COST AND PERFORMANCE REPORT

In Situ Permeable Reactive Barrier for Contaminated Groundwater
at the Moffett Federal Airfield
Mountain View, California

September 1998

EPA

Prepared by:

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

SITE INFORMATION

Identifying Information:

Moffett Federal Airfield
Mountain View, California

CERCLIS #: Not applicable

ROD Date: Not applicable

Treatment Application:

Type of Action: Pilot Test

Period of operation: April 1996 - Ongoing (Performance data collected through July 1997)

Quantity of material treated during application: 284,000 gallons of groundwater

Background [2]

Historical Activity that Generated Contamination at the Site: Service and support for Navy aircraft

Corresponding SIC Code: 3728 (Aircraft parts and Auxiliary Equipment)

Waste Management Practice That Contributed to Contamination: Leaking underground and aboveground storage tanks, waste sumps; on-site migration of contaminants from Silicon Valley plume

Location: Mountain View, California

Facility Operations [1, 2]:

- Moffett Federal Airfield (MFA) is a former Navy facility providing support, training, operation, and maintenance associated with Navy aircraft. Aircraft engine repairs and aircraft maintenance have been performed on site for many years. Cleanup and contaminant identification activities have been underway at MFA since 1987.

- This report addresses a Permeable Reactive Barrier (PRB) pilot study that, if effective, will be scaled up to remediate a large portion of the shallow aquifer at MFA. Currently, the PRB intercepts and treats contaminated groundwater immediately downgradient of a single source area at MFA. This site is complicated by the presence of a large groundwater plume that crosses MFA from off-site sources. The Navy is working with the responsible parties for the off-site sources to remediate the groundwater contamination.

- Remedial investigations were started in August 1990 and completed in April 1991 by International Technology Corporation and Tetra Tech EM, Inc.

- Contaminants in the area of the PRB consist primarily of chlorinated solvents. Specific activities that contributed to the source at MFA included dry cleaning operations.

- The Navy and Department of Defense Environmental Security Technology Certification Program (ESTCP) is funding this PRB as a pilot study for treating a portion of the large plume that crosses MFA.

- Remedial performance monitoring is being conducted by Tetra Tech EM and the PRB performance evaluation is being conducted by Battelle Memorial Institute (Columbus operations).

Regulatory Context:
The PRB was constructed as part of a voluntary pilot-scale study to demonstrate the effectiveness of the PRB for treating a groundwater plume of chlorinated solvents.

Groundwater Remedy Selection:
An *in situ* PRB was selected for a pilot study at this site.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Lead: U.S. Navy

Oversight: EPA

Treatment System Vendors:
Tim Mower*
Tetra Tech EM
1099 18th Street, Ste. 1960
Denver, CO 80202
303-312-8874

Chuck Reeter*
Naval Facilities Engineering Service Center
1100 23rd Ave., Code 411
Port Hueneme, CA 93043-4370
805-982-4991

*Indicates primary contacts

Remedial Project Manager:
Stephen Chao (Navy Project Manager)
Bldg. 210
Department of the Navy
EFA - West
900 Commodore Drive
San Bruno, CA 94066

EPA Contact:
Lynn Suer
EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
415-744-2396

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [2, 3]

Primary Contaminant Groups: Halogenated volatile organic compounds (VOCs)

- Contaminants detected near the location of the treatment wall include perchloroethene (PCE), trichloroethene (TCE), *cis-* and *trans*-1,2-dichloroethene (1,2-DCE), 1,1-dichloroethene (1,1-DCE), and 1,1-dichloroethane (1,1-DCA). Historically, 1,2-DCE and TCE are the predominant groundwater contaminants in the vicinity of the PRB.

- Maximum contaminant concentrations detected during 1991 investigations include 20,000 µg/L of TCE and 500 µg/L of PCE. In June 1996, TCE levels of over 5,000 µg/L were measured upgradient of the wall location. This may indicate that the plume originates from a continuous source.

- Figure 1 is a contour map that depicts TCE concentrations detected in February/March 1995. The 2,000 µg/L TCE contour line is closest to the treatment wall location.

- Dense nonaqueous phase liquid (DNAPL) presence is likely because of elevated concentrations detected in groundwater samples and processes known to have occurred at the facility. The maximum concentration of TCE detected was near 2% of its solubility limit.

- In 1991, the TCE plume was estimated to be over 10,000 feet long and 5,000 feet wide. Contaminants have been detected to a depth of 70 feet. The volume of the contaminant plume was estimated to be 5.6 billion gallons in the remedial investigation (RI) report. The PRB at MFA is treating a small part of this plume located in a shallow aquifer immediately downgradient of a source area.

MATRIX DESCRIPTION (CONT.)

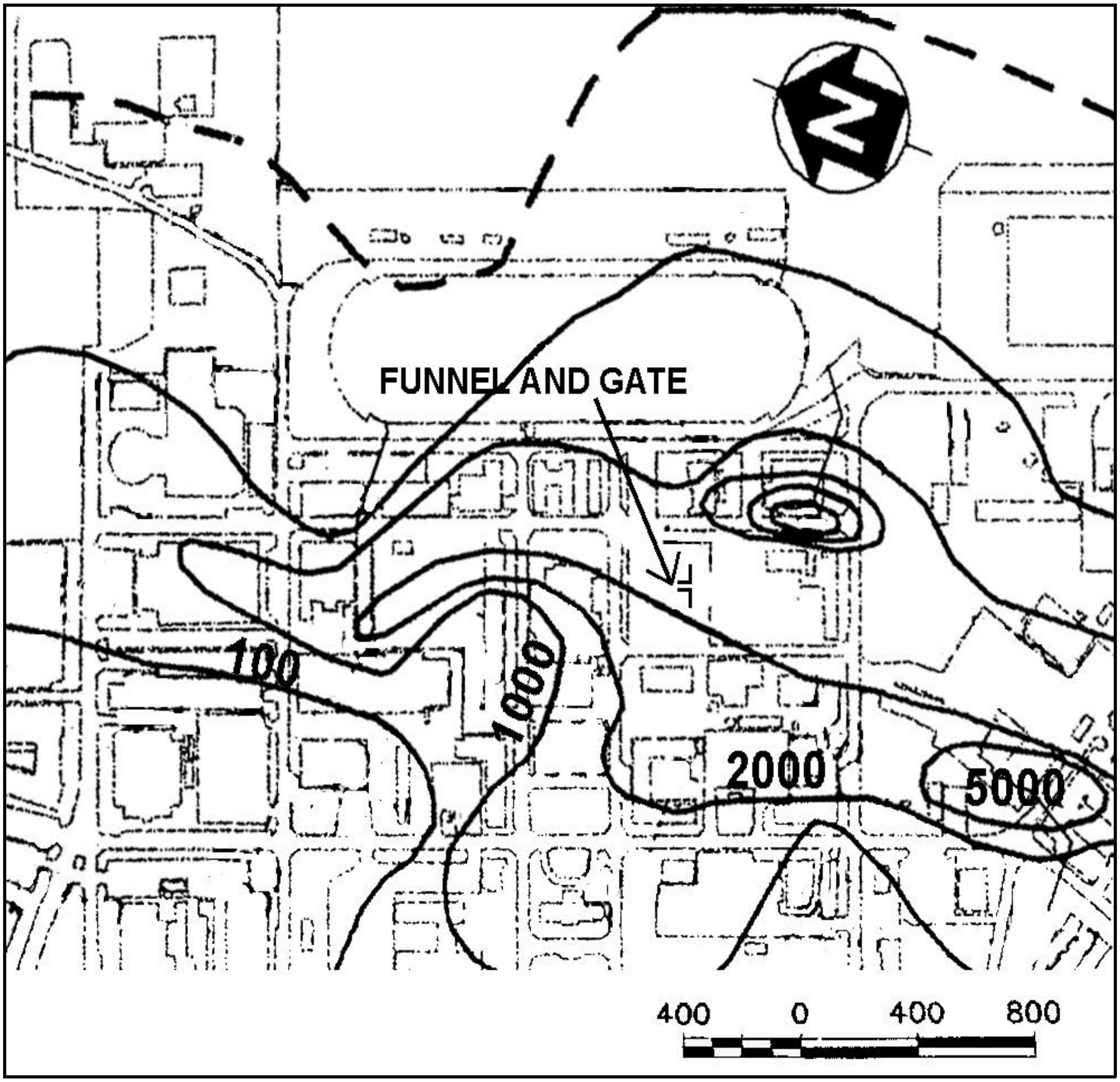

Figure 1. TCE Concentration (µg/L) (February/March 1995) [2]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance [2]

Hydrogeology:

Five distinct hydrogeologic units have been identified beneath this site. Groundwater is found approximately five feet below ground surface. MFA lies on a relatively flat depression, known as Santa Clara Valley, present between the San Andreas and Hayward Faults. Regionally, the Santa Clara Valley contains up to 1,500 feet of interbedded alluvial, fluvial, and estuarine deposits. These sediments consist of varying combinations of clay, silt, sand, and gravel. Subsurface sediments have been divided into the A, B, and C aquifers. Most contaminants at MFA are found within the A aquifer, which includes two permeable zones. The PRB is designed to treat only those contaminants in the A1 unit.

Unit A1	Surficial Sediments	Fine- to coarse-grained material. Uppermost permeable zone, highly contaminated. A discontinuous confining bed is present beneath this unit. Upward hydraulic gradients are present between units A1 and A2.
Unit A2	Surficial Sediments	Fine- to coarse-grained material. Highly contaminated and having a continuous 5- to 7-foot thick clay aquitard beneath. Upward hydraulic gradients are present between the A and B aquifers.
Unit B1	Fluvial Sediments	Thin sand and gravel beds in a fine-grained matrix. Not contaminated, highly conductive (similar to A aquifer).
Unit B2	Fluvial Sediments	Thin sand and gravel beds in a fine-grained matrix.
Unit C	Estuarine Sediments	Fine to medium clayey and silty sand.

Tables 1 and 2 include technical aquifer information and technical wall data, respectively.

Table 1. Technical Aquifer Information

Unit	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
A1	25	1 - 400	0.005 - 2	North
A2	40	30 - 200	0.15 - 1	North
B1	45	0.3 - 50	0.0014 - 0.22	North
B2	15	0.4 - 40	0.0018 - 0.18	North
C	>100	Not available	Not available	Not available

Source: [2]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Permeable Reactive Barrier (PRB)

Supplemental Treatment Technology

None

System Description and Operation

Table 2. Treatment Wall Data

Unit	Flow-Through Thickness	Conductivity (ft/day)	Material	Vertical Thickness
Flow Control Zone	2 feet	>1,000	Pea gravel	18 feet
Continuous Treatment Wall	6 feet	1,000	100% Granular iron	18 feet
Flow Control Zone	2 feet	>1,000	Pea gravel	18 feet

Source: [2,4]

System Description [2, 3, 4, 7]

- The PRB is a passive, *in situ* treatment technology that makes use of natural groundwater flow to carry contaminants through the reaction zone.

- The PRB, installed in 1996, is a funnel and gate iron treatment wall system. The components include two sheet pile walls, permeability zones upgradient and downgradient of the wall, and the reactive zone. Table 2 provides technical wall data. Figures 2 and 3 illustrate the layout and dimensions of the PRB.

- Two sheet pile walls measuring 20 feet in length extend at a 90^{o} angle from the wall (perpendicular to groundwater flow direction). These walls act as a funnel to force more of the contaminant plume through the PRB.

- The PRB is composed of 100% granular iron, has 6 feet of flow-through thickness, is 10 feet wide, and 18 feet high beginning 5 feet below ground surface. The flow control zones upgradient and downgradient of the wall are composed of pea gravel and have 2 feet of flow-through thickness.

- The PRB extends down through Unit A1, but is not keyed into the low conductivity unit comprised of clayey fine sand to silty clay that is found at a depth of approximately 23 to 25 feet below ground surface. This material is not classified as an aquitard; however, it is believed to inhibit contaminant transport to Unit A2. The iron filings begin at a depth of 5 feet below ground surface, which corresponds with the groundwater table. Native soil was backfilled above this depth. Two feet of concrete and bentonite were placed below the iron to prevent downward migration of contaminants.

- The PRB utilizes reactive zero-valent iron to dehalogenate the chlorinated compounds to chloride and ethylene.

- The actual residence time in the treatment zone for the dechlorination and reduction reactions has been estimated to be approximately 96 hours based on the highest concentration scenario. A minimal residence time of 48 hours is required to degrade contaminants to meet cleanup goals.

TREATMENT SYSTEM DESCRIPTION (CONT.)

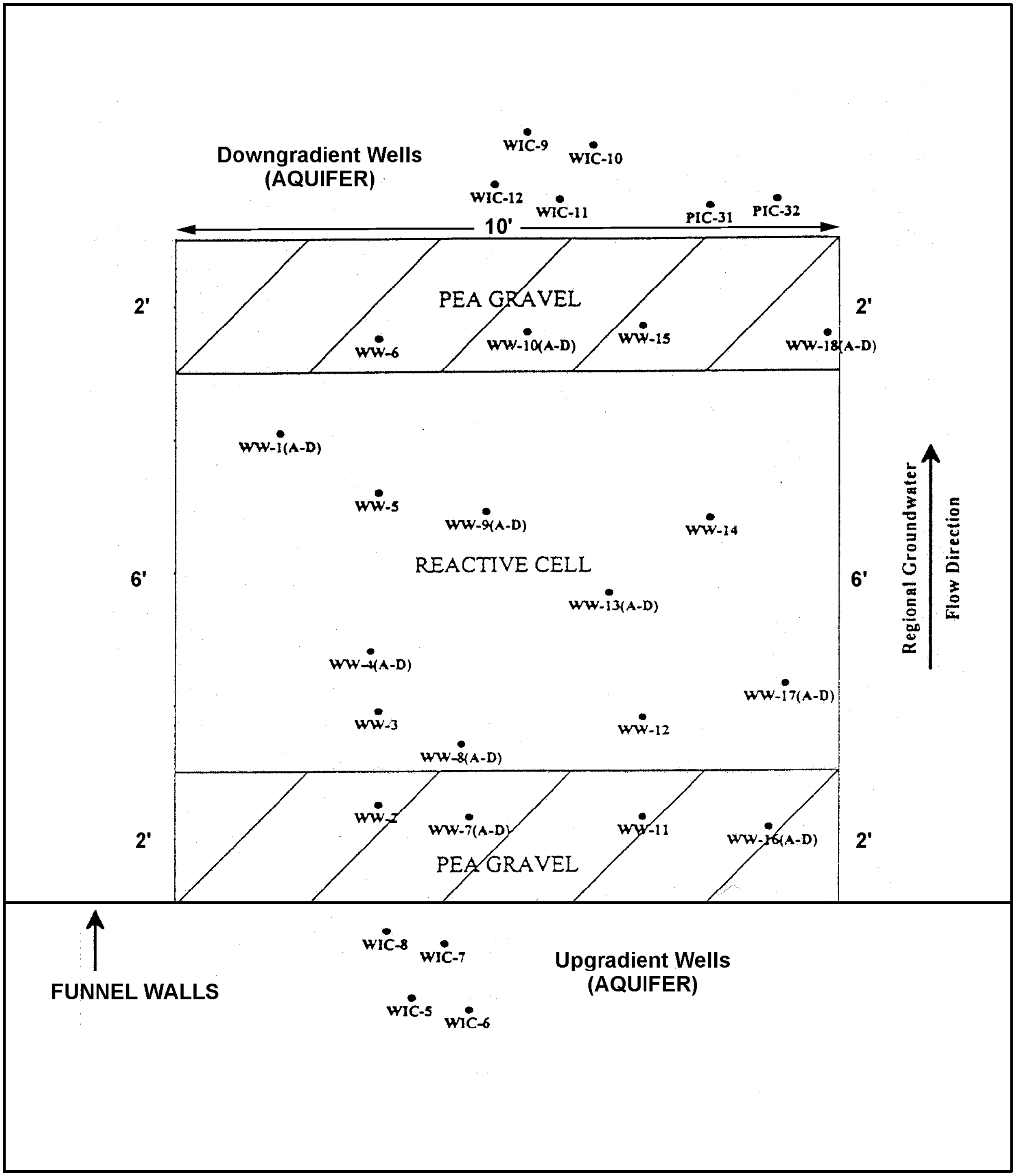

Figure 2. Funnel and Gate Plan View [3]

TREATMENT SYSTEM DESCRIPTION (CONT.)

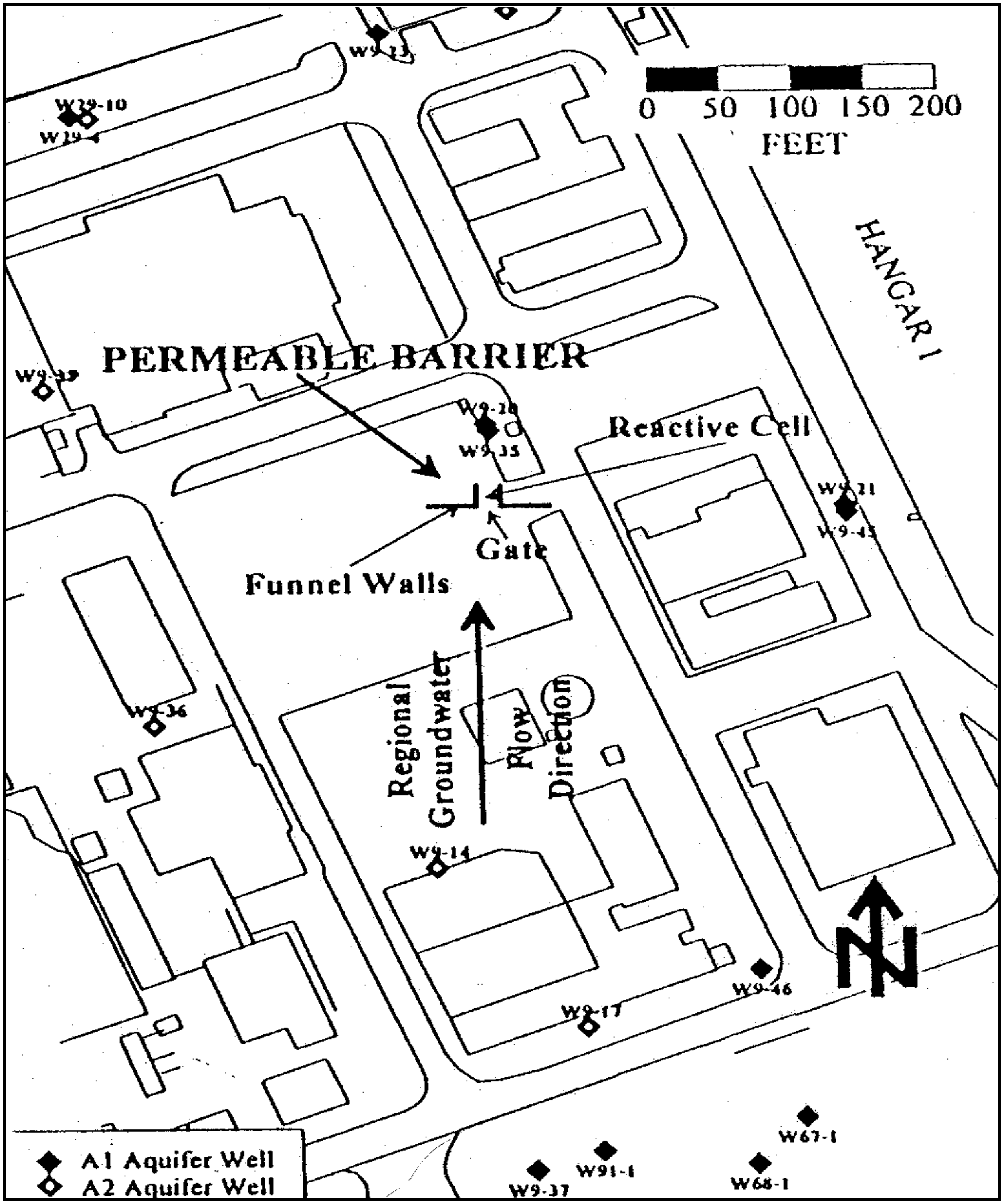

Figure 3. Site Plan [2]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation Source (Cont.)

- Twenty-eight multi-level monitoring wells are located within the treatment zone. These wells are placed at 1 to 2 foot intervals to monitor contaminant concentration reduction through the wall. Four wells are located both upgradient and downgradient of the treatment zone to monitor influent and effluent concentrations.

System Operation [1, 2, 7-10]

- Quantity of groundwater treated:

Time Frame	Approximate Volume Treated
1996-1997	*284,000 gallons*

Based on average groundwater velocity of 0.5 ft/day, and dimensions of 10 feet wide and 18 feet deep [2].

- Since April 1996, the PRB has been 100% operational.

- There have been no maintenance requirements for the treatment wall to date. The reactive media may need to be replaced if the wall becomes clogged or ineffective. The monitoring plan requires monitoring of the wall for plugging and continued effectiveness. Sampling in December 1997 indicated no significant clogging.

- Monitoring wells and research sampling points are sampled quarterly, for piezometric head to evaluate groundwater velocity and flow direction through the treatment wall.

Operating Parameters Affecting Treatment Cost or Performance

Table 3 presents operating parameters affecting cost and performance for this technology.

Table 3: Performance Parameters

Parameter	Value
Average Flow Rate through Treatment Wall	0.5 ft/day [Estimate used for calculation purposes [9]]
Required Residence Time	48 hours

Source: [1]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

Table 4 presents a timeline for this pilot-scale project.

Table 4: Project Timeline

Start Date	End Date	Activity
4/95	8/95	Lab tests and column studies performed
8/95	1/96	Treatment wall designed
1/96	---	Procurement process begun
4/96	5/96	3-week construction period
6/96	---	First sampling event conducted
9/96	---	Second sampling event conducted
1/97	---	Third sampling event conducted
4/97	---	Fourth sampling event conducted
7/97	---	Fifth sampling event conducted (in conjunction with tracer test)
10/97	---	Sixth sampling event conducted

Source: [1]

TREATMENT SYSTEM PERFORMANCE

Treatment Performance Goals [1]

The objectives of the pilot project are to: (1) demonstrate and validate the PRB technology in remediating groundwater contaminated with chlorinated hydrocarbons; (2) evaluate the long-term effectiveness of the barrier from a hydraulic standpoint; and (3) develop cost and performance data [7].

Performance Data Assessment [3, 6]

- Data from sampling events in January, April, and July 1997 showed that chlorinated VOC concentrations were being reduced as the groundwater moves through the reactive zone. For example, TCE concentrations measured in upgradient wells during April 1997 were reduced to below the detection limit within the reactive zone. PCE and 1,2-DCE were also reduced to below the detection limit within the reactive zone.

- Figure 4 shows that *cis*-1,2-DCE and TCE concentrations decrease as the groundwater flows through the PRB. An average of the January 1997 and April 1997 data at specific intervals through the wall was used to generate this figure. TCE concentrations in the upgradient wells are near 1,000 µg/L; at 4 feet into the PRB, TCE concentrations are approximately 1 µg/L. *Cis-1,2*-DCE concentrations begin near 200 µg/L upgradient and decrease to less than 10 µg/L by the 4-foot interval.

- Figure 5 presents mass flux data calculated for the January, April, and July sampling events. This figure indicates that mass removed by the PRB has increased from .007 lbs/day to .0086 lbs/day over the three sampling events. TCE and *cis*-1,2-DCE concentrations were used for this calculation as they account for most of the total contaminant mass entering the PRB.

TREATMENT SYSTEM PERFORMANCE (CONT.)

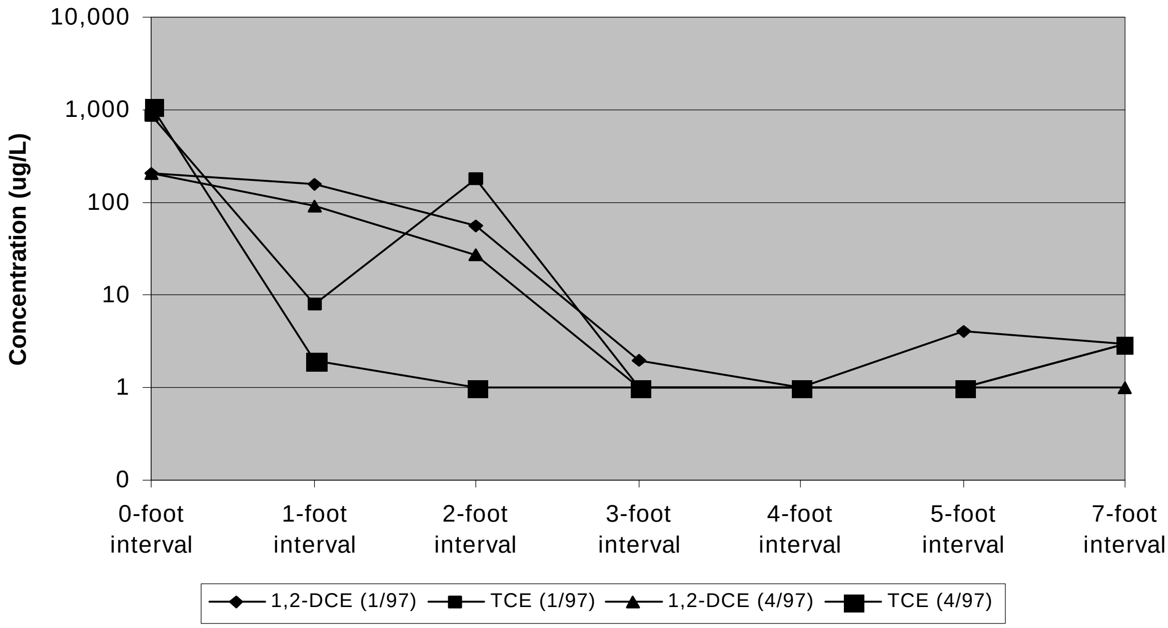

Figure 4. Concentration Reduction Through the PRB ***[3]***

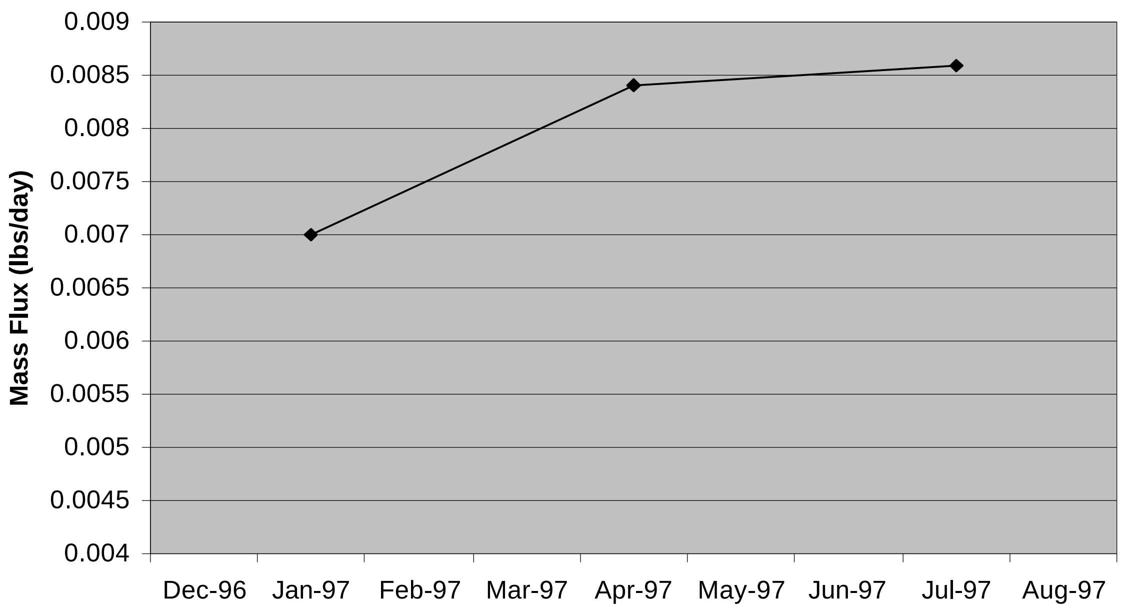

Figure 5. Mass Removal Through the PRB (January - July 1997) ***[3]***

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- A tracer test was performed in July 1997 to assess performance of the PRB and to determine groundwater flow direction and velocity measurements within the treatment wall. The tracer test was performed using potassium bromide tracers. The results of the tracer test indicated that some lateral flow occurs within the wall and flow patterns appear to be rather complex (not always in straight lines). The flow patterns are attributed to the differential compaction of granular iron throughout the wall. Overall, flow velocities were lower than expected based on previous site characterization and modeling.
- Results from the tracer test indicate that flow velocity through the cell ranges from 0.05 to 0.45 ft/day. According to the contractor that performed the test (Battelle Columbus Operations), these flow velocities were much lower than were predicted by site characterization and modeling (about 3 ft/day), water level measurements (up to 5 ft/day), and downhole velocity measurement (1.1 to 6.1 ft/day) [6, 7].
- Cores of *in situ* iron were collected in December 1997 and analyzed for evidence of precipitates and corrosion materials that may reduce hydraulic and remedial effectiveness of the barrier. Microbial analysis of cored material also was conducted to assess presence of iron oxidizing or sulfate reducing bacteria [7].

Performance Data Completeness [1]

- Seventy-two monitoring wells are sampled quarterly. After one year of operation, the monitoring schedule may be adjusted if needed. The large number of wells are sampled for research purposes. According to Battelle, this number of wells exceeds the typical protocol necessary to demonstrate that the PRB is functioning properly and meeting treatment goals.
- Data from the January, April and July 1997 quarterly sampling events were available for this report. Additionally, a tracer test study was performed in July and also available for this report.
- In Figure 4, 2 µg/L is the detection limit. When data was reported as below detection limits, half the detection limit (1 µg/L) was used in the future.

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of California requirements. All monitoring was performed using EPA-approved methods, Method 353.1, Method N-601, SW-846 Method 8240, SW-846 Method 8020. Laboratory reports for the April 1997 sampling event indicated that detection limits were unacceptably high for the A1 aquifer zone wells and upgradient pea gravel wells due to excessive sampling dilution. The laboratory was asked to reanalyze samples. However, because the holding time had elapsed, the affected wells were resampled in July 1997.

The Navy is the lead for this site. MFA is responsible for on-site activities and oversight. EPA views the research activity as a means of remediating for a portion of the plume.

Cost Analysis

All costs for design, construction, and operation of the treatment system at this site are borne by the Navy and DoD.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Capital Costs

Remedial Construction	
System Installation	$323,000
Iron	$50,000
Total Remedial Construction	$373,000

Operating Costs

Monitoring/Analytical	$32,000[a]

[a]First annual monitoring and analytical contract

Cost Data Quality

Actual capital and operating and maintenance cost data are available from the Navy contact for this site.

OBSERVATIONS AND LESSONS LEARNED

- The cost for groundwater remediation at this site over one year was approximately $405,000 ($373,000 in capital costs and $32,000 in operating costs), corresponding to a unit cost of $1,400 per 1,000 gallons of groundwater treated.
- Based on sampling data from the January, April, and July sampling events, concentrations of PCE, TCE, and 1,2-DCE are being reduced as groundwater passes through the reactive zone.
- Data from monitoring points within the iron show that, by the fourth foot of iron, contaminant concentrations were reduced below detection limits.
- Mass flux was calculated from the quarterly data and an estimate of groundwater velocity from the tracer test conducted in July. Mass flux data have increased over the three sampling events indicating an increase in influent concentrations, while treatment goals continue to be met.
- ESTCP is sponsoring performance monitoring and cost data collection for technology certification and validation. Performance sampling is scheduled to continue on an annual basis for at least two more years. The final technology evaluation report is planned to be completed by August 1998. Proposals are being presented to continue the sampling process annually or semiannually.

REFERENCES

1. Draft Performance Monitoring Plan, Battelle Columbus Operations, Cleveland, Ohio, September 16, 1996.
2. Draft Operable Unit 4 Feasibility Study Report, PRC Environmental Management, Inc., Denver, Colorado, August 3, 1992.
3. April 1997 Monitoring Report for the Pilot Permeable Barrier at Moffett Federal Airfield, Battelle, September 1997.
4. Phone Conversations with Deidre O’Dwyer, June 21, 1997.
5. Phone Conversations with Tim Mower, Tetra Tech EM Inc., May 28, 1997.
6. Field Tracer Application to Evaluate the Hydraulic Performance of the Pilot-Scale Permeable Barrier at Moffett Federal Airfield, Battelle, October 1997.

References (Cont.)

7. Permeable Reactive Wall Remediation of Chlorinated Hyrdocarbons in Groundwater at Moffett Federal Airfield, Mountain View, California, IBC Proceedings, January 1998.

8. Comments on draft report from Chuck Reeter, NFRSC, July 8, 1998.

9. Comments on draft report from Michael Gill, Region IX RPM, July 17, 1998.

10. Comments on draft report from Tim Mower, Tetra Tech EM Inc., July 17, 1998.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.