Cost and Performance Summary Report
In Situ Chemical Oxidation, Soil Vapor Extraction, and In Situ Bio-Stimulation at Hanner's Dry Cleaners, Pompano Beach, Florida

Summary Information [Refs. 2, 4, 5, 15, 17, 18]

The currently inactive Hanner's Dry Cleaners operated from the early 1960s to 1989. The facility is located at 209 West Atlantic Boulevard (the northwest corner of the intersection of West Atlantic Boulevard and West [Old] Dixie Highway) in Pompano Beach, Florida. Conventional laundry machines were used at the facility and, according to the owner, approximately 80 gallons of tetrachloroethene (PCE) were added into the dry cleaning machines every 2 weeks while the facility operated. During operation, two 550-gallon underground storage tanks (USTs) were used at the site. According to the owner, one of the tanks contained diesel oil used as fuel for the boilers, and the other contained mineral salt or Stoddard Solvent. One tank was located on the north side of the facility and the other was located on the east side; both were registered as diesel storage tanks. Both USTs were removed in 1990. The last building present on the site was demolished in 2000; currently, only the concrete slab floor remains. After closing in 1989, the facility was included in the Florida Department of Environmental Protection (FDEP) Drycleaning Solvent Cleanup Program (DSCP).

A site assessment concluded that both soil and groundwater at the facility had been contaminated with halogenated volatile organic compounds (VOCs) and that the plume extended beyond the boundaries of the site. PCE in soil was detected at concentrations as high as 37,200 micrograms per kilogram (µg/kg), and trichloroethene (TCE) was detected at concentrations up to 3,320 µg/kg. Concentrations of total chlorinated ethenes in groundwater have been detected as high as 225,589 micrograms per liter (µg/L) in what has been identified as the core of the contamination plume. Concentrations of PCE in this area have also exceeded 20 percent of solubility (200,000 µg/L), indicating that residual dense nonaqueous phase liquid (DNAPL) is likely to be present. The groundwater plume extends from the northwestern area of the site to the southeast. The core of the plume lies approximately 6 to 30 feet (ft) below ground surface (bgs) and is directly beneath the former eastern UST.

Based on analytical data, FDEP initially developed the following remediation strategy for the site:

- Limited excavation of accessible soils in the vadose zone where concentrations exceed the FDEP soil leachability cleanup goals in the area of the former eastern UST.
- Soil vapor extraction (SVE) for the soils beneath the concrete floor slab and in the area adjacent to the limited excavation where contaminant concentrations exceed the leachability cleanup goals.
- In situ chemical oxidation to reduce groundwater contamination in the core plume area to Natural Attenuation Default Criteria (NADC) concentrations.

- Quarterly groundwater sampling and monitored natural attenuation in the off-site plume areas.

The limited soil excavation in the area of the former eastern UST was carried out in May 2000. A total of 3,150 cubic ft (ft^3) of contaminated soil in the vicinity of the former eastern UST was removed, treated, and disposed off site. SVE was conducted at the site on a nearly continuous basis for a year (April 2001 to May 2002). Contaminant concentrations in the soil had been reduced to below detection limits at the end of system operation.

The chemical oxidation application consisted of two pilot-scale injections conducted in June and August 2000, and three full-scale injections conducted in May 2001, October 2001, and April 2002, using a modified Fenton's reagent. Chemical oxidation was able to reduce groundwater contamination, but the NADC concentrations were still exceeded in the source area. These residual elevated levels prompted a second excavation of soil in June 2004 of an area approximately 16 by 14 ft and 18 ft deep within the core plume area (the saturated zone). A total of 128 tons (95 cubic yards) of soil was removed and disposed off site and air sparging was then implemented in the excavated area in June 2004. In addition, biostimulation was conducted by adding sodium thiosulfate and ethyl lactate to groundwater in the excavation area to enhance the reductive dechlorination that was occurring.

Additional in situ biostimulation, in the form of ethyl lactate injections, was conducted to further enhance reductive dechlorination at the site. A pilot test occurred in November 2004, and four full-scale injections of ethyl lactate were conducted in February and June 2006 and in February and April 2007.

FDEP Facility ID:	069601962
Type of Action:	Drycleaning Solvent Cleanup Program
Lead:	Metcalf & Eddy, Inc
Oversight	Florida Department of Environmental Protection

Timeline

1989 – 1996	Environmental investigation of the site and adjacent properties leads to detection and characterization of halogenated VOCs in groundwater and soil.
June 1990	Two USTs removed from the site.
March 28, 1997	Site included in the FDEP DSCP.
April 2000	SVE system installed.
May 10, 2000	Limited soil excavation implemented in the vicinity of former

	eastern UST (vadose zone).
April 2001	SVE system activated.
May 9, 2001	In situ chemical oxidation – first full-scale injection.
October 31, 2001	In situ chemical oxidation – second full-scale injection.
April 11, 2002	In situ chemical oxidation – third full-scale injection.
May 2002	SVE system deactivated.
June 2, 2004	DNAPL-contaminated soil excavated from source area (saturated zone).
June 4-7, 2004	Air sparging begins in excavation area.
February 2006	In situ bio-stimulation – first full-scale injection.
June 2006	In situ bio-stimulation – second full-scale injection.
February 2007	In situ bio-stimulation – third full-scale injection.
April 2007	In situ bio-stimulation – fourth full-scale injection.

Factors that Affected Cost or Performance [Refs. 2, 3, 18]

Based on tests conducted before the remedial actions were initiated, the surficial soils beneath the site were found to consist of medium-grain quartz sand with silt and limestone fragments. The groundwater table is encountered at an average depth of 7 ft bgs with an estimated annual variation of 2 ft. Groundwater flows in an east-southeast direction and is not affected by the City of Pompano Beach well field, which lies more than 2,000 ft east-northeast of the site.

Sheet piles were installed to allow for excavation below the water table without requiring soil dewatering during the second excavation event in June 2004. Because of the high conductivity of the aquifer below the site, dewatering would have resulted in a large volume of water that would have required treatment and discharge.

Listed below are the key matrix characteristics for the technologies employed at the site and the values measured for each during the site characterization.

Matrix Characteristics [Refs. 3, 4, 7, 15, 18]

Parameter	Value
Soil Classification:	Medium grain quartz sand
Clay Content or Particle Size Distribution:	Medium grain sands with silt
Hydraulic Conductivity:	92 ft/day in shallow subsurface zone (17 ft bgs) and 15 ft/day at a depth of 75 ft bgs
Depth/Thickness of Zone of Interest:	7 ft bgs for soil contamination. 7 to 40 ft bgs for groundwater contamination
Porosity:	0.3 (estimate)
Total Organic Carbon:	2 to 20 mg/L dissolved carbon
Presence of NAPLs:	DNAPL presence inferred because PCE detected at twenty times solubility

Treatment Technology Description [Refs. 2- 4, 6, 7, 15, 17]

SVE

The full-scale SVE system for the site was based on a vapor extraction pilot test conducted before remediation began. The pilot test system consisted of a single 30-foot horizontal vapor extraction well (VEW) (VEW-1). A 30-foot VEW was used instead of a standard 10-foot VEW because it could better capture the plume. The monitoring system for the pilot test consisted of five vacuum monitoring points (VMPs) (VMP-1 to VMP-5) that were installed for the test and used together with previously existing monitoring wells (MW001, MW002, MW005, and MW007). Based on the results of the pilot test, it was recommended that a second 10-foot horizontal extraction well (VEW-2) be installed for the full-scale operation.

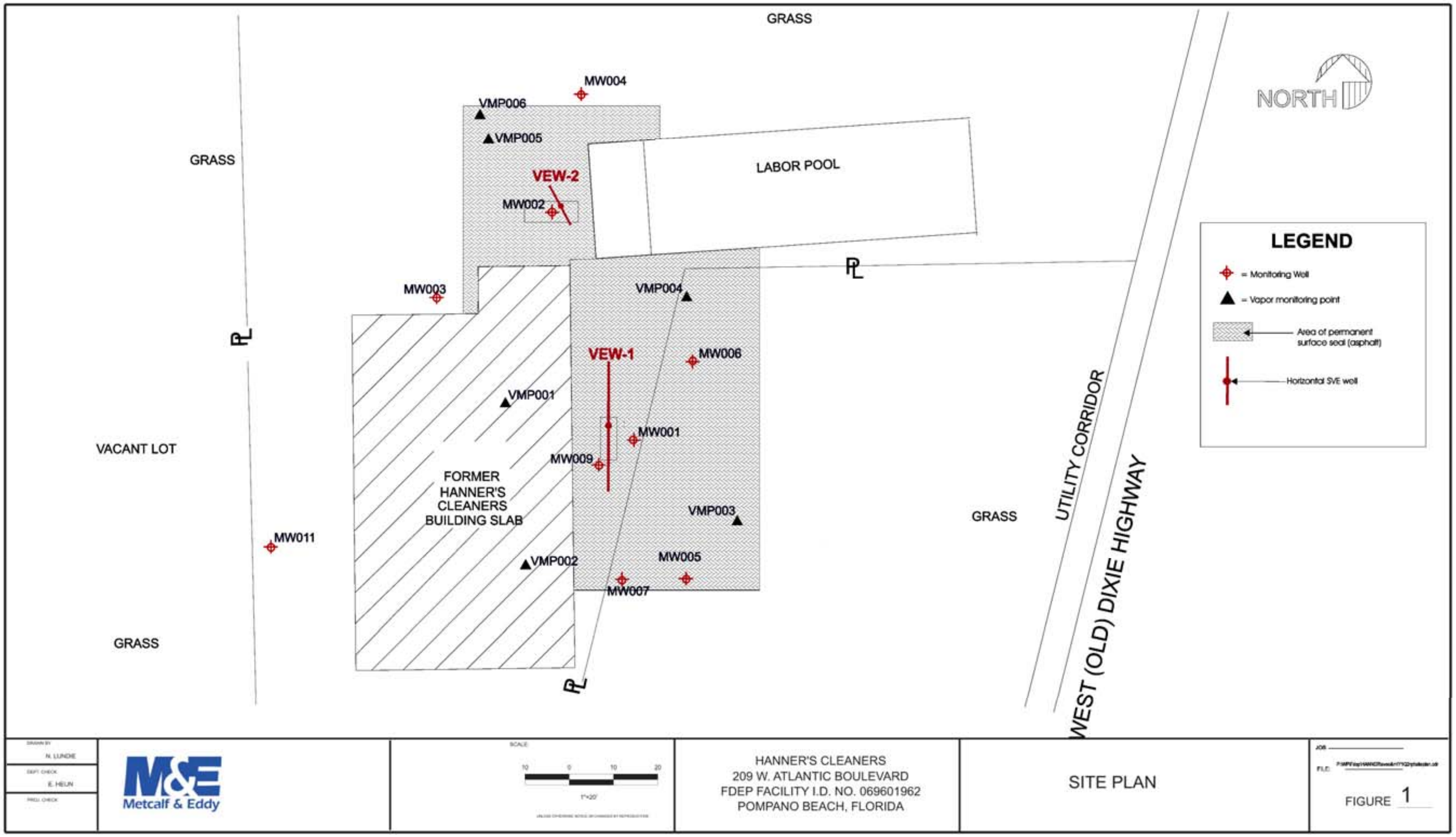
The full-scale SVE system consisted of two VEWs (VEW-1 and -2), installed at approximately 4 ft bgs. Piping ran from each VEW in parallel through separate air-water separators, particulate filters, and carbon canisters. Both units shared a 20-horsepower regenerative blower to create a vacuum. Off-gas was treated using carbon adsorption by running the extracted soil vapor through four 140-pound carbon vessels that contained granular activated carbon (GAC). These vessels were situated in two sets of two vessels each, running in parallel. A sixth VMP (VMP-6) was installed during construction of the full-scale SVE system. Figure 1 shows the location of each VEW and VMP.

The SVE system was monitored using several different approaches. Vacuum was measured at the SVE blower, at the VEW wells heads, and at other key points throughout the system. VMPs measured the radius of influence for each horizontal VEW. Vapor samples were collected at the influent of the first carbon vessel, the influent to the second vessel, and in the final effluent to measure for halogenated VOCs.

In Situ Chemical Oxidation

The design and operation of the full-scale in situ chemical oxidation system for the initial groundwater remediation at the site was based on the results of a bench-scale feasibility test and a pilot study. The bench-scale test evaluated the performance of chemical oxidation technologies from four different vendors. Results of the testing led to selection of the ISOTEC (In Situ Oxidative Technologies, Inc.) process. A field pilot test was conducted after FDEP approved the selected in situ chemical oxidation process. The pilot test consisted of six 4-inch-diameter injection wells (IWs) installed to a depth of 30 ft bgs. Two injection events were conducted during the pilot test. The first injection delivered 5,280 gallons of 12 percent hydrogen peroxide and 2,640 gallons of chelated iron catalyst. The second injection delivered 7,700 gallons of 12 percent hydrogen peroxide and 3,000 gallons of chelated iron catalyst.

Figure 1. Location of Vapor Extraction Wells and Vacuum Monitoring Points



The ISOTEC process uses a Fenton-type reaction with a proprietary, chelated iron catalyst and hydrogen peroxide. The reagent consisted of ISOTEC Catalyst 4260 and a 12 percent stabilized hydrogen peroxide oxidant. According to the vendor, the proprietary reagents allow for field propagation of the Fenton's reaction under near-neutral pH conditions, while enhancing the mobility of the iron ions and improving the stability of hydrogen peroxide. The process generates hydroxyl radicals as oxidizing agents and produces carbon dioxide, water, and chloride ions as products of a complete oxidation.

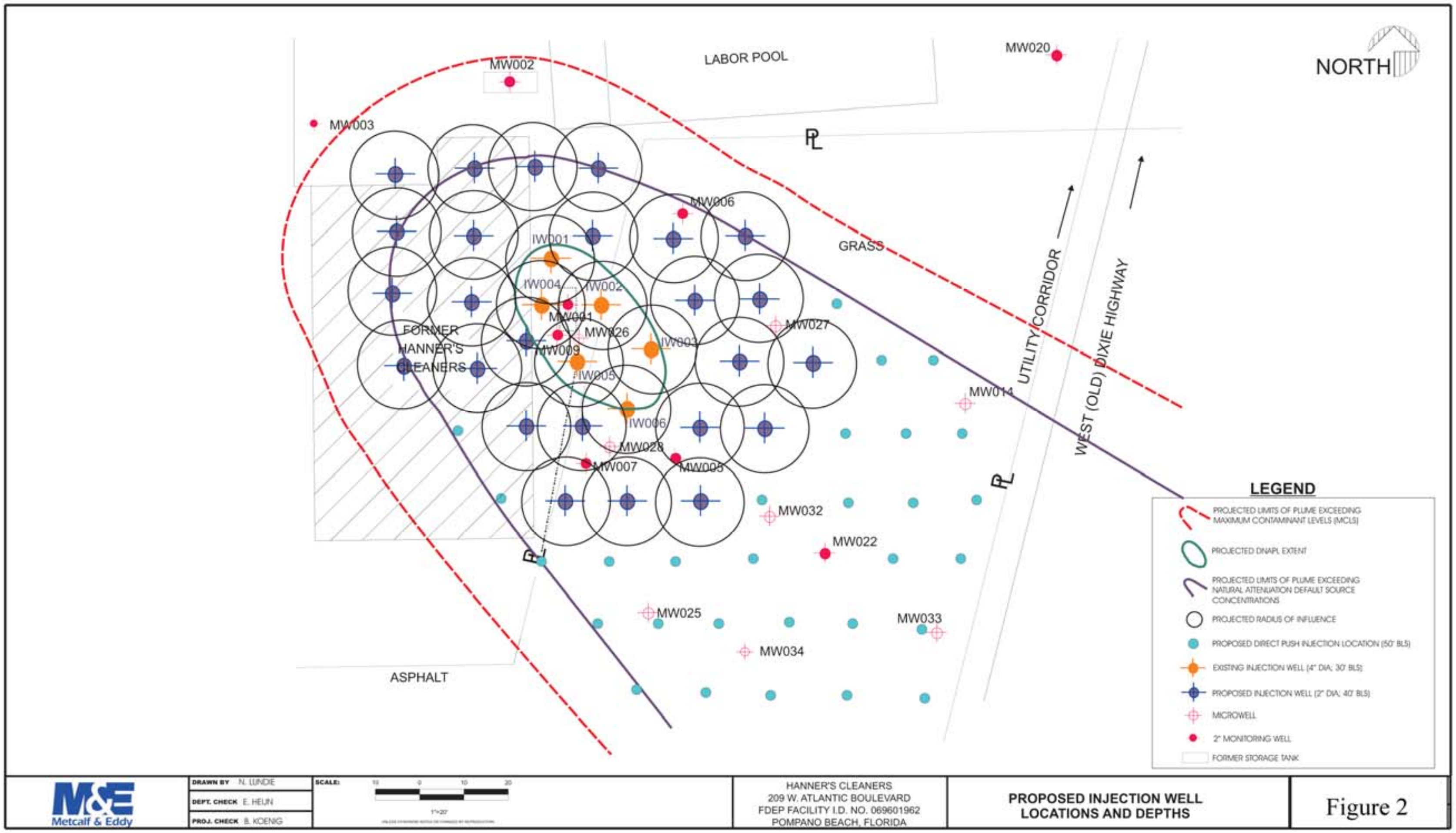
A total of three full-scale injection events were conducted during the initial groundwater remediation phase with 36,000 gallons, 48,000 gallons, and 25,000 gallons of reagent delivered during each event. The reagent was delivered during each event through 31 IWs and 30 direct-push points. The IW system consists of the six 4-inch-diameter wells that were used during the pilot study and 25 2-inch-diameter wells that were installed for the full-scale application of the system. Existing IWs used during the pilot study had been installed to a depth of 30 ft bgs, and new IWs were installed to a depth of 40 ft bgs. The direct-push injectors were installed to deliver the reagent to either 50 ft bgs or refusal, whichever depth was attained first. Figure 2 shows the locations of the 31 IWs and the locations for the 30 direct-push points. Also in Figure 2 is the projected radius of influence for each injector.

Field monitoring was carried out in selected wells while injection was in progress to evaluate the radial influence of the injections. Samples from these selected wells were analyzed for turbidity, ferrous iron, dissolved oxygen, conductivity, pH, temperature, redox potential, hydrogen peroxide, and chloride. Additional samples were collected after injection had been completed, from wells upgradient and downgradient of the source and in the source area. These additional samples were analyzed for halogenated VOCs, ferric iron, sulfate, sulfide, chloride, total organic carbon, and total dissolved solids. Samples were also collected 1 year after each injection to measure the iron concentration and pH in the temporary zones of discharge around the injection points. These samples were collected in accordance with a variance from the FDEP Underground Injection Control Rule. In addition, off-gas release was monitored during chemical injection to measure the degree of pressure generated during the oxidation reaction.

In Situ Biostimulation

Reductive dechlorination was observed at the site when groundwater restabilized after the in situ chemical oxidation treatment. Sodium thiosulfate and ethyl lactate were added to the groundwater in the excavation that was created in June 2004, as part of a pilot test, to promote this reductive dechlorination. Sixteen pounds of sodium thiosulfate was added to the groundwater by first dissolving the salts in water and then pouring the mixture into the excavation. In addition, 6 gallons of ethyl lactate was added to provide a substrate for the anaerobic bacteria to carry out reductive dechlorination.

Figure 2. Location of the Injection Wells and Proposed Location for Direct-Push Points



Additional pilot testing to evaluate the acceleration of reductive dechlorination associated with ethyl lactate was conducted in November 2004 with the injection of a total of 4.5 gallons of ethyl lactate. After post-injection sampling and monitoring, four additional full-scale injections were conducted in February and June 2006 and in February and April 2007. The amounts of ethyl lactate injected during each of the four injections were 44 gallons, 51 gallons, 44 gallons, and 51 gallons.

After the April 2007 injection, groundwater samples were collected from 12 monitoring wells and seven injection wells. Monitoring well samples were analyzed for VOCs and total organic carbon. In addition, three of the monitoring well samples were analyzed for ethanol. The seven injection well samples were analyzed only for total organic carbon. Before samples were collected, all sampling locations were screened in the field for pH, temperature, conductivity, dissolved oxygen, redox potential, and turbidity.

Listed below are the key operating parameters for the technologies applied at the site and the values measured for each of them.

Operating Parameters [Refs. 4, 15]

Parameter	Value
In Situ Chemical Oxidation	
pH:	6.5 to 7.5
Injection Flow Rate:	3 to 5 gallons per minute
Reagent Components:	ISOTEC Catalyst 4260 12 percent hydrogen peroxide
Amount of Reagent Injected:	127,620 gallons total (two pilot and three full scale injections)
Number of Injectors:	31 IWs and 30 direct-push points
Soil Vapor Extraction	
Air Flow Rate:	385 to 490 ft^3 per minute
Operating Pressure/Vacuum:	10 to 14 inches of water gauge for VEW-1 and VEW-2

Performance Information [Refs. 1-4, 7-15, 17]

The cleanup objective for groundwater at the site was to substantially reduce on-site contamination and prevent contaminant from migrating off site. To achieve this objective, contaminant concentrations in groundwater would need to be reduced to below NADCs. These criteria were to be achieved by implementing in situ chemical oxidation. Subsequent remediation technologies, such as in situ biostimulation, have attempted to reduce contamination levels to below Groundwater Target Levels (GCTLs), which are based on the maximum contaminant levels (MCLs). The cleanup objective for soil was to reduce contaminant concentrations to below leachability regulatory levels for dry cleaning solvent contaminants. Tables 1 and 2 list the individual contaminant cleanup goals for soil and groundwater.

Table 1: Soil Leachability Levels	
Tetrachloroethene (PCE):	30 µg/kg
Trichloroethene (TCE):	30 µg/kg
Cis-1,2-dichloroethene:	400 µg/kg

Table 2: Groundwater Natural Attenuation Default Criteria	
Tetrachloroethene (PCE):	300 µg/L
Trichloroethene (TCE):	300 µg/L
Cis-1,2-dichloroethene:	700 µg/L
Trans-1,2-dichloroethene:	1000 µg/L
Vinyl Chloride:	100 µg/L

Soil Vapor Extraction

The full-scale SVE system was activated on April 17, 2001, and ran for 1 year, until it was shut off on May 3, 2002. During the April to July 2001 period, the influent concentrations fluctuated, requiring the amount of contaminants recovered to be estimated. Estimates were based on the average air flow rates and influent concentrations during this period. It was estimated that 4.5 pounds of the estimated 11.01 pounds of PCE had been removed. In addition, an estimated 11.3 pounds of total halogenated VOCs was removed during this period.

In early May 2001, an apparent desorption of contaminants was observed from the GAC. Additional vapor samples were therefore collected to confirm this observation and document whether the discharge limits were being exceeded. The contaminant emission rates were calculated using the highest observed concentrations in the final effluent streams. Calculations indicated that emissions were not exceeding the target level of 5.5 pounds per day for any single hazardous air pollutant (HAP) and 13.7 pounds per day for total HAPs, as specified in the FDEP memorandum dated March 13, 2000. As a result, it was determined that the off-gas no longer needed to be treated, and the GAC system was removed on June 29, 2001.

An estimated 17 pounds of PCE and 36 pounds of total halogenated VOCs were recovered from the soil during the August to November 2001 period of operation. With an estimated pre-remediation level of 11.01 pounds of PCE in the soil, it was suggested by the site lead that the vapor sample collected during this period may have reflected a vapor-phase rebound effect caused by a period of system downtime and also a higher level of vapor-phase concentrations as a result of the chemical injections for the groundwater remediation. The method used for calculating the amount of contaminants recovered may have overestimated the amount recovered since the higher concentrations were limited to periods during and after the chemical injections.

The November 2001 to February 2002 period of operation experienced many of the same events as the previous period. A total of 13 pounds of PCE and 29 pounds of total halogenated VOCs were removed from the soil. As with the previous period, it was speculated by the site lead that the amount of contaminants recovered was overestimated, considering that the estimated pre-remediation amount of PCE was 11.01 pounds. Vapor samples of system off-gas were collected once during this quarter, with results showing no contaminant concentrations above detection limits.

During the final period of operation — February to April 2002 — the system ran continuously except for 1 week when it was intentionally shut off to avoid potential contamination by chemical reagents from the in situ chemical oxidation injections. Effluent concentrations during this period remained below analytical method detection limits. An estimated 0.84 pounds PCE and 0.84 pounds of total halogenated VOCs were removed from the soil. These values were calculated based on the assumption that the average concentrations were one-half the analytical method detection limit. This assumption was applied because no halogenated VOCs were detected in the vapor samples.

Confirmatory soil samples also were collected during this period. Figure 3 shows the locations of the soil samples, and Table 3 compares contaminant concentrations in selected areas before and after SVE. Only two samples (SB028 and SB030) contained contaminants at concentrations that exceed the soil leachability regulatory level of 30 µg/kg for PCE (SB028 at 37.4 µg/kg and SB030 at 293 µg/kg); both of these samples were collected at 6 ft bgs. Since the groundwater table fluctuates between 5 to 7 ft bgs throughout the year, it is possible for soil at 6 ft bgs to become re-contaminated. Contaminant concentrations in samples collected in these two locations at 3 ft bgs were below leachability regulatory levels. In addition, areas that corresponded to pre-remediation samples SB011, SB012, SB013, and SB018 were excavated and backfilled with clean fill during installation of VEW-1. Therefore, these areas were not sampled after the system had been shut off. Because cleanup objectives were achieved for soil above the water table, it was concluded that no further action was required for soil and the SVE system was deactivated.

In Situ Chemical Oxidation

Results from a pilot test supported the feasibility of implementing in situ chemical oxidation at the site to remediate groundwater. After two injections, results from the pilot test showed that concentrations of total halogenated VOCs in the test area had been reduced by 63 percent on average. TCE and PCE exhibited the best overall reduction, while vinyl chloride showed the poorest. It was speculated that the reason for the poor reduction in vinyl chloride was the slower reduction rate of vinyl chloride compared with PCE and TCE. Furthermore, oxidation of PCE and TCE might have been incomplete, resulting in the formation of vinyl chloride.

Figure 3. Locations of Soil Samples

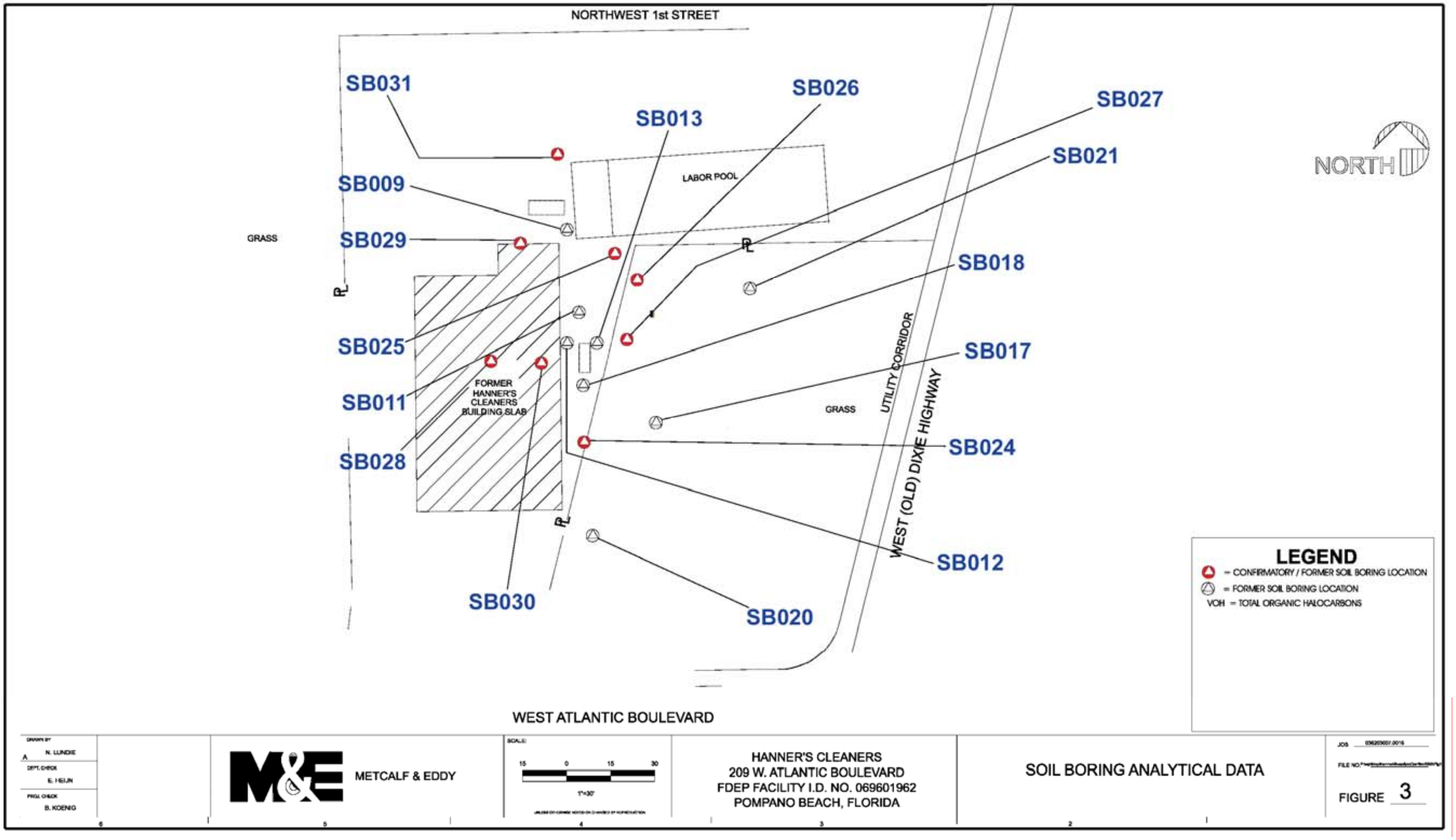


Table 3: Comparisons of Soil Analytical Results Before and After SVE

Point ID	SB024				SB025			
Date	4-Jun-99		13-May-02		4-Jun-99		13-May-02	
Depth BLS	4	6	3	6	4	6	3	6
Tetrachloroethene (µg/kg)	221	12.2	1.15	1U	120	1	3.38	3.72
Trichloroethene (µg/kg)	4.09	1	1U	1U	5.78	1	1U	1U
Trans-1,2-Dichloroethene (µg/kg)					1U	1	1U	1U
Cis-1,2-Dichloroethene (µg/kg)	3	1	1U	1U	2.07	1	1U	1U
Total VOHs (µg/kg)	228	12	1	1U	128	1	3	4

Point ID	SB026				SB027			
Date	4-Jun-99		13-May-02		4-Jun-99		13-May-02	
Depth BLS	4	6	3	6	4	6	3	6
Tetrachloroethene (µg/kg)	414	167	3.09	1U	1700	97.9	13.9	12.5
Trichloroethene (µg/kg)	24.4	3.13	1U	1U	148	1U	1U	1U
Trans-1,2-Dichloroethene (µg/kg)								
Cis-1,2-Dichloroethene (µg/kg)	17.6	2.34	1U	1U	25.5	1U	1.78	1U
Total VOHs (µg/kg)	456	172	3	1U	1874	98	16	13

Point ID	SB028				SB030			
Date	4-Jun-99		13-May-02		4-Jun-99		13-May-02	
Depth BLS	4	6	3	6	4	6	3	6
Tetrachloroethene (µg/kg)	58.7	259	1U	37.4	760	1420	16.1	293
Trichloroethene (µg/kg)	1U	10.8	1U	1.2	38.7	99.4	1U	39.8
Trans-1,2-Dichloroethene (µg/kg)					1U	1U	1U	1
Cis-1,2-Dichloroethene (µg/kg)					1U	33	1U	27.6
Total VOHs (µg/kg)	59	270	1U	38	799	1552	16	361

Point ID	SB031			
Date	4-Jun-99		13-May-02	
Depth BLS	4		3	6
Tetrachloroethene (µg/kg)	57.7		1U	10.1
Trichloroethene (µg/kg)	1U		1U	1U
Trans-1,2-Dichloroethene (µg/kg)				
Cis-1,2-Dichloroethene (µg/kg)				
Total VOHs (µg/kg)	58		1U	10

1U – MDL/Undetected
µg/kg – Micrograms per kilogram

The first full-scale injection was completed on May 9, 2001. Samples were collected at the beginning of June 2001 from 10 monitoring wells (MW001, MW007, MW009, MW025, MW026, MW027, MW028, MW032, MW033, and MW034), representing a variety of depths and locations within the plume. The samples showed that concentrations of total halogenated VOCs across the 10 monitoring wells had been reduced by 79 percent after the first full-scale injection event. The June samples also showed some local increases in several wells. The largest increase was seen in well, MW025, where the concentration of total halogenated VOCs increased from 25 µg/L to 154 µg/L. According to the vendor, natural attenuation of off-site contamination was occurring by the end of August. Data from off-site wells (MW018, 023, 024, 029, 030, and 031) showed a reduction in total VOC concentrations to below the detection limit in samples from four of the six wells. In addition, data indicated that the highest concentrations of contaminants were in the plume area south and southeast of the source. These data were considered in planning the second injection event.

The second injection was completed on October 31, 2001. Sample collection for this event was completed on January 21 and 22, 2002. The results of the injection were similar to the first injection. Overall concentrations of contaminants were further reduced, but there were some local increases in several wells. The ISOTEC technical managers speculated that this increase may have been caused by a combination of incomplete oxidation, desorption, and mobilization. During the second injection event, direct-push injectors were used for the first time in the source area and may have contacted pockets of contamination that might not have been affected by previous injections.

The third and final injection was completed on April 11, 2002. The first round of sampling for this event was completed on July 11 and 12, 2002. This injection continued to further reduce the overall contaminant concentrations, with results for all but eight wells exceeding the NADC. A second round of sampling was completed on November 11 and 12, 2002. The data from this round of sampling showed that dissolved concentrations of contaminants rebounded overall between July and November. The total halogenated VOC concentrations for all the tested wells in November 2002 averaged 387 percent greater than those in July 2002. The increase in concentrations was most notable in, and downgradient of, the source area. Individual concentrations for vinyl chloride and cis-1,2-dichloroethene were especially high. Overall, the concentration of total halogenated VOCs from all wells sampled increased by a factor of four.

These results suggest that re-establishment of equilibrium conditions at the site is a slow process, possibly governed by the desorption and slow diffusion of contaminants from interior pore spaces into the portion of the aquifer subject to advective flow. Analytical results also showed that the remaining site contaminants were comprised almost entirely of degradation products of the original compounds. These products indicate that the relatively short reactive lifespan of the chemical oxidants may not allow contact with and oxidation of the remaining contamination, which may be removed from the main paths of advective flow.

Overall, chemical oxidation had reduced the size of the plume from 36 acres to 0.2 acre and had successfully reduced the source area concentrations of PCE and TCE by an order of magnitude.

Based on results of the second round of sampling after the third full-scale injection, that a fourth injection was not necessary. Instead, excavation of the remaining DNAPL-contaminated saturated soil in the source area, along with limited air sparging, was chosen. The soil was excavated on June 2, 2004, with air sparging being conducted from June 4 to 7, 2004. Contaminant concentrations measured in the source area after excavation and air sparging showed that all contaminants except for PCE were reduced to levels below the GCTLs. PCE concentrations remained above the GCTLs but below the NADC. Table 4 shows the values for the GCTLs.

Table 4: Groundwater Cleanup Target Levels	
Vinyl Chloride:	1 µg/L
Trans-1,2-Dichloroethene:	100 µg/L
Cis-1,2-Dichloroethene:	70 µg/L
Trichloroethene:	3 µg/L
Tetrachloroethene:	3 µg/L

After air sparging was completed, sodium thiosulfate was added to the groundwater to reduce dissolved oxygen levels, and ethyl lactate was added to provide substrate for anaerobic bacteria to promote reductive dechlorination. It was observed that the sodium thiosulfate was effective in reducing the dissolved oxygen concentrations in groundwater. However, it was also noted that other factors, such as the in situ oxygen demand and the addition of lactate, may have contributed to the observed decrease in the dissolved oxygen concentrations.

In Situ Biostimulation

Groundwater samples were collected on May 9 and 10, 2007, approximately 3 weeks after the April 2007 injection event. Samples were collected from 12 monitoring wells (MW001R2, MW005 through MW007, MW028, MW032, MW034 through MW038, and MW040) and from seven injection wells (IW002, IW003, IW005, IW007, IW020, IW032, and IW033). Vinyl chloride was detected in samples from 10 of the 12 monitoring wells, with the highest concentration of 27.2 µg/L detected in MW040. The GCTL for vinyl chloride was exceeded; results ranged from 2.15 µg/L in samples from MW006 to 9.44 µg/L in MW036. The only other VOC detected was cis-1,2-dichloroethene, but none of the measured concentrations exceeded the GCTL. The pH, temperature, dissolved oxygen, and redox potential measurements for each sampling location were within the range where reductive dechlorination is considered possible. Total organic carbon was detected in all of the sample locations and ranged from 5.04 milligrams per liter (mg/L) (MW038) to 462 mg/L (IW007). Total organic carbon concentrations at 15 of the sample locations were below the ideal level for dechlorination of 20 mg/L. Ethanol was not detected in any of the samples collected. Table 5 shows a comparison of contaminant concentrations in select areas before and after each lactate injection.

Table 5: Comparison of Select Monitoring Wells Following Lactate Injections

	MW001R2 (scr. 5 to 15 ft bls, 0.75 in dia)						MW005 (scr. 5 to 15 ft bls, 2 in dia)					
Sample Event	**Lactate Baseline**	**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**		**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**
Date	**28-Jun-04**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**30-Mar-07**	**9-May-07**	**3-Nov-05**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**
Tetrachloroethene (µg/L)	3	1U	1U	1U	1U	2U	2.05	1U	1U	1U	1U	2U
Trichloroethene (µg/L)	1	1U	1U	1U	1U	2U	1U	1U	1U	1U	1U	2U
Cis-1,2-Dichloroethene (µg/L)	5550	1U	3.03	1U	2U	2U	1U	1U	1.11	2.23	2.08	4.07
Trans-1,2-Dichloroethene (µg/L)	15	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U
Vinyl Chloride (µg/L)	412	0.05U	7.73	0.63	1U	8.22	1U	0.05U	1U	1.41	1.94	5.42

	MW006 (scr. 5 to 15 ft bls, 2 in dia)						MW007 (scr. 5 to 15 ft bls, 2 in dia)					
Sample Event		**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**		**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**
Date	**3-Nov-05**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**30-Mar-07**	**9-May-07**	**3-Nov-05**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**
Tetrachloroethene (µg/L)	3.73	1U	1U	0.62	1U	2U	3.46	1U	1U	1U	1U	2U
Trichloroethene (µg/L)	1U	1U	1U	1U	1U	2U	1U	1U	1U	1U	1U	2U
Cis-1,2-Dichloroethene (µg/L)	3.6	1U	4.32	2.86	3.71	4.62	1U	1U	1.38	1U	0.68	2U
Trans-1,2-Dichloroethene (µg/L)	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U
Vinyl Chloride (µg/L)	1U	0.05U	1U	1U	0.98	2.15	3.28	18.6	4.72	2.55	218	2.67

	MW028 (scr. 24 to 30 ft bls, 0.5 in dia)					MW032 (scr. 21 to 27 ft bls, 0.5 in dia)					
Sample Event	**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**		**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**
Date	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**	**3-Nov-05**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**
Tetrachloroethene (µg/L)	1U	1U	1U	1U	2U	1U	1U	1U	1U	1U	2U
Trichloroethene (µg/L)	1U	1U	1U	1U	2U	1U	1U	1U	1U	1U	2U
Cis-1,2-Dichloroethene (µg/L)	1U	1U	1U	2U	2U	1U	3.39	1U	0.56	2U	2U
Trans-1,2-Dichloroethene (µg/L)	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U
Vinyl Chloride (µg/L)	12.1	2.33	1.68	1.29	3.01	24.6	6.34	3.67	2.34	1.96	2.89

Table 5: Comparison of Select Monitoring Wells Following Lactate Injections (continued)

	MW034 (scr. 22 to 28 ft bls, 0.5 in dia)						MW035 (scr. 15 to 20 ft bls, 0.75 in dia)					
Sample Event		**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**	**Lactate Baseline**	**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**
Date	**3-Nov-05**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**	**28-Jun-04**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**
Tetrachloroethene (µg/L)	1U	1U	1U	1U	1U	2U	1U	1U	1U	1U	1U	2U
Trichloroethene (µg/L)	1U	1U	1U	1U	1U	2U	1U	1U	1U	1U	1U	2U
Cis-1,2-Dichloroethene (µg/L)	1.9	1U	1.39	1.01	0.68	2U	28	1U	4.31	3	3.26	5.44
Trans-1,2-Dichloroethene (µg/L)	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U
Vinyl Chloride (µg/L)	3.84	0.05	0.94	2.45	2.05	4.67	3	5.1	4.63	3.36	3.54	7.22

	MW036 (scr. 15 to 20 ft bls, 0.75 in dia)						MW038 (scr. 15 to 20 ft bls, 0.5 in dia)				
Sample Event	**Lactate Baseline**	**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**	**Post Lactate #2**	**Post Lactate #3**	**Post Lactate #4**	**Post Lactate #5**	**Post Lactate #6**
Date	**28-Jun-04**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**31-Mar-07**	**10-May-07**	**6-May-06**	**13-Sep-06**	**7-Feb-07**	**30-Mar-07**	**9-May-07**
Tetrachloroethene (µg/L)	1U	1U	1U	1U	1U	2U	1U	1U	1U	1U	2U
Trichloroethene (µg/L)	1U	1U	1U	1U	1U	2U	1U	1U	1U	1U	2U
Cis-1,2-Dichloroethene (µg/L)	10	1U	1.31	3.34	1.57	2U	1U	1U	1U	2U	2U
Trans-1,2-Dichloroethene (µg/L)	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U
Vinyl Chloride (µg/L)	4	0.05	1.69	5.27	2.21	9.44	3.13	0.5U	1U	1U	1U

	MW040 (scr. 33 to 38 ft bls, 0.75 in dia)		
Sample Event	**Post Lactate #3**	**Post Lactate #5**	**Post Lactate #6**
Date	**13-Sep-06**	**31-Mar-07**	**10-May-07**
Tetrachloroethene (µg/L)	1U	1U	2U
Trichloroethene (µg/L)	1U	1U	2U
Cis-1,2-Dichloroethene (µg/L)	1.22	2U	2U
Trans-1,2-Dichloroethene (µg/L)	1U	1U	1U
Vinyl Chloride (µg/L)	27.4	11.1	27.2

1U – MDL/Undetected
µg/L – Micrograms per liter

Based on the field screening data, the groundwater geochemistry is within the tolerance range to support reductive dechlorination. However, the ethyl lactate may have been rapidly consumed and could leave less-than-optimal energy levels to sustain the anaerobic reductive dechlorination process based on of the large number of sampling locations (15 of 19 sample locations) where total organic carbon levels are below 20 mg/L.

Performance Data Quality

The majority of the performance data were obtained from samples analyzed at off-site laboratories. The samples were analyzed using standard laboratory analysis methods. No irregularities or errors in data quality were reported in the available references.

Cost Information

The total cost for all the remediation components at the site was $1,688,148. This total included $203,048 for the remedial investigation, $113,643 in design costs, $1,215,237 for implementation of the remedial action, and $136,220 in operation and maintenance costs. The total cost for the reductive dechlorination component (included in the total cost provided above) was $331,045, consisting of the pilot test, lactate injection at full scale, and groundwater monitoring.

Observations and Lessons Learned [Refs. 1, 2, 17]

Soil at the former Hanner’s Dry Cleaners was recommended for no further action after a limited excavation of assessable contaminated soils around the UST and a year-long operation of SVE. The limited excavation removed 3,150 ft^3 of soil that contained contaminants at concentrations that exceeded the FDEP soil leachability cleanup goals. The rest of the contaminated soil in the vicinity was remediated with a SVE system that ran from April 2001 to May 2002. No contaminants were detectable in the system blower effluent during the last two quarters of SVE operation. Substantial reduction in the soil contamination was also confirmed by soil samples collected in May 2002, where no contaminants were detected at concentrations above the leachability cleanup level.

Initial groundwater remediation consisted of two pilot-scale and three full-scale injections of modified Fenton’s reagent to address the source zone, where DNAPL was suspected. This chemical oxidation had reduced the overall size of the plume from 36 acres to 0.2 acre and successfully reduced the concentrations of PCE and TCE in the source area by an order of magnitude but not below the NADC. Additional remediation, which included excavation of DNAPL-contaminated soil in the source area and air sparging in the excavated area, reduced concentrations of halogenated VOCs to below the GCTLs except for PCE and vinyl chloride, which remained above the GCTL but below the NADC.

After chemical oxidation was implemented, in situ biostimulation using ethyl lactate injection was conducted to enhance reductive dechlorination that was occurring at the site. After one pilot-scale injection and four full-scale injections, analytical results indicated that all VOCs concentrations in groundwater were below the GCTLs except, vinyl chloride. In addition, total organic carbon levels were observed to be less than the ideal (20 mg/L) in many of the sampling locations, likely indicating that ethyl lactate was rapidly consumed, which could lead to less–than-optimal energy levels required to sustain reductive dechlorination. It was recommended that the ethyl lactate injections continue, but on a monthly basis, so that the rapid consumption of the lactate would not hinder the reductive dechlorination process. Additionally, it was recommended that another excavation be conducted to remove contaminated soil from underneath the concrete floor slab.

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