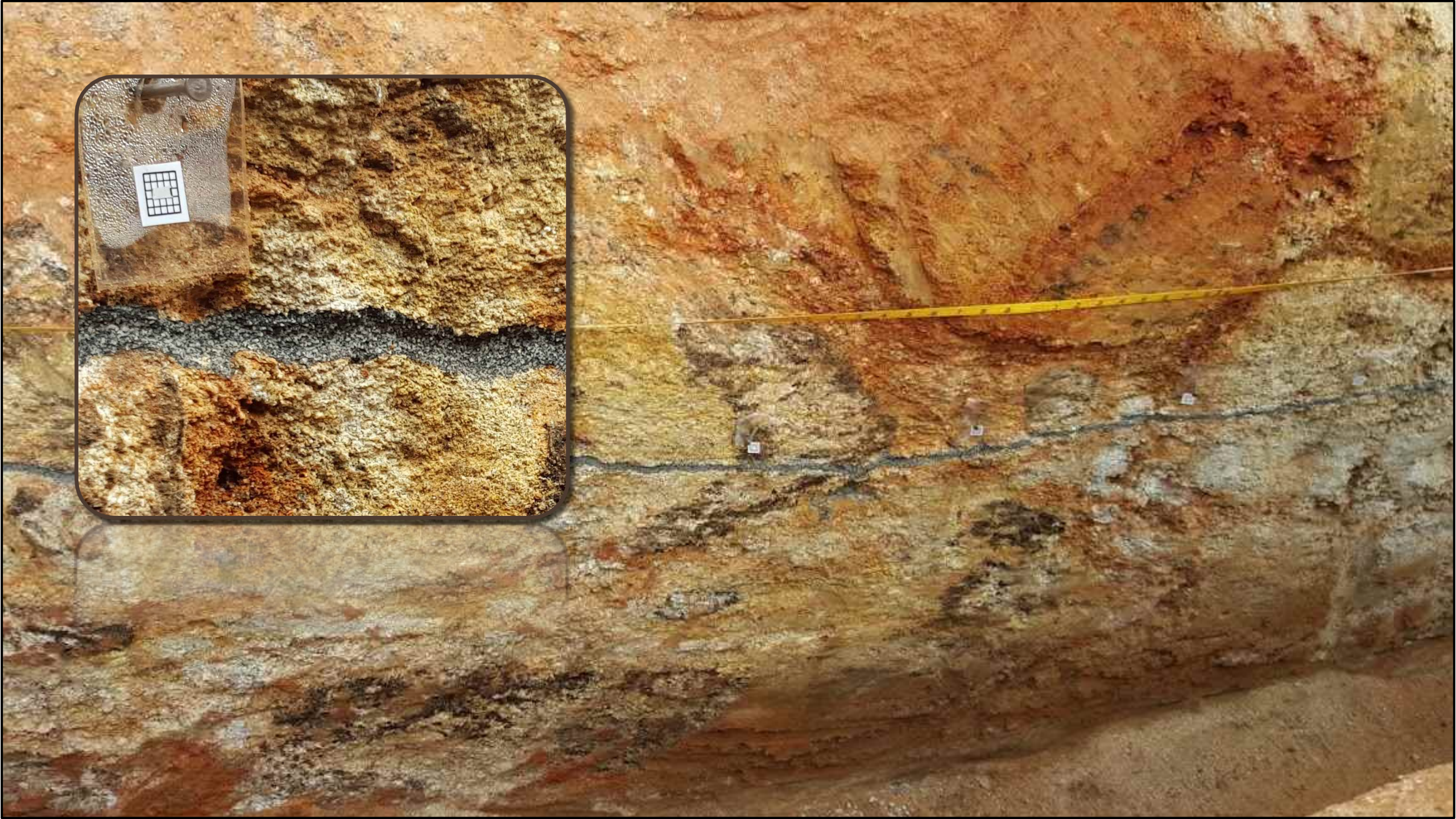


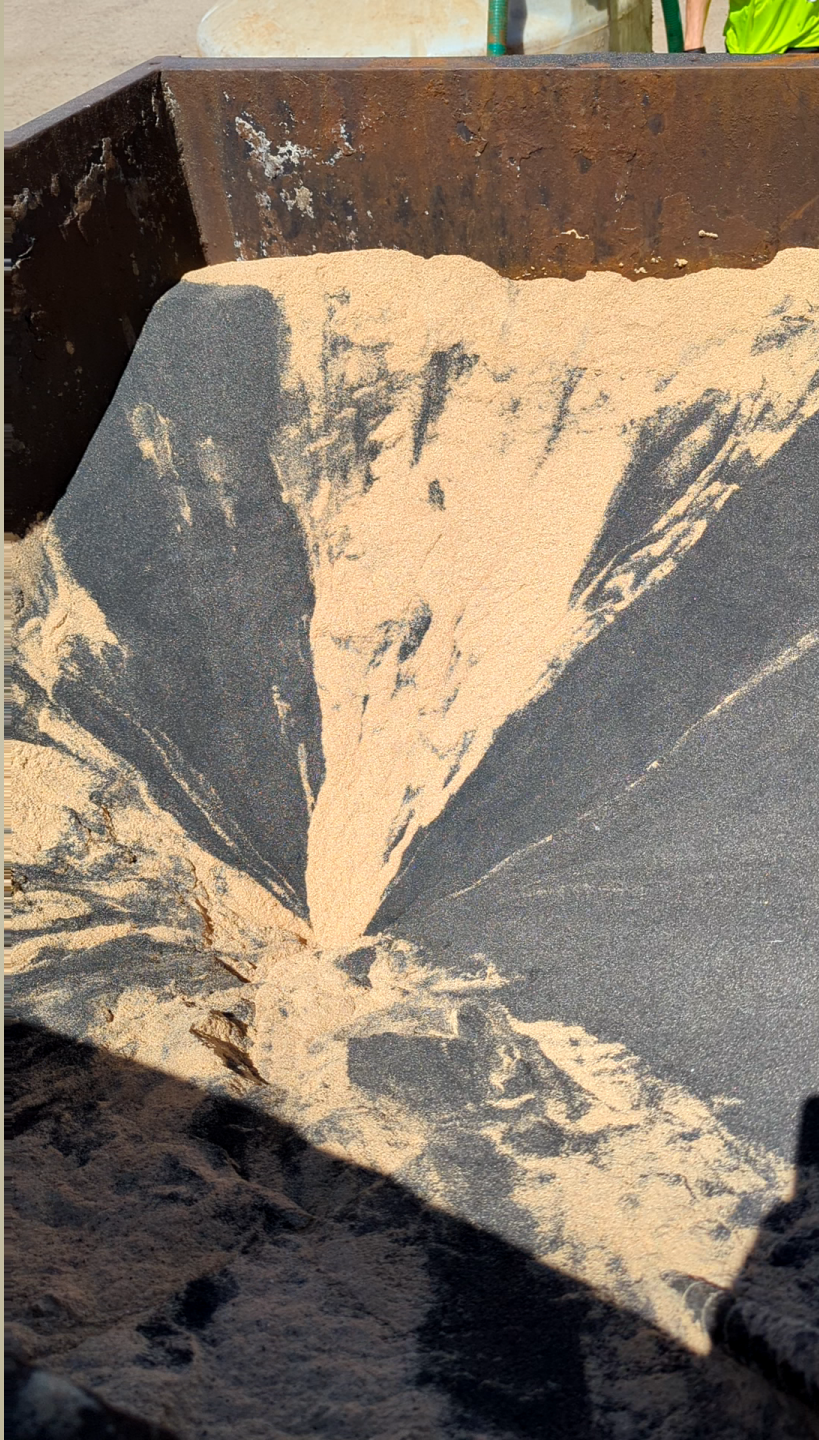
Long-Term Performance of Microscale ZVI Delivered to Low-Permeability Formations via Hydraulic Fracturing



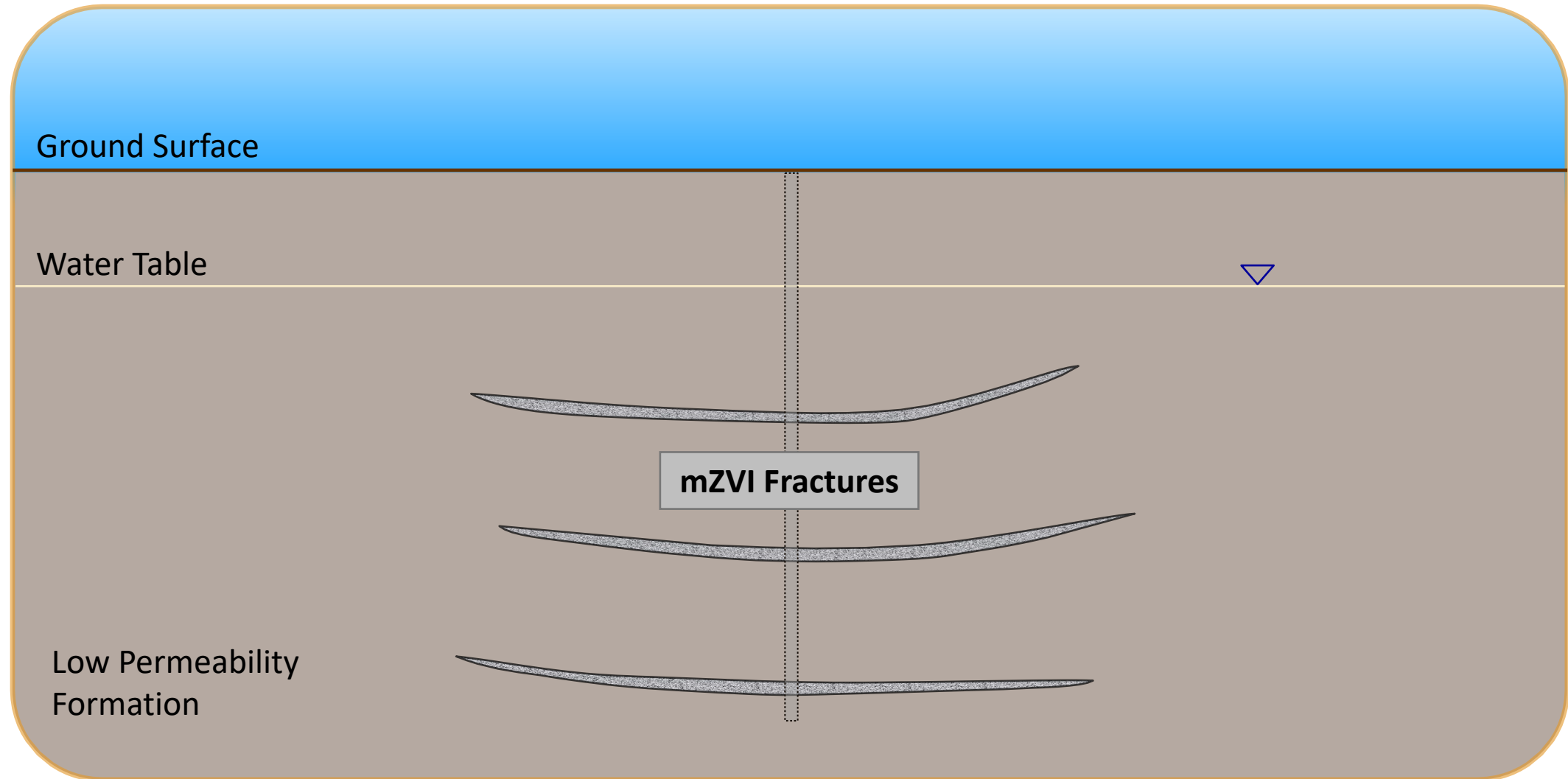
2024 Chlorinated Conference | Denver USA | June 2-6



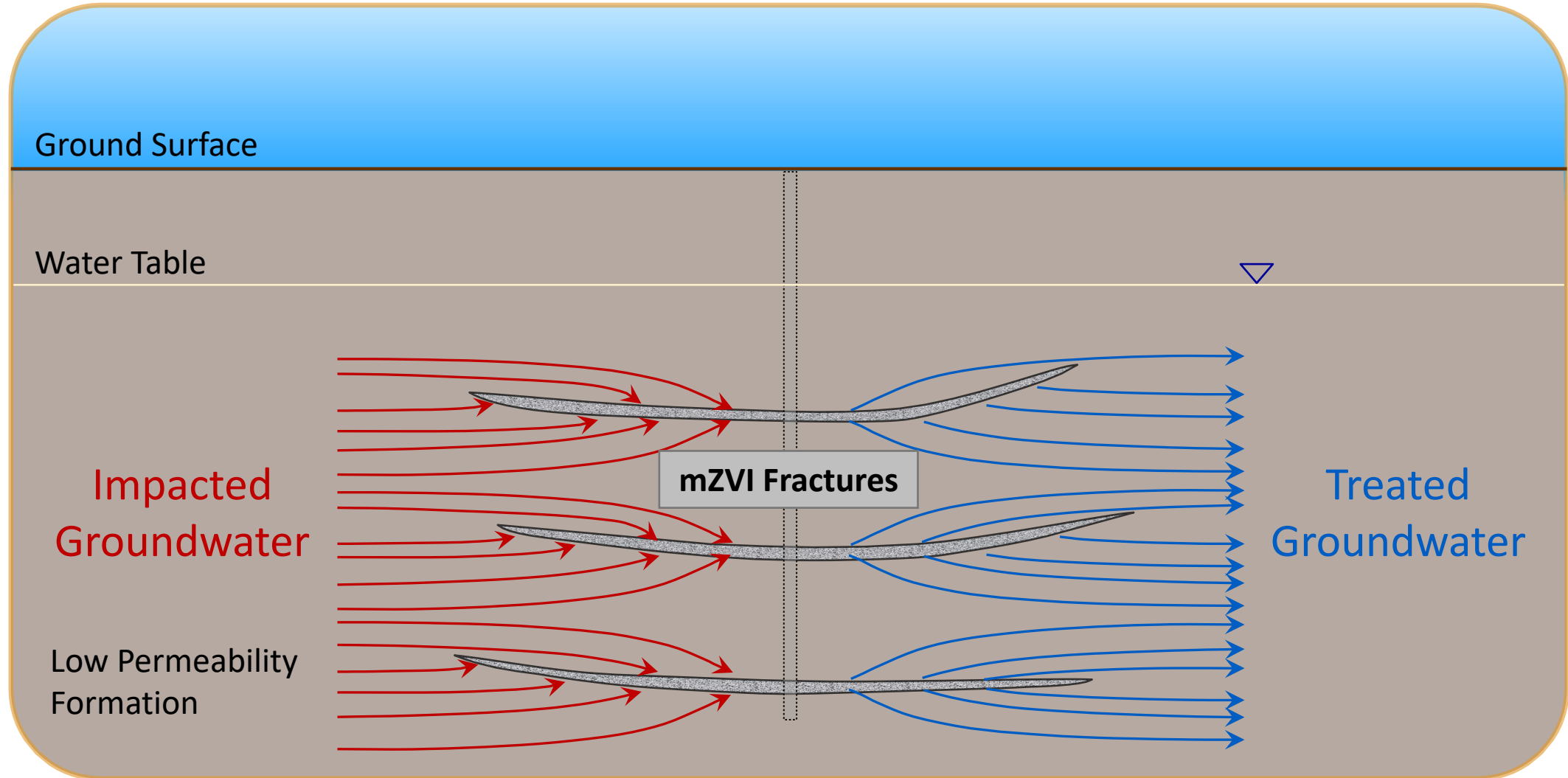




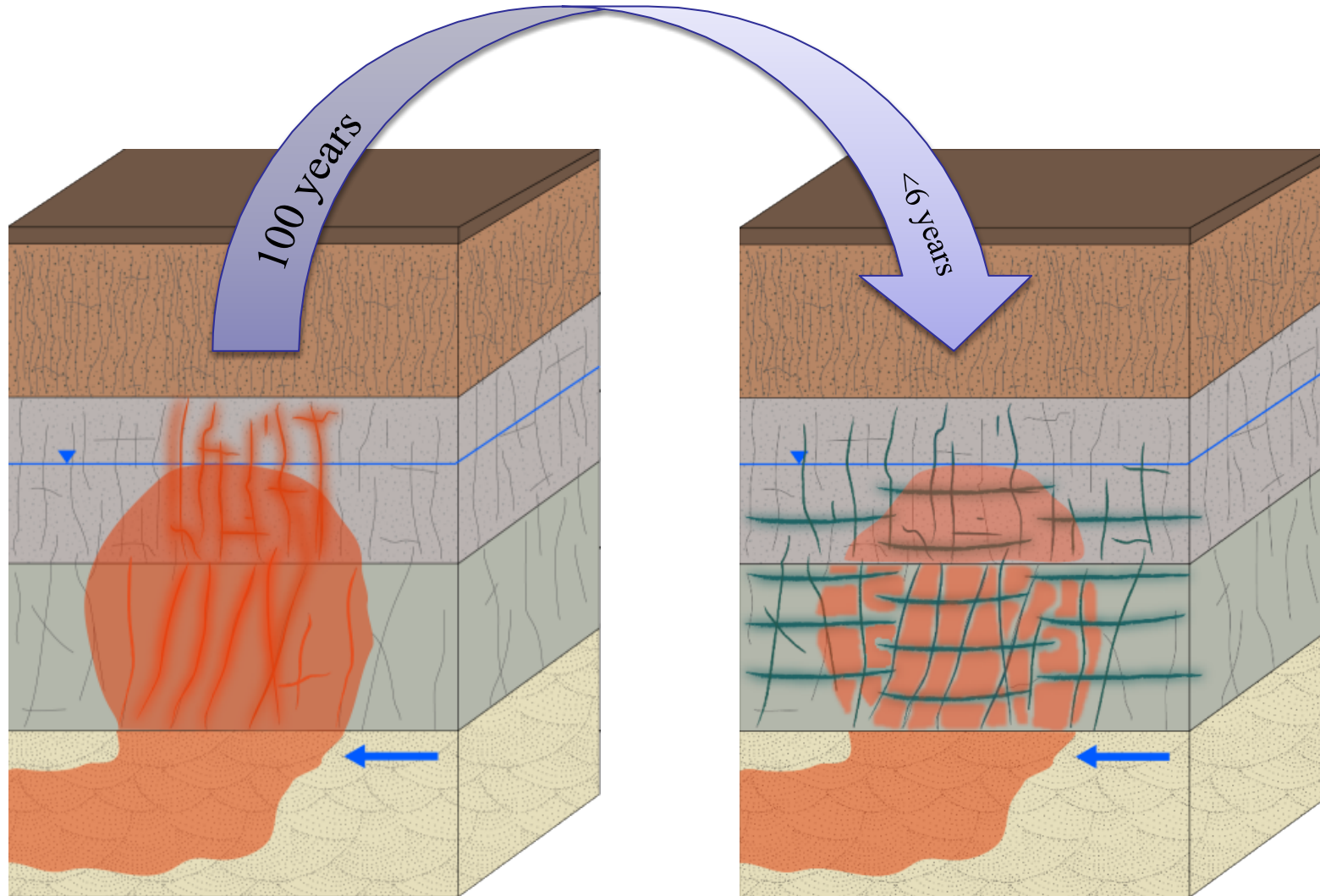
Stacked ZVI Fractures



Contaminant Capture & Treatment in ZVI Fractures



Network of ZVI Fractures – Source Zone Treatment



Case Study Acknowledgements



- Dylan Eberle and Neal Durant

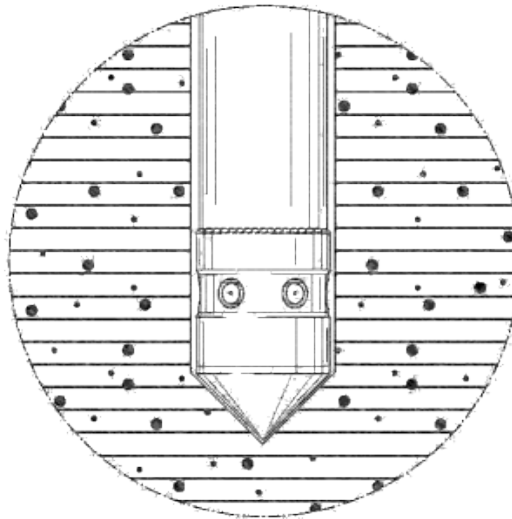
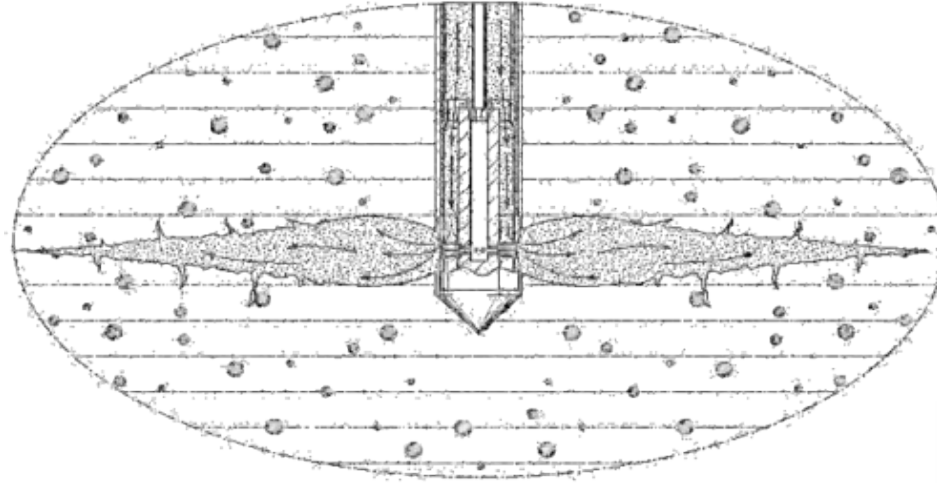


- John Foster, Stan Golaski,
and George Maalouf



Rogers & Callcott
ENGINEERING | ENVIRONMENTAL | LABORATORY

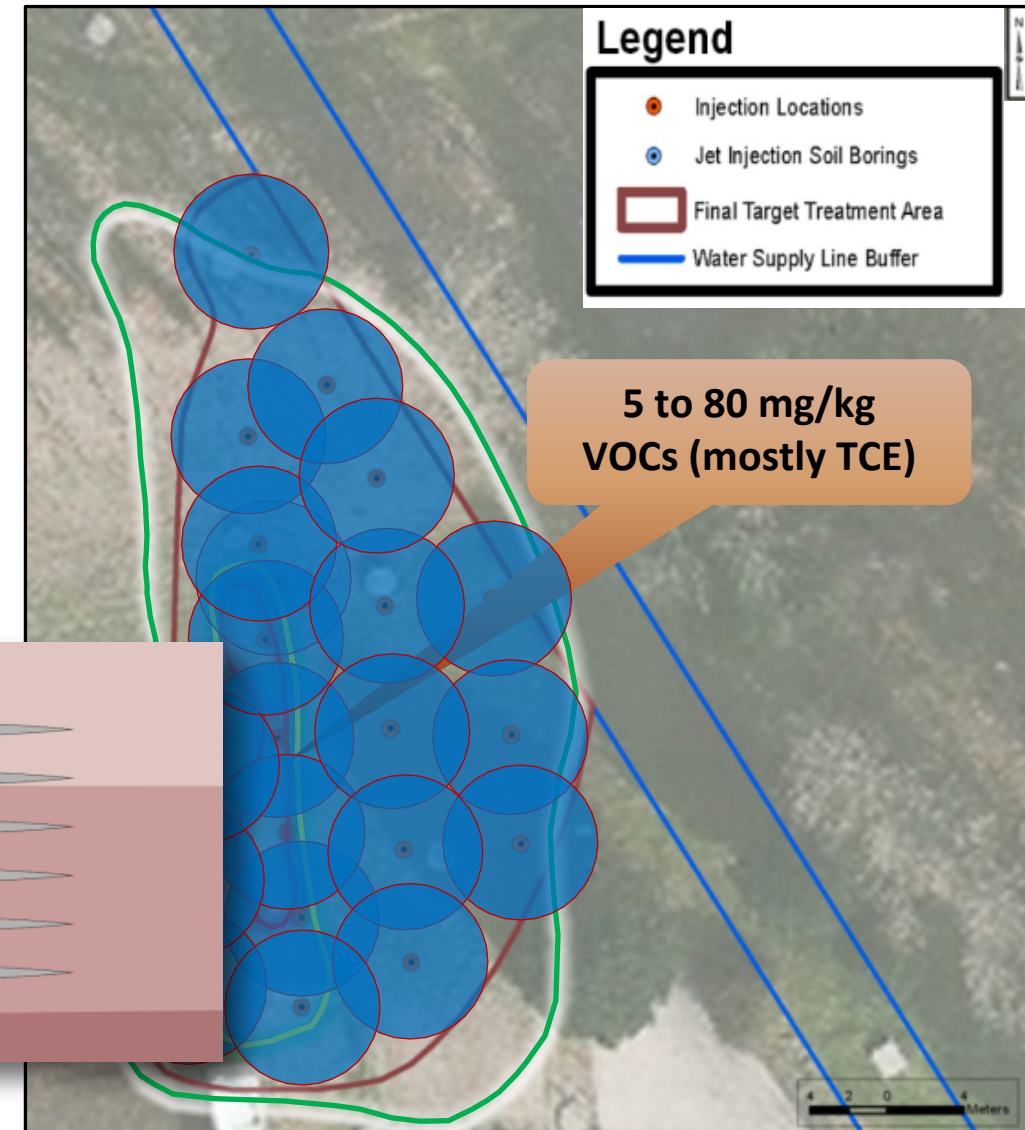
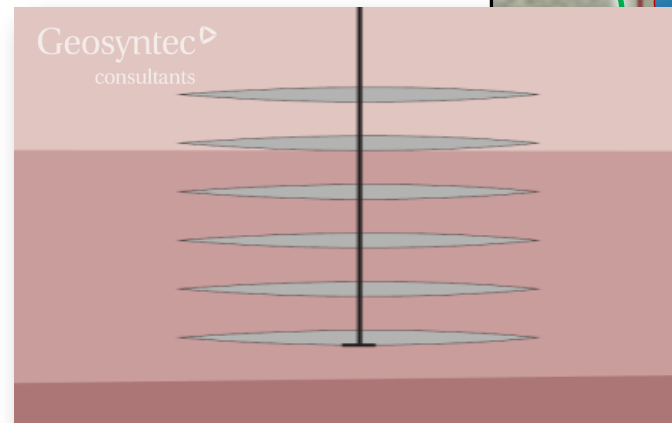
Case Study - ZVI Treatment of TCE in Glacial Clay Till





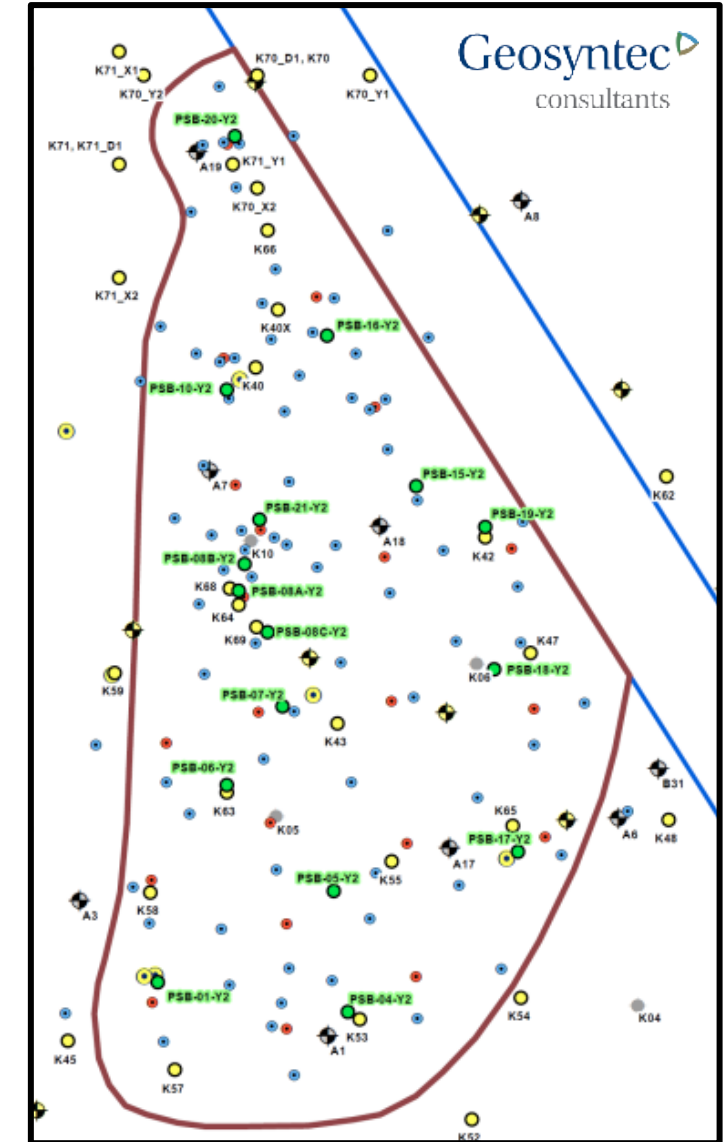
Remedial Design

- 7,500 ft² (700 m²) Target Treatment Area
- 12 ft (4 m) fracture radius
- 21 locations, 121 fractures
- 5-7 discrete injection depths
- 110,200 lbs mZVI (50 MT)
(0.7% ZVI by dry wt soil)

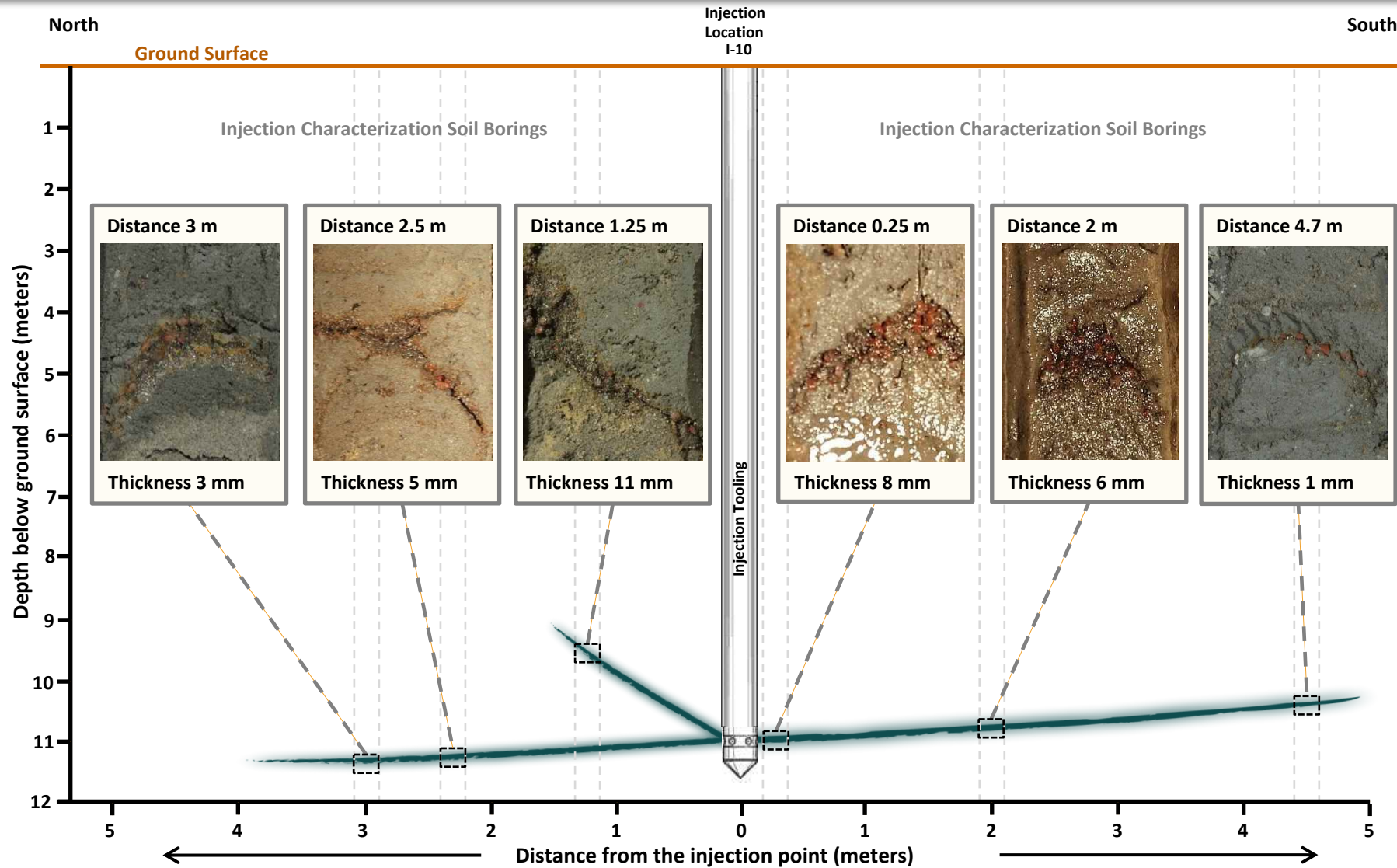


Performance Monitoring in Soil

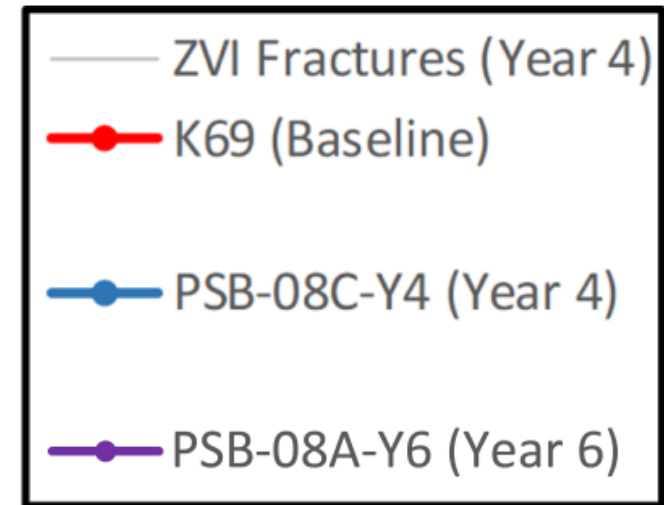
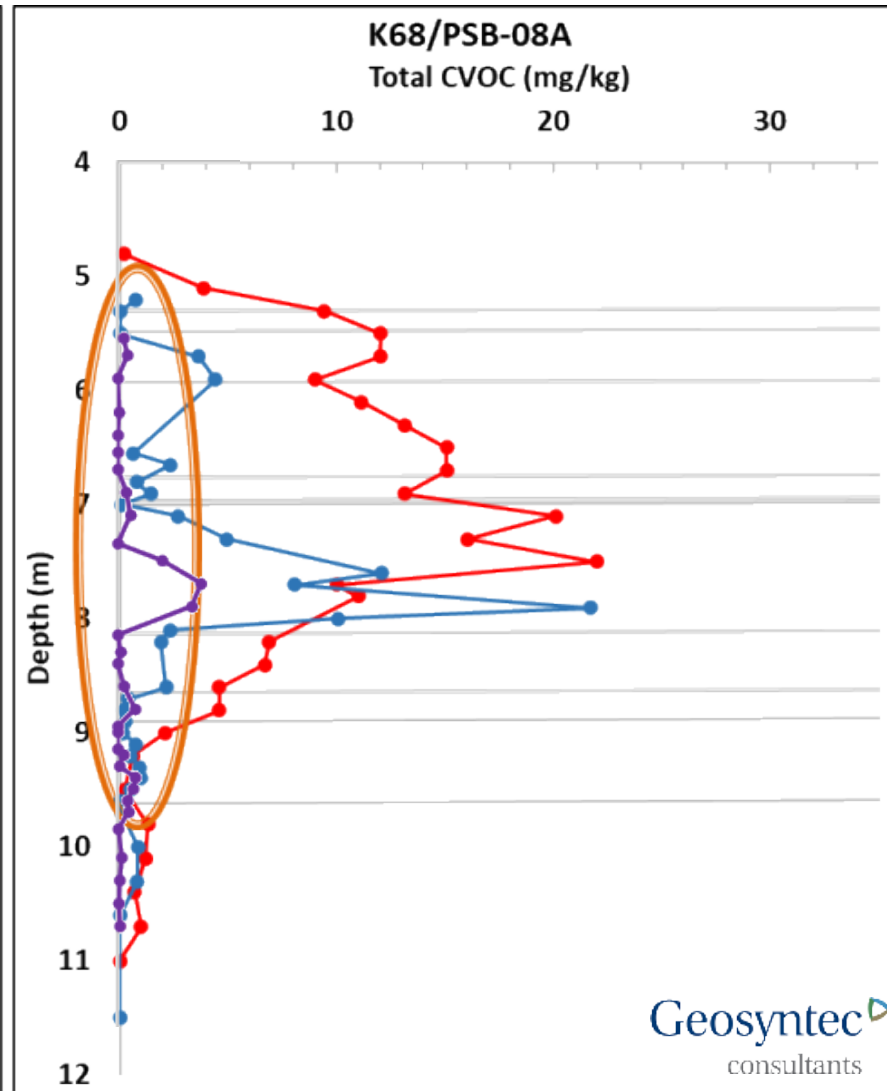
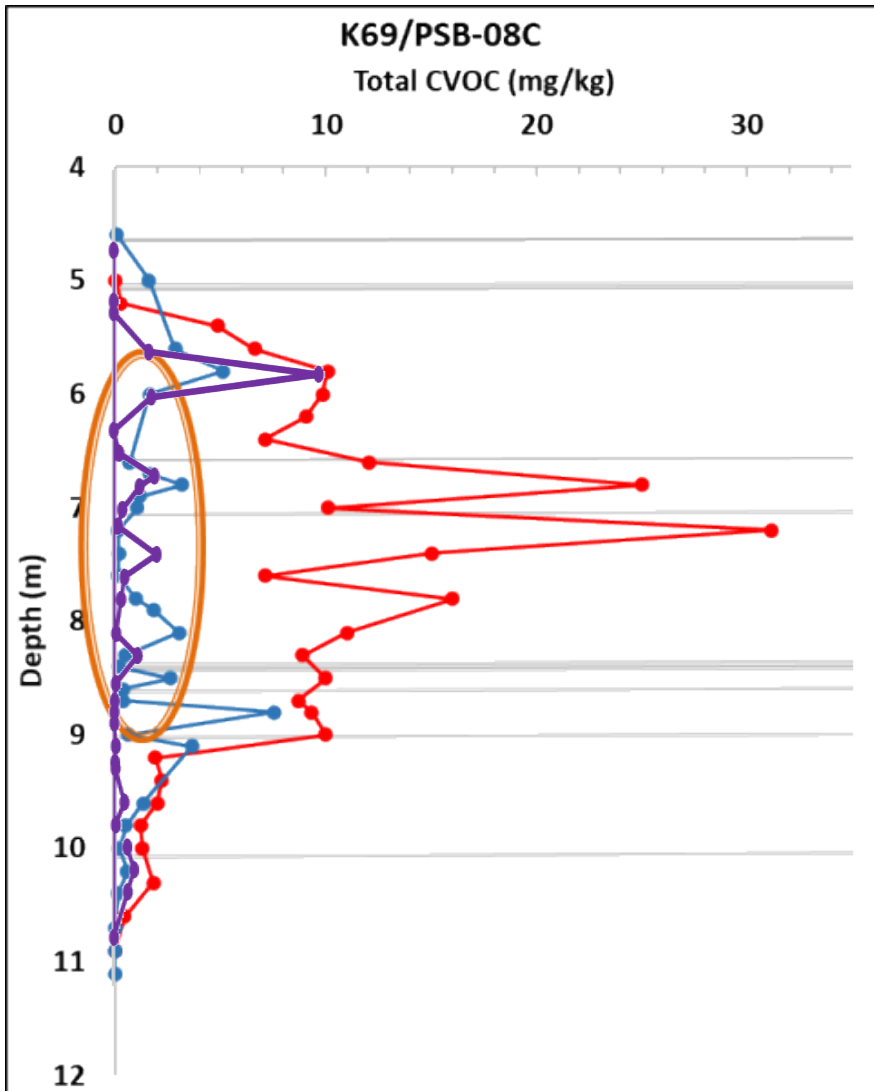
- Soil cores to assess fracture distribution
 - Visual identification
 - Magnetic susceptibility
- Soil sampling in Years 1 thru 4 & Year 6 at ~14 locations
- Total VOC mass calculations using EVS model



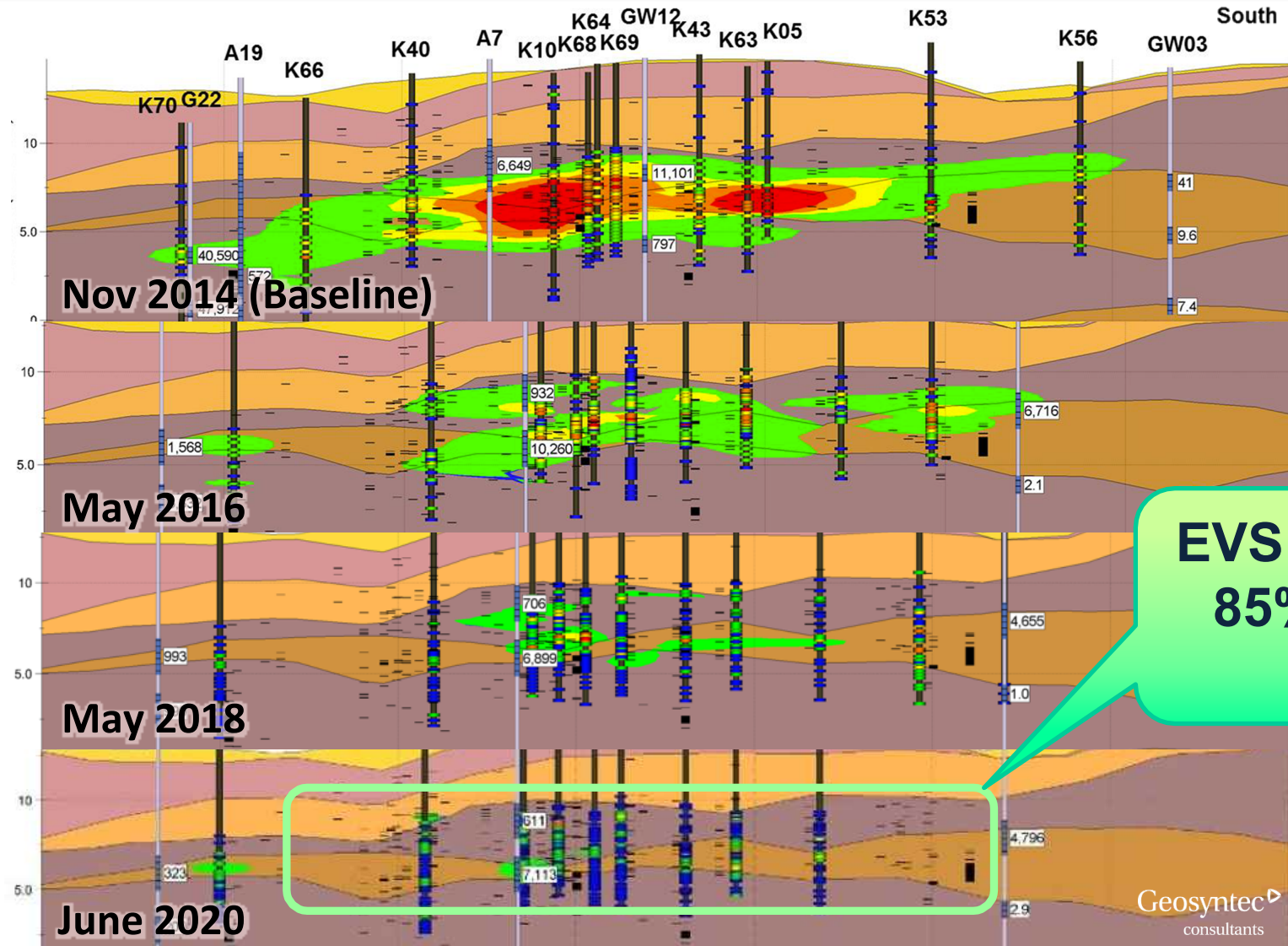
ZVI Fractures in Clay Till



VOCs in Soil – Pre- and Post-Treatment

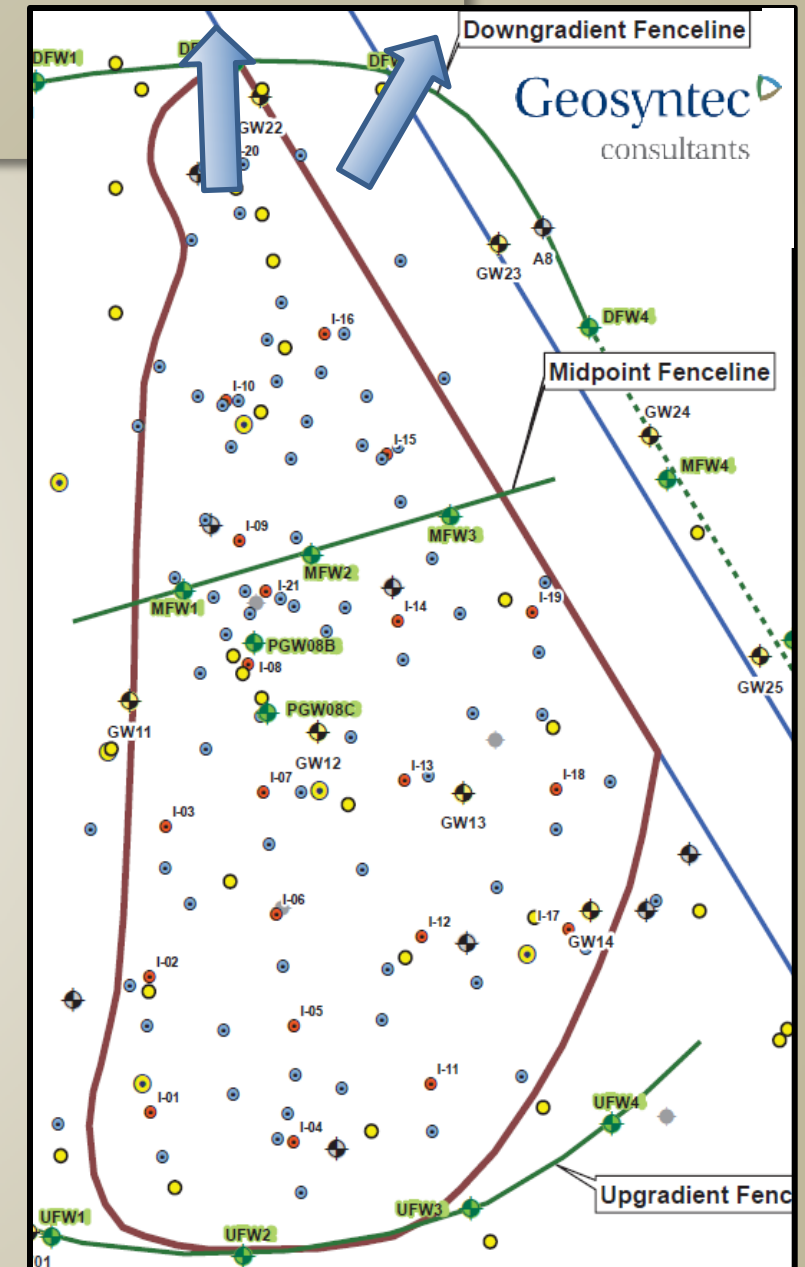


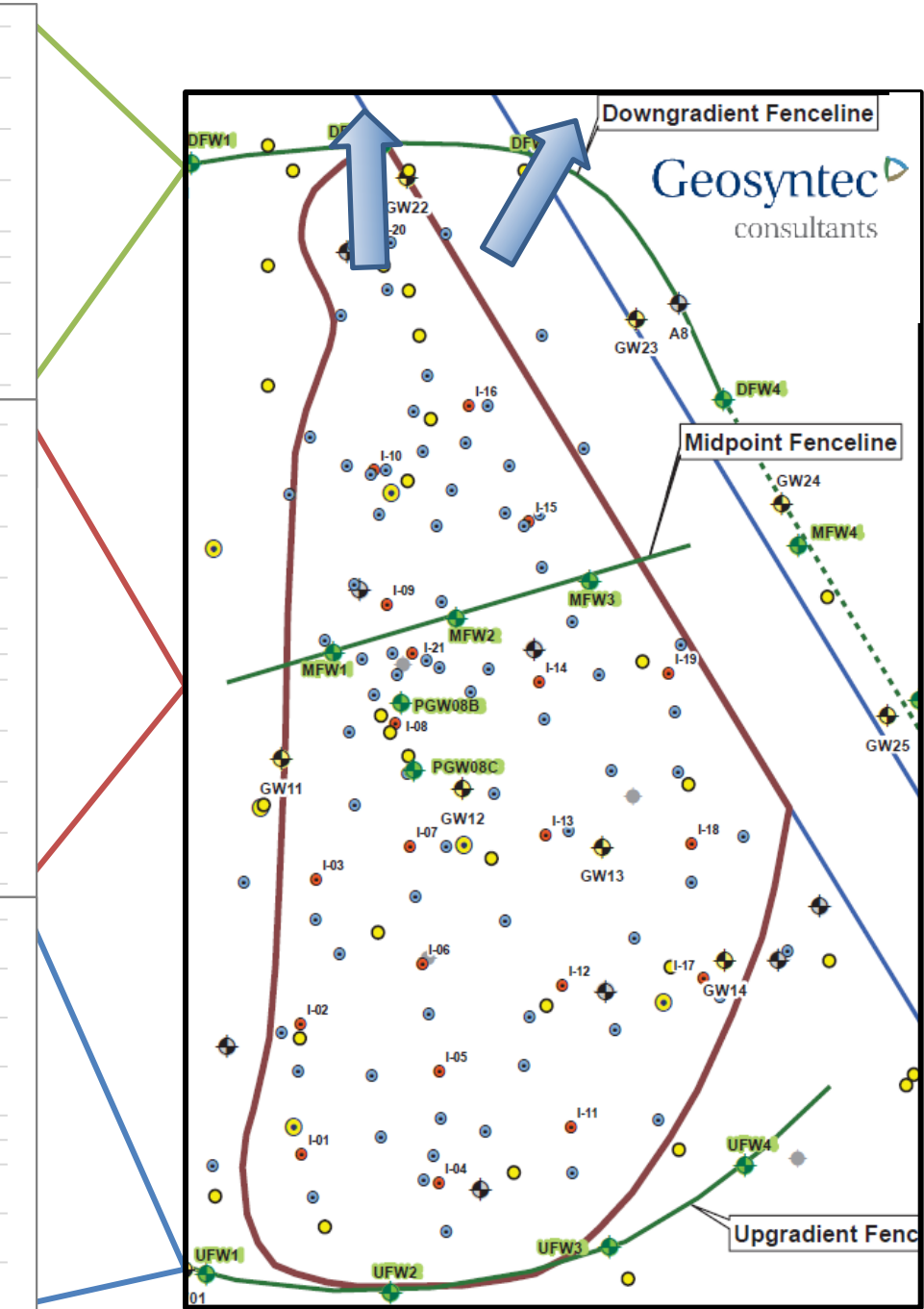
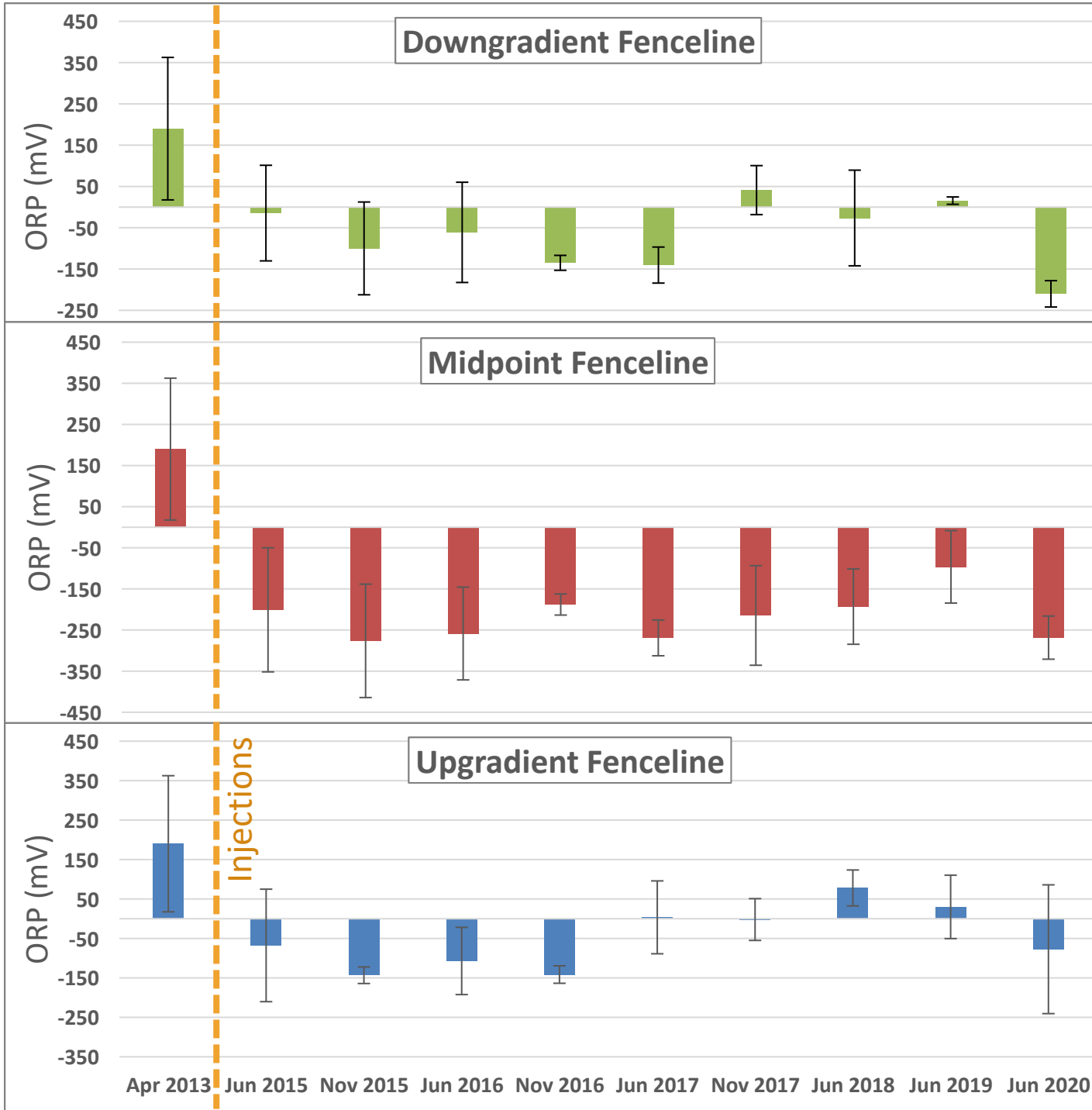
Distribution of Total VOCs in Soil – Baseline to 6 Years



Performance Monitoring in GW

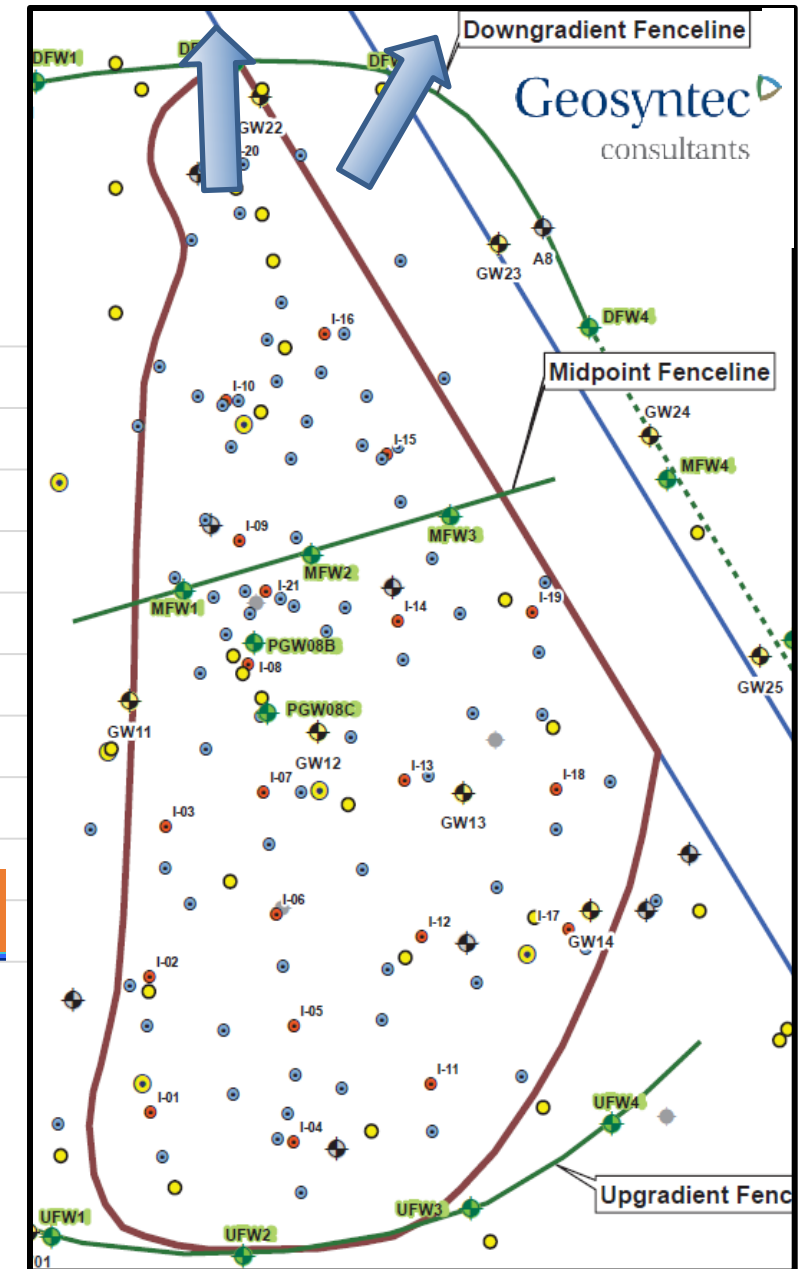
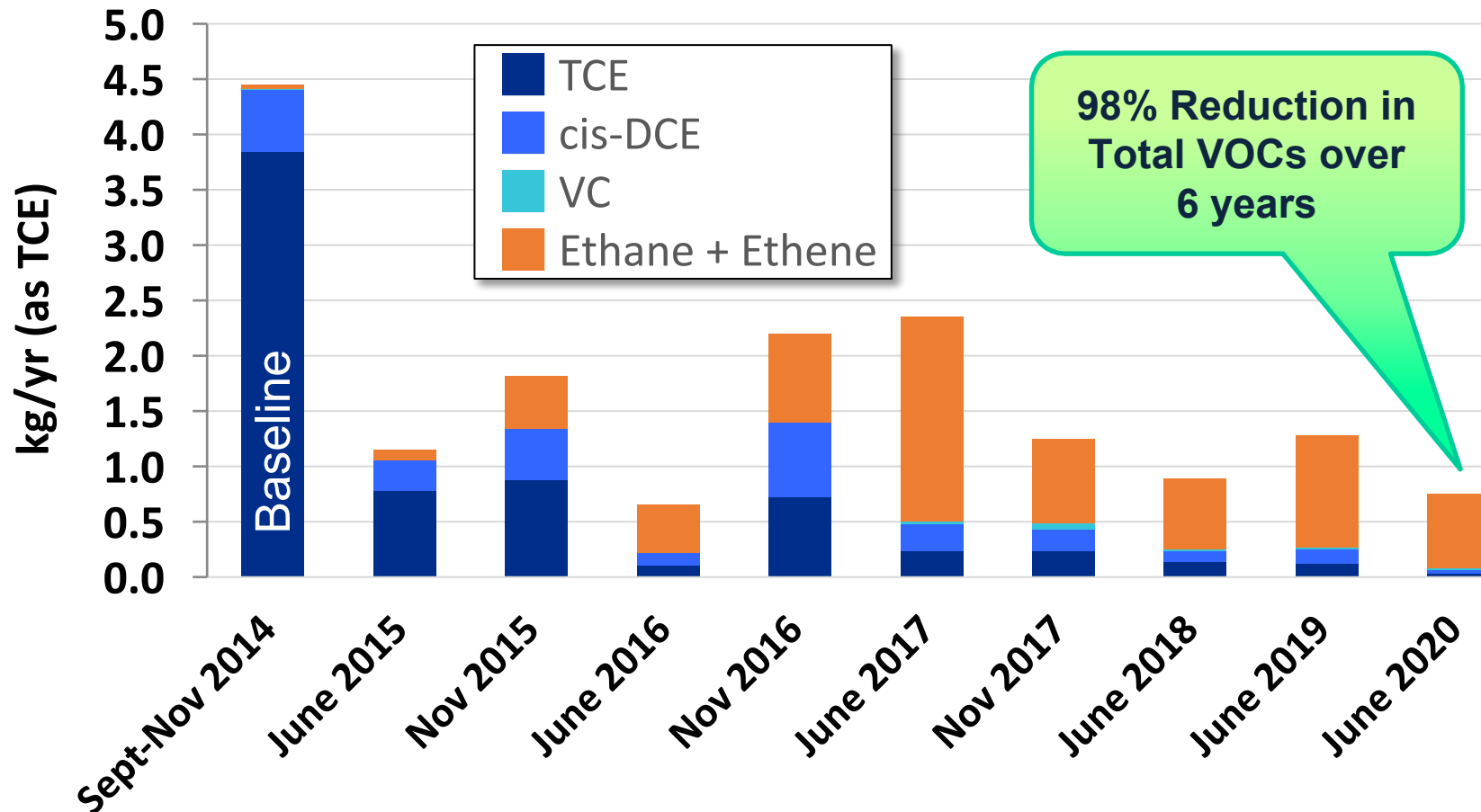
- Groundwater sampling 2 times per year at ~13 well clusters (3 wells per cluster)
- ORP measurements collected during low-flow sampling
- Total VOC mass discharge analysis using transect method



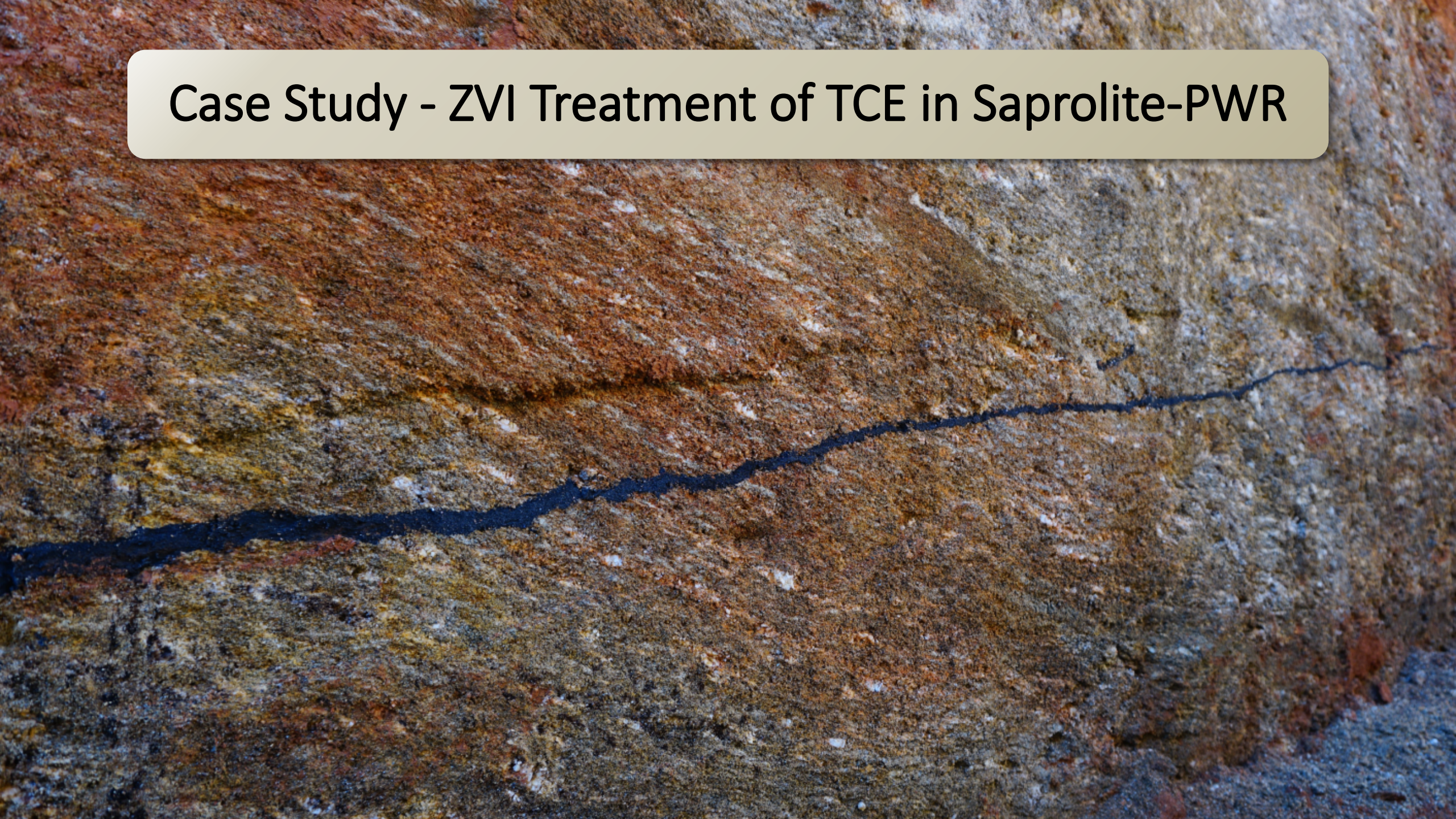


Performance Monitoring in GW

Mass Discharge of VOCs across Downgradient Fenceline



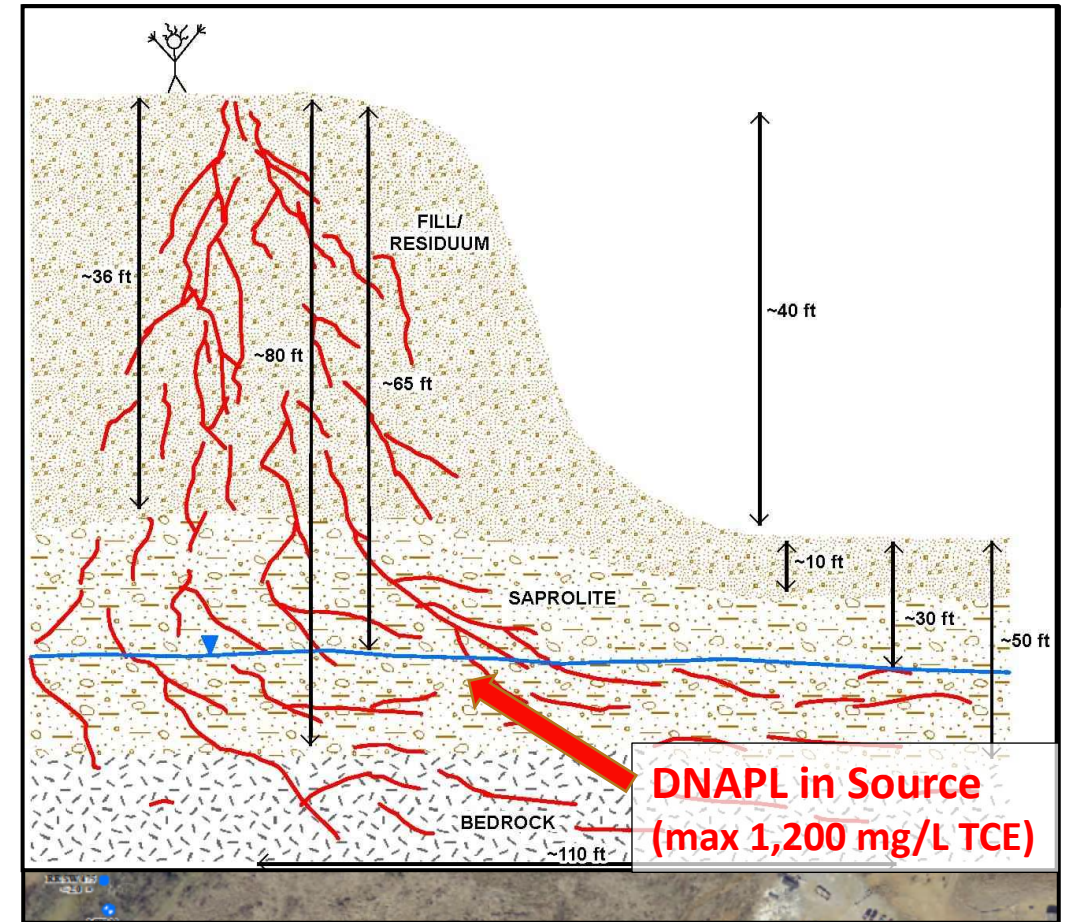
Case Study - ZVI Treatment of TCE in Saprolite-PWR



Case Study - ZVI Treatment of TCE in SC Piedmont



- TCE source zone in saprolite, transition zone, and metamorphic bedrock
- 15-Acre TCE plume
- Treatment goals
 - Deplete DNAPL source zone
 - Mitigate offsite impacts

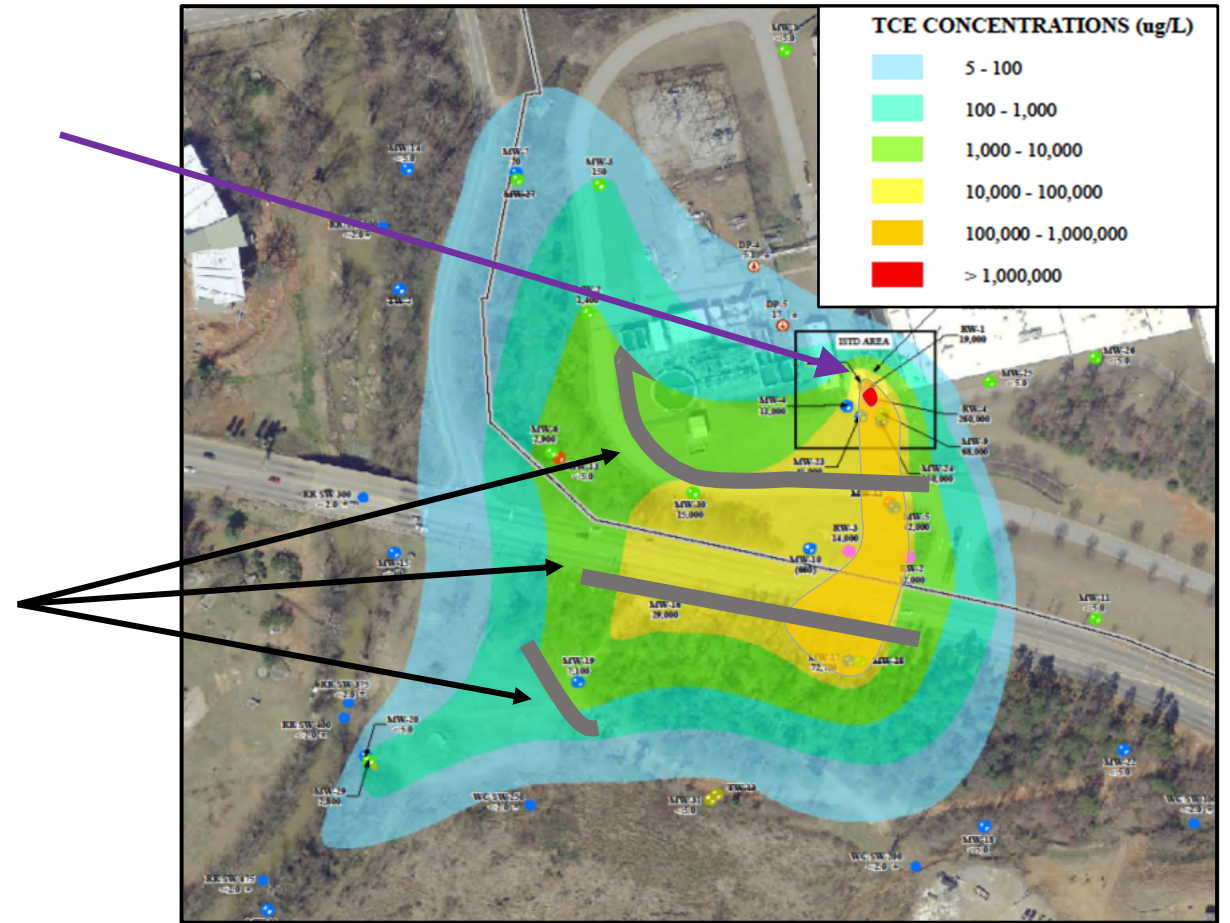


Combined Remedy for TCE Source & Plume

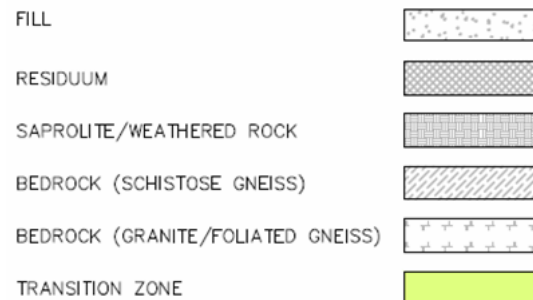
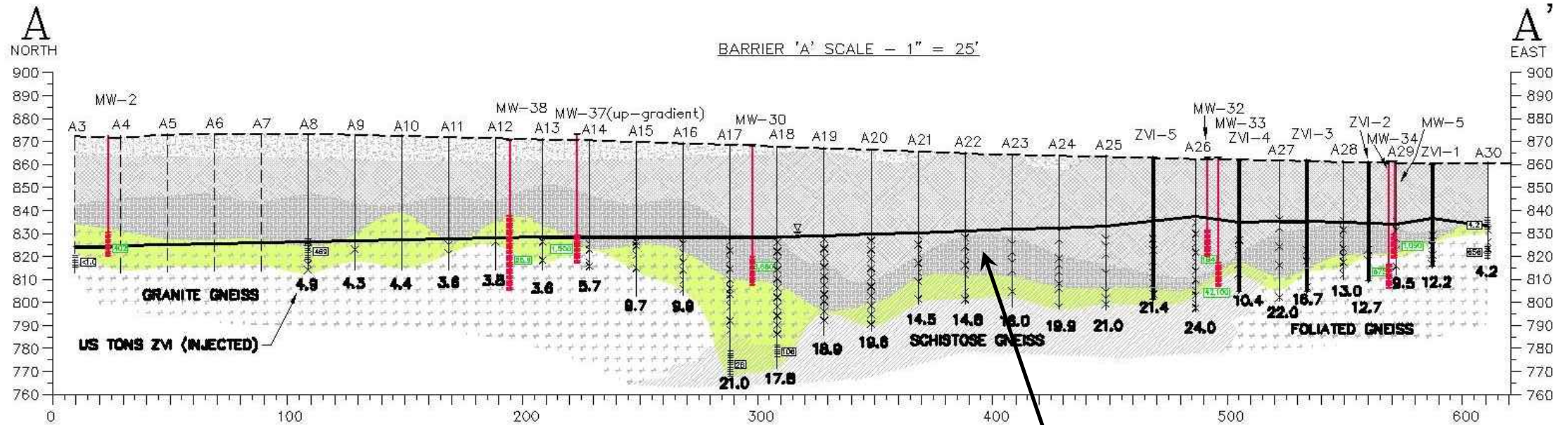


Source Treatment with KMnO_4
Grid configuration of injection wells
Rapid source depletion

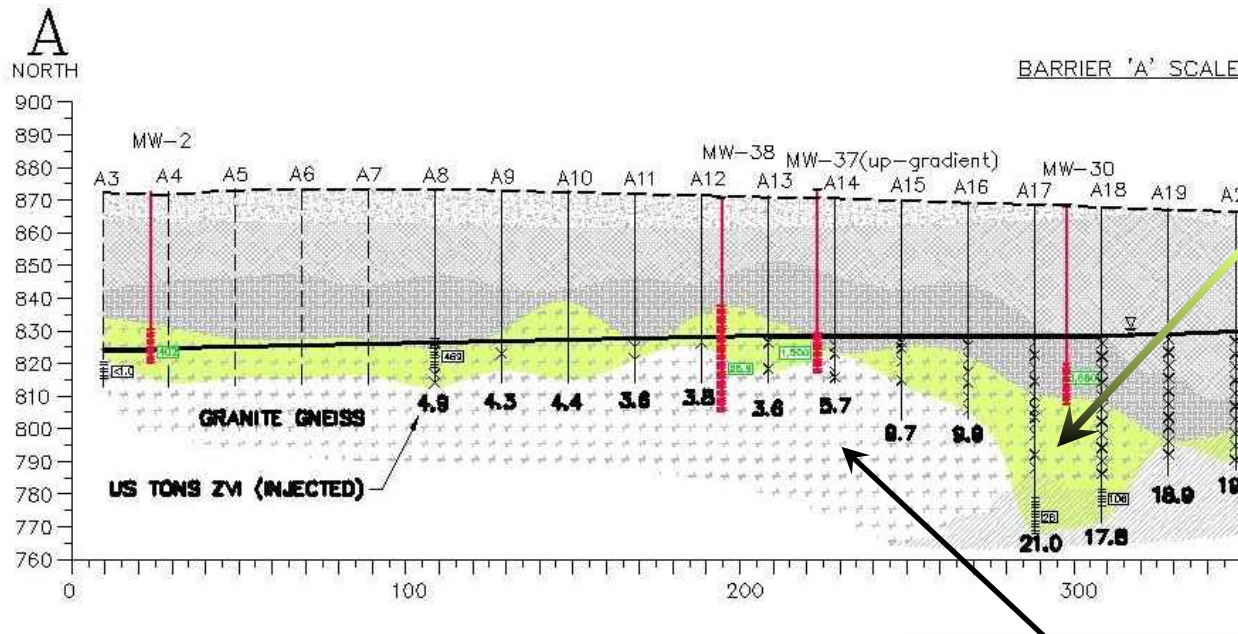
Plume Treatment with ZVI
Linear configuration of injection wells
Long-term treatment



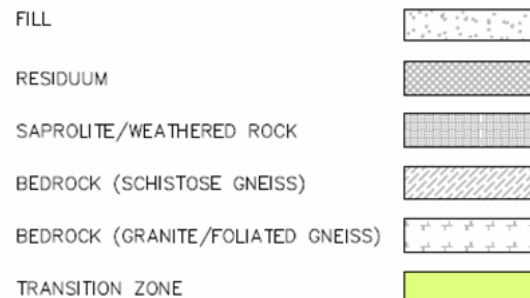
Target Zones - Saprolite



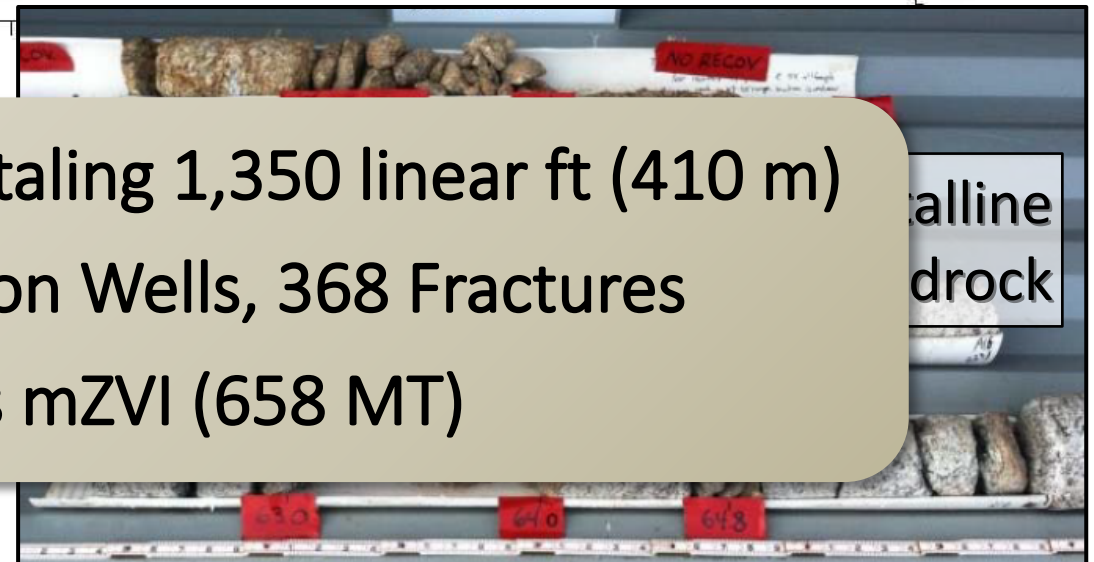
Target Zones - Transition Zone & Upper Bedrock



Partially
Weathered
Rock (PWR)

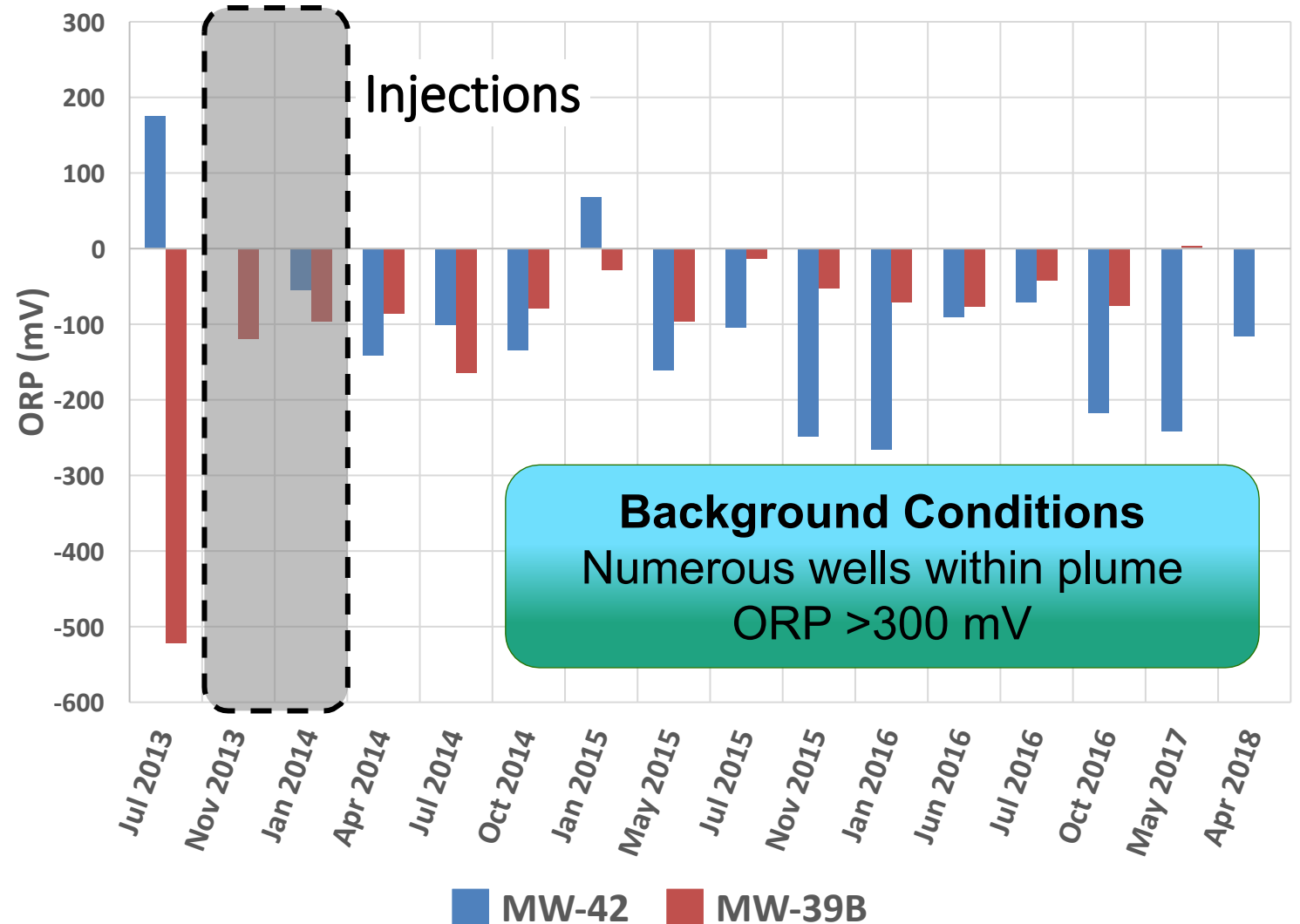


- 3 PRBs totaling 1,350 linear ft (410 m)
- 78 Injection Wells, 368 Fractures
- 1.45M lbs mZVI (658 MT)



alline
drock

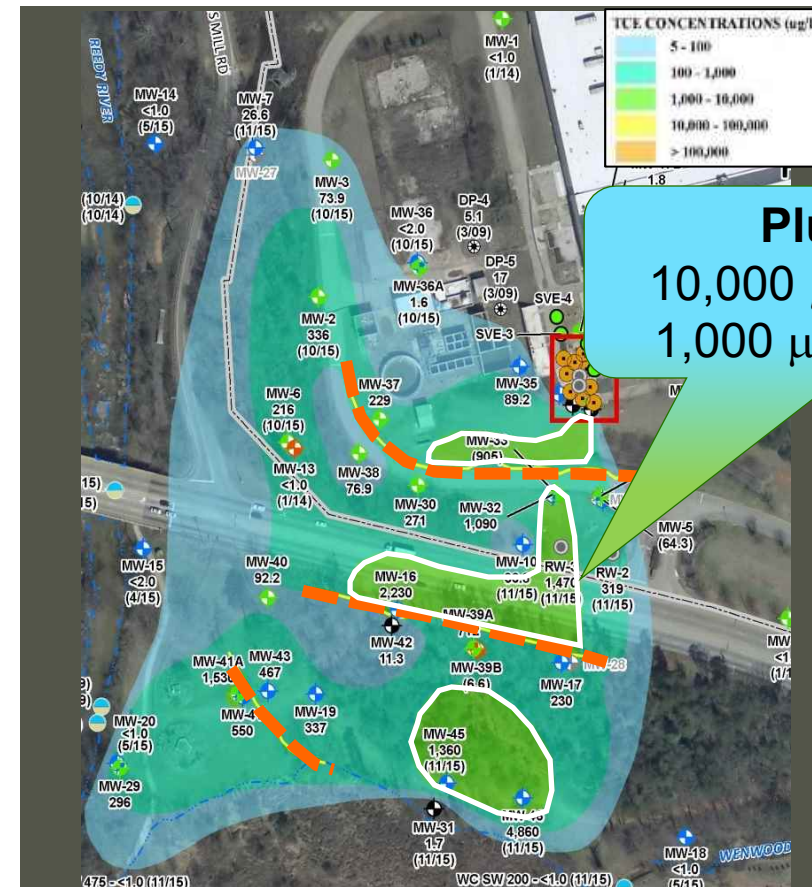
Groundwater Performance – ORP Measurements



Plume Treatment – 1,000 $\mu\text{g/L}$



Pre-Injection Q1 2013



Post-Injection Q1 2016

Plume Treatment – 1,000 $\mu\text{g/L}$

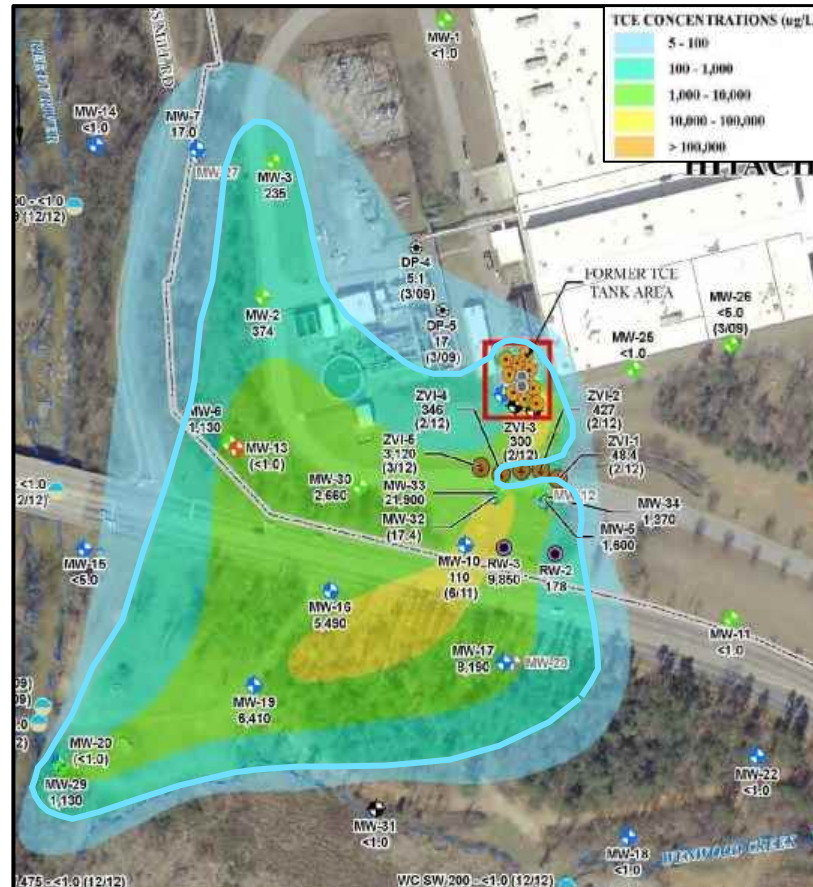


Pre-Injection Q1 2013

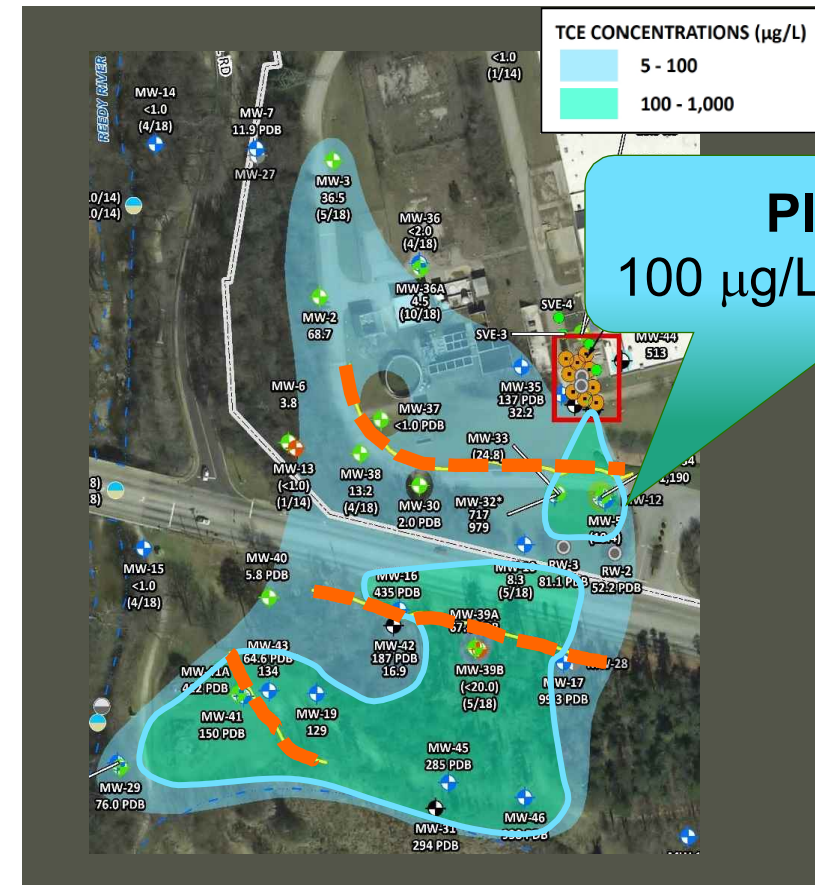


Post-Injection Q1 2018

Plume Treatment – 100 $\mu\text{g/L}$



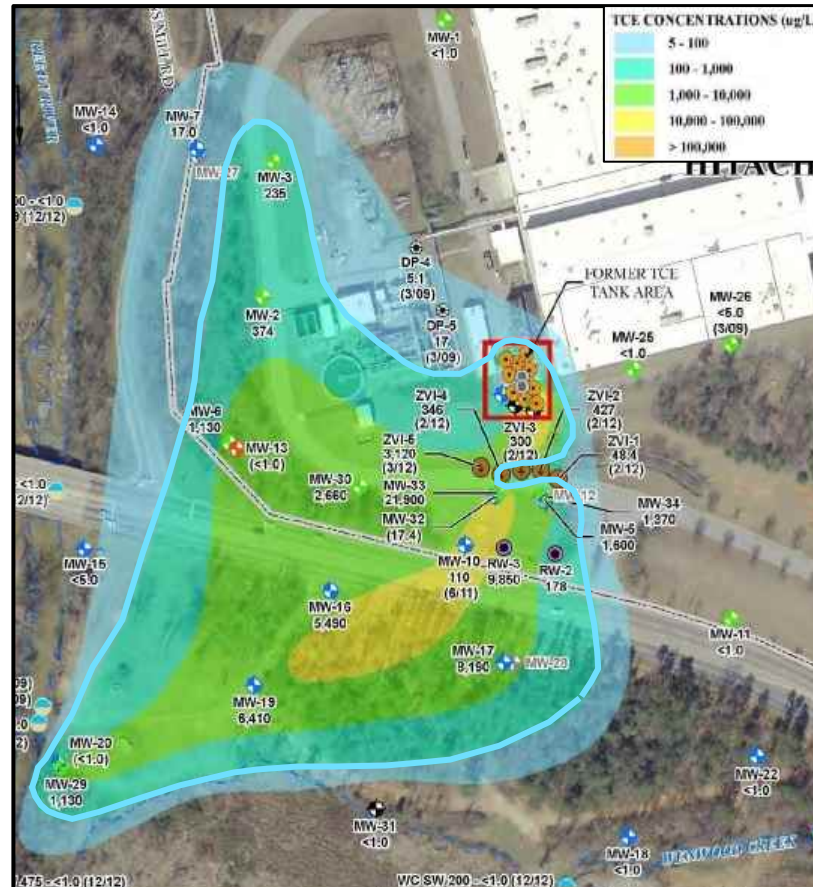
Pre-Injection Q1 2013



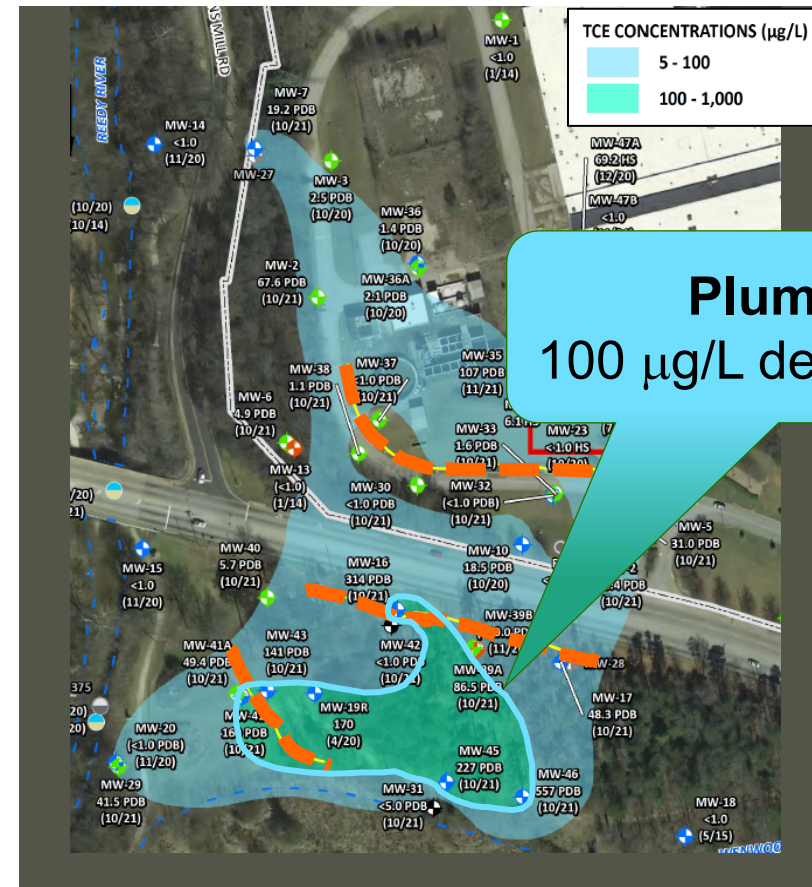
Post-Injection Q2 2019

Plume Area
100 $\mu\text{g/L}$ decreased 70%

Plume Treatment – 100 $\mu\text{g/L}$



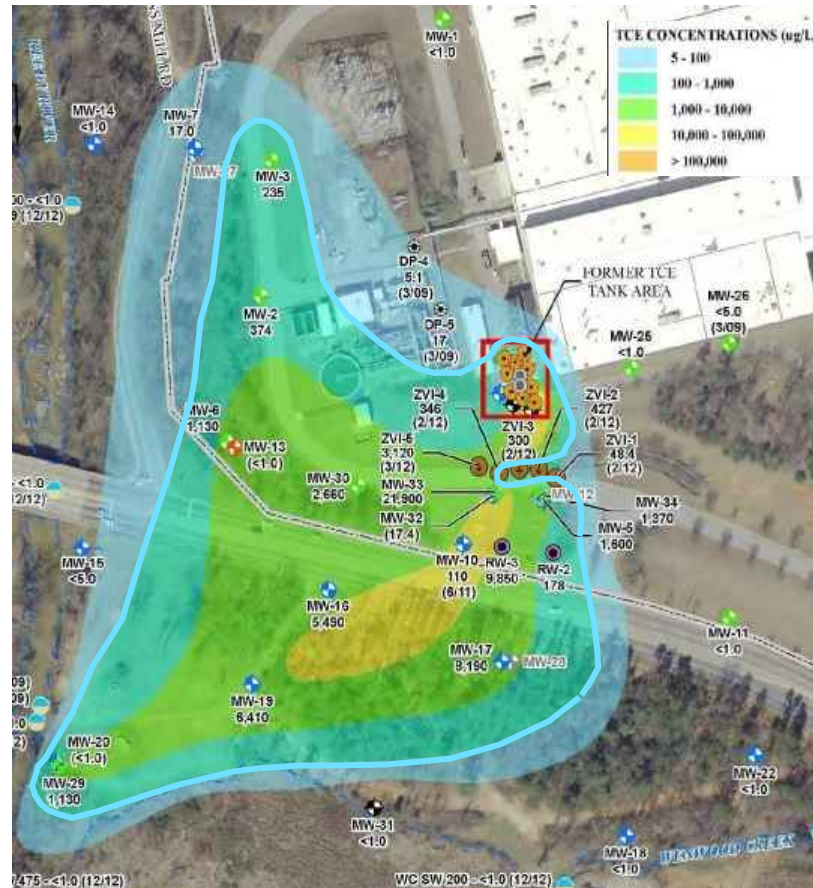
Pre-Injection Q1 2013



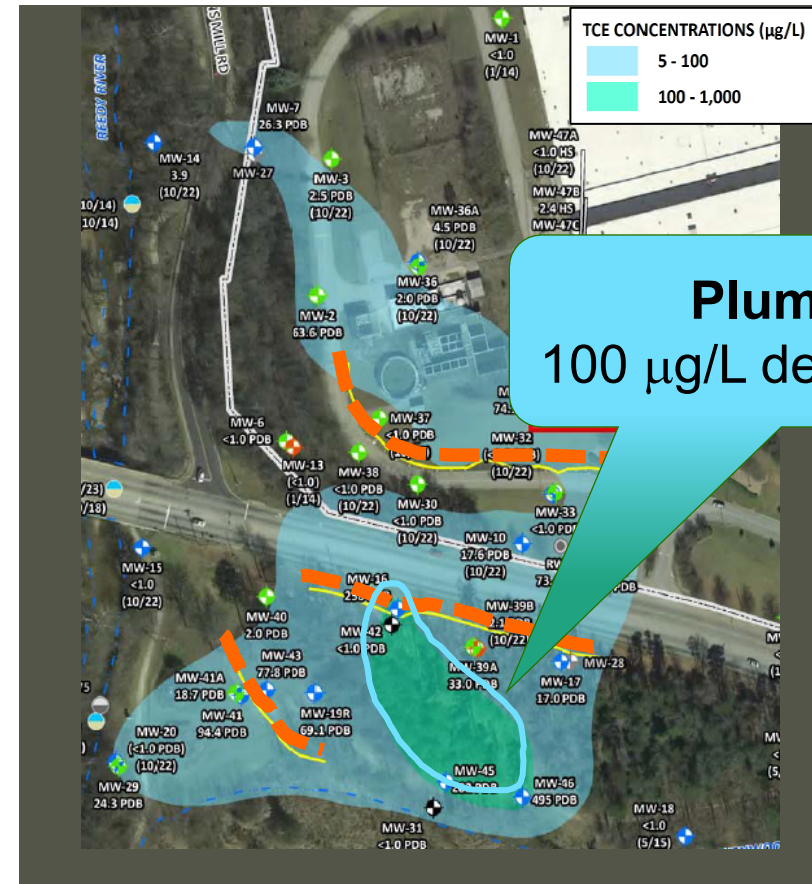
Plume Area
100 $\mu\text{g/L}$ decreased 86%

Post-Injection Q4 2021

Plume Treatment – 100 $\mu\text{g/L}$



Pre-Injection Q1 2013



Post-Injection Q4 2023

Long-Term Performance of mZVI Delivered to Low-Permeability Formations via Hydraulic Fracturing



- Specialized hydraulic fracturing creates fractures with predictable form in low-permeability and heterogeneous formations
- Fractures filled with microscale ZVI are effective in both source zone and PRB applications
- ZVI in fractures persists for more than six years in varied geologic & geochemical settings



Questions?



Drew Baird
dbaird@frx-inc.com
864.546.9449