Optimizing Injection-Based Remediation in Bedrock: Lessons from DNAPL Remediation by Chemical Oxidation

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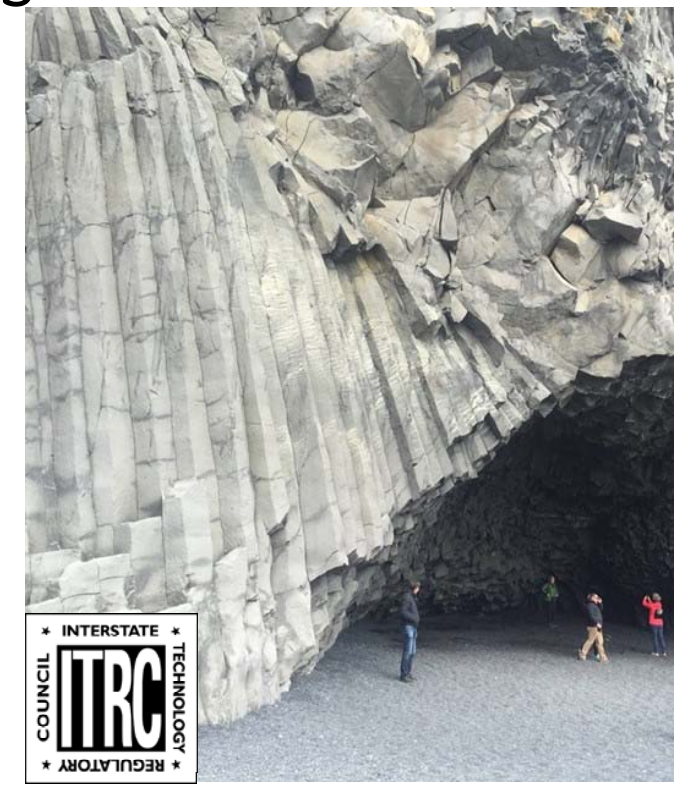
Bedrock Remediation Challenges

- Incomplete understanding of groundwater flow and contaminant transport
- Difficulties in site characterization
- Cost of investigation / remediation
- Unrealistic remedial objectives

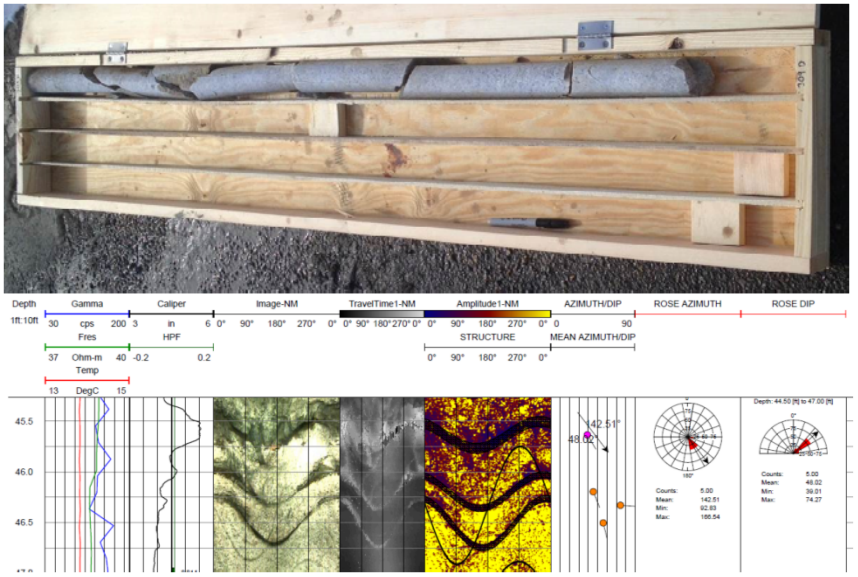


Characterization and Remediation of Fractured Rock (FracRx-1)
http://fracturedRX-1.itrcweb.org

Focus on Geology

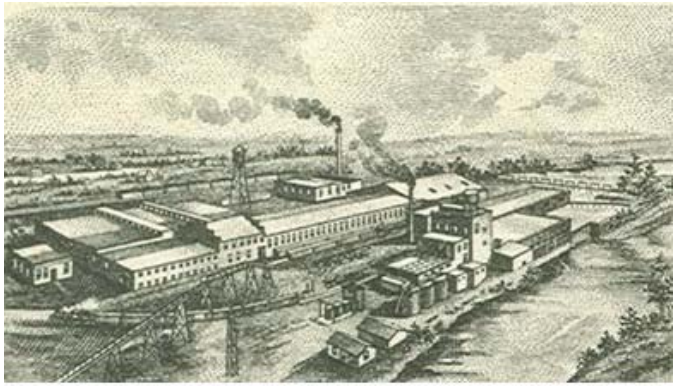
- How does site geology impact the answers to these questions?
  - Where is the contamination?
  - Where is it traveling?
  - How did it get there?
  - What amendment is being delivered?

- Injected amendments likely to follow path similar to groundwater flow



Site Setting

- Paper mill, textile manufacturing, dry cleaning
- PCE primary contaminant – >120 mg/L
  - Likely DNAPL
- Superfund-lead site
  - ROD: demolition, soil excavation, ISCO in groundwater and fractured rock
  - 50-ppb is GW remediation target
- GW flow is south towards river
  - GW depth ~5 -35 ft bgs



Site Bedrock

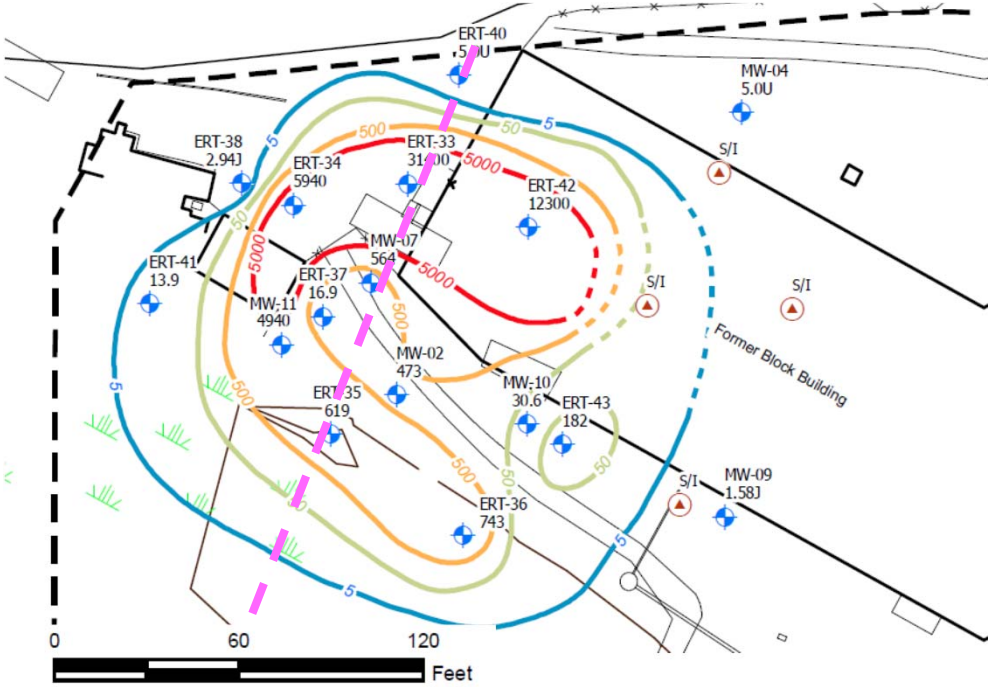
- Glacial till & floodplain deposits - 4 to 5-ft thick
- Bedrock
  - **interbedded & fractured limestone**
  - dolomitic limestone
  - dolomitic sandstone
  - granitic gneiss at ~140 feet bgs
- Carbonate bedrock
  - Upper Carbonate (UC) – to 50-60’
  - Middle Carbonate (MC) – to 80-90’
  - Lower Carbonate (LC) - to 140’

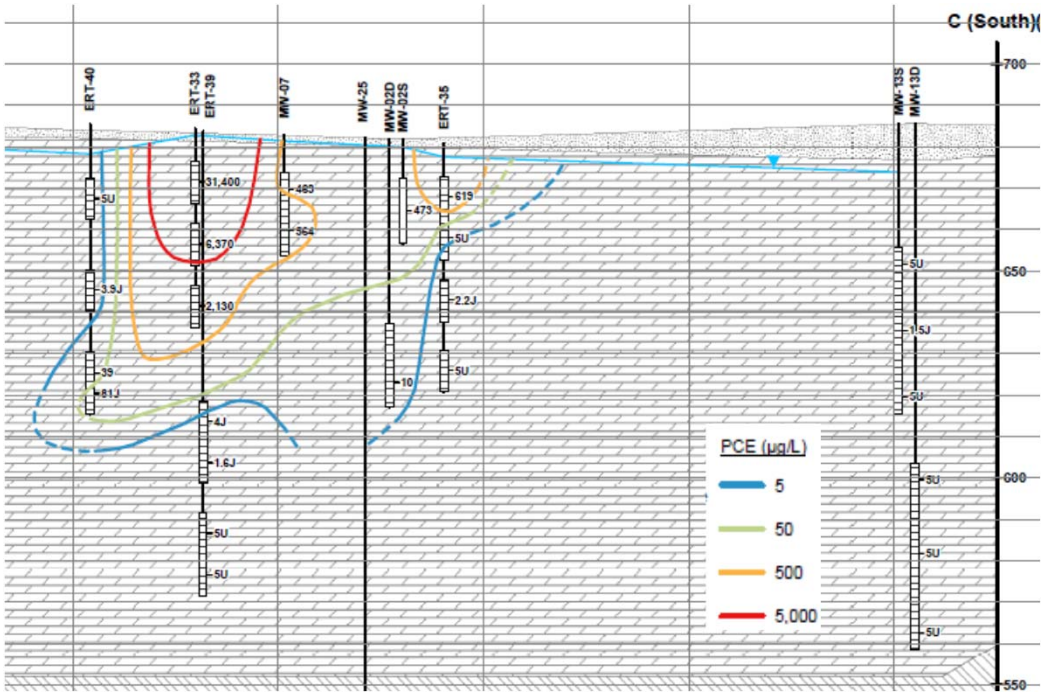
Site Bedrock

- Geophysical investigation
  - bedding plane fractures slightly dip away from the river
  - vertical fractures strike toward river.
  - predominantly low angle (<10°) bedding planes

- Consistently no flow or very little vertical groundwater flow (upward) within the carbonate bedrock boreholes

PCE in Site Bedrock



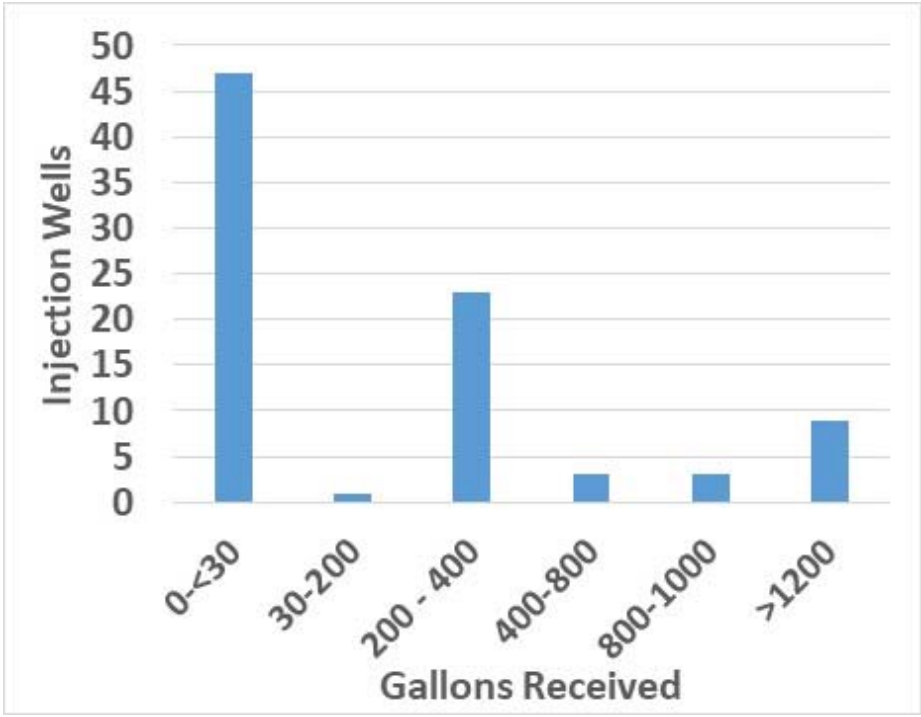


Bedrock Groundwater Remediation

- Air hammer drill rigs installed injection wells
  - 43 IWs: 30-ft bgs, 2”, 20-ft screens
  - 19 nested IWs: 2”, 20-ft screens (@ 30 & 75-ft bgs)
  - 4 nested IWs: 2”, 20-ft screens (@ 30 & 55-ft bgs)
- Injection wells for chemical oxidation injections
  - Sodium persulfate selected as oxidant

Injection Event 1

- Sodium Persulfate
  - Molar ratio of base:persulfate < 0.5:1
  - Overburden and Bedrock
  - 24,300 gallons injected in bedrock
- Higher Injection rates (~5-10 gpm)
  - Significant daylighting
- Many IWs did not receive ISCO
  - >60% of volume into 12 wells (of 89)
- PCE results mixed (decreased some / increased many)
  - Increase in sulfate, chloride, and CO2 in many wells



Injection Event 2

- Chemical Oxidation primarily treats aqueous phase PCE

- Can non-aqueous phase PCE be made more available for treatment?
- Modified Fenton's Reagent (MFR) solubilizes DNAPL
  - Bubble agitation
  - Free radicals
    - $O_2\bullet^-$ surfactant-like effect
  - Globule breakdown

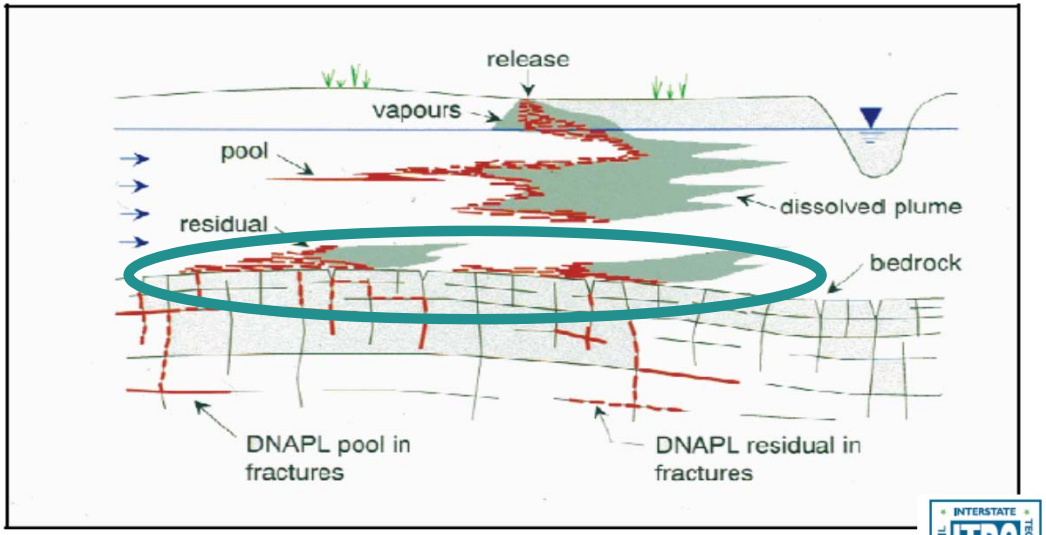
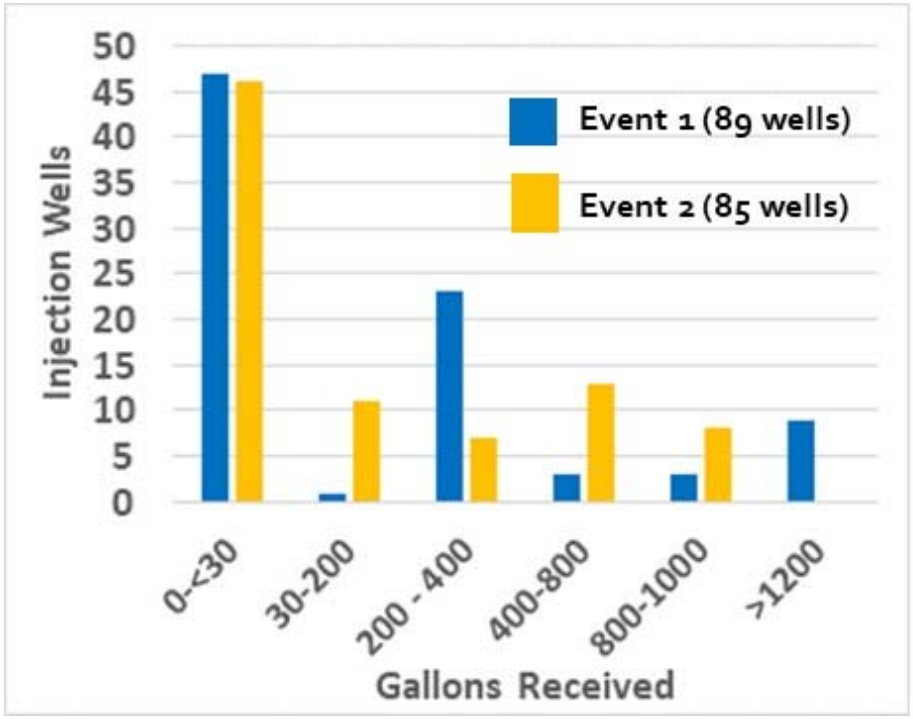


Figure 1-1. Conceptual site model of a DNAPL source zone.
(*Source:* U.K. Environmental Agency 2004)

In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones, ITRC, June 2008

Injection Event 2

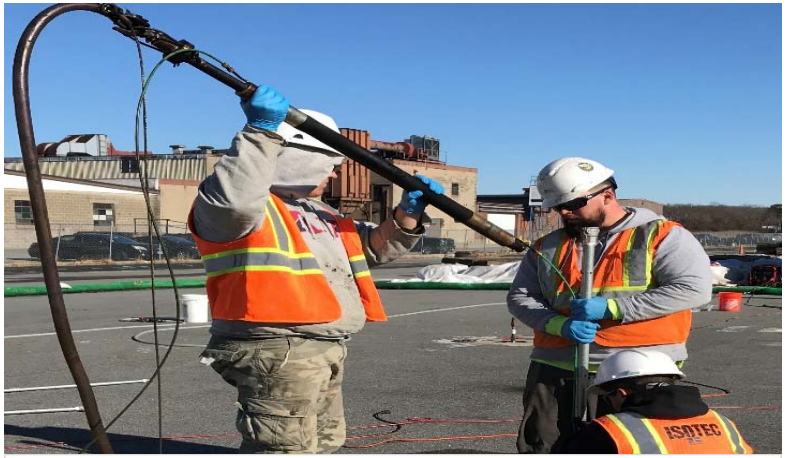
- Modified Chemical Oxidation
  - Base Buffer Capacity Test
  - 2:1 molar ratio of base:persulfate
  - Bedrock: BASP
  - Overburden: MFR + BASP (1:1 v/v)
- Lower injection rates & more pumps
  - 85 wells
  - 0.5-1.5 gpm / Less daylighting
  - Multiple attempts into wells
  - 18,900 gallons injected in bedrock

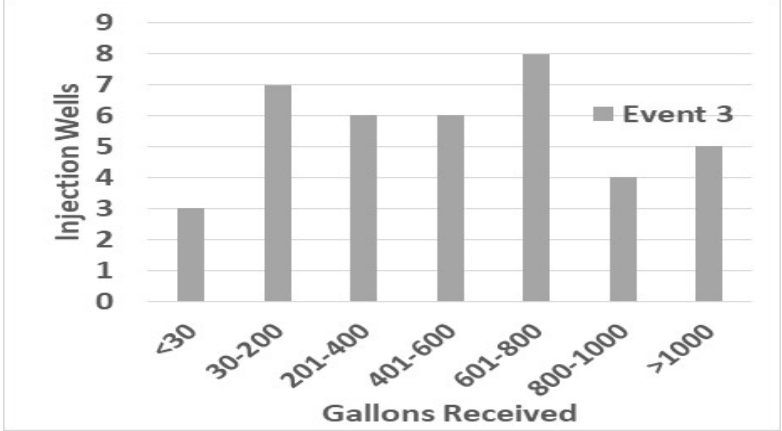


Large increases in PCE concentration in BR

Injection Event 3

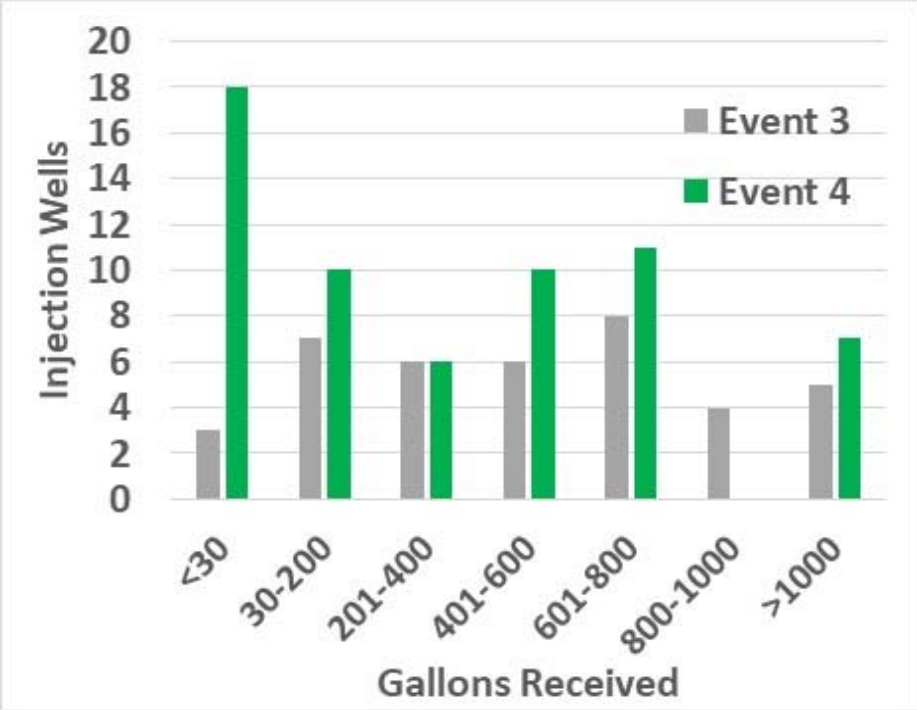
- BR Well Modifications
  - Removed casings and screens
  - Re-install casings keyed into bedrock
  - Open boreholes for injection
- Bedrock: BASP
  - Straddle Packers to target intervals
  - 39 wells
  - MFR (5% H2O2) in 13 BR boreholes (pilot)
  - 20,700 gallons injected in bedrock





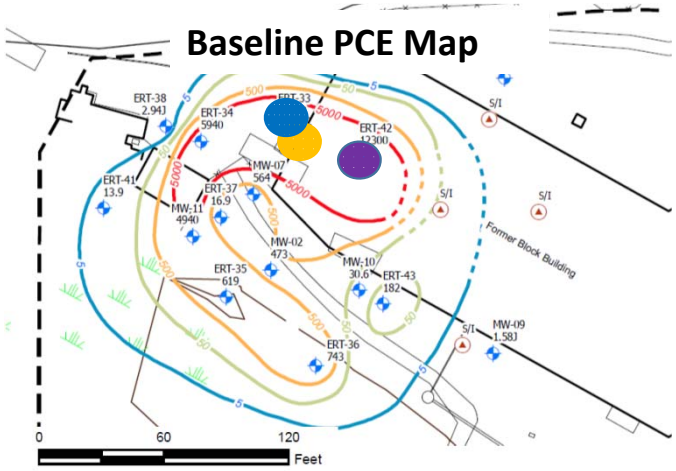
Injection Event 4

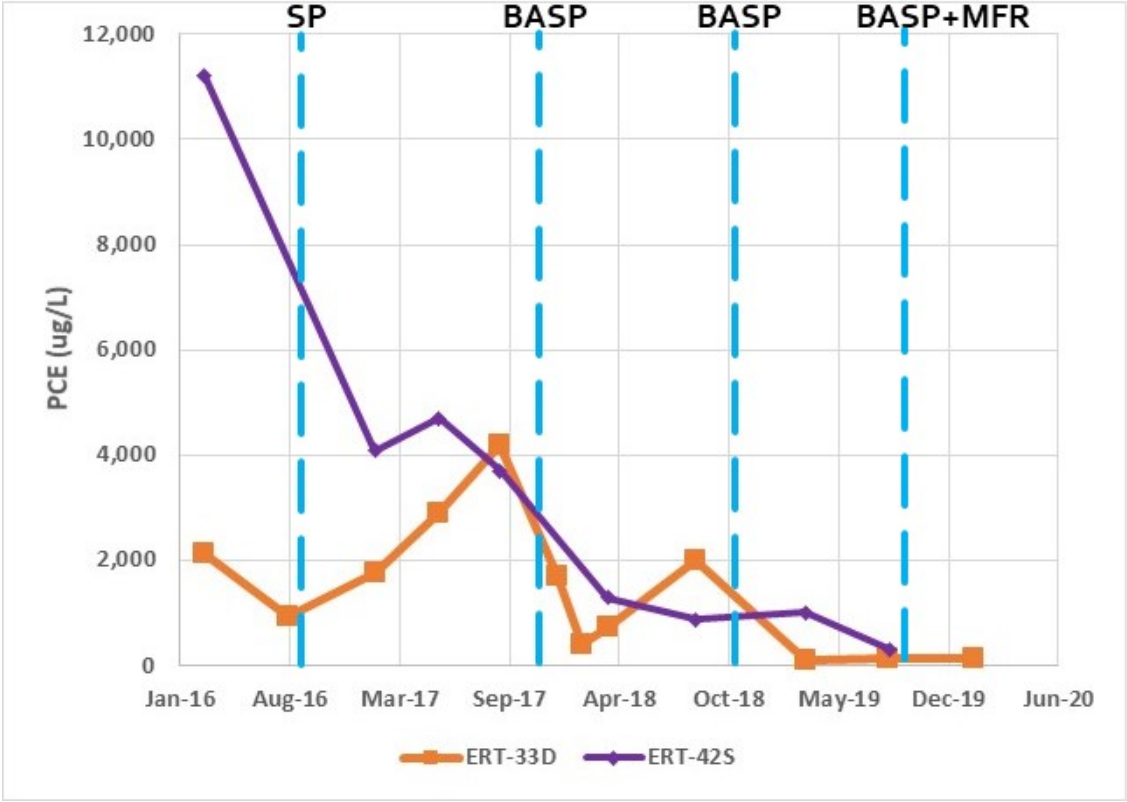
- Additional BR injection points
  - Not all boreholes connected
- Increased injection volume into BR
  - 62 wells
  - MFR + BASP in 24 wells (MFR:BASP ~ 1:1 v/v)
  - Straddle Packers
  - 26,000 gallons injected in bedrock



Performance Results

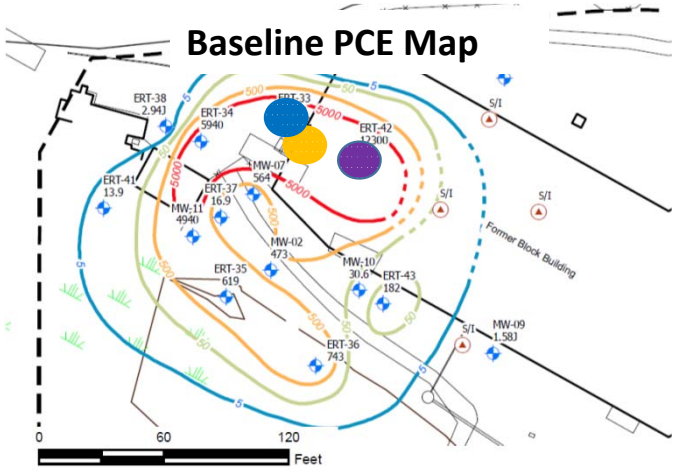
- Source Area Wells:
  - ISCO effective treatment for aqueous phase contamination

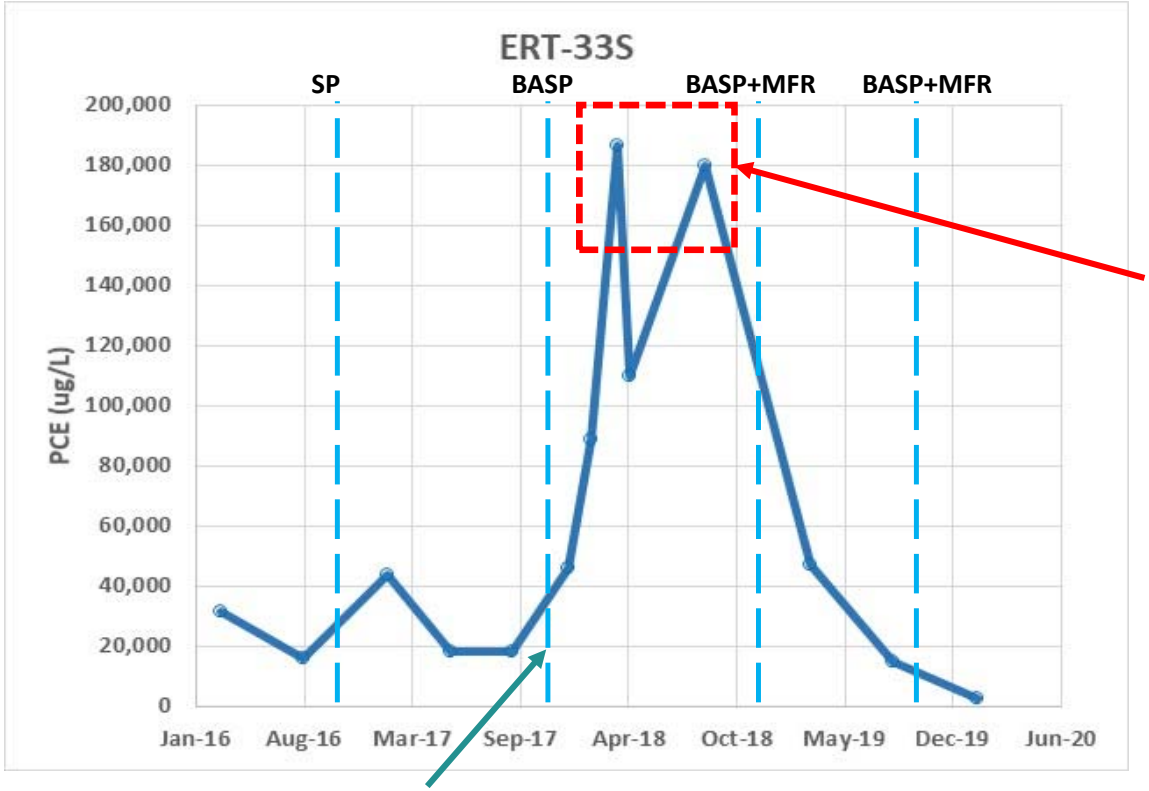




Performance Results

- Looking at long view for DNAPL treatment



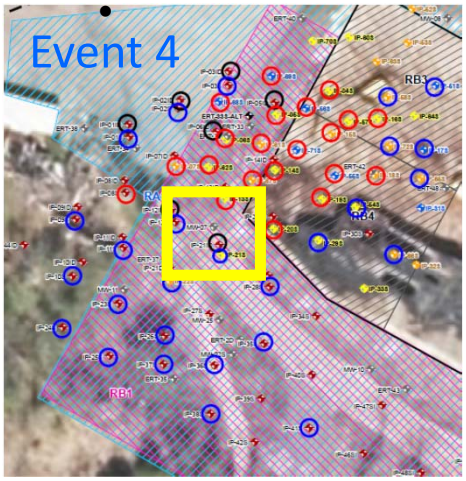


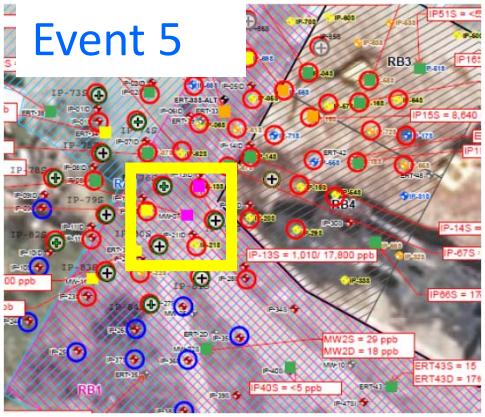
Aqueous solubility of PCE 150-200 mg/L

MFR + BASP at BR interface – desorption of DNAPL

Performance Results

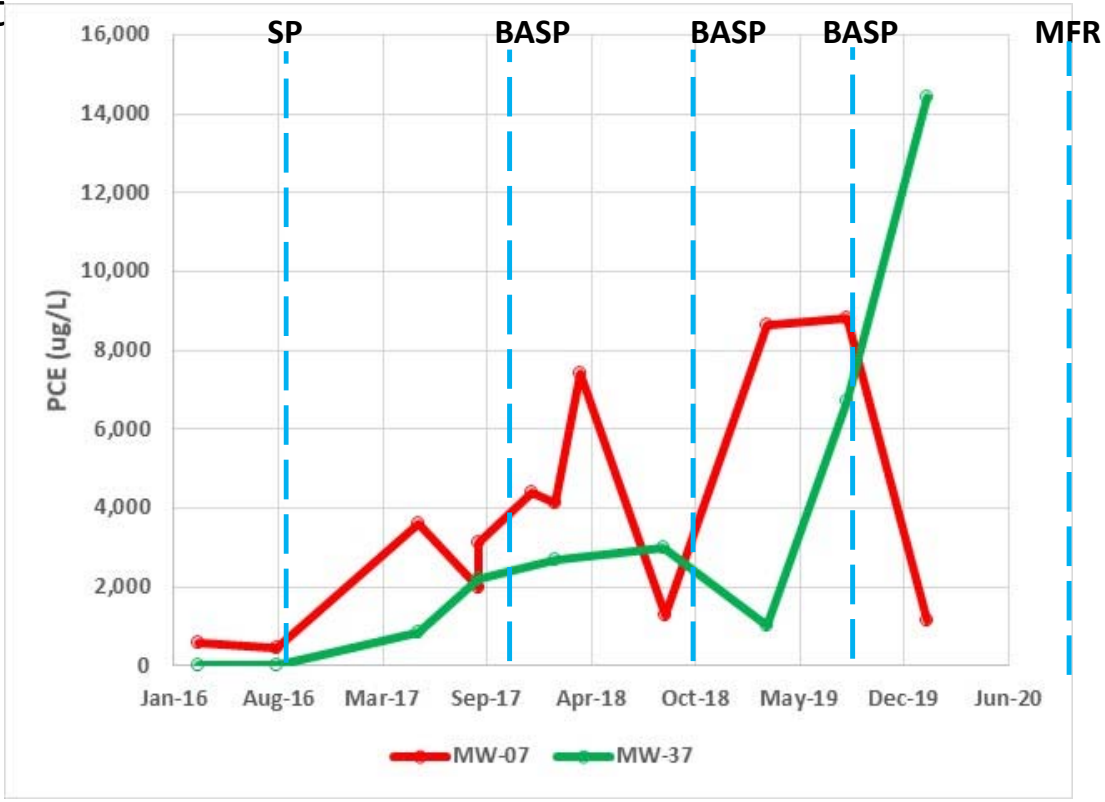
- Looking at long view for DNAPL treatment
  - Migration and/or Localized DNAPL





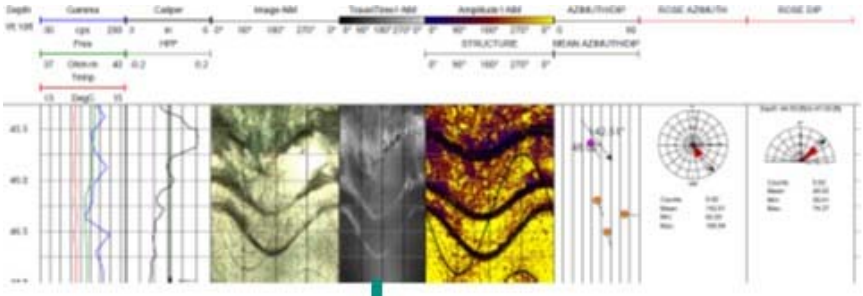
BASP

BASP+MFR



Summary

- If at first you don't succeed…
  - Re-evaluate Conceptual Site Model
  - Optimize Remedial Design
- …Try again



Thank You

Jeff Catanzarita (USEPA ERT)

ISOTEC REMEDIATION TECHNOLOGIES

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