Case Study: New Delivery Method to Inject Remedial Amendments into a Difficult Aquifer

RemTech Presentation
October 17, 2019

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Gerren Feeney, B.Sc. - Premier
Introduction – Agenda

- Introduction
  - What is a Difficult Aquifer?
- Site Background
  - Data Review & Gap Analysis
  - Bench-scale Treatability Testing
  - Historical Remediation Activities
- Delivery Approach for Difficult Aquifer
  - Pilot-Test Results
  - Full-Scale In-situ Program
  - Performance Monitoring
- Conclusions / Lessons Learned
Introduction – Presenters

• **Nathan Lichti, B.A.Sc., P.Eng.**
  • Environmental Engineer at Vertex
  • University of Waterloo, Ontario
  • 12+ years experience as remedial contractor

• **Gerren Feeney, B.Sc.**
  • Project Manager at Premier
  • University of Guelph, Ontario
  • 11+ years experience as environmental consultant
What is a Difficult Aquifer for Injection?
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Three Standard Injection Methods:

1) Permanent Injection Well
2) Direct Push Injection Point
3) Open Borehole Packer Injection

Overburden

Bedrock

Typical Plume in Overburden/Bedrock

Good for sandy formations under low pressure (<100 psi)

Good for tighter formations under high pressure

Good for bedrock formations under low to high pressure
What is a Difficult Aquifer for Injection?

Three Standard Injection Methods:

1) Permanent Injection Well
2) Direct Push Injection Point
3) Open Borehole Packer Injection

Deep Plume in Tight Overburden Soils

Formation too Tight for Low Pressure Injection

Plume too Deep for Direct Push Rod Advancement

Borehole Packer Not Applicable for Overburden
What is a Difficult Aquifer for Injection?

Three Standard Injection Methods:

1) Permanent Injection Well
2) Direct Push Injection Point
3) Open Borehole Packer Injection

A Different Injection Method is Required

Deep Plume in Tight Overburden Soils

Overburden

Bedrock
Case Study
Site Background – Site Location
Timeline

- **Initial ESA Work (2013)**
- **Bench Test #1 ZVI Options (Dec-Mar)**
- **Bench Test #2 Lactate + KB-1® (Dec-Apr)**
- **Enhanced Bio Injection #1 (Feb-Apr)**
- **Pre-Injection Sampling Round (Jan)**
- **Enhanced Bio Injection #2 (Nov)**
- **BOS Pilot Injection #1 (Jan 2018)**
- **BOS Full-Scale Injection (Jan-Apr)**
- **BOS Pilot Injection #2 (Apr)**
- **Additional Well Install (Aug)**
Timeline

Initial ESA Work (2013)

2014

- Bench Test #1
  - ZVI Options (Dec-Mar)

2015

- Bench Test #2
  - Lactate + KB-1® (Dec-Apr)

2016

- Pre-Injection Sampling Round (Jan)
- Enhanced Bio Injection #1 (Feb-Apr)
- BOS Pilot Injection #1 (Jan 2018)

2017

- Regular Quarterly GW Sampling (Apr 2016 – Present)
- Enhanced Bio Injection #2 (Nov)
- BOS Pilot Injection #2 (Apr)

2018

- Additional Well Install (Aug)

2019

- BOS Full-Scale Injection (Jan-Apr)
Industrial manufacturing facility located in the GTA

ESA site characterization work completed in 2013/2014
- No soil concentrations > applicable Table 3 SCS limits
- cVOC impacted groundwater in southeast corner
  - Laterally and vertically delineated
  - Unknown source!
Site Background – ESA Approach - Site Characterization & Delineation

Inferred Plume Area

Inferred 100 ug/L cVOC Contour

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Site Background – ESA Approach - Site Characterization & Delineation

Target Treatment Zone

Inferred extent of VOC groundwater impacts exceeding SCS

Legend:
- Property Boundary
- Borehole Interval
- Screened interval for Monitoring Well (0.05m I.D.)
- Silty Clay
- Sandy Silt
- Silt
- Sand

SANDY SILT
SILT
SAND

PREMIER ENVIRONMENTAL SERVICES

VERTEX
Site Background – ESA Approach - Site Characterization & Delineation

Inferred GW Depth: 9-11 mbgs
Inferred GW Flow - Southeast

62% Sand; 33% Silt; 5% Clay within aquifer

- $k = 10^{-6}$ m/s
- $k = 10^{-5}$ m/s
- $k = 10^{-7}$ m/s

Contaminants | Units | BH301 | BH205 | BH106 | BH206
--- | --- | --- | --- | --- | ---
cVOC's | ug/L | 38 | 529 | 808 | 1037

62% Sand; 33% Silt; 5% Clay within aquifer
**Timeline**

- **Initial ESA Work (2013)**
- **Bench Test #1 ZVI Options (Dec-Mar)**
- **Bench Test #2 Lactate + KB-1® (Dec-Apr)**
- **2014**
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- **2017**
  - BOS Pilot Injection #1 (Jan 2018)
  - BOS Pilot Injection #2 (Apr)
- **2018**
  - Additional Well Install (Aug)
- **2019**
  - BOS Full-Scale Injection (Jan-Apr)
Bench Test:
Vertex retained to conduct Bench Testing using soil and groundwater from the site to evaluate:

- Plume Treatment via Enhanced Bio
- Permeable Reactive Barrier with ZVI
Bench Test Results:

- Biostimulation (0.2% or 1.0% sodium lactate) was **not successful** in reducing cVOCs below the applicable SCS.
- Biostimulation with bioaugmentation (KB-1®) **was successful** in reducing cVOCs below the SCS.
- 1.0% by weight ZVI mixture was **not successful** in reducing cVOC below the SCS.
- 30% by weight ZVI mixture **was successful** in reducing cVOC conc. below the applicable SCS.
Timeline

Initial ESA Work (2013)

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BOS Pilot Injection #2 (Apr)

Additional Well Install (Aug)

2019

BOS Full-Scale Injection (Jan-Apr)
2016 Injection Summary

Selected Approach: In-situ injection of sodium lactate biostimulant with KB-1® bioaugmentation

- Primary goal to reduce mass of contaminants
- Sodium lactate – electron donor
- KB-1® - metabolize contaminants
2016 Injection Summary

Injection Plan:

- Grid of 150 temporary injection points (over ~1,025 m² plume)
- Advance Injection Rods with Geoprobe to depth
- Inject Shallow Interval (10-13 m bgs) and Deep Interval (13-16.5 m bgs)

Injection delivery approach did not work
2016 Injection Summary – Delivery Issues

Delivery Issues

• Shallow Interval (10-13 m bgs):
  • Geoprobe could advance injection rods to depths
  • Rod breakage at 4 of 12 locations
  • The male thread snapped off inside the female thread due to extended hammering – stress on the rods

• Deep Interval (13 – 16.5 m bgs):
  • Geoprobe could not advance rods to depth
  • Switched to Hollow Stem Augers (HSA) for Deep
  • HSA were able to advance to target depths
  • Attempted injection thru HSA didn’t work
  • HSA very slow – Schedule Restraints

Decent Injection ROI but breakage at 1/3 of locations

Direct Push not Viable for deep

Temporary Point Injection not going to work
2016 Injection Summary – Delivery Issues

Revised Approach

- Finished Injection program with Permanent Injection Wells
  - 19x shallow wells (10-13 m bgs)
  - 18x deep wells (13-16.5 m)
- Injected 20% Sodium Lactate Solution + KB-1®:
  - 18,550 L via temporary points
  - 106,400 L via permanent wells
- Field Monitoring:
  - Average hydraulic influence of +0.36 m
  - Partial Geochem Shift
    - ORP_{AVG} = +38 mV (Pre-Inj)
    - ORP_{AVG} = -39 mV (Post-Inj)
    - KB-1 should have < -75 mV
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Site Background – Performance Monitoring

No more deep impacts (only shallow impacts remaining)

Additional Amendments Added

Fluctuating cVOC Conc. > SCS
**Next Steps**

**Next Steps?**
- Collected 2+ years of analytical and geochemistry data
- Completed additional Enhanced Bio injection, and well cleaning event
  - Enhanced Bio just not working for wells along property boundary

<table>
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<tr>
<th>Pros</th>
<th>Cons</th>
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</table>
| **Enhanced Bio** (Sodium Lactate + KB-1)  | Delivery issues
Lab proof of concept
Some success at site
Cannot maintaining ORP < -75 mV
KB-1® not thriving |
| **Trap and Treat BOS 100®**               | How to deliver a slurry?                  |
| Does not depend on geochemistry
Persistence
No maintenance or re-application       |

Decided to undertake BOS 100® Pilot-Test to see if delivery was feasible
Timeline

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What is BOS 100®?

- Consists of GAC impregnated with iron

Mechanisms:
- “Trap” the contamination within the GAC matrix
- “Treat” the contamination via reductive dechlorination within the GAC matrix

Injection Delivery:
- Mixed as a slurry
- Injected under high pressure
- Typically use Direct-Push rig with pre-strung 2.25” rods
- Slurry will not pass through well screen
BOS 100® is a slurry of granular carbon & iron

Cannot Inject Through Well Screen

Attempted Injection via Pre-Strung Rods

Deep Plume in Tight Overburden Soils

Overburden

40 ft

Could not advance rods even to shallow interval
Mobilize Sonic Drill Rig

- Needed rig that could quickly pre-drill BHs

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**Step #1**

**Borehole Pre-Drill**

**Deep Plume in Tight Overburden Soils**
BOS 100® Pilot-Test – Delivery Attempt #2

Backfill Process:
• Add backfill in lifts

Step #2
Bentonite/Grout Backfill

Needed backfill material that can be drilled through while providing sufficient injection resistance?
Tested a variety of materials

Deep Plume in Tight Overburden Soils

Overburden
In the image, the text reads:

**Injection Process:**
- Mobilize direct push rig
- Advance 2.25” pre-strung rods down pre-drilled BH to top of injection interval

The diagram illustrates the injection process, focusing on Step #3: Injection Via Pre-Strung Rods. The deep plume is depicted in tight overburden soils, and the overburden layer is shown. The depth indication of 40 ft is also visible on the diagram.
Results:

- Injected up to 500 L per IP
  - 100 L/depth interval
- Injection pump pressure ranged from 300-1,000 psi
- Observed Radius of Influence of 1.2 to 1.5 m
- Average analytical results at BH206 as follows:
  - 1,1-DCE: 47 ug/L to 0.7 ug/L
  - 1,1,1-TCA: 625 ug/L to 5.0 ug/L
Additional Delineation

Recall our inferred plume
BOS 100® Full Scale Injection

**Injection Details:**
- Injection Grid of 180 locations on a 2.25 m grid spacing, split out over 5 zones
  - Active facility receiving deliveries
- Completed Injection over 3 months
  - Sonic 5 days per week (3-6 BHs/day)
  - Injection 50% of time (6-9/day)
- Totals:
  - 5,600 kg of BOS 100®
  - 83,500 L of slurry injected
  - Average Pump Pressure of 430 psi
Field Results:

- **Field Monitoring:**
  - Minimal daylighting
  - Good hydraulic influence ranging from +0.25 m to +2.04 m
  - Average hydraulic influence +0.70 m

- **Visual Inspection**
  - BOS 100® has black colour
  - Amendment can be visually observed as grey to black discolouration
**Injection Delivery Challenges:**

- **Winter Weather**
  - Shut-down for 4 days (temp < -20 °C)
  - 3 partial injection days due to line freezing issues
- **Injection Tip Clogging**
  - Problems with Bentonite Grout clogging injection tip while pushing down
  - Developed method of pulsing water as injection tip is advanced
Timeline

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2017

2018

2019

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Analytical Results – 1,1,1-TCA

1,1,1-TCA Std = 640 ug/L
Analytical Results – 1,1,1-TCA

1,1,1-TCA Std = 640 ug/L

Date

Enhanced Bio Inj #1
Enhanced Bio Inj #2

1,1,1-TCA Concentration (ug/L)

BH106
BH205
BH301
BH106R
BH205R
BH206
BH206R
BH207
BH302
MW18-01
MW18-02
MW18-03
MW18-04
BH106R
BH205R
BH206R
Analytical Results – 1,1,1-TCA

1,1,1-TCA Concentration (ug/L)

Date

Enhanced Bio Inj #1
Enhanced Bio Inj #2
BOS 100® Pilot-Test
BOS 100® Full Injection

1,1,1-TCA Std = 640 ug/L
Analytical Results – 1,1-DCE

1,1-DCE
Std = 1.6 ug/L
Analytical Results – 1,1-DCE

1,1-DCE Std = 1.6 ug/L
Analytical Results – 1,1-DCE

1,1-DCE Concentration (ug/L)

1,1-DCE Std = 1.6 ug/L

Date


Enhanced Bio Inj #1
Enhanced Bio Inj #2
BOS 100® Pilot-Test
BOS 100® Full Injection

BH106
BH205
BH206
BH207
BH301
BH302
MW18-01
MW18-02
MW18-03
BH106R
BH205R
BH206R
Analytical Results – Average 1,1-DCE Concentrations

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**LEGEND**
- PRE-BOS INJECTION INFERRED PLUME
- PROPERTY BOUNDARY
- EXISTING BUILDING
- FENCELINE
- EXISTING MONITORING WELL LOCATION
- EXISTING UNDERGROUND UTILITY CONCENTRATION EXCEEDS MEC

**TABLE 3 (CSF 2011)**
Lessons Learned:

• Deep plumes in tight overburden soils are very “Difficult Aquifers” to treat via conventional injection methods
• Bench & Pilot-Testing is critical!
• The Sonic Pre-Drilling Approach can provide a cost-effective alternative
• The Sonic Pre-Drilling Approach can provide a delivery method for otherwise inaccessible “Difficult Aquifers”
• R&D for new Injection Methods should not be completed in the winter!
Questions

Thank You for Your Time

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