Installation of a Full Scale Permeable Reactive Barrier at a Former Manufacturing Site in California

Grant Hocking, Melanie A. Thurman, Chad N. Givens and Chris M. Lacko
GeoSierra LLC, Atlanta, USA

ABSTRACT: Azimuth controlled vertical hydraulic fracturing technology was used to construct a full scale in situ iron permeable reactive barrier (PRB) at intermediate and moderate depths as part of a natural biodegradation remedy for a carbon tetrachloride (CT) plume at a former manufacturing site in California. A pilot PRB was completed on site in 2001 and the full scale PRB was an extension to that pilot system. The iron permeable reactive barrier was constructed in two overlapping panels with the shallow panel installed from approximately 35 to 65-feet below ground surface and the lower panel installed 100-feet down gradient from approximately 60-feet to 117-feet bgs with iron thickness varying from 3-inches to 6-inches based on plume-specific design cases. The shallow panel is 485-feet in length and contains 378 tons of iron filings. The lower panel is 375-feet in length and contains 1,050 tons of iron filings. Groundwater monitoring wells were installed prior to construction of the pilot PRB and additional monitoring wells were constructed prior to extension of the pilot to full scale. Post PRB quality assurance testing has verified that the constructed PRB meets design specifications and groundwater sampling continues to verify remedy effectiveness in reducing contaminant concentrations in the CT plume. Groundwater monitoring at the site indicates the PRB has been effective in reducing CT concentrations in groundwater within the short time frame since the pilot PRB was installed in 2001.

INTRODUCTION & BACKGROUND

The Site is located approximately 60 miles east of San Francisco, in Contra Costa County in the city of Oakley, California. The Site is bounded on the north by the San Joaquin River, and on the south by The Atchison Topeka and Santa Fe rail line. Geologic data from well installation and cone penetrometer testing (CPT) previously conducted confirm a series of fining upward sequences associated with fluvial deposition. Organic peat and mud are encountered near ground surface in some of the low-lying areas adjacent to the San Joaquin River. Sediments underlying the Site consist of a predominantly permeable alluvial aquifer ranging from 100 to 140-feet thick overlying the massively bedded silty clay Montezuma Formation (200 to 300-feet thick beneath the Site). The alluvial aquifer is divided into three local units at the Site: the surficial, upper, and lower aquifers. Groundwater flow in all three of these aquifers is from south to north, with the aquifers hydraulically connected to the San Joaquin River and Little Break. In the vicinity of Little Break, groundwater flow in the Upper and Surficial Aquifers is oriented more to the northeast than in other areas of the Site. The PRB will be installed within the Lower Aquifer. Three distinct groundwater plumes have been designated as Plume 1, 2, and 3 based on the plume constituents, apparent source areas, transport pathways, and aerial distribution. Plume 1 has been identified as the highest priority of the groundwater remediation effort. The main VOCs in Plume 1 include carbon tetrachloride (CT) (the primary constituent based on concentration and mass), 1,1,2-trichlorotrifluoroethane (CFC-113), trichlorofluoromethane (CFC-11), and 1,2-dichloroethane (EDC). Chlorinated solvents, such as TCE and CT, will be abiotically reduced in the PRB, Gillham and O'Hannesin (1994) and Roberts et al (1996). Iron passivation by nitrate needs to be addressed in any PRB design, Schlicker et al (2000).

Verification of the zero valent iron technology and emplacement methodology was previously demonstrated with the construction of a pilot PRB, constructed over a 5-month period and completed in February 2001. Following three years of performance evaluation, it was decided to implement two additional subsurface iron PRBs at the site, an upper barrier and a lower barrier, as shown in plan on Figure 1. The Upper Barrier will have a total length of 485 feet, measured from the western end of the pilot PRB. The first 110-feet will parallel the pilot PRB, and the remaining 375-feet will extend east parallel to the Lower Barrier. The Upper Barrier will begin at the top of the Upper Aquifer (~30-feet) and extend approximately 30-feet through the U/L Aquitard, finishing near the top of the Lower Aquifer (~60-feet). The Lower Barrier will extend 375-feet from the eastern end of the existing pilot PRB, beginning near the top of U/L Aquitard (~50-feet bgs) and extending approximately 60-feet through the Lower Aquifer to finish at the top of the Montezuma Formation (~110-feet).

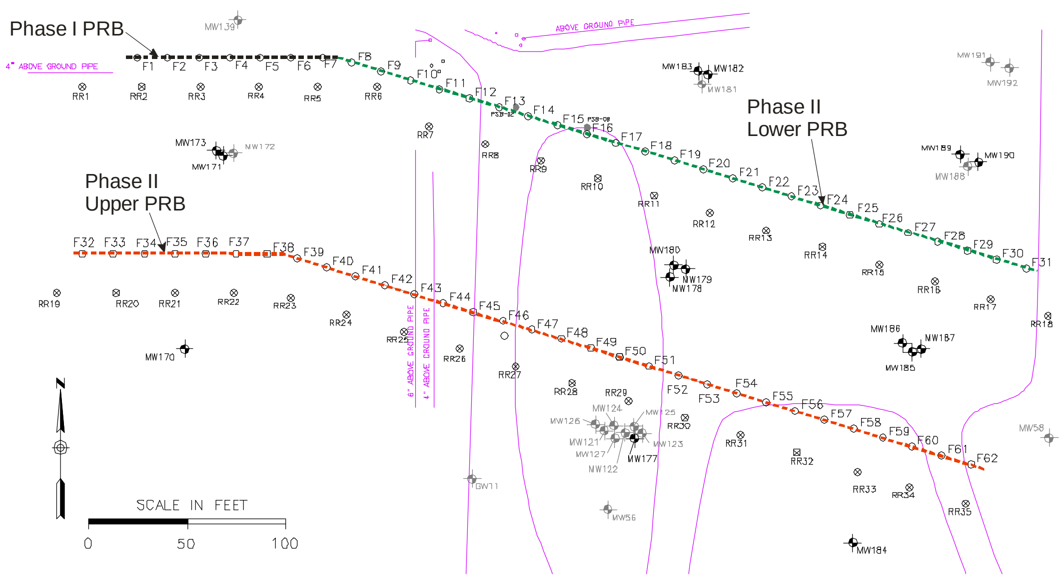

Figure 1. Plan View of PRB Upper and Lower Segments

The vertical dimensions are approximate for both barriers; the actual starting depth of the shallow panel and completion depth of the lower panel will be field verified based on the physical locations of the bottom of the S/U Aquitard and Montezuma Formation, respectively. Both the shallow and deep panels will key into the respective Upper and Lower Aquitards a sufficient distance in order to prevent "short circuiting" above or below the barriers. The two parallel panels will be offset laterally by approximately 100-feet, with the shallow panel located upgradient of the deep panel, to facilitate construction and minimize hydraulic interference between the two panels. The major components of the selected groundwater remedy consist of:

- An iron PRB to transform dissolved VOCs into non-toxic products before groundwater migrates off site
- Implementation of an environmental monitoring plan to evaluate the effectiveness of the PRB

PRB CONSTRUCTION

GeoSierra LLC was retained to design and construct the full-scale extension to the pilot iron permeable reactive barrier (PRB) previously installed at the Site in March 2001. The pilot PRB, referred to as Phase I, of 110-feet (ft) in length was constructed in 2001 from a depth of 45-ft down to a total depth of 117-ft below ground surface (bgs). The full-scale PRB, referred to as Phase II, is comprised of two segments: 1) Lower Panel – 375-feet (ft) in length, installed from a depth of approximately 55 to 60-ft below ground surface (bgs) to a total depth of 115 to 117-ft bgs; and 2) Upper Panel – 485-feet (ft) in length, installed from a depth of approximately 35 to 40-ft bgs to a total depth of 55 to 60-ft bgs. The panels have varying average iron-effective-thicknesses of 3, 4.5, and 6 inches (in.) to treat differing levels of influent contamination, which varies along the alignment of the PRB.

Groundwater containing constituents of potential concern (COPCs) and constituents of interest (COIs, such as inorganic elements) has been identified at the Oakley Site, with sources related to the former manufacturing areas and Waste Management Areas. For convenience, the contaminated groundwater has been categorized into three regions identified as Plumes 1, 2, and 3. The plume designations are based on differences in apparent source areas, transport pathways, areal distribution and, to some degree, differences in plume COPCs and COIs.The PRB installation program is directed at mitigating potential off-site migration of contaminants from Plume 1 in the upper and lower aquifers. The purpose of the PRB is to significantly reduce the levels of volatile organic compounds (VOCs) present in the plume including carbon tetrachloride (the primary constituent based on concentration and mass), 1,1,2-trichlorotrifluoroethane and trichlorofluoromethane.

PRB construction activities were initiated in February, 2005 with site preparation activities, pre-PRB hydraulic pulse interference testing (HPIT), and the drilling and installation of resistivity receiver strings and frac casing strings as shown on Figure 2. The PRB was constructed perpendicular to the natural groundwater flow direction. The PRB's geometry was monitored and mapped in real time by the active resistivity method, with images of the fracture PRB geometry displayed during the injections. The PRB was constructed from hydrofracturing casings, spaced approximately 15-ft apart along the PRB alignment (Figure 1). For the lower panel (F-8 through F-31), each frac casing string had four (4) frac casings for the four distinct injection horizons. For the upper panel (F-32 through F-62), each frac casing string had one (1) frac casing for the injection horizon with the exception of F-50 through F-62 which had two (2) frac casings for the two injection horizons. The final geometry of the PRB involved the injection of 1,420 tons of iron filings to construct two PRB panels. For the lower panel, the PRB has an average thickness as follows: 1) F-8 to F-25 – 6-in; 2) F-26 to F-28 – 4.5-in; and 3) F-29 to F-31 – 3-in. The total injected cross-sectional area is approximately 25,822 ft^2. For the upper panel, the PRB has an average thickness as follows: 1) F-32 to F-43 – 4.5-in;

and 2) F-44 to F-62 – 3-in. The total injected cross-sectional area is approximately 21,796 ft^2 as shown on Figure 3. The injections from the hydrofracturing casings formed coalesced fractures, as quantified by the active resistivity mapping and confirmed from adjacent frac casing response.

Figure 2. Hydrofracture Well Casing and Resistivity String Installation

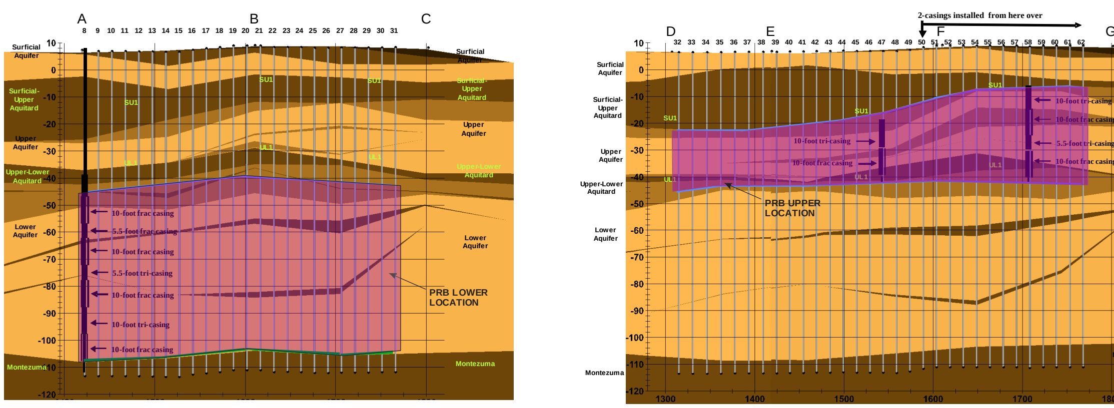

Figure 3. As Built Geometry of Phase II Permeable Reactive Barrier

CONSTRUCTION QA/QC TESTS

Post-PRB QA/QC verification testing was completed to evaluate the impact on the groundwater flow regime by the installation method and to quantify the in place installed PRB average thickness. Pre- and post-PRB hydraulic pulse testing indicated that the installed PRB did not impact the formation hydraulic characteristics. Inclined borings (30?) from the vertical inclination and quantification of the subsurface materials in the borings using an electrical resistivity probe (ERP) were completed at twelve (12) locations along the upper and lower PRB panels. These inclined borings confirmed that the PRB panels were installed at the design specified thicknesses along the PRB alignments.

Post-PRB hydraulic pulse interference tests were conducted following the completion of hydrofracturing activities to quantify that the constructed PRB was as permeable as the existing subsurface formation. Hydraulic pulse interference tests 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 pulse source and receiver wells. The transient nature of the test, involving the time delay and attenuation of the hydraulic pulse, enables the formation's complete hydraulic properties to be computed as detailed in Hocking (2001). The hydraulic pulse interference tests utilized the same pulse test wells as used previously for the pre-PRB pulse test. As with the pre-PRB pulse tests, the pulse tests were conducted with a cyclic injection of potable water in the source well typically at a rate of 10 gallons per minute with a pulsed injected time interval of 60 seconds and a shut in time interval also of 60 seconds. A comparison of typical pre and post-PRB hydraulic pulse test data is shown on Figure 4 for the first injection cycle.

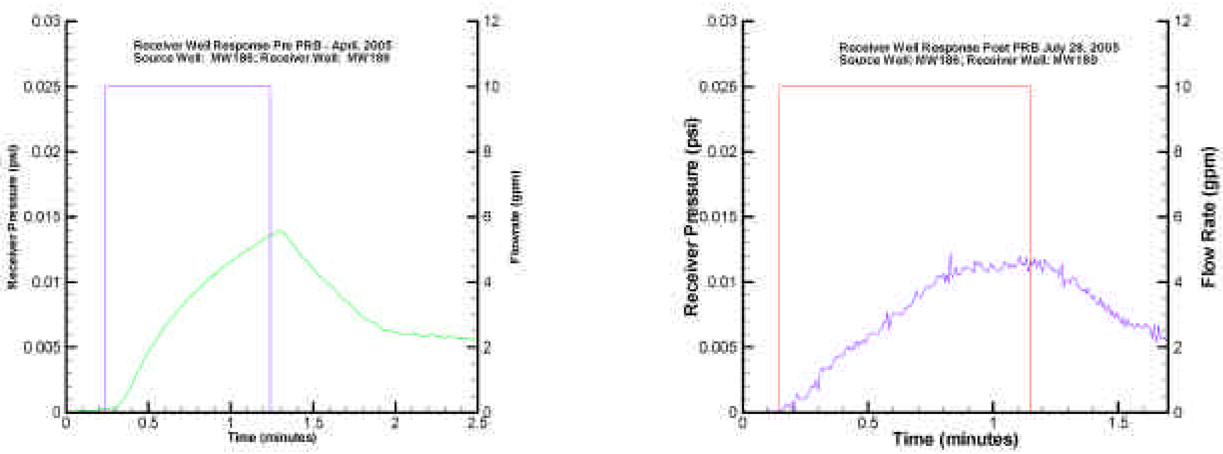

Figure 4. Typical Pre- and Post-PRB Hydraulic Pulse Test Data

The Phase II PRB was profiled by inclined direct push electrical resistivity probe to determine that the PRB thickness was within specification at various chosen locations along the PRB alignment. Angled borings (30?) from the vertical inclination were completed at twelve (12) locations to the desired depth with minimal deviation. A total of ten (10) inclined borings were originally advanced and two were redrilled in adjacent locations due to insufficient data to verify the thickness of the PRB along the alignment. A schematic of the inclined boring and electrical resistivity probe (ERP) data collection activities completed at the Site and equipment used is shown in Figure 5. The inclined profiles quantified that the PRB was installed to the correct thickness at various locations along its alignment.

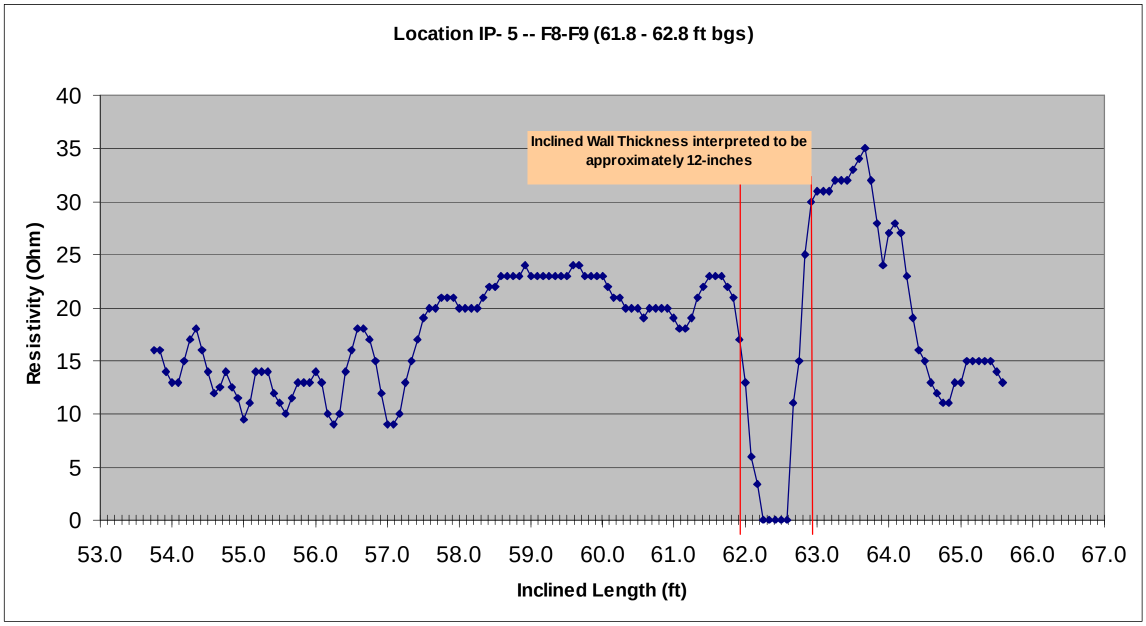

Figure 5. Typical Post-PRB Resistivity Probe Data for Inclined Profile IP-5

CONCLUSIONS

In 2001, the Phase I PRB was constructed from seven (7) hydrofracturing wells F-1 through F-7 using the azimuth controlled vertical hydrofracturing technology. The same technology was selected for the construction of the Phase II PRB comprised of a lower panel and an upper panel. Prior to PRB hydrofracturing activities, water and power utilities, fifty-five (55) hydrofracturing wells, and thirty (30) resistivity receiver strings were installed for the construction and QA/QC real time monitoring during installation of the Phase II PRB panels. Hydrofracturing production rates for the completion of Phase II PRB averaged 26.2 tons per day and a total of 1420 tons of iron were injected. The installation of the PRB included pre-and post-PRB hydraulic pulse interference testing. The final geometry of the constructed Phase II lower PRB panel extended approximately 375-ft in overall length from a depth of approximately 55.5 ft. down to a maximum depth of 115-117-ft bgs. The final geometry of the constructed Phase II upper PRB panel extended approximately 485-ft in overall length from a depth of approximately 35.5 ft. down to a maximum depth of 60-ft bgs. The total Phase II as-built PRB panels have a cross-sectional area of 47,618 ft^2. The overall PRB remedy with Phase I and II have a cross-sectional area of 54,733 ft^2. Post-PRB QA/QC Verification testing was completed to evaluate the impact on the groundwater flow regime by the installation method and to quantify the in place installed PRB average thickness. Post-PRB hydraulic pulse testing indicated that the installed PRB did not impact the formation hydraulic characteristics. The Phase II PRB was profiled by an inclined direct push electrical resistivity probe to determine that the PRB thickness was within specification at various chosen locations along the PRB alignment. The inclined profiles quantified that the PRB was installed to the correct thickness at various locations along its alignment.

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