COST AND PERFORMANCE REPORT

Sequential Anaerobic/Aerobic Biodegradation of PCE
at Watertown, Massachusetts

March 2000

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

Sequential Anaerobic/Aerobic Biodegradation of PCE
at Watertown, Massachusetts

Summary Information [1,3]

Site Name, Location	Watertown, Massachusetts	
EPA ID Number	Not provided	
Mechanism(s)	Anaerobic Reductive Dechlorination (Cometabolic and Direct)	Aerobic Oxidation (Cometabolic and Direct)
Technology	Nutrient Addition Electron Donor Addition (Lactate)	Oxygen Addition Elecron Donor Addition (Propane)
Configuration	Groundwater Recirculation	
Technology Scale	Field Demonstration	
Media/Matrix Treated	Groundwater	
Contaminants Targeted	TCE, PCE	
Period of Operation	Anaerobic: November 1996 to July 1997; Aerobic: August 1997 to ongoing (data available through October 1997)	

Site History/Source of Contamination [1,2,5]

The Watertown site has been used since the late 1800's for a variety of operations, including a coal gas manufacturing plant, which ceased operations in the 1930's, and a metal plating shop, which ceased operations in 1990. The site is currently being used as a manufacturing facility for electric switch assembly. Soil and groundwater at the site are contaminated with chlorinated solvents, including trichloroethene (TCE) and tetrachloroethene (PCE), from past operations and waste disposal practices.

A field demonstration of the Two-Zone Plume-Interception Treatment Technology developed by Harding Lawson Associates (HLA, formerly ABB Environmental Services, Inc.) was conducted at the Watertown site under the Superfund Innovative Technology Evaluation (SITE) program. The field demonstration is currently ongoing. This report addresses the results through October 1997.

Geology/Hydrogeology [1,2]

Soil at the Watertown site consists of about 13 feet (ft) of sand and gravel over approximately 7 ft of silty sand. Glacial till about 5-ft thick acts as an aquitard and separates the sand layer from the underlying bedrock (light grey, moderately weathered, amorphous Cambridge Argillite). Groundwater is encountered approximately 8 ft below ground surface (bgs).

Matrix Characteristics for the Watertown Site [1]

Matrix Characteristic	Value
Soil Type	Sand, gravel, and silt
Soil Permeability	Not Provided
Depth to Groundwater	8 ft bgs
Fraction of Organic Carbon	Not Provided
DNAPL Presence	Not Provided
Hydraulic Conductivity	Not Provided
pH	Not provided
Porosity	Not Provided
Hydraulic Gradient	Not Provided
Groundwater Velocity	Not Provided

Technology Description [1,2]

The technology demonstrated at the Watertown site is a "two-zone" enhanced bioremediation process that uses sequential anaerobic and aerobic biodegradation processes to degrade PCE and TCE. The first zone is designed to operate under highly reducing conditions to stimulate anaerobic bacteria to dechlorinate solvents. While complete degradation can occur under these conditions, according to the vendor, the process may be slow; whereas under aerobic conditions, completing the degradation of DCE and VC is relatively fast. Therefore, a second zone, designed to operate under aerobic conditions, is used to stimulate methanotrophic bacteria to complete degradation by oxidizing DCE and VC.

The field demonstration system, shown in Figure 1, consisted of three injection wells and three extraction wells. The injection/extraction wells were used to develop a groundwater recirculating cell that covered a surface area of approximately 10 ft by 20 ft. The wells were constructed of 4-inch diameter PVC pipe and screened from 13 to 20 ft bgs. Five monitoring wells, with 5-ft screens at 15 to 20 ft bgs, were located between the injection and extraction wells, and additional monitoring wells were located outside of the treatment cell, as shown in Figure 2. Nutrients and a carbon source were injected into the groundwater through the three "up-gradient" wells and extracted through the three "down-gradient" wells.

During the period of operation, a relatively constant recirculating flow rate of 0.25 gallons per minute (gpm) was used along with an amendment injection rate of 10 mL/min or about four gallons per day (approximately 1% of the recirculating flow). The system was operated under anaerobic conditions for eight months (through late July 1997), then changed to aerobic conditions, as described below.

Figure 1: Process Diagram [1]

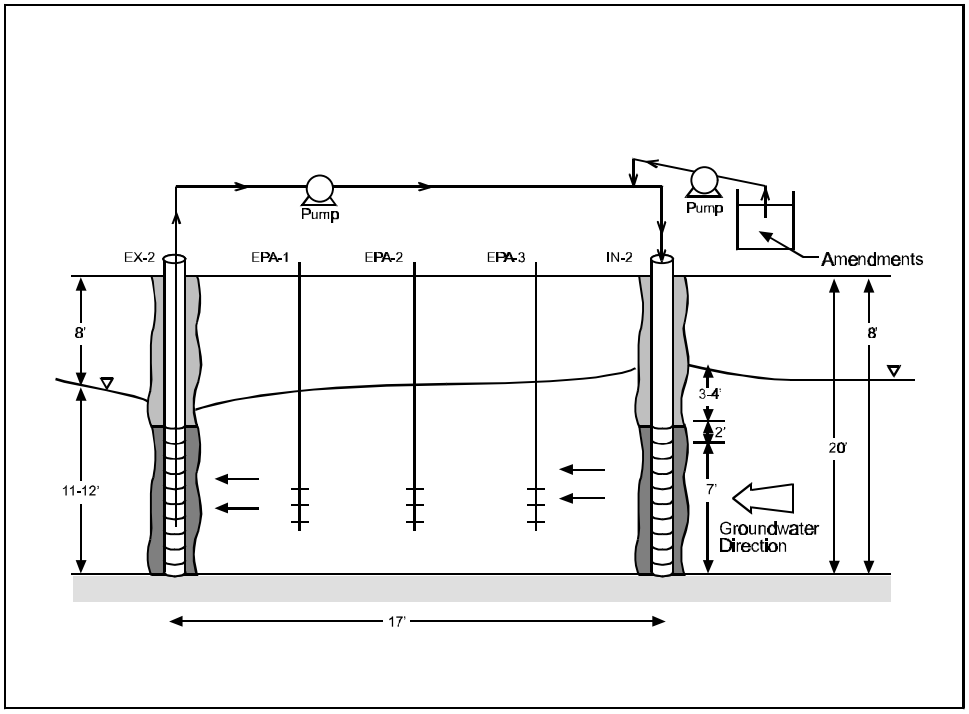
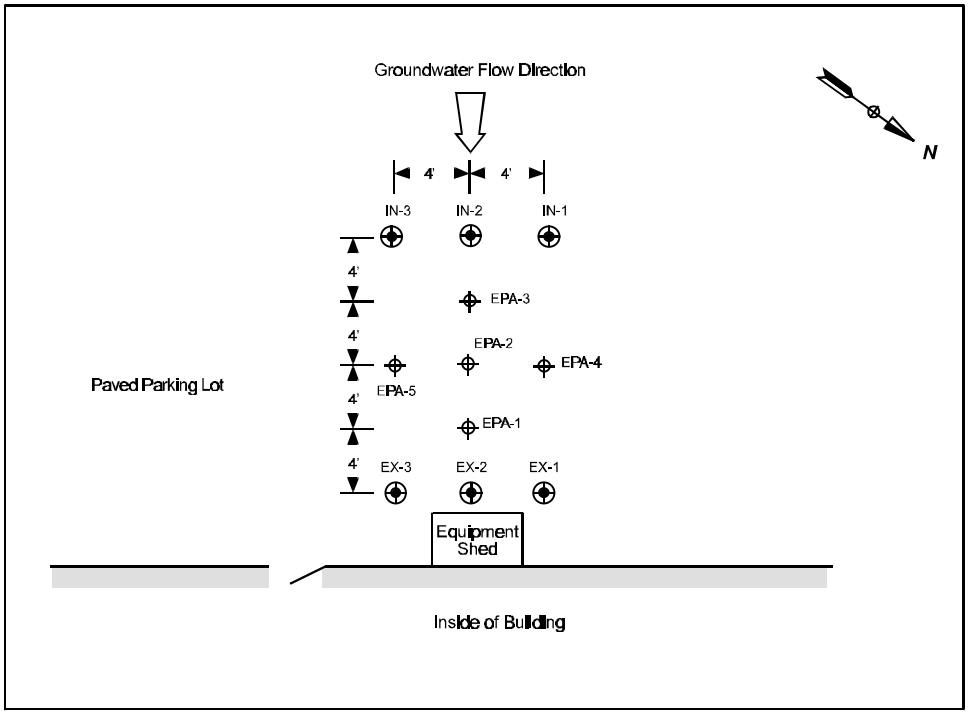


Figure 2: Well Locations [1]



Anaerobic conditions (November 1996 to July 1997):

Amendments were added to the recirculating flow (continuous addition) to enhance anaerobic biological dechlorination. Initially, ammonia chloride (25 mg/L), potassium tripolyphosphate (25 mg/L), lactic acid (100 mg/L), yeast extract (5 mg/L), and sodium hydroxide (at concentrations needed to neutralize the pH of the amendment batch) were added. From April to June 1997, amendments were pulsed into the system and the concentration of lactic acid was increased to 250 mg/L to lower redox conditions. In June 1997, the concentration of lactic acid was increased to 350 mg/L and the system was operated under anaerobic conditions until late July 1997.

Aerobic conditions (August 1997 to ongoing - data available through October 1997):

In July 1997, "socks" containing oxygen release compound (ORC) were suspended inside the three injection wells to provide a continuous release of oxygen into the recirculating groundwater flow. However, it took about a month before aerobic conditions were established. The reason for the lag period was attributed to the presence of residual carbon in the system that had to be degraded before aerobic conditions were established in the injection wells.

Because levels of methane in the groundwater had decreased from 150 to 200 ug/L at the beginning of the demonstration to 50 to 100 ug/L at the start of the aerobic phase, methane was added to the system to enhance aerobic bacteria activity. Methane was added on a weekly basis starting about two months after the ORC socks were installed in the injection wells.

Technology Performance [1]

Anaerobic Conditions (November 1996 to July 1997):

During the first four months of operation under anaerobic conditions (November 1996 to February 1997), limited degradation was observed. Data from February 11, 1997 showed that the concentrations and relative ratio of PCE and TCE to DCE and VC were relatively uniform throughout the treatment cell.

After four to five months of operation (March to April 1997), significant increases in DCE were observed along with decreases in TCE concentrations, indicating that reductive dechlorination was occurring. However, no significant increases in VC concentrations were observed until July 1997, 8 months after operations began.

Methane levels declined continuously during this period from 0.2 to 0.3 mg/L at the beginning of the demonstration to 0.05 to 0.1 mg/L in July, 1997. These results indicate that methanotrophic conditions were not achieved during the anaerobic phase; most of the reductive dechlorination was therefore attributed to sulfate-reducing bacteria. Sulfide was detected in wells during the last two months of the anaerobic phase.

By July 1997, TCE concentrations had been reduced from about 12 mg/L at the beginning of the demonstration to less than 1 mg/L. In addition, there was an overall reduction of about 80% in the mass of total VOCs, as measured in well IN-2 as of July 1997.

Aerobic Conditions (August 1997 to ongoing - data available through November 1997):

Data on the aerobic phase of the demonstration have been collected through November 1997. These data show that VOC levels, primarily DCE and vinyl chloride, have started to decrease in the groundwater. In addition, DCE epoxide, a transient biodegradation product of aerobic degradation of DCE, was detected during two sampling events, indicating that aerobic VOC-degrading bacteria have been stimulated. HLA is continuing to collect data on the aerobic phase of the demonstration. During the aerobic phase over a period of about 3 months, the degradation half-life for vinyl chloride was approximately 45 days, and for the latter month of this period was about 22 days.

Technology Cost [4]

The cost for the field-scale pilot study through November 5, 1997 was approximately $150,000. No estimates were provided about the projected costs for a full-scale system using this technology.

Summary Observations and Lessons Learned [1,2,4]

Under anaerobic conditions, TCE in groundwater was reduced by reductive dechlorination (from 12 mg/L to less than 1 mg/L) and there was an overall reduction of about 80% of the total VOC mass in well IN-2. Data indicate that methanogenic conditions were not achieved during the anaerobic phase and most of the reductive dechlorination was attributed to sulfate-reducing bacteria.

During the anaerobic phase, there was a lag time of four to five months before significant reductive dechlorination was observed; substantial increases in vinyl chloride were observed, eight months after the demonstration began. Possible reasons for the lag time include: the redox conditions may have been too high; there may have been insufficient electron donor present (lactic acid); or an acclimation period may have been required before anaerobic degradation occurred.

A period of about one month was required to establish aerobic conditions after ORC socks were placed in the wells. This lag time was attributed to the presence of residual carbon that had to be degraded before aerobic conditions could be established. Initial results indicate that VOC levels, primarily DCE and vinyl chloride, are decreasing. However, HLA is continuing collect data on the aerobic phase.

The EPA contact for this application stated that future applications should consider not starting in the winter, start when the anaerobic process can go quickly, use a higher level of lactate, and drive the oxidation potential down quickly. [4]

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References:

1. Lewis, Ronald. Sequential Anaerobic/Aerobic Biodegradation of Chlorinated Solvents: Pilot-Scale Field Demonstration. Presented at the University of Massachusetts Amherst Conference, October 1997.

2. Designing and Applying Treatment Technologies. Remediation of Chlorinated and Recalcitrant Compounds. Presented at the First International Conference on Remediation of Chlorinated and Recalcitrant Compounds. Monterey, California. May 1998.

3. SITE Technology Profile. ABB Environmental Services, Inc. Two-Zone, Plume Interception, In Situ Treatment Strategy. August 1995.

1. E-Mail from Dr. Ron Lewis, U.S. EPA to Dawn Carroll, U.S. EPA. 1999. Comments on Bio Document. January 21.

2. Fax Transmittal from Dr. Willard Murray, Harding Lawson Associates, to Richard Weisman, Tetra Tech. 1999. Case Study #8, In Situ Bio of Chlorinated. February 21.