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Zero-Valent Iron Permeable Reactive Barrier to Remediate Volatile Organic Compounds in Groundwater

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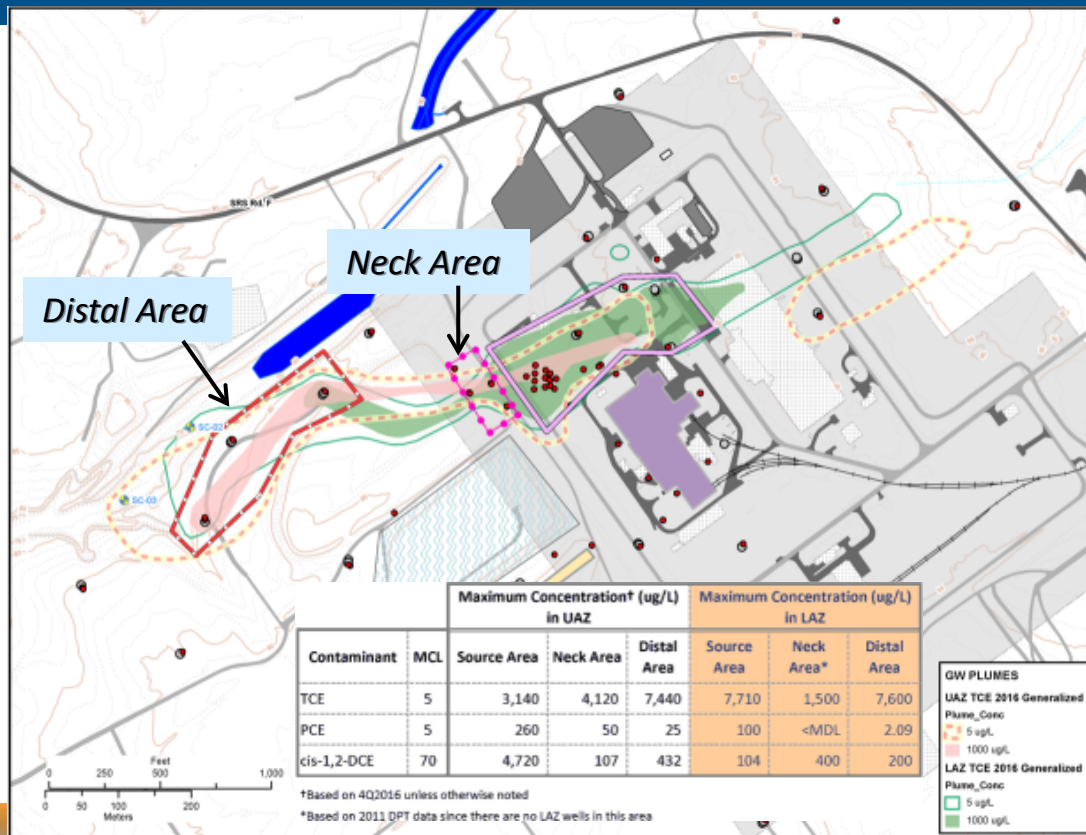
Philip Prater, USDOE

*2024 Chlorinated Conference – June 6, 2024
Denver, Colorado*

- **Site Background**
- **Pre-Design Investigation**
- **ZVI-PRB Design**
- **ZVI-PRB Installation**
- **Effectiveness Monitoring Results**
- **Conclusions and Lessons Learned**

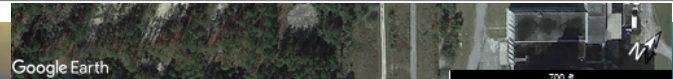
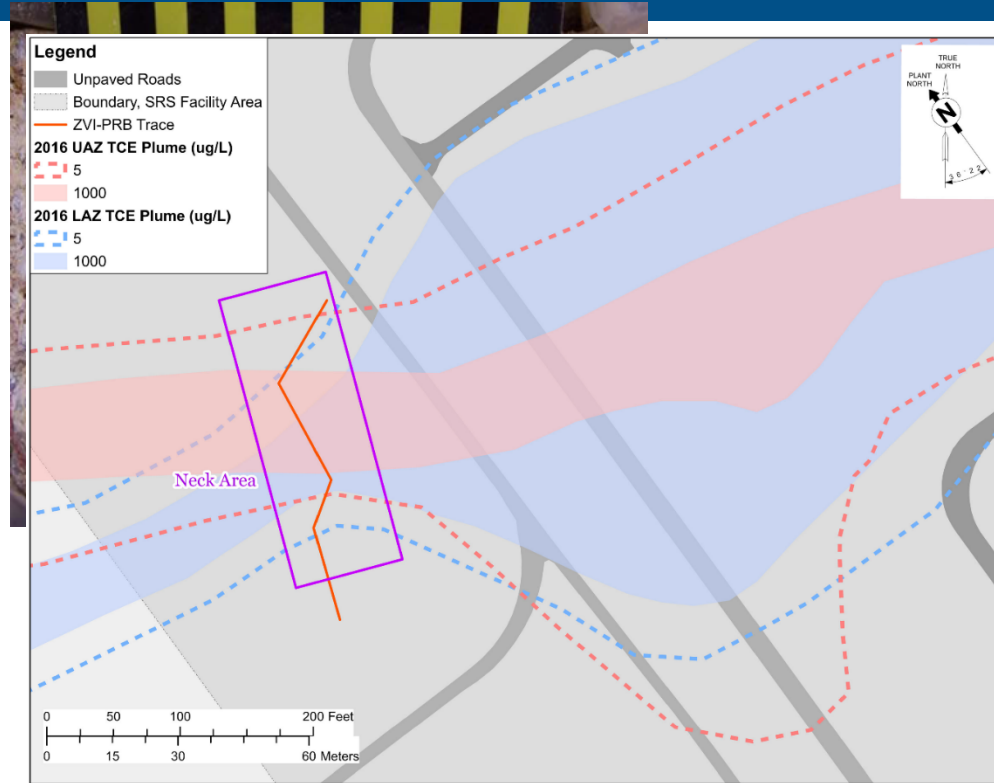
Site Background

- **Closed nuclear reactor**
 - Operated until 1988
- **VOC contamination, primarily TCE**
- **Source remediation completed in 2011**
- **Core Team agreed to a NTC RA in Neck Area**
 - ZVI-PRB selected



Site Background

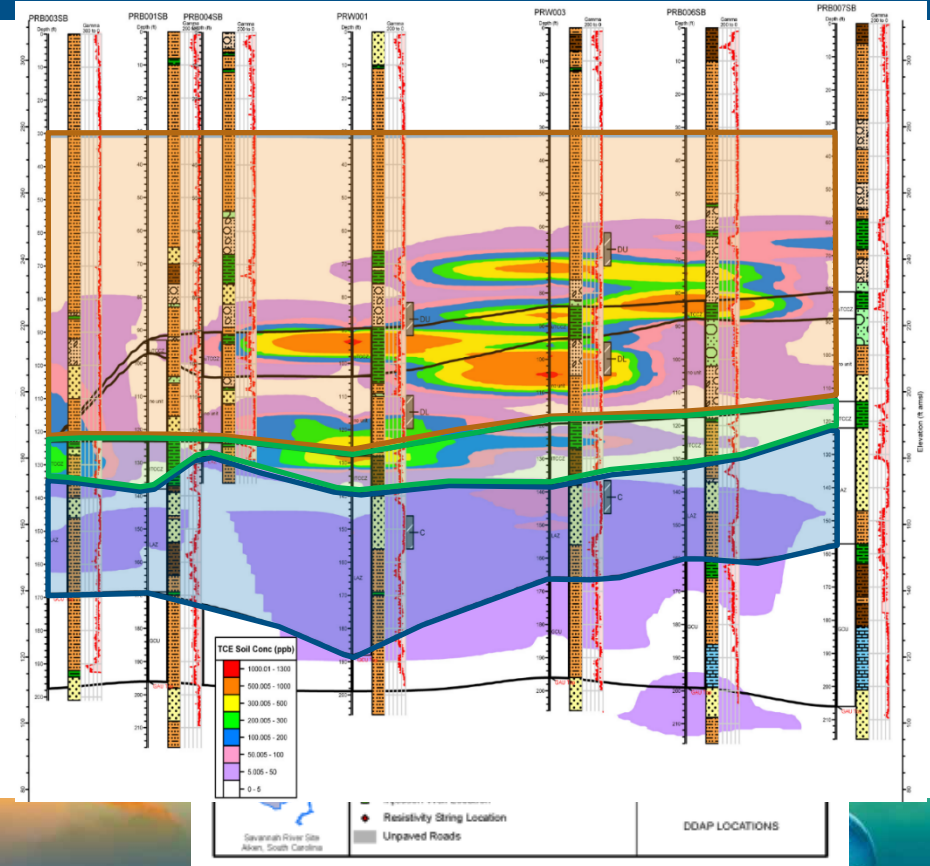
- Groundwater at 35 ft bgs
- Impacted aquifer is ~170 ft thick
- Aquifer divided by semi-confining zones
- Neck Area is zone of plume narrowing
 - Subsurface geologic feature of coarse sands, gravels, and cobbles



Pre-Design Investigation



- Developed to support ZVI-PRB design
 - Monitoring well installations
 - 9 soil borings with soil sampling/core descriptions
 - Iron-soil analysis
 - Treatability study to evaluate TCE half-lives and ZVI for long-term performance



Neck Area Pre-Design Investigation



• Treatability Testing

— Objective

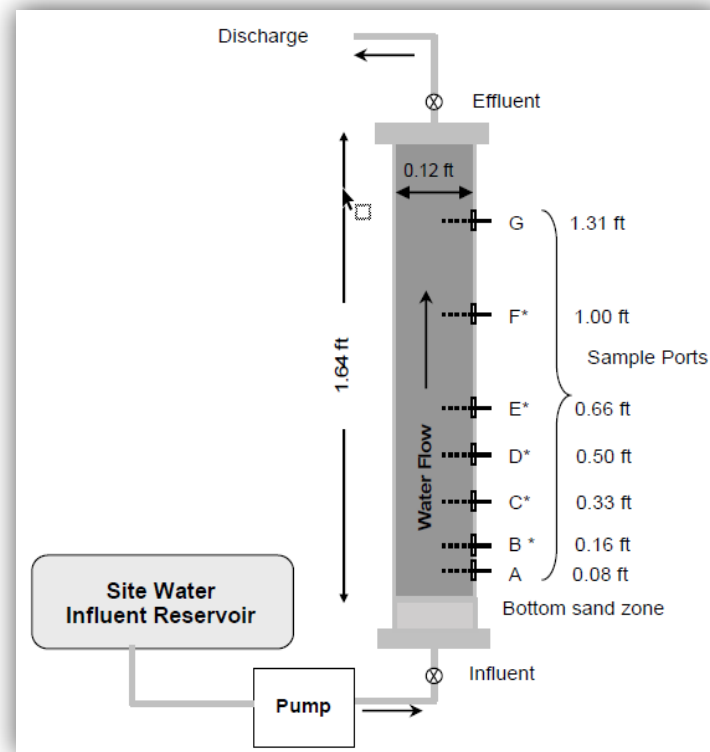
- Quantify cVOC degradation rates
- Determine passivation/precipitation potential

— Two column tests were performed

- 2.1 ft/day and 0.6 ft/day
- Site groundwater used; TCE spiked to 7,700 ug/L

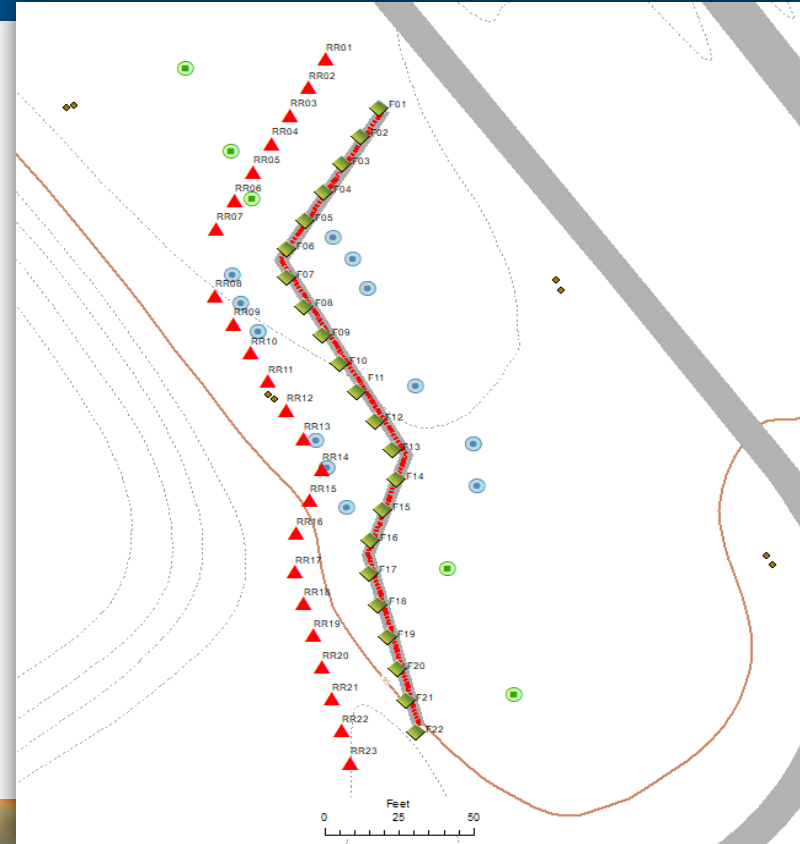
— Results

- Potential for precipitation are low
- 5 hours of residence time achieved 90% reduction

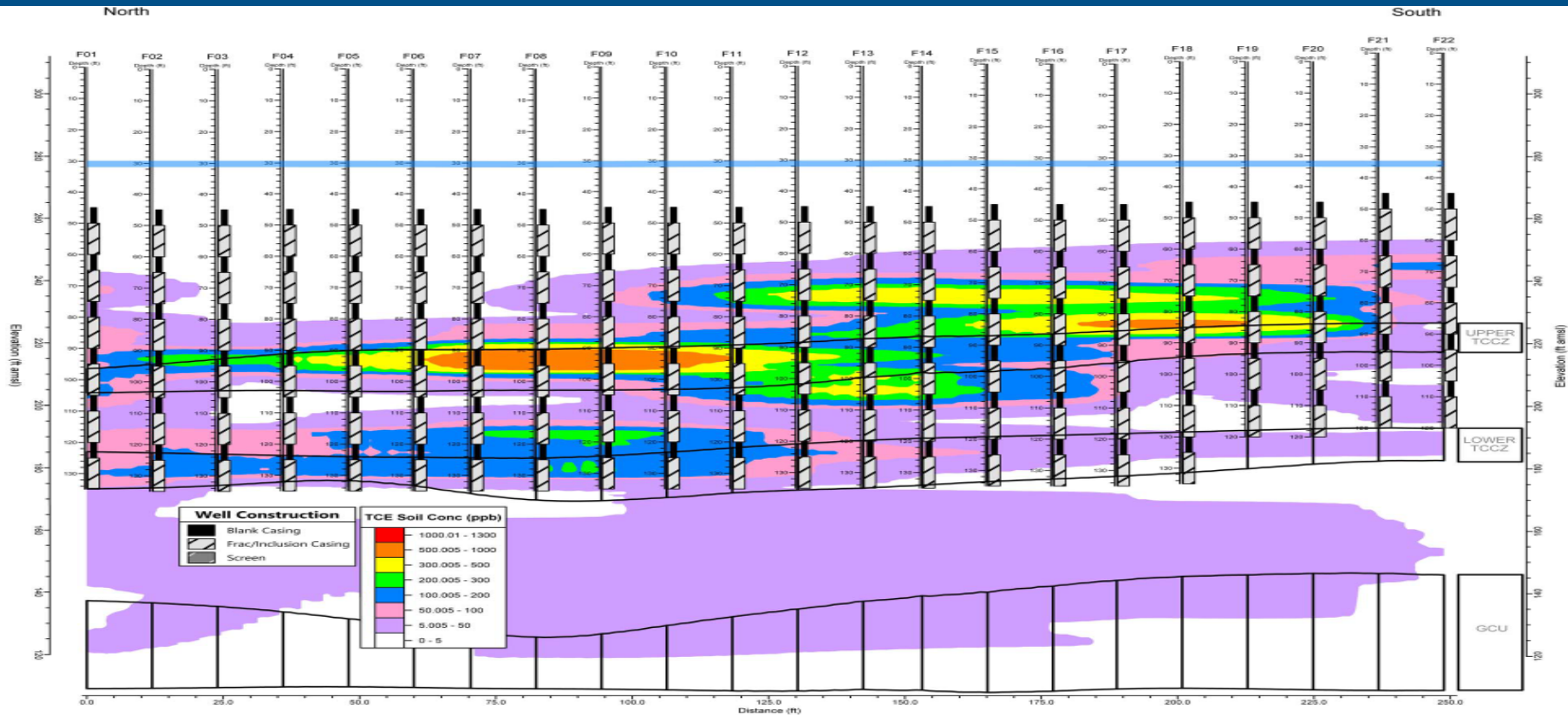


ZVI-PRB Design

- 264-ft long (23,040-ft²)
- 12-ft Frac well spacing (22)
- 4-in average thickness (ZVI)
- Up to 760 tons of ZVI to be emplaced
 - Peerless Aggregate Product 14D and 8/50D
- Depth from 45-ft to 135-ft
- Target treatment area for >50 ppb soil concentrations
- Constructed primarily in the UAZ
- Keyed into the lower confining zone



ZVI-PRB Design



ZVI-PRB Installation

- **Installed using Azimuth-Controlled Vertical Inclusion Propagation**
 - Installed permanent injection wells
 - Relies on pore pressure relief between injection wells
 - Used hydroxypropylguar as a carrier
 - Enzyme added to ensure fast breaking of the gel



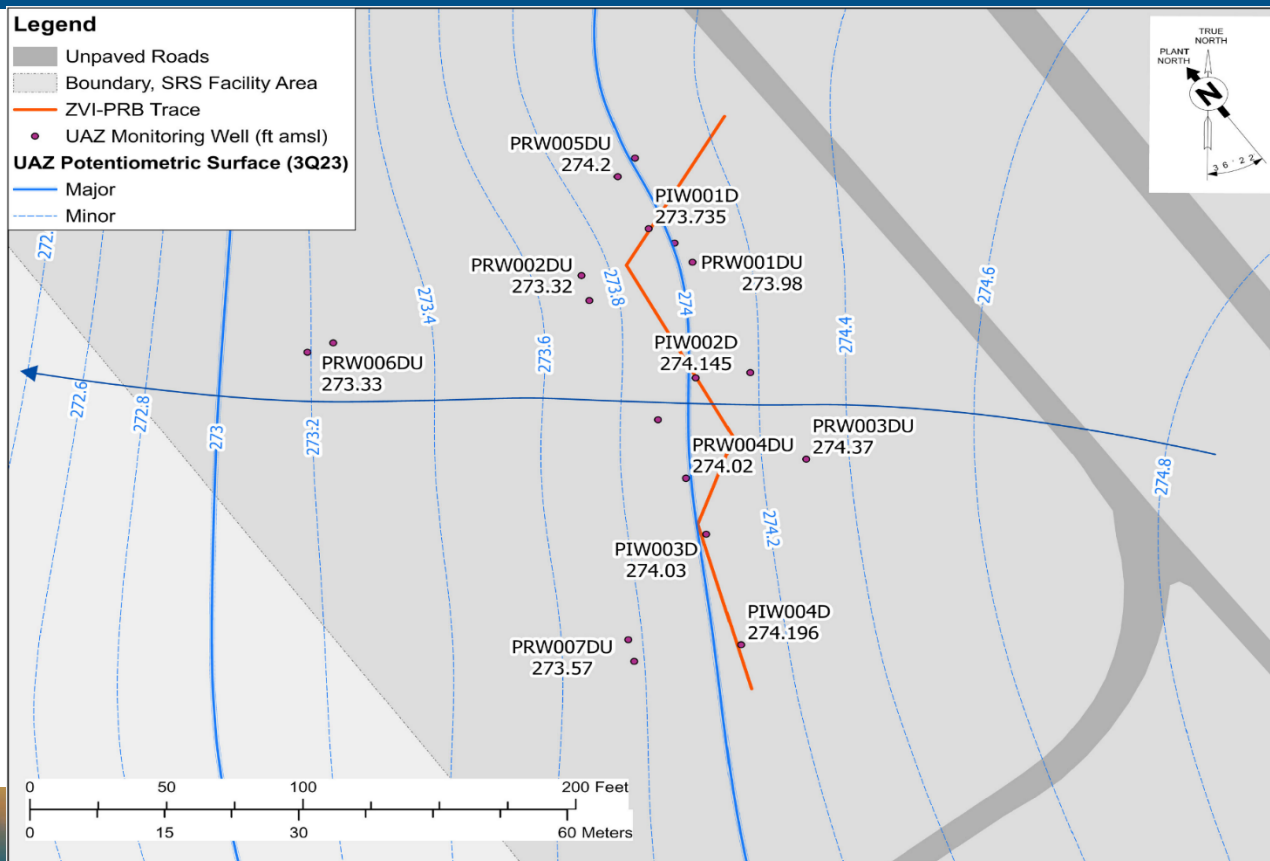
ZVI-PRB Installation

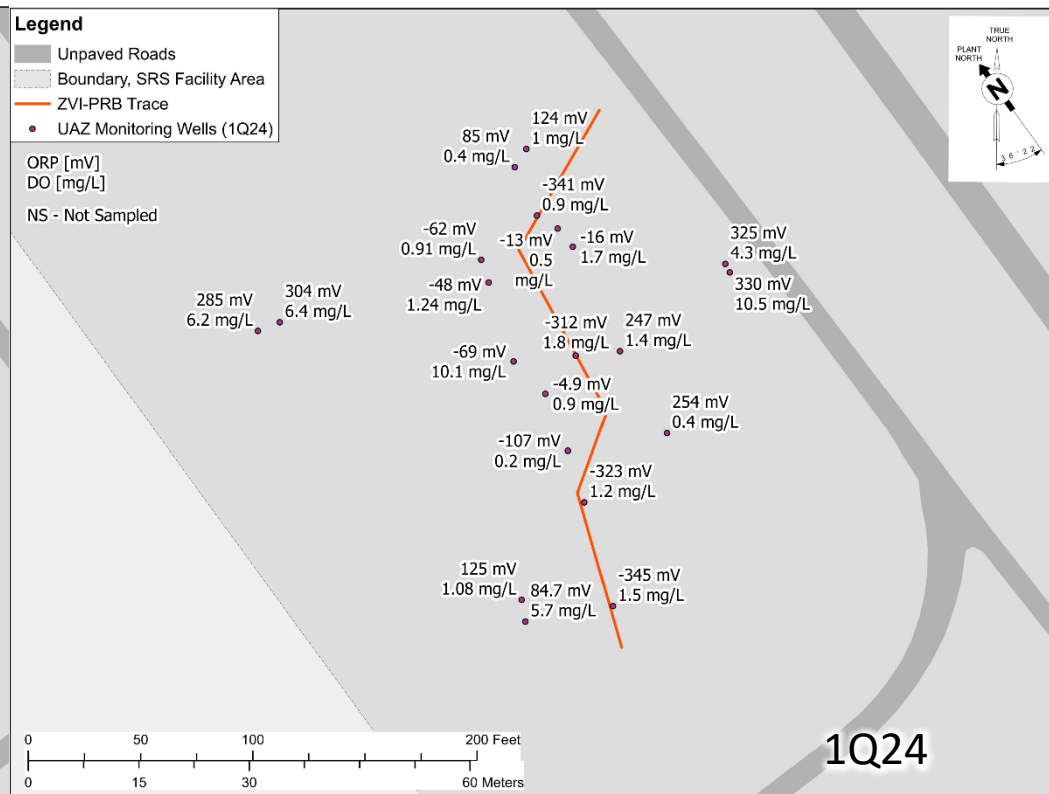


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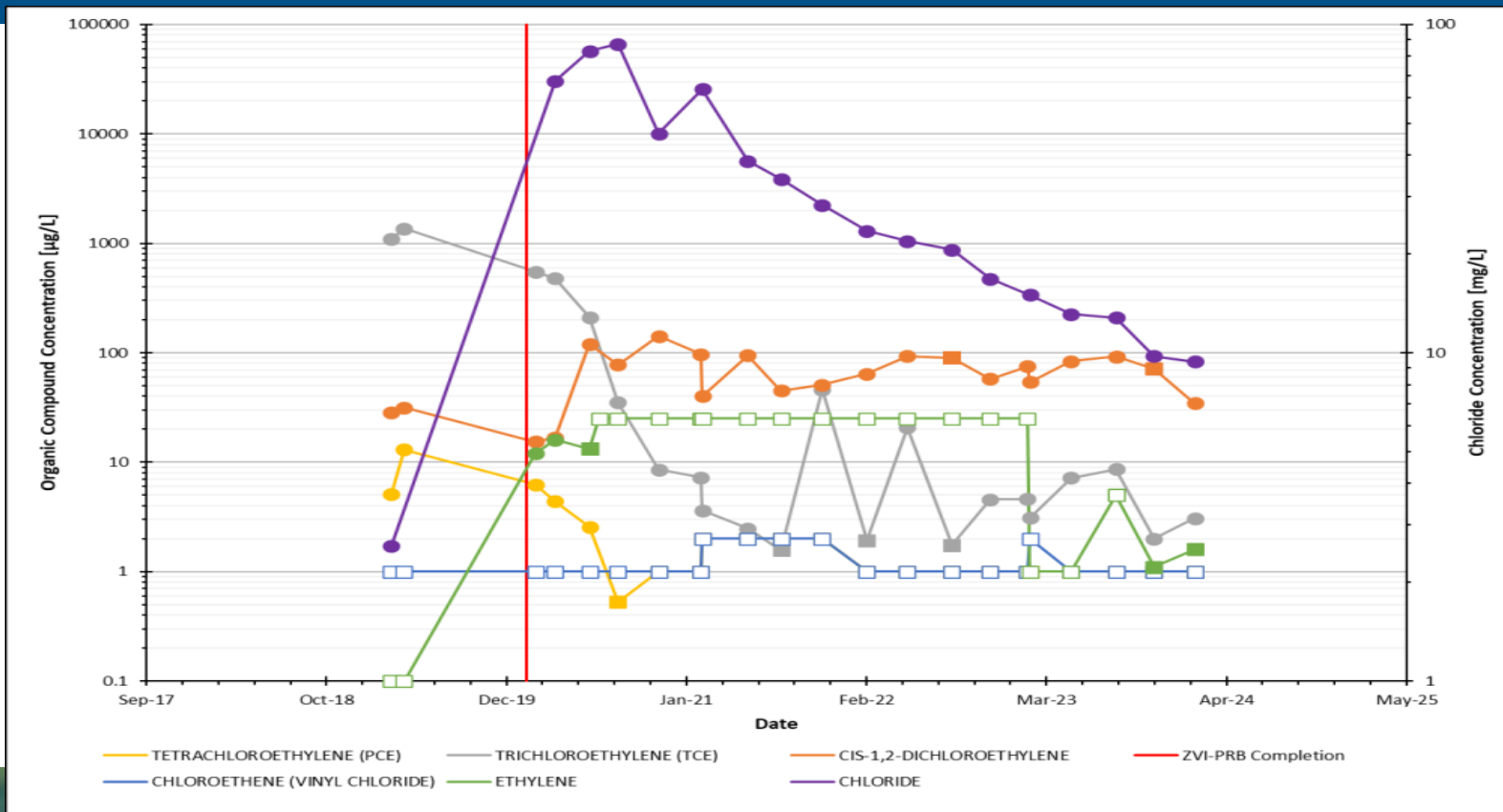
ZVI-PRB Effectiveness Monitoring Results







ZVI-PRB Effectiveness Monitoring Results



- **Field implementation challenges:**

- Cluttered job site

- *Damaged one injection well and one monitoring well*
 - ***Solution: flush mounted monitoring wells***

- Hot temperatures

- *Gel breaking before injections*
 - ***Solution: time-out to optimize enzyme ratio***
 - *Algae growth in frac tanks*
 - ***Solution: truck water in daily***

- Short circuiting

- *Monitoring wells installed nearby prior to ZVI-PRB installation presented a concern*
 - ***Solution: sanded off prior to construction***

- **Technical challenges:**
 - In-wall well sample planning
 - *Missed first six months of data due to requirements that were not planned for*
 - Data quality issues with field measurement techniques and laboratory MDLs
 - *Solution: educate samplers in field; renegotiate laboratory contracts*
- **Pre-design investigation played key role in successful ZVI-PRB design and implementation to meet the Removal Action Objective**
- **Overall, the project was implemented successfully with promising results**

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Backup Slides



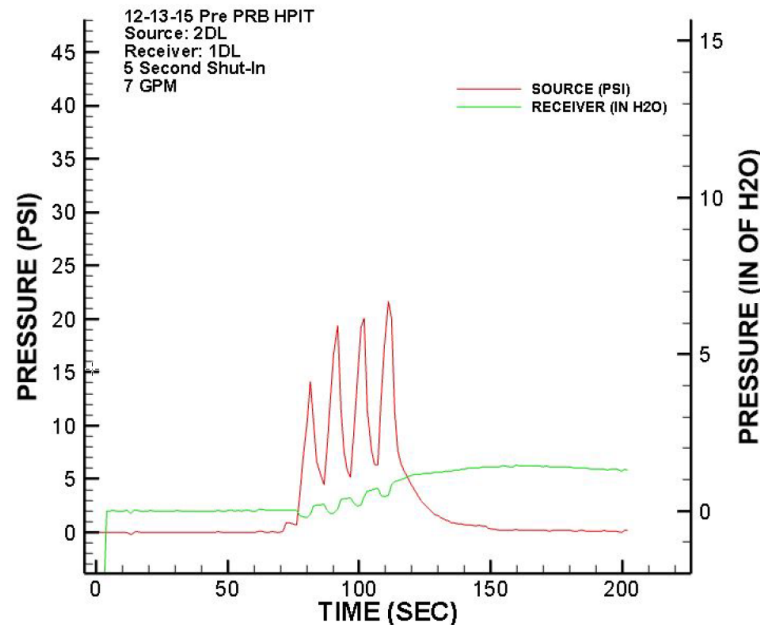


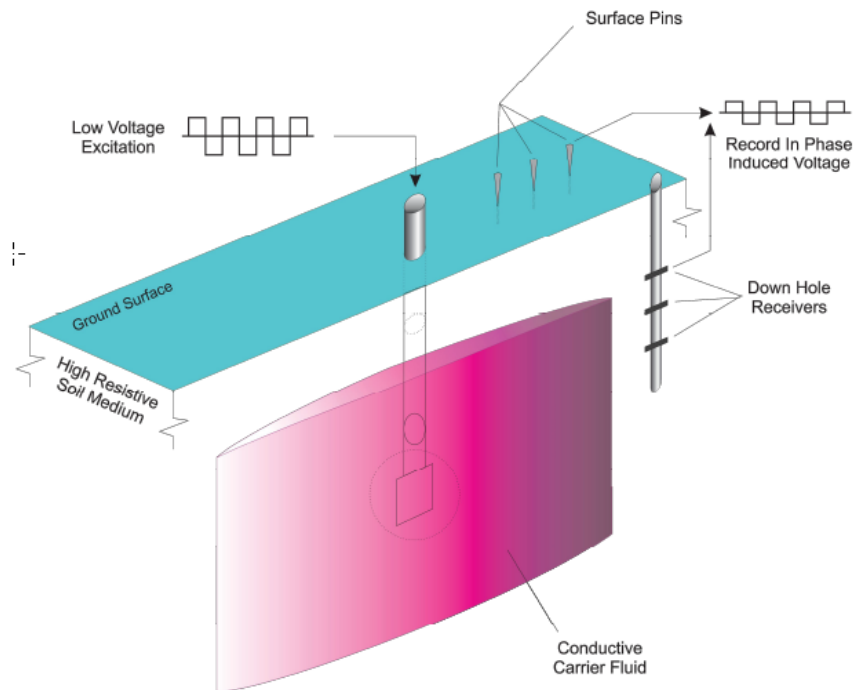
Backup Slides



- **Hydraulic Pulse Interference Testing**

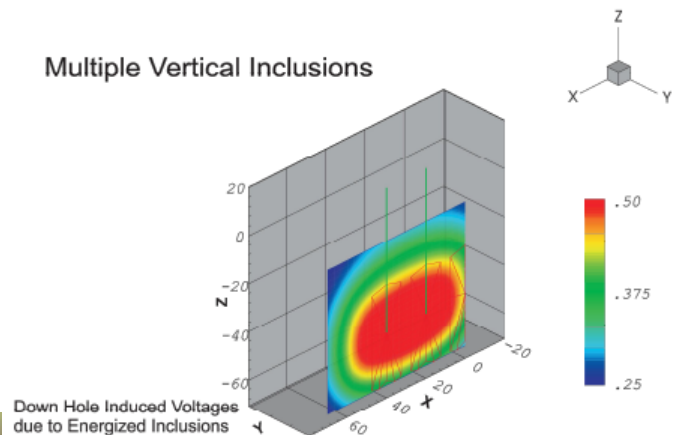
- Determine K_h of surrounding soils at the planned ZVI-PRB installation
- Performed by isolating screen zones of both wells pairs to be tested with inflatable packers and pressure transducers
- Permeability ranged from 3.01 – 88.85 ft/day
 - Historical site data ranged from 0.17 – 4.2 ft/day



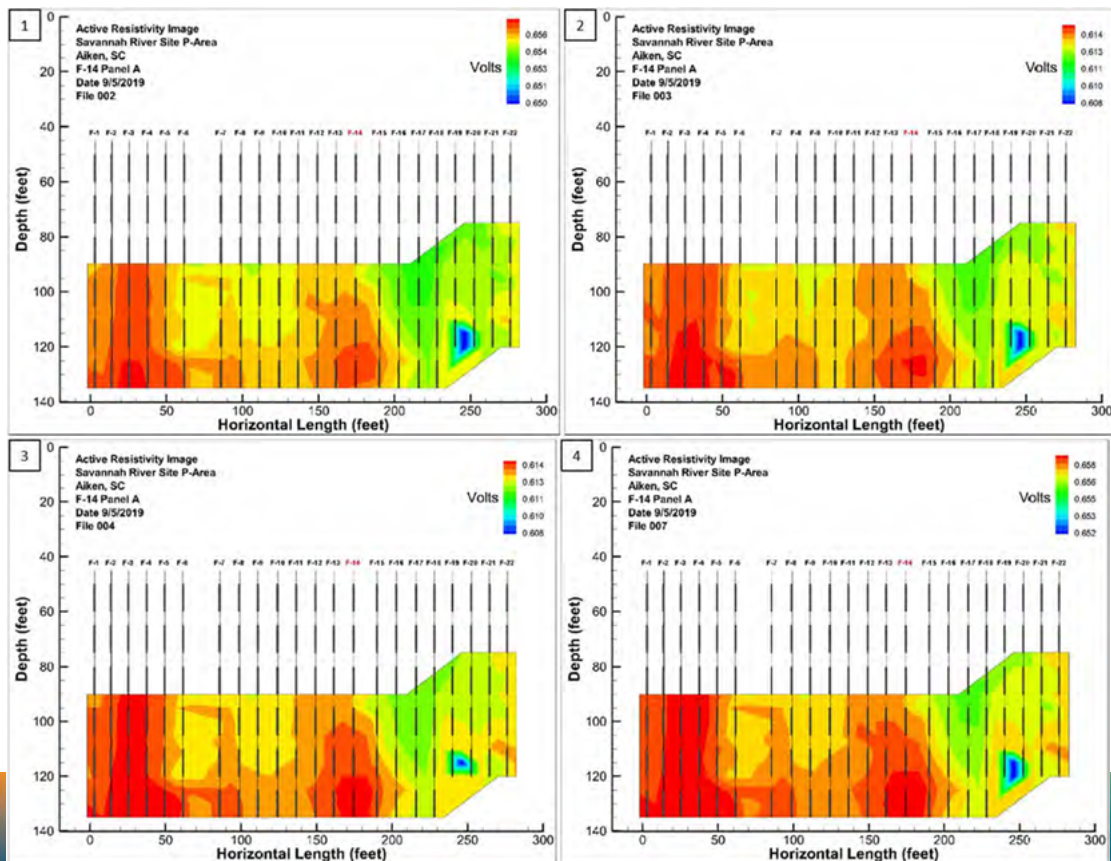


*Real-time monitoring of PRB
propagation with resistivity points*

Multiple Vertical Inclusions

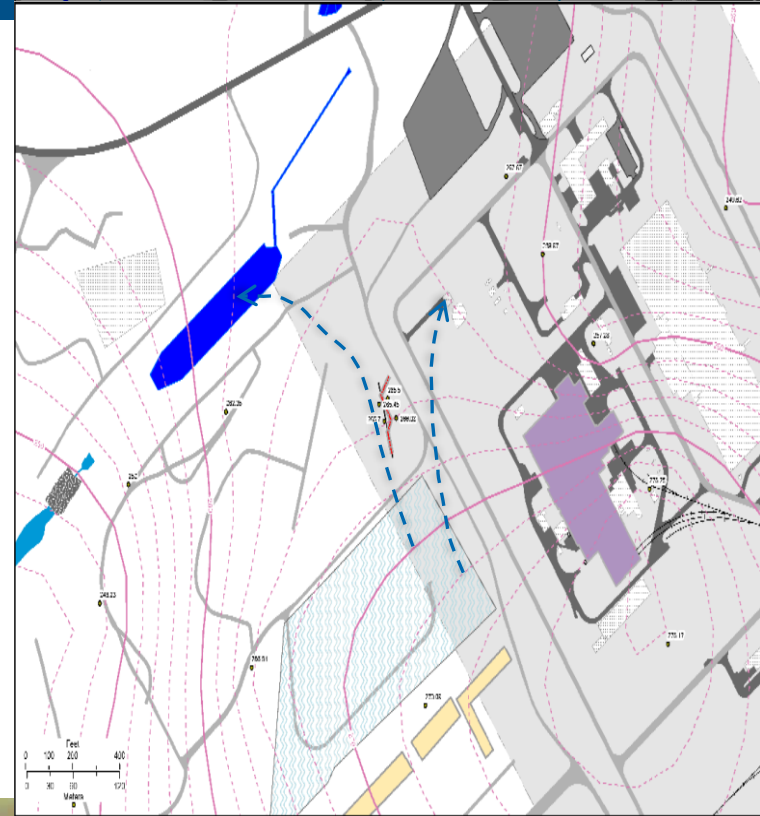


Backup Slides



Backup Slides

- **ZVI selection and PRB thickness**
 - Ensure ZVI had high K and porosity
 - Monte Carlo simulations
- **Target the UAZ only**
 - ZVI-PRB should intersect groundwater flow
 - *LAZ flow does not intersect ZVI-PRB*
 - TCE soil data indicate 95% TCE mass in UAZ soils



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- **Monitoring Network**

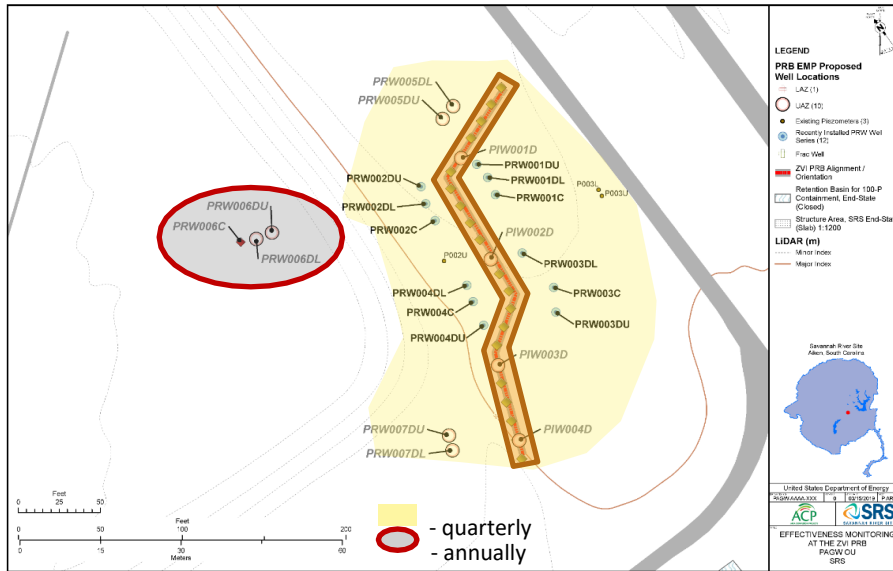
- In Wall Wells (4 wells)
- Wells near ZVI PRB (19 wells)
- Wells downgradient of ZVI PRB (3 wells)

- **Analytes**

- Water levels
- Reducing conditions
- VOCs
- Dissolved gases/chloride

- **Reporting**

- Annually for five years
 - Data from April – March
 - First report submitted in summer of 2021
 - Three years of reporting completed



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