

DNAPL Bioremediation-RTDF

Subsurface Contaminants Focus Area



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DNAPL Bioremediation-RTDF

Tech ID 1737

Subsurface Contaminants Focus Area

Demonstrated at
Dover Air Force Base
Dover, Delaware

INNOVATIVE TECHNOLOGY

Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at <http://www.em.doe.gov/ost> under "Publications."

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SECTION 1 SUMMARY

Technology Summary

Problem

At many U.S. Department of Energy (DOE) and other government and industrial sites, chlorinated organic compounds have been used in industrial applications as solvents, cleaners, and degreasing agents. As a result of spills and past disposal practices, these compounds are now found as contaminants in soils and groundwater. Organic contaminants in the groundwater are often laterally dispersed over large areas and vertically dispersed to depths hundreds of feet below the ground surface. These groundwater contaminants are difficult to treat; the baseline technique of pump-and-treat is very expensive over the life of the project, often projected to be in excess of 30–200 years.

The Dover Air Force Base (Dover AFB), Delaware, has been operating for about 50 years. Historic maintenance and repair activities at Dover AFB resulted in solvent spills and subsequent groundwater contamination by trichloroethylene (TCE), cis-1, 2-dichloroethene (cDCE), and perchloroethylene (PCE) with average concentrations of 4,800 micrograms/Liter ($\mu\text{g/L}$), 1,200 $\mu\text{g/L}$, and 3 $\mu\text{g/L}$, respectively.

How It Works

At Dover AFB, the U.S. Environmental Protection Agency (EPA)-sponsored Remediation Technologies Development Forum (RTDF) Bioremediation of Chlorinated Solvents Work Group (Work Group) carried out the bioremediation work described in this Innovative Technology Summary Report (ITSR). This RTDF Work Group is a consortium, of industry, government, and academia members formed in 1992 to develop safer, more effective, and less costly characterization and treatment technologies focusing on the use of bioremediation.

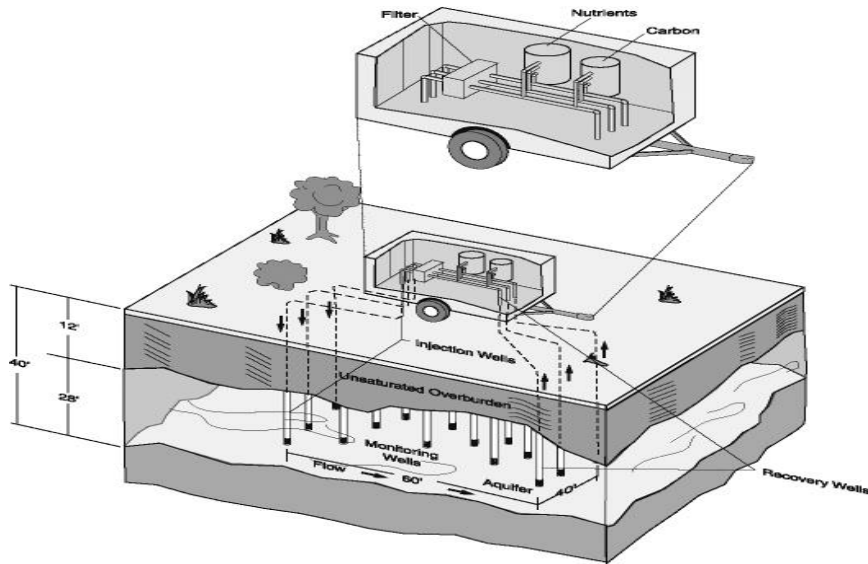
The Work Group has sponsored work on three in situ bioremediation processes: cometabolic bioventing (for treatment of the vadose zone), intrinsic bioremediation (for treatment of the bulk of the plume), and accelerated anaerobic bioremediation (for treatment of more concentrated areas of a plume).

Cometabolic bioventing used a technique to efficiently deliver oxygen and a cometabolite (such as toluene, propane, or methane) to the vadose zone to remediate TCE. A Phase I cometabolic bioventing study at the Building 719 site at Dover AFB, Delaware was conducted from 1998 to 1999. A Phase II study was initiated at Hill AFB Operable Unit 2, in Utah, in 1999.

The Work Group conducted a four-year Phase I intrinsic bioremediation study at the Area 6 at Dover AFB, Delaware, where chloroethylenes are present in shallow groundwater. Industrial Work Group members and the Interstate Technology Regulatory Cooperation (ITRC) Work Group published the “Natural Attenuation of Chlorinated Solvents Principles and Practices Manual” and developed a two-day training course based upon the Phase I study.

Additional information related to the Work Group activities is available at www.rtdf.org.

The in situ bioremediation (ISB) process is one that enhances the ability of native microorganisms to degrade subsurface contaminants through biochemical processes. Aerobic ISB refers to the process of nutrient injection to accelerate aerobic co-metabolism of chlorinated organic compounds. Anaerobic ISB, as used in the Area 6 Phase I study, involves the use of nutrient injection to accelerate reductive dechlorination reactions to convert chlorinated organic compounds (chloroethenes) to ethene. The elements of in situ accelerated anaerobic bioremediation (referred to hereafter as AAB) include nutrients, substrate (electron donor), electron acceptor, and/or microorganisms (Figure 1). AAB involves injection of additives into the groundwater through injection wells and extraction of the groundwater through recovery wells. The extracted groundwater is filtered; nutrients, substrate, and microorganisms are added and then



reinjecting. Through reductive dechlorination, chlorides are removed from the organic compounds in a sequential process mediated by microorganisms until only ethene or other innocuous products remain.

Figure 1. Conceptual picture of in-situ bioremediation process.

Chloroethenes act as electron acceptors for microbially-mediated reactions in which chlorine atoms are sequentially replaced with hydrogen atoms under anaerobic conditions. Thus, PCE is reduced to TCE, which is reduced to 1,2-DCE, which is reduced to vinyl chloride, which is reduced to ethene as shown in the following pathway. A sufficient electron donor source is the primary requirement to facilitate this reaction. The technology can be implemented in two ways: in a source area to remove a contaminant mass or as a barrier to prevent ongoing migration of a contaminant plume.



During the reductive dechlorination process, the chlorinated ethenes act as electron acceptors and thus assist in the respiration process of the microorganisms. The respiration process is carried out in the presence of an appropriate electron donor (food source), providing microorganisms with the energy for growth and cell maintenance.

At Dover AFB, AAB included the extraction of groundwater through extraction wells, injection of the nutrients, substrate, electron acceptor, and/or microorganisms into the groundwater through injection wells. The extracted groundwater is filtered; then nutrients, substrate, electron acceptor, and microorganisms are added, and the groundwater is reinjected. The native microbial community at Dover AFB was augmented. Operations were conducted from a process-control building. Pulse-feeding on a 7-day cycle delivered substrate and nutrients into the treatment area. Redox conditions in the aquifer were altered from aerobic to anaerobic by adding carbon-based substrate and inorganic nutrients. Routine cleaning of injection wells was used to maintain injection flow rates due to biofouling of the injection well screen and potentially the gravel pack and surrounding geologic formation.

Potential Markets

The potential markets for this technology include DOE, U.S. Department of Defense (DoD), and commercial sites that have moderately permeable, saturated zones contaminated with volatile organic compounds (VOCs).

Advantage over the Baseline

AAB has the potential to be a more efficient and cost-effective treatment of contaminated groundwater, including Dense, Non-aqueous Phase Liquids (DNAPLs), than the baseline pump-and-treat technology.

Demonstration Summary

This report covers a demonstration that took place between May 1996 and March 1998 at the Dover AFB in Delaware. The demonstration/study was conducted by the RTDF Bioremediation Work Group, which is composed of Dow, DuPont, General Electric, Geosyntech, ICI, Monsanto, Novarits, U.S. EPA, U.S. DoD, U.S. DOE and Zenica. The field-scale demonstration included two phases: one stimulating indigenous microorganisms and one using bioaugmentation with an imported culture of microorganisms from Largo, Florida. Additional detail is available in Lutz, et.al., 2000.

The demonstration site was located in Area 6 of the Dover AFB. The depth to groundwater in the demo area is 10 to 12 ft, and the saturated thickness is approximately 38 ft. Although the aquifer acts as one unconfined unit, for demonstration purposes, it was divided into 3 zones of equal thickness: an upper zone of fine sand, an intermediate zone of fine to medium sand, and a deep zone of medium sand. The demonstration site characteristics are described in more detail in Section 3, Performance.

Key Results

- Complete in situ degradation of chlorinated solvents to ethene was accomplished using groundwater recirculation and amendment system, through augmentation of the native microbial community with a culture from Largo, Florida.
- There appears to be a threshold of carbon below which anaerobic bacterial stimulation will not occur. Addition of substrate was conducted for 3 months at a nominal feed concentration of 100 milligrams per liter (mg/l) as lactate. This level of feed was not sufficient to induce anaerobic redox conditions in a significant portion of the aquifer, and no observable dechlorination took place during this period. Soon after the feed concentration was doubled, the redox conditions became strongly negative, and dechlorination activity ensued.
- Non-native microorganisms were found to flourish when added to the Dover AFB aquifer system.
- Pulse feeding of substrate and nutrients can be an effective method for amending the subsurface.
- Adding carbon-based substrate and organic nutrients altered redox conditions in the aquifer.
- The model MT3D simulated the 3-D transport of a carbon-based substrate so that the well layout and pulse feeding could meet delivery objectives.

Commercial Availability

- At Kelly AFB, Texas, AAB is being used in remediation of VOC-contaminated groundwater.
- A training course for AAB has been developed through the Interstate Technology Regulatory Committee and is being made available across the U.S.

Contacts

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at <http://www.em.doe.gov/ost> under "Publications." The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The Tech ID for DNAPL Bioremediation - RTDF is #1737.

SECTION 2 TECHNOLOGY DESCRIPTION

Overall Process Definition

The AAB system includes injection and extraction wells, a nutrient/substrate injection system, and a groundwater sampling system. A system of three extraction and three injection wells aligned perpendicular to groundwater flow was used to create a semi-isolated recirculation system. The extraction and injection wells were spaced 20 ft apart as shown in Figure 2. Extraction wells were spaced 60-ft downgradient from the injection wells. Monitoring wells were spaced within the demo area along the downgradient flow path at distances ranging from 4 to 55 ft from injection well 2, in order to monitor each of the side flow paths of the demonstration area and surrounding areas. Upgradient and downgradient locations were also selected.

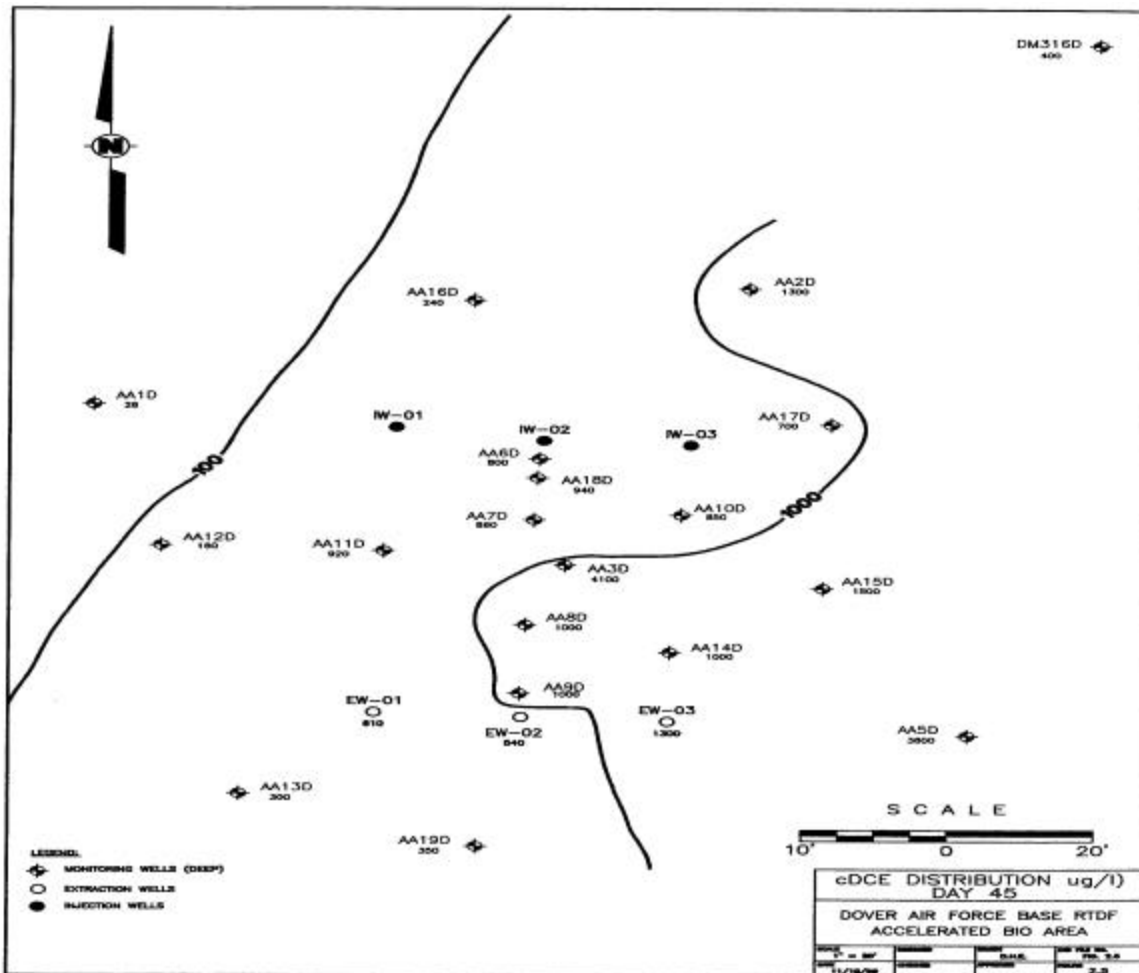


Figure 2. Location of injection/extraction wells at Dover AFB.

- Groundwater flow and transport modeling (using the Model MT3D) was used as a tool to help design the system. This model proved to be an accurate predictive tool. Tracer studies using sodium bromide injected into the groundwater recirculation system, conducted during the startup phase, were used to validate the model. The results of modeling showed that the injection/recovery well layout and pulse feeding could be operated to meet a range of travel time and substrate delivery objectives.
- The system was designed to operate as a semi-isolated recirculation pilot area to ensure sufficient residence time for degradation of the chlorinated volatile organic compounds (CVOCs), and that the

substrate concentration in the injected water would be adequate to facilitate CVOC degradation within a sufficient area between and downgradient of the injection wells.

- Flow control valves in each injection line allowed adjustment of flow to the injection wells individually.
- A process flow diagram is presented in Figure 3. Flow rate, totalized flow, and pressure were monitored in each line. Flow-control valves in each extraction line and variable frequency drives for extraction pumps provided the capability to vary flow from each well.

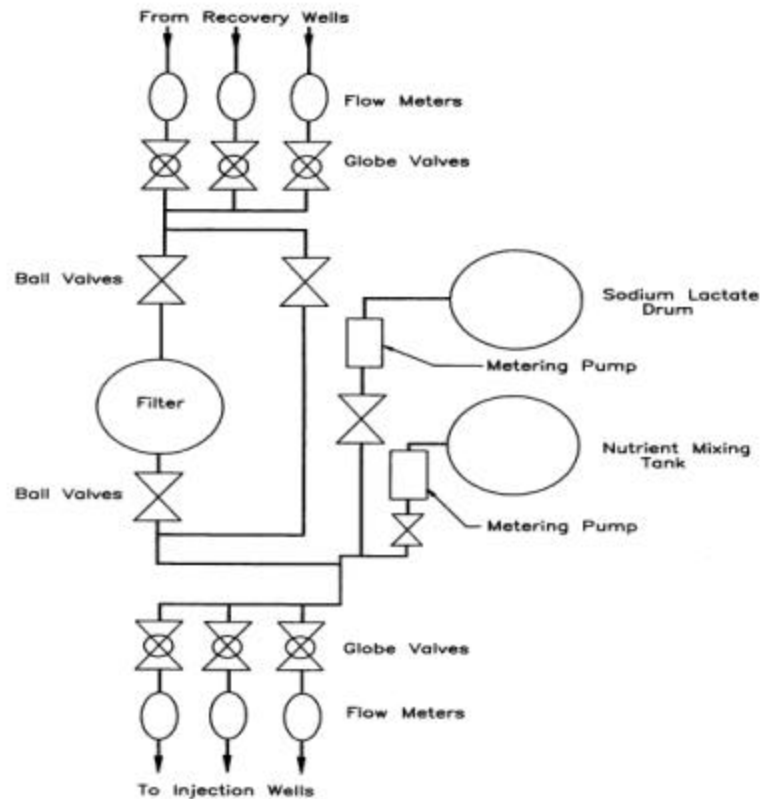


Figure 3. Process flow diagram for accelerated anaerobic bioremediation (reprinted with permission from E. Lutz, Lutz et. al, 2000).

System Operation

- Addition of sodium lactate and inorganic nutrients altered redox conditions in the aquifer. The redox potential in the groundwater went from +200mV at the outset of recirculation to an average of -200mV after nine months of amendment addition.
- Pulse feeding of nutrients (food-grade dibasic ammonium phosphate and yeast extract) and sodium lactate occurred on a seven-day cycle.
- Groundwater was extracted, passed through a filter and control valve, and reinjected with nutrients and sodium lactate added.
- The system was designed to limit groundwater aeration and minimize iron fouling.
- As a result of injection-rate fluctuations caused by biofouling, various methods were used to clean the well screens to keep the injection wells functioning at the design rate. These methods include:
 - Well redevelopment,
 - Acid and bleach additions,
 - Manual screen brushing,

- Hydrogen peroxide treatment, and
- Well surge-block treatment.

- The U.S. Air Force required that the prefabricated modular building designed to house the operating equipment meet the Dover AFB architectural standards. The building housed control equipment, mixing tanks, metering pumps, piping, and additive supplies. The groundwater extraction and injection lines and utility lines were run underground to the control building.
- Operations were conducted from a process-control building.
- Because the demonstration performance using only indigenous microbes paralleled laboratory work closely over the first 6 months of operation and no degradation beyond cDCE was observed in either, the decision was made to conduct bioaugmentation with an imported dechlorinating culture from Largo, Florida.
- During system operation, a groundwater-sampling schedule was followed. Basic water chemistry parameters were measured biweekly in the extraction and interior monitoring wells, and monthly in the exterior monitoring wells. VOCs of concern and degradation products were measured weekly in the extraction and interior monitoring wells, and monthly in the exterior monitoring wells.

SECTION 3 PERFORMANCE

Demonstration Plan

Performance of the technology is based upon a field-scale demonstration at Area 6 of the Dover AFB in Delaware.

- The demonstration site in Area 6 of the Dover AFB overlies a portion of a groundwater contaminant plume, which contains average TCE concentrations of approximately 4,800 µg/L, and average cis-1, 2-dichloroethene concentrations of approximately 1,200 µg/L. Contaminant mass within the demonstration area was estimated at 3.6 lbs. Contamination is more widespread in the deep zones of this shallow aquifer (depth to groundwater in this area is 10 to 12 ft and the saturated thickness is approximately 38 ft as noted below).
- The saturated thickness at the demonstration site is approximately 38 ft and the depth to groundwater is approximately 10 to 12 ft. Although the aquifer acts as one unconfined unit, for monitoring purposes it was divided into three zones of roughly equal thickness. Based on characterization findings and subsequent aquifer studies, the deep zone was used for pilot study.
- Groundwater flow is primarily horizontal and the gradient direction is about 10° west of south. Groundwater flow velocity under natural non-pumping conditions is approximately 0.3 ft/day.
- Hydraulic conductivity in the deep zone of the aquifer was determined to be 60 ft/day.
- Laboratory tests conducted in columns (flow-through systems) and bottles (static systems) appeared to be accurate predictive techniques for assessing the presence and bioremediation potential of organisms needed for dechlorination.

Results

Although contaminant concentrations were elevated on one side of the demonstration area relative to the other, concentrations became more uniform as groundwater recirculation was initiated.

- Complete in situ degradation of chlorinated solvents to ethene was accomplished in a groundwater recirculation and amendment system through augmentation of the native microbial community using an imported culture from Largo, Florida.
 - After a lag period of approximately 90 days, the augmenting culture began transforming cDCE to vinyl chloride and ethene.
 - Complete dechlorination of solvents occurred first between the injection well and the nearest monitoring well (a distance of about 4 ft).
- Pulse feeding of substrate and nutrients was effective in amending the subsurface.
- Evidence from the demonstration suggests that the augmenting culture multiplied in the subsurface.
- The total amount of groundwater circulated during the demonstration (May 1996–March 1998) was approximately 2.7 million gallons.
- Although contaminant concentrations were elevated on one side of the demonstration area relative to the other, concentrations became more uniform as groundwater recirculation was initiated.
- Prior to the demonstration, the Dover AFB aquifer was aerobic. By day 152 of the demonstration conditions in the demonstration area had become anaerobic. After 568 days of operation, dissolved oxygen, nitrate, and sulfate were completely depleted.
- Iron was an important electron acceptor. Dissolved ferrous iron concentrations increased from 0.01mg/l to 60mg/l during the operation.

- Figure 4 shows concentrations (microM) of the various chloroethene compounds versus time in well 7D during the demonstration.

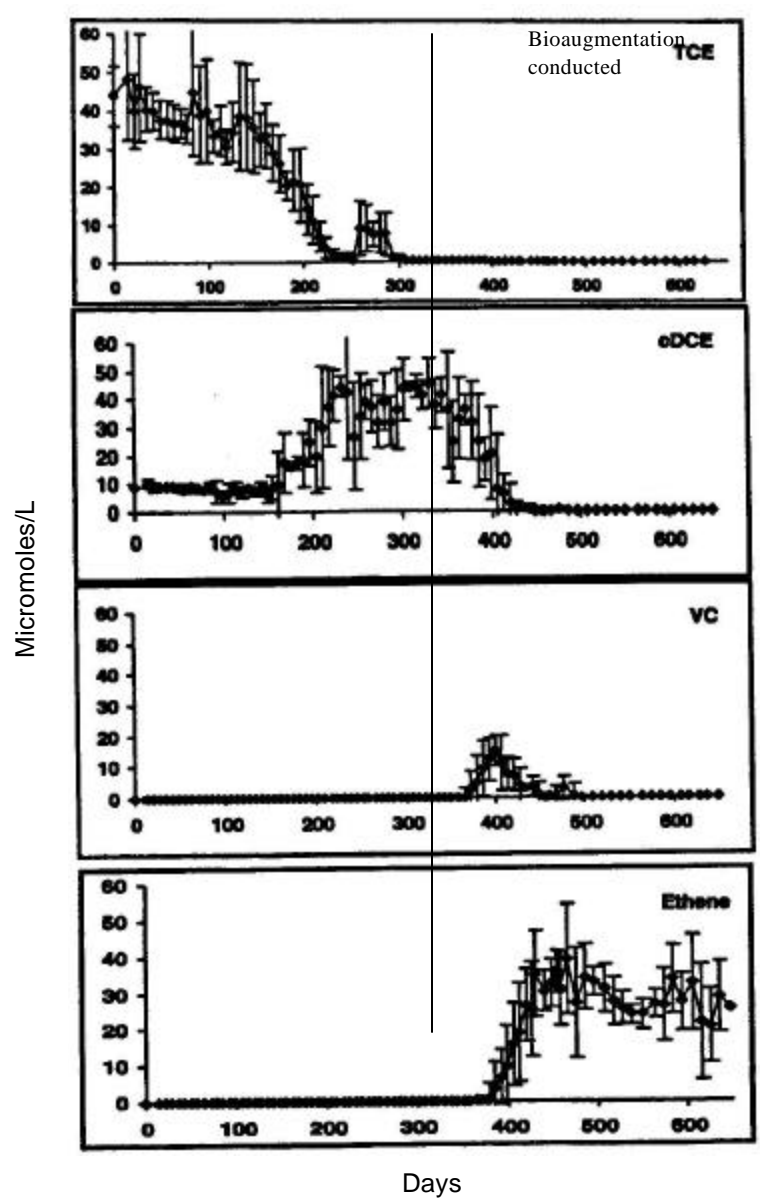


Figure 4. Chloroethene concentrations (μM) in monitoring well 7D during pilot study operation (adapted from Ellis et.al, 2000).

SECTION 4 TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

- AAB with aqueous nutrient injection is competitive with conventional baseline technology of pump-and-treat.
- AAB was successfully demonstrated at the DOE Hanford Site in Washington State in 1995 and 1996, and at the INEEL TAN site in 1999–2000.
- Aerobic in situ bioremediation has been successfully demonstrated and deployed to treat groundwater at the DOE Savannah River Site in Aiken, South Carolina.
- Other innovative technologies with potential application for treatment of groundwater contaminated with VOCs and/or DNAPLs include in well vapor stripping, in situ thermal technologies, and in situ oxidation. A summary of attributes of these alternative technologies is presented in Table 1.
 - In Well Vapor Stripping is best suited for sites with contaminants that are sufficiently mobile. The presence of low permeability layers limits the applicability of this technology.
 - In Situ Oxidation can provide relatively rapid reaction and treatment times at sites with hydraulic conductivity greater than 10^{-8} centimeters per second, a depth to groundwater of greater than 5 ft and less than 6 inches of free product on the water table. This technology is not applicable at sites with greater than 6 inches of free product, with high organic carbon content, or where the pH is greater than eight.

Table 1. Comparisons of alternative technologies

Technology	Capital Cost	Operating Cost	Waste Mgmt. Cost	Potential Worker or Environmental Exposure?	Contaminant Transfer or Destruction?	Applicable to Source Areas?	Applicable to Large NAPL Volumes?	Applicable to Dissolved Phase?	Potentially Hazardous Materials or Energy?	Risk of Deleterious Source Mobilization?
Pump and Treat	Medium	Low to Medium	Low to Medium	Yes	Transfer	No (except containment)	No	Yes	No	No
Thermal (Steam or Electrical)	High	High	Medium to High	Yes	Both	Yes	Yes	No	Yes	Yes
Chemical Oxidation	Low to Medium	Low to Medium	Low	No	Destruction	Yes	Yes	No	Yes	No
Surfactant or Cosolvent Flooding	Medium to High	Medium	High	Yes	Transfer	Yes	Yes	No	No	Yes
Aerobic Bioremediation	Medium	Low to Medium	Low	No	Destruction	No	No	Yes	Yes	No
Conventional Anaerobic Bioremediation	Low to Medium	Low to Medium	Low	No	Destruction	No	No	Yes	No	No
Anaerobic Bioremediation with Bioavailability Enhancement	Low to Medium	Low to Medium	Low	No	Destruction	Yes	No	Yes	No	No

Technology Applicability

- AAB is effective for remediation of groundwater contaminated with VOCs (TCE in this demonstration).
- AAB has been successfully deployed at the INEEL TAN site in a deep fractured, basalt aquifer using indigenous microorganisms, to remediate TCE-contaminated groundwater, to remediate TCE and PCE-

contaminated groundwater at Kelly Air Force Base, Texas, and has been selected for deployment at the Oak Ridge Y-12 site.

- AAB requires distribution of nutrients and substrate within the treatment zone; low permeability zones may not be treated or may require additional technology advancements for this technology to be effective.
- Aquifer conditions must be suitable to support microbial growth. Aquifer limiting conditions include toxicity due to high contaminant concentrations or other toxic substances, and pH. Aquifer-specific-treatability tests are necessary.
- In situations similar to Dover AFB, the native microbial community must be augmented with an imported dechlorinating culture to achieve successful AAB.

Patents/Commercialization/Sponsor

- General Electric is applying for a patent for microbial cultures for AAB.
- INEEL is working with commercial companies (North Wind Environmental, Inc. and IRW Technologies, Inc.) to accelerate broad application of AAB.

SECTION 5 COST

Methodology

The costs for the bioremediation research, development, and demonstration efforts at Dover AFB were collected as actuals throughout the period of performance. Costs for the AAB at Dover AFB were estimated based on the percentages of time and effort required to perform the demonstration (without the additional research and development which were included at Dover). Operating costs include all costs from the end of construction to the end of the project, which was 568 days.

The costs for the baseline pump and treat technology were estimated based on a scaled-down version (due to the smaller size of the pilot area) of cost estimates provided in the final feasibility study (using 1994 dollars) for the entire Area 6 at Dover AFB. Table 2 shows a comparison of estimated costs for AAB and pump and treat at Dover AFB.

Table 2. Breakdown of capital and operating costs

Item	Actual Bioremediation Study Costs	Estimated Bioremediation Application Costs (Start to Finish)	Estimated P&T Costs (15 Years)	Estimated P&T Costs (30 Years)
CAPITAL COSTS				
Laboratory Studies	\$ 150,000	\$ 150,000		
Site Preparation	\$ 9,742	\$ 9,742	\$ 2,000	\$ 2,000
Building	\$ 39,818	\$ 39,818		
Process Equipment	\$ 24,067	\$ 24,067	\$ 176,000	\$ 176,000
Utility Hookup	\$ 50,716	\$ 50,716	\$ 10,000	\$ 10,000
Pumps	\$ 18,224	\$ 9,112	\$ 2,100	\$ 2,100
Monitoring Wells	\$ 82,906	\$ 41,453		
Injection Wells	\$ 30,400	\$ 30,400		
Extraction Wells	\$ 24,000	\$ 24,000	\$ 131,550	\$ 131,550
Other	\$ 5,690	\$ 5,690		
OPERATING COSTS				
Direct Labor				
Field Operator	\$ 168,000	\$ 88,600		
Technical Oversight	\$ 33,000	\$ 17,500		
Direct Materials				
Substrate	\$ 6,710	\$ 3,600		
Nutrients	\$ 581	\$ 300		
Supplies	\$ 10,140	\$ 5,400		
Utilities	\$ 569	\$ 400	\$ 17,250	\$ 34,500
Sampling	\$ 11,004	\$ 2,756	\$ 67,500	\$ 135,000
Shipping	\$ 22,869	\$ 5,729		
Laboratory Analysis			\$ 186,000	\$ 372,000
Volatiles	\$ 286,000	\$ 71,710		
Anions/Substrate	\$ 52,400	\$ 13,115		
GAC Treatment			\$ 76,125	\$ 152,250
Overhead	\$ 5,283	\$ 1,323		
Process Maintenance	\$ 9,450	\$ 9,450	\$ 15,000	\$ 30,000
Total Operating Cost	\$ 606,006	\$ 219,883	\$ 361,875	\$ 723,750
Total Capital Cost	\$ 435,563	\$ 384,998	\$ 321,650	\$ 321,650
TOTAL	\$1,041,569	\$ 604,881	\$ 683,525	\$1,045,400

Cost Analysis

Table 3. Summary of estimated cost savings for bioremediation as compared to two pump and treat scenarios (15 and 30 years)

	Bioremediation	Pump & Treat (15 Years)	Pump & Treat (30 Years)
Total Capital Cost	\$ 384,998	\$ 321,650	\$ 321,650
Total Operating Cost	\$ 219,883	\$ 361,875	\$ 723,750
Total Treatment Cost	\$ 604,881	\$ 683,525	\$ 1,045,400
Duration of Treatment Required (years)	1	15	30
Annualized Operating Cost	\$ 211,020	\$ 24,125	\$ 24,125
Net Present Value (4.2% Discount Rate)	\$ 596,018	\$ 586,169	\$ 728,874
Cost Savings/(Loss)		9,849	(132,856)

A more detailed report containing cost estimates for bioremediation versus pump and treat was prepared by MSE Technology Applications, Inc. (Massart and Hogan, 2000). This report also describes a cost model which could be used to compare these technologies under various remediation conditions (e.g. different pumping rates).

Cost Conclusions

The estimated net present value cost of conducting bioremediation on a site comparable to the Dover AFB site chosen for this demonstration would be \$596,018 as shown in the table above (Table 3); this represents an annualized estimated cost savings of \$132,856 over a 30-year pump and treat operation.

On a per unit basis, under these conditions, bioremediation costs approximately \$165,560 per pound of contaminant treated, while a 30 year pump and treat operation would cost approximately \$202,465 per pound of contaminant treated. Consequently, in addition to a significant reduction in treatment time, net savings of approximately \$36,905 per pound of contaminant would be realized with the use of bioremediation.

SECTION 6 OCCUPATIONAL SAFETY AND HEALTH

Summary

The baseline technology (groundwater pump and treat) presents an exposure risk to site workers from investigation-derived waste, groundwater monitoring well purge water, well drilling equipment, and groundwater monitoring equipment. AAB technology has similar exposure risks during the initial construction of the injection/withdrawal and monitoring well systems, and similar exposure risks during sampling/monitoring, although the operational period for AAB is significantly less than for pump and treat. During the operation of AAB, exposure to site workers should be significantly reduced from the baseline technology.

Technology-Specific Health and Safety Risks

- There are no unusual health and safety issues related to the installation and operation and maintenance of in situ bioremediation.

Worker Safety

AAB technology does not require any unusual health and safety measures. Routine site safety procedures for site remediation projects may include:

- Level D personal protective equipment,
- applicable OSHA training,
- reagents used in the process (sodium lactate and dibasic ammonium phosphate) are easily managed using standard chemical handling techniques.

Community Safety

- AAB does not produce any significant routine release of contaminants.
- No unusual or significant safety concerns are associated with the transport of equipment, samples, waste, or other materials associated with AAB.
- No harmful microbes were detected at the demonstration site after the use of AAB.

Lessons Learned

- No new occupational safety and health lessons were learned from the one-year operating campaign at INEEL.

SECTION 7 REGULATORY AND POLICY ISSUES

Regulatory Considerations

- An underground injection permit was required for the field test at Dover AFB.
- Future application of AAB may require underground injection permits and NEPA review (at DOE sites).

Risks, Benefits, Environmental and Community Issues

Environmental Impact

- Surface disturbance at the AAB site is minimal.

Socioeconomic Impacts and Community Perception

- AAB has minimal economic or labor force impact.
- AAB is viewed by the public as a "green" technology but the importation of foreign cultures requires a proactive approach.

SECTION 8

LESSONS LEARNED

Implementation Considerations

- Subsurface augmentation with culture that had been grown in an aqueous medium supported advective transport of dechlorinating organisms throughout the pilot area. Augmentation was only performed in the center of three injection wells; however, dechlorination ultimately was occurring in all three flow paths.
- There appears to be a threshold level of carbon below which anaerobic bacterial stimulation will not occur. Addition of substrate was conducted for three months at a nominal feed concentration of 100 mg/l as lactate. This level of substrate feed was not sufficient to induce anaerobic redox conditions in a significant portion of the aquifer, and no observable dechlorination took place during this period. Soon after the substrate feed concentration was doubled, the redox conditions moved strongly negative and dechlorination activity ensued.
- Nonnative organisms can flourish when added to an aquifer system. Evidence from the pilot study suggests that the augmenting culture multiplied in the subsurface. Dechlorination was not observable until a sufficient lag time had elapsed. Presumably this was a period of growth for the dechlorinating culture. Initial activity appeared to be concentrated between 8 and 15 ft downgradient of the injection well. However, after seven months, full dechlorination was taking place between the injection well and the first monitoring well location, a distance of about 4 ft, and then ultimately, throughout the entire demonstration area.
- Laboratory tests conducted by the RTDF in columns and bottles appear to be accurate predictive techniques for assessing the presence of organisms needed for dechlorination. In the multitude of bottle tests and in all column tests the results were the same: dechlorination beyond cDCE was not stimulated in the soils from the pilot area. Pilot test results confirmed this conclusion. Therefore, future applications of this technology could save money by limiting laboratory degradation studies to microcosms only, and not performing extensive testing similar to Dover.
- Pulse feeding of substrate and nutrients can be an effective method for amending the subsurface. The pilot feeding strategy was to keep the nutrients and carbon source separated until mixing is required in the subsurface to effect use by organisms. There was no fouling of surface equipment or piping resulting from biogrowth, and dechlorination was not limited in the subsurface for any appreciable distance from the injection wells. Longer separation of the pulses with increased carbon concentrations may be needed to prevent the biofouling that was experienced in the injection wells. Batch addition over very short periods of time has been suggested as one variant of the pulse feed strategy that might be effective in preventing biofouling.

Design Issues

- Factors that will control injection protocols, remediation system siting, and monitoring include site geology (especially permeability and heterogeneity), concentrations of native nutrients (such as native total organic carbon), and natural oxidation potential of the subsurface (i.e. aerobic or anaerobic conditions).
- The model used in the design of the demonstration proved to be an accurate predictive tool. Tracer studies conducted during the startup phase of the demonstration were used to validate the model and calibrate the adjustment of certain assumptions. Later use of the model was made when augmentation planning was in progress.

- Biofouling can be a significant operating problem for groundwater recirculating systems. Addition of growth substrates to the recirculated flow appears to promote significant biofouling of the injection well screen and possibly the gravel pack and surrounding geologic formation. Under the operating methodologies used at Dover AFB, routine cleaning of injection wells became necessary to maintain design injection flow rates.

Technology Limitations and Needs for Future Development

- Better mechanisms for effective distribution of nutrients and substrate into low permeability zones of an aquifer are required to facilitate implementation of AAB.

Technology Selection Considerations

- This technology yields significant economic and efficiency gains over the baseline pump-and-treat technology for remediation of groundwater contaminated with VOCs.

APPENDIX A REFERENCES

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APPENDIX B

ACRONYMS AND ABBREVIATIONS

AAB	Accelerated Anaerobic Bioremediation
AFB	Air Force Base
cDCE	Cis-1, 2-Dichloroethene
CVOC	Chlorinated Volatile Organic Compounds
DCE	Dichloroethene
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DNAPL	Dense, Non-aqueous Phase Liquid
EPA	U.S. Environmental Protection Agency
INEEL	Idaho National Engineering and Environmental Laboratory
ISB	In Situ Bioremediation
ITSR	Innovative Technology Summary Report
mg/l	Milligrams Per Liter
OST	Office of Science and Technology
PCE	Perchloroethylene
RTDF	Remediation Technologies Development Forum
TCE	Trichloroethylene
µg/L	Micrograms Per Liter
VOC	Volatile Organic Compounds