



*Installation and Verification of a ZVI-PRB
Using Vertical Inclusions to Eliminate Offsite
CVOC Migration*

*Eighth International Conference on Remediation of
Chlorinated and Recalcitrant Compounds*

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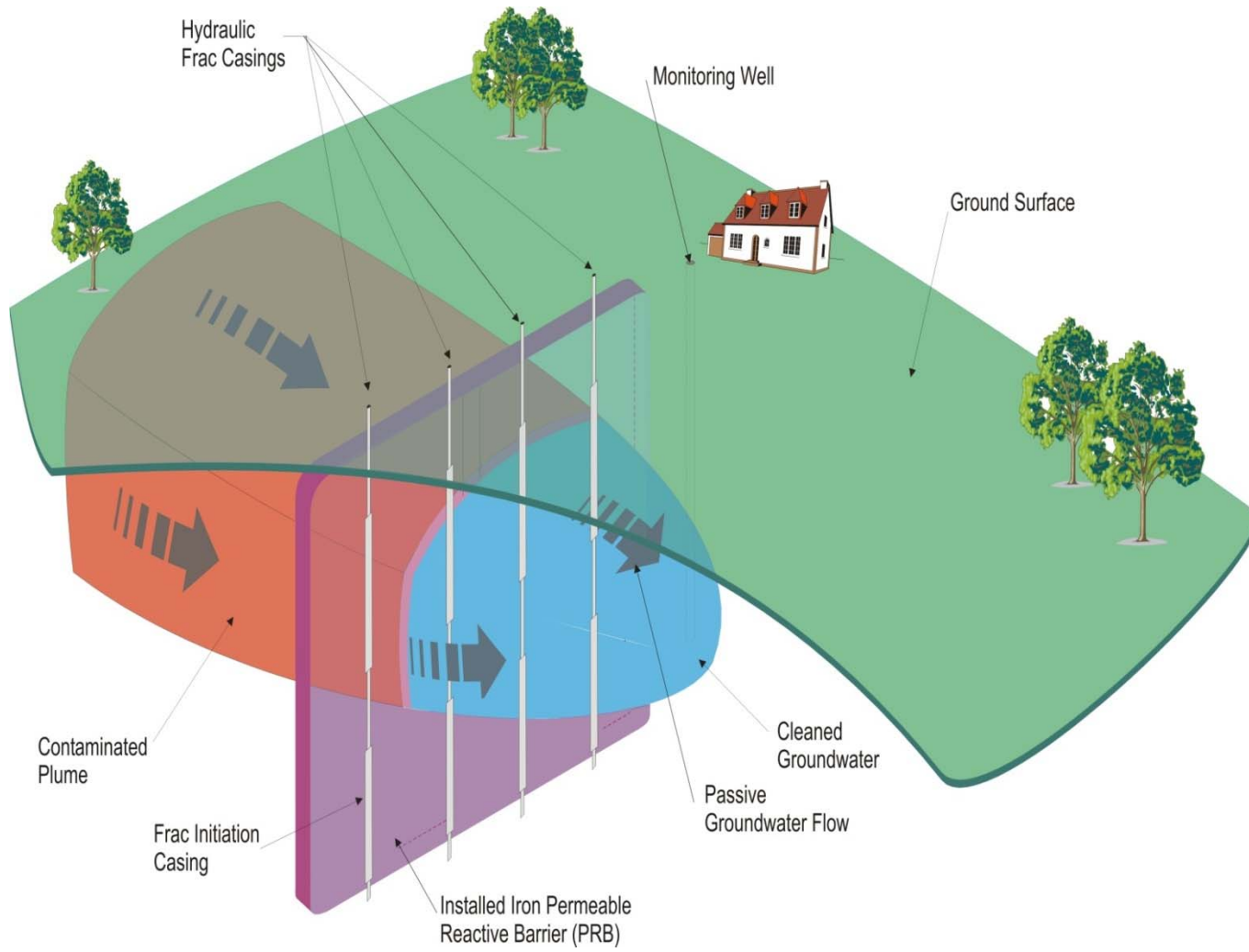
Presentation Overview

- Introduction
- Site Description/History
- Background Design Summary
- ZVI-PRB Installation
- Geometry, Thickness and Conductivity Verification
- Monitoring Results

Introduction

- GeoSierra Environmental, Inc. is the exclusive United States License holder for 4 hydraulic fracturing and geophysical monitoring patents
- Uncontrolled Hydraulic Fracturing vs. Controlled Vertical Inclusions
- Vertical Inclusion Process (VIP) used at twenty (20) total pilot and full-scale ZVI PRBs from 15' to 115' bgs to virtually any depth
- VIP process can be used to install from ZVI PRBs, source area remediation, water well permeability enhancement
- Active resistivity real time monitoring can be used to ensure lateral geometry – 2D or 3D

Introduction (cont'd)



Introduction (cont'd)

- ZVI degrades chlorinated ethenes through sequential dechlorination
- ZVI source is recycled engine block tailings
- Delivered in 3,000 lb supersacks
- Injected within cross linked food grade guar
- Enzymes breakdown gel with 1 – 3 hours leaving pure ZVI perpendicular to groundwater flow
- Degradation of sugars and starches by indigenous microbes immediately starts dechlorination process

Introduction (cont'd)

- “Green Technology” benefits include:
 - Utilizes waste from engine block manufacturing
 - No external power sources (e.g. grid power) used to install the ZVI PRB
 - Utilizes self generating power unit with ULSD fuels and mineral oil based hydraulic oil
 - No ongoing operations and maintenance
 - No groundwater extraction and disposal
 - No ongoing power consumption
 - Land surface can be reclaimed



Site Description and History

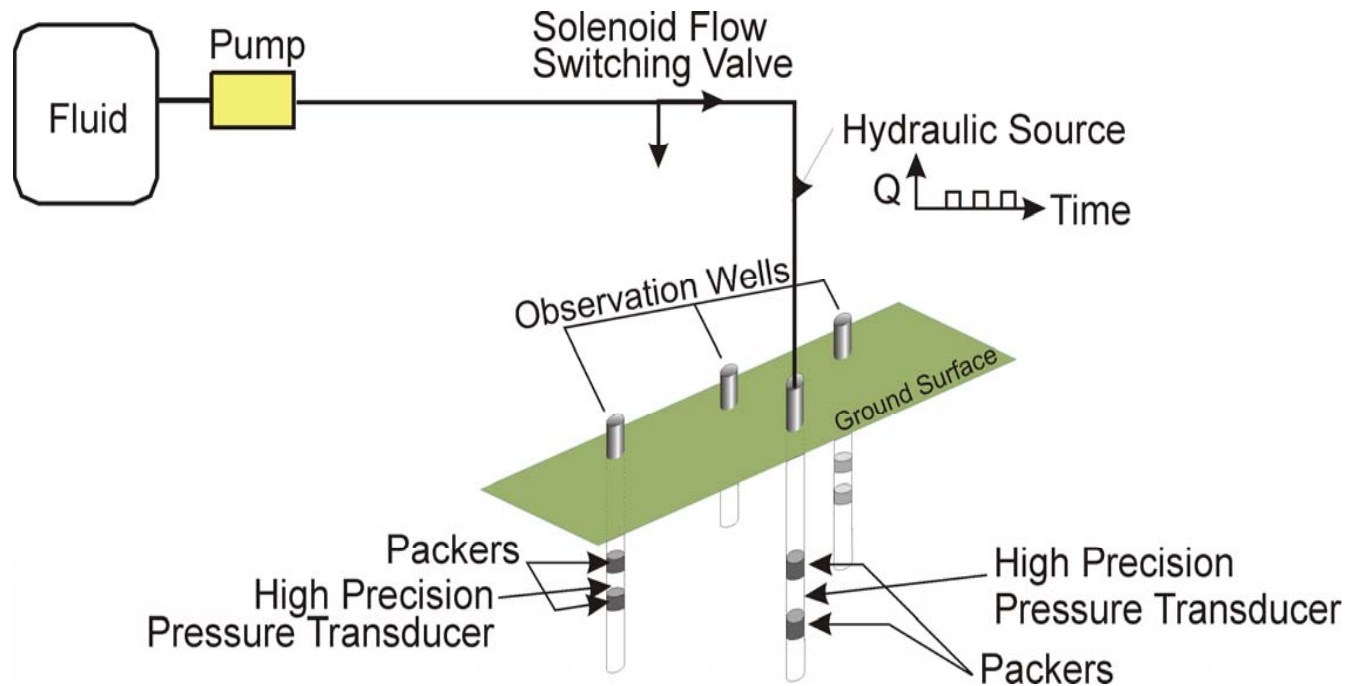
- Abandoned manufacturing facility that utilized PCE/TCE for parts cleaning
- Previous source area soil AOCs closed through soil mixing/ISCO
- Extensive groundwater investigations for +20 years
- Active perimeter P&T System
- Hypothesis: Groundwater migration through subterranean buried channel
- Hydrogeology:
 - Shallow glacial till
 - Deeper sand/gravel unconfined aquifer with interbedded silts/clays
 - Lower confining layer at ~90' BGS
 - Gradient of approx 0.006 ft/ft
 - K ranging from 10 – 150 ft/day
 - PCE/TCE Concentrations up to 2,000 ug/l

Site Description and History (cont'd)

- Dissolved phase groundwater plume migrating past P&T system downgradient
- Downgradient receptors include homes, businesses, schools and ultimately discharge to river
- Upgradient chemical oxidation ongoing to eliminate source area contamination
- Goal of IRM PRB:
 - Reduce groundwater concentrations migrating offsite through channel to below IAQ screening levels.
 - Setup long term MNA Remedy

Background Design Summary

- Baseline column study used to determine site specific half lives
- Pre-PRB Installation Hydraulic Pulse Interference Testing across planned PRB location



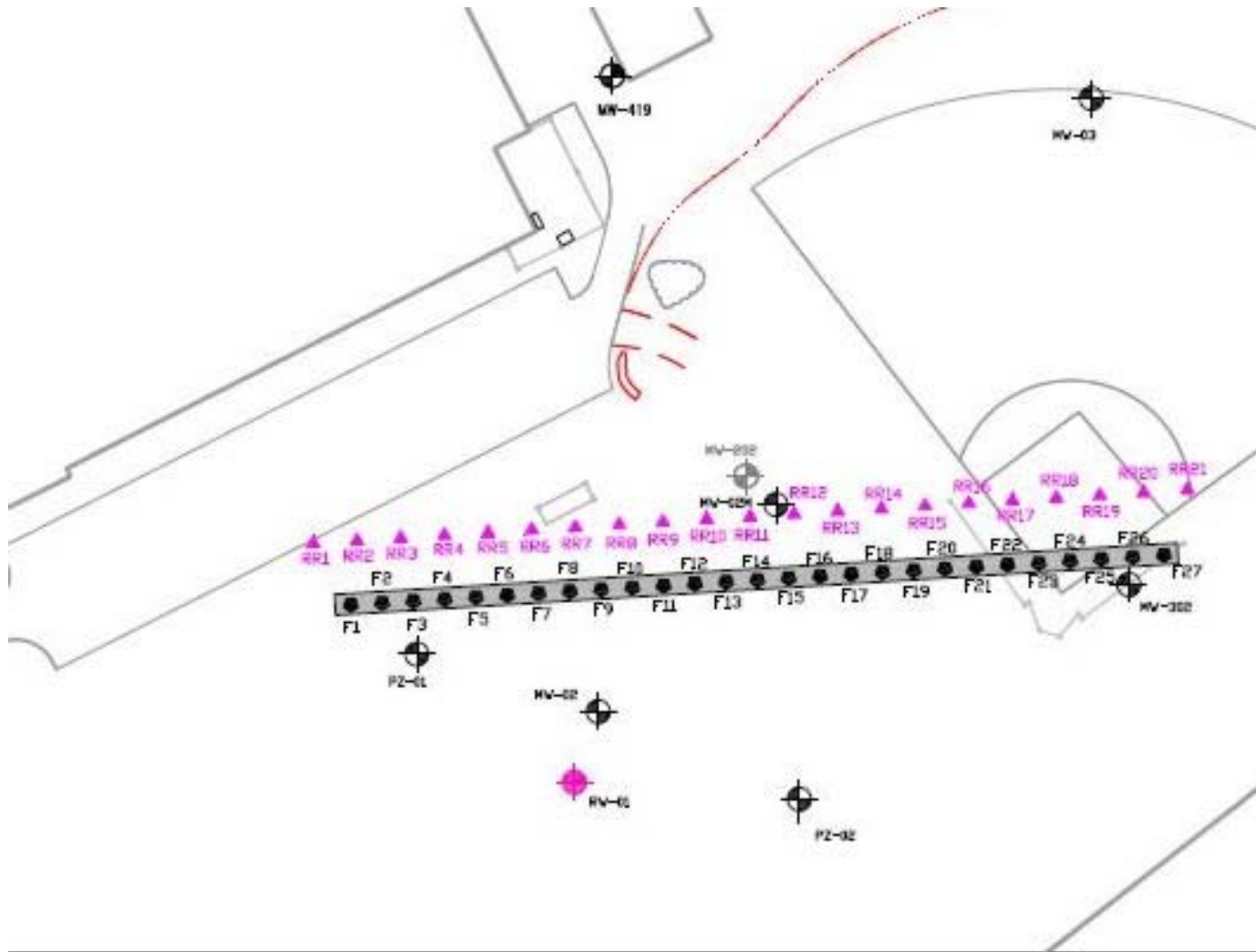
Background Design Summary (cont'd)

- Probabilistic design utilizing twenty (20) Monte-Carlo simulation scenarios for numerous recent and historic data and geologic parameters
- GeoSierra developed 2-D fracture modeling to estimate VIP extents
- Newly published multi-component reactive transport model used to evaluate mineral reactivity on iron surfaces
- Multi component model also evaluated life expectancy of ZVI PRB to 30-year life cycle inclusive of effects of inorganic passivation
- Based on the plume dimensions and various modeling scenarios, the ZVI-PRB was designed as follows:
 - 400-linear feet (l.f.) in total length, 720 tons of iron from 50 – 90' bgs
 - Consistent 6-inch nominal thickness

Background Design Summary (cont'd)

- During drilling, confining layer located 10-feet deeper than expected
- Hypothesized subterranean channel significantly more predominant and “channeling” groundwater migration
- PRB lengthened on ends and deeper in core
- New PRB dimensions:
 - 465-l.f. length
 - Total depth 100’ bgs
 - 891 tons of iron
- “Adaptive Site Management Approach” utilized to address hydrogeologic variations during installation
- No delays to project implementation

Background Design Summary (cont'd)

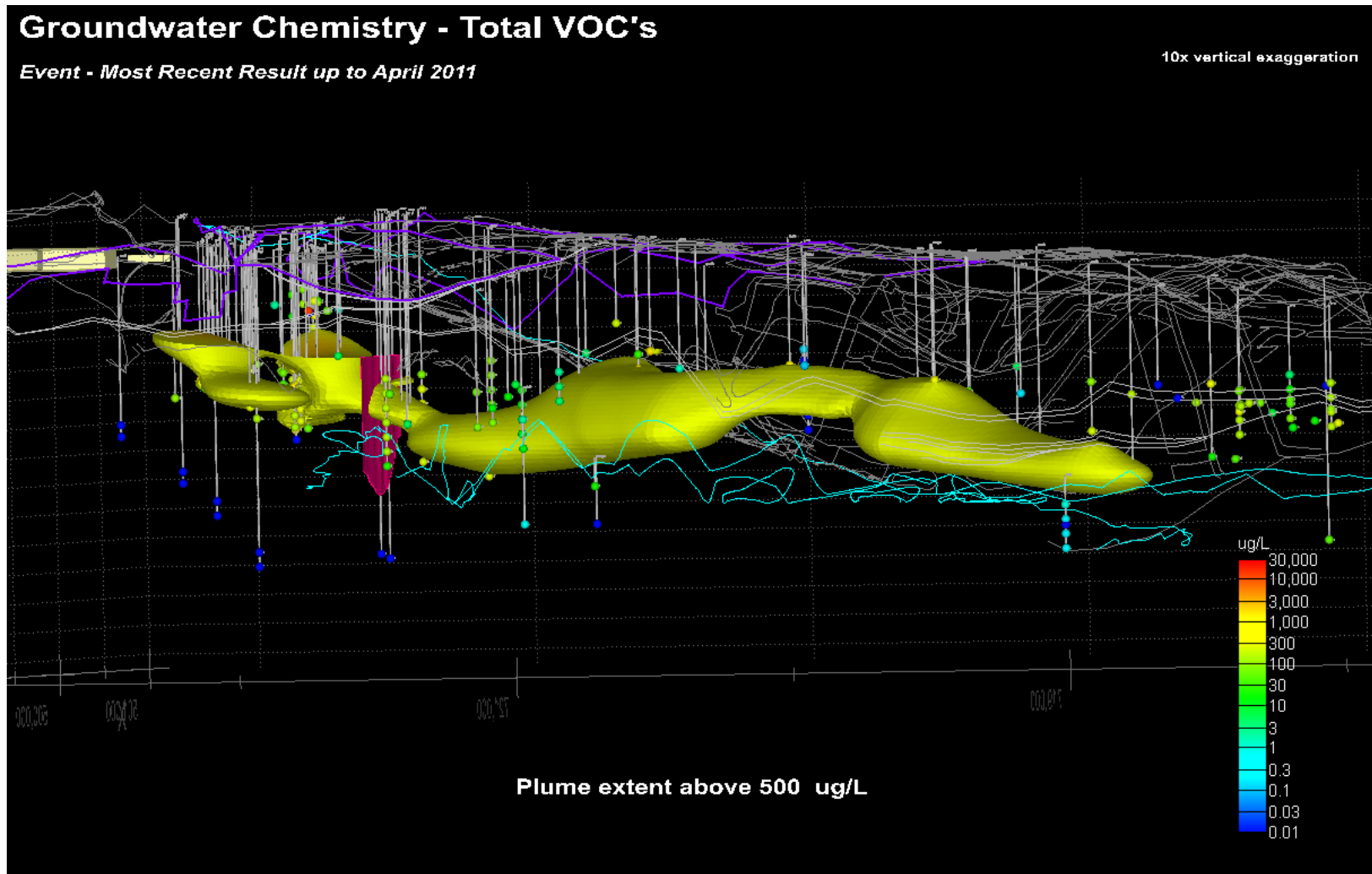


Background Design Summary (cont'd)



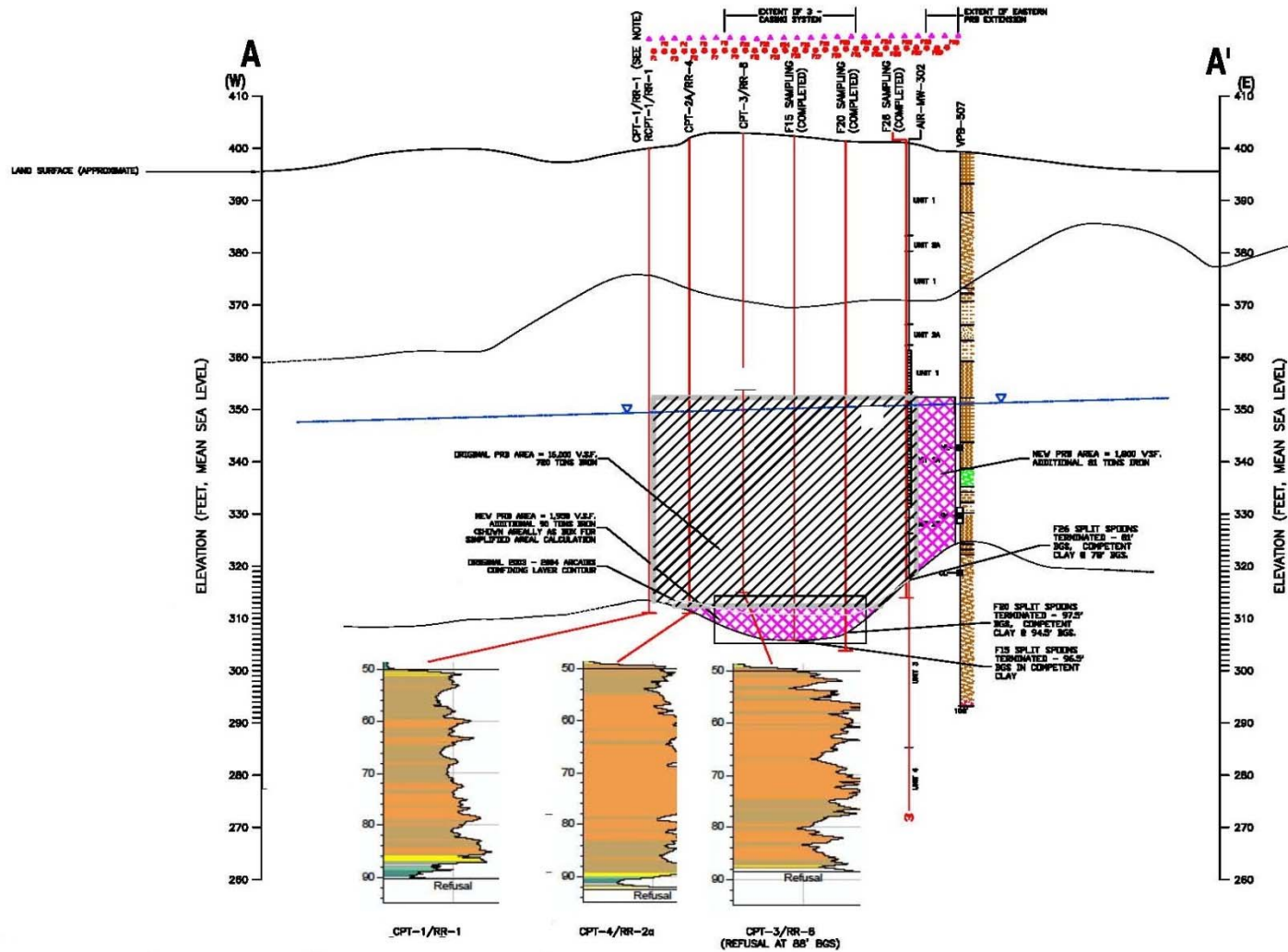
Modeling screenshot courtesy of CRA.

Background Design Summary (cont'd)



Modeling screenshot courtesy of CRA.

Background Design Summary (cont'd)



ZVI-PRB Installation

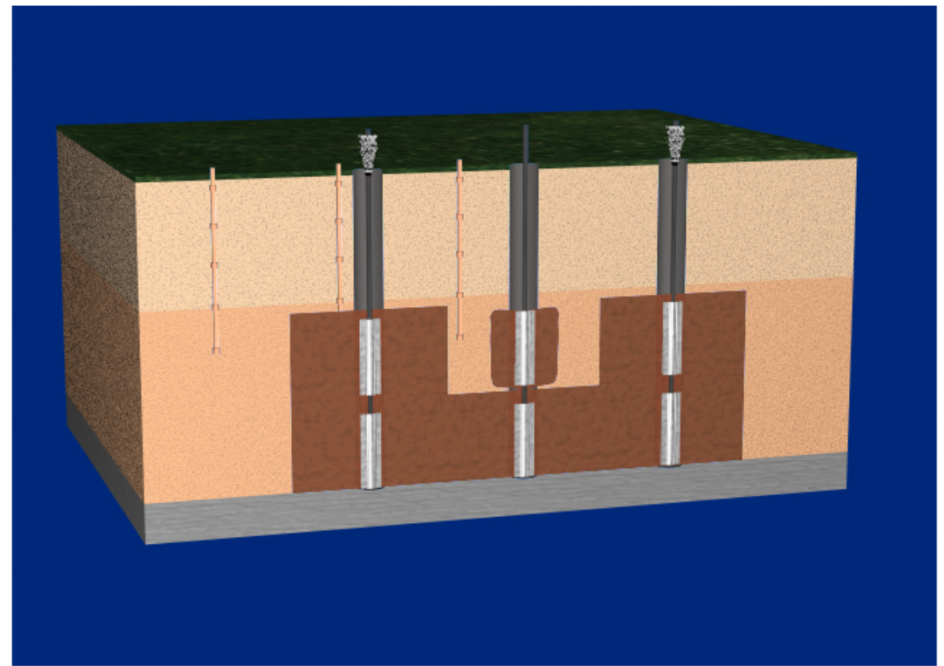
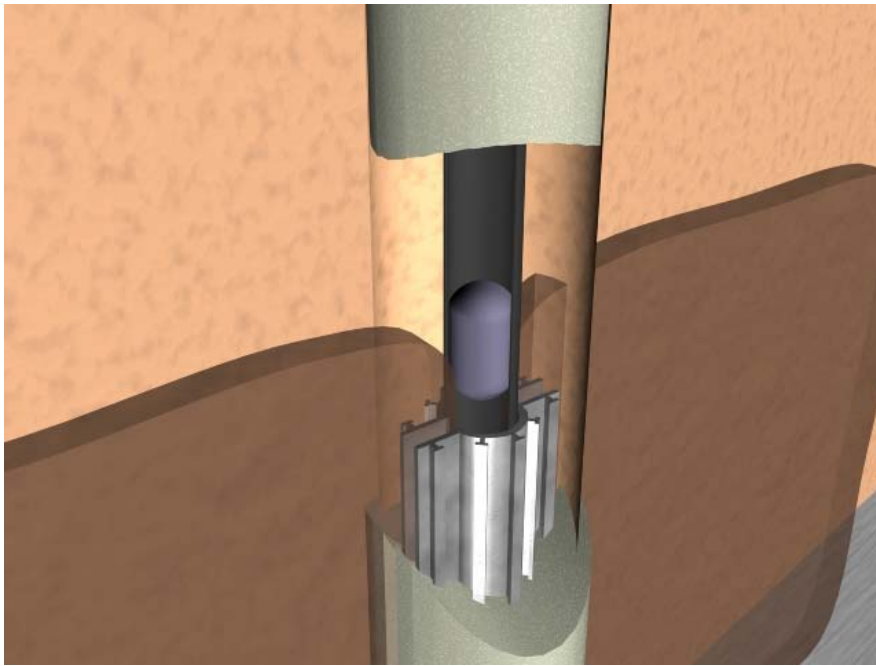


ZVI-PRB Installation (cont'd)



ZVI-PRB Installation (cont'd)

- Injections occur through VIP wells that dilate under pressure to allow migration of cross linked iron gel vertically into the formation.



ZVI-PRB Installation (cont'd)

- Injections through custom mixing, blending and pumping systems



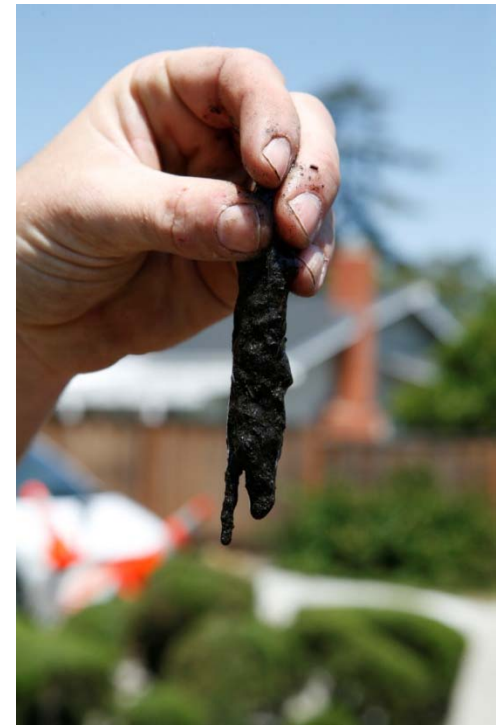
ZVI-PRB Installation (cont'd)

- Injections through custom mixing, blending and pumping systems



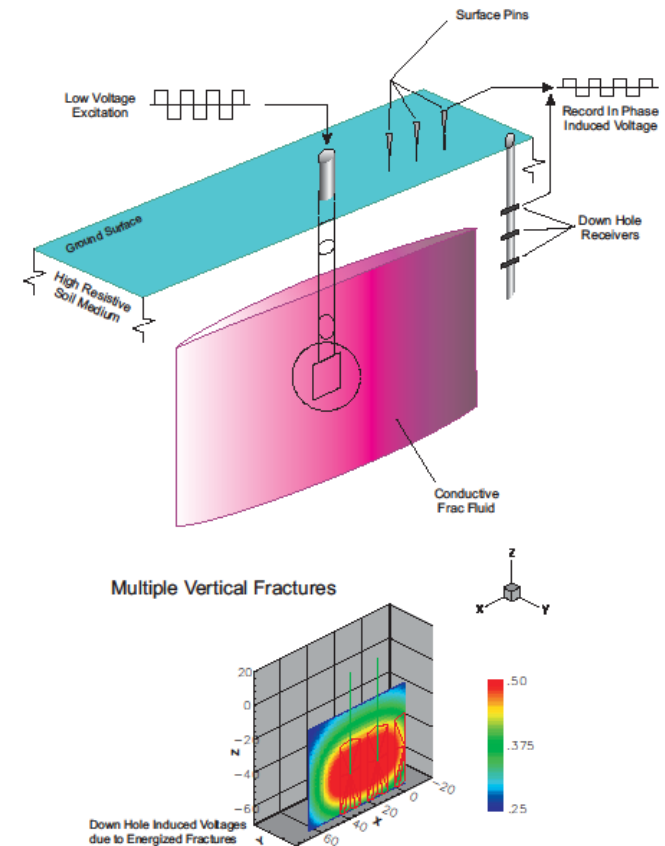
ZVI-PRB Installation (cont'd)

- VIP wells installed via mud rotary and hollow stem auger
- Injection and monitoring equipment, injection gels, enzymes and iron mobilized to the site
- Remote mixing system facilitates mixing of gel and transfer to pumping system
- Gel mix QA/QC parameters including
 - pH – 4 – 5 s.u. to enhance enzyme destruction of cross-linked guar
 - Viscosity – high enough to suspend iron without settling
 - Resistivity – substantial contrast against background soil resistivity to monitor inclusion propagation with active resistivity system

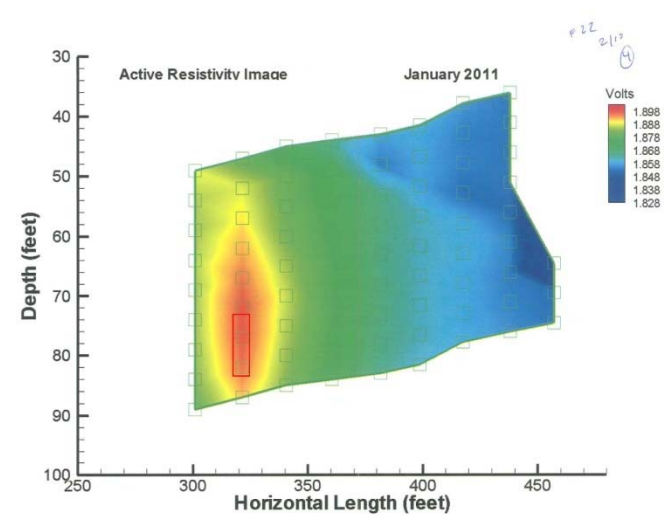
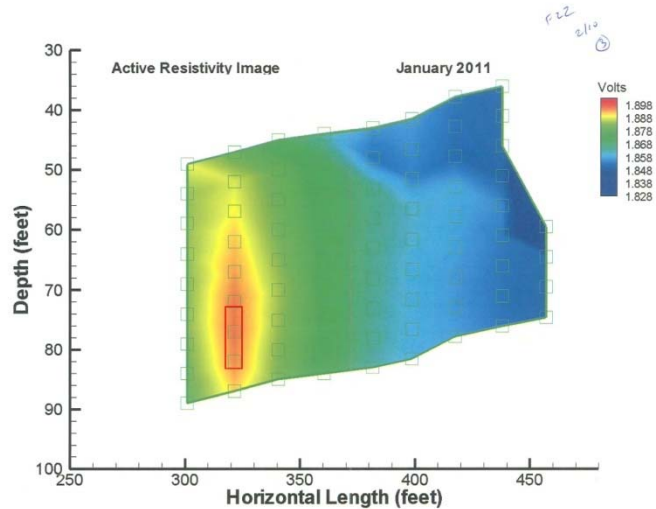
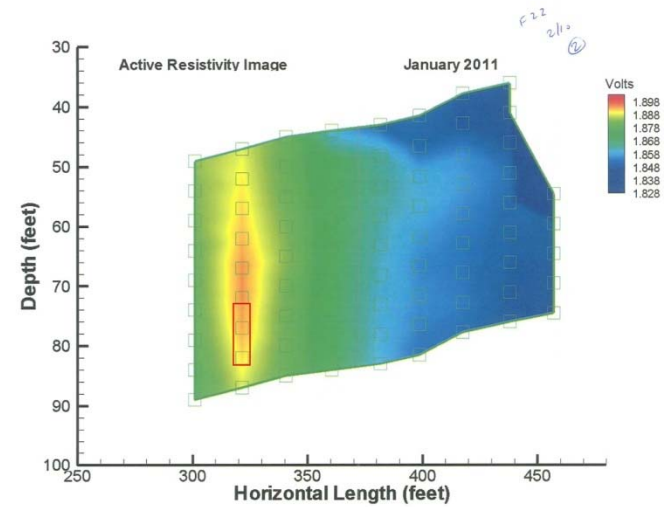
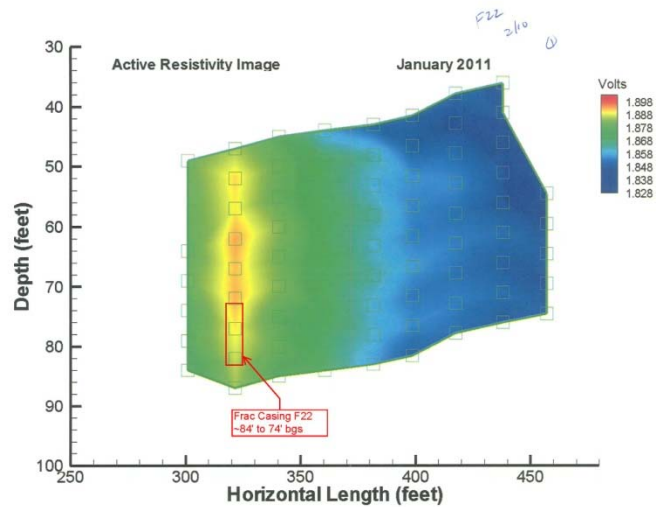


Geometry, Thickness and Conductivity Verification

- Real time VIP monitoring through active resistivity system
- Resistivity receivers installed on 20-foot centers
- Low voltage, 97 hz square wave charges the casing and excites the gel/iron mixture during fracturing
- Propagation of the excited iron through the formation is logged by the downhole receivers and reduced via inverse algorithms to images
- Geometry is used to verify coalescence of the wall from end to end



Geometry, Thickness and Conductivity Verification (cont'd)



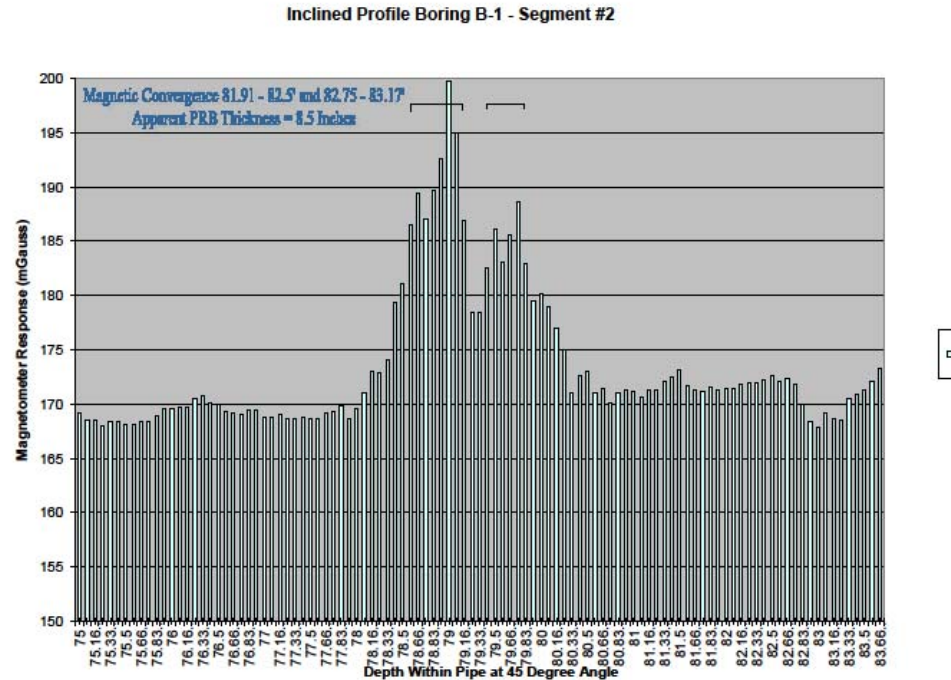
Geometry, Thickness and Conductivity Verification (cont'd)

- Following completion of installation, thickness verification completed with inclined profile borings thru PRB
- Utilized Sonic Drilling methods
- Attempts to minimize disturbance during installation of 2-inch PVC casing through PRB and collect intact core
- Following installation of casing, insert 3-axis magnetometer and collect readings before, within and following exit of PRB
- Multiple runs up and down casing measures the low level magnetic field generated by the iron PRB



Geometry, Thickness and Conductivity Verification (cont'd)

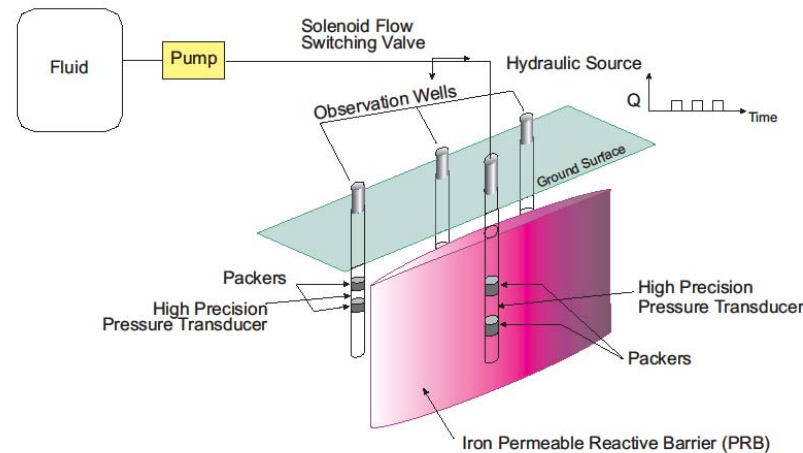
- Verification of installation per the design specifications was completed using the inclined profile boring and magnetometer:



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Geometry, Thickness and Conductivity Verification (cont'd)

- Following installation, the post-PRB installation Hydraulic Pulse Interference Test was re-run on the same wells from the previous test to confirm the PRB has no impact on groundwater flow



Test Location	Pre-PRB Installation Hydraulic Pulse Interference Testing			Post-PRB Installation Hydraulic Pulse Interference Testing			Percent Change Pre - Post
	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/sec)	Storativity (1/ft)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/sec)	Storativity (1/ft)	
<i>Pulse Test Data Summary</i>							
PRB Well Pairs							
Source Well AIR-MW-2M; Receiver Well AIR-PZ-01	22.7	8.01E-03	2.38E-07	28.2	9.95E-03	3.38E-07	24%
Source Well AIR-MW-02M; Receiver Well AIR-PZ-02	5.7	2.01E-03	7.71E-07	11.4	4.02E-03	2.92E-07	100%

Summary of Results

- A total of 891 Tons of ZVI were emplaced to build a 465-foot long, 50 to 60-foot tall ZVI-PRB
- Installation was completed in approximately 6-months throughout the winter
- Following ZVI-PRB construction, GeoSierra and the Consultant continue monitoring
- To date, reduction of CVOCs in the channel flowing through the PRB range are > 90% and continue to fall
- Perimeter P&T system shutdown permanently

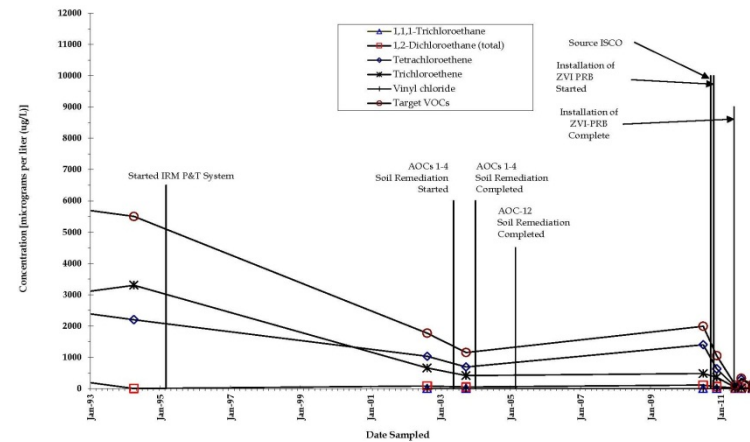


FIGURE C-1
Time Trends in Concentrations of Primary Target VOCs and TVOC
Detected in Monitoring Well AIR-MW-02

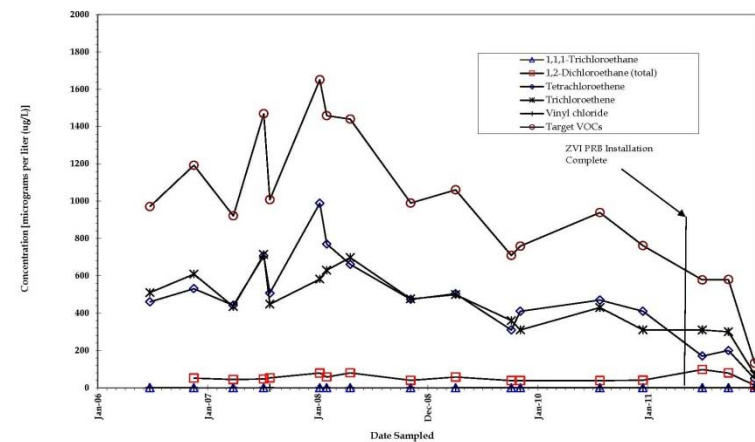


FIGURE C-1
Time Trends in Concentrations of Primary Target VOCs and TVOC
Detected in Monitoring Well AIR-RW-01

Thank You!

QUESTIONS?

For More Information, Please Contact:

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