Cost and Performance Report

Permeable Reactive Barriers Interim Summary Report:
Permeable Reactive Barriers
Using Injection and Other Emerging Technologies

May 2002

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

Introduction

The report provides an interim summary of 16 projects (six full-scale and ten pilot-scale) using permeable reactive barriers (PRBs) constructed using injection or another emerging technology for the treatment of contaminated groundwater. Contaminants are removed from the groundwater flow system by physical, biological, or chemical processes (EPA, 2002a).

Table 1 summarizes available information about the 16 projects, including year of installation, specific contaminants treated, PRB configuration and wall dimensions, installation method, installation depth, reactive media used, and cost data. Each of the PRBs was installed between 1995 and 2002.

Information on 14 projects was obtained from *Installation Profiles* published by the Remediation Technologies Development Forum[1] (RTDF) and which are available online at <www.rtdf.org>. Information about the Tacony Warehouse PRB was obtained from the Federal Remediation Technologies Roundtable (FRTR) <www.frtr.gov>. Information about the PRB installed at the Arrowhead Associates Former Metal Plating Operation was provided by the U.S. Environmental Protection Agency (EPA) Region 3 Remedial Project Manager for the site. The 16 projects are:

Full-Scale Projects

- Caldwell Trucking – *Northern New Jersey*
- Former Dry Cleaning Facility – *Westphalia, Germany*
- Former Industrial Site – *Brunn Am Gebirge*, *Austria*
- Arrowhead Associates Former Metal Plating Operation Superfund Site – *Montross, Virginia*
- Marzone Inc./Chevron Chemical Company – *Tifton, Georgia*
- Tacony Warehouse – *Philadelphia, Pennsylvania*

Pilot-Scale or Demonstration Projects

- 100D Area, Hanford Site – *Hanford, Washington*
- Cape Canaveral Air Force Station – *Cape Canaveral, Florida*
- Launch Complex 34, Cape Canaveral Air Force Station – *Cape Canaveral, Florida*
- DuPont – *Oakley, California*
- DuPont – *Kinston, North Carolina*
- Industrial Site – *Belfast, Northern Ireland*
- Massachusetts Military Reservation (MMR) CS-10 Plume – *Falmouth, Massachusetts*
- SAFIRA Test Site – *Bitterfeld, Germany*
- Savannah River Site TNX Area – *Aiken, South Carolina*

[1] The RTDF has an ongoing effort to track PRB projects in the field and to periodically update information about those projects. When the case study was prepared, RTDF had published *Installation Profiles* for 47 PRB projects. The RTDF selects PRB projects for its web site based on availability of information, and includes mostly sites that have been in the field for relatively longer periods of time, as well as sites with relatively greater amounts of information. While not a representative sample of sites, the projects tracked by the RTDF provide a cross-section of the general types of projects in which PRBs had been installed. In addition, the RTDF is performing a longer-term review of project performance, and the data available for the case study is a snapshot of data available to date.

- X-625 Groundwater Treatment Facility, Portsmouth Gaseous Diffusion Plant – *Piketon, Ohio*

Summary of PRB Projects Using Injection and Other Emerging Technologies

Contaminants Treated

Thirteen of the 16 PRB projects were used to treat groundwater contaminated primarily with chlorinated volatile organic compounds (VOCs), including tetrachloroethene (PCE), trichloroethlene (TCE), dichloroethlene (DCE), methylene chloride, vinyl chloride (VC), carbon tetrachloride, and chloroform. The other three sites (Arrowhead Associates, Marzone Inc., and the 100D Area) treated hexavalent chromium, pesticides, cyanide, heavy metals, and other VOCs. The Marzone Inc. site used activated carbon to treat pesticides and other VOCs, including alpha-hexachlorobenzene (BHC), beta-BHC, 1,1-dichloro-2,2-bis(p-chlorophenyl) ethane (DDD), dichlorodiphenyltrichloroethane (DDT), lindane, methyl parathion, ethylbenzene, and xylene.

PRB Configuration

Of the 16 sites, nine employed a reactive wall configuration, six used reaction vessels, and one was configured with a funnel and gate. The reactive wall configuration was intended to intercept and treat the flow of contaminated groundwater without affecting groundwater flow. In the reaction vessel configuration, groundwater was routed through natural or engineered preferential pathways to a reaction vessel. Water flow through a reaction vessel was designed to be perpendicular to groundwater flow, rather than parallel to the flow, which is characteristic of a continuous reactive wall configuration. For example, the Industrial Site in Belfast used a circular *in situ* reaction vessel filled with iron, installed at a depth of 40 feet below ground surface (bgs). Two 100-foot bentonite cement slurry walls were installed in the subsurface to direct water into the reaction vessel. A schematic of the reactive vessel configuration used at the Tacony Warehouse site is illustrated in Figure 1. The funnel and gate PRB configuration was designed to capture groundwater over a large area and direct it to a smaller reactive zone.

PRB Installation Method

All 16 of the sites described in the report, used some form of injection or other emerging technology to install the PRB. The construction technologies used to install the PRBs include the following technologies: caisson auger, deep soil mixing, horizontal wells, hydraulic fracturing, injection, jetting, large diameter vertical shafts, Mandrel H-beam, and vibrated I-beam.

Hydraulic fracturing (hydrofracturing), used at four sites, is a process where a tool referred to as a “frac tool” is driven into the ground and initiates a fracture process in the subsurface material. The tool is placed to the desired depth through a borehole and the interval for fracturing is isolated. A fine-grained iron then is suspended in biodegradable slurry and pumped under low pressure into the formation. That fracturing fluid causes the soil to separate, creating an iron treatment zone several inches in width. Several fractures propagated from boreholes located along the line of installation coalesce to create a continuous PRB resembling a thin vertical plane of iron. Parallel fractures can be installed to increase the flow-through thickness of the iron. Hydrofracturing was used at the Caldwell Trucking site to install two continuous treatment walls that ranged in depth from 15 feet to 50 feet below ground surface (bgs). The process also was used at one other full-scale PRB and two pilot scale PRBs.

Jetting was used at both the Former Industrial Site in Brunn Am Gebirge, Austria, and the DuPont site in Kinston, North Carolina. The process involved installation of an iron reactive zone using high pressures to jet a finer-grained iron into the natural aquifer formation. A jetting tool was advanced into the formation to the desired depth. Iron then was suspended in biodegradable slurry and injected from nozzles as the jetting tool was withdrawn.

Figure 2 is a schematic of the Savannah River site PRB that was installed using horizontal wells. The installation wells are not shown in this figure.

PRB Installation Depth

The 16 PRBs were constructed to maximum depths ranging from 15 feet bgs at the DuPont Kingston site to 120 feet bgs at the MMR CS-10 site. At the X-625 site, the bedrock was located between 32 feet and 40 feet bgs. A treatment area was constructed 3 feet to 5 feet below the contact between the aquifer and the bedrock. The groundwater, upon entering the subsurface treatment area, flowed through a series of canisters filled with iron. At the Caldwell Trucking site, the water table is located between 5 feet and 15 feet bgs; the barrier system begins at approximately 15 feet bgs. The PRB installed at the Launch Complex 34 site at Cape Canaveral consisted of 11 overlapping columns of iron mixed into the soil at a depth of approximately 40 feet bgs and keyed into a clay layer at that depth.

Reactive Media Used

Iron is the most common reactive media used in PRB installations (U.S. Air Force Research Laboratory, 2000) Iron can be used alone, as it was at four of the 16 sites profiled, or mixed with a biodegradable slurry, such as guar gel, when being injected into the subsurface, as was done at six of the sites. Iron also can be combined with native soil and gravel, as was done when using the deep soil mixing technique performed at one of the sites. Activated carbon was used as a reactive media at two sites, sodium dithionite at one site, and hydrogen-activated systems at one site. The Westphalia Site used a combination of reactive media: iron mixed with gravel, as well as iron sponge that was comprised of wood shavings or wood chips impregnated with hydrated iron oxide. At most of the sites using hydrofracturing, guar gum was mixed with the iron prior to injection of the reactive media to facilitate the iron filling the fractures. At the SAFIRA Test site, *in situ* hydrogen activation systems were used in a pilot study, with and without palladium catalyst. At that site, groundwater was collected from vertical well shafts and piped through 20 reactors with varied materials.

Project Performance

Table 2 summarizes the performance data provided for the six full-scale PRBs. At the six sites, the PRBs reduced individual contaminant concentrations that had ranged from 0.8 micrograms per liter (µg/L) to 94,000,000 µg/L to as low as non-detect levels to 340 µg/L. Information on the longevity of the six PRBs included in the report was not available. Two of the PRBs (Marzone and Tacony) had met or were meeting cleanup goals and one had not met its the cleanup goals. The Caldwell Trucking profile did not provide the site-specific cleanup goals, only stated that they had not been met. For the remaining three full-scale projects, cleanup goals were not established or performance data not provided. Quantitative information about cleanup goals was not provided for all sites.

Table 2

Permeable Reactive Barriers Using Injection or Other Emerging Technologies Summary of Project Performance

Summary of Project Performance						
Project	**Contaminant**	**Influent Concentration (µg/L)**	**Effluent Concentration (µg/L)**	**Cleanup Goal (µg/L)**	**Reported % Reduction**	**Calculated % Reduction**
Full-Scale Projects						
Caldwell Trucking	TCE	8,000	50	NP	NP	94%
Former Dry Cleaning Facility	PCE	20,000	33	NP	NP	99%
	1,2-DCE	500	NP	NP	NP	NP
Former Industrial Site	Polycyclic Aromatic Hydrocarbons	8,600	NP	NP	NP	NP
	Phenols	340	NP	NP	NP	NP
	BTEX	79,000	NP	NP	NP	NP
	Hydrocarbons	6,600	NP	NP	NP	NP
	TCE	0.8	NP	NP	NP	NP
	cis-DCE	27	NP	NP	NP	NP
Former Metal Plating Facility	Cyanides	NP	NP	NP	NP	NP
	Heavy metals	NP	NP	NP	NP	NP
	VOCs	NP	NP	NP	NP	NP
Marzone Inc./Chevron Chemical Company	BHC	60,000	ND	0.03	NP	99%
	beta-BHC	98,500	ND	0.1	NP	99%
	DDD	7,600	ND	0.77	NP	99%
	DDT	9,300	ND	0.54	NP	99%
	Xylene	94,000,000	ND	10,000	NP	99%
	Ethylbenzene	6,100,000	ND	700	NP	99%
	Lindane	54,600	ND	.2	NP	99%
	Methyl parathion	47,000	ND	3.9	NP	99%
Tacony Warehouse	Total toxic organics	NP	2,130	NP	NP	NP
Pilot-Scale Sites						
100 D Area	Cr^{6+}	2,000	8	NP	NP	99%
Cape Canaveral Air Station	TCE	90,000	NP	NP	NP	NP
	DCE	170,000	NP	NP	NP	NP
	Vinyl chloride	7,000	NP	NP	NP	NP
Launch Complex 34	TCA	18,100	1	NP	NP	100%
	DCA	4,554	340	NP	NP	93%
	DCE	2,500	40	NP	NP	98%
	VC	180	290	NP	NP	-61%
DuPont –	CCl_4	40,000	NP	NP	NP	NP

Summary of Project Performance						
Project	**Contaminant**	**Influent Concentration (µg/L)**	**Effluent Concentration (µg/L)**	**Cleanup Goal (µg/L)**	**Reported % Reduction**	**Calculated % Reduction**
Oakley	$CHCl_3$	3,000	NP	NP	NP	NP
	Freon 11®	10,000	NP	NP	NP	NP
	Freon 113®	3,000	NP	NP	NP	NP
DuPont-Kinston	TCE	300	NP	2.8	95%	NP
Industrial Site	TCE	390,000	NP	500	99.7%	NP
	cis-1,2-DCE	NP	100	NP	99.7%	NP
Massachusetts Military Facility	PCE	300	NP	NP	NP	NP
	TCE	15	NP	NP	NP	NP

Summary of Project Performance						
Project	**Contaminant**	**Influent Concentration (µg/L)**	**Effluent Concentration (µg/L)**	**Cleanup Goal (µg/L)**	**Reported % Reduction**	**Calculated % Reduction**
SAFIRA Test Site	Benzene	NP	NP	NP	NP	NP
	MCB	NP	NP	NP	NP	NP
	o-DCB	NP	NP	NP	NP	NP
	p-DCB	NP	NP	NP	NP	NP
	TCE	NP	NP	NP	NP	NP
	cis-1,2-DCE	NP	NP	NP	NP	NP
	trans-1,2-DCE	NP	NP	NP	NP	NP
	Sulfate	1,000	NP	NP	NP	NP
	Chloride	1,300	NP	NP	NP	NP
Savannah River Site TNX Area	TCE	25	5	NP	NP	80%
	cis-DCE	50	NP	NP	NP	NP
	CT	45	NP	NP	NP	NP
	NO_3	70,000	NP	NP	NP	NP
X-625 Groundwater Treatment Facility	TCE	150	<5	NP	NP	97%

ND = Below detection levels
NP = Not provided

Project Cost

Cost information was available for 14 of the 16 projects. Data was provided about installation costs and design costs (for some projects) but not about operation and maintenance costs. For the sites that provided cost data about design, costs ranged from $30,000 to $292,000 per site. The costs to install the PRBs ranged from $130,000 to approximately $5 million per site.

Table 3 summarizes unit costs calculated for four full-scale PRB applications that provided cost information. The following table summarizes unit costs calculated using total project costs based on the length of wall constructed ($ per linear foot) and the area (length times maximum depth) of wall constructed ($ per square foot). No cost adjustments were made to normalize project costs in relation to the date when the costs were incurred or the geographic location of the project.

Table 3

Permeable Reactive Barriers Using Injection and Other Emerging Technologies
Summary of Unit Costs

Summary of Unit Costs					
Project (Installation Method)	**PRB length (feet)**	**PRB Maximum Depth[1] (feet)**	**Installation Cost (Excluding Design Cost When Provided)**	**Cost per Linear Foot ($)**	**Cost per Square Foot ($)**
Caldwell Trucking (hydraulic fracturing)	240	35	$1,120,000	$4,667	$133
Former Dry Cleaning Facility (mandrel-h-beam)	74	NP	$130,000	$1,757	Not calculated
Former Industrial Site (jetting)	720	30	$650,000	$903	$30
Marzone Inc./Chevron Chemical Company (vibrating I-beam)	400	NP	$520,000	$1,300	Not calculated

Note: [1] Average depth not provided

Based on the available cost data, no clear trends in unit costs based on length or depth of the PRBs are evident. Table 4 summarizes the matrix characteristics and operating parameters for the 16 projects that may have affected cost and performance for the PRB applications.

Table 4

Permeable Reactive Barriers Using Injection and Other Emerging Technologies
Operating Parameters

Operating Parameters	
Parameter	**Range of Values**
Soil Classification:	Varied
Clay Content and/or Particle Size Distribution:	Not provided
pH:	Not provided
Porosity:	Not provided
Depth Below Ground Surface or Thickness of Zone of Interest:	15 to 120 feet bgs
Total Organic Carbon:	Not provided
Presence of Nonaqueous-Phase Liquids:	Not provided
Groundwater Flow Rate:	1 gallon per minute (gpm) to 5 gpm (provided for three projects)
Type of Reactive Media:	Iron, sodium dithionite, activated carbon, hydrogen-activated systems

Lessons Learned Related to PRBs Using Injection and Other Emerging Technologies

The following is a summary of lessons learned from the 16 projects included in the report.

PRB Configuration

- The funnel and gate system was chosen for the Marzone Inc. site because it created a smaller impact on the surrounding community; however, subsequent to installation, flushing of the system was required every three to four weeks to maintain groundwater flow. The flow improved after gas vents were added to the system (which allowed gas pockets that were forming in the system to be released to the ambient air), and the activated carbon vaults were changed to an upflow configuration.

PRB Installation Method

- Guar gum gel was used for the iron installation at the Caldwell Trucking site. The guar gum broke down too slowly because the low temperature and high pH at which the gel was formulated slowed the enzymatic degradation. A solution consisting of a pH buffer and additional enzymes was injected after installation, speeding up the degradation of the guar gum and allowing contaminated water exposure to the iron, thereby depleting the TCE in the system.

- At the MMR CS-10 Site, where hydraulic fracturing was used, control of the fracturing was lost when a propagating fracture came across monitoring wells that were not accurately located prior to project commencement. The *Installation Profile* for the site states that the experience indicated the importance of detailed subsurface investigation prior to installation of the PRB.

Reactive Media Used

- At the SAFIRA Test Site, a combination of treatment technologies (hydrogen-activation systems with and without palladium catalyst) was used to address the complex mixture of contaminants in the groundwater.

Project Performance

- At the X-625 site, reduction of the hydraulic conductivity caused by the precipitation of minerals in the system was noted. The *Installation Profile* for the site states that the life of the reactive media depends on the iron corrosion rates, which are influenced by the sulfate levels in the groundwater at the site. The iron corrosion renders the reactive media less effective in degrading groundwater contaminants.

- Performance of the Caldwell Trucking Site PRB was poor, likely due to the changes in groundwater flow regime resulting from the injection of granular iron into the fractured bedrock. Prior to injection, the upper bedrock at the site had large open fractures which had acted as conduits for the groundwater. When the fractures were filled with granular iron, the hydraulic conductivity of the system was lowered, limiting the amount of groundwater exposed to the PRB, and diverting a large amount of the water above and around the PRB. The flow of groundwater should be taken into consideration when applying granular iron to bedrock.

- The Former Industrial Site in Austria protected the system from oxygen entering through the groundwater in order to help avoid aerobic microbiological activity, which could cause the depletion of the reactive media (such as the activated carbon used at the site). The method of protection was not identified in the profile.

Project Cost

- At the Savannah River site, cost efficiencies were realized because the PRB system was constructed using an existing foundation and conventional well drilling techniques.

- Unit costs for the five full-scale PRB applications with cost information ranged from $903 to $4,667 per linear foot (for four sites) and from $30 to $133 per square foot (for two sites).Other matrix characteristics, such as soil classification; clay content and particle size distribution; pH; porosity; depth bgs or thickness of zone of interest; total organic carbon; presence of NAPLs; groundwater flow rate; and type of reactive media, also may be direct or indirect factors in project cost.

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Analysis Preparation

The case study was prepared for EPA's Office of Solid Waste and Emergency Response Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc., under Contract No. 68-W-02-034.

Table 1

Permeable Reactive Barriers Using Injection and Other Technologies
Project Summary Information

Site Name and Location	Year Installed	Construction Methods	Configuration	Wall Dimensions (Length and Maximum Depth[1])	Reactive Media	Contaminant	Install Cost (Design Cost)
Full-Scale Projects							
Caldwell Trucking Site, Northern New Jersey	1998	Hydraulic fracturing	Wall	240 ft long, 65 ft bgs	Fe^0	TCE	$1,120,000
Former Dry Cleaning Facility, Westphalia, Germany	Not provided	Mandrel (H-beam)	Wall	74 ft long, depth not provided	Fe^0 and iron sponge	PCE, DCE	$130,000 ($30,000)
Former Industrial Site, Brunn am Gebirge, Austria	1999	Jetting	Reactive vessel	720 ft long barrier with four 9-ft diameter vessels, 30 ft bgs	Activated carbon	PAHs, phenols, hydrocarbons, BTEX, TCE, DCE	$650,000 ($100,000)
Arrowhead Associates Former Metal Plating Operation Superfund Site, Montross, Virginia	2002	Hydraulic fracturing	Wall	1,168 ft long, 42 ft deep	Fe^0	Cyanides, heavy metals, VOCs	Not provided
Marzone Inc./Chevron Chemical Company, Tifton, Georgia	1998	Vibrating I-beam	Funnel and gate	400 ft long, depth not provided	Activated carbon	BHC, DDD, DDT, lindane, methyl parathion, xylene, ethylbenzene,	$520,000 ($230,000)
Tacony Warehouse, Philadelphia, Pennsylvania	2000	Caisson auger	Reactive vessel	4 ft diameter, unspecified depth	Fe^0	PCE, TCE, DCE, DCA, VC	$607,000

[1]Average Depth Not Available
May 24, 2002 exchange rate - $1 U.S. = DM 2.128215

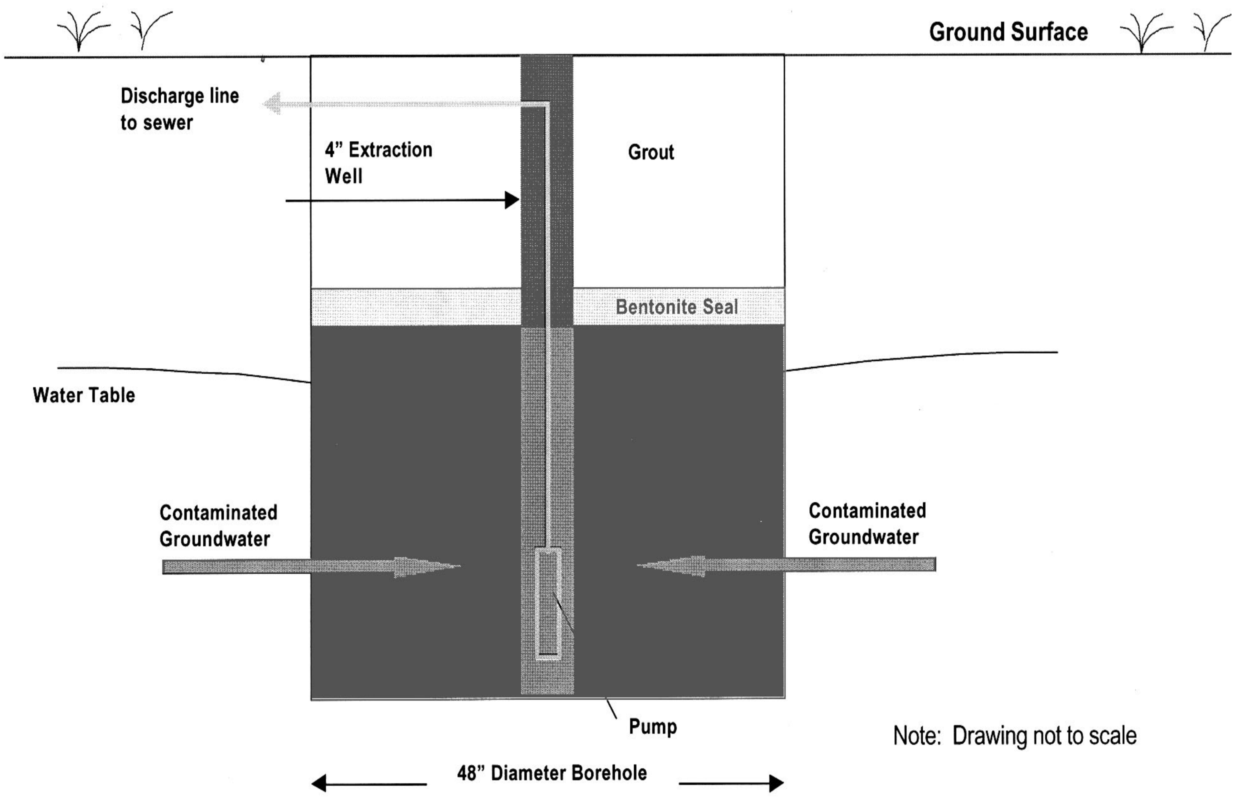
Site Name and Location	Year Installed	Construction Methods	Configuration	Wall Dimensions (Length and Maximum Depth[1])	Reactive Media	Contaminant	Install Cost (Design Cost)
Pilot-Scale and Demonstration Projects							
100D Area, Hanford Site, Hanford, Washington	1997	Injection	Wall	150 ft long, 100 ft bgs	Sodium dithionite	Cr^{6+}	$480,000
Cape Canaveral Air Force Station, Cape Canaveral, Florida	Not provided	Vibrated I-beam and jetting	Wall	Two walls, 70 ft long each, 45 ft bgs	Fe^0	TCE, DCE, VC	$809,000 ($292,000)
Launch Complex 34, Cape Canaveral Air Force Station, Cape Canaveral, Florida	1999	Deep soil mixing	Wall	Approximately 40 ft long, 40 ft bgs	Fe^0 and gravel	TCE, DCE	$220,000
DuPont, Oakley, California	Not provided	Hydraulic fracturing	Wall	110 ft long, 120 ft bgs	Fe^0 (granular cast iron)	CT, chloroform, Freon	$1,000,000 ($150,000)
DuPont, Kinston, North Carolina	1999	Jetting	Wall	375 ft long, 15 ft bgs	Granular Fe^0	TCE	$200,000
Industrial Site, Belfast, Northern Ireland	1995	Not provided	Reactive vessel	Two 100 ft long funnel walls, 16 ft bgs	Fe^0	TCE, DCE	$375,000
Massachusetts Military Reservation CS-10 Plume, Falmouth, Massachusetts	1998	Hydraulic fracturing	Wall	Two walls, 48 ft long each, 120 ft bgs	Fe^0	PCE, TCE	$160,000
SAFIRA Test Site, Bitterfeld, Germany	1999	Large diameter shafts	Reactive vessel	75 ft bgs, multiple 10 ft diameter shafts	Hydrogen-activation systems	Benzene, MCB, DCB, TCE, DCE	11 mill DM (about $5 million) [2]

Site Name and Location	Year Installed	Construction Methods	Configuration	Wall Dimensions (Length and Maximum Depth[1])	Reactive Media	Contaminant	Install Cost (Design Cost)
Savannah River Site, TNX Area, Aiken, South Carolina	1997	Not provided	Reactive vessel	Not provided	Fe^0	TCE, DCE, CT, Nitrate	$119,000
X-625 Groundwater Treatment Facility, Portsmouth Gaseous Diffusion Plant, Piketon Ohio	1996	Horizontal wells	Reactive vessel	500 ft long, 30 ft bgs	Fe^0	TCE	Not provided

[1]Average Depth Not Available
May 24, 2002 exchange rate - $1 U.S. = DM 2.128215

Figure 1

Tacony Warehouse Treatment Cell – Example of Reactive Vessel Configuration

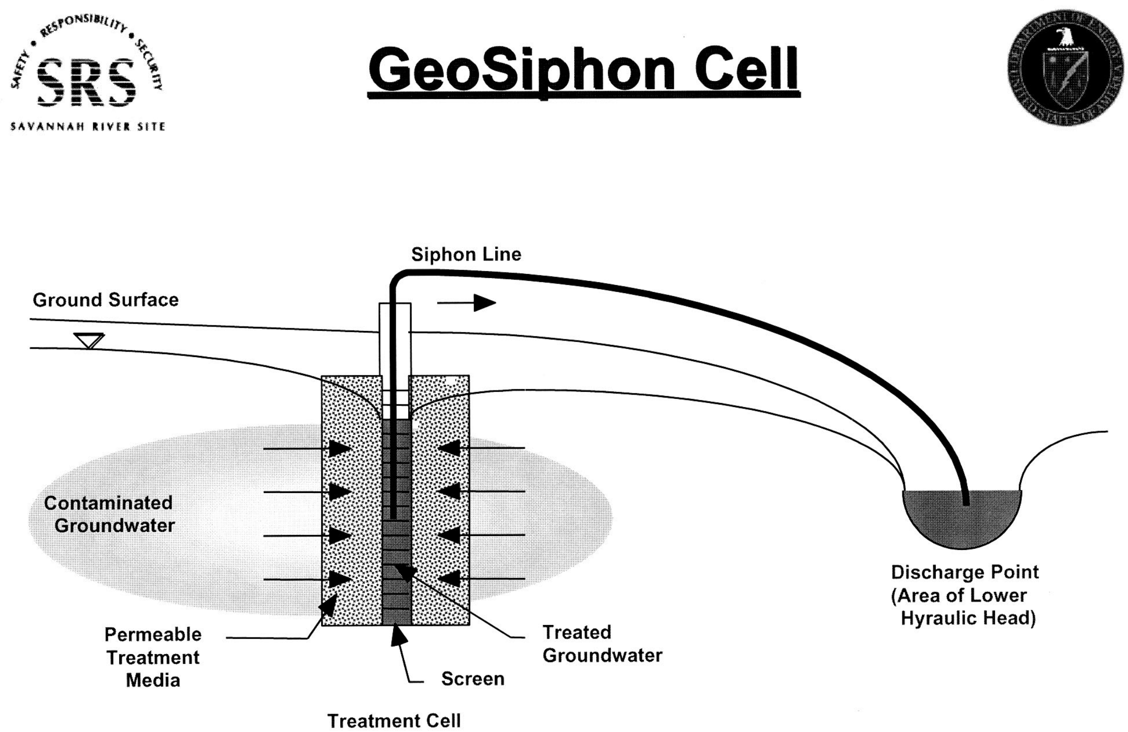


Note 2: 48" diameter borehole filled with zero-valent iron.

Source: FRTR

Figure 2

Savannah River Site- Example of Geo-Siphon Reaction Vessel



Source: RTDF

Permeable Reactive Barrier Project Profile:
Caldwell Trucking, Northern New Jersey, NJ

Installation Year: 1998
Contaminants: TCE
Reactive Media: Fe^0
Cost: $1,120,000
Construction: Hydraulic Fracturing, Permeation Infilling
Point of Contact:
John Vidumsky
DuPont Specialty Chemicals
Barley Mill Plaza, 27/2226
Lancaster Pike and Route 1
Wilmington, Delaware 19805
Telephone: (302) 892-1738
Facsimile: (302) 892-7641
Email: john.e.vidumsky@usa.dupont.com

A full-scale permeable reactive barrier (PRB) system was installed at Operating Unit (OU) 2 of the Caldwell Trucking Superfund Site in northern New Jersey in 1998. The PRB is located approximately 3,000 feet downgradient of the source area, and immediately upgradient of a "seep" where groundwater discharges to surface water. The barrier is designed to reduce initial trichloroethylene (TCE) concentrations of 6,000 µg/L to 8,000 µg/L in the groundwater to below 50 µg/L prior to discharge to surface water.

The Caldwell Trucking site encompasses 11 acres near the Passaic River that were used for disposal of septic wastes in unlined ponds from the 1950s to 1984 and industrial waste containing lead and TCE. The site contains areas of glacial deposition overlying basalt flows with an average conductivity of approximately 0.1 in/sec. Groundwater flow occurs in a 25-foot deep sand and gravel aquifer confined below an impermeable clay layer at an average elevation of 160 feet above mean sea level. The water table is located approximately 5 feet to 15 feet below ground surface. A fractured basalt zone is located below the sand/gravel aquifer at 100 feet to 125 feet above mean sea level. Approximately half of the groundwater flow is in the sand and gravel unit, and half in the upper fractured basalt. Water from both units discharges through the "seep". Studies indicated that the rate of natural attenuation occurring at this site is 3,000 kg/yr.

The PRB system was installed in unconsolidated sands and a fractured basalt zone using a combination of hydraulic fracturing (in the unconsolidated formation) and permeation infilling (in the fractured basalt). The barrier system is 50 feet deep, beginning about 15 feet below ground. The system consists of two 3-inch walls, 150 feet and 90 feet in length and uses 250 tons of zero-valent iron (Fe^0) as the reactive material. Construction of the PRB system involved hydraulic fracturing of the upper sand/gravel zone, using 15 hydrofrac/infilling wells at 15 feet intervals, and permeation infilling of the lower sedimentary zone (pumping a gel containing the Fe^0 down a well into the fractured bedrock through an open borehole). Total installation cost of the PRB system (both walls) at this site is estimated at $1,120,000: $670,000 for the 90-foot (hydrofracing) wall and $450,000 for the 150-foot (permeation infilling) wall. This includes the cost of design, construction, materials, and the reactive material.

Monitoring wells and surface waters have been sampled at least monthly for volatiles and metals, and other parameters have been measured. To date, the barrier has achieved only 50% degradation of TCE in the groundwater, from an upgradient concentration of 7,000 µg/L to a downgradient concentration of less than 3,500 µg/L. The PRB is clearly not achieving the performance for which it was designed. Other remedial measures are currently being pursued.

Lessons Learned

The poor performance of PRB is believed to be due to changes in the groundwater flow regime resulting from the injection of granular iron into the fractured bedrock. current theory is that the upper bedrock contains relatively large open fractures that acted as major conduits to groundwater flow. The hydraulic conductivity of these fractures was reduced by the infilling with granular iron. This reduction in hydraulic conductivity, coupled with the shallow gradients in the vicinity of the PRB, resulted in diversion of groundwater flow upward into the sand and gravel unit, as well as sideways around the infilled zones. These effects must be carefully considered in any application where granular iron is introduced into bedrock fractures.

Another unexpected condition was the slow breaking of the guar gum gel used for the iron installation. The low temperature and high pH at which the guar gum gel was formulated slowed its enzymatic degradation after it was in place. As a solution, a pH buffer and additional enzyme were injected. Guar breakdown then occurred and TCE reductions were observed. Otherwise, the gel has not interfered with the barrier's permeability nor impacted the iron's reactivity.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile

Former Dry-Cleaning Site, Rheine, Westphalia, Germany

Installation Year: Not provided
Contaminants: PCE; 1,2-DCE
Reactive Media: Fe^0, iron sponge
Cost: $160,000
Construction: Continuous Wall
Point of Contact: Dr. Martin Wegner
Mull & Partner
Ingenieurgessellschaft mbH
Osteriede 5
30827 Garbsen Germany
Telephone: 49-5131-4694-55
Fax: 49-5131-4694-90
Email: Wegner@mullundpartner.de

A full-scale permeable reactive barrier (PRB) was installed at a former dry-cleaning site in an urban area in Rheine, Westphalia in Germany. The mandrel construction method was chosen because it was determined to be easier and less expensive than continuous sheet piling construction. Perchloroethylene (PCE) and 1,2-dichloroethylene (1,2-DCE) are the primary contaminants of concern at the site. Initial maximum concentrations in the plume were 20,000 µg/L for PCE and 500 µg/L for 1,2-DCE. The plume is 1,640 feet long and 820 feet wide. The distance from the center of contamination to the treatment wall is about 1,300 feet.

The plume is present in a loamy sand aquifer that extends 16 feet to 33 feet below grade. The water table is about 10 feet below the ground surface. The hydraulic conductivity varies between about 0.3 and 2.8 feet/day.

The PRB is a continuous reactive wall that varies between 2 and 3 feet wide and is 74 feet long. The PRB was constructed by drilling a line of overlapping 3-foot diameter boreholes which were filled with reactive material to groundwater level, and with clean soil to ground surface level. The PRB uses two reactive media: 69 tons of granular zero-valent iron mixed with gravel at a 1:2 volume ratio (34.5 tons each of zero-valent iron and gravel) in 33 feet of the wall and 85 tons of iron sponge in 41 feet of the wall. A concrete-filled borehole separates the two segments. (Iron sponge consists of wood shavings or wood chips impregnated with hydrated iron oxide. It is used for removal of hydrogen sulfide in oil and gas processing operations.)

Design costs were $30,000. Installation costs including construction and reactive material totaled $93,000. An additional $13,000 was spent on monitoring and $24,000 on the installation of gas measurement devices.

This is the first continuous treatment wall in Germany and was built as a research project with no specific target cleanup concentrations. However, the PRB has resulted in significant reduction in the concentration of contaminants—especially PCE. The effluent concentration of PCE from the granular iron section of the wall is 33 µg/L (from 17,000 µg/L in the affluent) and 400 µg/L from the iron sponge section of the wall (from 14,500 µg/L in the affluent). There has been only a low level of metabolite production. No vinyl chloride was observed in the affluent or effluent of the PRB. There was measurable production of hydrogen only at the very beginning of the

remediation process—simultaneous with a complete reduction of nitrogen to ammonia. Groundwater samples are being collected monthly.
Due to increasing microbial activity at the site of the PRB, hydrogen emission is decreasing. Nitrate now is reduced to nitrogen or di-nitrogen oxide. The sulfate effluent concentration is decreasing due to the sulfate reduction to sulphured hydrogen.

The concentration of dissolved iron and manganese in the reactive barrier and the effluent remain below 0.3 to 0.1 mg/L (i.e., below the affluent concentrations).

No significant changes in the degradation efficiency of the in *situ* reactor have so far been detected. The next steps involve observing whether the precipitation of the various mineral phases within the reaction zone affects the degradation efficiency, and whether there are differences with respect to the media used. Solid phase samples will therefore be removed from the barrier in the forthcoming phase of the in *situ* test to investigate the surface properties of the iron materials. Characterization of the established microorganisms is also planned.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project. A schematic diagram of the PRB and a photograph of the installation are available through a link in the online installation profile.

Permeable Reactive Barrier Project Profile:
Former Industrial Site, Brunn am Gebirge, Austria

Installation Year: 1999
Contaminants: PAH, Phenoles, BTEX, hc, TCE, cDCE
Reactive Media: Activated Carbon
Cost: $750,000
Construction: Adsorptive Reactors with Hydraulic Barrier
Point of Contact: Peter Niederbacher
Engineering Consultant for Technical Geology
Weidlinger Strasse 14/3
A 3400 Klosterneuburg
Austria, Austria
Telephone: 43-2243-22844
Facsimile: 43-2243-22843
Email: niederbacher@geol.at

A full-scale permeable reactive barrier (PRB) system was installed at the site of a former tar plant and linoleum production plant in Brunn am Gebirge, Austria in 1999. The system of adsorptive reactors combined with a hydraulic barrier was designed to adapt to the landscaping and architecture of a business park, fit into the local environment, be operational within a restricted time frame, and cost far less than excavation and disposal. Polynuclear aromatic hydrocarbons (PAH); phenols; benzene, toluene, ethylbenzene, xylene (BTEX); hydrocarbons (HC); tricholoroethylene (TCE); and cis-dichloroethylene (cDCE) are the contaminants of concern at the site. Investigation indicated contamination of the unsaturated and saturated zone with maximum concentrations of 8.6 mg/L for PAH, 0.34 mg/L for phenoles, 29 µg/L for benzene, 50 µg/L for toluene, 6.6 mg/L for HC, 0.8 µg/L for TCE, and 27 µg/L for cDCE. The total area involved is greater than 376,600 feet^2.

The site is located near the western edge of the southern Vienna Basin, a pull apart Alpine structure filled with tertiary sediments. The general profile shows 0 to 7 feet of anthropogenic deposits on top and alluvial sediments (sandy silty gravel) 10 feet to 20 feet thick. These sediments are underlain by shales of the mid Pannonian age with intercalations of coarser layers in which artesic water occurs. The top of the tertiary sediments shows a relief, roof-like dip from east to west, a north to south oriented erosional depression, and a rising shoulder toward the east where the confining layer reaches the surface. The groundwater table is 7 feet to 13 feet below ground surface (bgs). The base of the aquifer is 10 feet to 20 feet bgs. Tests indicated permeabilities ranging from 9.8×10^{-3} to 3.3×10^{-5} ft/sec. The natural groundwater flow is west to east with a bend to the southeast, following the erosional depression. This causes a migration of contaminants outside of the property's boundary.

In order to accommodate a groundwater pond planned at 5 feet below the actual groundwater level and avoid polluting the pond, a site-adapted solution was developed. It called for the installations of four adsorptive reactors filled with a total of 23 tons of activated carbon combined with a hydraulic barrier 2 feet to 5 feet thick. The west to east directed 720 feet long jet grouting barrier cuts into the shoulder of tertiary shales at its eastern edge. This forms an L-shaped barrier which keeps contaminated groundwater separated form the catchment area and the artificial pond. The adsorptive reactor units are located close to the barrier. Four wells 9 feet in diameter and 26 feet to 30 feet deep were drilled to install the filter units. The base of the wells are several meters into the confining layer. The filter units are made of cylindrical glass fiber fortified synthetic material with filter windows at the aquifer level. The activated carbon is 350 cubic feet to 420 $feet^3$ in each filter. The contaminated water enters the reactor through filter windows, passes the reactor column and is collected at the bottom of the filter cylinder. The outlet of each reactor crosses the barrier and is led to the monitoring and collection shaft. At that point, the level of draw down is controlled by changing the outlet level to the discharge system. Design costs were $100,000. Installation, including construction and materials, ran $650,000.

The system has been effective in causing a significant draw down north of the catchment area, forcing the groundwater to enter the adsorptive reactors. The groundwater flow was induced to reverse direction by 180° on the way to the filter units. The levels of contamination continue to vary depending on the highs and lows of the groundwater and probably as a result of the general draw down of the groundwater level. A uniform trend cannot be observed at this time. However, it is expected that the level of contamination will decline as a result of natural attenuation. Water samples are taken at both the intakes and discharges of the reactors and at the monitoring wells quarterly. The water level is controlled by sensors and wireless transmissions and control measurements are taken manually. An additional investigation of the long term behavior of the system is performed as part of the PEREBAR Project of the European Community.

Lessons Learned

Protecting the system from O_2 entering into the groundwater helps avoid aerobic microbiological activity. Careful selection of materials for those parts which come into contact with the groundwater and reactor material is essential.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project. A website <www.pereber.bam.de> with additional information about the site is available through a link in the online installation profile.

Permeable Reactive Barrier Project Profile:
Arrowhead Associates Former Metal Plating Operation Superfund Site, Montross, VA

Installation Year: 2002
Contaminants: Cyanides, Heavy Metals, Volatile Organic Compounds (VOCs)
Reactive Media: Fe^0 Filings
Cost: Not provided
Construction: Hydrofracturing
Point of Contact: Ron Davis
Remedial Project Manager
U.S. EPA, Region 3
1650 Arch Street
Philadelphia, Pennsylvania 19103
Telephone: (215) 814-3230
Facsimile: (215) 814-5102
Email: davis.ron@epa.gov

In 2002, a full-scale permeable reactive barrier (PRB) treatment cell was being installed at the Arrowhead Associates Former Metal Plating Operation Superfund site in Montross, Virginia to treat groundwater contaminated with cyanides, heavy metals, and volatile organic compounds (VOCs). Cleanup of this site is a cooperative effort by the Virginia Department of Environmental Quality (VDEQ) and U.S. EPA Region 3.

The former metal plating facility is located two miles southeast of the town of Montross, Virginia. The property encompasses approximately 30 acres of land in Westmoreland County, and is owned by Arrowhead Associates. The facility operated as a cosmetic case manufacturer facility from 1966-1979, when it began to be used as a cosmetic case filling facility. The PRB was selected for groundwater remediation in 1995.

The PRB is being installed by mixing iron filings with biodegradable slurry, and injecting the material into the subsurface using hydrofracturing. Hydrofracturing requires the drilling of boreholes, which are used to insert the “frac tool” into the subsurface. This tool creates a vertical notch to begin the fracture. A fracture is then induced and filled with granular iron suspended in a hydrated and cross-linked guar slurry. The propagating fracture from one frac well coalesces with the emplaced material from the adjacent well, thus forming a continuous vertical wall. The wall will be approximately 1,165 feet long, range from 15 to 42 feet deep, and be between 3 to 4.5 feet thick upon completion.

Construction of the wall was not complete as of April 10, 2002, and no performance data were available. Information on projected completion date was not provided.

Note: Information about the project was provided by the EPA Region 3 RPM in April 2002.

Permeable Reactive Barrier Project Profile:
Marzone Inc./Chevron Chemical Company, Tifton, GA

Installation Year: 1998
Contaminants: BHC, Beta-BHC, DDD, DDT, Xylene, Ethylbenzene, Lindane, And Methyl Parathion
Reactive Media: Activated carbon
Construction: Funnel and Gate
Point of Contact: Annie Godfrey
U.S. EPA Region 4
61 Forsyth Street
Atlanta, Georgia 30303
Telephone: (404) 562-8919
Fax: (404) 562-8896
Email: godfrey.annie@epa.gov

A permeable reactive barrier (PRB) was installed in August 1998 at Operable Unit 1 of the Marzone Inc., site in Tifton, GA, to remediate groundwater contaminated with pesticides and volatile organic compounds (VOCs). The Marzone facility was used as a pesticide formulation facility from 1950 until the 1980s.

A 1994 Record of Decision originally selected a pump-and-treat system to remediate the groundwater. During remedial design activities, however, it was determined that an in *situ* treatment system such as a funnel-and-gate system may be a more appropriate technology for the specific site conditions. Groundwater contaminants of concern and their initial maximum concentrations are: alpha-hexachlorobenzene (BHC) (60 mg/L); beta-BHC (98.5 mg/L); DDD (7.6 mg/L); DDT (9.3 mg/L); xylene (94,000 mg/L); ethylbenzene (6,100 mg/L); lindane (54.6 mg/L); and methyl parathion (47 mg/L).

Soils in this area consist of a mixture of sand, sandy clay, and clay. A shallow aquifer is located at a depth of 7 feet and a deeper aquifer exists at approximately 25 feet. Hydraulic conductivity is estimated at 2.9-4.6 ft/day.

The modified funnel-and-gate system comprises a 400-foot barrier wall that was installed using a vibrating beam technology. A collection trench lined with geotextile and filled with granular drain material was constructed upgradient of and parallel to the barrier wall. Groundwater collected in this trench moves by way of a slotted well screen and associated piping into treatment vaults containing approximately 1,800 pounds of activated carbon located between the collection trench and barrier wall. From the treatment vaults, groundwater moves slowly (1-2 gal/min) by way of piping through the barrier wall and into a distribution trench of similar construction as the collection trench but running perpendicular to the barrier wall.

Design costs for the Marzone PRB system were $230,000. Installation costs, including construction, materials, and reactive material, are estimated at $520,000.

Cleanup goals for the contaminants of concern are: 0.00003 mg/L for alpha-BHC, 0.0001 mg/L for beta-BHC, 0.00077 mg/L for DDD, 0.00054 mg/L for DDT, 10 mg/L for xylene, 0.7 mg/L for ethylbenzene, 0.0002 mg/L for lindane, and 0.0039 mg/L for methyl parathion. Sampling of the treatment vault effluent is conducted on a monthly basis. Contaminant concentrations in the effluent have been below detection levels.

Lessons Learned

The funnel-and-gate system was selected for use because if offered less impact to the surrounding community than other treatment technologies, while being partially self-operational. Immediately after construction, flushing of the system was required every 3-4 weeks in order to maintain flow. Improvements were made to the system to allow venting of gas pockets, which were forming in the system. The activated carbon vaults were also changed to an upflow configuration. Since these improvements were made, the system has been operating effectively.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile:
Tacony Warehouse, Philadelphia, PA

Installation Year: 2000
Contaminants: Tetrachloroethene (PCE); Trichloroethene (TCE), cis 1,2- and trans-1,2-Dichloroethene (DCE); Vinyl Chloride
Reactive Media: Iron filings
Cost: $607,300
Construction: Subsurface Permeable Treatment Cell
Point of Contact: Mark Stephens
Remedial Project Manager
U.S. EPA, Region 3
1650 Arch Street
Philadelphia, Pennsylvania 19103
Telephone: (215) 814-3353
Facsimile: (215) 814-5102
Email: stephens.mark@epa.gov

In 2000, a full-scale permeable reactive barrier (PRB) treatment cell was installed at the Tacony Warehouse in Philadelphia, Pennsylvania, to treat groundwater contaminated with tetrachloroethene (PCE); trichloroethene (TCE); cis 1,2- and trans-1,2-dichloroethene (DCE); and vinyl chloride (VC). This site is a Superfund remedial site that is a cooperative effort by the U.S. Department of Defense and U.S. EPA Region 3.

The Tacony Warehouse is located on 14.2 acres of land adjacent to the Delaware River in northeast Philadelphia. The area was used for multiple purposes including vehicle maintenance, a boiler building, a steam plant, underground storage tanks, transformer substations, and as a pesticides building. The facility was in operation from 1943 until 1992. The source of chlorinated solvents in the groundwater at the site is unknown.

The subsurface geology consists of alluvium deposits directly overlying crystalline bedrock. The soil consists of mainly coarse sand and gravel interbedded with clay, silt, and fine sand. The depth to bedrock is approximately 35 feet bgs. The aquifer is highly stratified with units of varying lithology and hydraulic conductivity. Groundwater was encountered between 8 and 16 feet bgs.

The remedy selected for this site was groundwater extraction using three extraction wells. One of these wells was the Tacony Treatment Cell (TTC). The TTC is a four-foot diameter well backfilled with iron filings around a four-inch extraction well. Groundwater is extracted from the surrounding aquifer into the treatment cell where reductive dehalogenation reactions occur while the water is in contact with the iron filings. Water is then discharged from the system and to the storm sewer.

The system began operation in 1998, and the cleanup goals were 5 µg/L each for PCE; TCE; 1,1-DCE; cis-1,2,-DCE; trans-1,2-DCE; and 1,1-DCA. The cleanup goal for VC was 10 µg/L. The discharge from the groundwater extraction system to the City of Philadelphia sanitary sewer is subject to permit conditions, with a concentration limit of 2.13 mg/L total toxic organic compounds.

As of June 1999, the concentrations in MW-9, the monitoring well immediately upgradient of the TTC, were as follows: PCE at 750 µg/L; TCE at 230 µg/L; cis-1, 2-DCE at 2,800 µg/L; and 1,1-

DCE; trans 1,2-DCE; 1,1-DCA; and VC were below detection levels. The combined discharge from the extraction wells met the discharge limit, however, individual wells did not meet the cleanup goals, and the system was continuing operation.

Note: Information about the project was obtained from the Federal Remediation Technologies Roundtable <www.frtr.gov>.

Permeable Reactive Barrier Project Profile:
100 D Area, Hanford Site, WA

Installation Year: 1997
Contaminants: Cr^{6+}
Reactive Media: Sodium dithionite
Construction: Injection
Point of Contact: Jonathan S. Fruchter
Batelle Pacific Northwest National Laboratory
P.O. Box 999 (K6-96)
Richland, Washington 99352
Telephone: (509) 376-3937
Facsimile: (509) 372-1704
Email: john.fruchter@pnl.gov

A large-scale treatability test of an in *situ* Redox Manipulation (ISRM) method was conducted successfully at the 100D Area of the U.S. Department of Energy (DOE) Hanford Site in Washington in 1997-1998. As a result, the technology is currently being deployed for full-scale remediation of a groundwater hexavalent chromium plume at the site.

The cost of design, construction, materials, and the reactive material is estimated to be $480,000. Cost for the 2,000 feet wall will be approximately $5,000,000. Hexavalent chromium concentrations of up to 2 mg/L have been detected within the 100D Area. Contamination resulted from the use of chromium-bearing anti-corrosion agents in onsite reactors.

The 100D Area is underlain by both glacial and fluvial sediments, predominantly sands and gravels. Hydraulic conductivity is approximately 100 ft/day. The upper surface of the contaminated aquifer is approximately 85 feet below ground surface and is approximately 15 feet thick, constrained at its lower boundary by an aquitard.

ISRM involves injection of a chemical reducing agent in the contaminant plume downgradient from the source area. This agent alters the chemical redox potential of aquifer fluids and sediments. Redox-sensitive metals migrating through the treatment zone are immobilized. The treatability test at Hanford's 100D Area began in September 1997 and consists of injecting sodium dithionite into a series of five existing wells to a depth of 100 feet below ground surface. Treated zones for each well overlap, creating a 150 feet long barrier that is approximately 50 feet wide.

The upcoming deployment will consist of about 40 wells to form a barrier approximately 2,000 feet long.

Sodium dithionite was injected into the first of the five wells in 1997 and 1998. As a result, aqueous chromate concentrations have been reduced below 8 µg/L. After the completion of a gas tracer test studying rates of reoxygenation in the treated plume, plans called for sodium dithionite to be injected into the remaining four wells in mid-1998, followed by a bromide tracer test to determine the effect of the treatability test on groundwater flow within the aquifer. Performance monitoring is expected to continue through the end of 1999 followed by emplacement of the full-scale barrier.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project. A website <www.envnet.org> with additional information about the project is available through a link in the online installation profile.

Permeable Reactive Barrier Project Profile
Cape Canaveral Air Station, FL

Installation Year: Not provided
Contaminants: TCE, DCE, Vinyl Chloride
Reactive Media: Fe^0
Construction: Continuous Walls with Overlapping Panels
Point of Contact: Jerry Hansen
Technology Center Division
Environmental Restoration Directorate
U.S. Air Force Center for Environmental Excellence
3207 North Road
Brooks AFB, Texas 78235-5363
Telephone: (210) 536-4353
Facsimile: (210) 536-4330
Email: jerry.hansen@hqafcee.brooks.af.mil

Side-by-side, pilot-scale demonstrations of two emplacement techniques for permeable reactive barriers (PRBs) are being conducted at the industrial area of Cape Canaveral Air Force Station, FL. The site is contaminated with 90 mg/L of trichloroethylene (TCE), 7 mg/L of vinyl chloride (VC), and 170 mg/L of dichloroethylene (DCE).

The water table at the site is about 5 feet below ground surface (bgs). Groundwater flow is in the range of 0.1-0.5 ft/day and changes with depth.

A major objective of the demonstration was to compare the two emplacement methods. Both wall systems included a 50-foot main wall followed by 10-foot wall placed 4 feet downgradient from it and a third 10-foot wall placed 4 feet downgradient of the second. This provided a total target length of 70 linear feet for each technique. In the first installation, a hollow mandrel, or vibrated beam, created a void that is 4 in thick, about 45 feet deep, and 32 in long for each panel of the wall. A vibratory hammer drove the beam to the required depth. The void was filled with the reactive material through a chute at the top of the mandrel. About 98 tons of 100% zero-valent iron was used to construct the wall, and adjacent panels were overlapped to provide continuity in the wall. In the second installation, high-pressure water jets, guided by a 36-in I-beam, were used in addition to the water to create the void for each wall panel. A vibratory hammer was used to drive the beam to depth. The void was filled with a slurry made by mixing zero-valent iron with guar gum and a binder. About 107 tons of zero-valent iron was used for this emplacement. As in the first installation, adjacent wall panels were overlapped to provide continuity.

Total cost for the two barriers at this site was $809,000. This includes design, construction, materials, and the reactive media. The design cost for both walls totaled $292,000. Mobilization and demobilization, construction, materials, and the reactive material for the mandrel system was $279,000. Mobilization and demobilization, construction, materials, and the reactive material for the jet-assisted grout system was $238,000.

Dedicated *in situ* flow sensors and groundwater monitoring wells were installed after construction of the walls to track performance.

Quarterly monitoring is scheduled to continue until November 1998, and a report of demonstration results is expected to be issued in 1999.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile:
Launch Complex 34, Cape Canaveral Air Force Station, Cape Canaveral, FL

Installation Date: 1999
Contaminants: TCE, trans-DCE, cis-DCE
Reactive Media: Fe^0
Cost: $220,000
Construction: Vibrated caissons filled with Fe^0, followed by deep-soil mixing.
Point of Contact: Debra R. Reinhart
University of Central Florida
PO Box 162993
Orlando, Florida 32816-2993
Telephone: (407) 823-2156
Fax: (407) 823-5483
Email: reinhart@mail.ucf.edu

A pilot-scale permeable reactive barrier (PRB) system was installed in 1999 to remediate the heavily contaminated subsurface at Cape Canaveral Air Force Station Launch Complex 34 (LC34). This site, which was used for Saturn rocket launches between 1959 and 1968. Cape Canaveral Air Force Station is located on an island on the eastern coast of central Florida, bordered by the Atlantic Ocean on the east and the Banana River on the west. The soil immediately below the surface consists of medium to fine sands with some shell and silt. The soil is primarily sandy with shell fragments and traces of silts to depths up to 30 feet. Below 30 feet, the soil is stratified with layers of clay and fine sands. Beyond a depth of 100 feet, limestone fragments ranging from 20-50% are found within the clay and sandy soils. Groundwater level is 3-7 feet below the surface. Major groundwater contaminants of concern are trichloroethylene (TCE) (0.005-29 mg/L) and daughter products of biological degradation of TCE: trans-dichloroethylene (0.25 to 0.8 mg/L) and cis-dichloroethylene (14-44 mg/L).

The soil immediately below the surface consists of medium to fine sands with some shell and silt. The soil is primarily sandy with shell fragments and traces of silts to depths up to 30 feet. Below 30 feet, the soil is stratified with layers of clay and fine sands. Beyond a depth of 100 feet, limestone fragments ranging from 20-50% are found within the clay and sandy soils. Groundwater level is 3-7 feet below the surface. The gradient for the entire site ranges from .010-.001 ft/min. Additional gradient measurements, calculated from water levels measured in piezometric wells installed at LC34, concluded that the gradient does not vary significantly with time in both direction and magnitude. Tests were also conducted to examine the effect of the ocean tide on groundwater levels. The results show no signs of local tidal influence on the groundwater level.

The PRB system consists of a series of 11 overlapping columns (each about 4 feet in diameter) that contain a mixture of Fe^0 (16% by weight), native soil (79% by weight), and gravel (5% by weight). The total barrier length is about 40 feet. The PRB was installed to a depth of about 40 feet below ground, ending just above an impermeable clay stratum, and is keyed into a clay layer that is about 40 feet below ground.

After considering several alternatives, the Deep Soil Mixing technique (DSM) was selected to construct the PRB. DSM, which is typically used for soil improvement or contaminant containment, offers a method of PRB construction that reduces the volume of contaminated soil requiring special disposal and minimizes construction worker exposure to hazardous materials. In addition, the DSM can readily reach depths of 150 feet and has proven to be a cost effective alternative to PRB construction. Use of the DSM presented some construction challenges related to iron placement, since this was the first application of the technique. These were solved in field. In addition, some distribution problems with iron within the wall leading to breakthrough of VC and cis-DCE were noted.

Quarterly sampling at the site continues. To date, monitoring data suggest that removal of the chlorinated solvents challenging the wall is successfully occurring. TCE and its daughter products are at non-detectable levels within the wall and are declining in downstream wells, with the exception of vinyl chloride. Values for breakthrough VC and cis-DCE are continuing to decline.

Lessons Learned

A PRB installed using the deep-soil mixing technique offers several advantages over other construction techniques and treatment methods. The DSM technique produced no contaminated excavated soils that required special disposal. Exposure of workers to hazardous chemicals was also minimized since the mixing occurred below grade. This is a passive, in situ remediation technique and aboveground treatment equipment is unnecessary during routine operation. Sufficient mixing during PRB construction is recommended to provide sufficient iron throughout the treatment barrier capable of complete destruction of TCE and all daughter products.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile:
DuPont, Oakley, CA

Installation Year: Not Provided
Contaminants: CCl_4, Chloroform, Freon 11®, Freon 113®
Reactive Media: Granular cast iron
Cost: $1,150,000
Construction: Continuous PRB constructed using vertically oriented hydraulic fracturing
Point of Contact: Stephen H. Shoemaker
DuPont
6324 Fairview Road
Charlotte, North Carolina 28210
Telephone: (704) 362-6638
Facsimile: (704) 362-6636
Email: Stephen.H.Shoemaker@USA.DuPont.com

A full-scale permeable reactive barrier (PRB) demonstration is being conducted at a DuPont site in Oakley, CA. Contaminants, including carbon tetrachloride (CCl_4), 20-40 ppm chloroform ($CHCl_3$), 1-3 ppm, trichlorofluoromethane (Freon 11®) 10 ppm, and trichlorotrifluoroethane (Freon 113®) at 3 ppm, are present.

The PRB was emplaced in a stratified, alluvial aquifer system consisting of fine to medium sands. The upper aquifer extends to a depth of 55 feet below ground surface (bgs), underlain by a 10-foot thick, leaky clay aquitard. The lower aquifer extends from 65-120 feet bgs, underlain by a very thick and competent clay aquitard. The PRB was emplaced across the entire thickness of the lower aquifer.

The goal was to prove the feasibility of emplacing a 6-in thickness of iron to a depth of 120 feet bgs using hydraulic fracturing.

A probabilistic design model was used to make use of all of the available design data and optimize the barrier thickness at a 90% confidence level. Flowing sands and the required 120-foot depth necessitated the use of hydraulic fracturing as the method of construction.

The PRB is 110 feet long and 6 in thick. The PRB begins at 65 feet bgs and extends to a depth of 120 feet below ground surface. Total design cost for the PRB system is estimated at $150,000. Installation cost, including construction materials and reactive materials totaled $1,000,000.

No problems were encountered except that DuPont's attempts to recover an intact core of the emplaced PRB at a depth of 120 feet in flowing sands were unsuccessful. Alternative methods of direct physical emplacement verification are currently being explored.

The lack of success at recovering an intact core from the emplaced PRB does not impact the efficacy of the emplacement technique or the performance of the PRB.

A 1-year monitoring program has begun to verify treatment performance before completing the remainder of the full-scale PRB.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile:
DuPont, Kinston, NC

Installation Year: 1999
Contaminants: TCE
Reactive Media: Granular Fe^0
Cost: $200,000
Construction: Continuous Jetted Wall with Overlapping Panels
Point of Contact: Richard C. Landis
DuPont Corporate Remediation Group
USA.DuPont.com
Barley Mill Plaza/ 27-2288
P.O. Box 80027
Wilmington, Delaware 19880-0027
Telephone: (302) 892-7452
Facsimile: (302) 892-7641
Email: Richard.C.Landis@

A full-scale pilot demonstration of a permeable reactive barrier (PRB) was installed at a DuPont plant in Kinston, NC in 1999. A jetted PRB design was chosen because the presence of numerous underground utilities along the wall alignment made trenching impractical. The 300 feet wide and 800 feet long plume contained trichloroethylene (TCE) in concentrations of 10-300 µg/L. The range of TCE concentrations in the soil was 10-100 mg/L.

The facility sits on a 650-acre site with a water-bearing zone from 5-15 feet below ground surface. The hydraulic conductivity is 0.39×10^{-3} in/sec and the groundwater velocity range is 0.05-0.1 ft/day. The plume is in shallow sand with a delineated 30-foot × 30-foot compact source zone of unknown origin.

The PRB is 375 feet long and 15 feet deep. The center 100 feet of the PRB is 4 in thick and the wings on both sides are 2 in thick. The reactive media consists of 100 tons of granular cast iron -30/+70 mesh. In addition to the PRB, the project also featured jetting of a clay/Fe^0 slurry directly into the source zone. Installation costs, including construction and materials, totaled approximately $200,000. Thise does not include treatment of the source zone.

The cleanup goal was based on the North Carolina groundwater standard of 2.8 µg/L for the plume. The source treatment reduced the TCE mass by 95%. The decrease in downgradient concentrations and the PRB performance are still under investigation. However, 13 of the 16 previously contaminated Geoprobe locations indicate non-detectable levels of TCE. Sampling is conducted quarterly.

A pump-and-treat system installed prior to 1999 and operating downgradient of the PRB is affecting the velocity through the PRB and its performance. DuPont is working out an agreement with the state to shut down the pump-and-treat system for one year in order to observe the PRB under ambient flow conditions.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project. Several slides providing additional information about the site are available through a link in the online installation profile.

Permeable Reactive Barrier Project Profile:
Industrial Site, Belfast, Northern Ireland

Installation Year: 1995
Contaminants: TCE; 1,2-cDCE
Reactive Media: Fe^0
Construction: Slurry Wall Funnel in *situ* reaction vessel
Point of Contact: Dale Haig
Golders Associates (UK), Ltd.
Landmere Lane
Edwalton, Nottingham NG124DG United Kingdom
Telephone: 44-115-9456544
Facsimile: 44-115-9456540
Email: DHaigh@GOLDER.com

A full-scale field test of a permeable reactive barrier (PRB) system was conducted at an industrial facility in Belfast, Ireland. A circular in *situ* reaction vessel filled with iron was installed to a depth of about 40 feet in December 1995, to treat up to 390 mg/L of trichloroethylene (TCE) and related breakdown products. Previous owners of the site had used chlorinated solvents while manufacturing electronic components. Years of spillage resulted in an intense but localized plume close to the current site boundary.

The TCE plume at this site is located in an area characterized by a thick deposit of till (up to 78 feet) underlain by Mercia mudstones. The till has silt, sand, and gravel lenses that allow contaminants to migrate from the source; however, migration is constrained by the specific orientation of the permeable lenses that contain discrete clay or clayey silt lenses. The depth of the barrier was chosen to intercept the horizon of low permeability that is present at a depth of around 33 feet. The site is characterized as having a water table approximately 20 feet below ground surface, and an underlying aquifer about 40 feet in depth. No information is provided porosity, transmissivity, hydraulic gradient, etc.

Two 100-foot bentonite cement slurry walls directed water to the inlet of the steel reaction vessel, which was 4 feet in diameter and contained a 16-foot vertical thickness of zero-valent iron. Groundwater flowed by gravity through the iron zone and discharged through a piped outlet on the downgradient side of the slurry wall. The vessel was equipped with a manhole to access the top of the iron zone, in the event that periodic scarification of the iron surface proved access was necessary. The system was designed to provide residence time of about 5 days.

The total cost of the system, including slurry walls, granular iron, reaction vessel, and engineering, was about $375,000.

The system was designed to meet groundwater quality criteria of 500 :g/L for TCE, which apply to groundwater beneath industrial land slated for redevelopment. Flow rates through the reactor have varied substantially since its installation, but data have shown an overall 99.7% reduction in TCE and cis-1,2-dichloroethylene (cDCE) levels through the reaction vessel. Both increased and decreased levels of cDCE resulting from reductive dehalogenation have been identified. TCE levels in the system have been decreasing in the effluent sample ports. Only low levels (in the range of 100 :g/L) of cDCE have been detected. Vinyl chloride, a common breakdown product of this process, has not appeared in appreciable quantities.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile
Massachusetts Military Reservation CS-10 Plume, Falmouth, MA

Installation Year: 1998
Contaminants: PCE, TCE
Reactive Media: Fe^0
Construction: Hydraulic Fracturing
Point of Contact: Robert W. Gillham
University of Waterloo
2400 University Avenue West
Waterloo, Ontario N2V 1T4 Canada
Telephone: (519) 888-4658
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Installation of a permeable reactive barrier (PRB) system to remediate groundwater contaminated with chlorinated solvents was completed by University of Waterloo researchers at the Massachusetts Military Reservation (MMR) near Falmouth, MA, in 1998.

The uniqueness of the project was the great depth of the site—the Chemical Spill 10 (CS-10) plume extends to about 120 feet below ground surface (bgs) near its source area. The demonstration program was pilot-scale in width, but full-scale in depth. The primary contaminants of concern at this site are perchloroethylene (PCE) and trichloroethylene (TCE), for which initial maximum concentrations of 300 µg/L and 15 µg/L, respectively, were identified. A 600 feet-wide contamination plume resulting from the maintenance of BOMARC missiles and related equipment during the 1960s exists in the area of MMR's Buildings 4642 and 4601, now known as the UTES site.

The CS-10 demonstration site is located in an area of glacial outwash sand and gravel, where the water table is located approximately 80 feet bgs. Groundwater flow velocity in the area is approximately 1 ft/day, and the horizontal hydraulic conductivity is approximately 200 ft/day. Maximum contaminant concentrations were identified at about 100 feet bgs.

Two iron walls approximately 20 feet apart were installed perpendicular to the contaminant plume using vertical hydrofracturing with a guar-based slurry. In the preliminary design for this project, installation methods were selected for their ability to emplace granular iron to the required depth. This installation technique required the drilling of 1 foot-diameter boreholes at 15 feet intervals along the wall. The "frac wells" were installed from ground surface to below the base of the contamination zone, and a specially-designed frac tool was used to cut a vertical notch for initiation of the fracture. A fracture was then induced and filled with granular iron suspended in a hydrated and cross-linked guar slurry. The propagating fracture from one frac well coalesced with the emplaced material from the adjacent well, thus forming a continuous vertical wall. The upgradient wall contains 44 tons of fine- to medium-granular iron (Master Builders GX-027), averages 3.3 inches in thickness and 48 feet in width, and extends from approximately 78 feet to more than 120 feet in depth.

A second wall, of similar dimensions, but consisting of a mixture of 5 tons of sand and 5 tons of granular iron, was emplaced to demonstrate the possible use of sand as a filler and permeability-increasing amendment for more highly reactive enhanced-iron materials. The upgradient, 100%-iron wall was verified by active resistivity and borehole radar tomography, hydraulic pulse interference testing, and borehole deviation measurements. More than 30 monitoring wells have been installed to monitor performance of the demonstration project.

Installation cost for this demonstration is estimated to be $160,000. This includes design, construction, materials, and the reactive media.

Although cleanup goals were not specified for this demonstration, cleanup to levels below maximum contaminant levels (MCLs) served as the target. Sampling of the groundwater upgradient and downgradient of the PRB system is conducted every 2-3 months. Results of the demonstration will be available upon its completion in mid-2000.

Lessons Learned

It was recognized early in the demonstration process that, depending upon the initial contaminant concentrations and flow velocity, this type of PRB system may require multiple walls to achieve a sufficient thickness. For the CS-10 source area plume, three walls with commercial iron of 3-inch thickness were expected to be needed for full treatment with an adequate factor of safety.

The 100% iron wall was installed successfully. During the installation of the second wall, however, fracturing control was lost when the propagating fracture came close to two screened monitoring wells deviating as much as 7 feet horizontally over their 150-foot length. Use of the system to remediate deep plumes such as thisthe requires that the proximity (3-dimensional coordinates) of screened monitoring wells to the wall installation be carefully planned and checked with borehole deviation testing. As a result of an unanticipated delayed break of the cross-linked guar during construction of the system, more time was required for reestablishment of groundwater flow through the wall. Accordingly, it was determined that an improved guar-iron mix design was needed to establish flow through reactive zones soon after installation of the walls.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.

Permeable Reactive Barrier Project Profile:
SAFIRA Test Site, Bitterfeld, Germany

Installation Year: 1999
Contaminants: C6H6; MCB; o-DCB; p-DCB; TCE; cis-1,2-DCE; trans-1,2-DCE
Reactive Media: Hydrogen-activation Systems with and without Palladium Catalyst
Construction: Vertical Wells Shafts and Horizontal Wells.
Points of Contact:
Dr. Holger Weiss
UFZ-Umweltforschungszentrum
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For more than 100 years, open pit lignite mining activities and the related chemical industries have had a serious impact on soil and groundwater quality in the Bitterfeld Region of Germany. Groundwater in the region has been contaminated over an area of about 10 mi^2. The SAFIRA test site in Bitterfeld was selected as a model location for the demonstration of different types of cleanup technologies under real-world conditions of an in *situ* pilot plant. A pilot test using reactive columns at the pilot plant was conducted to treat groundwater contaminated with benzene (C_6H_6), chlorobenzene (MCB), 1,2-dichlorobenzene (o-DCB), 1,4-dichlorobenzene (p-DCB), trichloroethylene (TCE), cis-1,2-dichloroethylene (DCE), and trans-1,2-DCE. High levels of sulfate (up to 1,000 mg/L) and chloride (up to 1,300 mg/L) are also present.

The goal of the demonstration is the development and implementation of innovative low-energy or passive water treatment technologies for mixed organic contaminants for full-scale in *situ* application. The SAFIRA test site is underlain by an upper and lower aquifer separated by a 26-foot thick lignite seam. The upper aquifer extends approximately 65 feet below ground surface (bgs) and is comprised of Quaternary glacio-fluvial sand and gravel with intercalated silt. The lower aquifer is about 91 feet-164 feet bgs and is comprised of Tertiary sands. The water table in the area averages 20 feet bgs.

Five 10-foot diameter vertical well shafts were drilled perpendicular to groundwater flow to a depth of 75 feet bgs. The distance between the well shafts is approximately 62 feet. Groundwater is collected from each shaft by two 33-foot long horizontal wells drilled at an angle of 60°. The pilot plant houses 20 reactors that range in length from 3 feet - 20 feet, depending on the technology it uses. The reactors are designed for a permanent system pressure of 3 bars (2.96 atmospheres) and are operated in a flow-through mode from bottom to top. Flow rates can be varied up to 106 gal/hr.

The combined cost for the installation and design of the pilot system was 11 million Deutsche Marks. Some problems were encountered during the pilot test. Anaerobic degradation of the chlorobenzene could not be shown in the reactors. In addition, sulfate reduction was found to cause catalyst poisoning.

Based on promising results of the pilot test and laboratory experiments, several physical/chemical methods were selected to be tested in a large-scale *in situ* application, including zeolite-supported palladium catalysis. The pilot project will conclude in June 2002. It is expected that the SAFIRA test site will receive additional public funding over the next few years.

Lessons Learned

One lesson learned from the pilot thus far is that it is likely the complex mixture of contaminants in the groundwater at Bitterfeld will require a combination of treatment technologies.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project. A website <www.safira.ufz.de> with additional information about the site is available through a link in the online installation profile.

Permeable Reactive Barrier Project Profile:
Savannah River Site TNX Area, Aiken, SC

Installation Year: 1997
Contaminants: TCE; cDCE, CT; NO_3
Reactive Media: Fe^0
Construction: GeoSiphon Cell
Point of Contact: Mark Phifer
Westinghouse SRC/SRS
Building 773-42A
Aiken, South Carolina 29808
Telephone: (803)-725-5222
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Email: mark.phifer@srs.gov

The GeoSiphon Cell (patent pending) was installed in the TNX flood plain at the Savannah River Site (SRS) by auger and caisson methods in July 1997. The cell was installed to demonstrate treatment of groundwater contaminated with chlorinated volatile organic compounds (cVOC). Groundwater contamination has been detected in the TNX water table aquifer, but not in the semi-confined or deep aquifers underlying the site. Predominant contaminants, and average concentrations of each, detected in the TNX flood plain are trichloroethylene (TCE) at 200-250 µg/L; cis-1,2-dichloroethylene (cDCE) at 20-50 µg/L; carbon tetrachloride (CT) at 15-45 µg/L; and nitrate (NO_3) at 10-70 mg/L.

The TNX Area is a semi-works facility for the Savannah River Technology Center, which is located 0.25 miles from the Savannah River near Aiken, SC. The facility was used for pilot-scale testing and evaluation of various chemical processes associated with the SRS. The water table elevation averages 100 feet above mean sea level under the TNX site, while the Savannah River elevation averages 85 feet. In the flood plain where contamination was detected, the water table aquifer is approximately 35-40 feet thick. It consists of interbedded sand, silty sand, and relatively thin clay layers. Based on testing and modeling analysis, the aquifer may be characterized as having a horizontal hydraulic conductivity of 65 ft/day, vertical hydraulic conductivity of 30 ft/day, effective porosity of 0.15, pore velocity of 3 ft/day, and a horizontal gradient of 0.007.

The TNX GeoSiphon Cell is a large-diameter (8 feet) well containing granular zero-valent iron (Fe^0) as a treatment media (in place of gravel pack). The cell passively induces flow by use of a siphon from the cell to the Savannah River. The flow is induced by the natural hydraulic head difference between the cell and the river. The passively-induced flow draws contaminated groundwater through the treatment cell, where the Fe^0 reduces the cVOCs to ethane, ethene, methane, and chloride ions. Treated water is discharged subsequently to the Savannah River.

During Phase I testing of this technology, which was completed in December 1997, flow through the TNX GeoSiphon Cell was induced by pumping and the treated water was discharged to the existing TNX National Pollutant Discharge Elimination System outfall. Testing indicated that TCE degradation is the limiting compound to treatment below the Primary Drinking Water Standard Maximum Contaminant Levels within the TNX GeoSiphon Cell. Data indicated that approximately 8 gal/hr of groundwater contaminated with 200-250 µg/L of TCE could be treated, while maintaining the average discharge TCE concentration below 5 µg/L. Field first order rate constants produced from the steady state TCE data increased with flow rate from 0.347 to

0.917/hr. Phase I system costs are estimated at $119,115, including $26,400 for iron, $27,411 for other construction materials, and $65,344 for mobilization, labor, rentals, and related installation expenses. Approximately 49.7 tons of 0.25-2.0 mm (particle size) granular cast iron was used in the installation of the first TNX GeoSiphon Cell (TGSC-1).

During Phase II, flow through the TNX GeoSiphon Cell was induced by siphon and the treated water was discharged to an existing outfall ditch that flows into the Savannah River. To allow continuous operation, the siphon line configuration was optimized to include an upward rise from the cell to the outfall ditch, an air chamber at the crest adjacent to the outfall ditch, and a steep drop into the outfall ditch with line termination in a sump. The head differential available to drive the system (approximately 1.4 feet) produced a continuous flow rate of 2.5-2.7 gal/minute. Approximately 1.2 feet of head was utilized to drive flow through the cell itself, and approximately 0.2 feet of head was utilized to drive flow through the siphon line. Based on these results, a new siphon line will be installed between the cell and a target location, thus producing a 5-foot head differential capable of inducing an estimated 9.5 gal/min through the GeoSiphon Cell.

Phase III of this demonstration project will involve installation and operation of a full-scale GeoSiphon Cell system for treatment of the entire TNX contaminated groundwater plume.

Lessons Learned

The GeoSiphon Cell was selected for use at the TNX Area because it offers passive, in situ treatment (no power requirements) at lower operating and maintenance costs than pump-and-treat technology. In contrast to funnel and gate or continuous permeable wall technologies, the GeoSiphon Cell could be constructed using an existing foundation and well drilling techniques. In addition, there is potential for accelerating cleanup through the use of induced flow rates greater than natural flow. With a maximum siphon lift of 25 feet, application of the GeoSiphon Cell technology was found to be limited to areas of shallow groundwater such as that existing at the TNX Area.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project. Several slides providing additional information about the site are available through a link in the online installation profile.

Permeable Reactive Barrier Project Profile:
X-625 Groundwater Treatment Facility, Portsmouth Gaseous Diffusion Plant, Piketon, OH

Installation Year: 1996
Contaminants: TCE
Reactive Media: Fe^0
Construction: Horizontal Well
Point of Contact: Thomas C. Houk
Portsmouth Gaseous Diffusion Plant
3930 US Route 23S
Piketon, Ohio 45661
Telephone: (614) 897-6502
Fax: (614) 897-3800
Email: uk9@ornl.gov

A pilot-scale field test of reactive media (zero-valent iron) for degrading trichloroethylene (TCE) in groundwater is currently in place at the X-625 Groundwater Treatment Facility at the U.S. Department of Energy's (DOE) Portsmouth Gaseous Diffusion Plant in Piketon, Ohio. Influent concentrations of TCE for the treatment facility range from 70 to 150 µg/L. Contamination resulted from past waste disposal practices at the plant.

The uppermost layer underlying the site is composed of approximately 30 feet of silt. The contaminated aquifer resides below this layer within a 2-foot to 10-foot layer of silty gravel and has a hydraulic conductivity of approximately 20 ft/day. Bedrock is 32 feet to 40 feet below ground surface (bgs).

The X-625 facility consists of a 500-foot horizontal well that collects TCE-contaminated groundwater from within the silty-gravel aquifer underlying the treatment area at a depth of 30 feet. This groundwater is fed into a building constructed at an elevation that is 3 feet to 5 feet below bedrock. The groundwater then is distributed through a series of canisters filled with zero-valent iron (Fe^0). The flow rate into the facility has been less than 1 gpm. The facility is currently being converted to accommodate a higher groundwater flow rate (5 gpm). After conversion, treatment will be through zero-valent iron in the form of foamed pellets. Electrochemical enhancement by passing a current through the iron media also is being considered.

Testing of the Fe^0 filings was conducted from March 1996 through March 1998. Results indicated a reduction of TCE concentrations to less than 5 µg/L after passage through the treatment system. Reductions in the hydraulic conductivity of the iron media due to mineral precipitation (e.g., iron oxides and iron sulfides) were observed. The life of the reactive media will be dependent on high Fe^0 corrosion rates influenced by the high sulfate levels in the groundwater.

Future sampling plans will be developed during conversion to the higher flow rate, which is expected to be completed by October 1998.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for the project.