Final Construction Report A-Zone Aquifer ZVI Permeable Reactive Barrier Project

HOOKSTON STATION SITE
PLEASANT HILL, CALIFORNIA

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EXECUTIVE SUMMARY

This document outlines the construction activities and quality assurance/quality control measures as part of the installation of an iron permeable reactive barrier (PRB) recently installed at an off-site location near the Hookston Station Site (site) in Pleasant Hill, California. The iron PRB was installed in the subsurface in a northwest-to-southeast orientation across Len Hester Park, proceeding parallel to and then across Hookston Road. The objective of the PRB is to degrade chlorinated volatile organic compounds in site ground water to non-toxic end products and thus limit downgradient migration of such chemicals in ground water.

The PRB was constructed using azimuth-controlled vertical hydrofracturing technology. It is approximately 480 feet in total length, oriented mostly perpendicular to ground water flow, with 180 linear feet of 3-inch average effective-iron-thickness and 300 linear feet of 4.5-inch average effective-iron-thickness, extending from 51 feet above mean sea level (MSL) (approximately 11 to 15 feet below ground surface (bgs) adjusting for topographic changes along the proposed alignment) to 19 feet MSL (approximately 44 to 48 feet bgs).

This Final Installation Report has been prepared to detail the construction activities associated with the PRB, describe the quality assurance/quality control measures that were implemented to assure that the PRB was constructed according to the 100% Design Specifications developed in November 2008, and to document minor deviations from the aforementioned specifications.

1.0 INTRODUCTION

GeoSierra Environmental, Inc. (GeoSierra) was retained by ERM-West, Inc. (ERM) to design and install an in situ zero-valent iron permeable reactive barrier (PRB) at the Hookston Station Site (site) in Pleasant Hill, California.

The subsurface PRB consists of one continuous reactive zone of zero valent iron (ZVI) approximately 480 feet in length. The PRB was installed from approximately 51 feet above mean sea level (MSL) down to approximately 19 feet MSL to intersect ground water flow through silts and higher-permeability sand lenses within the A-Zone aquifer. The PRB was installed in a northwest-to-southeast orientation across the southern portion of Len Hester Park, and extends parallel to and then across Hookston Road. A series of boreholes were drilled along the PRB alignment and two fracture casings (frac casings) were installed in each borehole to facilitate construction of individual 15- to 16-foot high panels. The PRB was constructed by injecting iron filings into the subsurface to create a continuous zone of iron filings approximately 32 feet in vertical height.

With construction of the PRB completed, ground water will flow through the iron filings unimpeded and the chlorinated solvent impacts present in ground water will be destroyed by the iron particles to non-toxic end products with a goal of clean ground water emerging downgradient from the PRB. The iron PRB is a passive treatment system and does not require any operation or maintenance.

The objective of the final ground water remedy for the site was to develop and install a PRB treatment system that will reduce the levels of chlorinated volatile organic compounds (CVOCs) encountered in the ground water to below cleanup goals established by the California Regional Water Quality Control Board, San Francisco Bay Region (RWQCB), in Order No. R2-2007-0009. The technology chosen to remediate the site ground water was zero valent iron (ZVI), patent numbers 5,266,213 and 6,287,472B1 by EnviroMetal Technologies Inc.

For ease of review, this report is divided into the following sections:

- Section 1 provides an introduction to the report, objectives, and background information.
- Section 2 provides a brief description of the site.
- Section 3 summarizes the selected remedy, including an overview of the iron PRB system technology, reactivity of ZVI, iron emplacement methods, and the design requirements and criteria for the system;
- Section 4 presents the PRB installation methods including the azimuth-controlled vertical hydrofracturing technology, gel, installation methods, and previous design issues.

- Section 5 describes results of verification testing conducted during and following installation of the PRB; and

- Section 6 presents a summary of the final PRB system installation.

These sections are supported by tables, figures and appendices, which summarize field collected quality assurance/quality control (QA/QC) results, resistivity imaging outputs, and the final post-PRB hydraulic pulse interference testing results.

2.0 SITE DESCRIPTION

2.1 Site Location and Access

The Hookston Station Site is in Pleasant Hill, California, as shown on Figure 1. A site plan is included as Figure 2 with the PRB orientation and location. The PRB was installed as one continuous reactive zone of ZVI extending approximately 480 feet on a northwest-to-southeast alignment with access to the site from both Hookston Road and Hampton Drive. As shown on Figure 2, approximately 250 linear feet (lf) of the PRB was installed within Len Hester Park, while approximately 230 lf is beneath Hookston Road.

2.2 Subsurface Site Characterization

The area of interest for the installation of a PRB treatment system is within the A-Zone aquifer extending from approximately 51 feet MSL down to approximately 19 feet MSL. The primary constituents in the ground water are CVOCs, specifically trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), vinyl chloride (VC), and 1,1-dichloroethene (1,1-DCE).

The site is underlain by approximately 80 feet of unconsolidated materials forming the A-Zone and B-Zone. In the vicinity of the PRB, the A-Zone extends from grade to 19 feet MSL and consists of clay, silty clay, clayey silt, and silt. The B-Zone generally extends from 19 feet MSL to -18 feet MSL and consists of silty sand, sand, sandy gravel, or gravelly sand. The PRB was installed in the A-Zone, which initially had a hydraulic conductivity ranging from 0.62 feet per day (ft/day) or 2.17×10^{-4} centimeters per second to as high as 65 ft/day or 2.3×10^{-2} centimeters per second, based on pre-PRB installation slug and pulse testing activities conducted by GeoSierra. The hydraulic gradient of the A-Zone is estimated to range from 0.001 to 0.004 feet per foot. The ground water flow direction of the A-Zone is to the northeast.

Based on historical sampling of ground water monitoring wells both upgradient and within the location of the PRB, concentrations of TCE in A-Zone ground water range from non-detect (ND) (generally less than 0.5 micrograms per liter [µg/L] to 9,500 µg/L); cis-1,2-DCE ranges from ND to 5,800 µg/L; 1,1-DCE ranges from ND to 1,100 µg/L; and VC ranges from ND to 1,400 µg/L.

3.0 REVIEW OF SELECTED REMEDY

This section summarizes the selected A-Zone ground water remedy, a process description of the ZVI technology, and the previously approved design requirements and criteria for the system.

3.1 Iron Permeable Reactive Barriers

3.1.1 Background

In situ passive iron PRBs have been placed at a number of sites, dating back to the first constructed at CFB Borden in 1991, by the University of Waterloo. The early iron reactive barriers were designed on the funnel and gate concept (Starr and Cherry, 1994). Recently, continuous permeable barriers have been installed by back hoe, continuous trenchers, and azimuth-controlled vertical hydrofracturing. The continuous permeable barriers do not modify the natural ground water flow, whereas funnel and gate systems do impact the flow.

Iron PRBs have significant advantages over conventional technologies for remediation of chlorinated-solvent-impacted ground water; the prime advantage is that the system is passive. It is a simple process that has been proven in both the laboratory and the field. Site characterization and laboratory bench-scale studies are sufficient to design and construct an iron reactive barrier. The first iron PRB was constructed in 1991 as a field trial, followed by two more in early 1995. During the past 15 years, a significant number of full-scale systems have been installed. The rapid increase in the number of reactive barriers installed reflects the increasing maturity and acceptance of ZVI as a proven and effective remedial technology.

3.1.2 Zero Valent Iron

Zero valent metals have been known to abiotically degrade certain compounds, such as pesticides as described by Sweeny and Fisher (1972), and halogenated compounds such as tetrachloroethene (PCE), TCE, VC, and isomers of DCE as detailed in Gillham and O'Hannesin (1994). In the case of ZVI, a first-order reduction process can approximate the abiotic degradation of halogenated aliphatics. The compounds are progressively degraded and eventually broken down into ethenes and ethanes, as described by Orth and Gillham (1996). In the presence of ZVI, the chlorinated compound TCE is predominantly degraded through the dichloroacetylene pathway with only a minor generation of daughter product cis-1,2-DCE. Therefore, the reductive process in the presence of ZVI generates significantly fewer daughter products than those generated due to natural degradation. In column experiments conducted during design activities, the molar fraction of TCE degraded into chlorinated daughter products such as cis-1,2-DCE and VC was 4% and 10%, respectively for the Hookston site, similar to the published mole fractions of 5 to 10% in scientific literature (Gillham and O'Hannesin, 1994). Five- and 10-year performance data of the Borden ZVI barrier indicated no decline in degradation performance over time (Gillham and O'Hannesin, 1998; Reynolds et al., 2002). Current expectations are that ZVI PRBs will function for at least 30 years with the possibility of a greater lifetime depending on site conditions.

3.1.3 Emplacement Methods

The placement of iron filings in the subsurface for passive in situ treatment of impacted ground water was first discussed by Gillham (1993). Iron filings have traditionally been placed by conventional technologies such as shoring and excavation, and trenching, and more recently by azimuth-controlled vertical hydrofracturing.

3.2 PRB Design Requirements and Criteria

The ZVI PRB was designed to reduce the levels of CVOCs in ground water to below cleanup goals specified in RWQCB Order R2-2007-0009. The design methodology considered all site-specific data, defined functional design requirements and design criteria for the system, and determined the most appropriate system design by use of a probabilistic forecast model of barrier performance. The Hookston Station ZVI PRB was designed to meet the following functional design requirements and criteria:

- Included consideration of geotechnical, hydrogeologic, and ground water chemistry data collected during previous investigations of the site;

- Considered the use of commercially available ZVI filings and the selected emplacement technique;

- Accommodated the variability of the site data, iron reactivity column test data, and installed PRB thickness;

- Will be designed for target CVOC parent and daughter products to have effluent concentrations below their associated site cleanup goals; and

- Was designed so that applicable QA/QC procedures can be implemented during construction.

4.0 PRB INSTALLATION METHOD

4.1 Full-Scale ZVI PRB Geometry

The PRB extends 480 feet in length from approximately 51 to 19 feet MSL, resulting in a cross-sectional area of approximately 15,360 square feet (ft^2). Most of the PRB (the portions within Len Hester Park and a small portion that crosses Hookston Road) is oriented approximately perpendicular to the direction of ground water flow. The final alignment of the PRB was selected based on pre-design investigations that were performed by the Hookston Station Parties. These investigations included detailed sampling and analysis of geologic materials and chemical distribution in this vicinity. Although the portion of the PRB that is oriented east-west along the northern side of Hookston Road is not directly perpendicular to ground water flow, it is positioned there to reduce the travel time of treated water migrating beneath residential structures, and therefore provide the residential neighborhood the most immediate benefit from this treatment technology.

4.2 PRB Emplacement Methods

The placement of iron filings in the subsurface for passive in situ treatment of impacted ground water was first discussed by Gillham (1993). Iron filings have traditionally been placed by conventional technologies such as shoring and excavation, trenching, and more recently by azimuth-controlled vertical hydraulic fracturing. Several other experimental methods have been investigated, namely (a) jet grouting, (b) driver/vibrated beam, and (c) deep solid mixing; however, these methods are still considered experimental and have not been used to install full-scale PRB systems.

A continuous PRB was selected as an optimum system since it would have minimal impact on the natural ground water flow pattern. Of all the PRB emplacement methods, azimuth-controlled vertical hydraulic fracturing technology was the only viable method of constructing an iron PRB at this site, since excavation would not be feasible based on the proximity to adjacent residences, the extension of the PRB into Hookston Road requiring substantial utility disconnects and rerouting, the depth constraints that would result in substantial cost impacts, and the necessity for a low impact installation method with little waste generation.

4.3 Selected Emplacement Method

4.3.1. Azimuth-Controlled Vertical Hydrofracturing

Azimuth-controlled vertical hydraulic fracturing was utilized to install the PRB at the Hookston Station Site, since it involves no soil excavation and causes minimal site disturbance, thus eliminating excavated waste issues, impact on utilities, and neighboring property owner concerns. Using the hydrofracturing technology, the PRB was constructed from a series of conventionally drilled boreholes along the PRB alignments, with a specialized frac casing grouted into the boreholes as shown on Figure 3. The PRB was constructed by injection of the iron filings into these frac casings with real-time QA monitoring of the injections to quantify the PRB geometry and iron-loading densities.

4.3.2. Hydraulic Fracture Cross-Linked Gel

The gel used to suspend and transport the iron filings into the subsurface must be of sufficiently high quality and purity to have no impact on the iron reactivity and permeability. Guar gum-based gels are potentially suitable; however, particular care needs to be taken in designing such gel mixtures. Of special importance is the “clean breaking” property of the gel in the presence of the iron and at ground water temperatures. The “breaking” of the gel refers to the breakdown of the gel starches into sugars. An enzyme is typically used to break these gels; however, at elevated pH, low temperatures, and in the presence of iron, most enzyme activity is extremely low.

The placement of iron PRBs by azimuth-controlled vertical hydrofracturing requires a fracturing fluid gel that is both compatible with the iron and the hydraulic fracturing process. The fracturing fluid must (1) be compatible with the formation and formation fluids, (2) be capable of controlling viscosity to carry the iron filings, (3) be an efficient fluid, (4) have minimal residue after breaking, and (5) have a low friction coefficient. A water-based fracturing cross-linked gel was used, hydroxypropylguar (HPG), a natural polymer used in the food industry as a thickener. The HPG gel is water soluble in the uncross-linked state and water insoluble in the cross-linked state. Cross-linked, the gel can be extremely viscous, ensuring the iron filings remain suspended in the gel at all times during installation.

The gel was mixed with the iron filings, cross-linked, and pumped into the formation by the injection equipment through the downhole initiation tooling. The gel is viscous and carries the iron filings to the extremes of the fracture propagation. Enzyme and other additives typically break down the HPG after about 1 to 2 hours. Upon breaking of the gel, the iron mixture in the ground becomes highly permeable with minimal residue. The composition of the fracturing gel is detailed in Table 1.

4.4 Summary of the HydroFrac Installation Methods

4.4.1 Overview of the Installation Method

The azimuth-controlled vertical hydraulic fracturing placed iron PRB was constructed from conventionally drilled wells installed along the barrier alignment as shown on Figure 2. Controlled vertical fractures were initiated at the required azimuth orientation and depth in each well inside of a specialized frac casing utilizing downhole frac initiation tools. The iron filings were blended and injected in the form of the highly viscous, degradable food-grade quality gel, HPG. Multiple casing well heads were injected with the iron-gel mixture to form a continuous PRB. The gel biodegrades into water and sugars by the use of a suitable enzyme and leaves an in situ permeable iron reactive treatment zone. The goal for hydraulic fracturing at the Hookston Station Site was 3 to 4.5 inches, depending on location.

Azimuth-controlled vertical hydrofracturing technology (Hocking, 1996; Hocking and Wells, 1997; and Hocking et al., 1998a and b) consists of an injection delivery system comprising three primary components: (1) the fracture initiation device, (2) the controlled pumping equipment, and (3) the real-time monitoring and inverse algorithms for determining fracture geometry. The fracture initiation device is used to control the fracture orientation and comprises a suite of tools and fracture well casings. The selection of the initiation device is dependent on the geological formation, depth, and the fracturing fluid required for the particular application. The hydraulic fracturing injection system consists of a mixing/blending and pumping system, which is specially designed to achieve a precise control of fracture fluid pressures and flow rates. The real-time monitoring system provides feedback response to ensure the fractures are propagating and constructed as planned.

The iron filings were transported to the site in 3,000-pound (lb), sealed, numbered bags. Prior to shipment, the iron reactivity and physical properties were analyzed by ERM. Discussions regarding these parameters are not included within the scope of this document. Once onsite, the 3,000 lb supersacks of iron filings were pre-loaded into 5,500-lb-capacity hoppers for discharge into the mixing and blending equipment.

The HPG was pre-mixed in a 3,000-gallon mixing tanks utilizing a Venturi blender and fed along with the iron filings into a 100-gallon mixing/blending tank. The iron and HPG were mechanically agitated to ensure the iron filings remain suspended and the mixture was then fed to the hydrofracturing pump and cross-linked in line on the pressure side of the pump.

The PRB installation was monitored in real time to ensure mixture consistency, and determine volume and weights of iron injected and the geometrical extent of the barrier, thus ensuring it was constructed as designed. A general layout of the monitoring system used during construction of a PRB is shown on Figure 4. During injection, the iron gel mixture was electrically energized with a low-voltage 100-hertz (Hz) signal. Downhole resistivity receivers were installed and monitored to record the in-phase induced voltage by the propagating fracture. By monitoring the fracture fluid-induced voltages and utilizing an incremental inverse integral model, the fracture fluid geometry was quantified and displayed during the installation process. As discussed below, resistivity strings were installed on 24-foot, lateral spacing to provide satisfactory PRB image resolution.

Post-PRB installation hydraulic pulse interference tests are used to demonstrate the minimal impact of the PRB on site hydrogeology. Hydraulic pulse interference tests (Johnson et al., 1966; Kamal, 1983) involve a cyclic injection of fluid into the source well and, by high precision measurement of the pressure pulse in a neighboring well, detailed hydraulic characterization between wells can be made. The pulse interference test is highly sensitive to hydrogeological properties between the wells, and relatively insensitive to conditions outside the wells. The hydraulic pulse interference test are relatively short duration tests of approximately 2 minutes maximum and involved the injection typically of less than 10 gallons of potable water. The test is a truly hydraulic transient test and can determine site hydrogeological properties, such as transmissivity and storativity, from generated “type curves.” Post-PRB pulse interference tests were conducted following installation of the PRB and a comparison of before and after pulse interference data is used to confirm the minimal impact the PRB has on the site hydrogeology and thus the minimal impact on ground water flow patterns. The results of the post-installation pulse interference testing are discussed in Section 5.

Strict QC procedures were required during construction of the PRB to provide the necessary assurance that the reactive barrier system's design performance requirements were achieved. Construction QC procedures and acceptance criteria concentrated on the following:

- In-line and batch consistency tests of the iron reactive mixture;
- Thickness and injected quantities of reactive iron;
- Geometry of the iron PRB monitored (active resistivity) during injection;
- Angled borings that were drilled into the PRB to verify emplaced thickness; and
- Quantification of hydraulic impact of the PRB from hydraulic pulse tests.

Testing of these parameters in addition to other QA/QC measures undertaken during construction of the PRB are further described below.

5.0 IRON REACTIVE PRB SYSTEM CONSTRUCTION

5.1 Iron PRB System

The iron PRB system consists of installing a reactive barrier perpendicular to the natural ground water flow direction. The ZVI barrier was installed using azimuth-controlled vertical hydrofracturing installation. The ZVI barrier is approximately 480 feet in total length, consisting of 3- and 4.5-inch-thick segments. The PRB was constructed within the confined silty-clay unit and range in depth from approximately 11 to 15 feet below ground surface (bgs) down to a total depth of 43 to 47 feet.

The PRB is approximately 15,360 ft^2 and was constructed from 40 hydraulic fracturing casing locations (denoted as F1 through F40), with each frac casing location containing an upper and lower casing installed along the PRB alignment as shown on Figure 2, with installation details provided on Figure 3. The iron PRB is 480 feet in total length and approximately 3 to 4.5 inches in average iron-effective-thickness with a total of 465 tons of iron filings injected into the subsurface. In addition to the frac wells, a total of 20 subsurface active resistivity receiver strings (denoted as RR1 through RR20) were installed offset upgradient from the PRB alignment, as shown on Figure 2, to monitor the geometry of the PRB during construction.

5.2 Construction Sequence

The construction of the iron PRB for the site required a specific construction sequence as follows:

1. Completed site preparation;
2. Installed active resistivity strings and hydraulic fracturing casings, simultaneously;
3. Install permeable reactive barrier while conducting real-time PRB installation monitoring;
4. Install angled borings to verify emplaced PRB thickness;
5. Conduct pulse tests after PRB installation; and
6. Clean site and demobilize.

5.2.1 Site Preparation

Prior to mobilization of frac equipment to the site, typical site setup activities included a temporary 6-foot, chain-link fence completely around the site; installation of silt fence; and site support facilities (fabrication areas, portable toilets, waste handling and storage areas, etc.). Each area was set up to accommodate different activities that would occur over the duration of project construction both within the park and along Hookston Road. Once the areas were prepared and the various support areas were constructed, the frac casing and resistivity string installation equipment were mobilized to the site.

5.2.2 Resistivity String and Frac Casing Installation

Following mobilization to the site, frac casing and resistivity string installation activities commenced within Len Hester Park. As detailed on Tables 2 and 3, the base elevation of the frac casings was targeted for approximately 21 ft MSL to allow the PRB installation and monitoring from 51 ft to 19 ft MSL, and the resistivity strings were targeted for a bottom receiver elevation at 19 ft MSL.

The installation of frac casings 1 to 40 were installed utilizing two separate methods. Although the design called for installation via mud-rotary techniques at all locations, overhead utilities present in the area of F37 to F40 necessitated use of a limited access, hollow-stem-auger rig. Because of this deviation, an alternative method of construction was implemented wherein the augers were advanced to the final depth of the frac casings (approximately 49 feet MSL to the base of the stinger), the augers were filled with a heavy drilling mud and then removed, while topping off the mud as the augers were withdrawn. Once the augers were withdrawn, the frac casings were set into the boreholes at the design elevation and the ground was allowed to set. The details regarding installation of F1 to F40 are included within Table 2.

To install the resistivity strings, a track-mounted Cone Penetrometer Rig (CPT) was mobilized to the site and utilized to install the resistivity strings. The results of the CPT logging were evaluated for unknown or concerning lithologic changes along the cross section that could inhibit construction of the wall to the Design Specifications. During the installation program, although some sand seams were noted towards the southeastern half of the PRB along Hookston Road, there were no significant deviations from the 100% Design. The final elevations of receivers are detailed on Table 3 and the installation CPT report is included as Appendix A.

5.2.3 PRB Installation with Active Resistivity Monitoring

Following installation of the frac casings and resistivity strings, the hydrofracture and monitoring equipment was mobilized to the site to begin installation activities. Some of the equipment mobilized included:

- (2) 3,000-gallon, stainless-steel mixing tanks;
- Glove box pump skid;
- 350-horsepower hydraulic power unit;
- Scale/auger unit;
- Blending skid;
- Pumping unit;
- Frac Trak trailer with electronic monitoring systems;

- 4,000 lb capacity concrete hoppers;
- 10,000 lb Lull and Moffet forktrucks; and
- Other miscellaneous support equipment.

PRB Construction F1 – F11 (Segment 1)

Following completion of mobilization and site-setup activities, PRB construction commenced at frac wells F1 to F11 in the lower panel following installation of the mechanical packers and riser pipe. As shown on Tables 4 and 5, a total of 118,350 lb of ZVI was injected to build the lower panel. This is approximately 22,000 lb higher than the Design Specification required, due to vertical migration of the iron into the shallow panel. During monitoring, the active resistivity system showed that leakoff was vertically higher than expected, potentially causing the deep wall to be thinner than designed. As such, an additional 2,000 lb of iron was injected into each of the lower frac casings to ensure that the proper thickness was constructed.

Once construction of the lower panel was complete, the packers and internal injection piping was removed from each well, each of the lower casings was filled with iron to approximately 2 to 3 feet above of top of the bottom frac casing and construction of the upper panel commenced. A total of 88,650 lb of iron was injected into the upper panel in Segment 1. One deviation from the design was noted during the upper panel construction and was related to the quantity of iron injected into frac well F1. Because of its proximity to a high-pressure, large-diameter gas main and the propagation of the fracture into the right-of-way at the surface near the gas main, the total design mass of iron was not injected into F1. A total of 5,856 lb of iron was injected compared to the 8,640 lb Design Specification. Because F1 is the first frac well in the PRB and is in the lower concentrated boundary area of the plume, there should be no effect on the performance of the PRB in this area due to the reduced mass of iron injected. Some surfacing and surface fracturing was noted during Segment 1 construction; however, increased viscosity in the gel (discussed further below) and lower individual injection volumes minimized surfacing. Primary pathways of surfacing were primarily previously abandoned investigation points that were not complete filled with bentonite or concrete. Selected resistivity images are included within Appendix B.

Upon completion of Segment 1, the equipment was relocated to install the PRB in Segment 2 from F12 to F25. Additionally, inclined profile borings were completed in the upper and lower panels of Segment 1 concurrent with Segment 2 construction. The results of the inclined profile borings are discussed further below.

PRB Construction F12 – F25 (Segment 2)

Following completion of Segment 1, GeoSierra commenced installation of the PRB in the lower panels from frac wells F12 through F25. Similar to Segment 1, the mechanical packers and riser pipe were installed to isolate the lower panel and allow lower panel construction. There were no deviations from the design for the Segment 2 lower panel. A total of 183,175 lb of iron was injected into the lower panel of Segment 2.

Once the packers were removed and the lower casings were filled with iron, construction of the upper panel commenced. The only deviation from Segment 2 was related to F20, where the mechanical packer became wedged inside the riser pipe and could not be removed. With the packer and riser pipe still in the well, the upper casing could not be injected. As such, frac wells F19 and F21 were over-injected with iron planned for F20. Instead of F19 and F21 receiving 13,000 lb of iron per the design, each received approximately 19,500 lb. Based upon the limited surfacing adjacent to wells F19, F20 and F21, fractures extended approximately 15 feet along the azimuth of the PRB, resulting in complete coalescence around frac well F20 from F19 and F21. This was also noted on resistivity imaging. A total of 183,447 lb of iron was injected into the upper panel of Segment 2.

Upon completion of Segment 2, the hydrofracture equipment was trailer-mounted to allow installation of the PRB into Segment 3 from F26 to F40. Additionally, inclined profile borings were completed in the upper and lower panels of Segment 2 concurrent with Segment 3 construction. The results of the inclined profile borings are discussed further below.

PRB Construction F26 – F40 (Segment 3)

The final segment for construction was Segment 3 from frac wells F26 to F40. Because these wells were all located within Hookston Road, all of the hydrofracture equipment had to be trailer-mounted to allow reopening of Hookston Road at the end of each day. Identical to the other two segments built on site, the lower panel of Segment 3 was completed first with no deviations from the design. In accordance with the design, a total of 180,450 lb of iron was injected into the lower panel.

Once the lower panel of Segment 3 was completed, the mechanical packers were removed and the completion of the upper panel within Segment 3 was completed. Similar to F20 in Segment 2, one deviation from the design occurred when the mechanical packer in F40 was sanded into the casing and it was not possible to remove it from the frac well. Based on this, GeoSierra injected as much of the iron as possible, per Design Specifications, and utilized a “chase” of clean gel in attempt to keep the casing clear to permit additional injections. A total of 3,857 lb of iron was injected in F40 before sanding of the casing prevented further injections. As discussed on site, the remaining 4,783 lb was injected in F38 and F39. Similar to F1, because F40 is located at the end of the PRB, there should not be detrimental effects on the PRB from the reduced quantity of iron injected into F40.

Following completion and verification of Segments 1 to 3, all frac wells and resistivity receivers were abandoned in accordance with the requirements of the State of California by a licensed drilling company and under the supervision of the Contra Costa County Environmental Health Department.

5.3 Construction Quality Assurance Monitoring

As outlined in the design, construction QA procedures were followed to ensure that the PRB was installed in accordance with the Construction Drawings and Technical Specifications. QA procedures focused on the following criteria:

- ZVI/gel mix design including mix density, resistivity, and viscosity (gel only);
- Hydrofracturing injection pressures;
- Approximate ZVI filings placement rate per square foot of PRB by determining the PRB geometry by active resistivity mapping and the weight of iron injected in each hydrofracturing casing;
- Post-installation angled borings into the PRB to verify thickness; and
- Pre- and post-PRB hydraulic pulse interference tests to quantify the PRB hydraulic effectiveness.

Each QA processes described above was implemented during the construction of the PRB. Additionally, a sampling on hydrofracturing injection pressures is included within Appendix C. Deviations from the Design Specifications and/or results of the QA Monitoring Program are discussed briefly below.

Forty-six batches of gel (approximately 134,000 gallons of gel) were mixed to complete injections and cleanout of equipment and hoses at the site. Due to vertical migration of the fractures throughout the project, the viscosity of the gel was increased from the Design Specifications in attempt to reduce the quantity of gel and iron from migrating vertically to the surface. Similarly, due to vertical migration of the gel/iron mixture into the unsaturated zone above the resistivity strings, the actual placement per square foot could not be calculated. Rather the estimated quantity required for each panel based on well spacing and the design height was calculated and used as a guide for injections. The results of these calculations are included on Tables 4 and 5. Aside from viscosity, there were no other significant deviations from the Design Specifications for the gel and iron mixture. The results of gel QA/QC monitoring are included as Table 6.

Hydrofracture injection pressures were monitored throughout the duration of injections and in general, low injection pressures were noted in all fracture wells. Fracture pressures typically ranged from approximately 10 to 80 pounds per square inch depending on depth and thickness of the segment under construction.

5.3.1 Active Resistivity Monitoring

During construction of the PRB, active resistivity mapping was utilized to track the propagation of the iron/gel mixture through the subsurface. As discussed above and shown on Figure 2, active resistivity strings were installed on 24-foot centers approximately 20 feet offset from the wall azimuth. Each resistivity string contained seven stainless-steel collars in direct contact with surrounding soil and ground water. The receivers were connected to individual 12-gauge copper wires that terminated at ground surface. Each individual receiver was then hardwired through a junction box and reel to the patch panel within Frac Trak trailer. Following installation, each connection was tested for continuity with the aquifer through a test box via excitement of each receiver and testing for signal in adjacent receivers.

Once the receivers were tested for continuity, up to nine strings each containing five active receivers was monitored during injections. During early injections of Segment 1, the entire array of seven receivers per string was monitored from 51 to 19 feet MSL; however, during construction of the shallow panels following completion of the deep panels, preferential current flow to the continuous deep panel resulted in washing out of the shallow well receiver signal. As such, subsequent injections in Segments 1 through 3 utilized only five receivers in the lower panel (approximately 19 to 44 feet MSL) and five receivers in the upper panel during monitoring (26 to 51feet MSL) to negate the washout effect.

During injection activities, a 100 hz square wave signal was generated within the Frac Trak trailer and sent to the active frac injection well to excite the gel/iron being monitored by the active resistivity system. Depending on location and local conductivity/resistivity properties adjacent to the frac well under injection, the signal current was increased or decreased to provide a crisp image compared to surrounding soil properties.

The resistivity outputs were used as a guide to ensure that gaps in the wall did not exist and that panels of iron overlapped during construction. Additionally in the deeper zone, initial outputs were used to estimate the panel thickness based upon tonnage injected at each location. The shallow zone thicknesses could not be calculated due to fracture migration vertically outside the active resistivity monitoring capabilities (e.g., above the water table). Because of the extensive lateral fracture propagation, individual fractures were calculated at approximately 0.75-inch to 1-inch thick; therefore, each well typically received a minimum of 4 to 8 fractures to meet the specified design criteria thickness of 3 to 4.5 inches, depending on the segment location and iron quantity injected. Included within Appendix B are outputs from the resistivity system for each frac well at various well injection timepoints. These images have been provided to show the lateral extent of influence from each frac well that was noted during injections. Generally, each well had as much as a 15- to 20-foot lateral fracture in each direction during construction and with a 12-foot, center-to-center spacing of the frac wells. This influence provided for significant overlap of iron panels. This was verified during inclined profile testing where iron thicknesses were verified at the center point between frac wells in both the shallow and deep PRB zones, as discussed below.

5.3.2 Post-Installation Inclined Profile Borings

As shown on Figure 2, a total of four post-installation inclined profile borings (ICPs) were completed within Segments 1 and 2 to confirm installed PRB thickness within both the shallow and deep panel segments. Borings were completed utilizing a variety or methods for the highest resolution results and minimal disturbance within the wall sections.

The first two borings, ICP-1 and ICP-2, were completed in Segment 1 between F-7 and F-8. Prior to testing the PRB thickness utilizing a downhole tiltmeter/magnetometer (AOSI EZ-Compass 3), a 2-inch, Schedule 40 polyvinyl chloride (PVC) casing was installed through the wall at approximately 46 degrees from vertical. GeoProbe rods (3.5-inch) were driven through the wall utilizing direct-push methods, in attempt to minimally disrupt the iron filings within the wall. Offsets were measured approximately 20 and 34 feet from the azimuth of the PRB and the borings were installed at the target angle. Once the borings were completed, the PVC casings were installed and the GeoProbe rods were removed. At the 46-degree angle and the offset distances from the PRB, the location and thickness of the PRB were measured between the frac wells at a targeted depth of approximately 20 and 35 feet bgs, or the center point of the upper and lower casings between the target frac wells. Once the casings were completed, the downhole magnetometer was inserted into the casing and measurements of localized magnetic field commenced at approximately 2 to 3 feet before and 2 to 3 feet after the anticipated location of the PRB. Magnetic field measurements were collected every 1 inch in the 4- to 6-foot measured interval to determine entrance and exit locations of the magnetometer within the PRB.

Segment 1 – ICP-1 and ICP-2
As shown on Figure 2, inclined profile ICP-1 was installed between Frac Wells F-7 and F-8 or at the approximate center location of Segment 1. ICP-1 was collected within the deep panel segment with an offset of 34 feet from the PRB azimuth. Following installation of the 2-inch casing at a 46-degree angle, the azimuth of the PRB should have been located at approximately 48.9 feet within the casing. Appendix D contains the output from the magnetometer following data reduction. The "h" value represents the combination of the "X" and "Y" (horizontal vectors combined to represent the field perpendicular to the PRB on a horizontal plane) magnetic field measurements, while the "z" value represents the vertical horizontal field measurement with no data reduction necessary. Based upon the data reduction and evaluation at this location, the PRB was encountered at approximately 48.16 feet within the casing and the magnetometer emerged from the PRB at approximately 48.58 feet, or within 6 inches of the anticipated PRB azimuth. When correcting for the declination angle of the casing compared to the vertical PRB, these measurements represent approximately 3.62 inches of iron.

The 3.62-inch-thick iron PRB is consistent with the quantity of iron injected within Segment 1, as one additional ton of iron was injected into the lower panel in frac wells F1 to F-11 to account for vertical migration of iron into the shallow segment. Finally, the 3.62-inch iron thickness exceeds the Design Specification for Segment 1, which was specified as 3 inches.

ICP-2 was installed utilizing the same technique as ICP-1 except with a 20-foot offset from the PRB azimuth. The 2-inch casing was installed at a 46.3-degree angle from vertical, which should have encountered the PRB at approximately 28.9 feet within the casing. As shown in Appendix D, the PRB was encountered at approximately 29.33 feet and the magnetometer emerged from the PRB at approximately 29.66 feet. Once corrected for the declination angle of the PVC casing, this represents a primary fracture thickness of 2.85 inches, or within 5% of 3 inches. In addition to the primary fracture measured, there were also secondary fractures measured on both sides of the primary fracture. As discussed earlier, additional iron was injected into the deep well within Segment 1 to account for vertical iron migration during the lower PRB construction. The secondary fractures described on outputs in Appendix D represent secondary fractures created during vertical migration from the deep zone. Once the secondary fracture thicknesses (approximately one-half-inch) are accounted for, the actual iron thickness in the shallow zone is above the 3-inch Design Specification (approximately 3.85 inches).

Segment 2 – ICP-3 and ICP-4

In an attempt to physically sample the thickness of the PRB, which has historically been extremely difficult to accomplish depending largely on site lithology, the casing installation method was changed to sonic methods for ICP-3 and ICP-4. The two borings were installed at approximately 25 feet and 35 feet offset from the PRB, targeting the bottom of the upper casing and center point of the lower casings. The sonic cores were collected from approximately 5 feet before the PRB and 5 feet after.

ICP-3 was installed approximately 25 feet from the anticipated azimuth of the PRB between F-13 and F-14. Cores were collected and analyzed at the surface to evaluate iron thickness and fracture locations. The sample core for this boring was successful in collecting samples of the iron and, similar to the magnetometer results from Segment 1, the primary fracture was surrounded on either side by secondary fractures from below, confirming the results and interpretation of ICP-2 in Segment 1.

Following installation of the 2-inch casing, the magnetometer study was performed on ICP-3 utilizing the same means and methods of data collection and reduction as previous borings. With the 25-foot offset and installation of the casing at a 47-degree angle, the azimuth of the PRB is calculated to be approximately 36.6 feet into the 2-inch casing. As shown in Appendix D, the primary PRB fracture was encountered at approximately 36 to 36.5 feet within the casing. The primary fracture thickness once corrected for the casing declination angle is approximately 5.17 inches, or in excess of the required 4.5-inch thickness in Segment 2. Additionally, secondary fractures were noted at approximately 31 and 33 feet inside the casing, which correspond to smaller secondary fractures identified in the recovered soil core.

ICP-4 was installed approximately 35 feet from the anticipated azimuth of the PRB between F13 and F14. Collection of soil cores was also attempted at this location; however, the cores collected were not viable based upon liquefaction of the soils immediately adjacent to the PRB from the sonic drill rig. This occurred when the sonic rods encountered stiff resistance that required significant time and effort to push through. That location was estimated to be within 2 to 3 feet of the azimuth of the PRB. This is also evident from the Segment 2, ICP-4 data reduction and output from the magnetometer. Three peaks of magnetism were encountered over approximately 3 feet of measurement. This measured data was confirmed during a second test within the same borehole to ensure data accuracy. The data in Appendix D show that three magnetic peaks with an effective iron thickness of over 9 inches were measured. Based on the mass of iron injected and the approximate fracture geometry at this location from active resistivity imaging, this thickness is not feasible; therefore, although iron was measured in this location, its exact thickness could not be confirmed with a degree of precision.

5.3.3. Post-PRB Installation Hydraulic Interference Pulse Testing

Hydraulic pulse interference tests (HPIT) were conducted prior to and following the installation of the PRB to verify that the PRB will not impact the natural ground water flow. The HPIT is highly sensitive and defines the degrees of hydraulic continuity between the source and receiver wells. The HPIT is a transient test and hydraulic properties, such as transmissivity and storativity, of the formation can be quantified.

The point-source HPIT can be modeled from the solution of a continuous point source in an infinite isotropic homogeneous medium (Carslaw and Jaeger, 1986) as given by equation (1). This fundamental solution can be modified to incorporate finite aquifer systems, confined and unconfined conditions, and anisotropic and heterogeneous conditions in a similar manner, as the line source solution has been modified in the petroleum literature. This line-source solution for continuous injection is the exponential integral, whereas the point-source solution is the complementary error function. The pressure response in a receiver well is given by the following equation:

$$\Delta p(t) = \frac{q}{4 * \pi * K * r_w * r_d} erfc\left(r_d \Big/ \sqrt{4 * t_d} \right) \tag{1}$$

where $\Delta p(t)$ is the pressure response at a given time, K is the formation hydraulic conductivity, S_s is the formation specific storage, r_w is the well bore radius of a source well, t_d is dimensionless time defined in equation (2), and r_D is the dimensionless distance defined by the following equation:

$$r_D = \frac{r}{r_w}$$

where r is the distance from the receiver well to the source well. The dimensionless time is defined as:

$$t_D = \frac{K * t}{r_w^2 * S_s} \tag{2}$$

where t is the elapsed time since the start of the injection.

A total of eight monitoring wells were tested in the vicinity of the PRB including MW-30A, MW-30A2, MW-31A, MW-31A2, MW-32A, MW-32A2, MW-33A, and MW-33A2. All wells were 2 inches in diameter with the "A" wells screened in the shallow A-

Zone horizon, while the “A2“ wells were screened in the deep A-Zone horizon. HPIT was conducted across all monitoring wells to provide detailed hydrogeological characterization of the site by cross hole paths, perpendicular to the PRB alignment.

Field Procedures

The source well injection system consists of an inflatable packer to isolate the injection horizon and a pressure transducer that is placed in the source well to monitor injection pressures. The receiver well system also consists of an inflatable packer isolating the high-precision pressure transducer from well bore storage effects. The injection flow rate is controlled by a constant flow rate direct drive pump with solenoid adjustable time interval switching values to modulate the periodic timed injection and shut-in of the source well.

During the HPIT, the source well’s flow rate and pressure are monitored along with all of the receiver pressure transducers. The pressure transducers must be of high precision and the flow rate and pressures must be continuously monitored and recorded at high data acquisition rates. To ensure the tests are repeatable, the pulse switching mechanism needs to be automatically controlled and recorded on the data acquisition system. To optimize the resolution of the test, the injection/shut-in time interval and/or injection flow rate was varied depending on site conditions and the distances between source and receiver wells.

Results

The interpretation of the point-source HPIT follows similar procedures to line source interpretation procedures using type curves as detailed in Hocking (2001). The HPIT arrangement, typical data, and type-curve matching are shown on outputs in Appendix E. The hydraulic pulse interference tests were conducted across the monitoring well pairs as follows:

Source Well	Receiver Well
MW-31A	MW-30A
MW-31A	MW-30A2
MW-31A2	MW-30A
MW-31A2	MW-30A2
MW-33A	MW-32A
MW-33A	MW-32A2
MW-33A2	MW-32A
MW-33A2	MW-32A2

The locations of the monitoring wells respective to the PRB are shown on Figure 2. Type-curve matching for all of the source-receiver well pairs detailed above is contained in Appendix E. The type-curve match assumed a confined aquifer from a depth of 5 feet down to a total depth of 45 feet.

The hydraulic conductivity and storativity values computed for each well pair are detailed in Table 7. The hydraulic conductivity calculated from the test data range from a low of 1.09 ft/day to a high of 64.2 ft/day. The calculated storativity values from the test data range from low 1.43E-05 to a high of 2.23E-04. The field data and best-fit type curves are contained in Appendix E for all hydraulic pulse interference test data. Based on these field data, good hydraulic connection exists between all well pairs, with higher conductivities encountered in the deeper well pairs compared to the shallow well pairs.

To compare the results from the pre- and post-PRB installation hydraulic pulse interference testing, the results from both test events are detailed on Table 7 in addition to the percent change between the events. In general, there is good agreement between both events with some variation in the shallow results, whereas the deep well pair results are well within the precision of the test. The combination of the construction of the shallow monitoring wells across the water table, the amount of open screen and the low water table all likely account for the less precise results in the shallow well pairs. Because the receiver wells are receiving the pulse across the aquifer, if monitoring wells are not screened fully within the saturated zone, attenuation of the pulse can occur faster than what is representative by the actual formation characteristics. This is evident by the higher conductivity and storativity value within the shallow well pairs from pre- to post-PRB testing, compared to a very small change in the deep well pairs with fully saturated screens.

Although the results varied slightly, the mean changes to the shallow and deep well pairs were approximately 2 and 0.45 ft/day, respectively. Based on these results, there are no apparent impacts of the PRB on the natural aquifer characteristics and ultimately natural ground water flow of the aquifer.

5.4 Construction Quantities

The PRB construction ultimately utilized the following materials to complete construction of the 480 lf PRB that is approximately 32 feet in height.

- Forty frac well injection locations were installed with two casings per location, utilizing a combination of mud-rotary and hollow-stem-auger techniques;

- Twenty resistivity strings were installed with seven receivers each, or a total of 140 receivers with all locations except RR-20 logged with a CPT rig;

- A total of 473 tons of granular iron was delivered and injected;

- A total of approximately 134,000 gallons of gel was utilized for pre-construction formation “slicking,” for injection equipment cleanout, out of spec gel batches and injection of the iron; and

- Four inclined profile borings were completed in Segments 1 and 2 and successfully verified in situ PRB thickness.

SUMMARY

ERM retained GeoSierra to design and install a ZVI PRB within the A-Zone aquifer within a residential neighborhood downgradient of the Hookston Station Site in Pleasant Hill, California. This report details the final installation activities, QA/QC monitoring, and results of the PRB installation. A brief photo journal is included as Appendix F. The ZVI PRB was installed in the subsurface extending from Len Hester Park to the south side of Hookston Road from the northwest to southeast. The objective of the PRB is to degrade chlorinated volatile organic compounds in site ground water to below approved cleanup goals.

Based on column testing and results of installation activities, a ZVI PRB should effectively reduce ground water impacts present at the site. The geology, ground water conditions, and depth of the PRB were all very amenable to construction by the azimuth-controlled vertical hydrofracture installation method.

The PRB was designed and installed to specification to achieve effluent CVOC concentrations below their respective cleanup goals. The PRB was built approximately 480 feet in total length and ranged from 3.85 to 5.15 inches in thickness, and is perpendicular to the local ground water flow direction. The PRB was constructed from approximately 51 feet MSL (approximately 11 to 15 feet bgs, adjusting for topographic changes along the proposed alignment) to 19 feet MSL (approximately 44 to 48 feet bgs). The PRB was constructed as one continuous, single wall.

The construction of the PRB commenced with drilling in March 2009 and was completed in June 2009, a total of 4 months. Due to surfacing issues within the shallow zone, an additional 4 weeks was needed to ensure construction of the PRB was within specification.

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TABLES

Table 1. Fracture Gel Composition Summary. Hookston Station ZVI PRB. Pleasant Hill, California.

G205001

Material Description	MSDS Product Name	Product per gallon of water
Zero Valent Iron	PL-14D-WWCA	10
Gel (Hydroxypropyl Guar)	GS-B-1	0.0533
Acetic Acid	GS-BA-1	0.58 - .75 mls
Gel Cross Linker	GS-BC-1	0.02 gals
Gel Enzyme Breaker	GS-BE-4	0.002 lbs
Sodium Chloride	Sodium Chloride	0.02 lbs

Table 2. Fracture Well Installation Details. Hookston Station ZVI PRB. Pleasant Hill, California

G205001

Frac Casing Number	Surface Elevation (ft MSL)	Bottom Casing Target Elevation (ft MSL)	Top Casing Target Zone Elevation (ft. MSL)	Total Depth of Boring (bgs)	Bottom Elevation of Frac Casing (Ft MSL)	Top Elevation of Frac Casing (Ft MSL)
F1	64.29	21	46	45	21.79	46.79
F2	65.07	21	46	46	21.57	46.57
F3	65.74	21	46	47	21.24	46.24
F4	66.14	21	46	47	21.64	46.64
F5	66.37	21	46	47	21.87	46.87
F6	66.43	21	46	47.5	21.43	46.43
F7	66.54	21	46	47	22.04	47.04
F8	66.67	21	46	47.5	21.67	46.67
F9	66.67	21	46	47.5	21.67	46.67
F10	66.69	21	46	47.5	21.69	46.69
F11	66.36	21	46	47.5	21.36	46.36
F12	66.56	21	46	47.5	21.56	46.56
F13	66.82	21	46	48	21.32	46.32
F14	67.12	21	46	48	21.62	46.62
F15	67.19	21	46	48	21.69	46.69
F16	66.97	21	46	48	21.47	46.47
F17	66.62	21	46	47.5	21.62	46.62
F18	66.25	21	46	47	21.75	46.75
F19	65.72	21	46	47	21.22	46.22
F20	64.84	21	46	46	21.34	46.34
F21	64.07	21	46	45.5	21.07	46.07
F22	63.34	21	46	45	20.84	45.84
F23	63.16	21	46	45	20.66	45.66
F24	63.61	21	46	44	22.11	47.11
F25	63.86	21	46	45	21.36	46.36
F26	64.13	21	46	45	21.63	46.63
F27	64.40	21	46	45	21.90	46.90
F28	64.62	21	46	46	21.12	46.12
F29	64.86	21	46	46	21.36	46.36
F30	65.01	21	46	46	21.51	46.51
F31	65.15	21	46	46	21.65	46.65
F32	65.20	21	46	46	21.70	46.70
F33	65.24	21	46	46	21.74	46.74
F34	64.24	21	46	46	20.74	45.74
F35	65.20	21	46	46	21.70	46.70
F36	65.14	21	46	46	21.64	46.64
F37	65.07	21	46	46	21.57	46.57
F38	65.25	21	46	46	21.75	46.75
F39	65.27	21	46	46	21.77	46.77
F40	64.91	21	46	46	21.41	46.41

Table 3. Resistivity String Installation Details. Hookston Station ZVI PRB. Pleasant Hill, California

RR String Number	Date Installed	Ground Surface Elevation (ft MSL)	End of Tip (bgs)	Elevation of Black Receiver (ft MSL)	Elevation of White Receiver (ft MSL)	Elevation of Red Receiver (ft MSL)	Elevation of Green Receiver (ft MSL)	Elevation of Orange Receiver (ft MSL)	Elevation of Yellow Receiver (ft MSL)	Elevation of Blue Receiver (ft MSL)	Location Along Alignment (ft)
RR1	3/6/2009	65.00	47.1	18.9	23.9	28.9	33.9	38.9	43.9	48.9	19
RR2	3/5/2009	65.01	47.1	18.9	23.9	28.9	33.9	38.9	43.9	48.9	33
RR3	3/5/2009	66.05	47.1	20.0	25.0	30.0	35.0	40.0	45.0	50.0	57
RR4	3/5/2009	66.19	47.2	20.0	25.0	30.0	35.0	40.0	45.0	50.0	81
RR5	3/5/2009	65.64	46.6	20.0	25.0	30.0	35.0	40.0	45.0	50.0	105
RR6	3/5/2009	64.85	45.9	20.0	25.0	30.0	35.0	40.0	45.0	50.0	129
RR7	3/4/2009	65.06	46.1	20.0	25.0	30.0	35.0	40.0	45.0	50.0	154
RR8	3/6/2009	66.16	47.2	20.0	25.0	30.0	35.0	40.0	45.0	50.0	179
RR9	3/6/2009	66.23	47.2	20.0	25.0	30.0	35.0	40.0	45.0	50.0	203.5
RR10	3/4/2009	64.64	45.6	20.0	25.0	30.0	35.0	40.0	45.0	50.0	226.75
RR11	3/7/2009	63.34	44.3	20.0	25.0	30.0	35.0	40.0	45.0	50.0	256
RR12	3/7/2009	63.62	44.5	20.1	25.1	30.1	35.1	40.1	45.1	50.1	276
RR13	3/9/2009	64.01	45.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	298
RR14	3/9/2009	64.45	46.0	19.5	24.5	29.5	34.5	39.5	44.5	49.5	322
RR15	3/9/2009	64.90	46.0	19.9	24.9	29.9	34.9	39.9	44.9	49.9	342
RR16	3/9/2009	65.26	46.5	19.8	24.8	29.8	34.8	39.8	44.8	49.8	376.75
RR17	3/7/2009	65.55	45.5	21.1	26.1	31.1	36.1	41.1	46.1	51.1	396.25
RR18	3/7/2009	65.67	45.0	21.7	26.7	31.7	36.7	41.7	46.7	51.7	420.25
RR19	3/7/2009	65.57	47.5	19.1	24.1	29.1	34.1	39.1	44.1	49.1	444.9
RR20	3/11/2009	65.33	45.0	21.3	26.3	31.3	36.3	41.3	46.3	51.3	474.9

Table 4. Deep PRB Iron Injection Summary Hookston Station ZVI PRB. Pleasant Hill, California

Frac Casing No.	Apr-09												May-09									Jun-09			Quantity of Iron Injected (tons)	Target (pounds)	Iron Loading (pounds/ sq.ft.)	Top of PRB (ft)	Bottom of PRB (ft)	Length of PRB (ft)	Cross-Sectional Area (ft^2)	Location along wall (ft)	Lbs Req'd for Wall Geometry (lbs)
	4	5	6	7	8	13	14	21	27	28	29	30	1	2	3	26	27	28	29	30	31	1	2	3									
LOWER PANEL																																	
F1	3156	2534		935	1980	2110																			10,715	10,640	45	15	47	13.54	433.3	6	9748.8
F2	4036	1994			2932	2172																			11,134	10,640	45	15	47	10.58	338.6	15.08	7617.6
F3	998	2110		1984	2046	3720																			10,858	10,640	45	15	47	12	384.0	27.16	8640
F4	2986	2018			2578	2108	1000																		10,690	10,640	45	15	47	11.21	358.7	39.08	8071.2
F5	1886	1896		2079	2973	2028																			10,862	10,640	45	15	47	12.04	385.3	49.58	8668.8
F6	4004	2072			2446	2026																			10,548	10,640	45	15	47	12.96	414.7	63.16	9331.2
F7	2124	2460		1964	2168	1998																			10,714	10,640	45	15	47	11.42	365.4	75.5	8222.4
F8	3004	1970			2437	3045																			10,456	10,640	45	15	47	10.79	345.3	86	7768.8
F9	1870	2032		1990	3020	1974																			10,886	10,640	45	15	47	11.875	380.0	97.08	8550
F10		1020			3022	1948	4766																		10,756	10,640	45	15	47	12.96	414.7	109.75	9331.2
F11	2012	2000		2006	1793	1934	986																		10,731	10,640	45	15	47	12.875	412.0	123	9270
F12								1054	2052	1991	3918	1991	2098												13,104	13,000	67.5	15	47	12.165	389.3	135.5	13138.2
F13								2098	962	4068	2288	3714													13,130	13,000	67.5	15	47	11.875	380.0	147.33	12825
F14								946	1948	2000	3796	2068	2002												12,760	13,000	67.5	15	47	12	384.0	159.25	12960
F15								1904	1979	3982	2012	3232													13,109	13,000	67.5	15	47	12.04	385.3	171.33	13003.2
F16								1006	1995	2048	4058	1980	2038												13,125	13,000	67.5	15	47	12	384.0	183.33	12960
F17									1992	4002	2122	3800	1156												13,072	13,000	67.5	15	47	12	384.0	195.33	12960
F18								1026	2034	1952	3987	1998	2044												13,041	13,000	67.5	15	47	11.55	369.6	206.88	12474
F19									1978	3977	1884	3900	1310												13,049	13,000	67.5	15	47	12.22	391.0	219.1	13197.6
F20								972	1988	200	3976	2098	1858	2059											13,151	13,000	67.5	15	47	12.78	409.0	231.88	13802.4
F21									2026	4046	2076	4037	976												13,161	13,000	67.5	15	47	12.78	409.0	244.66	13802.4
F22								1076	983	1818	3162	1452	1558	3105											13,154	13,000	67.5	15	47	10	320.0	254.66	10800
F23									2003	2998	1487	3464	1530	1647											13,129	13,000	67.5	15	47	13.5	432.0	268.16	14580
F24								958	2016	2018	2753	1484		1088	2587										12,904	13,000	67.5	15	47	12	384.0	280.16	12960
F25									2051	3047	1544	3504	1990	1150											13,286	13,000	67.5	15	47	11	352.0	291.16	11880
F26																	1434	1538	4117		1905	2047	2152		13,193	13,000	67.5	15	47	12.75	408.0	303.91	13770
F27																		1552	2044	2076	2093	2962	2547		13,274	13,000	67.5	15	47	12.25	392.0	316.16	13230
F28																	1500	1480	3968		1942	1940	2307		13,137	13,000	67.5	15	47	12	384.0	328.16	12960
F29																1020	1539	1480	2012	1966	1949	1997	1160		13,123	13,000	67.5	15	47	11.85	379.2	340.01	12798
F30																	1750	1559	3839		2106	2094	1701		13,049	13,000	67.5	15	47	12.1	387.2	352.11	13068
F31																962	1530	1539	1972	1888	2002	2051	1308		13,252	13,000	67.5	15	47	12.3	393.6	364.41	13284
F32																	1576	1449	4128		1884	1980	2208		13,225	13,000	67.5	15	47	11.9	380.8	376.31	12852
F33																	1475	1467	2077	2094	2161	2032	1964		13,270	13,000	67.5	15	47	12.1	387.2	388.41	13068
F34																	1490	1546	4019		2020	1937	2182		13,194	13,000	67.5	15	47	11.75	376.0	400.16	12690
F35																	2499	1633	2016	1940	1889	1967	1129		13,073	13,000	67.5	15	47	12	384.0	412.16	12960
F36																	1509	1475	3931		2066	1986	2212		13,179	13,000	67.5	15	47	12	384.0	424.16	12960
F37																		1393	1999	2000	1996	1430			8,818	8,640	45	15	47	10.6	339.2	434.76	7632
F38																					1988	1918		4929	8,835	8,640	45	15	47	10.6	339.2	445.36	7632
F39																				2145	2098	1590	1971	1045	8,849	8,640	45	15	47	13.13	420.2	458.49	9453.6
F40																					1978		2260	4741	8,979	8,640	45	15	47	12.33	394.6	470.82	8877.6
Subtotals	26,076	22,106	0	10,958	27,395	25,063	6,752	11,040	26,007	38,147	39,063	38,722	18,560	9,049	2,587	1,982	16,302	18,111	36,122	14,109	30,077	27,931	25,101	10,715	481,975	476,600				479.82			

Table 5. Shallow PRB Iron Injection Summary. Hookston Station ZVI PRB. Pleasant Hill, California

Frac Casing No.	**Apr-09**						May-09												Jun-09															Quantity of Iron Injected (tons)	Target (pounds)	Iron Loading (pounds/ sq.ft.)	Top of PRB (ft)	Bottom of PRB (ft)	Length of PRB (ft)	Cross-Sectional Area (ft^2)	Location along wall (ft)	Lbs Req'd for Wall Geometry (lbs)
	14	15	16	17	18	19	2	3	4	5	6	11	12	14	15	16	17	18	2	3	4	10	11	12	13	14	15	16	17	24	25	26	27									
UPPER PANEL																																										
F1	798	1032	954																															2,784	8,640	45	15	47	13.54	433.3	6	9748.8
F2		3076	1017	1978	616	502	1162	513																										8,864	8,640	45	15	47	10.58	338.6	15.08	7617.6
F3	1472	1002	1976	1932	1260	682	858																											9,182	8,640	45	15	47	12	384.0	27.16	8640
F4		2496	2028	1996	1386	1020																												8,926	8,640	45	15	47	11.21	358.7	39.08	8071.2
F5	1509	2572	2024	1968	744																													8,817	8,640	45	15	47	12.04	385.3	49.58	8668.8
F6		2402	2020	2016	1359	1002																												8,799	8,640	45	15	47	12.96	414.7	63.16	9331.2
F7	1697	2444	1993	1916	627																													8,677	8,640	45	15	47	11.42	365.4	75.5	8222.4
F8		2348	1990	2011	1011	1552																												8,912	8,640	45	15	47	10.79	345.3	86	7768.8
F9	1642	2520	1982	2020	365																													8,529	8,640	45	15	47	11.875	380.0	97.08	8550
F10		2528	2046	2080	659	1314																												8,627	8,640	45	15	47	12.96	414.7	109.75	9331.2
F11	1522	2548	1948	2028	1020																													9,066	8,640	45	15	47	12.875	412.0	123	9270
F12										2630	1038	2280	1944	1890	2096	904																		12,782	13,000	67.5	15	47	12.165	389.3	135.5	13138.2
F13							1001			939	2346	1082	1838	1977	2086	1870																		13,139	13,000	67.5	15	47	11.875	380.0	147.33	12825
F14										2008	938	1636	1943	2078	1886	2850																		13,339	13,000	67.5	15	47	12	384.0	159.25	12960
F15									974	1038	2202	1002	2266	2084	1950	1695																		13,211	13,000	67.5	15	47	12.04	385.3	171.33	13003.2
F16										1938	1088	1988	2104	1975	2034	2072																		13,199	13,000	67.5	15	47	12	384.0	183.33	12960
F17									1098	1020	2026	936	2028	2006	2034	2114																		13,262	13,000	67.5	15	47	11.775	376.8	195.33	12717
F18										2090	974	2166	1971	1978	2038	1944																		13,161	13,000	67.5	15	47	11.885	380.3	206.88	12835.8
F19									966	950	1820	1056	1626	1930	2110	1968	3444		1044	1021	1138													19,073	19,500	67.5	15	47	12.5	400.0	219.1	13500
F20																																		0	0	67.5	15	47	12.78	409.0	231.88	13802.4
F21									1080	1110	2204	1068	1982	2108	1898	2036	1023		1039			990	1220											17,758	19,500	67.5	15	47	11.39	364.5	244.66	12301.2
F22										1052	956	968	1080	1157	1101	1331	1080	507	1005	953	1052		540											12,782	13,000	67.5	15	47	11.75	376.0	254.66	12690
F23									1038	1012	1557	444	1112	1056	1095	1121	1745		1041			1198	752											13,171	13,000	67.5	15	47	12.75	408.0	268.16	13770
F24										1974	548	1006	950	989	989	1367	1053	469	965	1004	1072		608											12,994	13,000	67.5	15	47	11.5	368.0	280.16	12420
F25									897	396	1581	448	1014	1018	987	1087	1461		940			1088	1056							644	426			13,043	13,000	67.5	15	47	11.875	380.0	291.16	12825
F26																					1036		1724	917	1250	1190	1194	874	1164	704	1067	1192	582	12,894	13,000	67.5	15	47	12.5	400.0	303.91	13500
F27																						1056	1008	1651	749	1072	1117	1554	912	901	1485	1226		12,731	13,000	67.5	15	47	12.25	392.0	316.16	13230
F28																					1020		1512	1040	1016	1090	1158	1059	1179	678	1474	1119	627	12,972	13,000	67.5	15	47	12	384.0	328.16	12960
F29																						1002	942	1620		1129	1146	1490	1023	1385	1337	1486	439	12,999	13,000	67.5	15	47	11.85	379.2	340.01	12798
F30																					976		1531	1015	1002	1151	1094	938	1049	739	1385	1330	409	12,619	13,000	67.5	15	47	12.1	387.2	352.11	13068
F31																						962	1056	1579		1129	1186	1510	1009	1224	1380	1348	611	12,994	13,000	67.5	15	47	12	384.0	364.11	12960
F32																					1029		1461	963	974	1244	1139	1053	998	673	1179	1386	796	12,895	13,000	67.5	15	47	12.2	390.4	376.31	13176
F33																						1022	1036	1443		978	1012	1502	977	1440	1292	1418	730	12,850	13,000	67.5	15	47	12.1	387.2	388.41	13068
F34																					1021		1558	1033	1039	1028	1067	977	819	707	1360	1490	682	12,781	13,000	67.5	15	47	11.75	376.0	400.16	12690
F35																						1066	900	1451		1055	1109	1569	1028	1533	1314	1494	520	13,039	13,000	67.5	15	47	12	384.0	412.16	12960
F36																					949		1627	1029	989	1179	1044	1023	1026	691	1511	1382	539	12,989	13,000	67.5	15	47	12	384.0	424.16	12960
F37																						914	1048	1552	487	976	940	1491	1036					8,444	8,640	45	15	47	10.6	339.2	434.76	7632
F38																					1042		1275	922	515	1251	1215	997	1064	850	1396	624		11,151	11,031	45	15	47	10.6	339.2	445.36	7632
F39																						953	1040	1600		1222	1318	1689	1123	1579	773			11,297	11,030	45	15	47	13.13	420.2	458.49	9453.6
F40																					1089		1749	1019										3,857	3,857	45	15	47	12.33	394.6	470.82	8877.6
Subtotals	8,640	24,968	19,978	19,945	9,047	6,072	3,021	513	6,053	18,157	19,278	16,080	21,858	22,246	22,304	22,359	9,806	976	6,034	2,978	11,424	10,251	23,643	18,834	8,021	15,694	15,739	17,726	14,407	13,748	17,379	15,495	5,935	448,609	454,598				479.95			

Table 6. Summary of Gel QA/QC Testing. Hookston Station ZVI PRB. Pleasant Hill, California

Date	Gel Batch No.	Gel Viscocity (cP)				Gel pH	Gel Resistivity (ohms-cm)	Batch Size/Remarks
		Temperature (^{o}C)	Shear Rate (sec-1)					
			1	10	100			
4/3/2009	1	16.5	2300	916	207	5.67	280	water PH 7.90
4/5/2009	2	19.6	1100/2700	940/850	189/200	7.05	260	viscosity not zeroed
4/6/2009	3	21.8	1800	650	165	6.90	270	
4/8/2009	4	15.1	1600	370	150	7.06	290	
4/13/2009	5	15.9	1200/1300	540/550	146/149	7.6 /5.22	300	Ph too high, 500 ml added ..retest
4/14/2009	6	14.1	1700	690	176	5.80	300	
4/15/2009	7	12.9	1250	500	132	6.24	280	
4/16/2009	8	15.2	1300	590	162	5.83	300	
4/17/2009	9	15.0	1400	610	158	5.52	305	
4/19/2009	10	18.5/19.1	900/1000	270/470	170	5.68	270	1/2 batch 1500 gallons
4/20/2009	11	20.6	1150	500	132	5.44	260	
4/21/2009	12	26.9	1500	600	152	5.29	270	
4/27/2009	13	18.0	1200	580	159	5.89	280	last of old gel

Date	Gel Batch No.	Gel Viscocity (cP)				Gel pH	Gel Resistivity (ohms-cm)	Batch Size/Remarks
		Temperature (°C)	Shear Rate (sec-1)					
			1	10	100			
4/28/2009	14	16.4	2000	950	247	6.2	290	new gel..acid lowered to 1750 ml
4/28/2009	15	18.6	2000	900	241	6.41	270	gel crosslink on wetside
4/29/2009	16	15.8	2200	980	242	6.25	270	very wet crosslink
4/30/2009	17	15.9	2200	1000	246	6.15	270	
4/30/2009	18	21.0	1500	800	210	6.26	270	
5/1/2009	19	18.3	2000	900	250	6.01	300	
5/2/2009	20	17.8	1700	600	171	6.51	290	
5/5/2009	21	19.8	1000	450	140	6.32	250	lot of overnight rain
5/11/2009	22	20.5	2000	890	221	6.08	270	
5/11/2009	23	23.6	1400	700	192	6.05	270	
5/14/2009	24	19.3	2100	890	235	6.11	305	gel sat in tank for 1 day while the power unit was down
5/15/2009	25	20.7	2000	850	224	6.16	300	
5/16/2009	26	25.3	1900	880	236	6.23	240	

Date	Gel Batch No.	Gel Viscocity (cP)				Gel pH	Gel Resistivity (ohms-cm)	Batch Size/Remarks
		Temperature (^oC)	Shear Rate (sec-1)					
			1	10	100			
5/17/2009	27	34.1	1600	740	210	5.92	240	very hot
5/27/2009	28	23.7	2000	820	221	6.1	250	machine stalled a few times while mixing
5/28/2009	29	23.4	2100	870	232	5.92	250	
5/29/2009	30	20.9	2200	1100	250	6.1	260	
5/30/2009	31	23.2	2300	800	230	6.47	260	
5/30/2009	32	23.9	1900	900	212	6.05	280	
6/1/2009	33	19.4	2200	950	227	5.92	300	
6/1/2009	34	24.1	2200	900	210	6.23	250	
6/2/2009	35	19.6	2500	1020	230	6.4	260	
6/3/2009	36	24.6	2000	870	210	6.12	250	
6/10/2009	37	19.7	2200	960	236	6.27	320	
6/11/2009	38	20.5	2500	1000	243	6.57	300	
6/12/2009	39	19.6	2100	970	219	5.94	290	

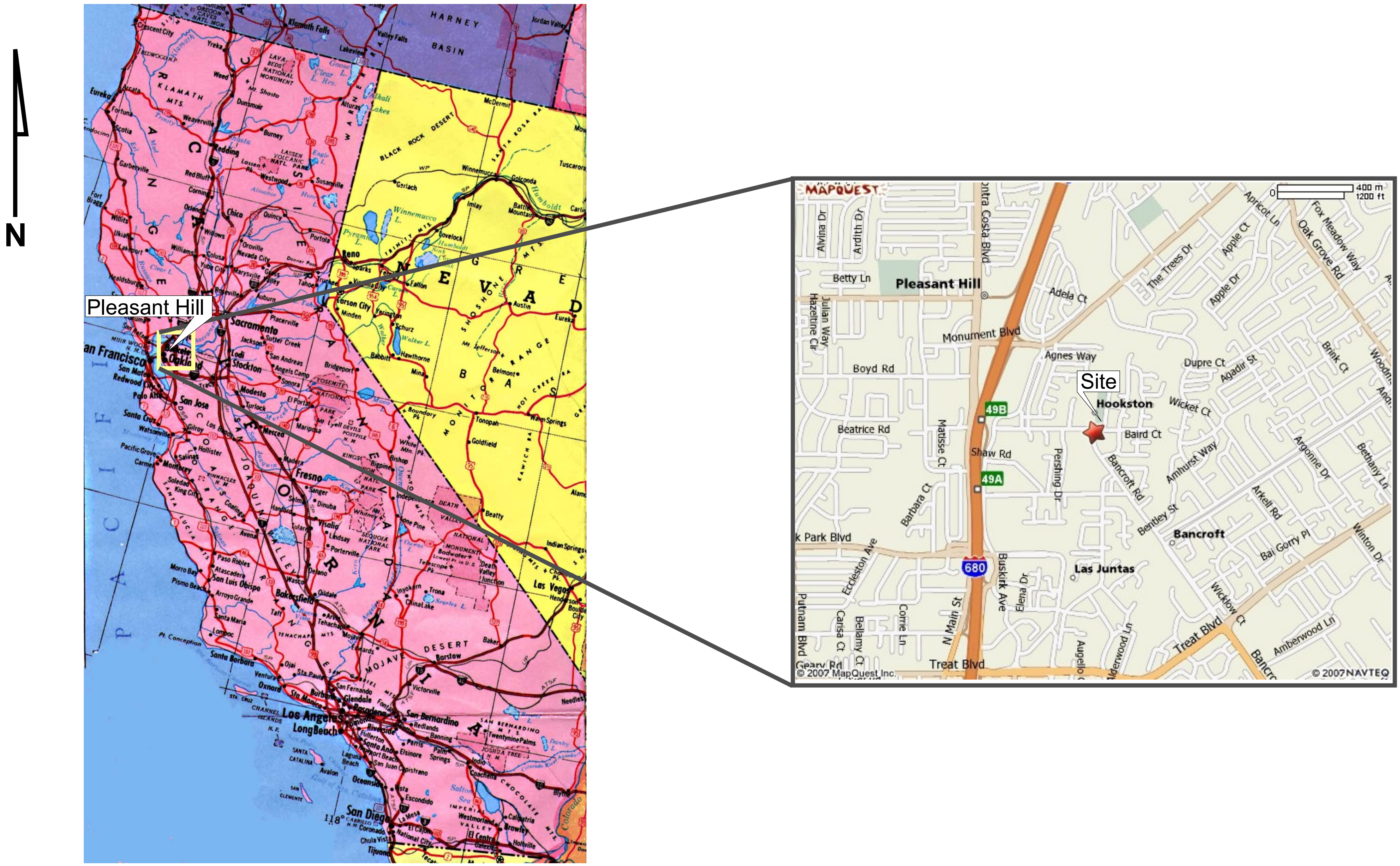
Table 6. Summary of Gel QA/QC Testing. Hookston Station ZVI PRB. Pleasant Hill, California

Date	Gel Batch No.	Gel Viscocity (cP)				Gel pH	Gel Resistivity (ohms-cm)	Batch Size/Remarks
		Temperature (^{o}C)	Shear Rate (sec-1)					
			1	10	100			
6/12/2009	40	24.8	1900	870	213	6.35	310	
6/14/2009	41	22.2	1900	870	208	5.87	280	
6/15/2009	42	21.3	2700	1300	221	5.85	330	
6/17/2009	43	21	2500	1000	227	5.6	350	2000 gal batch-30 pds of salt 1200 ml of acid
6/24/2009	44	23.1	2400	940	212	5.85	620	only 30 lbs of salt
6/24/2009	45	21.4	2800	1000	225	6.23	/	no salt!
6/25/2009	46	24.2	3000	1400	250	5.86	/	1000 gal no salt

Table 7. Summary of Hydraulic Pulse Interference Test Results. Hookston Station ZVI PRB. Pleasant Hill, California.

	Pre-PRB Installation Hydraulic Pulse Intereference Testing			Post-PRB Installation Hydraulic Pulse Intereference Testing			
Test Location	**Hydraulic Conductivity (ft/day)**	**Hydraulic Conductivity (cm/sec)**	**Storativity (1/ft)**	**Hydraulic Conductivity (ft/day)**	**Hydraulic Conductivity (cm/sec)**	**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%**

FIGURES



GeoSierra Environmental, Inc.

Medford, NJ
Atlanta, GA

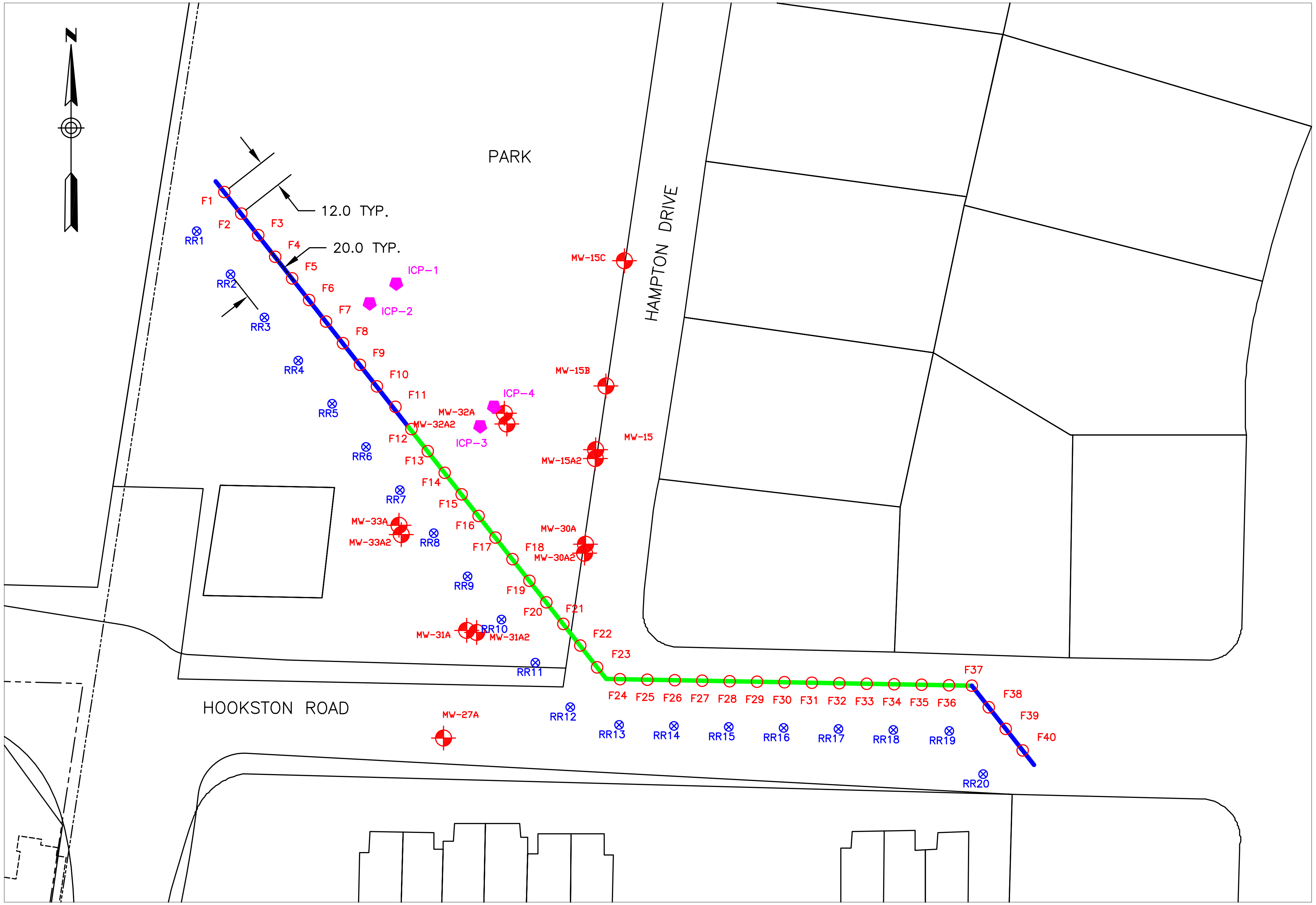
TITLE

HOOKSTON STATION SITE
LOCATION MAP

CLIENT/PROJECT

HOOKSTON STATION
PLEASANT HILL, CALIFORNIA

DRAWN MAT	DATE 8/23/08	JOB NO. G205001	
CHECKED JGO	SCALE	DWG. NO.	REV. NO.
REVIEWED	FILE NO. Figure 1	SUBTITLE	FIGURE NO. 1



LEGEND

○ F1 FRAC INJECTION WELLS (40 TOTAL)
⊗ RR1 RESISTIVITY STRINGS (20 TOTAL)
⬟ ICP-1 CONFIRMATION BORINGS (4 TOTAL)
⌖ MW-27A EXISTING A-ZONE MONITORING WELLS
━ 3-INCH PRB THICKNESS (180 LINEAR FEET)
━ 4.5-INCH PRB THICKNESS (300 LINEAR FEET)

0 50
FEET

GeoSierra Environmental, Inc.

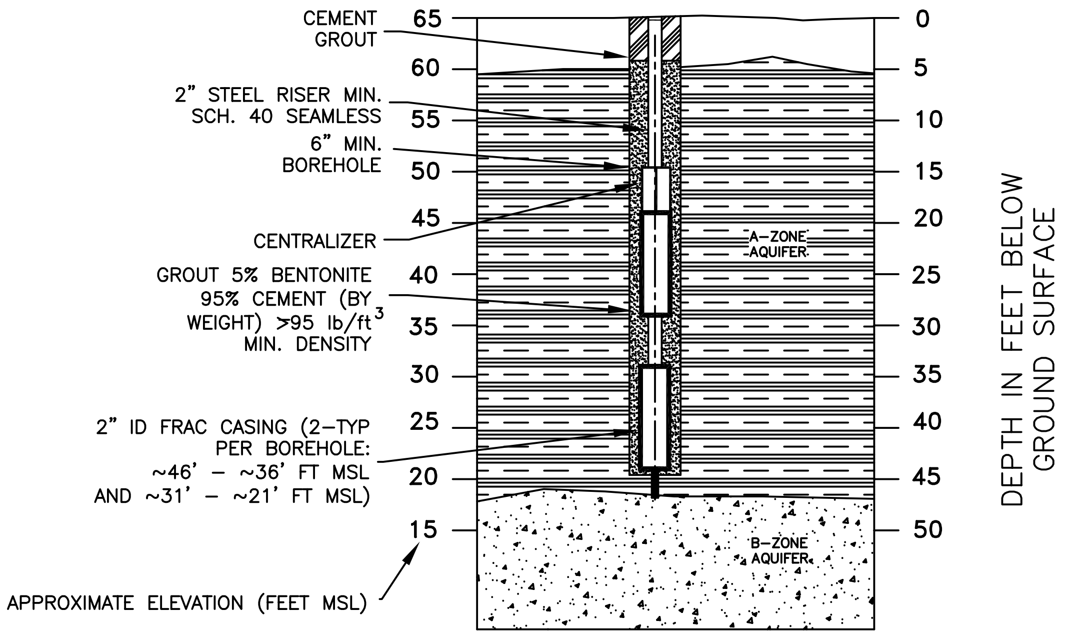
MEDFORD, NEW JERSEY
ATLANTA, GEORGIA

DWG. NO. 205001012	
REV. NO.	JOB NO. 205001
DATE 09/09	DRAWN KDD
SCALE AS SHOWN	CHECKED
FILE NO.	REVIEWED

CLIENT/PROJECT
ERM – HOOKSTON STATION
PLEASANT HILL, CALIFORNIA

TITLE
PERMEABLE REACTIVE
BARRIER LOCATION PLAN

FIGURE NO.
2

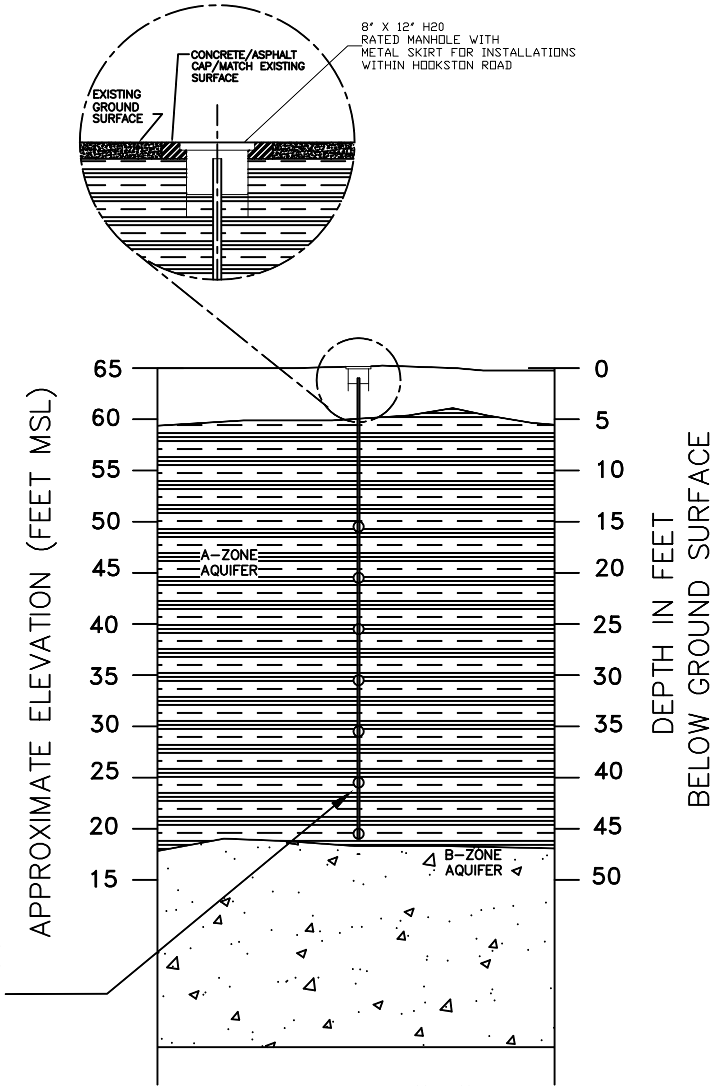


DETAIL "A"
HYDROFRACTURE WELLS (F)

(NTS)

PAVED AND UNPAVED AREA WELLS

FRAC CASINGS ARE F1 THRU F40

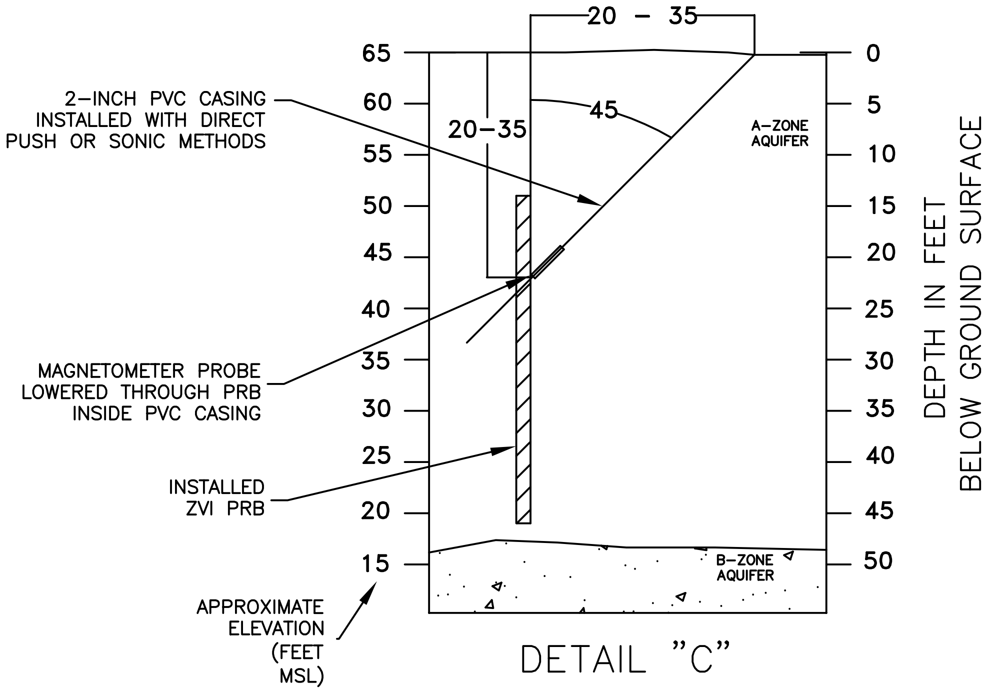


DETAIL "B"
RESISTIVITY STRING LOWER PRB

PAVED AND UNPAVED AREA WELLS

(NTS)

PRB RESISTIVITY STRINGS= RR1 THRU RR20



DETAIL "C"
CONFIRMATION BORING DETAILS

(NTS)

PRB CONFIRMATION BORINGS ICP-1 TO ICP-4

LEGEND

□	FRAC INITIATION CASING & TOOLING
▮	SOIL SAMPLE CORE/SPLIT SPOON/SONIC SAMPLE

NOTES

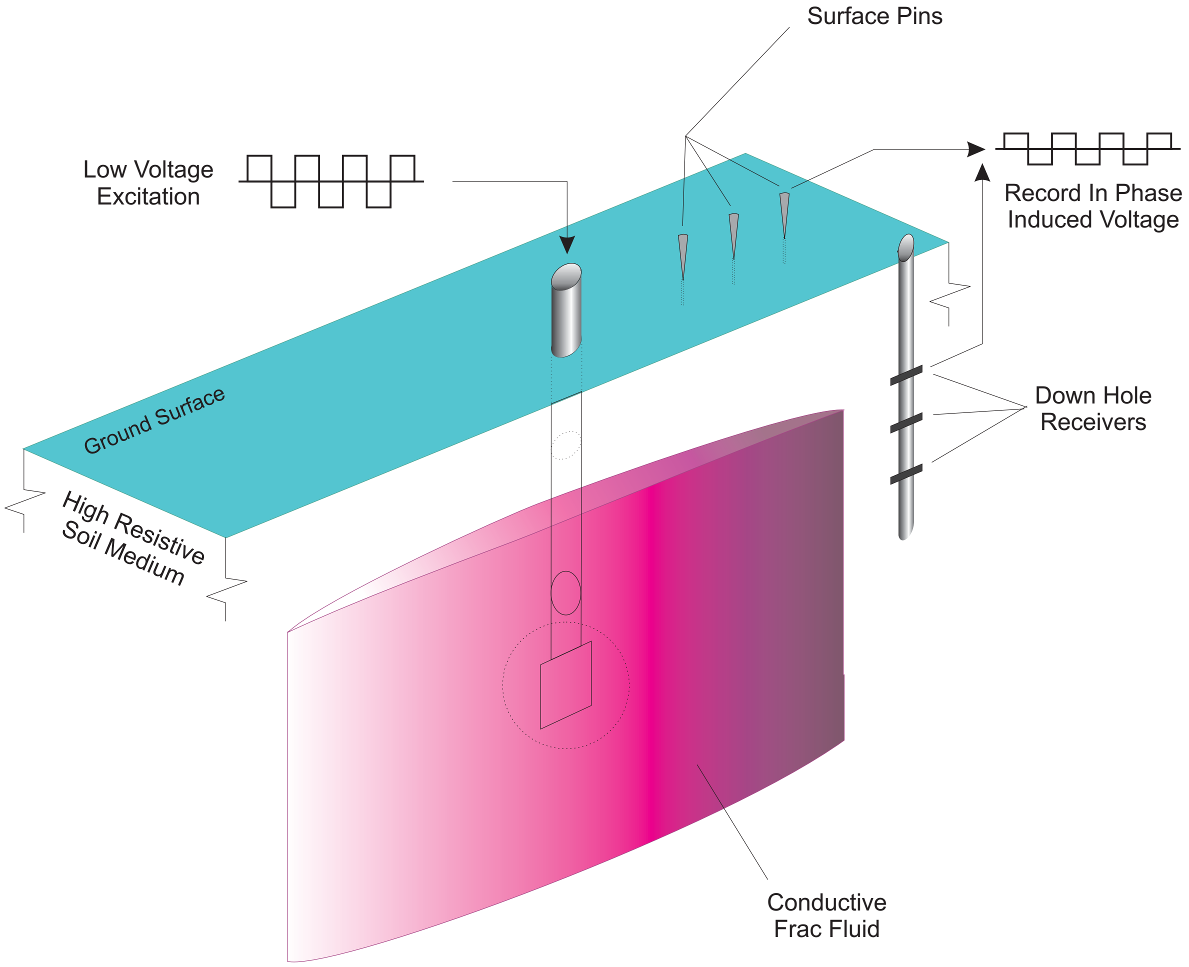
WIRE COLOR CODE FOR RESISTIVITY RECEIVER STRINGS (BOTTOM TO TOP):

BLUE
YELLOW
ORANGE
GREEN
RED
WHITE
BLACK

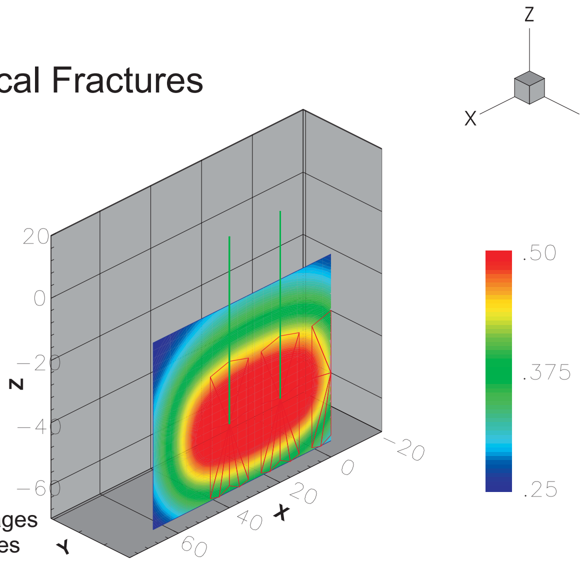
GeoSierra Environmental, Inc.

MEDFORD, NEW JERSEY
ATLANTA, GEORGIA

DWG. NO. 205001013		CLIENT/PROJECT: HOOKSTON STATION PLEASANT HILL, CALIFORNIA
REV. NO.	JOB NO. 205001	
DATE 9/09	DRAWN KDD	TITLE: HYDROFRACTURE WELL CASING RESISTIVITY STRING AND QA/QC BORING INSTALLATION DETAILS
SCALE NONE	CHECKED	FIGURE NO. 3
FILE NO.	REVIEWED	



Multiple Vertical Fractures



Down Hole Induced Voltages
due to Energized Fractures

GeoSierra
Environmental, Inc.
Medford, NJ
Atlanta, GA

TITLE
TYPICAL MONITORING SYSTEM LAYOUT

CLIENT/PROJECT
HOOKSTON STATION
PLEASANT HILL, CALIFORNIA

DRAWN	MAT	DATE	8/23/09	JOB NO.	G205001		
CHECKED	JGO	SCALE	NTS	DWG NO.		REV. NO.	
REVIEWED		FILE NO.	Figure 3.cdr	SUBTITLE		FIGURE NO.	4