COST AND PERFORMANCE REPORT

Aerobic Degradation Field Demonstration at Site 19,
Edwards Air Force Base, California

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

Aerobic Degradation Field Demonstration
at Site 19, Edwards Air Force Base, California

Summary Information [1,2,3]

Site Name, Location	Edwards Air Force Base, CA
EPA ID Number	CA1570024504
Mechanism(s)	Aerobic Oxidation (Cometabolic and Direct)
Technology	Electron Acceptor Addition (Oxygen and Hydrogen Peroxide) Electron Donor Addition (Toluene)
Configuration	Groundwater Recirculation
Technology Scale	Field demonstration
Media/Matrix Treated	Groundwater
Contaminants Targeted	TCE
Period of Operation	February 5, 1996 to April 1, 1997

Site History/Source of Contamination [3,7]

Edwards Air Force Base (AFB), located on the western portion of the Mojave Desert, about 60 miles north of Los Angeles, covers approximately 301,000 and is used for aircraft research and development. From 1958 through 1967, engines for the X-15 rocket airplane were maintained in facilities at the site, and trichloroethene (TCE) was used to clean the engines. The used TCE was disposed of at Site 19, an area of about 53 acres on the west side of Rogers Dry Lake, resulting in groundwater contamination. The contaminant plume extends approximately 3,200 ft down-gradient from the contamination source, and nearly the same distance cross-gradient. This site was added to the National Priorities List (NPL) on August 30, 1990, and is being addressed through Federal actions. A Record of Decision (ROD) had not been signed for this facility at the time of this report.

A field demonstration of aerobic biodegradation was performed at Site 19. The area of the plume used for this field demonstration was about 400 meters (m) east of the contamination source.

Geology/Hydrogeology/Contaminant Characterization [3,8,9,10]

The Site 19 demonstration area contains two relatively homogeneous aquifers. The upper, unconfined aquifer is 8 m thick, and is separated by a 2 m aquitard from the lower confined aquifer. The lower, confined aquifer is approximately 5 m thick and lies above weathered bedrock. At the demonstration site, the concentration of TCE in the groundwater plume varied between 500 and 1,200 micrograms per liter (μg/L), with average TCE concentrations in the upper and lower aquifer of 680 and 750 μg/L, respectively. No 1,1-DCE was found at the site prior to the demonstration.

Matrix Characteristic	Value
Soil Type	fine to medium sized sand mixed with some silt
Depth to Groundwater	9 m below ground surface (bgs)
Thickness of Aquifer(s)	15 m (total)
Fraction of Organic Carbon	0.0001 to 0.0004
Hydraulic Conductivity	1.5 to 5.5 x 10^{-3} cm/sec to east/southeast (average 3.4 x 10^{-3} cm/sec)
Groundwater Velocity	6.9 centimeters/day

Technology Description [3,4,6,8]

The in situ bioremediation treatment system used at this site, shown in Figure 1, consisted of two 8-in diameter, PVC treatment wells installed approximately 24 m deep and spaced 10 m apart. Each treatment well was screened in both the upper and lower aquifers (15 m and 10 m, respectively), and a submersible pump, placed in each well, was used to draw contaminated water into the well through one of the screens. The initial flow rate for the wells was 38 liters per minute (L/min) to limit drawdown in the upper aquifer and pressure changes in the lower aquifer. The primary substrate (toluene) and oxygen were introduced into the wells via feed lines and mixed with the water using static mixers inside the wells. The groundwater, containing TCE, toluene, and oxygen, was discharged from the second screen into the aquifer, where a treatment zone developed around the well. Treatment well 1 (T1) withdrew water from the upper aquifer and discharged it into the lower aquifer, while treatment well 2 (T2) withdrew water from the lower aquifer and discharged it into the upper aquifer. This process recirculated the water between the two aquifers creating a bioreactive treatment cell.

Treatment system operation included groundwater pumping, pulsed addition of toluene, and addition of dissolved oxygen (DO, as gaseous oxygen) and hydrogen peroxide (H_2O_2). The system was operated for 444 days. The demonstration included five phases, during which time the operating parameters were varied as follows:

(1) pre-operational studies (days 0 - 33)
(2) establishment of a toluene-degrading consortium (days 34 - 55)
(3) pre-steady-state operation (days 56 - 136)
(4) steady-state operation (days 142 - 271)
(5) balanced flow operation (days 317 - 444)

Operating parameters for steady-state and balanced flow periods, which correspond to results provided below, are shown in Tables 1 and 2.

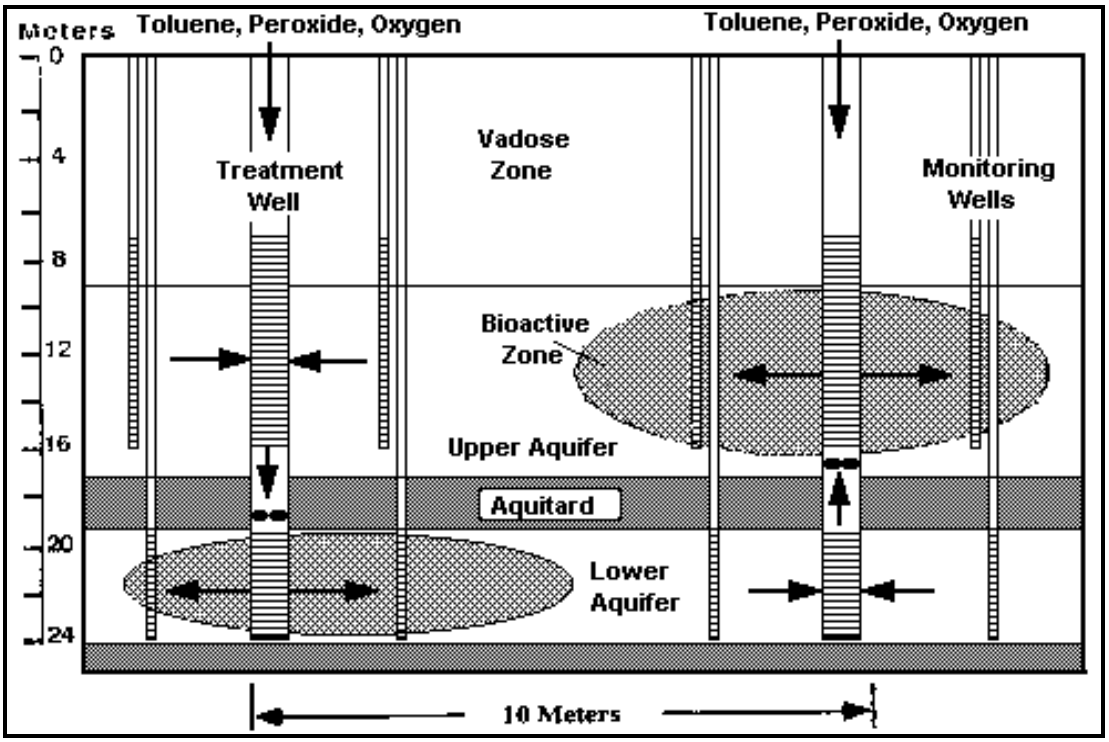
Table 1. Operating Parameters for Steady-State Operation (Days 142 - 271) [3]

Treatment Well	Groundwater Pumping Rate (L/min)	Toluene Addition (mg/L)	Toluene Addition - Pulses per Day	DO Addition (mg/L)	H_2O_2 Addition (mg/L)
T1	25	0 - 11.6	0.67 - 1	44	17 - 117
T2	38	13.4	1	29	47 - 63

Table 2. Operating Parameters for Balanced Flow Operation (Days 317 - 444) [3]

Treatment Well	Groundwater Pumping Rate (L/min)	Toluene Addition (mg/L)	Toluene Addition - Pulses per Day	DO Addition (mg/L)	H_2O_2 Addition (mg/L)
T1	25	9.0	0.67	44	47
T2	25	9.0	0.67	44	47

Figure 1: Cross-section of two-well treatment system used at Edwards AFB [3]



Technology Performance [2,8,9,10]

The objectives of the pilot study at Edwards AFB were to evaluate the advantages and limitations of *in situ* bioremediation for full-scale aquifer remediation. Specific remedial goals (contaminant concentrations in groundwater) were not established for the demonstration.

An area of 480 m^2 (0.12 acres) was monitored using 20 monitoring wells. Fourteen of the monitoring wells surrounded treatment wells T1 and T2 in a diamond formation, and two wells were nested between the treatment wells. Other wells were located at the "compass points" (North, South, East, West) surrounding the site. The 14 diamond formation wells and three of the four compass point wells were screened in both the upper and lower aquifers, allowing sampling from each aquifer independently. 10,500 samples were collected and analyzed automatically at the site throughout the course of the demonstration.

Comparison of measured TCE concentrations at the treatment well discharge screens, and at monitoring wells located 7.5 m away from the screens, allowed estimation of TCE removal in the bioactive treatment zones surrounding the discharge screens. The results from these analyses, during steady-state and balanced flow operation, are presented in Table 3.

Table 3. TCE Concentrations During Steady-state and Balanced Flow Operation [3]

Treatment Well - Aquifer	Operating Period (Days)	Average TCE Concentration in Treatment Well (µg/L)	Average TCE Concentration in Monitoring Well 7.5 m Distant (µg/L)	TCE Removal % (average and standard deviation)
T1 - lower	145 - 204	80	17	79 ± 42
T1 - lower	212 - 271	63	26	59 ± 22
T1 - lower	365 - 444	107	18	83 ± 16
T2 - upper	145 - 204	304	46	85 ± 9
T2 - upper	212 - 271	254	29	89 ± 7
T2 - upper	365 - 444	171	24	86 ± 9

Table 3 shows that the average reduction of TCE during steady-state operation (days 145 - 271) was 87% in the upper aquifer bioactive zone and 69% in the lower aquifer adjacent to treatment well T1 discharge screen. During balanced flow operation (days 365 - 444), the average removal of TCE was 86% and 83% in the upper and lower aquifer bioactive zones, respectively. Over the duration of the demonstration, TCE concentrations were reduced by 97.7%, from 1,150 µg/L (groundwater moving into the study area) to 27 µg/L (groundwater moving out of the study area) and toluene removal generally exceeded 99.98% . According to the researchers the overall TCE concentration reduction of 97.7% is higher than the removals reported in Table 3 as groundwater recirculated through the bioactive zone multiple times during the overall demonstration. The dual-well system was found to be technically feasible for remediation of TCE in a two aquifer system.

No information was provided about potential degradation products from this demonstration. The researchers presumed that toluene degraded aerobically to carbon dioxide and water, and TCE was cometabolized, ultimately producing carbon dioxide, water, and chloride ions. No exceptions to established quality assurance/quality control (QA/QC) protocols were noted in the available information.

Technology Cost [5]

Table 4 provides the actual cost for the in situ bioremediation treatment system used for the demonstration at Edwards AFB, including capital and operation and maintenance costs. Software is available [5] for estimating costs of applying this technology at a site with specified characteristics. These actual costs are provided as an example in the software user's guide.

Table 4. Actual Costs for the Field Demonstration at Edwards AFB [5]

Cost Element	Actual Cost (1995-1996 $)
Capital - Treatment wells (2)	30,000
Capital - Other treatment equipment - flow sensors and controllers, static mixers, packing assembly, deionized water system, pumps and ancillary equipment, tubing and connectors, valves and fittings)	32,707
Capital - Monitoring wells	190,000
Capital - Monitoring equipment (pumps and ancillary equipment, tubes and connectors, valves and fittings, miscellaneous supplies)	70,746
Total Capital Costs	**323,453**
Annual O&M - Materials - Well Redevelopment ($4,000/well-year x 2 wells)	8,000
Annual O&M - Materials - Hydrogen Peroxide, 30%	4,633
Annual O&M - Materials - Toluene	47
Annual O&M - Materials - Oxygen Gas	1,674
Total Annual O&M Costs	**14,354**

Volume of Water in Test Area	1,160 m^3
Volume of Water Pumped	12,132 m^3 from upper to lower aquifer 16,063 m^3 from lower to upper aquifer

Summary Observations and Lessons Learned [3]

The dual-well system met the objectives of the pilot study, and was found to be technically feasible for remediation of TCE in a two aquifer system. In addition, this technology might be feasible for use in a single aquifer system where low permeability layers separate lower and upper zones, and where vertical hydraulic conductivity is significantly lower than horizontal conductivity. Alternatively, with a relatively homogeneous single aquifer system, groundwater might be pumped to the surface from one location and then reinjected at another location with chemical amendments added at the surface or down-well at the injection location.

Prevention of well clogging was found to be an important operational concern for application of this technology. In this demonstration, site operators used well redevelopment (three times in the upper and twice in the lower aquifer) and addition of hydrogen peroxide to control clogging. Control of clogging contributed most to the operational costs of this application. Clogging was found to depend on the characteristics of the aquifer; the coarser the material, the less likely it is to clog.

The extensive network of monitoring wells was a key contributor to capital cost of this application. The monitoring system was installed to allow a detailed evaluation of the treatment system's performance. Monitoring of this magnitude would likely not be required for a full-scale application.

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References:

1. U.S. EPA. 1998. Fact Sheet. Edwards Air Force Base, California, http://epainotes1.rtpnc.epa.gov. December 15.

2. Record of Telephone Conversation. 1998. Richard Weisman, Tetra Tech EM Inc. and David Steckel, Edwards Air Force Base. December 1.

3. McCarty, Perry L., Mark N. Goltz, Gary D. Hopkins, Mark E. Dolan, Jason P. Allan, Brett T. Kawakami, and T.J. Carrothers. 1998. Environmental Science Technology. Full-Scale Evaluation of In Situ Cometabolic Degradation of Trichloroethylene in Groundwater Through Toluene Injection. Volume 32, Number 1: 88-100.

4. Lang, Margaret M., Paul V. Roberts, and Lewis Semprini. 1997. Groundwater. Model Simulations in Support of Field Scale Design and Operation of Bioremediation Based on Cometabolic Degradation. Volume 35, Number 4: 565-573.

5. U.S. Air Force, Center for Environmental Excellence, Environmental Restoration Division. 1998. Installation Restoration Program: Aerobic Cometabolic In Situ Bioremediation Technology Guidance Manual and Screening Software User's Guide. Prepared for Air Force Research Laboratory, Airbase and Environmental Technology Division, Tyndall AFB, Florida. <http://en.afit.af.mil/env/insitubio.html>.

6. E-mail Transmittal. 1999. From David Steckel, Edwards Air Force Base, to Dawn Carroll, U.S. EPA. Review of EPA Bio Document. January 25.

7. E-mail Transmittal. 1999. From David Steckel, Edwards Air Force Base, to Dawn Carroll, U.S. EPA. Review of EPA Bio Document. January 29.

8. Fax Transmittal from Perry McCarty, Stanford University, to Dawn Carroll, U.S. EPA. 1999. Suggested Changes to Case Study #2, Edwards Air Force Base. February 1.

9. Hopkins, Gary D. and Perry L. McCarty. 1995. Environmental Science Technology. Field Evaluation of In Situ Aerobic Cometabolism of Trichloroethylene and Three Dichloroethylene Isomers Using Phenol and Toluene as Primary Substrates. Volume 29: 1628-1637.

10. Dolan, Mark E. and Perry L. McCarty. 1995. Environmental Science Technology. Methanotrophic Chloroethene Transformation Capacities and 1,1-Dichloroethylene Transformation Product Toxicity. Volume 29: 2741-2747.