes) in GW
- Some dechlorination following ERH
Objectives

- Create horizontal biobarrier between clay and bedrock through injection of slow-release electron donor
  - Emulsified Vegetable Oil (EVO)
- Take advantage of residual ERH heat to promote rapid VOC dechlorination
Post ERH Bioremediation

Approach

1. Inject EVO & KB-1 Plus® into bedrock wells, with groundwater recirculation
2. Inject EVO & KB-1 Plus® into ERH wells in overburden
3. Monitor degradation (16 months)
EISB Implementation

- No injection (obstruction)
- Deeper overburden “pressurized” injection
- Shallow overburden “no pressure” injection
- Bedrock recirculation

<table>
<thead>
<tr>
<th>Location</th>
<th># Wells</th>
<th>% EVO</th>
<th>Total Volume (L)</th>
</tr>
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<tbody>
<tr>
<td>Deep</td>
<td>26</td>
<td>4 %</td>
<td>100,000</td>
</tr>
<tr>
<td>Shallow</td>
<td>29</td>
<td>4 %</td>
<td>40,000</td>
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<tr>
<td>Bedrock</td>
<td>4 IW, 2 EW</td>
<td>0.5 %</td>
<td>57,000</td>
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<tr>
<td>Parameter</td>
<td>General Result</td>
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<td>-----------------------</td>
<td>-----------------------------------------------------</td>
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<tr>
<td>TOC</td>
<td>Increase by &gt;100 mg/L</td>
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<tr>
<td>Methane</td>
<td>&gt;10,000 µg/L</td>
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<tr>
<td>DO, ORP</td>
<td>DO &lt; 1mg/L, ORP &lt; -70 mV</td>
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<tr>
<td>Anions – SO₄, NO₃, Cl</td>
<td>Nitrate and sulfate near depleted</td>
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<tr>
<td></td>
<td>Chloride increase by 10 to 100 mg/L</td>
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<tr>
<td>Dehalococcoides</td>
<td>Increase by several orders of Magnitude</td>
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<tr>
<td>pH</td>
<td>Temporary decrease</td>
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<tr>
<td>ERH Residual Heat</td>
<td>Post-ERH (Jan ‘10): up to 37°C</td>
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<td>Baseline (June ‘10): 26 - 37°C</td>
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<td>Sept 2010: 28 - 34°C</td>
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<td>Jan 2011: 17 - 26°C</td>
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<td>May 2011: 24 - 30°C</td>
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<td>Nov 2011: 21 - 26°C</td>
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• VC/cDCE decreases post-injection
• Daughter product generation (ethene)
• VOCs remain low/ND for 16 months
• Chloride increase 130 mg/L

Starting concentrations: cDCE 2300 µg/L; VC 2200 µg/L; 1,1-DCE 500 µg/L
VOCs Concentrations – Bedrock

• VOC decreases after EVO
• Daughter product generation (VC, ethene, CA)
• Rebound of some daughters in Q4
• Chloride increase 90 mg/L

Starting concentrations: TCE 4900 µg/L; cDCE 3400 µg/L; VC 310 µg/L; 1,1-DCE 2100 µg/L
Pre-EISB Baseline CI-Ethenes

- Dechlorination generally <40%
- VOCs > 5,000 ug/L many wells
- Low VC and ethene
Post-EISB Baseline Cl-Ethenes

- Ethene dominates (%>95)
- Chlorinated ethenes generally ND (< MCLs)
- Similar trends for ethanes
Increase in Dehalococcoides

DHC increase post-EVO injection by up to an order of magnitude
Conclusions

ERH

• Effective remediation of overburden
• VOCs remained in underlying groundwater

EISB

• EISB injections facilitated by ERH infrastructure
• Effective delivery to target zone
• VOCs degrading over 16 months
• Many locations TCE/DCE/VC are ND (<MCLs)
• Some rebound in bedrock wells
Questions?

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