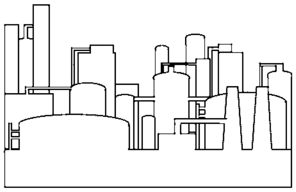

Groundwater Remediation in Residential Areas Surrounding BRAC Sites

Robin S. Futch, Roshni P. Sadarangani, and Walter Peck

A full-scale iron permeable reactive barrier (PRB), composed of three segments, was constructed down to a depth of approximately 40 feet below ground surface (bgs) in an off-base residential area surrounding the former Kelly Air Force Base (AFB) in San Antonio, Texas. The PRB was designed to remediate trichloroethene (TCE)- and tetrachloroethene (PCE)-contaminated groundwater so the groundwater would meet drinking water standards. The PRB was constructed by azimuth controlled vertical hydraulic fracturing (ACVHF) technology in a residential neighborhood with numerous subsurface and overhead utilities. All sections of the PRB were constructed to the design specifications of approximately 3 inches in thickness from a depth of approximately 20 feet to a total depth of 40 feet bgs. The ACVHF method of construction was chosen due to the existing utilities, the requirement to minimize disturbance to the neighborhood, and the constraints of the worksite (residential two-lane road). This article describes the construction challenges and logistics that had to be managed to satisfy site-specific constraints for installing an in situ *PRB within a residential neighborhood as part of the overall site remediation strategy for the former Kelly AFB. © 2005 Wiley Periodicals, Inc.**

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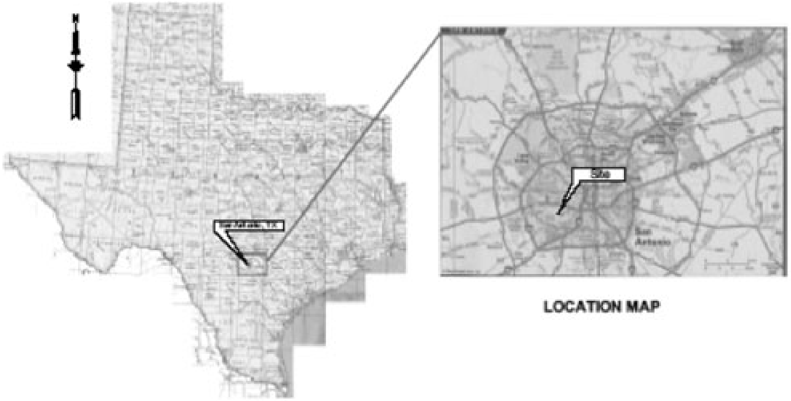
Exhibit 1. Former Kelly AFB Site Location Map



INTRODUCTION

The Air Force Real Property Agency (AFRPA) is implementing innovative technologies to clean up legacy contamination around the former Kelly Air Force Base (AFB) as part of Base Realignment and Closure (BRAC) activities. A full-scale iron permeable reactive barrier PRB) was constructed as a component of the remediation strategy for the restoration of groundwater in off-base areas at the former Kelly AFB (**Exhibit 1**).

PRBs were chosen as the technology of choice for remediation in off-base residential areas because there are minimal operation and maintenance (O&M) costs, no energy consumption (as there is with pump-and-treat technologies), and because PRBs are a passive *in situ* treatment technology that will work effectively for years. Trenching was considered a less desirable installation option because of the numerous underground utilities; the location in a busy urban area with businesses, schools, and residences; and minimal workspace (a two-lane road), where one lane had to remain open during the day and both lanes had to be reopened at night.

The PRB was installed in three segments:

- Segment I is 1,180 feet in length, ranging from approximately 20 feet to a total depth of 40 feet below ground surface (bgs), and lies along Commercial Street, San Antonio, Texas.
- Segment II is 400 feet in length, with a treatment depth of approximately 20 feet to 40 feet bgs, and lies along Collingsworth Street, San Antonio, Texas.
- Segment III is 320 feet in length, with a treatment depth of 20 feet to 40 feet bgs, and is located on private property between Division and Britton Streets.

The City of San Antonio (COSA) is a well-developed urban area with industrial facilities, retail stores, and residential neighborhoods. The

PRB construction site is in a mixed retail business and residential section of the city, located off base in Bexar County, San Antonio, Texas. Tetrachloroethene (PCE) and trichloroethene (TCE), common industrial solvents used at the former Kelly AFB to degrease engine parts, entered the shallow groundwater over time. Subsequently, a groundwater plume was created within the subsurface due to leaks, spills, or past approved disposal practices. This plume is present both on and off base.

The two main objectives of the remediation strategy included preventing further off-base migration of contaminated groundwater and to ensure groundwater concentrations in off-base areas meet acceptable standards.

SITE GEOLOGY

The subsurface lithology consists of overlying organic clay from the ground surface down to a depth of 5 feet bgs. Beneath the overlying organic clay is a low-permeability clay with silt, sand, and caliche occurring from a depth of 5 feet down to approximately 22 feet bgs. This is underlain by a saturated permeable gravel and cobble zone with silt, sand, and clay down to a depth ranging from 27 to 45 feet bgs. The gravel zone is underlain by a lean clay unit known as the Navarro Formation and acts as a bedrock aquitard.

The site conditions existing during frac well installation and PRB construction presented unique challenges to the project.

The groundwater potentiometric head varies in elevation throughout the PRB construction site and the saturated permeable gravel zone is discontinuous and varies in thickness. The hydraulic gradient in the area is approximately 0.009 feet per foot (ft/ft). The hydraulic conductivity of the permeable gravel unit varies widely from less than 1 to more than 100 feet per day (ft/day). Groundwater in the off-base area where the PRB was installed is contaminated with low concentrations of PCE and slightly higher concentrations of TCE.

SITE CONDITIONS

The site conditions existing during frac well installation and PRB construction presented unique challenges to the project. Daily requirements during the drilling portion of the project included limited work hours and the requirement that all equipment be removed from the COSA right-of-way (ROW) on a daily basis. This resulted in a minimum of an hour of downtime daily since all on-site equipment had to be set up and removed from the street daily. **Exhibits 2** and **3** show the worksite during a typical workday and the street at the end of every day per the city's requirements.

In addition to site access constraints, all COSA street cut permits required traffic flagmen onsite daily. A local security firm, composed of off-duty law enforcement personnel, was used to coordinate lane closures, traffic management, and detours, and for interfacing with the local community. This was a significant cost to the project but also provided a tremendous asset. Street cut permits had to be renewed and fees paid every 60 days to COSA for working in the ROW block by block. In addition to traffic management, bus rerouting, and grounding and deener-

Exhibit 2. Typical Daily Setup during Drilling Program

gizing overhead power lines, the relocation of other overhead lines (telephone and cable) also had to be managed at each block. All drilling locations were initially cored through the street and then "soft-dug" to 6 feet bgs to ensure no utilities were impacted in the installation of the frac wells, resisitivity receivers, and monitoring wells. This was a significant cost to the project but also provided certainty that no utilities would be adversely impacted. For the duration of the project (five months), no underground utilities were impacted temporarily or disabled.

The azimuth controlled vertical hydraulic fracturing (ACVHF) method for PRB construction was the optimal solution for this site because during the drilling and placement of the frac casings and resistivity receivers, worksites had to be reopened at the end of the day to allow traffic to resume normal patterns. The only ongoing disruption was during injection of the iron to construct the PRB. Due to the footprint of the frac injection equipment, COSA officials allowed the frac equipment to remain in the ROW Mondays through Saturdays, with the requirement that overnight security and one lane of traffic be opened nightly. All equipment was removed on Saturdays and remobilized back onsite on Monday mornings to resume PRB construction.

PRB DESIGN

The objective of the PRB is to degrade volatile organic compound (VOC) contaminants in the site groundwater to nontoxic end products and prevent further off-site migration of contaminated groundwater. In order to confirm the suitability of the zero valent iron (ZVI) technology at the site, a reactive bench-scale column test was conducted on site-specific groundwater in the presence of medium-fine granular iron filings (representative ZVI sources for PRB construction). The bench-scale column test quantified the degradation rates of the target VOCs in the site-specific groundwater and confirmed the site-specific

Exhibit 3. Typical View of Street at the End of Day

groundwater was in fact suitable for an iron PRB. Iron PRBs in suitable groundwater environments are expected to have a useful life of 30 years (Puls & Wilkin, 2002; Reynolds, Gillham, & O'Hannesin, 2002).

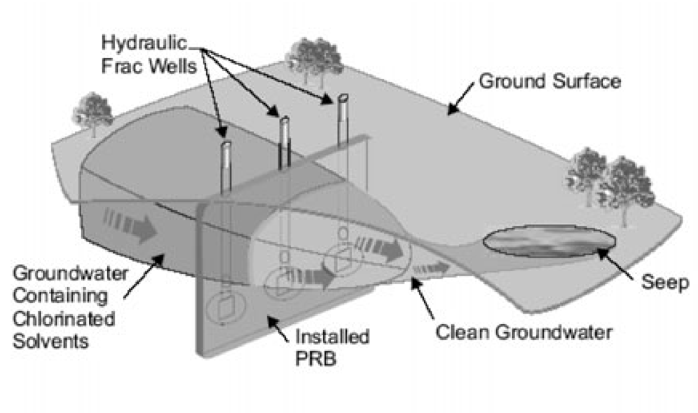
The PRB design methodology uses a multispecies VOC probabilistic model to quantify the overall reactive barrier system performance based on the expected variability of design input parameters (Hocking, Wells, & Thurman, 2002). These parameters include hydrogeologic data and VOC influent concentrations, VOC degradation half-lives and pathways, PRB porosity, and PRB iron-effective thickness. The geology, groundwater conditions, and proposed depth of the PRB at the former Kelly AFB were suitable for construction by the ACVHF installation method at the depths proposed. The ACVHF PRB installation method has previously been used to install seven full-scale iron PRB systems and two full-depth pilot scale systems. Four of these PRBs extend deeper than 100 feet bgs and would have been impossible to install by trenching.

PRB CONSTRUCTION

The ACVHF installation method for PRB construction provides a way to install PRBs without digging a trench (**Exhibit 4**). For the Kelly PRBs, six-inch boreholes were drilled every 12 feet along the planned PRB alignment (**Exhibit 5**). Specialized frac casings were aligned in the borehole in a closed position and grouted in with cement. The PRB was constructed by injecting approximately 510 tons of iron into 188 frac casings along the alignment of the PRB (**Exhibit 6**). Each frac casing string consisted of an aligned casing, which allowed the PRB to be built from the bottom up.

The iron filings were mixed with a food-grade starch, and an enzyme and special cross-linker additive were added on the pressure side of the frac pump. The enzyme and cross linker were mixed instantly with the cross-linker, causing the starch to become a highly vis-

Exhibit 4. General Schematic of ACVHF (Trenchless) Method of PRB Construction



cous gel containing ten pounds of iron filings per gallon of gel. The enzyme was used in order to break the gel down to harmless water and sugars after it had transported the iron filings to their destination. The gel carrying the iron filings was pumped into the frac casing, causing the casing to open. This created a controlled vertical fracture directed by pore pressure relief to adjoining frac casings. The gel and iron filings were pumped from the casing and fractures were propagated as a result of the pumping and pore pressure relief. Within two to three hours, the gel was reduced by the enzyme to harmless water and sugars, and the permeable wall of iron filings was left behind.

Exhibit 5. Layout of PRB Alignment Off Base at Former Kelly Air Force Base

Exhibit 6. Layout of PRB Construction Equipment— Instrumentation Trailer and Pumping Unit

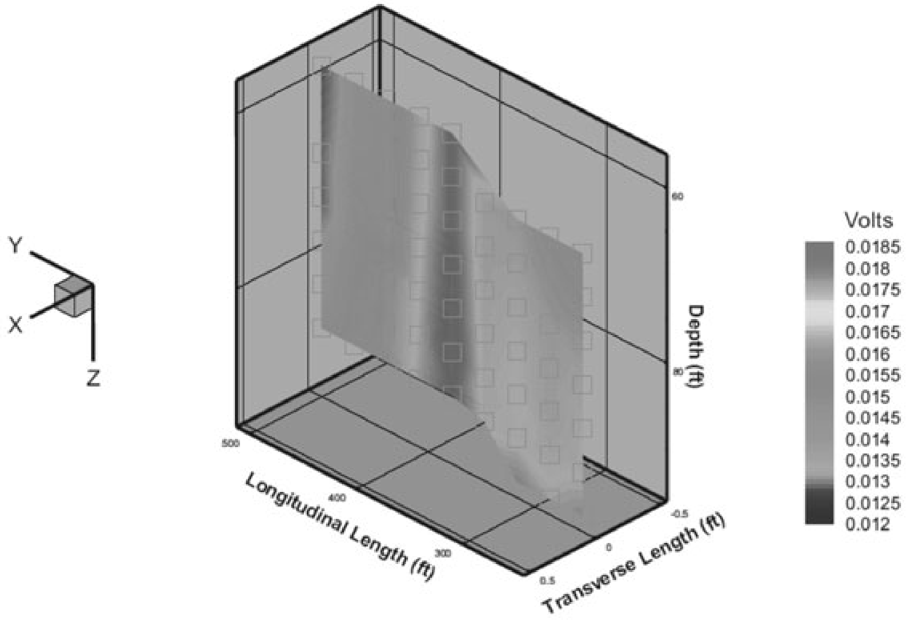
The location of the PRB segments (Exhibit 4) required a great deal of coordination with local city government officials and the control and management of traffic as described previously. The construction of the PRB included the installation of 188 frac wells, 60 resistivity receivers, ten monitoring wells, and the injection of approximately 510 tons of iron into the subsurface. All of the iron (510 tons) had to be transported to the PRB construction site in 3,000-pound hoppers, and the gel (150,000 gallons) had to be transported in 700-gallon tanks by flatbed trucks from the site staging area four miles away. This required drivers with commercial drivers' licenses (CDLs) to transport the materials.

Because the project activities had to be completed within the COSA ROW, close coordination was a crucial aspect of successful project execution. The project was executed successfully due to close coordination between the PRB construction team, the technical project manager at AFRPA, the Community Response (CR) team at the AFRPA, and COSA officials in the ROW Division.

PRB CONSTRUCTION QUALITY ASSURANCE

The geometry of the PRB was imaged in real time from the 60 subsurface resistivity receivers. Using an inverse active resistivity imaging method, the resistivity receivers produced an image that enabled verification that the PRB extended continuously over its planned length and depth intervals. The gel and iron filings mixture was excited with a low voltage charge during injection, which resulted in the emission of a 100 Hertz (Hz) signal. This signal was detected by downhole receivers and transmitted to a computer system in the instru-

Exhibit 7. Sample Resistivity Profile Generated in Real Time during Iron Injection

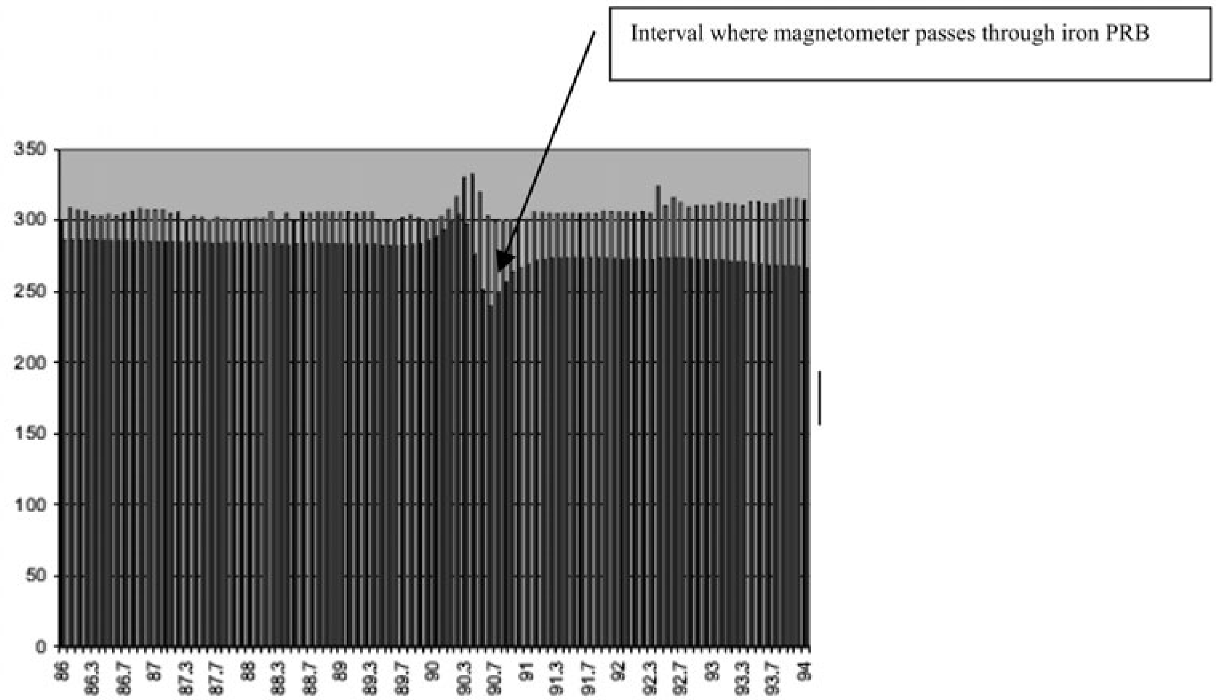


mentation trailer, where the injection was displayed in a three-dimension graphic format similar to the hypothetical sample in **Exhibit 7**.

Hydraulic pulse interference tests were conducted across the PRB alignment prior to and following PRB construction. The pulse tests were used to quantify hydraulic conductivity of the soils and to validate the hydraulic effectiveness of the PRB (i.e., to demonstrate the PRB is more permeable than site soils). The groundwater monitoring wells installed as part of the project served as both PRB performance groundwater monitoring wells and construction monitoring hydraulic pulse interference test wells. The hydraulic pulse interference test source wells were pulsed and the hydraulic pressure response recorded on the other side of the barrier in downgradient groundwater monitoring wells. From the responses of these monitored pressure pulses, the extent of the hydraulic effectiveness of the barrier was quantified. PRB thickness verification measurements are scheduled to be conducted by inclined profiling (30°) from the vertical inclination in the near future to verify the installed thickness is as designed. **Exhibit 8** shows a representative inclined profile from another site where an inclined-driven magnetometer was used to measure the magnetic flux between the native soils and the iron PRB.

Ten groundwater monitoring wells were installed, five upgradient and five downgradient. The groundwater monitoring wells were sampled prior to PRB construction and will be sampled periodically for a full range of VOCs, metals, and inorganics.

Exhibit 8. Sample Inclined Profiling Test Data



Note: Magnetometer readings while placing the probe from 86 feet to 94 feet bgs; inclination: 30º

COORDINATION WITH THE LOCAL COMMUNITY

The AFRPA Community Involvement (CI) team worked extensively in the local community during the year prior to the beginning of the project, informing residents of the pending PRB construction (**Exhibit 9**). These efforts included:

- sending informational letters to residents within a four-block radius of the project site;
- participation in fairs and parent-staff meetings at the local elementary school to keep local residents informed about the project;
- preparation of a letter on the current status of the project for distribution to all students, parents, and staff;
- preparation of PRB project fact sheets in both English and Spanish for distribution by the project team to residents inquiring about the nature of the project; and
- preparation of signs in English and Spanish for use at the worksite.

CONCLUSION

The capability of an iron PRB to reduce high levels of VOC contamination in groundwater coupled with its long-term cost effectiveness

Exhibit 9. AFRPA Worksite Sign

were primary reasons for the selection of the iron PRB as a treatment remedy at the former Kelly AFB off-base areas. The ACHVF method was selected as the installation method due to the limited workspace available and the existence of numerous underground and overhead utilities. PRB installation activities had minimal impact on the local community. School buses and city transportation progressed as normal, with minimal changes in routes. Area businesses were not forced to close operations during PRB construction, and the site was maintained at all times in a safe condition, with zero accidents or incidents. The project involved the coordination and management of a myriad of complexities. Projects of this nature with site constraints and access issues require extensive coordination among city officials, the local residential and business community along the project work site, and effective communication among all parties to achieve project success. Risk management of utility issues; realistic budgeting; effective project planning upfront; ongoing communication, and working in close coordination, with COSA and AFRPA officials; and extensive CI outreach with the local community are key factors that enabled this project to be completed successfully and to progress in a timely manner. ❖

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