GeoSierra Environmental, Inc.

# *Installation and Verification of a Vertical Hydraulically Fractured ZVI PRB in a Residential Setting*

## *Seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds*

**Jim Ortman, Kevin D. Dyson, P.E., Peter J. Palko, CHMM, P.E., - Geosierra**

**Brian Bjorklund, P.G., Arun Chemburker, P.E. – ERM West, Inc.**

**Medford, NJ - Alpharetta, GA**

**www.geosierraenv.com**

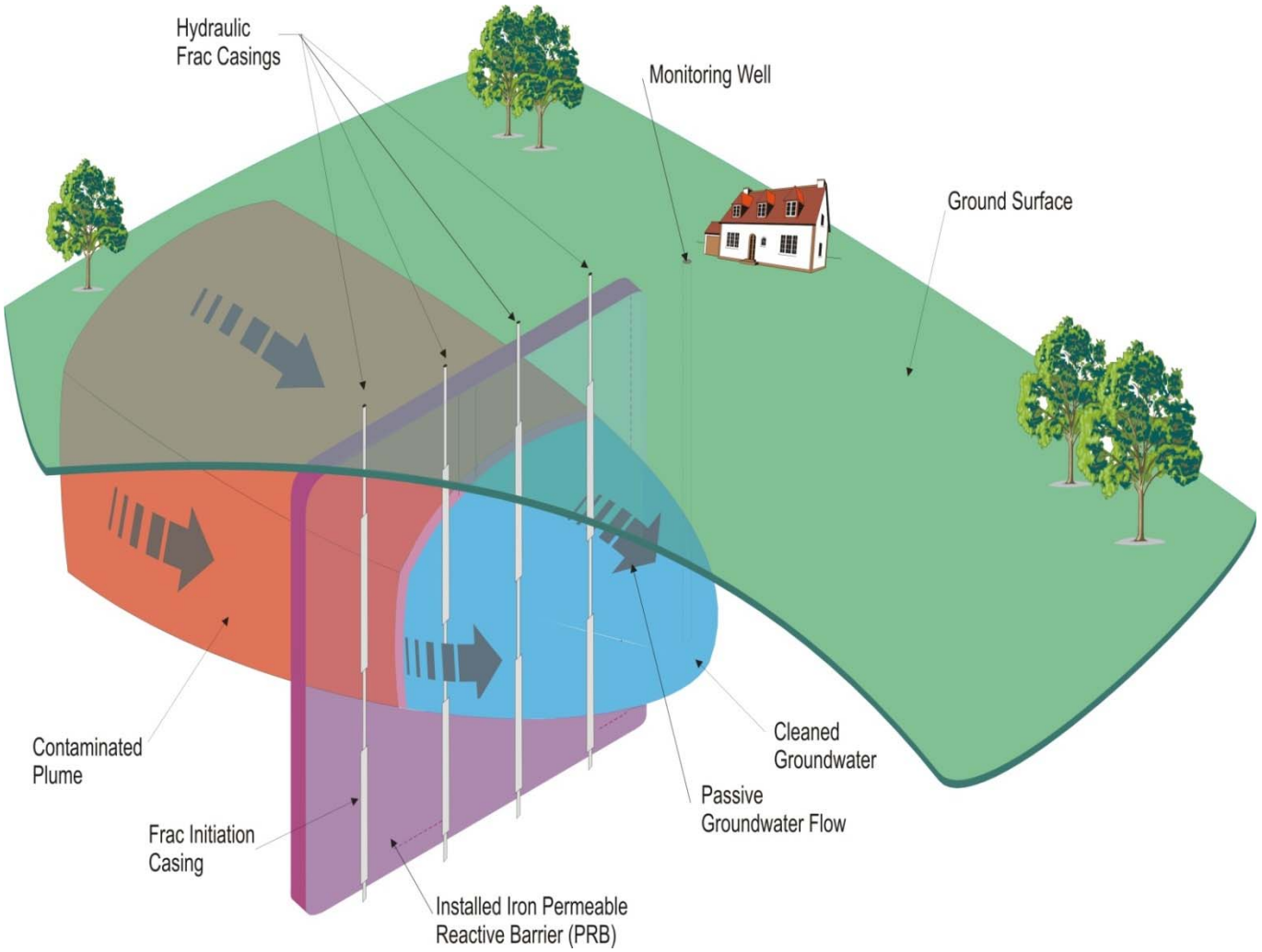
# Presentation Overview

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

# Introduction

- Geosierra Environmental, Inc. formed in 2007 following purchase of Geosierra, LLC. assets and licensing rights
- Exclusive North America License holder for 4 hydraulic fracturing and geophysical monitoring patents
- Hydraulic Fracturing implemented at seventeen (17) total pilot and full-scale ZVI PRBs from 15’ to 115’ bgs to virtually any depth
- Vertical hydraulic fracturing can be used to install from 3-inch to 9-inch thick pure iron PRBs
- Active resistivity real time monitoring used to ensure lateral fracture geometry

# Introduction (cont'd)






GeoSierra Environmental, Inc.

# 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

- Former manufacturing facility that utilized TCE for degreasing operations
- Groundwater plume in two major distinct lithologic units (A and B Zones):
  - A1-Zone from 15’ bgs to ~25’ bgs (targeted zone for PRB)
    - Consists of clay, silty clay, clayey silt and silt
    - Hydraulic conductivity ranges from 0.62 – 11.5 ft/day
  - A2-Zone from 25 to ~50’ bgs (targeted zone for PRB)
    - Consists of clay, silty clay, clayey silt and silt with interbedded lenses of coarse grained sand zones
    - Hydraulic conductivity ranging from 10.5 – 65.3 ft/day
  - Hydraulic gradients ranging from 0.001 – 0.004 ft/ft
  - B-Zone from 50’ bgs to 80’ bgs (treatment via source ISCO)
    - Consists of silty sand, sand, sandy gravel or gravelly sand
    - Hydraulic conductivity significantly higher that A-Zone

# Site Description and History (cont'd)

- Dissolved phase groundwater plume flowing beneath local park and under residences
- Current vapor intrusion system installed within residential crawl spaces to reduce indoor air quality issues
- High traffic area including intersection that handles traffic flow to local elementary school
- Upgradient chemical oxidation ongoing to eliminate source area contamination



GeoSierra Environmental, Inc.

# Site Description and History (cont'd)

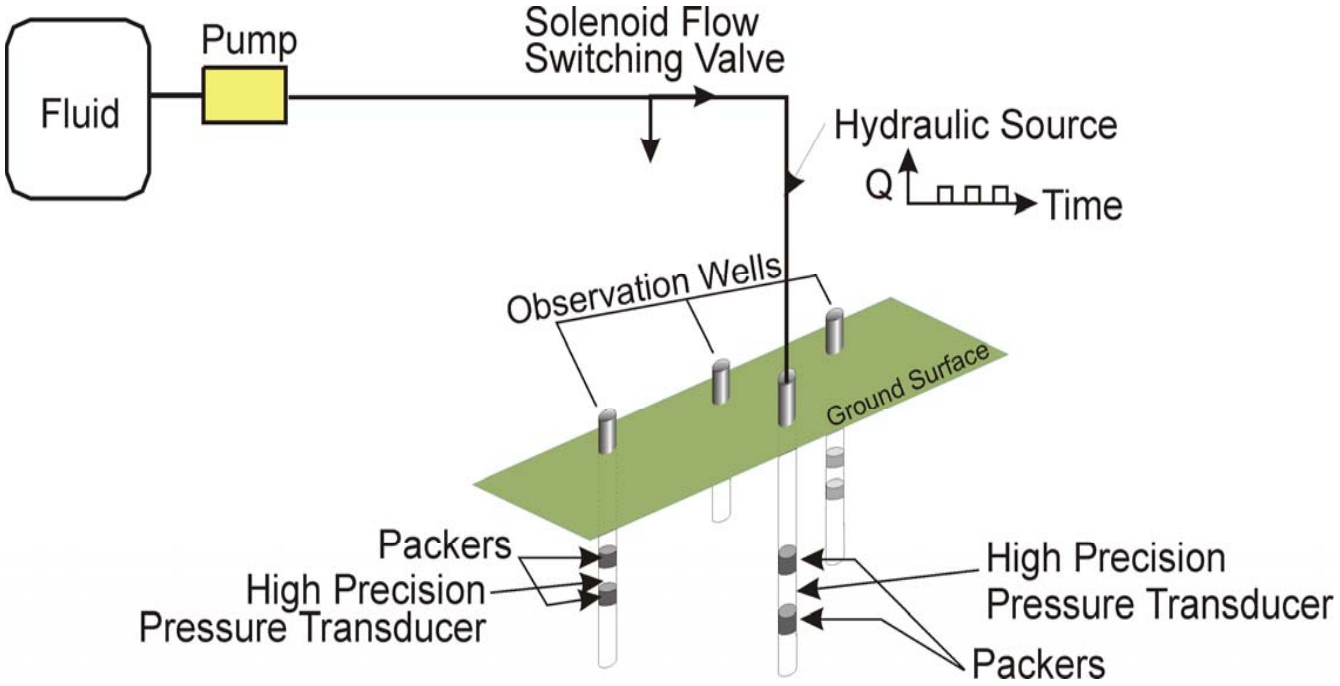
- Site plan showing iso-concentration contours:




GeoSierra Environmental, Inc.

# Background Design Summary

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



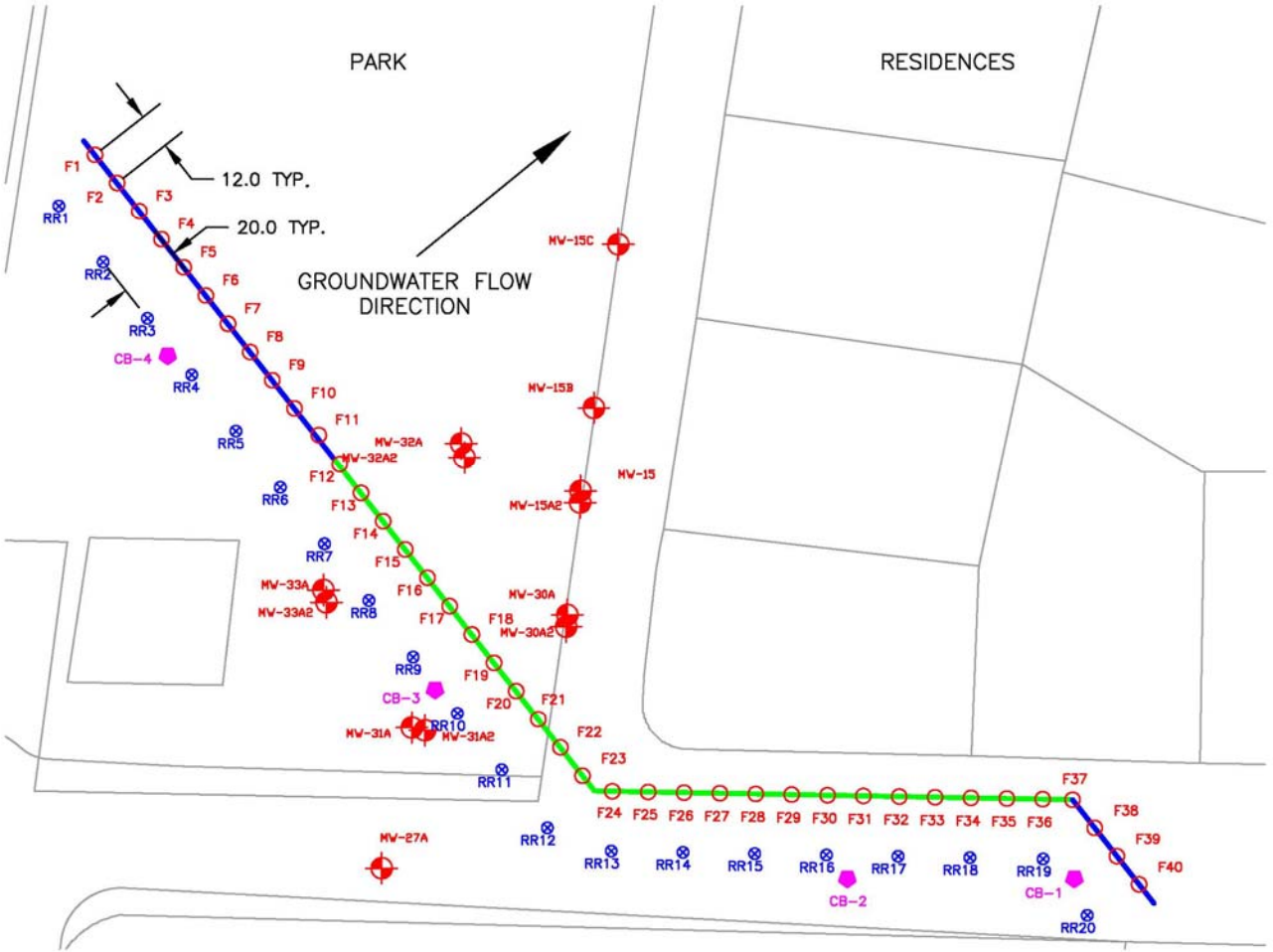



GeoSierra Environmental, Inc.

# Background Design Summary (cont'd)

- Complete MIP survey conducted by ERM along PRB alignment
- Probabilistic design utilizing twenty-five (25) Monte-Carlo simulation scenarios for numerous recent and historic data and geologic parameters
- 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, detailed hydrogeologic assessments and various modeling scenarios, the ZVI-PRB was designed as follows:
  - 480-linear feet (l.f.) in total length, 455 tons of iron from 15 – 48' bgs
  - The core was designed as 4.5-inch thickness over 300-l.f.
  - The boundaries were 3-inch on either end over 180-l.f. length

# Background Design Summary (cont'd)






GeoSierra Environmental, Inc.

# ZVI-PRB Installation

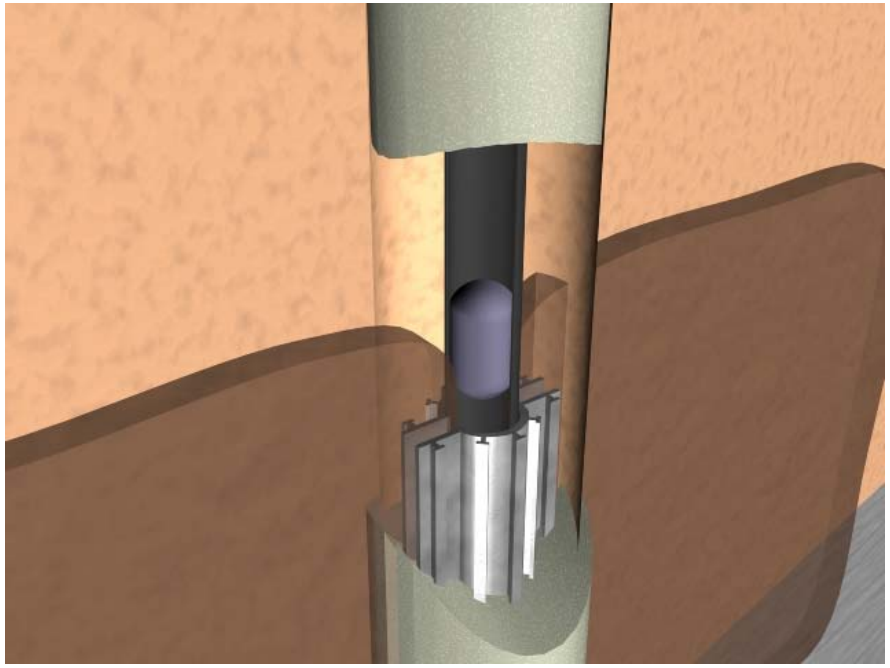
- Installation of frac wells consisting of two (2) frac casings per well at 40-locations (resistivity receivers located under cones)

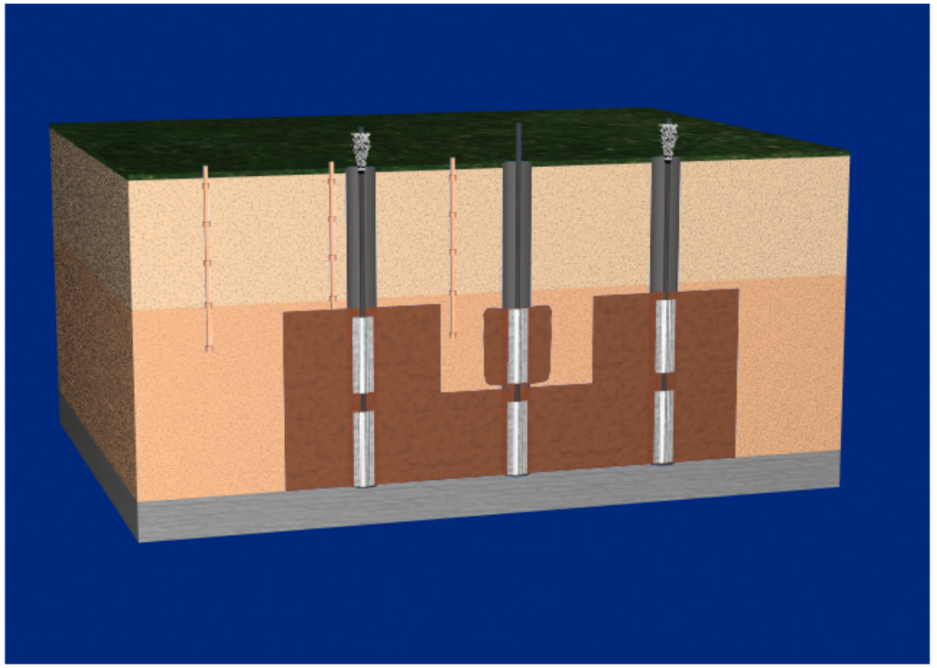


GeoSierra Environmental, Inc.

# ZVI-PRB Installation (cont'd)

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







GeoSierra Environmental, Inc.

# ZVI-PRB Installation (cont'd)

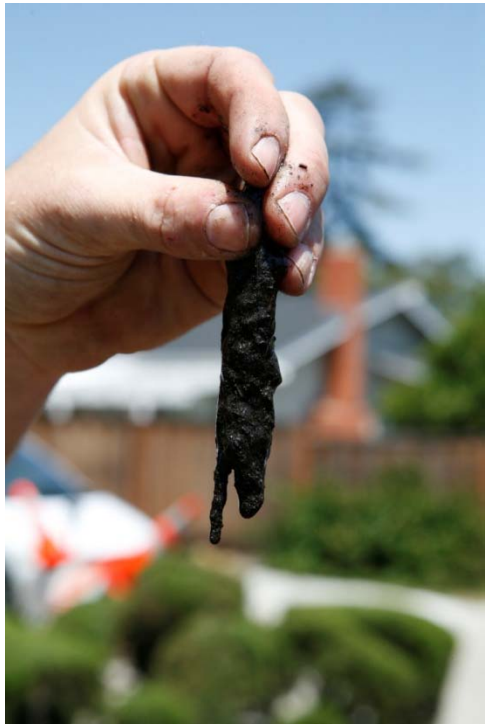
- Injections through custom mixing, blending and pumping systems



GeoSierra Environmental, Inc.

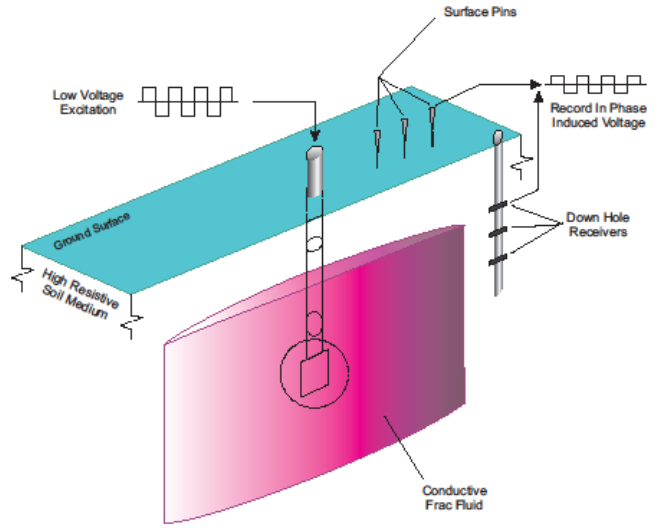
# ZVI-PRB Installation (cont'd)

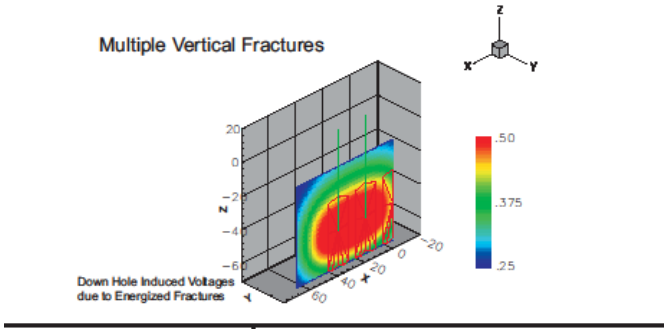
- Frac wells installed via mud rotary and hollow stem auger
- Injection and monitoring equipment, injection gels, enzymes and iron mobilized to the site
- Remote mixing system facilitates mixing of gel and transfer to pumping system
- Gel mix QA/QC parameters including
  - pH – 4 – 5 s.u. to enhance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



# Geometry, Thickness and Conductivity Verification

- Real time fracture 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
- Fracture geometry is used to verify coalescence of the wall from end to end

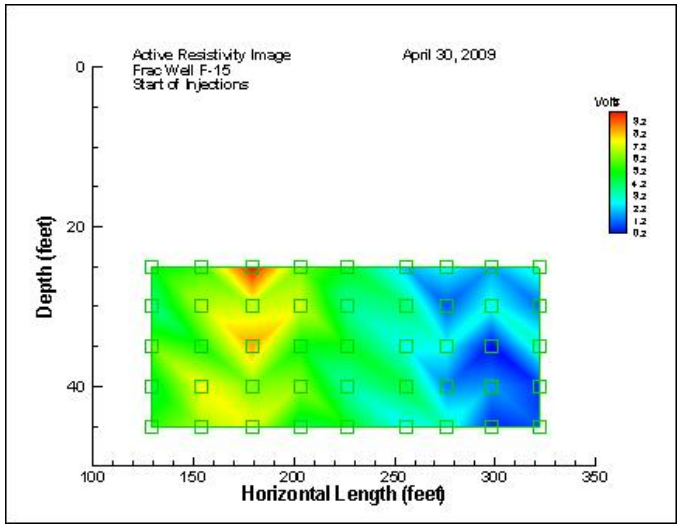


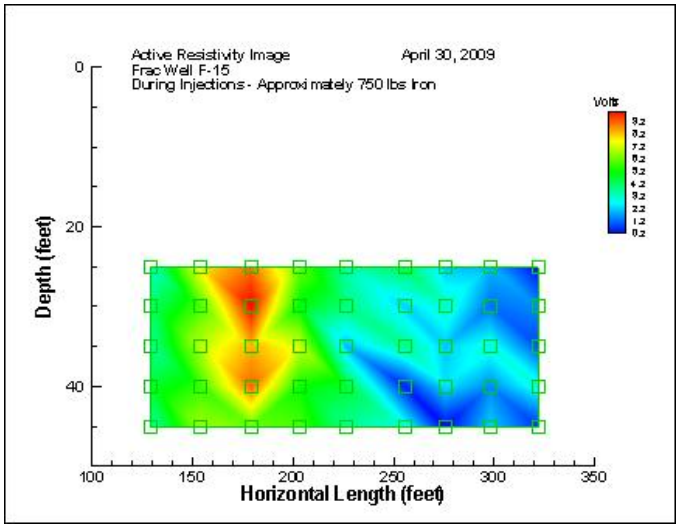



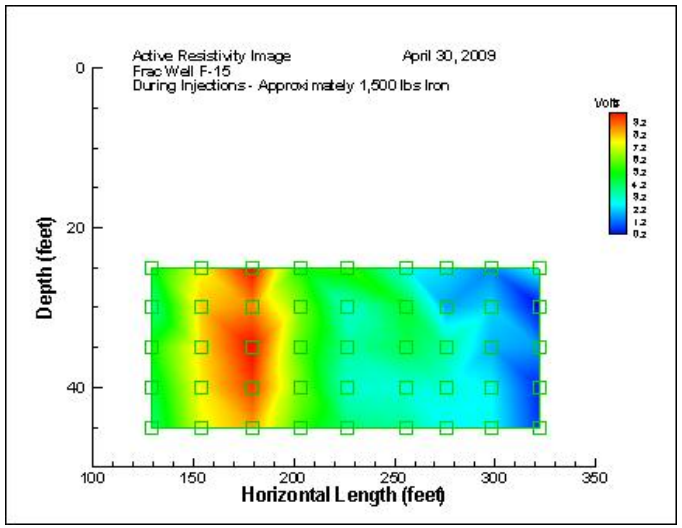


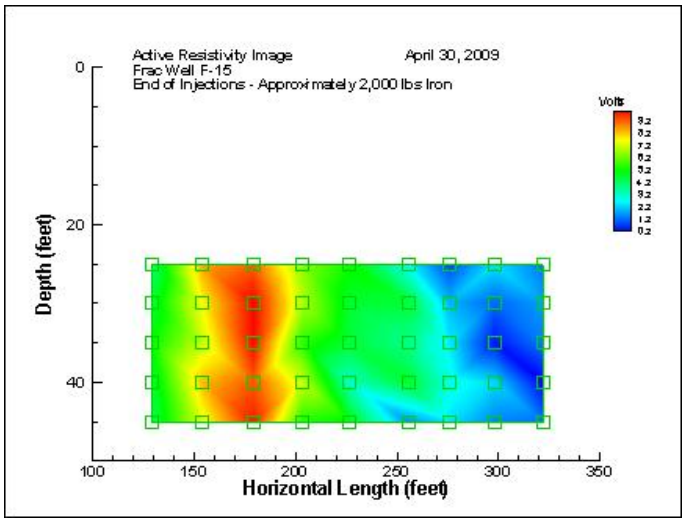

GeoSierra Environmental, Inc.

# Geometry, Thickness and Conductivity Verification (cont'd)



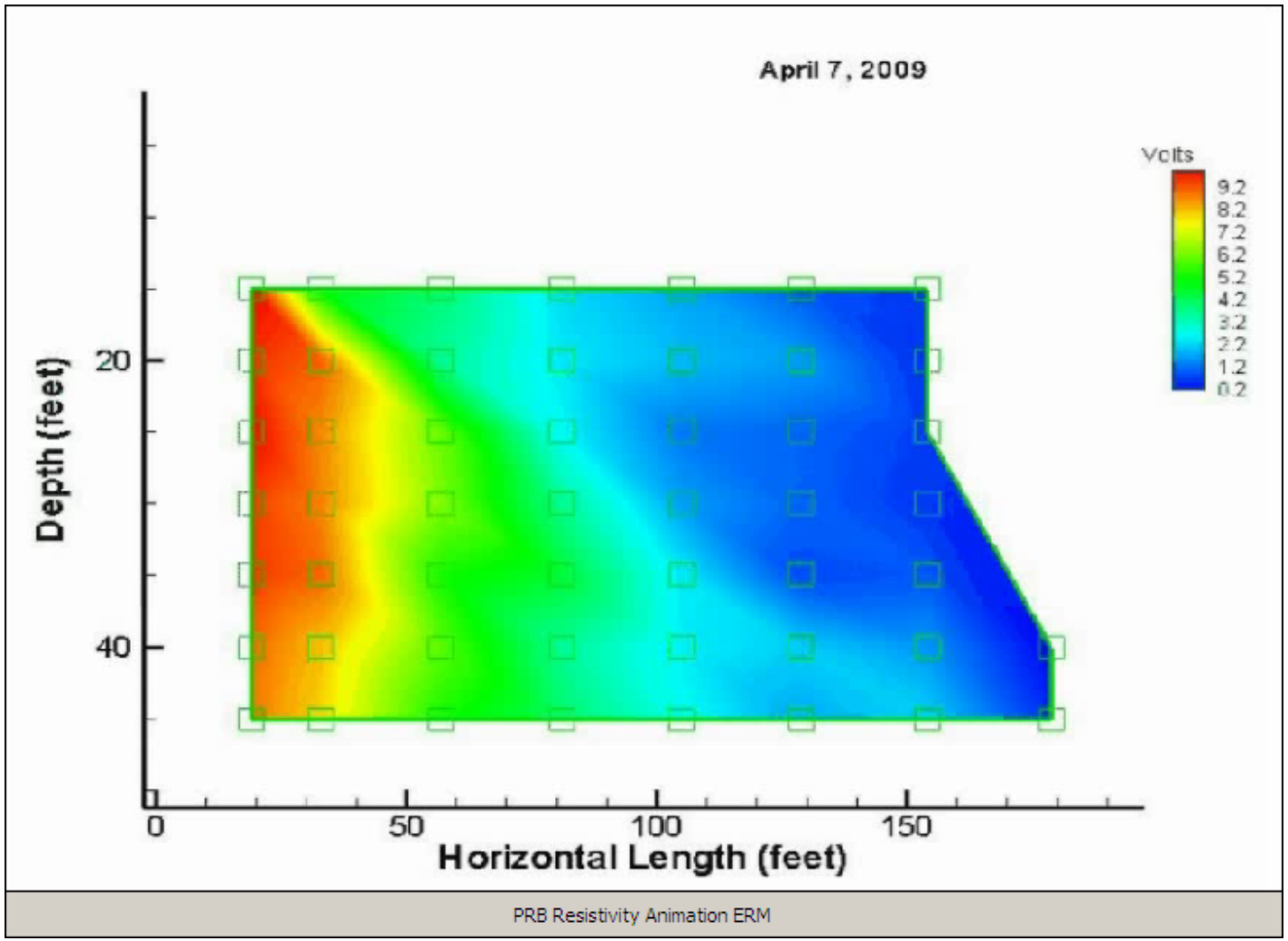






GeoSierra Environmental, Inc.

# Geometry, Thickness and Conductivity Verification (cont'd)






GeoSierra Environmental, Inc.

# Geometry, Thickness and Conductivity Verification (cont'd)

- Following completion of installation, thickness verification completed with inclined profile borings thru PRB
- Utilized Geoprobe and 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

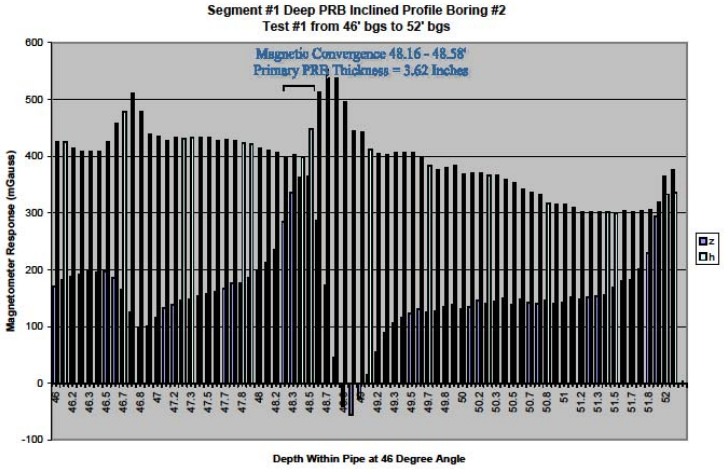



GeoSierra Environmental, Inc.

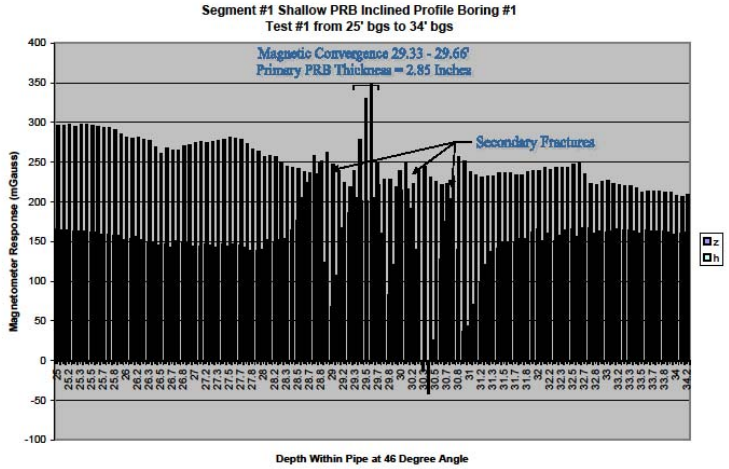
# Geometry, Thickness and Conductivity Verification (cont'd)

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

Deep PRB Section




Shallow PRB Section (note secondary fractures from Deep PRB Section)






GeoSierra Environmental, Inc.

# 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

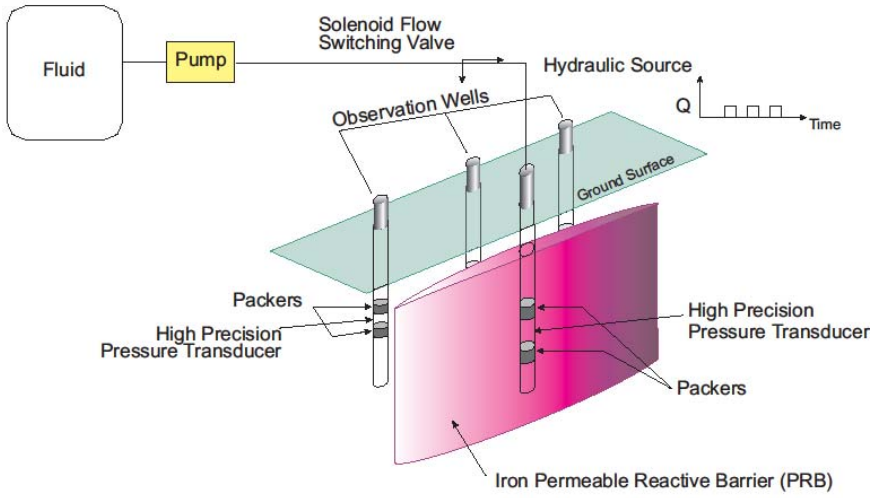



Table 7. Summary of Hydraulic Pulse Interference Test Results, [redacted] ZVI PRB, [redacted] California. G205001

| Test Location | Pre-PRB Installation Hydraulic Pulse Intereference Testing: Hydraulic Conductivity (ft/day) | Pre-PRB Installation Hydraulic Pulse Intereference Testing: Hydraulic Conductivity (cm/sec) | Pre-PRB Installation Hydraulic Pulse Intereference Testing: Storativity (1/ft) | Post-PRB Installation Hydraulic Pulse Intereference Testing: Hydraulic Conductivity (ft/day) | Post-PRB Installation Hydraulic Pulse Intereference Testing: Hydraulic Conductivity (cm/sec) | Post-PRB Installation Hydraulic Pulse Intereference Testing: Storativity (1/ft) | Percent Change Pre Post |
|---|---|---|---|---|---|---|---|
| *Pulse Test Data Summary* | | | | | | | |
| *Shallow Well Pairs* | | | | | | | |
| Source Well MW31A; Receiver Well MW30A | 11.5 | 4.06E-03 | 1.17E-04 | 15.3 | 5.40E-03 | 1.17E-04 | 33% |
| Source Well MW33A; Receiver Well MW32A | 0.615 | 2.17E-04 | 1.43E-05 | 1.09 | 3.85E-04 | 1.43E-05 | 77% |
| *Shallow Wells Average Conductivity* | **6.06** | **2.14E-03** | **6.57E-05** | **8.20** | **2.89E-03** | **6.57E-05** | **35%** |
| *Shallow Wells Geometric Mean Conductivity* | **2.66** | **9.38E-04** | **4.09E-05** | **4.08** | **1.44E-03** | **4.09E-05** | **54%** |
| *Shallow Wells Standard Deviation from Mean* | **7.70** | **2.72E-03** | **7.26E-05** | **10.05** | **3.54E-03** | **7.26E-05** | **31%** |
| *Deep Well Pairs* | | | | | | | |
| Source Well MW31A2; Receiver Well MW30A2 | 10.5 | 3.70E-03 | 2.17E-04 | 10.9 | 3.85E-03 | 2.17E-04 | 4% |
| Source Well MW33A2; Receiver Well MW32A2 | 65.3 | 2.30E-02 | 2.04E-04 | 64.2 | 2.26E-02 | 2.04E-04 | -2% |
| *Deep Wells Average Conductivity* | **37.90** | **1.34E-02** | **2.11E-04** | **37.55** | **1.32E-02** | **2.11E-04** | **-1%** |
| *Deep Wells Geometric Mean Conductivity* | **26.18** | **9.24E-03** | **2.10E-04** | **26.45** | **9.33E-03** | **2.10E-04** | **1%** |
| *Deep Wells Standard Deviation from Mean* | **38.75** | **1.37E-02** | **9.19E-06** | **37.69** | **1.33E-02** | **9.19E-06** | **-3%** |
| *Combined Well Pairs* | | | | | | | |
| Source Well MW31A; Receiver Well MW30A2 | 32.9 | 1.16E-02 | 7.08E-05 | 50.3 | 1.77E-02 | 7.08E-05 | 53% |
| Source Well MW31A2; Receiver Well MW30A | 22.9 | 8.08E-03 | 2.23E-04 | 19.0 | 6.70E-03 | 2.23E-04 | -17% |
| Source Well MW33A; Receiver Well MW32A2 | 16.5 | 5.82E-03 | 3.17E-05 | 24.8 | 8.75E-03 | 3.17E-05 | 50% |
| Source Well MW33A2; Receiver Well MW32A | 54.8 | 1.93E-02 | 3.26E-05 | 52.3 | 1.85E-02 | 3.26E-05 | -5% |
| *Combined Wells Average Conductivity* | **31.78** | **1.12E-02** | **8.95E-05** | **36.60** | **1.29E-02** | **8.95E-05** | **15%** |
| *Combined Wells Geometric Mean Conductivity* | **28.73** | **1.01E-02** | **6.36E-05** | **33.37** | **1.18E-02** | **6.36E-05** | **16%** |
| *Combined Wells Standard Deviation from Mean* | **16.77** | **5.92E-03** | **9.08E-05** | **17.16** | **6.05E-03** | **9.08E-05** | **2%** |

GEOSIERRA ENVIRONMENTAL, INC. Table 7 - Pre - Post HPIT Results Summary

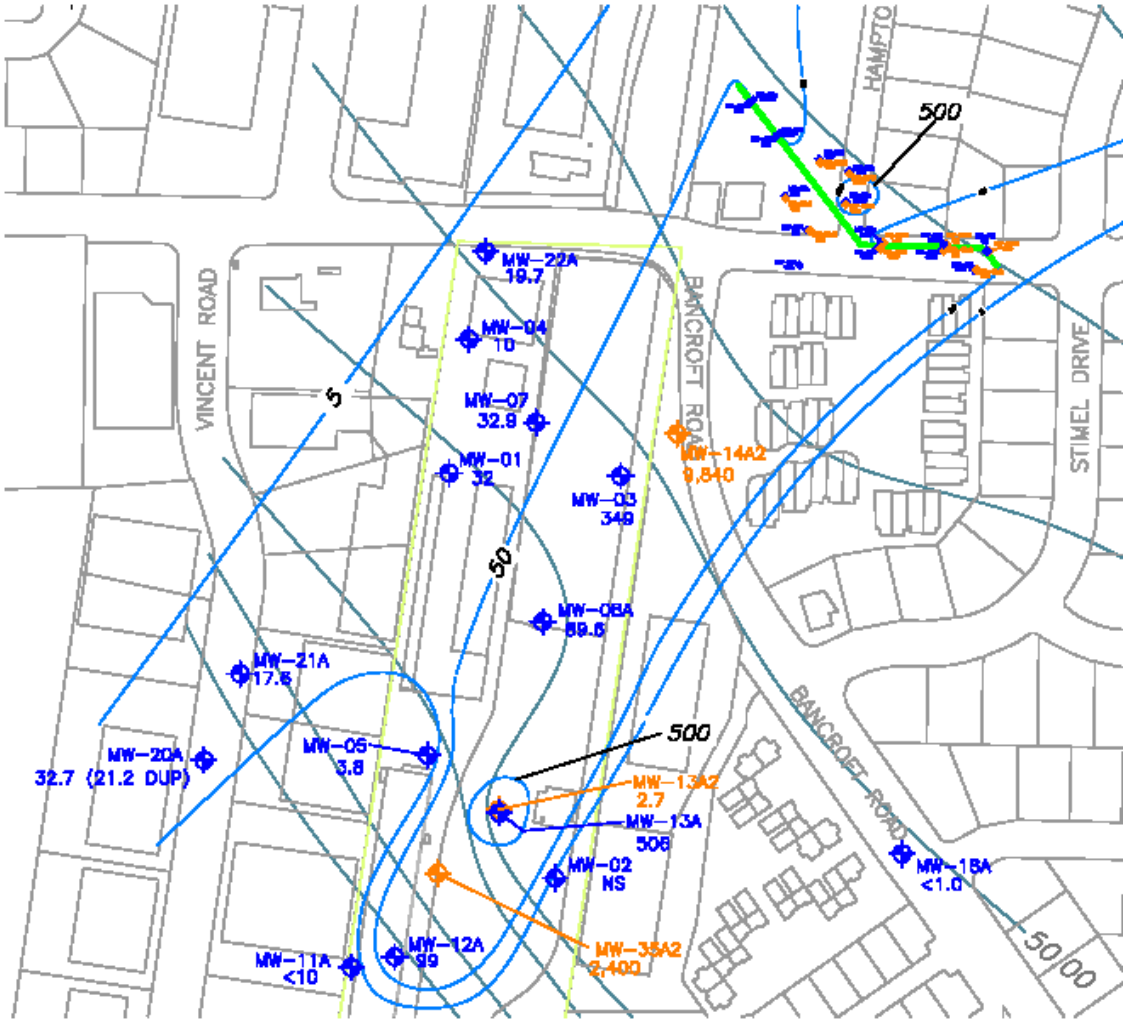


GeoSierra Environmental, Inc.

# Summary of Results

- A total of 465 Tons of ZVI were emplaced to build a 480-foot long, 33-foot tall ZVI-PRB
- Installation was completed in approximately 4-months with little impact on residences and local traffic conditions
- Following ZVI-PRB construction, ERM installed monitoring wells immediately up and downgradient to monitor influent and effluent water quality and CVOC trends
- A total of eight (8) pairs were installed between 4 and 10 feet up and downgradient
- To date reduction of CVOCs through the PRB range from 88% to 97% in 7 of 8 monitoring wells with downward trends in the 8$^{th}$ well
- Groundwater enters the PRB between 50 and 500 PPB and exits at less than the MCL for TCE in 6 of 8 monitoring wells with the remaining two wells quickly approaching MCLs

# Summary of Results

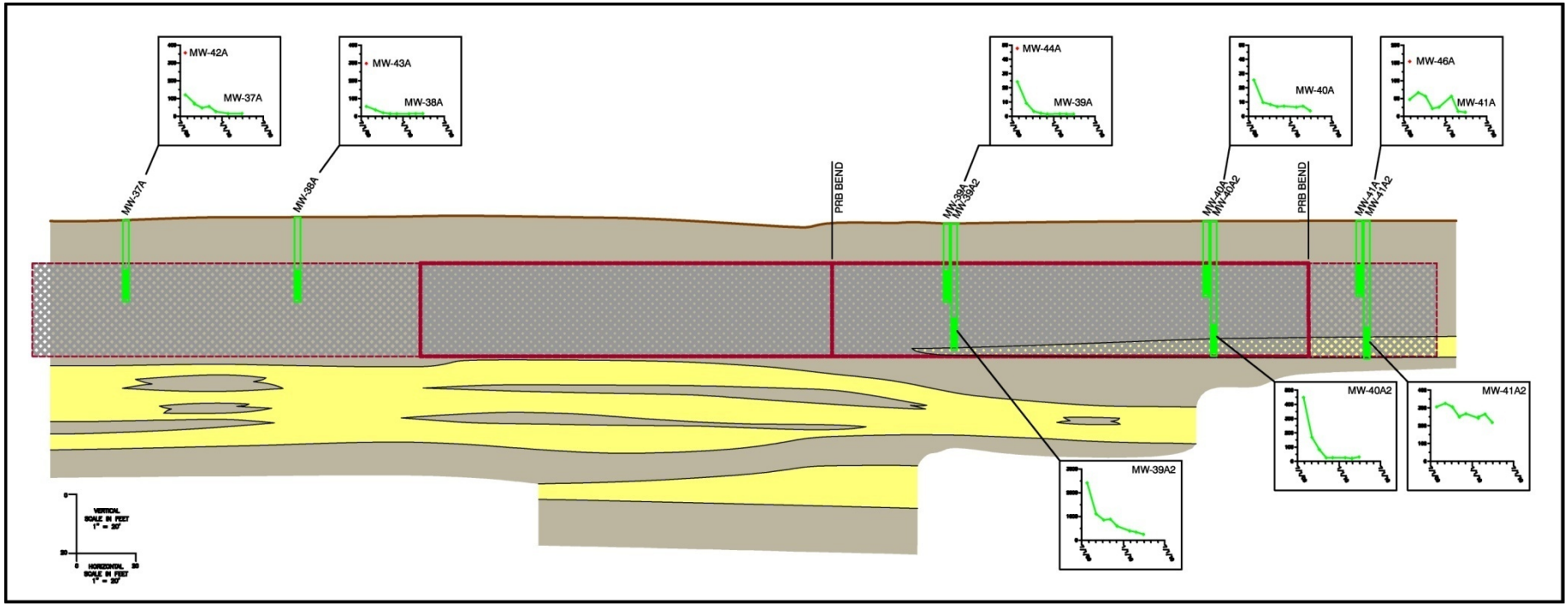





GeoSierra Environmental, Inc.

# Summary of Results

- Cross section of sampling results






GeoSierra Environmental, Inc.

# Thank You!

- We would like to thank the ERM, West, Inc. crew of Brian Bjorklund, Arun Chemburkar, John Moe and others for supporting this project!