ENHANCED IN-SITU BIOREMEDIATION

Implementation Design & System Operation

CONTACT!!!

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Impacts of Geology / Contaminant Distribution

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Delivery system Design / Selection

Mike Marley : ~ 1:45 to 3:00pm

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Establishing Contact

- EISB has been applied successfully in a variety of geologies
  - Relatively Easy
    - Homogeneous soils with residual impacts
    - Primarily dissolved plumes (be careful with implementation strategy)
  - Not as Easy
    - NAPL lenses
    - Heterogeneous
    - Rapid groundwater flow
  - Difficult and / or Expensive
    - Thick pore filled NAPL layers
    - Matrix diffusion / mass transfer dominated
    - Highly - heterogeneous / preferential pathways
    - Very low permeability soils

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Establishing Contact

- Key factors:
  - Detailed geology / hydrogeology – at remediation selection / design available site specific information very variable
    - Especially in bedrock
  - Contaminant mass distribution / architecture
    - Typically not well known
      - Phase distribution (aqueous, soil, NAPL)
      - Architecture-specifics of phase distribution
      - Pore filled NAPL – lenses and layers
  - Implementation strategy
    - Site logistics
    - Contaminant phase – e.g. next slide
    - Substrate / added bacteria – mobility
      - E.g. low mobility – slow release for mass transfer dominated conditions

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Phase Distribution

example: soil / groundwater

Contaminant	Average Concentration (μg/L)	Organic carbon fraction in soil f_{oc} (%)	Calculated Concentration on Soil (μg/Kg)	Mass in GW (%)	Mass on Soil (%)
VC	1,000	0.1	2	**99%**	**1%**
DCE	1,000	0.1	49	**78%**	**22%**
TCE	1,000	0.1	126	**57%**	**43%**
VC	1,000	0.5	12	**93%**	**7%**
DCE	1,000	0.5	245	**41%**	**59%**
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VC	1,000	1	25	**87%**	**13%**
DCE	1,000	1	490	**26%**	**74%**
TCE	1,000	1	1,260	**12%**	**88%**

Requires different implementation strategies

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Bedrock

Matrix Diffusion

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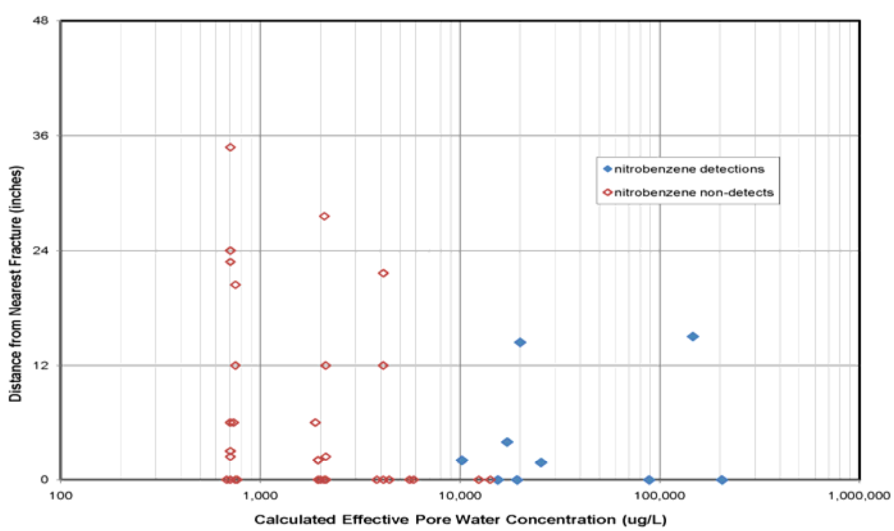
Pore Water Nitrobenzene Distribution in Sandstone



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Site 2 – Hydrogeology

- Passaic Formation bedrock
  - Siltstone and shale (“red beds”)
  - Gently-dipping bedding plane fractures
  - Steeply-dipping joints
- Water table 30’ deep, in bedrock
- Fracture data (mean values)
  - Spacing (s) = 0.36 m
  - Aperture (e) = 180 microns
  - Fracture porosity = e/s = 0.0005
- Matrix data (mean values)
  - Porosity = 0.056
  - Bulk density = 2.62 g/cm^3
  - f_{oc} = 0.00075

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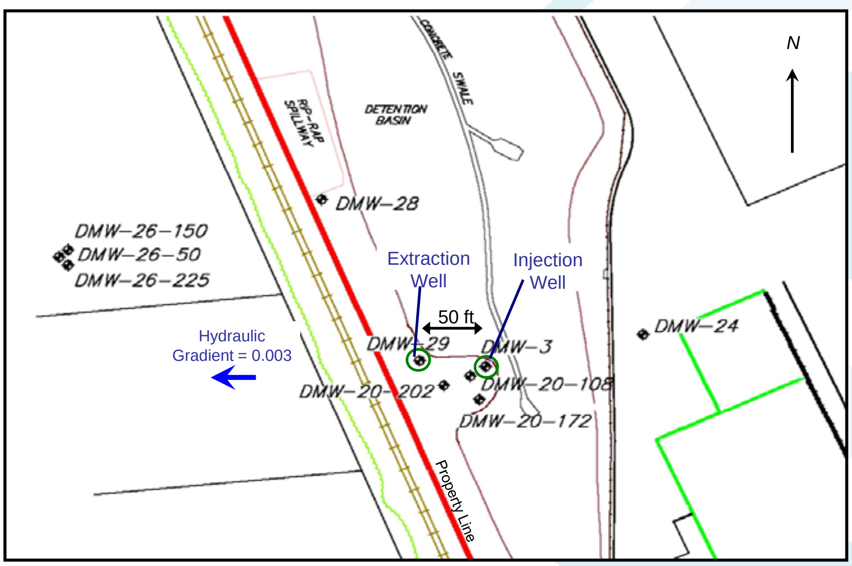
Tracer Test Area



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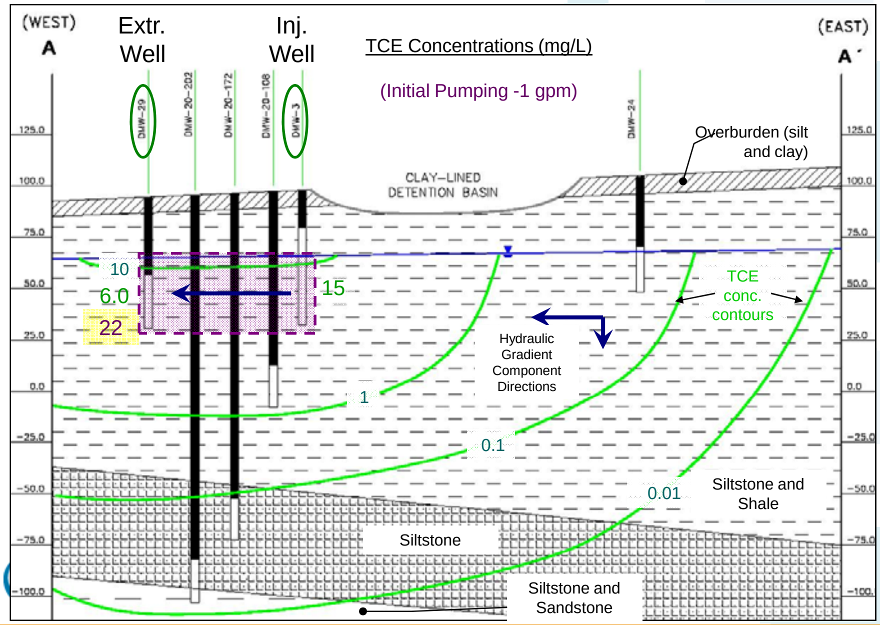
Tracer Test Setting – TCE Source Area



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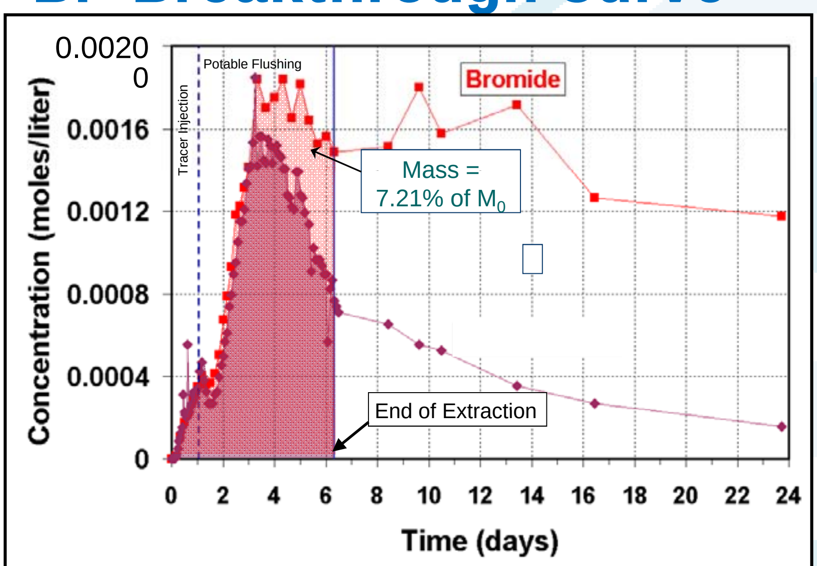
Br⁻ Breakthrough Curve



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Heterogeneous Soils

- Mass Distribution
- Preferred Pathways
- Mass Transfer / Diffusion Limitations

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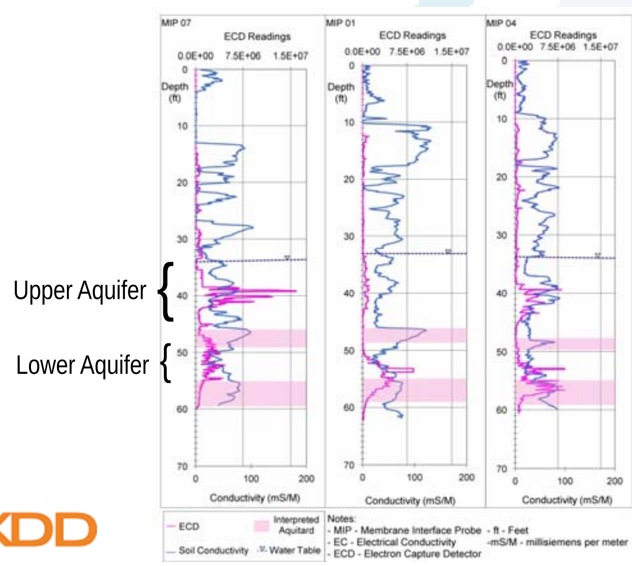
Membrane Interface Probe – Geology & VOC Mass Distribution – Site 3



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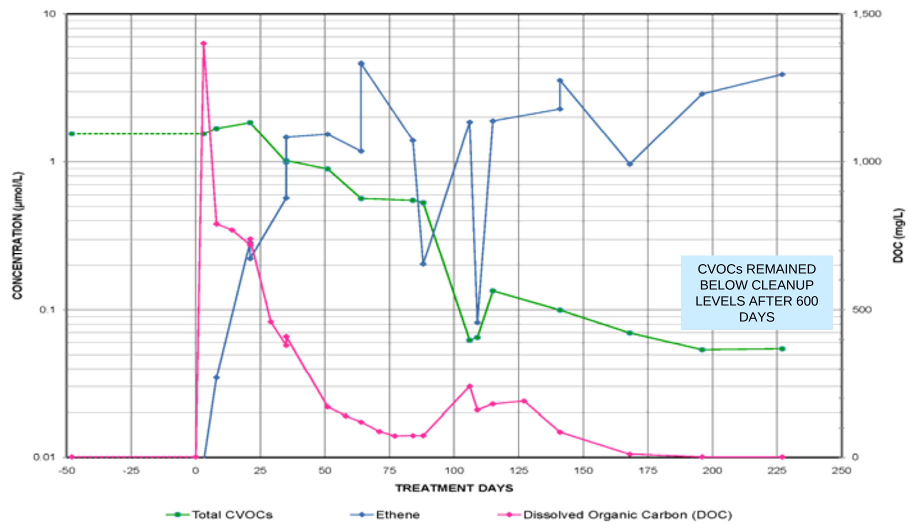
Lower Aquifer CVOC, Ethene, and DOC Concentrations Within EISB Treatment Area



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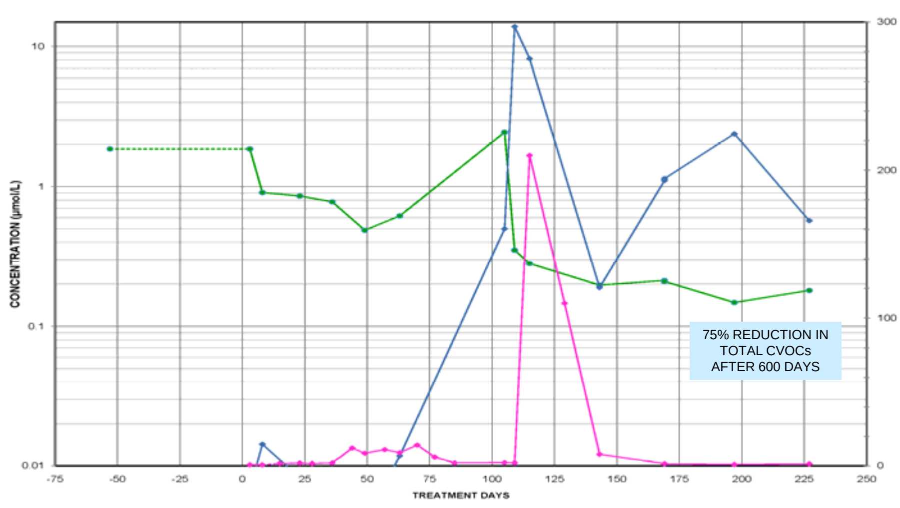
Lower Aquifer CVOC, Ethene, and DOC Concentrations Downgradient of EISB Treatment Area



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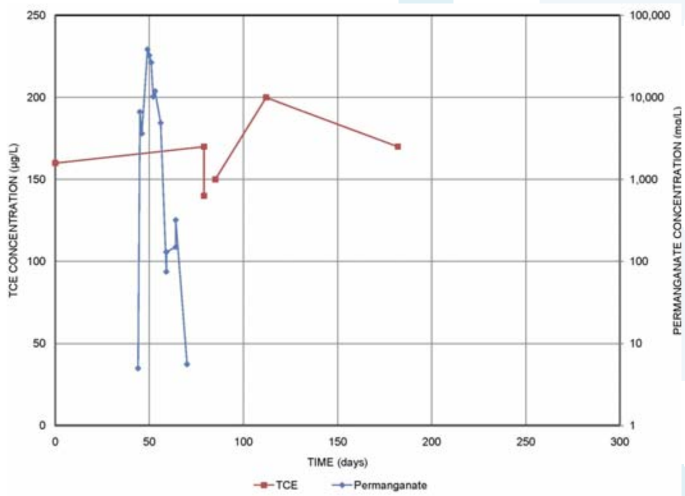
Upper Aquifer TCE and Permanganate Concentrations Rapid Groundwater Flushing – Preferred Pathways



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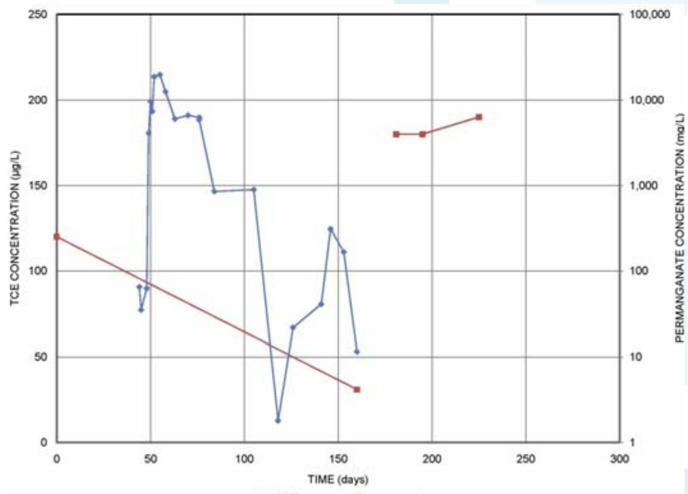
Upper Aquifer TCE and Permanganate Concentrations-Moderate Groundwater Flushing



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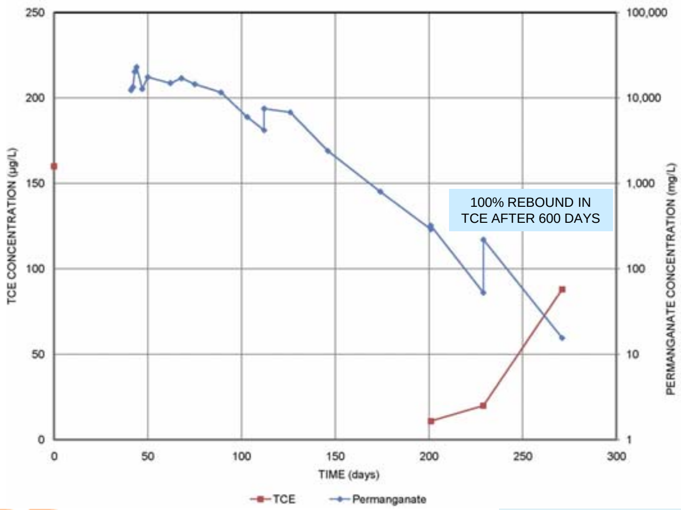
Upper Aquifer TCE and Permanganate Concentrations-Slow Groundwater Flushing



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Establishing Contact: Injection Strategies

- **Options**
  - Direct injection
    - Flow down
  - Recirculation
  - Push - Pull

- **Strategy may change during treatment**

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Direct Injection vs. Recirculation

Direct Injection

- **What it is:**
  - Injection of reagents through DPT or fixed points into the subsurface
- **What it does:**
  - Displaces pore water and contacts stationary contamination (soils or NAPL) with some mixing with groundwater
- **Best suited for:**
  - Stationary contamination (soils or NAPL)
  - Higher COC concentrations with higher remedial goals
  - High or low mobility substrates

Recirculation

- **What it is:**
  - Extraction of groundwater from a set of extraction wells, addition of reagents and reinjection of amended reagents into a separate series of injection wells
- **What it does:**
  - Assures contact with extracted groundwater while treating soil
- **Best suited for:**
  - contamination in the aqueous phase is a concern
  - Plume control
  - Enhanced contact time
  - Access is limited
  - High mobility substrate

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Direct Push Temporary Injection Point

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Phase Distribution

example: soil / groundwater

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Requires different implementation strategies

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Recirculation System

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Pull – Push vs. Flow Down

Pull - Push

- **What it is:**
  - Extraction of a set volume of groundwater, addition of reagents, and reinjection of the groundwater into the sample location from which it was extracted
- **What it does:**
  - Assures contact with extracted groundwater while treating soil
  - Minimizes aqueous contamination displacement
- **Best suited for:**
  - Small sites and where mass of contamination in the aqueous phase is a concern
  - High or low mobility substrates

Flow Down

- **What it is:**
  - Injection of reagents into lines of injection wells within or upgradient of impacted source and allow reagents to flow down to contact the source
- **What it does:**
  - Allows for lesser numbers of injection points
  - Treatment of inaccessible areas
- **Best suited for:**
  - Sites with faster moving groundwater
  - Access is limited
  - High mobility substrates

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Establishing Contact:

Additional Design Issues

- Injection Volume vs. Pore Volume
  - Lesser percent pore volume injected
    - Will primarily treat preferential pathways or limited radius from injection point
    - More dependent upon diffusion and groundwater transport
  - Higher percent pore volume injected
    - Greater distribution via advective flow
    - Less dependent upon diffusion and groundwater transport
- Fluid Density
  - Injected fluids can be denser than water so need to understand potential for vertical migration / control of the reagents especially in more uniform / permeable soils
- # Applications
  - Higher number of applications if mass transfer dominates even with low mobility – slow release substrates

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EISB Design / Application Conclusions

- Keys to meeting goals
  - Understanding COC mass distribution
  - Understanding target area geology / hydrogeology
  - Selecting appropriate injection strategy
  - Having realistic design and end-point expectations

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Questions?

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