CASE STUDY

Groundwater Remediation of a Contaminated Site using Enhanced Anaerobic Bioremediation

by Shawn Turner, David Anderson, Brendan Brown, and Michael Edgar

Chlorinated solvents are a common threat to drinking water sources throughout the United States. While handling and disposal practices today are more closely regulated and monitored, this has not always been the case. With dry cleaners using tetrachloroethene (PCE) and industrial manufacturing facilities commonly using a variety of solvents from trichloroethene (TCE) to methylene chloride, past releases have threatened our drinking water supplies. Once released to groundwater, these solvents and their breakdown products can remain in drinking water aquifers for decades.

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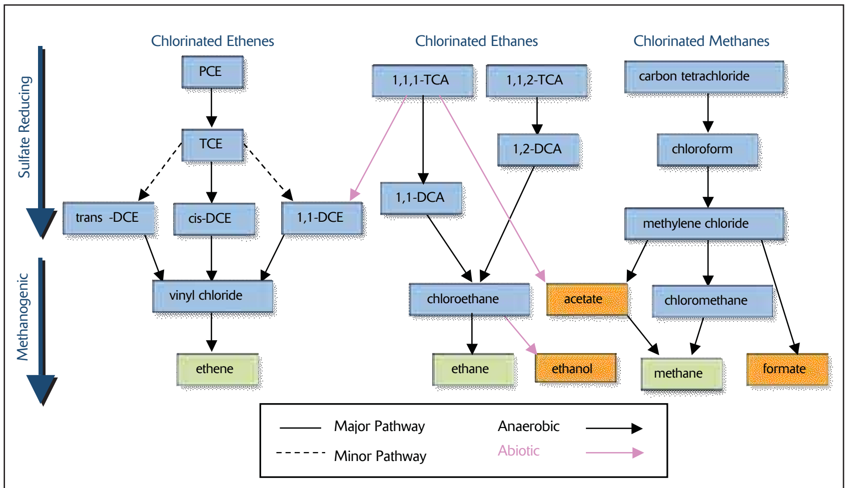
Horizontal well installation using a unique one-pass trenching technology at the former Viktron/PEC Industries site in Orlando, FL.



Source: Modified from ITRC (1998) and Vogel et al. (1987)

Figure 1. Anaerobic degradation pathways for chlorinated VOCs.

Several chlorinated ethenes, ethanes, and methanes were present at the site.

Florida Case Study

The former Viktron/PEC Industries site consists of severely contaminated groundwater at a nine-acre parcel of land in the tourism district of Orlando, FL. Chlorinated solvents, previously used in printed circuit board production in the 1970s, were stored in drums on an unlined and uncovered storage area. Spills from the drums and the wastewater treatment system resulted in solvents being released into the environment and leaching into the groundwater. Methylene chloride, 1,1-dichloroethene (DCE), 1,1,1-trichloroethane (TCA), and vinyl chloride were the most prevalent volatile organic compounds (VOCs) detected in the surficial aquifer. A solution was needed to remediate site groundwater to State of Florida Groundwater Cleanup Target Levels (GCTLs).

Researching a Solution

Site assessment activities revealed extremely high concentrations of groundwater contamination, including methylene chloride at up to 2,000,000 micrograms per liter (µg/L), far exceeding the Florida GCTL of 5 µg/L for groundwater. Several other chlorinated solvents, and their daughter products, were also present at concentrations far above their respective Florida GCTLs, including chlorinated ethenes, ethanes, and methanes.

After studying various options—such as monitoring, physical containment, hydraulic containment, in-situ chemical oxidation, enhanced thermal processes, surfactant flushing, excavation and off-site disposal, and on-site treatment of excavated soils—enhanced anaerobic bioremediation (EAB) was selected as the remedial solution.

The major processes by which chlorinated VOCs biodegrade are anaerobic reductive dechlorination, aerobic co-metabolism, and direct oxidation. For EAB, the primary focus is on the anaerobic reductive dechlorination pathways (see Figure 1), which involve the replacement of chlorine atoms in the VOC molecule with a hydrogen atom. This is the most prevalent biological reaction and it occurs naturally in many anaerobic environments. An electron donor, usually molecular hydrogen, is necessary for the reduction to occur. Based on successful pilot studies, potassium lactate was selected as an electron donor that would provide adequate molecular hydrogen and establish aquifer conditions optimal for EAB. Once complete reductive dechlorination of the chlorinated solvents has occurred, nontoxic compounds such as ethene, ethane, and methane are produced.

With traditional applications of bioremediation, an electron donor and/or microbes are injected into the aquifer, and distribution is largely left to the natural groundwater movement. For this project, traditional bioremediation was further enhanced through an innovative application of groundwater recirculation. The use of groundwater recirculation provides a mechanism for "mixing" of the electron donor, microbes (naturally occurring or injected), and contaminants, allowing for more efficient treatment of high concentrations of chlorinated VOCs in a complex geologic setting.

Since EAB was an emerging technology at the time of project inception, a pilot test on a 100-ft^2 area established the effectiveness of EAB at remediating such elevated concentrations of contaminants. Previously untested on a highly contaminated area with mixed chlorinated solvent plumes, EAB using potassium lactate proved not only to be more successful than other technologies, but also posed fewer health risks and was significantly more cost-effective.

An environmentally friendly option, EAB maximizes the naturally occurring bacteria *Dehalococcoides* spp. By injecting potassium lactate into groundwater through a series of wells, the naturally occurring bacteria at the site underwent an unprecedented bacterial population boom (see Figure 2)—removing the need to introduce additional dechlorinating bacteria, often required with EAB remediation.

Also, because it is an in-situ technology, EAB eliminates the contamination in the ground, mitigating the risks typically associated with extraction technologies, such as accidental contaminant release to the environment or worker exposure. Since environmental responsibility was one of the cornerstones of this remediation project, sustainable solutions were incorporated throughout the project wherever possible.

Enhanced Bioremediation

Contaminants were present in all three water-bearing zones of the surficial aquifer system—which is composed of sand, sandy clay, and clay. The three separate water-bearing zones of the surficial aquifer system include an unconfined shallow zone, a semi-confined intermediate zone, and a confined deep zone to 40 ft below surface (see Figure 3). Having contamination in three distinct zones in an area of low transmissivity further complicated the remediation challenge.

In response, an innovative groundwater recirculation system with EAB was designed and installed to treat the contaminated groundwater. The treatment system includes a groundwater recirculation system using horizontal wells that intersect and extract groundwater from all three water-bearing zones. The corresponding vertical wells re-inject lactate-amended groundwater back into individual target zones. Extensive aquifer testing and computer modeling were conducted to optimize well placement and pumping rates.

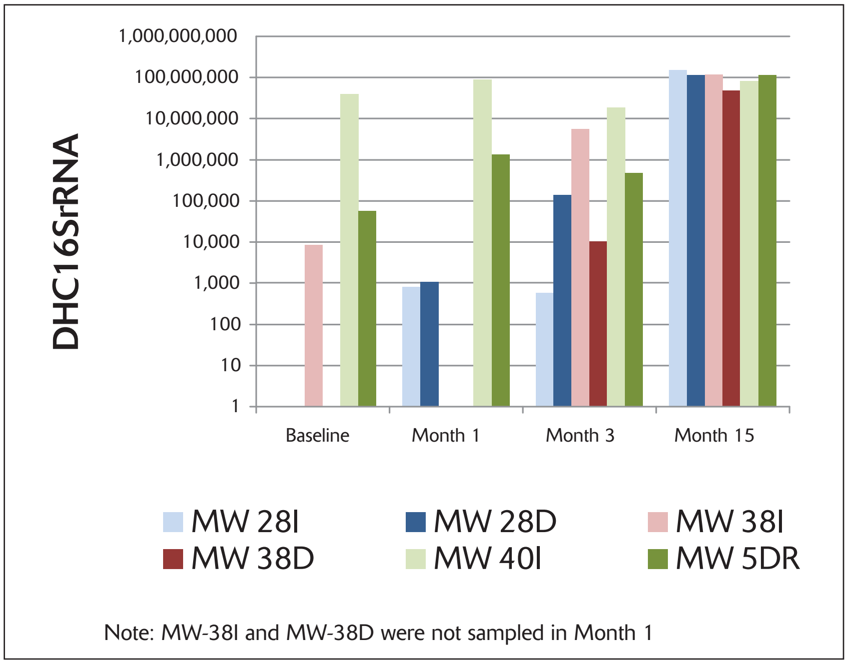
This innovative well system—comprised of horizontal recovery and vertical injection wells—effectively controls the groundwater flow and "floods" the contaminated zones with lactate to enhance the growth of existing dechlorinating bacteria. Continually recirculating the groundwater ensures that the electron donor, bacteria (*Dehalococcoides* spp.), and contaminants are in constant contact, creating an environment not typically achieved with traditional injection techniques. Complex hydraulic well systems also prevent the contaminated groundwater from flowing off site.

In all, 50 vertical injection wells and three horizontal recovery wells were installed. The three horizontal extraction wells transport groundwater to the onsite water treatment plant, where lactate is added prior to reinjection into the aquifer. This mixing speeds up the reductive dechlorination process and results in a complete breakdown of chlorinated solvents into harmless byproducts, effectively cleaning the groundwater.

Using horizontal wells to recover groundwater is not only more effective in this geological setting, but because there are fewer wells, it reduces electricity usage, as well as general operations and maintenance, saving on overall costs.

Vertical wells at the site boundaries are used to extract groundwater, preventing offsite migration of contaminants and protecting nearby land. The groundwater from the perimeter of the site—with lower concentrations of contaminants—is discharged to an onsite holding tank, and then batch processed through a 425-gallon-per-minute onsite treatment plant, where it is treated with a high-efficiency air stripper and discharged to the sanitary sewer (see Figure 4). Batch processing with a large air stripper significantly cuts down on system operation time, saving electricity.

Figure 2. *Biological growth.*



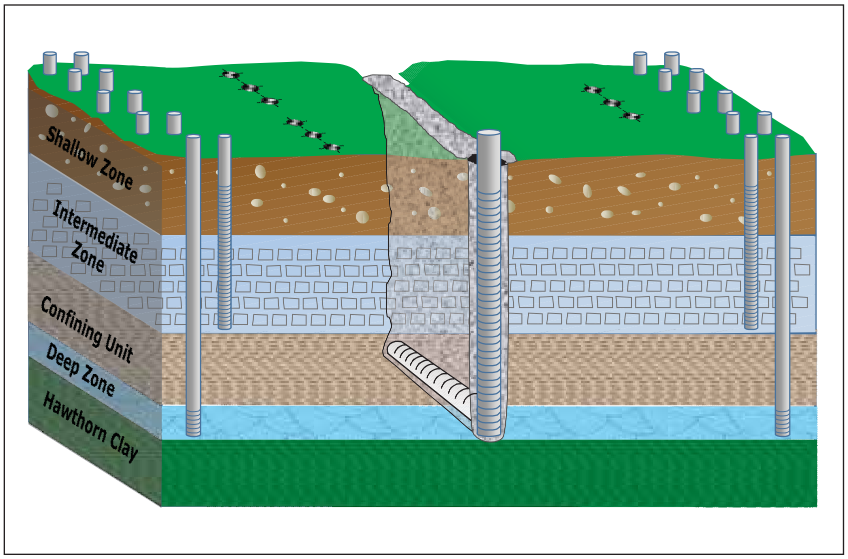


Figure 3. Hydrogeology and well network.

Designed specifically to treat contaminated groundwater, the plant cleans water from the vertical site boundary (hydraulic control) wells to municipal standards, allowing discharge to the city sanitary sewer system for final disposal. Because most of the contamination is remediated in situ, only a small portion of the groundwater is treated with air stripping prior to final discharge, further saving on energy and disposal costs.

The treatment plant and extraction systems are monitored and controlled by a sophisticated control system, which can be operated remotely via wireless modem. The plant was designed for ease of use, as well as flexibility, allowing it to be expanded or modified as needed in the future.

To install the horizontal wells, a unique one-pass trenching technology was used, which excavated the trench and installed the filter media in a single step, thereby cutting through three zones of the surficial aquifer. Standard trenching methods require dewatering and substantial benching or shoring of the trench, which increases the volume of contaminated waste to be disposed, as well as the associated costs. Based on the groundwater modeling performed, the use of traditional vertical extraction wells would have required up to 40 extraction wells. To cover the same area with horizontal wells, only three 100-ft segments were required, which were installed in three days. Because of the shorter operational time, the use of a one-pass trencher required less energy than traditional drilling technologies and thus reduced the amount of air emissions released during the process. Additional cost savings were realized by the reduced number of pumps, piping, gauges, and well vaults required.

Conditions optimal for reductive dechlorination are monitored through a detailed flow monitoring and sampling program. Based on the monitoring

Figure 4. Onsite treatment system.

results, operation of the horizontal wells—which are on a separate control system—can be optimized to redistribute the groundwater to spots where the conditions are not yet optimal. Areas that have achieved successful EAB conditions can be shut off, allowing natural processes to continue and saving energy. This cycling system reduces energy use and costs by only operating select wells based on field observations.

Successful Solution

At this time, all design and construction activities at the site have been completed, and the treatment system is online. Although the site is currently a light industrial and commercial location, it can reach full economic potential and accommodate development following successful cleanup. In addition, the flexible groundwater treatment system can be expanded or modified so that remedial efforts can be tailored based on future land usage.

Initial results have shown immediate and impressive reduction in groundwater contaminant levels. Within the first six months of full-scale operation, VOC mass was reduced by more than 90%. At startup, the highest concentration area had more than 2,000,000 µg/L of methylene chloride. After six months, the methylene chloride in this target area had been completely remediated and has not since been observed above laboratory method detection limits.

Significant reductions in total VOC mass in the EAB remediation cells demonstrate the effectiveness of the systems. Based on September 2009 analytical data, the estimated total VOC mass had been reduced from 2,897 lb (prior to system start-up) to 75 lb of total VOC mass. These values represent a greater than 97% reduction in contaminant mass in less than two years of operation. **em**

More Information

Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Groundwater; Interstate Technology and Regulatory Cooperation (ITRC) Workgroup, In Situ Bioremediation Subgroup, 1998.

Vogel, T.M.; Criddle, C.S.; McCarty, P.L. Transformations of Halogenated Aliphatic Compounds; *Environ. Sci. Technol.* **1987**, *21* (8), 722-736.