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Big Question(s)
What, How, Where and When

- What: Should I be measuring?
- How: Should I be measuring?
- Where: Should I be measuring?
- How Often: Should I be measuring?

Presentation Outline
- Basic Review & Philosophy
- Conceptual Site Model (CSM)
- Site Characterization vs. Performance Monitoring
- Pilot vs. Full-scale
- Review of Methods
- Case Studies Results
- Conclusion
Basic Review

Chemistry

Basic chemistry requires:
- Right reaction conditions
- Sufficient amount of reactants and
- Enough time

In practice: Adjust Loading & Achieve ROI

Basic Review

How?

Must have good data quality!

Precision vs Accuracy

From: "Characterization of Concentrations at the Groundwater Interface to Evaluate Vapor Intrusion" Poster at AWWA-West—Chris Bonniwell and Francis Ramacciotti, GHD
Basic Review
Conceptual Site Model (CSM)

Where is the Problem? How Dynamic is the System?

Site Characterization vs. Performance Monitoring

- Same Site Characterization
  - Plus
- Indication of the Chemistry
- Confirmation of Radius of Influence (ROI)

Site Characterization vs. Performance Monitoring

<table>
<thead>
<tr>
<th>Reagent</th>
<th>Direct Indicator</th>
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</thead>
<tbody>
<tr>
<td>Permanganate</td>
<td>Purple/pink</td>
</tr>
<tr>
<td>Persulfate</td>
<td>Electrical Conductivity/Sulfate</td>
</tr>
<tr>
<td>ZVI</td>
<td>Magnetism/ORP</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>Temperature</td>
</tr>
<tr>
<td>Carbon</td>
<td>ORP/TOC</td>
</tr>
<tr>
<td>ROI</td>
<td>Tracers, Conformational Probing</td>
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Pilot vs. Full-scale Performance Monitoring

- Cast a wider Net During the Pilot
- “Field Optimization”
- Process Monitoring
- Performance Objectives/Corrections

Review of Methods

Planning The Plan

Performance Monitoring Plan Should Be:
- Site Specific
- Contaminant Dependent
- Based on the CSM
- Dynamic
- Consider Final Site Use
- Clearly Defined

Review of Methods

Planning Your Plan

Additional Considerations:
- Define Success
- Budget
- Compliance Monitoring
- Limitations
Review of Methods
Parameter Selection & Evaluation

- Chemical
- Physical
- Biological Processes
- Soil
- Air
- Water

Monitoring to evaluate changes in condition and progress towards meeting a performance objective

Parameter Matrix
- Source
- Plume
- Background Sampling Location
- Essential
- Valuable
- Conditional Data Needs Evaluation

Recommended Resources

Mini Case-Studies
- Typical Size Bioremediation
- Typical Size ISCO
- Large-Scale with Multiple Pilot
- Large-Scale with "Field Optimization"

Source: Rob Schade, Strategyn
Case Study II – Southern NJ Commercial Site

Site Overview

Contaminants of Concern

BTEX and Chlorinated VOCs

- Benzene
- Toluene
- PCE
- TCE

Goal
Reduce Saturated Soil and GW Impact in the Source Area, Specific to BTEX, by 75%+

Baseline GW Concentrations (ppb)

<table>
<thead>
<tr>
<th>contaminant</th>
<th>GW - 1,000</th>
<th>GW - 12,000</th>
<th>GW - 10.5</th>
<th>GW - 9.3</th>
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<tbody>
<tr>
<td>Benzene</td>
<td>1,850</td>
<td>(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>12,000</td>
<td>(600)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCE</td>
<td>10.5</td>
<td>(1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCE</td>
<td>9.3</td>
<td>(1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources

- BTEX: Former Gas Station USTs
- BTEX: Former Bulk Fuel Storage

CVOCs: Former Dry Cleaner Treatment Area

Treatment Area

- Fine – Medium Sand
- Semi-Confining Clay
- Base

Estimated k (ft/day)

0.41 ft/day

Estimated Porosity

30%

SOD (g/kg)

1.2

Remedial Approach

Base - Activated Sodium Persulfate
Direct - Push Injection Grid

Species Zone

- MW - 1, MW - 6
- Deep - MW - 21
- Plume - MW - 15, MW - 23

Essential Parameters

Physical

- Water Quality Parameters: Water Levels

Chemical

- VOCs (including Daughters): Sulfate, Sodium
- Persulfate Test Kit

Valuable Parameters

Chemical

- Soil VOCs @ 6 Months
- Fractionated EPH @ 6 Months

Physical

- GW TRF @ 6 Months

Conditional Parameters

Chemical

- Standard Method

Performance Monitoring Plan

Timing

- Baseline: 1 Week, 2 Weeks
- Monthly for 6 Months

Spatial

- Source Map: MW 1: Source Deep - MW 21
- Plume: MW 15, MW 23

Southern NJ Commercial Site

Field Implementation

Caustic Totes in Containment
Persulfate Mixing
Southern NJ Commercial Site
Field Implementation

EC-01 – 3-ft Away
EC-02  6-ft Away

Field Optimization
EC-Logging for Radius of
Influence Confirmation

Is the Remediation Working?
Round One – 2 Weeks

- Skipped 1-week event
- Source Wells Only - immediately adjacent to injection area
  - No positive persulfate test kits in treatment area and interval
  - No elevated pH readings
  - Increased temperature
- Data Set is Inconclusive!
### Is the Remediation Working?

**Round Two - 1 Month**
- Water Quality
  - Same Trend
- Analytical
  - Surprising Results
- 180° Change of Interpretation
  - Analytical data
  - Up and Side-Gradient Data
  - Re-analysis of MIHPT Logs
- Raises New Questions

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### Is the Remediation Working?

**Round 3**
- 3 Months Post-Injection
- Water Quality
  - Same Trend
- Analytical
  - First Signs of Rebound

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### Is the Remediation Working?

**Final Round**
- 6 Months Post-Injection
- Water Quality
  - Temp Rebound, WL Elevated 3 to 4 feet
- Analytical

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Is the Remediation Working?

Conclusions
- Supplemental Injections
- What Happened?
  - Treatment Interval Selection
  - Residence Time
- Persulfate was effective, but was it the right choice?
- Re-Evaluate Monitoring Plan
  - Up/Gradient Wells
  - Further Downgradient Wells
  - Earlier Events

Performance Monitoring
Large-Scale with Pilot

Performance Monitoring
Full-Monty

- VOCs
  - Parent
  - Daughters
- Dissolved Gases
  - Ethene
  - Acetylene
- DOC
- Tracer dyes

- Field Measurements
  - ORP, DO
  - pH
  - Etc.
- Nitrate
- Ferrous Iron
- Manganese
- Sulfate & Sulfide
- Methane
- Alkalinity

- qPCR
  - Dehalococcoides
  - Dehalobacter
  - Dehalogenases
- Compound Specific Isotope Analysis (CSIA)
Performance Monitoring Pilot Scale Studies

- MLR Gradient Orientation Distance:
  - Cell 2: 12 ft
  - Cell 3: 25 ft
  - Cell 3-30: 80 ft
  - Cell 3-30: 90 ft
  - Cell 4: 150 ft

- Geochemistry:
  - ETSU
  - OTC: Tannin, GB

- Median pore 
  - length: 0.5

- Initial Injection Polishing

Performance Monitoring Full-Scale

- Chemical
  - VOCs: Parents
  - Dissolved Gases: Ethylene
  - DOC
  - Trace Elements

- Geochemical
  - Field Measurements:
    - CN, DO
    - pH
    - Etc.
    - Nitrates
    - Ferrous Iron
    - Manganese
    - Sulfate & Sulfide
    - Methane
    - Alkalinity

- METs
  - qPCR:
    - Dehalococcoides
    - tDNA
    - tRNA and sRNAs
    - Dehalobacter
    - Dehalogenaminos
  - Comp. Specific Isotopic Analysis (CSIA)

- Overview
  - All Sites were Below USEPA MCLs and KDA ESKs within Months of Injections

- Typical Injection Design
  - Injection Point Spacing
    - High Conc: 40-50 feet on center
    - Low Conc: 20-25 feet on center
  - Loading Rates:
    - 0.35 percent of soil mass (low conc.)
    - 0.49 percent of soil mass (high conc.)
  - Injection Depths:
    - 10-44 feet bgs

- Full-Scale Performance Monitoring Successfully Completed

- Dec. 2014
- Oct. 2017
- Mar. 2018

- Total Sites: 82
- Total Injection Area: 875,699 sq. ft.
- Total Soil Mass Treated: 1,111,999 tons
- Duration (field days): ~500 days

- On Average All Sites were Below USEPA MCLs and KDA ESKs within Months of Injections
Injection of additional ZVI and organic substrate via pneumatic fracturing and injection of organic substrate and microbes.
Performance Model

“Remediation Management of Complex Sites” Webinar, ITRC.

Compare Predicted with Actual Performance

Lessons Learned
- Be Patient - Consistency Creates Trends
- Be Diligent – Utilize Data
- Be SMART™ – Follow or Improve Plans

Be Ready
- Revise Monitoring Plan – Time & Space
- Revisit Reagent Selection
- Refine Injection Tools and Approach