COST AND PERFORMANCE REPORT

Demonstration of Two Recirculating Well Technologies
(UVB and NoVOCs) at the CS-10 Plume
at the Massachusetts Military Reservation
Cape Cod, Massachusetts

May 2002

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

SITE INFORMATION

IDENTIFYING INFORMATION

Site Name: Massachusetts Military Reservation (MMR)

Location: Cape Cod, Massachusetts

CERCLIS #: MA2570024487

ROD Date: September 1995

TREATMENT APPLICATION

Type of Action: Remedial

Scale: Demonstration

Period of Operation: Pilot testing - December 21, 1996 - May 1997
Continued operation of pilot systems through May 4, 1999

Quantity of Groundwater Treated During Application:

Pilot test (through May 1997) - UVB wells treated 23 million gallons; no information was provided for quantity of groundwater treated for the NoVOCs pilot test or for the continued operation of the systems through May 1999.

BACKGROUND

Historical Activity that Generated Contamination at the Site: Vehicle maintenance and fueling; storage of petroleum, oils, and lubricants (POL)

Waste Management Practice That Contributed to Contamination: Fuel spills and leaks from engine maintenance operations and underground storage tanks

Facility Operations [1,3,5]:

- MMR is a military training facility located in the upper western portion of Cape Cod, Massachusetts, about 60 miles southeast of Boston. MMR encompasses 21,000 acres and has three main areas: (1) the industrial area in the southern part of the reservation where the U.S. Coast Guard, Army National Guard, and Air National Guard facilities are located; this area contains aircraft runways, maintenance areas, access roads, housing, and support facilities; (2) the northern area, also known as Camp Edwards, which is used primarily by the Army National Guard and contains the 2,200-acre Impact Area, associated military training ranges, and the U.S. Coast Guard Air Station Cape Cod; and (3) the Veterans Administration Cemetery, located in the southwestern corner of MMR.

- Historical operations in the industrial area have included motor pools with vehicle maintenance and repair, parts cleaning, and painting operations; storage of petroleum products and hazardous materials; and disposal of wastes in landfills, drywells, sumps, and a sewage treatment plant. Leaks and spills from these operations resulted in soil and groundwater contamination, including contamination of the sole-source aquifer supplying drinking water for the western part of Cape Cod, known as the Upper Cape Aquifer.

- Installation Restoration Program (IRP) investigations performed from 1982 to 1985 identified more than 70 areas of concern at MMR and confirmed the presence of volatile organic compounds (VOCs) in residential wells and municipal drinking water supplies. MMR was added to the National Priorities List in 1989. Under a Federal Facilities Agreement signed in 1991, EPA is providing oversight of the MMR IRP activities.

- A Technical Review and Evaluation Team (TRET) was established in 1996 to provide technical assistance related to the remedial design plan for MMR. Members of the TRET include the Air Force, Army, EPA, Massachusetts Department of Environmental Protection (MADEP), Massachusetts Division of Fisheries and Wildlife, and U.S. Geological Service (USGS). The TRET recommended that pilot-scale testing of recirculating well technology be performed in the southeastern area of the CS-10 plume within the industrial area to evaluate the effectiveness of this innovative technology for reducing concentrations of contaminants in the groundwater.

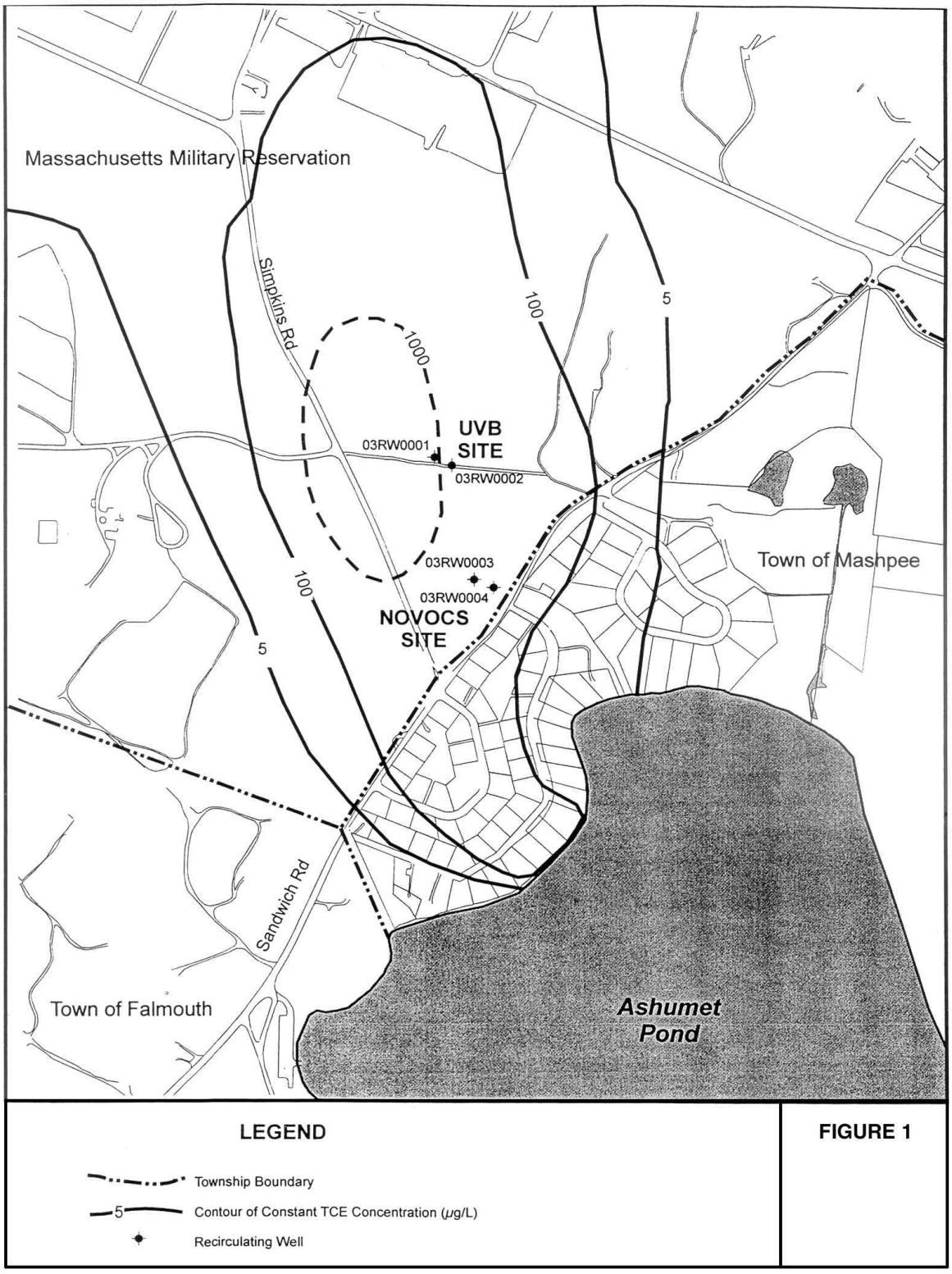
- The CS-10 plume (Figure 1) is one of several plumes originating from MMR, and was determined to be migrating towards Ashumet Pond (Figure 1). The primary source of the CS-10 groundwater plume was the 38-acre area of the former Boeing Michigan Aerospace Research Center Missile Site and Unit Training Equipment Site. Operations in this area included maintenance of fuel and engine systems, fueling and fuel removal, and power plant operation and resulted in contamination of soil and groundwater. The contaminants of concern within the CS-10 plume area are VOCs including trichloroethene (TCE), tetrachloroethene (PCE), and 1,2-dichloroethene (DCE).

- This report addresses the results of pilot-scale tests of two recirculating well technologies within the CS-10 plume: (1) UVB recirculating well technology, operated by SBP Technologies, Inc., under agreement with IEG Technologies Inc., the technology vendor; and (2) NoVOCs recirculating well technology, operated by Metcalf and Eddy, Inc., under agreement with EG&G Environmental, the technology vendor. The locations of the pilot tests are shown in Figure 1.

- The pilot test systems were originally scheduled to operate for a five-month period (late December 1996 to May 1997). EPA then decided to continue operation of the CS-10 pilot systems until the extraction, treatment, and reinjection (ETR) system became operational. The CS-10 ETR system was on line May 18, 1999 and the CS-10 recirculating well pilot test systems were permanently shut down on May 4, 1999.

Regulatory Context: Two recirculating well technologies were tested on a pilot-scale basis at the CS-10 plume at the recommendation of the TRET. The pilot testing was performed prior to installation of a groundwater extraction system, identified as the interim remedy for CS-10 groundwater contamination in the Record of Decision (ROD) signed in September 1995.

Figure 1. Location of UVB and NoVOCs Test Sites [1]



Groundwater Remedy Selection: The ROD specified extraction, treatment, and reinjection as the interim remedy for the CS-10 groundwater contamination. As stated in the ROD, selection of the final remedy will be based on the results of comprehensive RI/FSs being performed at the site.

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MATRIX DESCRIPTION

Matrix Identification [1,3,4]

Type of Matrix Processed through the Treatment System: Groundwater

Contaminant Characterization

Primary Contaminant Groups: VOCs

- The primary contaminants of concern in the CS-10 plume area are TCE, PCE, and 1,2-DCE. During the RI, conducted in 1993, concentrations of contaminants in the plume were found to be as high as 3,200 ug/L for TCE, 500 ug/L for PCE, and 58 ug/L for 1,2-DCE. In 1999, TCE concentrations as high as 4,000 ug/L were found in the CS-10 plume. Information was not provided about the concentrations of VOCs in the specific portions of the CS-10 plume where the pilot tests were conducted.

- The CS-10 plume has two distinct lobes - an easternmost lobe and a westernmost lobe.

- In 1993, the CS-10 plume extended approximately 12,500 feet downgradient from the source area, with a width of up to 3,600 feet and a thickness ranging from about 40 to 80 feet. In 1999, the CS-10 plume extended approximately 17,000 feet downgradient from the source area, with a width of up to 4,000 feet and a thickness of up to 140 feet.

Matrix Characteristics Affecting Treatment Costs or Performance [1]

Hydrogeology

MMR's geology includes three sedimentary units - Buzzards Bay Moraine, Sandwich Moraine, and Mashpee Pitted Plain (MPP). The CS-10 plume lies within the MPP unit, consisting of well to poorly sorted, fine- to coarse-grained sands, with discontinuous silty and clayey layers occurring in deeper sections of the unit. The unit is underlain by fine-grained lacustrine sediments and basal till, and by bedrock in some areas. A single alluvial aquifer (Sagamore Lens Aquifer) underlies MMR. The aquifer is unconfined and is recharged by infiltration from precipitation.

The specific hydrogeology for the UVB and NoVOCs pilot test areas was characterized during the drilling of the monitoring wells for the pilot tests. Groundwater flow in these areas is predominantly to the southeast and the aquifer is approximately 230 ft thick. Depth to groundwater ranges from 20 to 25 ft at the UVB site and from 10 to 15 ft at the NoVOCs site. Three hydrostratigraphic zones were identified beneath the test sites - upper, middle, and lower. These zones are underlain by bedrock.

Table 1 presents information about the hydrostratigraphic zones at each test site, including data on hydraulic conductivity and anisotropy. A vertical hydraulic gradient is present at the UVB site between a depth of 80 and 125 ft below mean sea level (msl), with the middle zone having a lower conductivity that prevents equilibration of the hydraulic heads. A high degree of vertical anisotropy (approximately 10) was observed within this zone at the UVB site.

Soil at both sites is predominately silt and sand with some clay and gravel. Table 2 presents the soil characteristics at each test site.

Table 1 - UVB and NoVOCs Test Sites - Hydrostratigraphic Zones [1]

Hydro-stratigra-phic Zone	Primary Lithology	Approximate Depth (ft below msl)	UVB Site Specific			NoVOCs Site Specific		
			K_h* (ft/day)	K_v* (ft/day)	Aniso-tropy	K_h* (ft/day)	K_v* (ft/day)	Aniso-tropy
Upper	sand	water table to 60	263	184	1.4	235	188	1.3
Middle	silty sand	60 to 130	152	15.2	10	162	29	5.6
Lower	sand and gravel	130 to 180	142	36.7	4	123	34	3.6

* K_h - Horizontal hydraulic conductivity; K_v - Vertical hydraulic conductivity

Table 2 - Soil Characteristics of the UVB and NoVOCs Test Sites [1]

Soil Parameter	UVB Site	NoVOCs Site
Porosity	14.3 - 36.3%	24.5 - 37.9%
Specific gravity	2.63 - 2.69	2.65 (average)

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Technology 1: UVB recirculating wells (with air stripping)
Technology 2: NoVOCs recirculating wells (with air stripping)

Supplemental Treatment Technology

Activated carbon filtration of air stripper vapors (for both technologies)

System Description and Operation [1,2]

- Two recirculating well technologies were pilot-tested within the CS-10 plume: (1) UVB recirculating well technology, and (2) NoVOCs recirculating well technology. The pilot tests were run concurrently and within the same general area (see Figure 1) to facilitate comparison of the two technologies under similar conditions.

- A description of the design and operation of the UVB and NoVOCs technologies used for the pilot tests is presented below, along with a description of the monitoring network.

- The pilot test systems were originally operated for a five-month period (late December 1996 to May 1997). As discussed above, EPA decided to continue operation of the CS-10 pilot systems until the ETR system became operational. The CS-10 ETR system was on line May 18, 1999 and the CS-10 recirculating well pilot test systems were permanently shut down on May 4, 1999.

UVB Technology

- A schematic of the UVB recirculating well system used for the CS-10 pilot test is shown in Figure 2. The technology uses an in-well stripping platform, operated under negative pressure, to transfer VOCs from water to air. As shown in Figure 2, the recirculating well has a four-screen design - two middle extraction screens (shown as a continuous screen on the figure) and one upper and one lower reinjection screens. Contaminated groundwater is pumped into the well through the extraction screens, and is then pumped to an air stripper, located in a vault at the well head. VOCs are stripped from the water under negative pressure, with the vapors filtered through granular activated carbon (GAC) prior to release to the atmosphere. Treated water from the air stripper is pumped back into the well and reinjected into the aquifer through the two reinjection screens.

- For the CS-10 pilot test, two UVB recirculating wells were used (03RW0001 and 03RW002), as shown on Figure 1. The wells were designed to induce two vertically adjacent recirculation cells that were intended to encompass the thickness of the plume (120 ft). All screens were 10 ft in length, with the extraction screens 0.015-inch slot and the injection screens 0.030-inch slot.

- In December 1996, the pumps began operating at 39 to 40 gpm at each recirculating well. In February 1997, the rate was increased to 59 to 61 gpm for the remainder of the pilot test. Each well was equipped with an air stripping unit that used a 7-hp vacuum blower to create negative pressure. A second air stripper unit was installed in March 1997. The influent air rate was increased gradually during the pilot test, ranging from 650 to 1,100 cfm. The air to water ratio ranged from 120:1 to 150:1 by volume. A second air stripper was added to each well in March 1997 to improve the efficiency of contaminant removal.

- Each well was equipped with an air treatment unit consisting of a primary 2,000 pound GAC unit and two secondary 140 pound units that were used during the servicing of the primary unit to treat vapors prior to release to the atmosphere.

NoVOCs Technology

- A schematic of the NoVOCs recirculating well system used for the pilot test is shown in Figure 3. The technology uses a double-cased, in-well vapor-stripping system to transfer VOCs from water to air. Pressurized air-lift pumping is used to extract water through screens located at the base of the plume (extraction screens are located at the outer and inner casings of the well) to the air stripper. VOCs are stripped from the water, with the vapors filtered through granular activated carbon (GAC) prior to release to the atmosphere. Treated water from the air stripper is directed through the reinjection screens (outer casing only) located in the upper portion of the plume. Water is reinjected into the aquifer as a result of the hydraulic head that develops in the outer annulus of the casing.

- For the CS-10 pilot test, two recirculating wells (03RW0003 and 03RW0004) were used, as shown in Figure 1. Each well was designed to induce the formation of one recirculation cell that was intended to encompass the thickness of the plume (110 ft). The outer extraction screens were 15 ft in length with 0.020 inch slot screens; the inner extraction screens were 20 ft long with 0.210 inch slot screens. The reinjection screens were 15 ft in length, with 0.020 inch slot screens. A fixed packer, just below the reinjection screens, was used to force the treated groundwater back into the top of the contaminated zone. The pumping rates for the recirculating wells were 160 gpm for 03RW0003 and 140 gpm for 03RW0004.

Figure 2. UVB Recirculating Well Schematic [1]

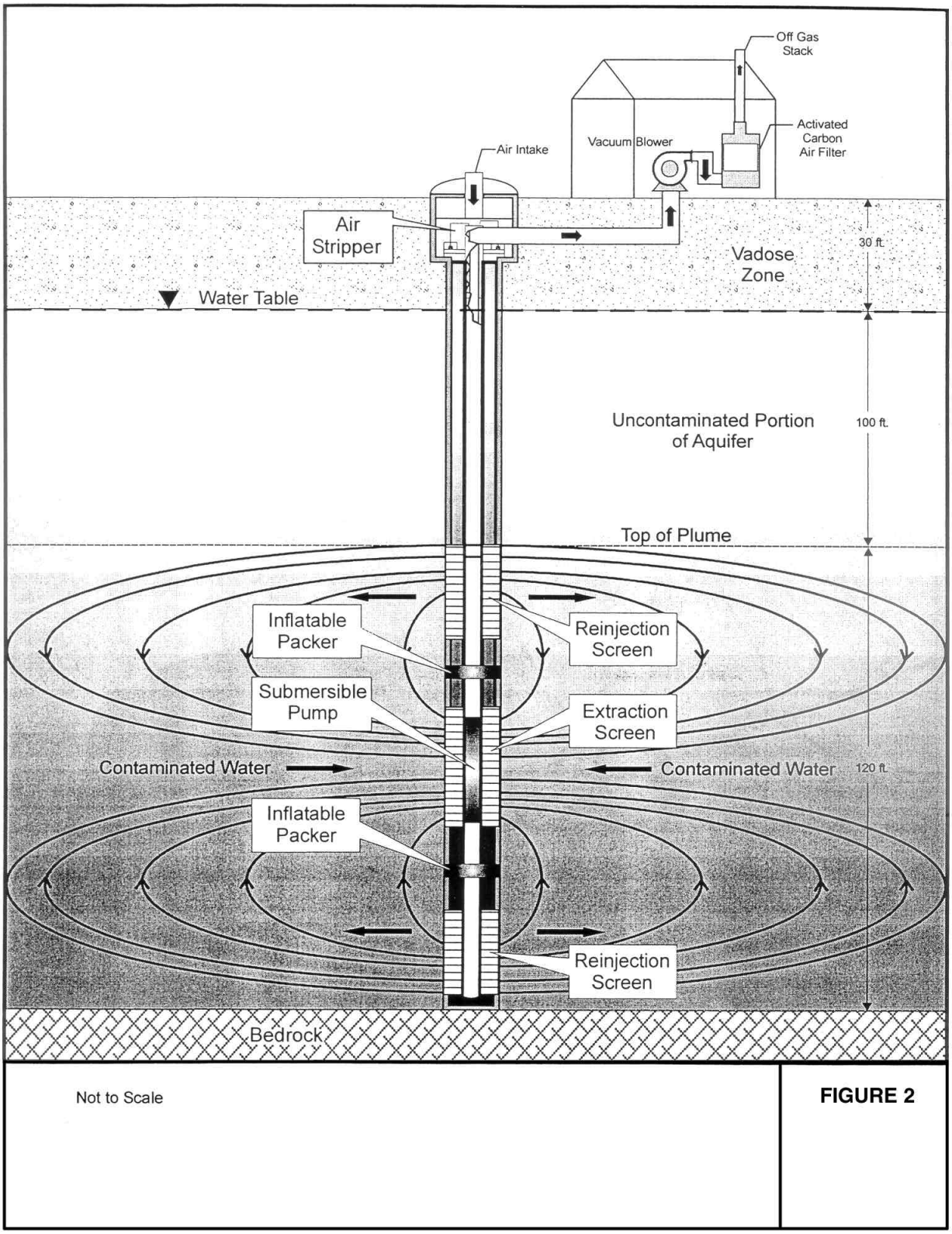
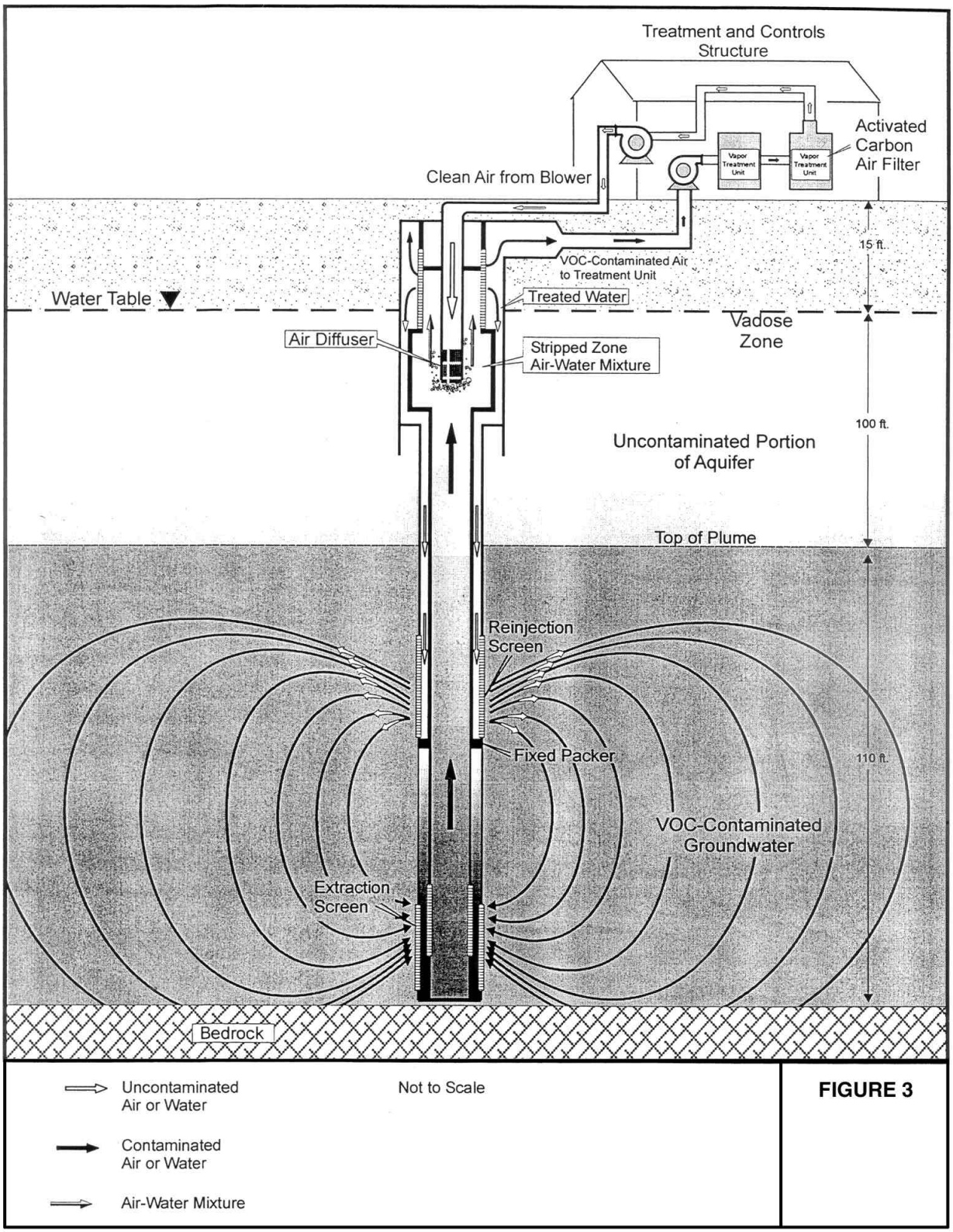


Figure 3. NoVOCs Recirculating Well Schematic [1]



- The air stripper included a 4-inch PVC injection air line and in-well diffuser. Two 30 hp regenerative blowers were used to supply filtered air to the diffuser. Air was reinjected back into the recirculating wells in a closed loop system.

- Air treatment included two 3,000 pound GAC units operated in series. A moisture separator, upstream of the carbon units, was used to remove water from the air stream prior to carbon treatment.

Monitoring Network

- The monitoring well network for each pilot test site was designed using data from the monitoring well survey. After the wells were installed at the test sites, it was determined that the well configurations were not oriented perpendicular to groundwater flow, as expected. Rather, the groundwater flow was oblique to the well configurations. According to Jacobs Engineering Group, the contractor to AFCEE for these tests, while having the well configurations oriented perpendicular to groundwater flow would have been optimal, the evaluation of the technologies was not significantly impaired by the oblique orientation of the wells.

- During the pilot test, a total of 24 monitoring wells were used to monitor the groundwater at each test site. The monitoring wells were grouped into eight clusters of three wells each. Wells within a cluster were screened at different depths to evaluate performance within the different hydrostratigraphic zones, as well as assess development of the recirculation cells at different depths.

- During the pilot tests, the monitoring wells were sampled monthly for VOCs, semivolatile organic compounds (SVOCs), 1,2-dibromoethane, metals, nitrates, and dissolved organic carbon. A total of five rounds of groundwater sampling were conducted as part of the pilot testing.

- In May 1997, 12 new monitoring wells were installed at each test site to continue monitoring the performance of the technologies. The new wells were installed in clusters of two (each well at a different depth), with the location based on the results of groundwater modeling that was performed using data from the pilot tests. The wells included two upgradient wells (to monitor influent contaminant concentrations); two crossgradient wells; and eight near-field wells, located between and downgradient of the cells (to monitor recirculation cell development and performance in treating groundwater contamination).

- The 12 wells were sampled once every two weeks for VOCs only from May to July 1997, for a total of four rounds of groundwater sampling. After July, the groundwater was monitored quarterly for VOCs until system shutdown in May 1999.

Operating Parameters Affecting Treatment Cost or Performance

Table 3 presents the major operating parameters affecting cost or performance for this technology for the pilot tests.

Table 3 - Performance Parameters for Pilot Test of UVB and NoVOCs Systems [1]

Parameter	Target Value for Pilot Tests
Performance Standard	TCE < 1 ug/L in discharge from air stripper (discharge from air stripper referred to as effluent, although all water was re-injected into subsurface)
Pumping Rate	UVB: 120 gpm (total for system) NoVOCs: 300 gpm (total for system)
Air Standards	Not provided

Timeline

Table 4 presents a timeline for the major milestones for the pilot tests.

Table 4 - Project Timeline [1]

Start Date	End Date	Activity
December 1996	May 1997	Pilot testing of UVB and NoVOCs technologies
May 1997	--	Installation of additional monitoring wells
June 1997	May 1999	Continued operation of the UVB and NoVOCs pilot systems
May 4, 1999	--	Shutdown of UVB and NoVOCs pilot systems
May 18, 1999	--	Start up CS-10 ETR system

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [1,4,5]

The pilot tests were conducted to assess the overall feasibility of using recirculating well technology as part of the remedy to cleanup contaminated groundwater at MMR. Feasibility was based on achieving "significant contaminant reduction" for the VOCs in the CS-10 plume. This goal was not further quantified in the available sources.

In addition, standards were established for the water treated by the air stripper and for emissions from the GAC units to the atmosphere. A performance standard was established as 1 ug/L for TCE in the discharge from the air stripper, with TCE used as a measure of total VOCs in the water, as shown in Table 3.

Performance Data Assessment [1,2]

- The performance of the UVB and NoVOCs pilot systems is discussed below for the pilot tests, conducted December 1996 to May 1997, and for the additional operation of these systems until May 4, 1999.

- The mass of contaminant removed by each system was estimated by Jacobs using two methods: (1) TCE concentrations in the groundwater ("water measurements"); and (2) TCE concentrations in the air ("air measurements"). These two methods provided varying results, as discussed below. The

water measurement was calculated based on the product of the change in concentration of TCE across the air stripper, the water flow rate, and the number of days operated. The air measurement was calculated based on the product of the TCE concentration entering the GAC unit, the air flow rate, and the number of days operated.

- Performance data for the pilot tests was evaluated based on the mass of TCE removed by the technologies, the changes in concentrations in the three hydrostratigraphic zones, and the changes in concentrations in the upper and lower recirculation cells, as well as the concentration of TCE in the discharge from the air stripper. The upper recirculation cell consists of the upper and part of the middle hydrostratigraphic zones, while the lower cell consists of the lower and part of the middle zones. The recirculation cells were examined for evidence of the formation and stability of recirculation areas.

- Performance data for the continued operation were evaluated based on the changes in concentrations in upgradient, crossgradient, and near (down) gradient wells.

UVB Recirculating Well Technology

Pilot Test - December 1996 to May 1997 [1,2]

- The UVB pilot test was conducted over a period of 153 days, and was operational 97% of the time.

- As shown in Figure 4, the cumulative mass of TCE removed during the pilot test (through May 1997) was about 18 kg, based on water measurements. TCE mass removal was also calculated using air measurements. The results (about 20 kg removed) were consistent with the mass removal estimated based on water measurements.

- The TCE mass flux rate of the system decreased from 0.25 kg/day to 0.15 kg/day within the first month of operation, and then to about 0.06 kg/day by the end of the test.

- During the pilot test, TCE concentrations in the groundwater were reduced in the upper and lower hydrostratigraphic zones, and remained relatively stable in the middle zone, as shown in Table 5.

- PCE and 1,2-DCE concentrations in groundwater decreased by 32% and 46%, respectively, during the pilot test. Jacobs concluded that PCE and 1,2-DCE did not appear to be a significant indicator of groundwater contamination at the site.

- During the first two months of operation, TCE concentrations in the air stripper effluent had decreased to 45 ug/L in well 03RW0001 and 20 ug/L in well 03RW0002 (a reduction of about 88%). By May 1997, two months after a second air stripper was installed, TCE concentrations in the effluent were reduced to 4.5 ug/L. The TCE concentration in the effluent from the UVB air stripper treatment system at the end of the pilot test remained at 4.5 ug/L, which was above the performance goal of 1 ug/L.

- In addition, TCE concentrations were monitored in the upper and lower portions of the UVB recirculation cells. These results (Table 6) indicated that TCE concentrations were being reduced in the lower portion of the recirculation cell but not in the upper portion of the recirculation cell.

Figure 4. TCE Mass Flux Rate and Cumulative TCE Removal from the UVB Recirculating Well System (Water Measurements) [2]

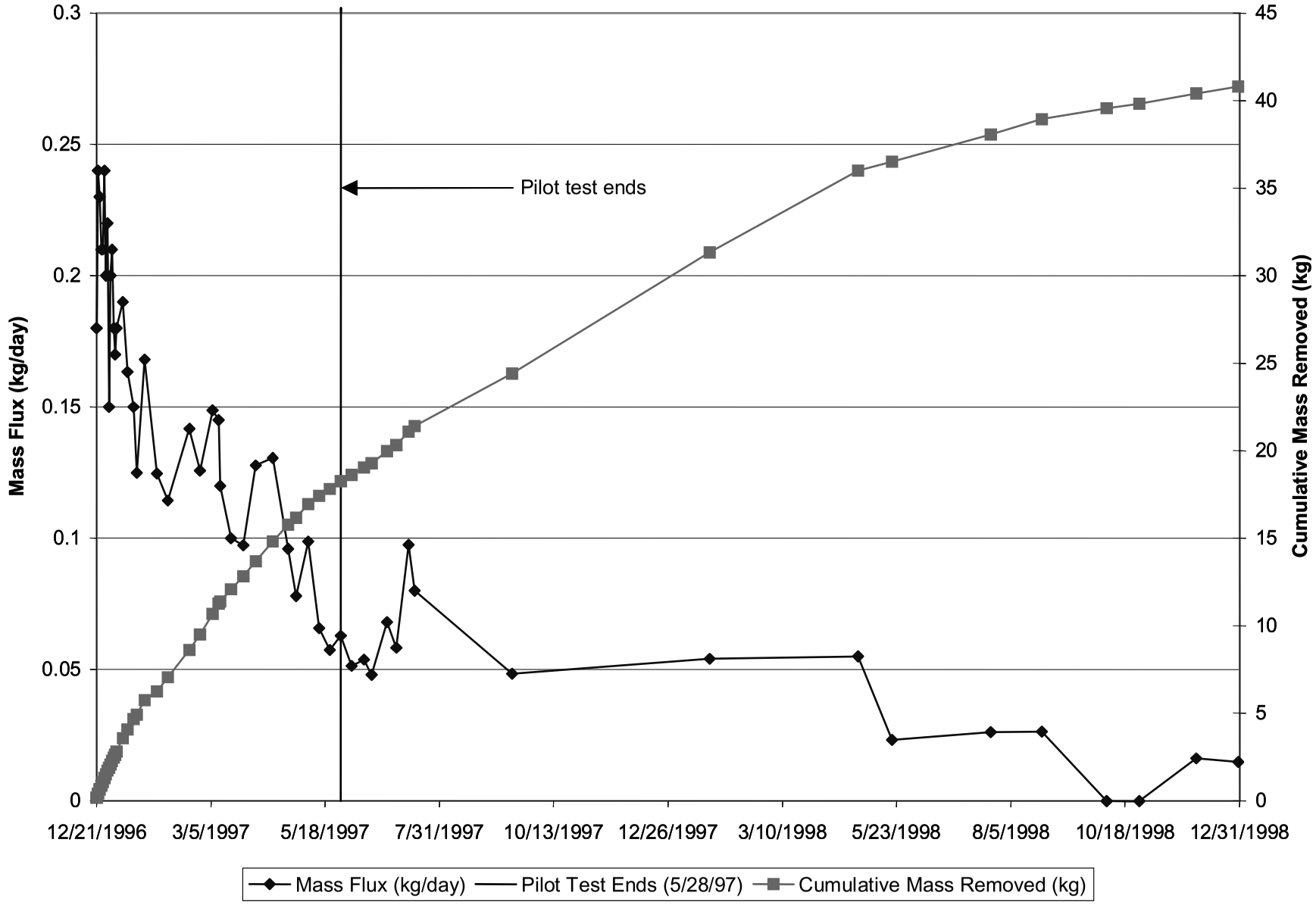


Table 5 - TCE Concentrations in Three Hydrostratigraphic Zones at UVB Test Site [1]

Zone	Results
Upper Zone	TCE concentrations were reduced to levels below quantification limit (<1 ug/L) by the end of the pilot test. However, TCE concentrations were less than 5 ug/L at the start of operations.
Middle Zone	TCE concentrations remained relatively stable at about 1,200 ug/L to 1,500 ug/L.
Lower Zone	TCE concentrations were reduced from levels as high as 3,900 ug/L to concentrations ranging from 45 ug/L to 440 ug/L.

Table 6 - TCE Concentrations in Upper and Lower Portion of UVB Recirculation Cell [1]

Portion of Recirculation Cell	Results
Upper Recirculation Cell	TCE concentrations remained the same or increased in wells screened in the upper portion of the recirculation cell. For example, TCE concentrations in well MW203E remained at about 1,200 ug/L, while concentrations in well MW207E increased from about 550 ug/L to 1,500 ug/L.
Lower Recirculation Cell	TCE concentrations generally decreased in wells screened in the lower portion of the recirculation cell. For example, in wells MW201F and MW206F, TCE concentrations decreased by more than 90% (3,200 ug/L to 300 ug/L, and 2,300 ug/L to 200 ug/L, respectively).

UVB Operation - June 1997 through May 1999 [2,5]

- Groundwater samples were collected from the 12 upgradient, crossgradient, and near field monitoring wells on a quarterly basis from June 1997 through April 1999. Table 7 presents a summary of these data.

- Since system startup, the UVB system has been operational 83 to 88% of the time. As shown in Figure 4, 41 kg of TCE were removed from the groundwater by the UVB recirculating well technology through December 31, 1998 (based on water measurements). During this period, the mass flux through the system decreased to 0.02 kg/day. Data available through April 1999 showed a cumulative TCE mass removed of 42.32 kg. The total mass of TCE removed by the system through shutdown on May 4, 1999 was estimated to be 42.5 kg, based on days of operation and previous daily mass removal rates.

NoVOCs Recirculating Well Technology

Pilot Test - December 1996 to May 1997 [2]

- The NoVOCs pilot test was conducted over a period of 157 days. The system was operational 80% of the time.

Table 7 - UVB System Performance June 1997 to May 1999 [2,5]

Well Cluster	Results
Upgradient well cluster	• Overall, TCE concentrations in upgradient wells have decreased, indicating that TCE influent concentrations to the UVB system are less than were found during the pilot study. • TCE concentrations decreased from as high as 3,760 ug/L (June 1997) to about 38 ug/L in the shallow well (03MW0223D) and 1,200 ug/L in the deep well (03MW0223F). • Results of the third and fourth quarter sampling in 1998 showed TCE concentrations in the shallow well remaining stable at 38 ug/L with some variation in the deep well (897 ug/L and 1,200 ug/L). • Results for the 1999 sampling round (March - April 1999) showed that TCE concentrations had decreased in the shallow well from 38 ug/L to 29 ug/L and in the deep well from 1,200 ug/L to 930 ug/L.
Crossgradient well cluster	• In the deep well (03MW222F), TCE concentrations initially decreased from about 15 ug/L to about 9 ug/L, remained relatively stable through the second quarter of 1998, then increased in the third and fourth quarters of 1998 to 16 ug/L and 27 ug/L, respectively. • TCE had not been detected in the shallow well (03MW222D) since the second quarter of 1997, and the well was removed from the sampling program.
Near-field well clusters	• Results of monitoring well sampling from these wells indicates that recirculation cell development is occurring in the UVB system and that the UVB system is continuing to reduce TCE concentrations in the groundwater. • Data from six of the eight near-field wells (03MW0202G, 03MW0203E, 03MW0204C, 03MW0204D, 03MW0206G, and 03MW0057A) have shown reductions in TCE concentrations since June 1997. – In downgradient well 03MW0203E, TCE concentrations have been reduced from 1,500 ug/L to 450 ug/L, with TCE concentrations in the 1999 sampling round ranging from 440-450 ug/L. – In wells located between the recirculating wells, 03MW0204C and 03MW0057A, TCE concentrations have been reduced to non detect and 838 ug/L, respectively. – During the fourth quarter of 1998, slight increases in TCE concentrations were observed in wells 03MW0202G and 03MW0203E (located near the recirculating well 03RW0001). The increases coincided with a shutdown of the recirculating well about two months before the sampling event. Decreases in TCE concentrations were observed during the 1999 sampling round, According to Jacobs Group, this indicates a strong hydraulic connection between the monitoring wells and the recirculating well. • TCE concentrations in two downgradient wells (03MW0204F and 03MW0206F) have fluctuated over time. During the 1999 sampling, TCE concentration in well 03MW0204F had decreased to 829 ug/L from 920ug/L in 1998. TCE concentrations in well 03MW0206F have increased from 790ug/L in November 1998 to 1,200 ug/L in 1999. According to Jacobs Group, these results suggest the zone of treated water created by the recirculation wells may be narrower than predicted by the modeling results.

- As shown in Figure 5, the cumulative estimated mass of TCE removed by the NoVOCs system during the pilot test was about 43 kg, based on air measurements. TCE mass removal was also calculated using water measurements, with an estimated mass removed of about 150 kg. However, there was considerable fluctuation with influent groundwater TCE concentrations and, according to Jacobs Group, the mass removal based on air measurements was considered to be more accurate. Reasons cited for using the air measurements included the observed consistent downward trend of TCE concentrations in influent air and consistency with the UVB system removal rates, taking into consideration the difference in pumping rates of the two systems.

- Information was not provided about the TCE mass flux rate of the system during the pilot test.

- During the pilot test, TCE concentrations in the groundwater remained stable, as shown in Table 8.

Table 8 - TCE Concentrations in Three Hydrostratigraphic Zones at NoVOCs Test Site [1]

Zone	Results
Upper Zone	TCE concentrations, which were below the detection limit (<1 ug/L) at the start of operations, remained below the detection limit for the duration of the pilot test.
Middle Zone	TCE concentrations, which were below the detection limit at the start of operations, remained below the detection limit for the duration of the pilot test.
Lower Zone	TCE concentrations remained relatively stable at about 1,300 ug/L.

- PCE and 1,2-DCE concentrations in groundwater at the test site decreased by 68% and 80%, respectively. Jacobs Group concluded that PCE and 1,2-DCE did not appear to be a significant indicator of groundwater contamination at the site.

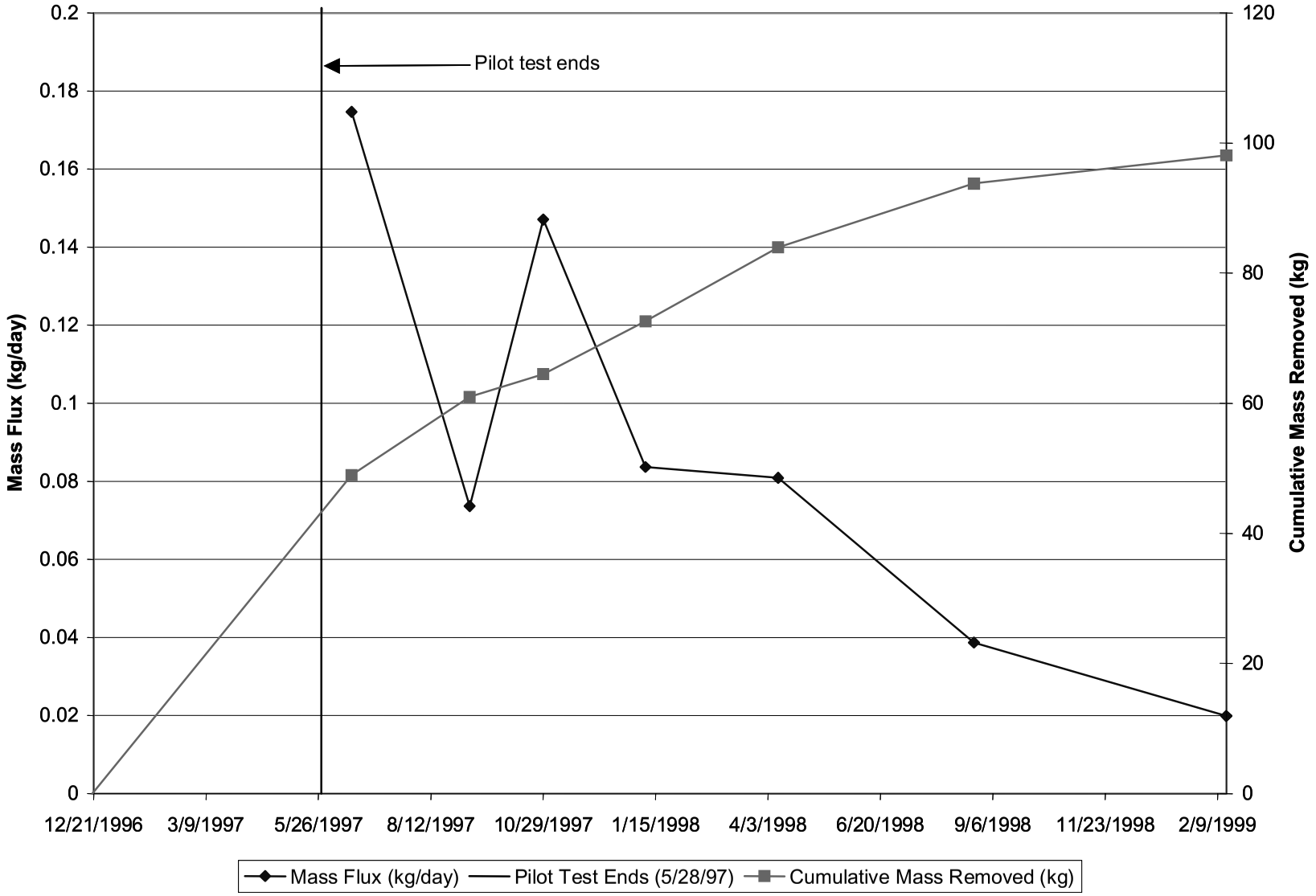
- In addition, TCE concentrations were monitored in the middle and lower portions of the NoVOCs recirculation cells. These results (Table 9) indicated that TCE concentrations were being reduced in the middle portion of the recirculation cell and increased in the lower portion. According to Jacobs Group, the increase in TCE concentrations in the lower portion of the recirculation cell is consistent with recirculation cell development.

Table 9 - TCE Concentrations in Middle and Lower Portion of NoVOCs Recirculation Cell [1]

Portion of Recirculation Cell	Results
Middle Recirculation Cell	TCE concentrations decreased in the majority of the monitoring wells screened in the middle portion of the recirculation cell. Reductions in TCE concentrations as high as 97% were observed in well 03MW213C (2700 ug/L to 100 ug/L), and 92% in well 03MW211E (2,300 ug/L to 150 ug/L).
Lower Recirculation Cell	In wells screened in the lower portion of the recirculation cell, TCE concentrations increased in wells 03MW209F (200 ug/L to 1,500 ug/L) and 03MW212F (600 ug/L to 800 ug/L).

- At the end of the pilot test, TCE concentrations in the effluent from the air strippers was 69 ug/L in the upgradient recirculating well and 43 ug/L in the downgradient recirculating well, above the target goal of 1 ug/L. The average stripping efficiency for the NoVOCs system was 92%.

Figure 5. TCE Mass Flux Rate and Cumulative TCE Removal from NoVOCs Recirculating Well System (Air Measurements) [2]



NOTE: Mass flux rate data not available for NoVOCs pilot test.

NoVOCs Operation - June 1997 through May 1999 [2,5]

- Groundwater samples were collected from the 12 upgradient, crossgradient, and near field monitoring wells on a quarterly basis from June 1997 through April 1999. Table 10 presents a summary of these data.

Table 10 - NoVOCs System Performance June 1997 to May 1999 [2,5]

Wells Cluster	Results
Upgradient wells	• The influent TCE concentrations to the NoVOCs system have varied significantly during this period of operation. • TCE concentrations in the shallow well (03MW0224C) initially decreased fro 2,490 ug/L in May 1997 to 1,400 ug/L in the fourth quarter of 1998, then increased to 3,400 ug/L in 1999. TCE concentrations in the deep well (03MW0224E) have generally decreased, with some variation observed. Concentrations decreased from 5,110 ug/L to 2,110 ug/L by the second quarter of 1998, then increased in the third and fourth quarter of 1998 to 2,900 ug/L. Sampling results for 1999 showed a decrease in TCE concentrations to 2,000 ug/L.
Crossgradient wells	• TCE concentrations in the shallow well (03MW022D) have varied between about 25 ug/L and 53 ug/L during operation, with the results from the 1999 sampling showing a decrease to 37 ug/L from 52.5 ug/L in May 1998. TCE concentrations in the deep well (03MW022E) have fluctuated significantly, with concentrations varying from 2,860 ug/L to 226 ug/L through the second quarter of 1998, then increasing to 4,200 ug/L by the fourth quarter of 1998. Results for 1999 show TCE concentrations in this well increasing to 4,800 ug/L.
Near field wells	• TCE concentration data for these wells has varied, with trends in TCE concentrations significantly affected by unplanned shutdowns of the system. According to Jacobs, the TCE concentration trend at one well only (03MW0212F) is consistent with the establishment of a recirculation zone. • TCE concentrations at well 03MW0212F initially increased to 1,940 ug/L in May 1997 then decreased to 320 ug/L in November 1998 and 240 ug/L in 1999.

- As shown in Figure 5, as of December 30, 1998, more than 90 kg of TCE were removed from the groundwater by the NoVOCs recirculating well technology (based on air measurements), and the mass flux through the system decreased to 0.02 kg/day. Data available through April 1999 showed a cumulative TCE mass removed of 98.1 kg. The total mass of TCE removed by the system through shutdown on May 4, 1999 was estimated to be 99.2 kg, based on days of operation and previous daily mass removal rates.

- Overall, data collected from June 1997 to April 1999 showed significant variation in TCE concentrations, and Jacobs indicated that this variation made interpretation of results difficult. According to Jacobs, a number of unplanned shutdowns of the NoVOCs system during this time (Table 11) affected system performance. In addition, variability in TCE concentrations in upgradient wells complicated the ability to interpret data from crossgradient and downgradient wells.

Table 11 - NoVOCs System Shutdowns [2,5]

Date	Reason for Shutdown
Fourth quarter 1997	Both NoVOCs wells were operated half time because of problems with spent carbon and equipment (a faulty float valve)
February 1998	Both NoVOCs wells were off-line for three weeks because of a faulty electrical relay
March 1998	Well 03RW0003 was taken off-line because of a problem with one of the blowers; operation was continued with one blower until September 1998
December 1998 and January 1999	Well 03RW0004 was taken off-line because of drilling operations to install the CS-10 extraction, treatment, and reinjection system
February 1999 through March 1999	Well 03RW0004 was taken off-line because of blockage of the well screen and internal components

Overall Performance of UVB and NoVOCs Recirculating Well Technology [1,2]

The results of the pilot study and continued operation of the two systems indicate that recirculating well technology has reduced concentrations of TCE, PCE, and 1,2-DCE in groundwater at the CS-10 test site. However, Jacobs indicated that an accurate comparison of the two technologies in terms of contaminant reduction could not be made from the available data for several reasons including differences in lithology and upgradient TCE concentrations at the two test sites, significant variation in TCE concentration reduction trends at the NoVOCs site (associated with unplanned shutdowns of the system), and differences in recirculation cell development.

Performance Data Completeness [1,2,5]

Groundwater monitoring data were available through April 1999. Data were available for the five rounds of groundwater sampling conducted during the pilot testing, with samples collected monthly (January to May 1997) and analyzed for VOCs, SVOCs, 1,2-dibromoethane, metals, nitrates, and dissolved organic carbon. In addition, data were available from additional monitoring wells, installed in May 1997 and sampled once every two weeks for VOCs only from May to July 1997 and quarterly for VOCs through April 1999.

Performance Data Quality [1,2,5]

The QA/QC program used throughout the remedial action met EPA and the State of Massachusetts requirements. All monitoring was performed using EPA-approved methods, and the site contacts did not note any exceptions to the QA/QC protocols.

TREATMENT SYSTEM COST

Procurement Process [1]

AFCEE contracted the operation of the UVB pilot test location to SBP Technologies, Inc., under agreement with IEG Technologies, Inc., the supplier of the UVB recirculating well technology. AFCEE contracted the operation of the NoVOCs pilot test location to Metcalf and Eddy, Inc., under agreement with EG&G Environmental, the supplier of the NoVOCs recirculating well technology.

Cost Analysis [5]

AFCEE provided the following information about the actual cost for the CS-10 recirculating well pilot test and subsequent operational period.

Element	Cost
Plans	$331,000
Construction	$554,000
Drilling	$1,583,000
Sampling	$635,000
Post Construction Report	$77,000
Project Management Support	$422,000
Proposal	$1,000
TOTAL	**$3,603,000**

OBSERVATIONS AND LESSONS LEARNED

The results of the pilot test and continued system operation indicate that recirculating well technology reduced the concentrations of TCE, PCE, and 1,2-DCE in groundwater at the CS-10 test site. After approximately two years of operation, the UVB and NoVOCs systems removed 42.5 kg and 99.2 kg of TCE, respectively. According to Jacobs, AFCEE's contractor for the pilot tests, the amount of contaminant removal between the two systems is comparable, considering the pumping rate of the systems - NoVOCs system (300 gpm) was about 2.5 times the UVB system (120 gpm).

According to Jacobs, the results of the pilot tests indicate that recirculating well system hydraulics are more sensitive to site specific hydrogeologic conditions than extraction, treatment, and reinjection. For example, the high degree of vertical anisotropy (10) observed in the middle hydrostratigraphic zone at the UVB site may have inhibited the development of the vertical circulation cells and potentially reduced the capture zone of a given well. In addition, modeling results indicated that the presence of low hydraulic conductivity layers (less than 1.5 ft/day) can inhibit the establishment of effective recirculation wells. As such, Jacobs indicated that designs for recirculation wells should optimize screen placement to avoid inducing vertical flow through low hydraulic conductivity layers.

REFERENCES

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4. U.S. EPA Record of Decision. Otis Air National Guard (Containment of 7 Groundwater Plumes), MA. September 25, 1995.

5. Letter from Smith, Spence, HQ AFCEE/MMR to Richard Weisman, Tetra Tech EM Inc., Additional Information for the Draft Case Study for MMR, December 18, 2001.

Analysis Preparation

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