

Successful Remediation of Chlorinated Solvents Using Source Treatment and Natural Attenuation

J. W. Mercer jmercer@geotransinc.com, G. C. Frederickson, D. Burnell (GeoTrans, Inc., Sterling, Virginia), S. Dublin (Caretta, Inc., Ft. Lauderdale, Florida), J. E. Donahue (LBFH, Inc., Ft. Pierce, Florida) and R.M. Ferris (City of Palm Beach Gardens, Florida)

Successful DNAPL source area remediation combined with rapid biodegradation of an associated chlorinated solvent plume at a site in Palm Beach Gardens, Florida has reduced aquifer concentrations to near or below state natural attenuation criteria. Cis-1,2-dichloroethene (DCE) and vinyl chloride (VC) were first detected in a municipal wellfield in early 1984. The contamination was traced to a limited (about 40 ft by 80 ft by 30 ft deep) tetrachloroethene (PCE) source area in a recreational field located approximately 900 ft north of municipal well PBG-11, along an elliptical flow path.

Source removal operations began in August 2001 and consisted of a down-gradient shallow, two-well, pump-and-treat (P&T) system, a soil vapor extraction (SVE) system, and an air sparge (AS) system. As of June 2005, the P&T system had removed approximately 158 pounds (lbs) of PCE and the SVE/AS system had removed 1,325 lbs of PCE. Between 1999 and 2005, PCE concentrations at a monitoring well inside the source decreased by almost 1,000 times from 200,000 parts per billion (ppb) in March 1999 to 340 ppb in June 2005. Site data indicate that this relatively small, shallow DNAPL source has been remediated to near the State of Florida natural attenuation clean-up goal of 300 ppb PCE in less than five years.

Flow and transport modeling was performed to evaluate natural attenuation processes between the source and PBG-11. Even before source remediation began, PCE disappears within about 200 ft of the source, and at PBG-11, only the daughter products, DCE and VC, have ever been observed. The calibrated half-lives were approximately 20 d for PCE, 25 d for trichloroethene (TCE), 100 d for DCE and 200 d for VC, indicating that rapid biodegradation will substantially reduce plume concentrations prior to reaching the wellfield. This site is an important example of successful DNAPL source area remediation combined with very rapid natural attenuation that is protective of the down-gradient municipal wellfield receptors.

Introduction

In 1984, sampling of the Lilac Street Wellfield located in Palm Beach Gardens (PBG), Florida by the United States Environmental Protection Agency (US EPA) identified the presence of volatile organic compounds (VOCs) in the municipal water supply (US EPA, 1984). Follow-up sampling in June 1984 of six active production wells identified the presence of DCE and VC in one production well, referred to as PBG-11, which was immediately taken out of service. On June 12, 1984, PBG-11 contained VC at a concentration of 23 ppb and DCE at 32 ppb. A second well, PBG-4, which was out-of-service in 1984, was sampled for the first time in 1987 and also found to contain DCE and VC. PBG-11 and PBG-4 were out of service from 1984 until 1991 when air strippers were installed at both wells. In 1991, both wells went into rotational operation at 300 gallons per minute (gpm) until 1993, when continuous operation began in order to control contaminant migration to the rest of the wellfield.

The source of the impacts to the production wells was believed to be generally north of PBG-11 based on operational histories of neighboring properties and monitoring results (Metcalf & Eddy, 1997). Directly north of PBG-11 was an industrial property referred to as the former Klock property (Figure 1) that historically used chlorinated solvents (ERM, 1995). Chlorinated solvent-impacted soils and groundwater were found in a swale (referred to as the swale source) near the northeast corner of the former Klock property at a drain field (Metcalf & Eddy, 1996, 1998). However, sampling of deep wells along the northern property boundary of the former Klock property also indicated a potential source to the north (ERM, 1997).

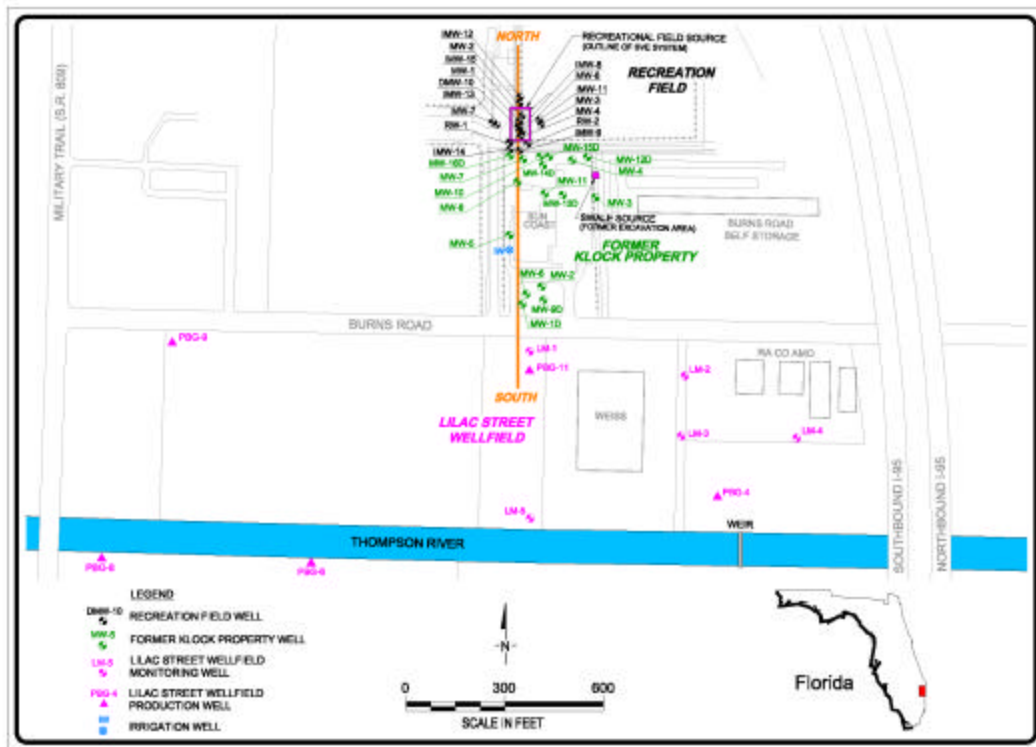


FIGURE 1. Site Map.

North of the former Klock property is a recreational field, which had never been used for commercial or industrial purposes, that was deeded to the City of Palm Beach Gardens on July 16, 1990. Extensive sampling in the recreational field (referred to as the recreational field source) identified the presence of high concentrations of chlorinated solvents in the soil and groundwater (Metcalf & Eddy, 1998). Regular groundwater monitoring indicated that the recreational field source is the dominant source of the chlorinated solvents detected at PBG-11 (Metcalf & Eddy, 1998).

This paper discusses the successful remediation of the recreational field source using a combination of P&T, SVE, AS, and natural attenuation within a five-year time period. Groundwater flow and transport modeling confirmed the extremely fast biodegradation rates of the chlorinated solvents in groundwater observed during monitoring. These fast rates combined with the reduction in source area mass are shown to be protective of the municipal wellfield.

Geology and Hydrogeology

The soil in the PBG area consists mainly of poorly sorted fine- to medium-grained sands to a depth of 120 ft below the ground surface (bgs) with layers of finer-grained silty sand and shell fragments throughout. Between 120 and 200 ft bgs, a sandy limestone with shell and sandstone lenses is present. The Lilac Street Wellfield production wells are screened within the lower portion of the limestone aquifer (e.g., PBG-11 is screened between depths of 150 to 180 ft bgs).

The depth to groundwater is variable but typically ranges between 7 and 10 ft bgs across the area of interest. Horizontal hydraulic gradients at the area of interest generally range from 0.0005 to 0.002 ft per horizontal ft to the south or southwest. Vertical hydraulic gradients are higher, averaging 0.05 ft per ft downward, largely due to the effects of pumping at the wellfield.

A pumping test conducted at production well PBG-10 in 1983 (Geraghty & Miller, 1992) determined a transmissivity of 52,100 gallons per day per ft (hydraulic conductivity of about 87 ft/d over an 80-ft aquifer thickness). Slug tests performed on shallow wells located on the former Klock property resulted in an estimated hydraulic conductivity in the range of 30 ft/d (ERM, 1995). These aquifer tests indicate that the shallow aquifer materials are less permeable than the deeper limestone portion of the aquifer where the production wells are screened.

Recreational Field Source and Remediation

The recreational field source area was identified in 1997 during a direct-push boring investigation (Metcalf & Eddy, 1998) in which a PCE concentration of 140,000 ppb was measured in a groundwater sample from 8 ft bgs. Shallow monitoring well MW-1 was installed at that location, and a groundwater sample collected on March 8, 1999 contained 200,000 ppb of PCE (Ardaman & Associates, 1999). This elevated PCE concentration is indicative of dense non-aqueous phase liquid (DNAPL) PCE (see e.g., Cohen and Mercer, 1993).

Based on a review of the site history, the recreational field source appears to be due to “mid-night” dumping. The City of Palm Beach Gardens took a three-pronged remedial approach to the cleanup of the recreational field source and to protect the wellfield: (1) source removal operations, (2) natural attenuation with monitoring, and (3) wellfield protection program involving air strippers installed on the municipal drinking water wells. As discussed below, both solute transport modeling and confirmation sampling show that this approach is effective.

A down-gradient shallow, two-well, P&T system was initiated on August 1, 2001 in order to maintain hydraulic control and detach the dissolved plume from the source. Particle tracking simulations using the groundwater flow model discussed below indicate that the recovery wells at their current 20 to 30 gpm total pumping rates are providing hydraulic containment of the plume emanating from the recreational field source area. The SVE system consisting of 8 horizontal wells was started on December 12, 2001. Once vapor concentrations were reduced, an AS system consisting of 12 sparging wells was initiated on December 3, 2002.

TABLE 1. PCE mass removed since system startup on August 1, 2001.

Quarter	Time Period	Total PCE Mass Removed (lbs)	
		P&T	AS/SVE
1	August – November 2001	61	Not On Line
2	November 2001 – March 2002	8.5	90
3	March – June 2002	32	105
4	June – October 2002	30	301
5	October 2002 – January 2003	17	352
6	January – March 2003	6	280
7	March – July 2003	1.1	120
8	July – October 2003	0.01	30
9	October 2003 – March 2004	1	9.1
10	March – June 2004	.75	15.4
11	June – November 2004	0.25	17.6
12	November 2004 – February 2005	0.1	2.6
13	February – April 2005	0.1	1.8
14	April– June 2005	0.1	0.9

The total PCE mass removed by the P&T and AS/SVE systems is shown in Table 1. As of June 2005 the P&T system had removed approximately 158 lbs of PCE and the AS/SVE system had removed over 1,325 lbs of PCE. Monitoring well MW-1 had a PCE concentration of 200,000 ppb on 3/8/99, but by mid-2005 the PCE concentration had declined to the range of 300 to 700 ppb (Figure 2). This suggests that the DNAPL source zone has been largely removed and that within less than five years residual source area concentrations are nearing the State of Florida natural attenuation clean-up goal of 300 ppb PCE. Monitoring well MW-16D, located slightly down-gradient of the two P&T wells, had a PCE concentration of 15,000 ppb on 1/27/97, but by 2005, PCE in this well was not detected.

Flow and Transport Modeling

Introduction. Groundwater flow and solute transport modeling was conducted to assess the effects of the three-pronged remedial approach on dissolved chlorinated solvents in the area of the recreational field source. The three-dimensional, finite-difference groundwater flow code MODFLOW (McDonald and Harbaugh, 1988) was used to simulate the groundwater flow field. Solute transport and biodegradation of chlorinated solvents were modeled using the MT3D99 code (Zheng, 1999).

Groundwater Flow Model. A local three-dimensional groundwater flow model was constructed based on a regional groundwater flow model produced by Arcadis Geraghty & Miller to support applications to modify South Florida Water Management District Water Use Permits (Geraghty & Miller, 1992; Seacoast Utility Authority, 1998). Details on the creation and calibration of the local flow model and particle tracking are contained in GeoTrans, Inc. (2003). A telescopic mesh refinement procedure was used to create the local model while preserving boundary conditions and hydraulic parameters from the regional model.

The groundwater flow model was calibrated using 1997 water-level measurements from sixteen monitoring wells on the former Klock property. Residual statistics for the

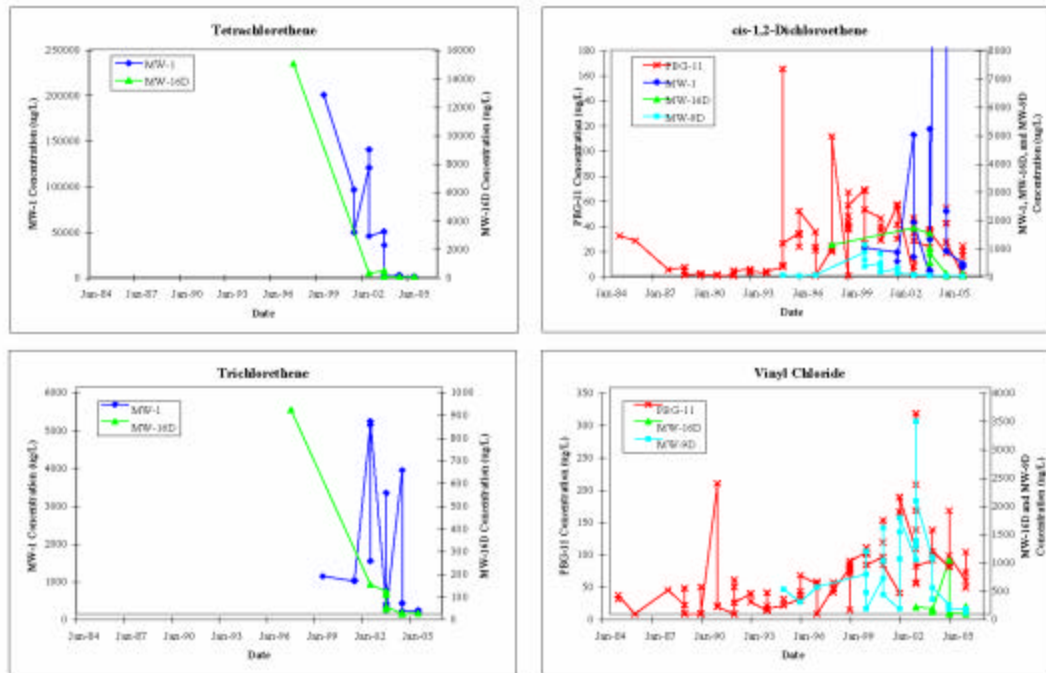


FIGURE 2. Chlorinated solvent time series plots for MW-1, MW-16D, MW-9D, and PBG-11.

calibrated groundwater flow model indicate good agreement between simulated and observed groundwater elevations. The slope of the simulated water table is slightly steeper than the actual measured slope. At the former Klock Property and recreational field, the simulated groundwater flow is to the south with a downward component of flow toward production well PBG-11, similar to observed flow gradients. The match with both vertical and horizontal groundwater flow directions provides increased confidence in the predictive capability of the model.

Solute Transport Model. Using the results of the steady-state flow model, groundwater transport modeling was conducted to simulate the approximate lateral and vertical extent of the dissolved chlorinated solvent plumes and to calibrate approximate chlorinated solvent biodegradation rates using average measured concentration data collected in 1997. First-order biodegradation rates for each dissolved chlorinated solvent compound were initially estimated based on average measured field data from similar sites (Aronson and Howard, 1997). Using these rates, however, resulted in a substantial overestimation of down-gradient chlorinated solvent concentrations, especially for PCE and TCE. Therefore, the degradation half-lives for the four chlorinated solvent compounds were reduced until the simulated plume extents were similar to observed 1997 plume configurations, with particular emphasis on concentrations at PBG-11 and the closest monitoring well, LM-1, which are both located in the central down-gradient portion of the chlorinated solvent plumes. The calibrated decay rates were then used to

simulate the approximate steady-state plumes that result from decreases in residual source area concentrations that may remain after source removal system operation. Details on the creation and calibration of the solute transport model are contained in GeoTrans, Inc. (2003).

The resulting calibrated half-lives were approximately 20 d for PCE, 25 d for TCE, 100 d for DCE, and 200 d for VC. PCE and TCE degradation rates were generally faster than rates measured in the field at other sites, although they were consistent with rates measured during laboratory microcosm studies (Aronson and Howard, 1997). DCE and VC degradation rates were generally more consistent with rates observed in the field at other sites, but still near the faster end of the observed range. These rates are consistent with the observed disappearance of PCE and TCE within a short distance down-gradient of the source areas and the more extensive DCE and VC plumes, and provide an indication of the rapid biodegradation that occurs in the study area. Chapelle and Bradley (1999) observed similar ethenes distributions at a site in Kings Bay, Georgia.

Additional simulations were made to assess the effectiveness of the AS/SVE source removal operations. The main assumption of these scenarios was that the AS/SVE system had successfully reduced the source contaminant mass, but that residual dissolved phase PCE was still being released to the groundwater. Therefore, the source was simulated as constant concentration cells with concentrations of 3,000 ppb, 300 ppb, and 3 ppb to represent differing effectiveness of the source removal operation. For these scenarios pumping at the two recovery wells was discontinued and pumping at the wellfield was set to typical rates. Figure 3 shows cross-sections through the center of the DCE and VC plumes using the three residual source concentrations and typical pumping at the wellfield. In the simulation with a residual source area concentration of 3,000 ppb, the VC plume is captured by PBG-11, but at very low concentrations. At residual source concentrations less than 3,000 ppb, however, the simulations show that the dissolved phase concentrations of all four compounds will be below detection limits prior to reaching the wellfield. This demonstrates that even without pumping at the recovery wells, enough source area contaminant mass has been removed so that within a short distance, natural biodegradation rapidly reduces the down-gradient concentrations of source residual contaminants.

Conclusions

This case study provides an example of successful DNAPL source remediation in which a three-pronged remedial approach was used to address chlorinated solvent contamination that emanated from a small, shallow DNAPL source and impacted a municipal drinking water well. DNAPL source removal operations consisting of a down-gradient shallow, two-well, P&T system and a source area AS/SVE system were initiated beginning in 2001. As of June 2005, the P&T system had removed approximately 158 lbs of PCE and the AS/SVE system had removed 1,325 lbs of PCE. PCE concentration at a monitoring well in the source declined from 200,000 ppb on 3/8/99 to 340 ppb on 6/16/05. This case study also provides an example of a robust natural biodegradation system down gradient of the DNAPL source.

Groundwater flow and solute transport modeling confirmed that biodegradation is a very rapid process at this site. Therefore, once source area mass is sufficiently removed, natural attenuation processes will reduce dissolved plume concentrations below MCLs

prior to reaching the wellfield. The modeling demonstrated that at residual concentrations of less than 3,000 ppb, none of the chlorinated solvent residual plumes will reach the wellfield at concentrations above analytical detection limits.

In summary, the results of the transport modeling indicate that the effectiveness of the removal action, the active biodegradation processes at this site, and the current well-head treatment undertaken at PBG-11 should provide reasonable assurance that the drinking water supply is protective of human health.

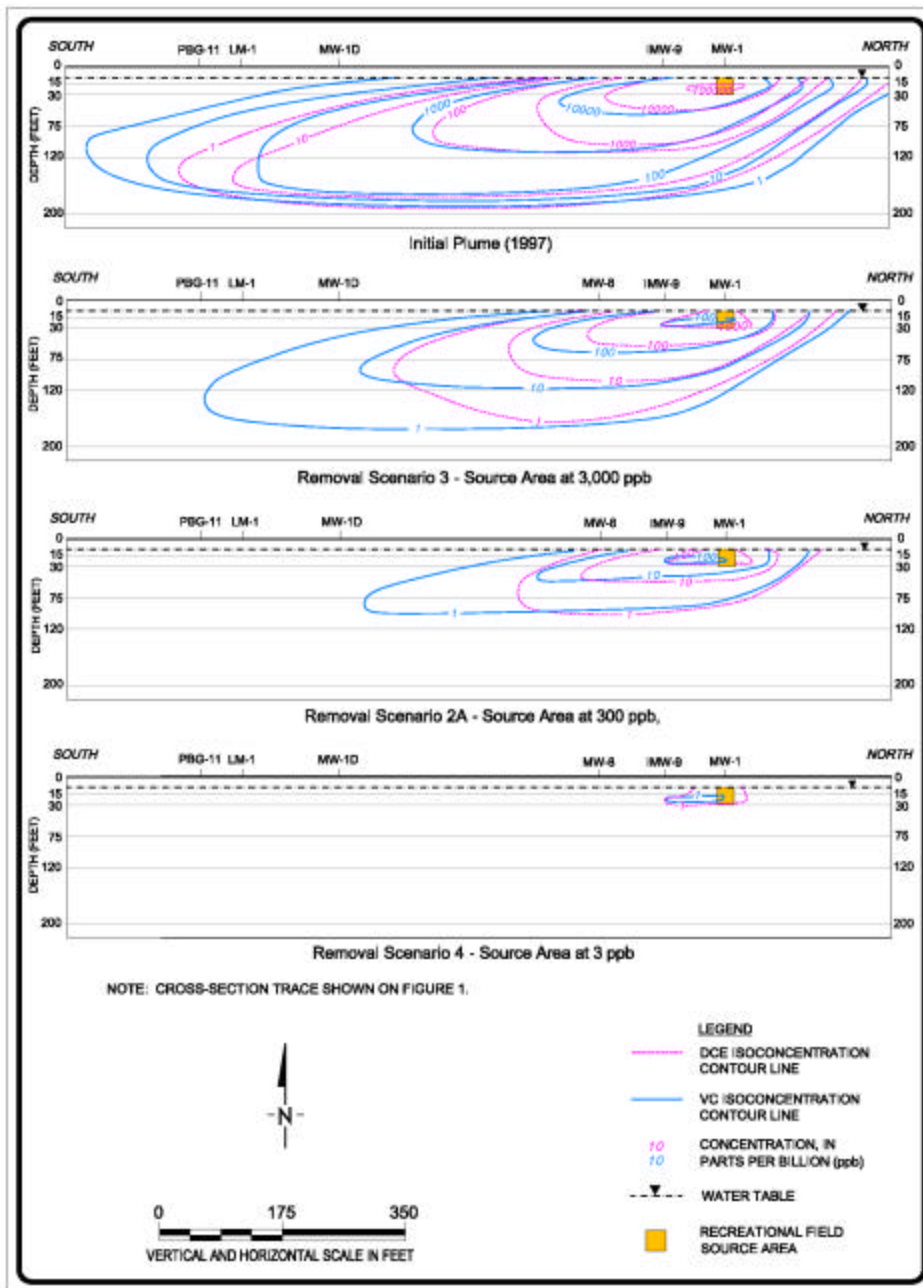


FIGURE 3. Cross-sections of Simulated DCE and VC Plumes for Source Area Removal Scenarios.

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