Field Experiments Using *In Situ* Bioremediation to Treat Trichloroethylene (TCE)-Contaminated Groundwater

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ABSTRACT: Three innovative technologies to remediate trichloroethylene (TCE) *in situ* were (or currently are being) evaluated at a TCE-contaminated groundwater site at Edwards Air Force Base (AFB), California. The three technologies all make use of groundwater recirculation to obviate the need to pump contaminated groundwater to the surface for treatment. The first technology, which implements aerobic cometabolic bioremediation to destroy TCE *in situ*, successfully reduced dissolved TCE concentrations from above 1 mg/L to 20-30 μg/L. The second technology, in-well vapor stripping (IWVS), is capable of treating dissolved TCE at concentrations in the tens to hundreds of mg/L. Finally, the third technology, bioenhanced in-well vapor stripping (BEHIVS), is a combination of the first two technologies, and is designed to reduce very high levels of TCE (tens to hundreds of mg/L) to concentrations that meet regulatory requirements (5 μg/L). Results of field evaluations of the first two technologies are presented, and the design of the BEHIVS system, as well as model predictions of BEHIVS performance and the current status of the technology field evaluation, is discussed.

INTRODUCTION

Trichloroethylene or TCE is, according to the Agency for Toxic Substances and Disease Registry, the most commonly detected contaminant at the approximately 330,000 hazardous waste sites across the U.S. (National Research Council, 1994). The U.S. Environmental Protection Agency suspects TCE is carcinogenic (Masters, 1997). Currently available strategies for containing migrating plumes of groundwater contaminated with TCE are plagued by various shortcomings. The drawbacks of current technologies, and the severity of the TCE contamination problem, have driven research to find new methods of containing TCE plumes *in situ*, with greater efficiency, and at lower costs.

TECHNOLOGIES EVALUATED

Aerobic cometabolic bioremediation

Aerobic cometabolic bioremediation is a remediation technology that takes advantage of the capability of indigenous microorganisms to degrade chlorinated compounds, such as TCE, when the microorganisms are provided an electron donor (primary substrate) and an acceptor (oxygen) in the presence of the chlorinated contaminant. The presence of the primary substrate induces a nonspecific enzyme which, fortuitously, cometabolically oxidizes the target contaminant while the microorganisms metabolize the primary substrate for growth and energy (Criddle, 1993). The effectiveness of this technology depends on being able to mix the primary substrate, oxygen, microorganisms, and target contaminant. In the implementation of aerobic cometabolic bioremediation at Edwards AFB discussed below, a system comprised of two

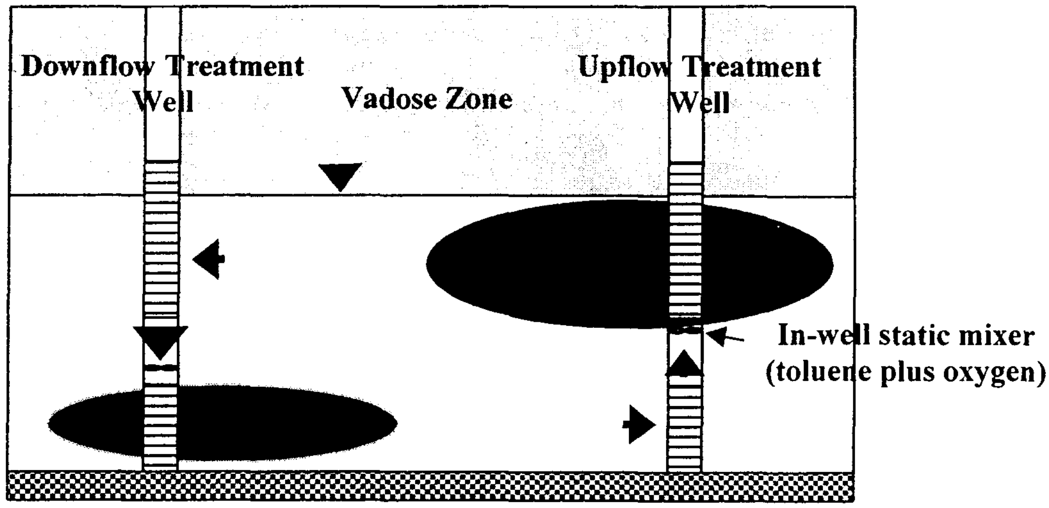

Figure 1. Aerobic Cometabolic Bioremediation Concept

groundwater circulation wells, one operating in an upflow mode, the other in a downflow mode, was used (Figure 1). Each treatment well was screened at two depths. A submersible pump installed between the two screens of each well drew TCE contaminated water into the well at one of the screened intervals. The primary substrate (toluene) and oxygen source (oxygen gas and hydrogen peroxide) were introduced into the well through feed lines, and mixed into the TCE-contaminated water using static mixers. The water (containing TCE, primary substrate, and oxygen) was discharged into the aquifer from the second screened interval. An *in situ* bioactive treatment zone was created in the aquifer around the discharge screen of each treatment well. Water was never brought to the surface, with the attendant savings in pumping cost. In addition to accomplishing *in situ* mixing, the pair of dual-screened treatment wells achieved another important purpose. Based on prior laboratory and field studies (Hopkins and McCarty, 1995; Jenal-Wanner and McCarty, 1997), it was estimated that achievable TCE reductions in the bioactive zones were limited to about 95%. In order to meet regulatory limits on TCE concentrations downgradient of the treatment system, greater reductions might be required. One way of attaining greater reductions is by recirculation, so that contaminated water passes through the bioactive zones multiple times for treatment. The pair of dual screened treatment wells, operating in upflow and downflow modes, effects this recirculation. The extent of recirculation (equivalent to the number of times contaminated water passes through the bioactive zones) is determined by the configuration of the system (treatment well pumping rate, distance between treatment wells, *etc.*) (Christ *et al.*, 1999).

Prior to the field evaluation at Edwards AFB, the technology had been demonstrated at both the laboratory and pilot scale (Wilson and Wilson, 1986; Hopkins *et al.*, 1993; Hopkins and McCarty, 1995; Jenal-Wanner and McCarty, 1997). Pilot-scale demonstrations conducted at Moffett Federal Airfield, California over several years quantified the rate and extent of contaminant biodegradation for various combinations of contaminants (TCE, vinyl chloride, cis- and trans-dichloroethylene) and primary substrates (methane, toluene, phenol) (Hopkins and

McCarty, 1995). Based on these studies, toluene was chosen as the primary substrate for the Edwards AFB field evaluation. These prior studies also demonstrated that aerobic cometabolic bioremediation was effective at treating TCE concentrations up to only a few mg/L.

In-well Vapor Stripping (IWVS)

In-well vapor stripping (IWVS) is a method for removing volatile organic compounds (VOCs) from groundwater without removing the water. Air is injected into a well and VOCs are volatilized. The VOC-rich vapor is removed and treated using granular activated carbon. By injecting air into the well, air lift pumping is effected and groundwater in the cleanup zone is recirculated and successively cleaned. Dissolved concentrations can be reduced by 90 to 99 percent within the cleanup zone (Gvirtzman and Gorelick, 1992, 1993; Gorelick and Gvirtzman, 1993, 1995).

IWVS operates on two principles. The first is that of groundwater recirculation. This occurs when air is injected into the well. Due to the density difference between the water outside the well and the water-bubble mixture within the well, a lift is created (Francois *et al.*, 1996). Water and air rise within the well, forcing additional water to flow from the aquifer into the well through a screen at the well bottom. The water and bubble mixture flows upward and exits the well through an upper screen straddling the water table. Because the water enters the well at the lower screened interval and returns to the water table, a groundwater circulation cell is developed in the vicinity of the well. The second operating principle is that of volatilization (Gvirtzman and Gorelick, 1992; Pinto *et al.*, 1997). When contaminated water enters the well at the lower screened interval, it encounters the injected air that has formed bubbles. The VOCs will volatilize and mass is transferred from the water to the gas phase. Given approximately 20 feet of contact distance between the contaminated water and the air bubbles, equilibrium partitioning occurs. The air within the well strips out the VOCs. This air is separated from water using a separator plate located above the upper screened interval and the VOC-enriched vapor is vacuumed off and treated by sorption onto granular activated carbon. The water exiting the well at the upper screened interval has then been depleted in VOCs and is returned to the aquifer where additional IWVS takes place or microbial degradation occurs. IWVS has efficacy at any level of contaminant concentration and can be particularly effective when VOC concentrations are high.

Bioenhanced In-well Vapor Stripping (BEHIVS)

BEHIVS combines aerobic cometabolic bioremediation with IWVS. These two technologies complement each other in that IWVS is amenable for sites contaminated with high concentrations of TCE and aerobic cometabolic bioremediation is appropriate as a polishing step. Together these two technologies offer the potential for near complete removal of high levels of TCE, such as would be found at a groundwater contamination source area. The proposed treatment system (Figure 2) consists of a single IWVS well that will be located near the source of TCE contamination and two biotreatment wells that will be located downgradient and on either side of the IWVS well. The IWVS well will treat the relatively high contaminant levels present near the source, reducing contaminant concentrations by approximately 90%, while the cometabolic bioremediation wells will "polish" the effluent from the vapor stripping well. The nutrients required for cometabolism, toluene and oxygen, will be added at the biotreatment wells.

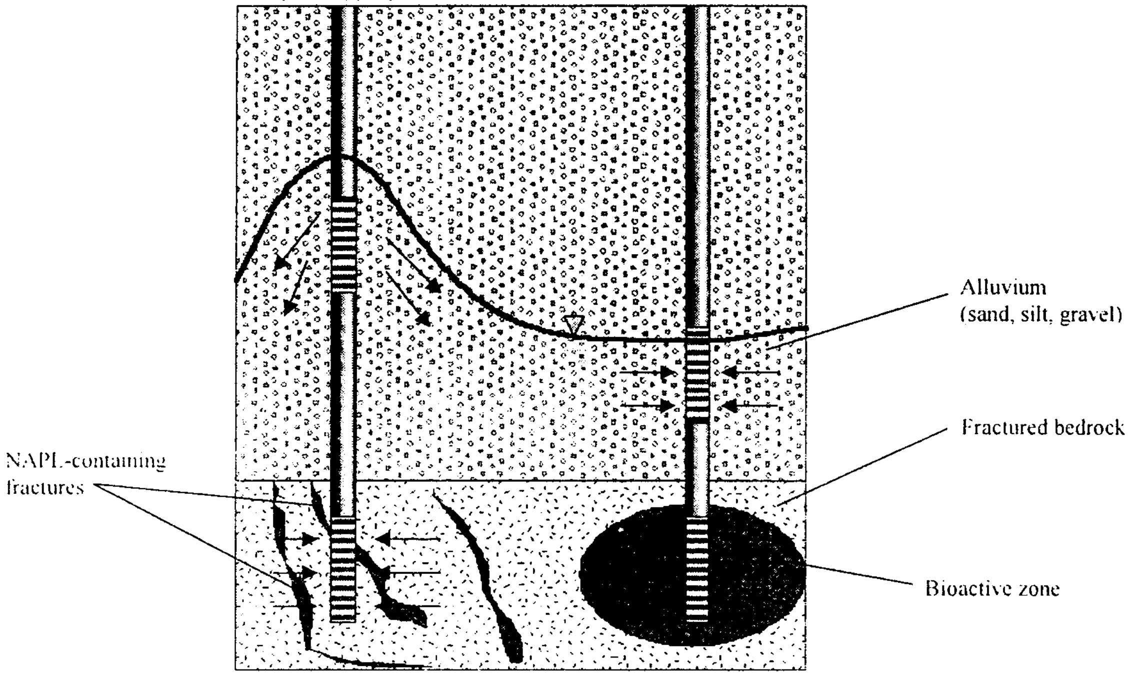

Figure 2. BEHIVS Concept

FIELD EVALUATIONS

McCarty *et al.* (1998) reported details of the evaluation of aerobic cometabolic bioremediation at Edwards AFB Site 19. TCE removals with each pass of contaminated water through the bioactive zones were approximately 85%. However, because of recirculation between the two biotreatment wells, overall TCE removal, comparing upgradient concentrations of about 1 mg/L, with concentrations downgradient of the treatment system of about 20-30 μg/L, was over 97%.

The details of the IWVS evaluation were reported by Pinto (2000). TCE removals of approximately 90% were achieved with each pass of contaminated water through the IWVS well. The overall removal, comparing concentrations upgradient and downgradient of the IWVS, was difficult to quantify, as the upgradient concentrations fluctuated. However, with relatively low upgradient concentrations (on the order of 100 μg/L) the IWVS system was able to attain the drinking water standard of 5 μg/L TCE downgradient. A second IWVS well was installed near the TCE contamination source area, and that well achieved a single-pass removal of 91%, and reduced TCE concentrations from approximately 2300 μg/L upgradient of the well to about 100 μg/L downgradient (Gandhi, 2001).

As of April 2001, the BEHIVS system had been constructed at the source area of the TCE contaminant plume at Site 19, and system testing was underway. Model simulations indicated that TCE concentrations at the source area could be reduced from several mg/L to 5 μg/L, and TCE mass reductions of over 3 kg could be achieved in 180 days (Gandhi, 2001).

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