

**APPENDIX A**  
**NATURAL ATTENUATION EVALUATION**

**Draft**

**Natural Attenuation Evaluation  
Former Chemical Laundry and Motor Pool Area 1500  
Parcel 94(7)**

**Fort McClellan  
Calhoun County, Alabama**

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# 1.0 Introduction

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The U.S. Army has selected Fort McClellan (FTMC), located in Calhoun County, Alabama, for closure by the Base Realignment and Closure Commission. The Army is conducting environmental studies of the impact of suspected contaminants at FTMC under the management of the U.S. Army Corps of Engineers (USACE)-Mobile District. The USACE contracted IT Corporation (IT) to complete the remedial investigation (RI) of the Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7). The RI determined the nature and extent of contamination and concluded that the concentrations of chlorinated solvents detected in groundwater present an unacceptable risk to human health (IT, 2002). The streamlined human health risk assessment identified trichloroethene (TCE) and vinyl chloride (VC) as chemicals of concern (COC) in site groundwater. In addition, the maximum detected concentration of chlorobenzene exceeded its maximum contaminant level (MCL) in the bedrock water-bearing zone. Based on the results of the RI, further investigation of the groundwater contamination at Parcel 94(7) was recommended. In April 2002, additional groundwater samples were collected from select wells at the site and analyzed for volatile organic compounds (VOC) and natural attenuation parameters. In addition, a feasibility study was initiated to screen remedial action technologies and process options for groundwater remedial alternatives. The objectives of this report are to evaluate whether natural attenuation is a feasible process option for groundwater remediation at Parcel 94(7). The results from this evaluation will be used in the screening, selection, and development of remedial alternatives in the feasibility study.

## 1.1 Site Description and History

Parcel 94(7) is located in the central area of the FTMC Main Post, east of Langley Avenue (formerly 5th Avenue) and south of St. Clair Road (formerly 22nd Street). Parcel 94(7) was the site of a former vehicle maintenance facility, or motor pool, which housed three gas stations during World War II. The three gas stations included Building 1494 (Parcel 133[7]), Building 1594 (Parcel 132[7]), and Building 1594A (Parcel 134[7]). Reportedly, two underground storage tanks were located at each building. Parcel 94(7) was also the location of two chemical impregnation plants reportedly used during the 1950s and 1960s. The impregnation facilities were used to launder and treat military garments used in chemical warfare material (CWM) training exercises to render them impermeable to CWM. Garments were chemically treated and impregnated with a mixture of wax and chemicals designed to neutralize CWM (IT, 2002).

1 **1.2 Summary of Geology and Hydrogeology**

2 A complete description of the site-specific geology and hydrogeology is presented in the RI  
3 report (IT, 2002). In belief, the geology at Parcel 94(7) is characterized as clayey silt and silty  
4 sand residuum overlying fractured, weathered limestone and interbedded weathered shale. The  
5 depth to bedrock ranges from 6 to 50 feet (ft) below ground surface (bgs). Groundwater in the  
6 residuum follows surface topography and flows eastward toward Ingram Creek. Groundwater  
7 flow within the bedrock aquifer, however, appears to be structurally controlled and flows  
8 approximately radially away from the axis of an anticlinal fold present at the site. The horizontal  
9 hydraulic gradient in both the residuum and bedrock aquifers is very low. Vertical gradients  
10 between residuum and bedrock, in general, exhibit either weak upward or downward flow.  
11 Hydraulic conductivity values calculated from slug tests yielded geometric mean values of  
12 approximately 4.1 feet per day (ft/day) for residuum wells and approximately 0.144 ft/day for  
13 bedrock wells. Average linear groundwater flow velocities were calculated to be approximately  
14 0.3 ft/day in residuum and approximately 0.027 ft/day in bedrock (IT, 2002).

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## 2.0 Natural Attenuation

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Natural attenuation is the combined effect of dispersion, dilution, volatilization, sorption, and biodegradation on dissolved contaminants in groundwater. The combined effect of these processes results in a concentration reduction that will render the contaminated groundwater nonhazardous. Generally, the only process that actually results in significant contaminant destruction during natural attenuation is intrinsic biodegradation or bioremediation.

Intrinsic biodegradation is the most important component of natural attenuation because it is usually the only destructive component of the process. Intrinsic bioremediation can occur in any environment that supports microbial activity. The rate of biodegradation may be slow due to the lack of a suitable respiratory substrate, such as oxygen, or inorganic nutrients, like fixed nitrogen, or an extreme pH, low soil moisture, or limited contaminant bioavailability. Elimination or containment of the contaminant source leads to the most expedient attenuation of groundwater contaminants. Natural attenuation is often able to limit contaminant migration even when a contaminant source continues to contribute contaminant to the groundwater. Accurate delineation of contamination, understanding of subsurface conditions and characteristics, and identifying contaminant migration rates and direction are critical for evaluating the success of natural attenuation, for defining the contribution of intrinsic biodegradation to concentration reduction, and for establishing regulatory support for its use at a site.

### 2.1 Natural Attenuation Lines of Evidence

There are three lines of evidence that can be used to elucidate the occurrence and prominence of intrinsic biodegradation (U.S. Environmental Protection Agency [EPA, 1998]). The EPA Office of Solid Waste and Emergency Response Directive 9200.4-17 identifies the three lines of evidence as follows:

- 1) *Historical groundwater and/or soil chemistry data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points. (In the case of a groundwater plume, decreasing concentrations should not be solely the result of plume migration.)*
- 2) *Hydrogeologic and geochemical data that can be used to demonstrate indirectly the type(s) of natural attenuation processes active at the site and the rate at which such processes will reduce contaminant concentrations to required levels.*

1                   3) *Data from field or microcosm studies (conducted in or with actual contaminated*  
2                   *site media) which directly demonstrate the occurrence of a particular natural*  
3                   *attenuation process at the site and its ability to degrade the contaminants of*  
4                   *concern.*  
5

6 The first and most direct approach to quantifying the influence of intrinsic biodegradation is the  
7 observation of decreased concentrations of target contaminants and increased levels of  
8 dechlorinated products over time. Under anaerobic conditions, TCE is reductively dechlorinated,  
9 yielding, in succession, cis-1,2-dichloroethene (DCE), VC, and finally ethene. Direct  
10 observation of this progression of events in groundwater is a strong, positive indicator of intrinsic  
11 biodegradation. The second line of evidence involves biologically mediated changes in  
12 groundwater chemistry, including concentration reduction in respiratory substrates, concentration  
13 increases in respiratory products, and changes in other groundwater parameters such as pH,  
14 dissolved chloride, and oxidation-reduction potential (ORP). The third line of evidence comes  
15 from microcosm studies where the biodegradability of the contaminants is demonstrated using  
16 actual contaminated site media under conditions that mimic those found in the subsurface at the  
17 site. All three lines of evidence were investigated to evaluate the occurrence of natural  
18 attenuation at Parcel 94(7).  
19

## 20 **2.2 Biodegradation**

21 Anaerobic reductive dechlorination is the most prominent mechanism by which chlorinated  
22 ethenes are biologically degraded under anaerobic conditions. During this process, the  
23 chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine  
24 atom is removed and replaced with a hydrogen atom. Because chlorinated ethenes are used as  
25 electron acceptors during reductive dechlorination, there must be an appropriate source of carbon  
26 for microbial growth in order for this process to occur (Bouwer, 1994). Potential carbon sources  
27 include natural organic matter, fuel hydrocarbons, or other anthropogenic organic compounds,  
28 such as lactate.  
29

30 The transformation of TCE under anaerobic conditions proceeds by sequential reductive  
31 dechlorination to cis-1,2-DCE, VC, and ultimately the innocuous end product ethene. The  
32 streamlined human health risk assessment identified TCE and VC as COCs in site groundwater.  
33 Although not selected as a COC, cis-1,2-DCE was also detected in Parcel 94(7) groundwater. In  
34 addition, chlorobenzene was selected as a COC because it was detected at concentration levels  
35 exceeding its MCL of 100 micrograms per liter ( $\mu\text{g/L}$ ). The presence of the daughter products  
36 cis-1,2-DCE and VC at Parcel 94(7) is likely a result of the reductive dechlorination of TCE.

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There is a decreased potential for less highly chlorinated ethenes (i.e., cis-1,2-DCE and VC) to act as electron acceptors and undergo further reductive dechlorination, often resulting in the transient accumulation of cis-1,2-DCE and VC. This phenomenon may be due to the increase in Gibb's free energy value of the chlorine-to-carbon bonds as the number of chlorine atoms on the molecule decreases. Thus, more energy may be required to remove the last chlorine atom from a chlorinated ethene than was required for the first. The increased energy requirement would also cause the reaction to be slower. Another reason behind the accumulation of cis-1,2-DCE and VC may be the lack of microbial populations capable of utilizing the chlorinated ethenes as electron acceptors. A common observation is that TCE is reductively dechlorinated under relatively mild reducing conditions, whereas cis-1,2-DCE and VC require increasingly stronger reducing conditions to be dechlorinated (Mohn and Tiedje, 1992). However, under aerobic and some anaerobic conditions the less highly chlorinated ethenes may be used as the primary substrate in biologically mediated oxidation-reduction reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded chlorinated ethene, resulting in the formation of carbon dioxide and chloride.

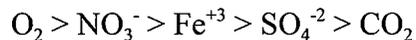
Because 1,2-DCE is a common solvent and may have been spilled along with TCE, determining that the DCE is derived from reductive dechlorination can be a critical factor supporting the occurrence of natural attenuation. Solvent manufacturing processes yield approximately the same amounts of cis-1,2-DCE and trans-1,2-DCE, which may then be fractionated by distillation (Biomedical and Environmental Information Analysis, 1989; Mertens, 1993). However, microbial dechlorination of TCE usually yields 10 to 100 times more of the cis- isomer than the trans- isomer (Bouwer, 1994; EPA, 1998; Fiorenza et al., 1994). The microbiological preference for producing cis-1,2-DCE may have to do with steric hindrances or enzyme active site configurations that favor removal of the chlorine atom located in the trans- position relative to the chlorine on the other carbon atom of TCE.

In addition to the COCs identified for site groundwater in the streamlined human health risk assessment, the concentration of chlorobenzene in FTA-94-MW11 (300 µg/L) exceeded its MCL of 100 µg/L. Chlorobenzene is susceptible to biodegradation under aerobic conditions via metabolic oxidation, resulting in the formation of chlorocatechol intermediates (Young and Cerniglia, 1995). These intermediates are difficult to detect using standard VOC analysis methods and were therefore not quantified during this investigation. As reported in the scientific literature, aerobic degradation half-lives for chlorobenzene in groundwater range from 136 to 300

1 days (Howard et al., 1991). Adequate levels of dissolved oxygen (DO) are required to sustain the  
2 aerobic biodegradation of chlorobenzene. The biodegradation of chlorobenzene under anaerobic  
3 conditions is significantly slower than the aerobic biodegradation rate, with a reported half-life of  
4 600 days (Howard et al., 1991). Therefore, the preferred degradation pathway for chlorobenzene  
5 is aerobic biodegradation.

### 7 **2.3 Geomicrobiology**

8 Biological monitoring parameters are indicators of microbiological activity in the subsurface.  
9 Microbial respiration is the biochemical process that leads to the oxidation of reduced organic  
10 carbon. Actively respiring microorganisms alter their environment. The effects of microbial  
11 respiration are observed in situ by comparing the concentrations of respiratory substrates within  
12 and outside the contaminated area. Frequently encountered respiratory substrates include oxygen  
13 ( $O_2$ ), nitrate ( $NO_3^-$ ), ferric iron ( $Fe^{+3}$ ), sulfate ( $SO_4^{-2}$ ), and carbon dioxide ( $CO_2$ ). Respiratory  
14 substrates are used preferentially based on the amount of energy that can be derived from each of  
15 them. Respiratory substrates are used in the following order:



17  
18  
19 Reductive dechlorination of TCE and other chlorinated solvents appears to occur only under  
20 extremely anaerobic, highly reduced conditions, such as sulfate-reducing conditions and  
21 methanogenic conditions. Sulfate reduction and methanogenesis are inhibited until  $O_2$ ,  $NO_3^-$ , and  
22  $Fe^{+3}$  have been depleted. Sulfate reduction provides more energy to microorganisms than  
23 methanogenesis, so that sulfate reducers out-compete methanogens and dominate the microbial  
24 population as long as sulfate is abundant. Sulfate reducers may dechlorinate TCE; however, they  
25 are not known to dechlorinate DCE or VC. Under methanogenic conditions TCE, DCE, and VC  
26 are all dechlorinated. Quantifying the abundance of the various respiratory substrates indicates  
27 areas in the subsurface where reductive dechlorination is likely to occur. Subsurface areas where  
28 less highly chlorinated hydrocarbons (e.g., DCE and VC) have been generated through reductive  
29 dechlorination should also have much lower concentrations of DO,  $NO_3^-$ ,  $Fe^{+3}$ , and probably  
30  $SO_4^{-2}$  than uncontaminated areas. Because  $Fe^{+3}$  is insoluble, groundwater is measured for  
31 increased ferrous iron ( $Fe^{+2}$ ) concentrations, the by-product of iron-based respiration.

32  
33 As discussed above, intrinsic biodegradation results in changes in the concentrations of microbial  
34 respiratory substrates and products. Expected changes in aerobic aquifers include depressed  
35 concentrations of DO and a change in ORP from positive to negative values within and  
36 downgradient of the contaminated plume. Anaerobic respiratory substrates such as nitrate and

1 sulfate should trend toward lower concentrations in groundwater located within and  
2 downgradient of the contaminated plume. Similarly, increases in the concentrations of the  
3 products of anaerobic respiration,  $\text{Fe}^{+2}$  and methane, are often apparent.

4

5 Alkalinity is another indicator of microbial respiration. Carbon dioxide is produced through  
6 mineralization of the contaminants, regardless of which respiratory substrate is used. Therefore,  
7 alkalinity may increase in groundwater experiencing intrinsic biodegradation.

8

9 The reductive dechlorination of chlorinated solvents releases chloride into groundwater. In areas  
10 where the groundwater has a very low background chloride concentration, an elevation in  
11 chloride concentration may be observed as a result of reductive dechlorination. However, in  
12 most cases the slight contribution of chloride to groundwater through reductive dechlorination  
13 will not be obvious.

### 3.0 Natural Attenuation Evaluation Methods

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Natural attenuation is typically demonstrated by examining changes in contaminant concentration and composition, changes in the concentrations of microbial respiratory substrates and products, and changes in groundwater chemistry parameters such as ORP, alkalinity, and chloride. Intrinsic biodegradation parameters were analyzed in select monitoring wells at Parcel 94(7). In addition, microcosms were established using site soil and groundwater to monitor the degradation of the VOCs under controlled laboratory conditions.

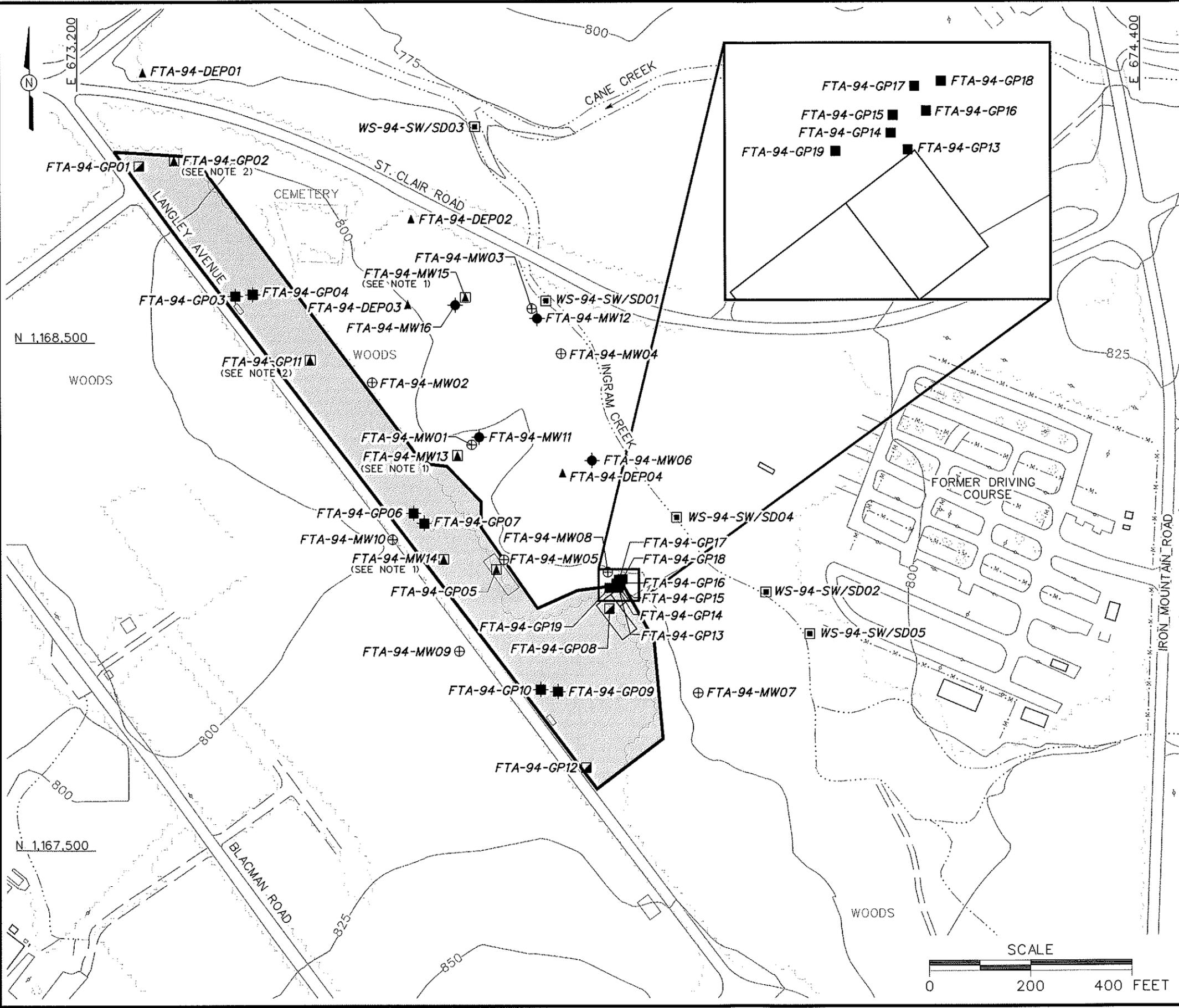
In April 2002, groundwater samples were collected from several monitoring wells at Parcel 94(7). The following five monitoring wells screened in the residuum water-bearing zone were sampled for VOCs and natural attenuation parameters: FTA-94-MW01, FTA-94-MW03, FTA-94-MW07, FTA-94-MW09, and FTA-94-MW10. To evaluate the occurrence of natural attenuation in the bedrock water-bearing zone at Parcel 94(7), the following five monitoring wells were sampled for VOCs and natural attenuation parameters: FTA-94-MW06, FTA-94-MW11, FTA-94-MW13, FTA-94-MW14, and FTA-94-MW15. Data obtained from FTA-94-MW09 were used as background values for this evaluation, since the well is not impacted with VOCs and is located upgradient of the contaminated groundwater. The locations of the monitoring wells sampled for evidence of VOCs and natural attenuation parameters are presented on Figure 3-1. The following sections describe the analytical and data evaluation methods used to investigate the occurrence of natural attenuation at Parcel 94(7).

#### 3.1 Groundwater Analysis

Groundwater samples were collected and analyzed for several natural attenuation parameters and for VOCs to evaluate the occurrence of natural attenuation. The analyses consisted of field measurements and laboratory measurements. The methods used for the field and laboratory analyses are presented in Table 3-1. The following parameters were analyzed in the field at the time of groundwater collection:

- Fe<sup>+2</sup>
- ORP
- pH
- Conductivity
- Temperature
- DO
- Turbidity.

DWG. NO.: \774645es.985  
 PROJ. NO.: 796887  
 INITIATOR: L. O'HARE  
 PROJ. MGR.: J. YACOBUB  
 DRAFT. CHCK. BY: S. MORAN  
 ENGR. CHCK. BY: S. MORAN  
 DATE LAST REV.:  
 DRAWN BY:  
 STARTING DATE: 03/13/02  
 DRAWN BY: D. BOWAR  
 02/03/03 09:38:54 AM  
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**LEGEND**

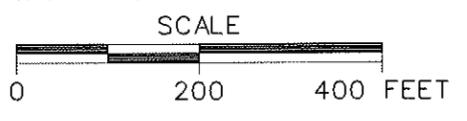
- UNIMPROVED ROADS AND PARKING
- PAVED ROADS AND PARKING
- BUILDING
- TOPOGRAPHIC CONTOURS (CONTOUR INTERVAL - 25 FOOT)
- TREES / TREELINE
- PARCEL BOUNDARY
- CULVERT WITH HEADWALL
- SURFACE DRAINAGE / CREEK
- FENCE
- UTILITY POLE
- SURFACE WATER/SEDIMENT SAMPLE LOCATION
- SURFACE AND SUBSURFACE SOIL SAMPLE LOCATION
- SURFACE SOIL SAMPLE LOCATION
- SUBSURFACE SOIL SAMPLE LOCATION
- GROUNDWATER, SURFACE AND SUBSURFACE SOIL SAMPLE LOCATION
- DEPOSITIONAL SOIL SAMPLE LOCATION
- RESIDUUM MONITORING WELL / GROUNDWATER SAMPLE LOCATION
- BEDROCK MONITORING WELL / GROUNDWATER SAMPLE LOCATION

**NOTES:**

1. BEDROCK MONITORING WELL.
2. RESIDUUM MONITORING WELL.

**FIGURE 3-1**  
**SAMPLE LOCATION MAP**  
**FORMER CHEMICAL LAUNDRY**  
**AND MOTOR POOL AREA 1500**  
**PARCEL 94(7)**

U. S. ARMY CORPS OF ENGINEERS  
 MOBILE DISTRICT  
 FORT McCLELLAN  
 CALHOUN COUNTY, ALABAMA  
 Contract No. DACA21-96-D-0018



**Table 3-1**

**Groundwater Analytical Methods  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

Parameter	Method
<b>Field Measurements</b>	
Iron(II)	Standard Methods for Analysis of Water and Wastewater, 3500-Fe D (Hach Field Kit # 25070-25 + portable spect.)
Temperature	Standard Methods for Analysis of Water and Wastewater, 2550 B
Conductivity	Standard Methods for Analysis of Water and Wastewater, 2510 B
Redox	Standard Methods for Analysis of Water and Wastewater, 2580 B
pH	Standard Methods for Analysis of Water and Wastewater, 4500-H+ or SW-846 Method 150.1
Dissolved Oxygen	Standard Methods for Analysis of Water and Wastewater, 4500-O (Hach Kit #25150-25 or electrode)
Turbidity	Standard Methods for Analysis of Water and Wastewater, 2130
<b>Fixed Laboratory Measurements (including microcosm analysis)</b>	
VOCs	SW-846, Method 8015B
Total Organic Carbon	Standard Methods for Analysis of Water and Wastewater, 5310 C
pH	Standard Methods for Analysis of Water and Wastewater, 4500-H+ or SW-846 Method 150.1
Alkalinity	Standard Methods for Analysis of Water and Wastewater, 20th Ed. 2320 B, EPA Method 310.1
Chloride	Standard Methods for Analysis of Water and Wastewater, 20th Ed. 4500-Cl- B or EPA Method 300
Nitrite/Nitrate	SW-846 Method 353.3 or EPA Method 300
Sulfate	SW-846 Method 375.4 or EPA Method 300
Methane, Ethene, Ethane	RSK 175, EPA Draft Method (Shaw E&I Biotechnology Lab)

1 Following analysis of the field parameters, groundwater samples were collected and shipped for  
2 analysis by a fixed laboratory for the following parameters:

- 3
- 4 • VOCs
- 5 • Chloride
- 6 • Nitrate and nitrite
- 7 • Sulfate
- 8 • Methane, ethane, ethene (dissolved gases)
- 9 • Alkalinity
- 10 • Total organic carbon (TOC)
- 11 • pH.
- 12

### 13 **3.2 Microcosms**

14 In support of the third line of evidence for the occurrence of natural attenuation (Section 2.1), the  
15 attenuation of site contaminants was evaluated in the laboratory by establishing microcosms  
16 using actual contaminated site soil and groundwater. Approximately three gallons of  
17 groundwater from monitoring well FTA-94-MW11 and 2 kilograms of soil from a soil boring  
18 near the same monitoring well were collected for a treatability study. The soil was collected  
19 from two depths, 24 to 28 ft bgs and 28 to 30 ft bgs. The two soil samples were composited in  
20 the laboratory prior to establishing the microcosms. Ten-gram aliquots of composited soil and  
21 approximately 30 milliliters of groundwater were placed in each 40-milliliter volatile organic  
22 analysis vial (filled to capacity, leaving no remaining headspace). The groundwater sample used  
23 to establish the microcosms did not contain adequate concentrations of chlorobenzene or TCE  
24 and its degradation products to enable tracking the contaminants throughout the study.  
25 Therefore, the vials were spiked with TCE and chlorobenzene at concentrations of 3 milligrams  
26 per liter (mg/L) and 1 mg/L, respectively. The vials were incubated upside-down at room  
27 temperature in an anaerobic glove box. Fifteen microcosms were established to allow triplicate  
28 analysis over five time points. Fifteen additional microcosms were established and stored in a  
29 refrigerator set at 4 degrees Celsius to inhibit microbial activity. The inhibited microcosms  
30 served as controls for the experiment to account for losses of contaminants due to laboratory  
31 procedures, sample handling activities, and abiotic transformations. Both sets of microcosms  
32 were analyzed concurrently using the same methods. The time points for analysis (baseline, 2  
33 weeks, 4 weeks, 8 weeks, and 12 weeks) were selected to track the activity in the microcosms  
34 and determine if biodegradation was reducing the contaminant levels over the duration of the  
35 incubation. Three microcosms from each treatment were sacrificed at each time point and were  
36 analyzed for VOCs, DO, pH, ammonia, phosphate, TOC, nitrate, nitrite, sulfate, chloride,  
37 methane, ethane, and ethene. The methods used for the analyses are listed in Table 3-1.

1  
2 As part of the treatability study, other microcosms were established using Parcel 94(7) soil and  
3 groundwater to evaluate the enhanced biodegradation of the VOCs in the presence of various  
4 organic carbon sources. Presenting the results of the enhanced biodegradation treatability study  
5 is beyond the scope of the natural attenuation evaluation.  
6

### 7 **3.3 Data Evaluation Procedures**

8 The data produced from the various analytical methods were evaluated for trends that indicate  
9 intrinsic bioremediation. In addition, attenuation and biodegradation rate constants were  
10 calculated for TCE in the bedrock water-bearing zone using the equation of Buscheck and  
11 Alcantar (1995). Attenuation and degradation rates were not calculated for cis-1,2-DCE, VC,  
12 and chlorobenzene due to insufficient spatial and temporal data. The concentration of TCE was  
13 first evaluated as a function of distance migrated using a first-order decay equation of the form:  
14

$$15 \quad C_d = C_o e^{-kd}$$

16  
17 where:

- 18  $C_d$  - TCE concentration at distance "d"
  - 19  $C_o$  - the initial TCE concentration at distance "zero"
  - 20 d - distance between the initial sampling point (distance "zero")  
and the downgradient sampling point (ft)
  - 21 k - attenuation rate constant (per foot)
- 22

23 The Buscheck and Alcantar analysis applies the one-dimensional steady-state analytical solution  
24 for the advection-dispersion equation presented by Bear (1979) to the rate of change per distance  
25 migrated. This part of the analysis adjusts the concentration change per distance migrated to  
26 accommodate dispersion, advection, and sorption. The biodegradation rate constant was  
27 calculated using the following equation:  
28

$$29 \quad \lambda = (v_c/4\alpha_x)([1+2\alpha_x(k/v_x)]^2 - 1)$$

30  
31 where:

- 32  $\lambda$  - biodegradation rate constant (per year)
- 33  $v_c$  - contaminant velocity (ft/year)
- 34  $v_x$  - linear groundwater velocity (ft/year)
- 35  $\alpha_x$  - longitudinal dispersivity (ft)
- 36 k - attenuation rate constant (per foot)

1 The distribution of TCE in the bedrock water-bearing zone was assumed to be at steady state.  
2 The analytical solution includes advection, dispersion, sorption, and decay. The longitudinal  
3 dispersivity,  $\alpha_x$ , was assumed to be 5 percent of the flow field. The flow field is the distance  
4 separating the two furthest wells in the flow vector. The soil-water distribution coefficient ( $K_d$ )  
5 was calculated using the following equation:

6

7 
$$K_d = K_{oc} f_{oc}$$

8

9 where:  $f_{oc}$  - fraction organic carbon (assumed to be 0.05 percent)  
10  $K_{oc}$  - organic carbon partitioning coefficient (from the  
11 scientific literature)  
12

13 The retardation factor (R) for TCE was calculated using the following equation:

14

15 
$$R = 1 + (\rho_b K_d / n)$$

16

17 where: R - retardation factor  
18  $\rho_b$  - soil bulk density  
19  $K_d$  - soil-water distribution coefficient  
20 n - porosity  
21

22 The contaminant velocity was calculated using the following equation:

23

24 
$$v_c = v_x / R$$

25

26 A biodegradation half-life was calculated for TCE by the following equation:

27

28 
$$t_{1/2} = (\ln 2) / \lambda$$

29

30 where:  $t_{1/2}$  - half-life (years)  
31  $\lambda$  - biodegradation rate constant (per year)

## 4.0 Results

---

The field and laboratory investigations evaluated parameters that give qualitative and quantitative indications of the occurrence of intrinsic biodegradation of the chlorinated ethenes and chlorobenzene. The combined evidence generated from several different aspects of this evaluation was evaluated for the occurrence of reductive dechlorination of the chlorinated ethenes in the residuum and bedrock water-bearing zones beneath Parcel 94(7). The data were also evaluated for evidence to support the aerobic or anaerobic biodegradation of chlorobenzene. The following sections present the results of the investigation as they pertain to the three lines of evidence used to demonstrate the occurrence of natural attenuation.

### 4.1 First Line of Evidence: Occurrence of Chlorinated Solvents and Biodegradation Products

The occurrence of chlorinated solvents and biodegradation products was evaluated in the residuum and bedrock water-bearing zones. To avoid confusing the results from the residuum with those from the bedrock, the discussion of occurrence of chlorinated solvents and their biodegradation products is presented separately for each water-bearing zone.

#### 4.1.1 Residuum Water-Bearing Zone

A summary of the VOC analytical data obtained from groundwater samples collected during the April 2002 sampling event is presented in Table 4-1. Historical VOC s data are presented in Table 4-2. The following five wells were sampled in the residuum water-bearing zone during the April 2002 event: FTA-94-MW01, FTA-94-MW03, FTA-94-MW07, FTA-94-09, and FTA-94-MW10 (Figure 3-1). TCE was detected in FTA-94-MW01 (18 µg/L), FTA-94-MW03 (1.5 µg/L), and FTA-94-MW07 (0.87 J µg/L). Only the TCE concentration in FTA-94-MW01 exceeds the MCL of 5 µg/L; nevertheless, the concentration in this well decreased from 53 µg/L in December 2000 to 18 µg/L in April 2002 (Table 4-2). The TCE reductive dechlorination daughter product cis-1,2-DCE was detected in FTA-94-MW01 (2.8 µg/L ) and FTA-94-MW03 (0.22 J µg/L ). The cis-1,2-DCE concentrations do not exceed the MCL of 70 µg/L. The detection of the TCE daughter product and the collocation of the cis-1,2-DCE and TCE are evidence that reductive dechlorination has occurred at the site. Cis-1,2-DCE undergoes further reductive dechlorination to yield VC, which was not detected in the residuum water-bearing zone during the April 2002 sampling event. Ethene, the desired end product of the reductive dechlorination of TCE, was also not detected in the residuum water-bearing zone. An evaluation of the historical data for the residuum water-bearing zone reveals that VC was detected in FTA-

**Table 4-1**

**Analytical Summary of VOC Results  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

(Page 1 of 2)

Location Code			FTA-94-MW01		FTA-94-MW03		FTA-94-MW06		FTA-94-MW07		FTA-94-MW09	
Sample No			ZC3001		ZC3002		ZC3003		ZC3004		ZC3005	
Sample Date			4/4/02		4/2/02		3/27/02		4/9/02		4/9/02	
Depth			Residuum		Residuum		Bedrock		Residuum		Residuum	
Chemical	Units	MCL	Result	Qual								
1,1,2,2-Tetrachloroethane	ug/L	-	1	U	1	U	0.54	J	1	U	1	U
Carbon disulfide	ug/L	-	1	U	0.45	J	1	U	1	U	1	U
Chlorobenzene	ug/L	100	1	U	1	U	1	U	1	U	1	U
Chloroform	ug/L	-	0.22	J	1	U	1	U	1	U	1	U
cis-1,2-Dichloroethene	ug/L	70	2.8		0.22	J	1	U	1	U	1	U
Methylene chloride	ug/L	5	0.72	J	0.23	J	0.31	J	2	U	0.37	J
trans-1,2-Dichloroethene	ug/L	100	0.6	J	1	U	1	U	1	U	1	U
Trichloroethene	ug/L	5	18		1.5		0.52	J	0.87	J	1	U
Vinyl chloride	ug/L	2	1	U	1	U	1	U	1	U	1	U
Ethene	ug/L	-	1	U	1	U	1	U	1	U	1	U

**Table 4-1**

**Analytical Summary of VOC Results  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

(Page 2 of 2)

Location Code			FTA-94-MW10		FTA-94-MW11		FTA-94-MW13		FTA-94-MW14		FTA-94-MW15	
Sample No			ZC3006		EMM3013		ZC3007		ZC3008		ZC3009	
Sample Date			4/8/02		12/18/00		4/3/02		4/5/02		4/2/02	
Depth			Residuum		Bedrock		Bedrock		Bedrock		Bedrock	
Chemical	Units	MCL	Result	Qual								
1,1,2,2-Tetrachloroethane	ug/L	-	1	U	1	U	1	U	1	U	1	U
Carbon disulfide	ug/L	-	1	U	1	U	0.32	J	1	U	1	U
Chlorobenzene	ug/L	100	1	U	300		1	U	1	U	1	U
Chloroform	ug/L	-	1	U	1	U	1	U	1	U	1	U
cis-1,2-Dichloroethene	ug/L	70	1	U	37		0.62	J	1	U	1	U
Methylene chloride	ug/L	5	0.3	J	1	U	0.31	J	2	U	0.86	J
trans-1,2-Dichloroethene	ug/L	100	1	U	8.3		1	U	1	U	1	U
Trichloroethene	ug/L	5	1	U	75		5.5		0.92	J	1	U
Vinyl chloride	ug/L	2	1	U	25		1	U	1	U	1	U
Ethene	ug/L	-	1	U	1	U	1	U	1	U	1	U

MCL - Maximum Contaminant Level

Shaded concentrations exceed the MCL

Qual - Laboratory qualifier

ug/L - micrograms per liter

U - Analyte was not detected or below method detection limits

J - Estimated value

Table 4-2

**Historical VOC Data  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

(Page 1 of 4)

Location Code Sample No Sample Date Depth Chemical			FTA-94-MW01						FTA-94-MW03			
			EM3007 11/16/98 Residuum		EMM3001 12/1/00 Residuum		ZC3001 4/4/02 Residuum		EMM3003 11/29/00 Residuum		ZC3002 4/2/02 Residuum	
Units	MCL	Result	Qual	Result	Qual	Result	Qual	Result	Qual	Result	Qual	
1,1,2,2-Tetrachloroethane	ug/L	-	ND		ND		1	U	ND		1	U
Carbon disulfide	ug/L	-	ND		ND		1	U	ND		0.45	J
Chlorobenzene	ug/L	100	3.4		16		1	U	ND		1	U
Chloroform	ug/L	-	ND		ND		0.22	J	ND		1	U
cis-1,2-Dichloroethene	ug/L	70	6.9		21		2.8		ND		0.22	J
Methylene chloride	ug/L	5	ND		ND		0.72	J	ND		0.23	J
trans-1,2-Dichloroethene	ug/L	100	0.97	J	4.6	J	0.6	J	ND		1	U
Trichloroethene	ug/L	5	25		53		18		2.5	J	1.5	
Vinyl chloride	ug/L	2	0.92	J	14		1	U	ND		1	U
Ethene	ug/L	-	NA		NA		1	U	ND		1	U

Table 4-2

**Historical VOC Data  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

(Page 2 of 4)

Location Code			FTA-94-MW06				FTA-94-MW07				FTA-94-MW09			
Sample No			EMM3008		ZC3003		EMM3009		ZC3004		EMM3011		ZC3005	
Sample Date			5/30/01		3/27/02		12/4/00		4/9/02		12/4/00		4/9/02	
Depth			Bedrock		Bedrock		Residuum		Residuum		Residuum		Residuum	
Chemical	Units	MCL	Result	Qual	Result	Qual	Result	Qual	Result	Qual	Result	Qual	Result	Qual
1,1,2,2-Tetrachloroethane	ug/L	-	ND		0.54	J	ND		1	U	ND		1	U
Carbon disulfide	ug/L	-	ND		1	U	ND		1	U	ND		1	U
Chlorobenzene	ug/L	100	ND		1	U	ND		1	U	ND		1	U
Chloroform	ug/L	-	ND		1	U	ND		1	U	ND		1	U
cis-1,2-Dichloroethene	ug/L	70	ND		1	U	ND		1	U	ND		1	U
Methylene chloride	ug/L	5	1.9	J	0.31	J	ND		2	U	ND		0.37	J
trans-1,2-Dichloroethene	ug/L	100	ND		1	U	ND		1	U	ND		1	U
Trichloroethene	ug/L	5	ND		0.52	J	1.5	J	0.87	J	ND		1	U
Vinyl chloride	ug/L	2	ND		1	U	ND		1	U	ND		1	U
Ethene	ug/L	-	ND		1	U	ND		1	U	ND		1	U

Table 4-2

**Historical VOC Data  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

(Page 3 of 4)

Location Code Sample No Sample Date Depth Chemical			FTA-94-MW10				FTA-94-MW11		FTA-94-MW13			
			EMM3012 11/30/00 Residuum		ZC3006 4/8/02 Residuum		EMM3013 12/18/00 Bedrock		EMM3015 7/18/01 Bedrock		ZC3007 4/3/02 Bedrock	
Units	MCL	Result	Qual	Result	Qual	Result	Qual	Result	Qual	Result	Qual	
1,1,2,2-Tetrachloroethane	ug/L	-	ND	1	U	1	U	ND		1	U	
Carbon disulfide	ug/L	-	ND	1	U	1	U	ND		0.32	J	
Chlorobenzene	ug/L	100	ND	1	U	300		ND		1	U	
Chloroform	ug/L	-	ND	1	U	1	U	ND		1	U	
cis-1,2-Dichloroethene	ug/L	70	ND	1	U	37		0.60	J	0.62	J	
Methylene chloride	ug/L	5	ND	0.3	J	1	U	ND		0.31	J	
trans-1,2-Dichloroethene	ug/L	100	ND	1	U	8.3		ND		1	U	
Trichloroethene	ug/L	5	ND	1	U	75		7		5.5		
Vinyl chloride	ug/L	2	ND	1	U	25		ND		1	U	
Ethene	ug/L	-	ND	1	U	1	U	ND		1	U	

**Table 4-2**

**Historical VOC Data  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

(Page 4 of 4)

Location Code			FTA-94-MW14				FTA-94-MW15			
			EMM3016		ZC3008		EMM3018		ZC3009	
Sample No			7/24/01		4/5/02		7/20/01		4/2/02	
Sample Date			Bedrock		Bedrock		Bedrock		Bedrock	
Depth										
Chemical	Units	MCL	Result	Qual	Result	Qual	Result	Qual	Result	Qual
1,1,2,2-Tetrachloroethane	ug/L	-	ND		1	U	ND		1	U
Carbon disulfide	ug/L	-	ND		1	U	ND		1	U
Chlorobenzene	ug/L	100	ND		1	U	ND		1	U
Chloroform	ug/L	-	ND		1	U	0.28	J	1	U
cis-1,2-Dichloroethene	ug/L	70	ND		1	U	ND		1	U
Methylene chloride	ug/L	5	ND		2	U	ND		0.86	J
trans-1,2-Dichloroethene	ug/L	100	ND		1	U	ND		1	U
Trichloroethene	ug/L	5	0.92	J	0.92	J	ND		1	U
Vinyl chloride	ug/L	2	ND		1	U	ND		1	U
Ethene	ug/L	-	ND		1	U	ND		1	U

MCL - Maximum Contaminant Level

Shaded concentrations exceed the MCL

Qual - Laboratory qualifier

ug/L - micrograms per liter

ND - Not Detected

NA - Not Analyzed

U - Analyte was not detected or below method detection limits

J - Estimated value

1 94-MW01 at a concentration of 14 µg/L during the December 2000 sampling event (Table 4-2).  
2 The decrease in the VC concentration in FTA-94-MW01 to the nondetect level is direct evidence  
3 for the biodegradation of VC. In addition, the decrease in VC concentration without the  
4 formation of ethene likely indicates that VC is degrading via metabolic oxidation, and not via  
5 reductive dechlorination.

6  
7 Chlorobenzene, which was detected in the bedrock water-bearing zone, was not detected in the  
8 residuum water-bearing zone during the April 2002 sampling event. An evaluation of the  
9 historical data for the residuum water-bearing zone reveals that chlorobenzene was detected in  
10 FTA-94-MW01 at a concentration of 16 µg/L during the December 2000 sampling event (Table  
11 4-2). The decrease in the chlorobenzene concentration in FTA-94-MW01 to the nondetect level  
12 is direct evidence for the biodegradation of chlorobenzene.

13  
14 Although the historical VOC data for the residuum water-bearing zone are limited to the past two  
15 years (with the exception of FTA-94-MW01, which has data dating back to 1998), an evaluation  
16 of historical concentrations of VOCs in the residuum water-bearing zone at Parcel 94(7) reveals  
17 that the concentrations of TCE, cis-1,2-DCE, VC, and chlorobenzene exhibit a decreasing trend.  
18 The decrease in concentrations indicates that natural attenuation is reducing contaminant levels  
19 and may be restoring groundwater at the site. However, since only two data points exist for most  
20 monitoring wells, continued monitoring for VOCs is recommended to further evaluate the effects  
21 of natural attenuation on groundwater restoration. The observed decrease in concentrations  
22 satisfies the first line of evidence for the occurrence of natural attenuation as specified by the  
23 EPA Office of Solid Waste and Emergency Response directive (EPA, 1998).

24  
25 Other chlorinated VOCs detected in residuum monitoring wells but not selected as COCs in the  
26 streamlined human health risk assessment include: chloroform, methylene chloride, and trans-  
27 1,2-DCE. The concentrations of these chemicals did not exceed their respective MCLs. These  
28 chemicals will not be evaluated in the natural attenuation evaluation because their concentrations  
29 do not warrant further investigation.

#### 30 31 **4.1.2 Bedrock Water-Bearing Zone**

32 A summary of the VOC analytical data obtained from groundwater samples collected during the  
33 April 2002 sampling event is presented in Table 4-1. Historical VOC data are presented in Table  
34 4-2. The following four wells were sampled in the bedrock water-bearing zone during the April  
35 2002 event: FTA-94-MW06, FTA-94-MW13, FTA-94-MW14, and FTA-94-

1 MW11 was not sampled during the April 2002 event; therefore, the results from the December  
2 2000 sampling event are presented in Table 4-1. TCE was detected in FTA-94-MW06 (0.52 J  
3  $\mu\text{g/L}$ ), FTA-94-MW11 (75  $\mu\text{g/L}$ ), FTA-94-MW13 (5.5  $\mu\text{g/L}$ ), and FTA-94-MW14 (0.92 J  $\mu\text{g/L}$ ).  
4 Only the TCE concentrations in FTA-94-MW11 and FTA-94-MW13 exceed the MCL of 5  $\mu\text{g/L}$ .  
5 The TCE reductive dechlorination daughter product cis-1,2-DCE was detected in FTA-94-  
6 MW11 (37  $\mu\text{g/L}$ ) and FTA-94-MW13 (0.62 J  $\mu\text{g/L}$ ). The cis-1,2-DCE concentrations do not  
7 exceed the MCL of 70  $\mu\text{g/L}$ . The detection of the TCE daughter product and the collocation of  
8 the cis-1,2-DCE and TCE are evidence that reductive dechlorination has occurred at the site. cis-  
9 1,2-DCE undergoes further reductive dechlorination to yield VC, which was not detected in the  
10 bedrock water-bearing zone during the April 2002 sampling event; however, it was detected at 25  
11  $\mu\text{g/L}$  in FTA-94-MW11 in December 2000. Ethene, the desired end product of the reductive  
12 dechlorination of TCE, was not detected in the bedrock water-bearing zone, indicating that  
13 reductive dechlorination is not proceeding to completion.

14  
15 Chlorobenzene was detected in FTA-94-MW11 in December 2000 at a concentration of 300  
16  $\mu\text{g/L}$ , which exceeds its MCL of 100  $\mu\text{g/L}$ . Bedrock monitoring wells sampled during the April  
17 2002 event did not exhibit any detections of chlorobenzene. Chlorobenzene degrades under  
18 aerobic conditions via metabolic oxidation. Continued monitoring of VOCs in the bedrock  
19 water-bearing zone is recommended to evaluate the effects of natural attenuation on groundwater  
20 restoration.

#### 21 22 **4.1.3 cis- to Total 1,2-DCE Ratio**

23 Biologically mediated reductive dechlorination of TCE favors the formation of cis-1,2-DCE to  
24 such an extent that less than 20 percent of the total 1,2-DCE will be trans-1,2-DCE. The ratio of  
25 cis- to total 1,2-DCE was calculated for residuum and bedrock monitoring wells with DCE  
26 detections, as presented in Table 4-3. The most recent cis-1,2-DCE and trans-1,2-DCE data were  
27 used to calculate the ratio. A cis-1,2-DCE to total 1,2-DCE ratio was calculated for residuum  
28 monitoring well FTA-94-MW01 and bedrock monitoring well FTA-94-MW11. The ratio in both  
29 wells is 82 percent, which strongly suggests the occurrence of reductive dechlorination in  
30 groundwater at Parcel 94(7).

**Table 4-3**

**cis-1,2-DCE to Total 1,2-DCE Ratio  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

LOCATION_CODE		FTA-94-MW01		FTA-94-MW03		FTA-94-MW11		FTA-94-MW13	
SAMPLE_NO		ZC3001		ZC3002		EMM3013		ZC3007	
SAMPLE_DATE		4/4/02		4/2/02		12/18/00		4/3/02	
DEPTH		Residuuum		Residuuum		Bedrock		Bedrock	
Chemical	Units	Result	Qual	Result	Qual	Result	Qual	Result	Qual
cis-1,2-DCE	ug/L	2.8		0.22	J	37		0.62	J
trans-1,2-DCE	ug/L	0.6	J	1	U	8.3		1	U
Total 1,2-DCE	ug/L	3.4		NA		45.3		NA	
Percentage of cis-1,2-DCE to Total 1,2-DCE	%	82%		NA		82%		NA	

Qual - Laboratory qualifier

ug/L - micrograms per liter

% - percent

U - Analyte was not detected or below method detection limits

J - Estimated value

NA - Not Applicable due to nondetect trans-1,2-DCE concentration

1 **4.1.4 Attenuation and Biodegradation Rates**

2  
3 **4.1.4.1 Chlorinated Ethenes**

4 Attenuation and biodegradation rate constants were calculated for TCE in the bedrock water-  
5 bearing zone along a downgradient flowpath. The vector that resembles the groundwater flow  
6 direction along the plume centerline in the bedrock water-bearing zone includes FTA-94-MW11,  
7 FTA-94-MW13, and FTA-94-MW14. The horizontal groundwater flow velocity in the bedrock  
8 water-bearing zone was calculated at 0.027 ft/day, which corresponds to 9.74 ft per year. The  
9 calculation of degradation rate constants of VOCs in the residuum water-bearing zone was not  
10 performed due to the lack of a well vector along the plume centerline.

11  
12 The attenuation and biodegradation rate constants for TCE are presented in Figure 4-1. The  
13 calculated attenuation half-life for TCE is 4.7 years, with a biodegradation half-life of 6.2 years.  
14 Biodegradation and mechanisms other than dispersion and adsorption accounted for  
15 approximately 76 percent of the total TCE attenuation. Using the site-specific attenuation rate,  
16 the time required until TCE attenuates to the MCL was estimated at 18 years (Table 4-4). The  
17 actual cleanup time would be longer, due to the formation of cis-1,2-DCE and VC as daughter  
18 products of the anaerobic reductive dechlorination of TCE. In addition, the attenuation half-lives  
19 may increase due to changes in geochemical and microbiological conditions at the site. For  
20 instance, aerobic conditions would inhibit the reductive dechlorination of TCE to cis-1,2-DCE  
21 and VC. Continued monitoring for VOCs is recommended to identify concentration trends and  
22 calculate temporal attenuation rate constants for cis-1,2-DCE and VC.

23  
24 **4.1.4.2 Chlorobenzene**

25 Chlorobenzene was not detected in the residuum or bedrock during the April 2002 sampling  
26 event. Historical groundwater data at Parcel 94(7) indicate detections of chlorobenzene in  
27 residuum monitoring well FTA-94-MW01 and bedrock monitoring well FTA-94-MW11. The  
28 concentration of chlorobenzene in FTA-94-MW01 was 3.4 µg/L in 1998 and 16 µg/L in 2000,  
29 but it decreased to nondetect (detection limit of 1 µg/L) in April 2002, indicating biodegradation.  
30 In the bedrock, chlorobenzene was detected in FTA-94-MW11 at a concentration of 300 µg/L in  
31 December 2000. Monitoring well FTA-94-MW11 was not sampled during the April 2002 event.  
32 Due to the lack of chlorobenzene distribution and the lack of historical data for FTA-94-MW11,  
33 a site-specific attenuation rate could not be calculated. The lack of chlorobenzene distribution at  
34 Parcel 94(7) is a possible indication that it rapidly degrades under the current aquifer conditions.  
35 Scientific literature reports that the degradation half-life for chlorobenzene in groundwater ranges

Figure 4-1

**TCE Attenuation and Biodegradation Rate Calculations in the Bedrock  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

Natural Attenuation Rate Calculation, Buscheck and Alcantar Equation,

Reference: Buscheck, T. E. and C. M. Alcantar (1995) Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Biodegradation in Intrinsic Bioremediation, eds. R. E. Hinchee, J. T. Wilson, and D. C. Downey, Battelle Press, Columbus, OH.

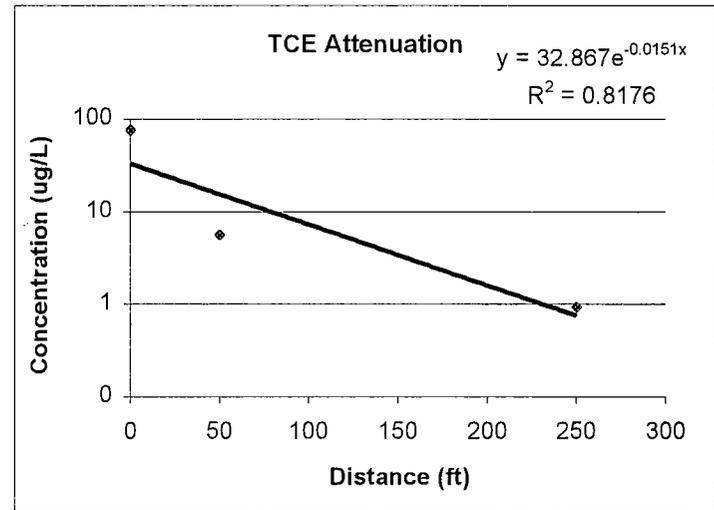
Bedrock	Slope of exponential regression versus distance (k/v <sub>x</sub> )		
MW Location	FTA-94-MW11	FTA-94-MW13	FTA-94-MW14
Feet Downgradient	0	50	250
Concentration (ug/L)	75	5.5	0.92

Slope      R<sup>2</sup>  
-0.0151    0.8176

Hydraulic Conductivity	0.144 ft/day
Groundwater Gradient	0.0278 ft/ft
Porosity	0.15 porosity
Average groundwater velocity, v <sub>x</sub> =	0.027 ft/day 9.74 ft/year

TCE	
$\lambda =$	$(v_d/4\alpha_x) ([1+2\alpha_x(k/v_x)]^2 - 1)$
$\alpha_x =$	5 % of flow field (distance separating two furthest wells) 12.5 ft
$f_{oc} =$	0.0005
$K_{oc} =$	107 L/kg
$K_d =$	$K_{oc}f_{oc}$ 0.0535 L/kg
$\rho_b =$	1.6 kg/L
$n =$	0.15
$R =$	$1 + (\rho_b K_d/n)$ 1.571
$v_e =$	$v_x/R$ 6.2019 ft/year

Intrinsic Biodegradation	Natural Attenuation
$(v_d/4\alpha_x) =$	0.1240 /yr
$(k/v_x) =$	0.0151 /ft
$[1+2\alpha_x(k/v_x)]$	1.3775
$\lambda =$	0.1113 /year
Half-life	6.2 years
	$k =$ 0.1471 /year
	half-life = 4.71 years
	$\lambda/k =$ 76%



**Table 4-4**

**Monitored Natural Attenuation Cleanup Time Estimates  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Clahoun County, Alabama**

Chemical	Biodegradation Rate Constant (per year)	Biodegradation Half-life (per year)	Attenuation Rate Constant (per year)	Attenuation Half-life (years)	Attenuation Half-life (days)	Percentage of Biodegradation (%)	Max Conc. (ug/L)	MCL (ug/L)	Cleanup Time (years)
TCE	0.111	6.2	0.147	4.7	1715.5	76%	75	5	18
Chlorobenzene	Not Determined	Not Determined	0.843	0.82	300	--	300	100	1.3

ug/L - micrograms per liter

MCL - maximum contaminant level

Notes:

- 1) The estimated cleanup time was calculated as the time it takes the maximum detected concentration to reach the MCL using the attenuation rate constant, and assuming first order degradation kinetics.
- 2) The actual cleanup time would be higher due to the likely formation of cis-1,2-DCE and vinyl chloride as a daughter product of TCE biodegradation.

at the site. For example, the complete consumption of bioavailable natural organic carbon would decrease the biodegradation rate constants because reductive dechlorination does not occur without the presence of a carbon and energy source.

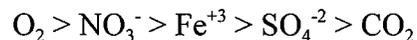
1 from 136 to 300 days (Howard et al., 1991). Using a half-life of 300 days to err on the  
2 conservative side, the time required for the chlorobenzene to attenuate from 300 µg/L to the  
3 MCL of 100 µg/L is estimated at 1.3 years (Table 4-4). Continued monitoring for chlorobenzene  
4 is recommended in order to identify concentration trends in the bedrock water-bearing zone and  
5 calculate a site-specific degradation rate if applicable.  
6

## 7 **4.2 Second Line of Evidence: Changes in Groundwater Geochemical Parameters**

8 Geochemical parameters were analyzed in groundwater samples collected during the April 2002  
9 sampling event. A summary of analytical data obtained from the field measurements is  
10 presented in Table 4-5, and analytical data obtained from the laboratory measurements are  
11 presented in Table 4-6. The geochemical data set obtained from FTA-94-MW09 was used as a  
12 background set for the evaluation. FTA-94-MW09 was selected as a background monitoring  
13 well because it is not impacted with chlorinated solvents and is located upgradient of the  
14 contaminated groundwater (Figure 3-1). The effects of microbial respiration are observed in situ  
15 by comparing the concentrations of respiratory substrates and products within the contaminated  
16 area with the concentrations in the background wells. To avoid confusing the results from the  
17 residuum with those from the bedrock, the discussion of changes in geochemical parameters is  
18 presented separately for each water-bearing zone.  
19

### 20 **4.2.1 Residuum Water-Bearing Zone**

21 As discussed in Section 2.1, respiratory substrates are used preferentially based on the amount of  
22 energy that can be derived from each of them. Respiratory substrates are used in the following  
23 order:



25  
26 The following discussion evaluates the respiratory processes that have occurred or are currently  
27 occurring in the residuum water-bearing zone beneath Parcel 94(7) and relates the findings to the  
28 occurrence of biodegradation of TCE, cis-1,2-DCE, VC, and chlorobenzene.  
29

30 The preferred terminal electron acceptor during microbial respiration is O<sub>2</sub>. The DO  
31 concentration was measured in the field using a low-flow method to minimize the aeration of  
32 groundwater samples. The DO results in the residuum monitoring wells ranged from 0.47 to  
33 4.53 milligrams per liter (mg/L), with a background concentration of 5.77 mg/L in FTA-94-  
34 MW09 (Table 4-5). The DO results indicate that aerobic conditions prevail in the residuum  
35 water-bearing zone. The ORP readings in the residuum monitoring wells ranged from 145 to 284

**Table 4-5**

**Natural Attenuation Parameters - Field Measurements  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

<b>Monitoring Well</b>	<b>DO mg/L</b>	<b>ORP mV</b>	<b>pH S.U.</b>	<b>Temperature C</b>	<b>Fe<sup>+2</sup> mg/L</b>	<b>Conductivity mS/cm</b>	<b>Turbidity NTU</b>
<b>Residuum</b>							
FTA-94-MW01	2.41	284	7.55	17.0	0	3.43	0.7
FTA-94-MW03	0.47	145	7.08	14.6	0	52.7	1.1
FTA-94-MW07	4.53	165	6.86	15.8	0	0.31	1.6
FTA-94-MW09 <sup>a</sup>	5.77	131	7.24	18.3	0.16	0.37	4.8
FTA-94-MW10	4.19	232	6.65	19.1	0	5.9	4
<b>Bedrock</b>							
FTA-94-MW06	0	164	6.89	13.8	0	44.4	0.5
FTA-94-MW11	NA	NA	NA	NA	NA	NA	NA
FTA-94-MW13	2.36	25	7.20	16.7	0.12	4.75	6.2
FTA-94-MW14	1.2	-56	7.71	21.0	0.03	3.26	3.2
FTA-94-MW15	0.74	-110	7.36	17.6	1.78	54.3	0.7

DO - dissolved oxygen

ORP - oxidation-reduction potential

S.U. - Standard Units

C - degrees celsius

Fe<sup>+2</sup> - ferrous iron

mg/L - milligrams per liter

mV - milliVolts

mS/cm - milliSiemens per centimeter

NTU - Nephelometric Turbidity Units

NA - Not Analyzed

**Notes:**

<sup>a</sup> FTA-94-MW09 screened in the residuum was selected as a background well for the residuum and bedrock zones, because the well is not impacted with chlorinated solvents and is located upgradient of the contaminated groundwater.

Table 4-6

**Natural Attenuation Parameters - Laboratory Measurements  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

Monitoring Well	TOC mg/L	pH S.U.	Alkalinity mg CaCO <sub>3</sub> /L	Chloride mg/L	Nitrite mg/L	Nitrate mg/L	Sulfate mg/L	Methane mg/L	Ethene mg/L	Ethane mg/L
<b>Residuum</b>										
FTA-94-MW01	1 U	6.5	136	2.2	0.5 U	0.5 U	9.2	0.001 U	0.001 U	0.001 U
FTA-94-MW03	1 U	6.3	218	3.3	0.5 U	0.5 U	7.2	0.022	0.001 U	0.001 U
FTA-94-MW07	1 U	6.3	178	2.4	0.5 U	0.5 U	8.2	0.001 U	0.001 U	0.001 U
FTA-94-MW09 <sup>a</sup>	1 U	6.5	180	2.3	0.5 U	0.5 U	4.3	0.001 U	0.001 U	0.001 U
FTA-94-MW10	1 U	5.9	260	2.7	0.5 U	0.5 U	16	0.001 U	0.001 U	0.001 U
<b>Bedrock</b>										
FTA-94-MW06	1 U	6.0	175	3.3	0.5 U	0.5 U	6	0.001 U	0.001 U	0.001 U
FTA-94-MW11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
FTA-94-MW13	1 U	6.4	220	2.6	0.5 U	1.1	9	0.027	0.001 U	0.001 U
FTA-94-MW14	1 U	6.5	109	0.4	0.5 U	1.2	23	0.373	0.001 U	0.001 U
FTA-94-MW15	1 U	6.5	210	4.3	0.5 U	0.5 U	32	0.004	0.001 U	0.001 U

TOC - Total Organic Carbon

S.U. - Standard Units

mg CaCO<sub>3</sub>/L - milligrams calcium carbonate per liter

mg/L - milligram per liter

U - Analyte was not detected or below method detection limits

NA - Not Analyzed

<sup>a</sup> FTA-94-MW09 screened in the residuum was selected as a background well for the residuum and bedrock zones, because the well is not impacted with chlorinated solvents and is located upgradient of the contaminated groundwater.

1 millivolts (mV), with a background reading of 131 mV. The high ORP readings correlate with  
2 the interpretation of the DO concentrations. The most highly impacted well in the residuum,  
3 FTA-94-MW01, exhibited a DO reading of 2.41 mg/L and an ORP of 284, indicating aerobic  
4 conditions. The aerobic conditions in FTA-94-MW01 are not favorable for the reductive  
5 dechlorination of TCE, since the complete reductive dechlorination of chlorinated ethenes only  
6 proceeds under extreme anaerobic conditions. However, the aerobic conditions are favorable for  
7 the biodegradation of cis-1,2-DCE, VC, and chlorobenzene via aerobic metabolic oxidation. The  
8 historical cis-1,2-DCE, VC, and chlorobenzene concentrations in FTA-94-MW01 indicate a  
9 decreasing trend, with nondetect concentrations for VC and chlorobenzene during the most  
10 recent sampling event. The concentration of cis-1,2-DCE in FTA-94-MW01 during the most  
11 recent sampling event was 2.8 µg/L, which is below the MCL of 70 µg/L.

12  
13 After O<sub>2</sub>, microorganisms preferentially use NO<sub>3</sub><sup>-</sup> as a terminal electron acceptor. Table 4-5  
14 indicates that NO<sub>3</sub><sup>-</sup> (nitrate) was not detected in any of the groundwater samples collected from  
15 the residuum monitoring wells, including the background well FTA-94-MW09. Nitrate  
16 reduction, which is thermodynamically favorable over reductive dechlorination, is not a likely  
17 mode of microbial respiration in the residuum water-bearing zone.

18  
19 Iron reduction is a common part of anaerobic microbial metabolism in groundwater. Ferric iron  
20 (Fe<sup>+3</sup>) is reduced to ferrous iron (Fe<sup>+2</sup>) during microbial respiration. This process results in an  
21 accumulation of soluble Fe<sup>+2</sup> in the groundwater where iron-reducing bacteria are active or have  
22 been active. Highly chlorinated compounds like TCE can undergo reductive dechlorination  
23 under iron-reducing conditions. However, less highly chlorinated compounds like DCE and VC  
24 do not typically undergo reductive dechlorination under iron-reducing conditions. Table 4-5  
25 presents the Fe<sup>+2</sup> concentrations in residuum monitoring wells. The data indicate that iron  
26 reduction is not a likely mode of microbial respiration in the residuum water-bearing zone.

27  
28 Reductive dechlorination of highly chlorinated compounds like TCE actively occurs under  
29 sulfate-reducing conditions, but the reductive dechlorination of DCE and VC is unlikely to occur  
30 under the same conditions. Sulfate-reducing conditions are favored when other electron  
31 acceptors such as O<sub>2</sub>, NO<sub>3</sub><sup>-</sup>, and Fe<sup>+3</sup> are depleted. Active sulfate reduction is often indicated by a  
32 depletion of sulfate in groundwater and a possible increase in sulfide. Concentrations of sulfate  
33 greater than 20 mg/L may cause competitive exclusion of reductive dechlorination (EPA, 1998).  
34 Table 4-6 indicates that the sulfate concentrations in the residuum monitoring wells ranged from  
35 7.2 to 16 mg/L, with a background concentration of 4.3 mg/L. The relatively low sulfate

1 concentrations in the groundwater indicate that sulfate concentrations are not likely to interfere  
2 with reductive dechlorination. However, the high DO and ORP readings indicate that the aquifer  
3 is under aerobic conditions, which does not favor sulfate reduction or reductive dechlorination.  
4

5 Dissolved methane is a good indicator of methanogenic anaerobic conditions with CO<sub>2</sub> being the  
6 terminal electron acceptor. Methanogenic conditions favor the complete reductive dechlorination  
7 of chlorinated compounds like TCE, DCE, and VC to the innocuous end product ethene.

8 Methane was detected only in one monitoring well, FTA-94-MW03, at a concentration of 22  
9 µg/L, indicating that methanogenic conditions are not prevalent in the residuum water-bearing  
10 zone. The complete reductive dechlorination of chlorinated ethenes is promoted under  
11 methanogenic conditions. Therefore, the conditions in the residuum water-bearing zone do not  
12 favor the complete reductive dechlorination of TCE. This is further evident from the lack of  
13 ethene detections in groundwater.  
14

15 Reductive dechlorination releases chloride ions into the groundwater. The chloride  
16 concentrations in the residuum monitoring wells ranged from 2.2 to 3.3 mg/L, with a background  
17 concentration of 2.3 mg/L in FTA-94-MW09. The chloride concentrations do not provide  
18 supportive evidence of reductive dechlorination in the impacted residuum water-bearing zone at  
19 Parcel 94(7).  
20

21 Regardless of the electron acceptor being used, organic carbon is required as a source of reduced  
22 carbon and energy to sustain microbial activity. TOC concentrations greater than 20 mg/L are  
23 considered adequate to support microbial activity. Analysis of groundwater samples collected  
24 from residuum monitoring wells did not detect TOC in any of the samples (detection limit of 1.0  
25 mg/L). Therefore, TOC concentrations in the residuum water-bearing zone at Parcel 94(7) do  
26 not provide carbon and energy sources to support reductive dechlorination.  
27

28 The alkalinity measured in the background well FTA-94-MW09 was 180-milligrams calcium  
29 carbonate per liter (mg CaCO<sub>3</sub>/L). Alkalinity values in the residuum wells ranged from 136 to  
30 260 mg CaCO<sub>3</sub>/L. There was no observed difference in alkalinity across the site. Therefore,  
31 alkalinity concentrations do not provide any evidence of microbial activity. The optimum pH  
32 range for microbial activity is between 6 and 8 standard units. Results of the field (Table 4-5)  
33 and laboratory (Table 4-6) pH measurements indicate that the pH in the residuum monitoring  
34 wells is within the optimum range for microbial activity. Therefore, the groundwater pH is not  
35 expected to inhibit biodegradation in the residuum water-bearing zone at Parcel 94(7).

1  
2 The qualitative assessment of the respiratory substrates and products indicates that the residuum  
3 water-bearing zone is under aerobic conditions, which favor the aerobic biodegradation of cis-  
4 1,2-DCE, VC, and chlorobenzene, but inhibit the anaerobic reductive dechlorination of the  
5 chlorinated ethenes. The decrease in the concentrations of cis-1,2-DCE, VC, and chlorobenzene  
6 without the detection of ethene is evidence that aerobic metabolic oxidation is the primary  
7 degradation pathway in the residuum water-bearing zone at Parcel 94(7).

#### 8 9 **4.2.2 Bedrock Water-Bearing Zone**

10 The following discussion evaluates the respiratory processes that have occurred or are currently  
11 occurring in the bedrock water-bearing zone beneath Parcel 94(7) and relates the findings to the  
12 occurrence of reductive dechlorination of TCE, cis-1,2-DCE, and VC and, alternately, to the  
13 occurrence of aerobic biodegradation of cis-1,2-DCE, VC, and chlorobenzene.

14  
15 The preferred terminal electron acceptor during microbial respiration is O<sub>2</sub>. The DO results in  
16 the bedrock monitoring wells ranged from nondetect to 2.4 mg/L, with a background  
17 concentration of 5.77 mg/L in FTA-94-MW01 (Table 4-5). The DO results indicate that two  
18 wells are under aerobic conditions, and two wells are under anaerobic conditions. The ORP  
19 readings range from -110 to +164 mV (Table 4-5), which also indicate various  
20 microenvironments in the bedrock water-bearing zone. ORP readings above 50 mV are  
21 generally indicative of aerobic conditions. The ORP readings in the bedrock water-bearing zone  
22 correlate with the interpretation of the DO readings and indicate that aerobic pockets exist in the  
23 bedrock water-bearing zone. Under aerobic conditions, reductive dechlorination of chlorinated  
24 ethenes is inhibited, while the aerobic biodegradation of cis-1,2-DCE, VC, and chlorobenzene is  
25 favored. The monitoring well nearest to FTA-94-MW11 (the monitoring well with the highest  
26 detections of COCs) screened in the bedrock water-bearing zone with measured DO and ORP  
27 readings is FTA-94-MW13. The DO and ORP readings from FTA-94-MW13 indicate aerobic  
28 conditions, which favor the biodegradation of cis-1,2-DCE, VC, and chlorobenzene detected in  
29 the bedrock water-bearing zone.

30  
31 After O<sub>2</sub>, microorganisms preferentially use NO<sub>3</sub><sup>-</sup> as a terminal electron acceptor. Table 4-6  
32 indicates that NO<sub>3</sub><sup>-</sup> was detected in two bedrock monitoring wells at concentrations around 1  
33 mg/L. This indicates that nitrate reduction is a likely mode of microbial respiration in the  
34 bedrock water-bearing zone. The microbial reduction of NO<sub>3</sub><sup>-</sup> will not occur until the DO has  
35 been consumed. The presence of NO<sub>3</sub><sup>-</sup> is further evidence that the bedrock water-bearing zone is

1 under aerobic conditions, which favor the biodegradation of cis-1,2-DCE, VC, and  
2 chlorobenzene via metabolic oxidation.

3  
4 Concentrations of  $\text{Fe}^{+2}$  above 1 mg/L generally indicate iron-reducing conditions. Table 4-5  
5 presents the  $\text{Fe}^{+2}$  concentrations in the bedrock monitoring wells. The  $\text{Fe}^{+2}$  concentrations range  
6 from nondetect to 1.78 mg/L, indicating a wide range of conditions throughout the bedrock zone.  
7 The concentration of  $\text{Fe}^{+2}$  exceeded 1 mg/L in FTA-94-MW15 (1.78 mg/L), which is evidence  
8 for the occurrence of iron reduction; however, the remainder of the wells indicate that iron  
9 reduction has not occurred to a great extent in the bedrock water-bearing zone.

10  
11 Active sulfate reduction is often indicated by a depletion of sulfate in groundwater and a possible  
12 increase in sulfide. Concentrations of sulfate greater than 20 mg/L may cause competitive  
13 exclusion of reductive dechlorination (EPA, 1998). Table 4-6 indicates that the sulfate  
14 concentrations in the bedrock monitoring wells ranged from 6 to 32 mg/L, with a background  
15 concentration of 4.3 mg/L in FTA-94-MW09. The sulfate concentrations may cause interfere  
16 with reductive dechlorination; however, the current aerobic conditions overshadow the potential  
17 sulfate effects on reductive dechlorination.

18  
19 Methane concentrations ranged from nondetect (detection limit of 0.001 mg/L) to 0.373 mg/L,  
20 with a nondetect background concentration in FTA-94-MW09. The elevated methane  
21 concentration was detected in FTA-94-MW14, which is not impacted with VOCs and has a  
22 nondetect concentration for TOC. Therefore, the source of the methane is likely upgradient, or  
23 the detection is an analytical anomaly. Predominantly, the low methane concentrations are  
24 further evidence of the lack of anaerobic biological activity in the bedrock water-bearing zone.

25  
26 The chloride concentrations in the bedrock water-bearing zone ranged from 0.4 to 4.3 mg/L, with  
27 a background concentration of 2.3 mg/L in FTA-94-MW09. There is no significant variation in  
28 the chloride concentrations. Therefore, chloride concentrations do not provide evidence of  
29 reductive dechlorination in the bedrock water-bearing zone.

30  
31 Organic carbon is required as a source of reduced carbon and energy to sustain microbial  
32 activity. TOC concentrations greater than 20 mg/L are considered adequate to support microbial  
33 activity. Analysis of bedrock groundwater did not detect TOC in any of the collected samples  
34 (detection limit of 1.0 mg/L). The TOC concentrations in the bedrock water-bearing zone at  
35 Parcel 94(7) are inadequate (non-existent) to provide a carbon and energy source to support  
36 reductive dechlorination.

1  
2 The qualitative assessment of the respiratory substrates and products indicates that the bedrock  
3 water-bearing zone is predominantly under aerobic conditions, with some pockets of slightly  
4 anaerobic conditions. Aerobic conditions favor the metabolic oxidation of cis-1,2-DCE, VC, and  
5 chlorobenzene while inhibiting the anaerobic reductive dechlorination of the chlorinated ethenes.  
6 Continued monitoring of the bedrock water-bearing zone is recommended to determine the  
7 effects of natural attenuation on groundwater restoration.  
8

#### 9 **4.2.3 EPA Screening Procedure**

10 Chemical and geochemical data collected from the residuum and bedrock water-bearing zones  
11 were evaluated using the EPA screening procedure to weigh the strength of evidence for  
12 reductive dechlorination (EPA, 1998). The screening procedure assigns a weighted value to each  
13 analytical parameter that is known to indicate the occurrence of reductive dechlorination. The  
14 sum of the weighted values for all parameters is the score for a given monitoring well location,  
15 which indicates the likelihood that natural attenuation is occurring at that particular location.  
16 Scores above 20 indicate strong evidence that reductive dechlorination is occurring. Scores  
17 between 15 and 20 are considered adequate evidence. Scores between 6 and 14 represent limited  
18 evidence, and scores of 5 or less are considered inadequate evidence of reductive dechlorination.  
19

20 The results of the screening for the residuum and bedrock water-bearing zones are presented in  
21 Table 4-7. The weighted scores for the residuum monitoring wells ranged from 4 to 7, with a  
22 background score of 1 for FTA-94-MW09. This range indicates inadequate to limited evidence  
23 that reductive dechlorination is occurring and confirms the results obtained from evaluating the  
24 first two lines of evidence. The weighted scores for the bedrock monitoring wells ranged from 2  
25 to 7, indicating inadequate to limited evidence for the occurrence of reductive dechlorination.  
26 Although the EPA screening results for the residuum and bedrock water-bearing zones do not  
27 support the occurrence of reductive dechlorination, the aerobic conditions are favorable for the  
28 aerobic biodegradation of cis-1,2-DCE, VC, and chlorobenzene.  
29

### 30 **4.3 Third Line of Evidence: Controlled Microcosm Studies**

#### 31 **4.3.1 Inhibited Control Microcosms**

32 Inhibited control microcosms were established to measure the loss of chlorinated solvents due to  
33 physical processes and experimental error. Table 4-8 and Figure 4-2 present the results of the  
34 inhibited control microcosms. TCE in the inhibited microcosms decreased slightly over the  
35 duration of the 12-week study. The absence of any cis-1,2-DCE, VC, or ethene indicates that  
36

Table 4-7

EPA Screening Procedure for Evidence of Natural Attenuation  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama

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Monitoring Well	pH (S. U.)	Temperature (Degrees C)	Dissolved Oxygen (mg/L)	ORP (mV)	TOC (mg/L)	Fe <sup>+2</sup> (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Alkalinity (mg/CaCO <sub>3</sub> )	Methane (mg/L)	Ethene (mg/L)	Ethane (mg/L)	cis-1,2-DCE (µg/L)	Total 1,2-DCE (µg/L)	% cis-1,2-DCE
<b>Residuum</b>																
FTA-94-MW01	6.5	17.0	2.41	284	1 U	0.00	9.2	2.2	0.5 U	136	0.001 U	0.001 U	0.001 U	2.8	3.4	82%
FTA-94-MW03	6.3	14.6	0.47	145	1 U	0.00	7.2	3.3	0.5 U	218	0.022	0.001 U	0.001 U	0.22 J	1 U	NA
FTA-94-MW07	6.3	15.8	4.53	165	1 U	0.00	8.2	2.4	0.5 U	178	0.001 U	0.001 U	0.001 U	1 U	1 U	NA
FTA-94-MW09 <sup>a</sup>	6.5	18.3	5.77	131	1 U	0.16	4.3	2.3	0.5 U	180	0.001 U	0.001 U	0.001 U	1 U	1 U	NA
FTA-94-MW10	5.9	19.1	4.19	232	1 U	0.00	16	2.7	0.5 U	260	0.001 U	0.001 U	0.001 U	1 U	1 U	NA
<b>Bedrock</b>																
FTA-94-MW06	6.0	13.8	0.00	164	1 U	0.00	6	3.3	0.5 U	175	0.001 U	0.001 U	0.001 U	1 U	1 U	NA
FTA-94-MW11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	37	45.3	82%
FTA-94-MW13	6.4	16.7	2.36	25	1 U	0.12	9	2.6	1.1	220	0.027	0.001 U	0.001 U	0.62 J	1 U	NA
FTA-94-MW14	6.5	21.0	1.20	-56	1 U	0.03	23	0.4	1.2	109	0.373	0.001 U	0.001 U	1 U	1 U	NA
FTA-94-MW15	6.5	17.6	0.74	-110	1 U	1.78	32	4.3	0.5 U	210	0.004	0.001 U	0.001 U	1 U	1 U	NA

Weighted Scores

Monitoring Well	pH	Temperature	Dissolved Oxygen	ORP	TOC	Fe <sup>+2</sup>	Sulfate	Chloride	Nitrate	Alkalinity	Methane	Ethene	Ethane	% cis-1,2-DCE	Score
<b>Residuum</b>															
FTA-94-MW01	0	0	0	0	0	0	2	0	2	0	0	0	0	2	6
FTA-94-MW03	0	0	3	0	0	0	2	0	2	0	0	0	0	0	7
FTA-94-MW07	0	0	0	0	0	0	2	0	2	0	0	0	0	0	4
FTA-94-MW09 <sup>a</sup>	0	0	-3	0	0	0	2	0	2	0	0	0	0	0	1
FTA-94-MW10	0	0	0	0	0	0	2	0	2	0	0	0	0	0	4
<b>Bedrock</b>															
FTA-94-MW06	0	0	3	0	0	0	2	0	2	0	0	0	0	0	7
FTA-94-MW11	0	0	0	0	0	0	2	0	2	0	0	0	0	2	6
FTA-94-MW13	0	0	0	1	0	0	2	0	0	0	0	0	0	0	3
FTA-94-MW14	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2
FTA-94-MW15	0	0	0	2	0	3	0	0	2	0	0	0	0	0	7

Table 4-7

**EPA Screening Procedure for Evidence of Natural Attenuation  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

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**Total Scores**

MW	Score	Classification
<b>Residuum</b>		
FTA-94-MW01	6	Limited Evidence
FTA-94-MW03	7	Limited Evidence
FTA-94-MW07	4	Inadequate Evidence
FTA-94-MW09 <sup>a</sup>	1	Inadequate Evidence
FTA-94-MW10	4	Inadequate Evidence
<b>Bedrock</b>		
FTA-94-MW06	7	Limited Evidence
FTA-94-MW11	6	Limited Evidence
FTA-94-MW13	3	Inadequate Evidence
FTA-94-MW14	2	Inadequate Evidence
FTA-94-MW15	7	Limited Evidence

Classification	Score
Strong Evidence	>20
Adequate Evidence	15 to 20
Limited Evidence	6 to 14
Inadequate Evidence	5 or less

<sup>a</sup> FTA-94-MW09 screened in the residuum was selected as a background well for the residuum and bedrock zones, because the well is not impacted with chlorinated solvents and is located upgradient of the contaminated groundwater.

TOC - Total Organic Carbon

S.U. - Standard Units

C - celsius

mg/L - milligram per liter

ORP - oxidation-reduction potential

mV - milliVolts

Fe<sup>+2</sup> - ferrous iron

mg CaCO<sub>3</sub>/L - milligrams calcium carbonate per liter

U - Analyte was not detected or below method detection limits

µg/L - micrograms per liter

NA - not analyzed

**Table 4-8**

**Inhibited Microcosm Results  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94  
Fort McClellan, Calhoun County, Alabama**

Analyte	Sampling Points				
	Initial	Week 2	Week 4	Week 8	Week 12
TCE (mg/L)	2.42	2.36	2.41	2.26	2.17
cis-1,2- DCE (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
trans-1,2-DCE (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
VC (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
Chlorobenzene (mg/L)	0.938	0.898	0.908	0.818	0.660
Methane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.001 U
Ethene (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.001 U
Ethane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.001 U
TOC (mg/L)	1.0 U	1.0 U	1 U	1.4	23
pH (S.U.)	6.6	7.0	7.0	6.6	6.8
Ortho-phosphate (mg/L)	0.5 U	0.5 U	0.74	0.5 U	0.5 U
Ammonia (mg/L)	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U
DO (mg/L)	11	9	8	6	NA
Nitrate (mg/L)	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Nitrite (mg/L)	0.5 U	0.5 U	0.50 U	0.5 U	0.5 U
Sulfate (mg/L)	11	11	12	12	12
Chloride (mg/L)	3.5	3.4	3.6	3.8	3.7

**Notes:**

mg/L - milligrams per liter

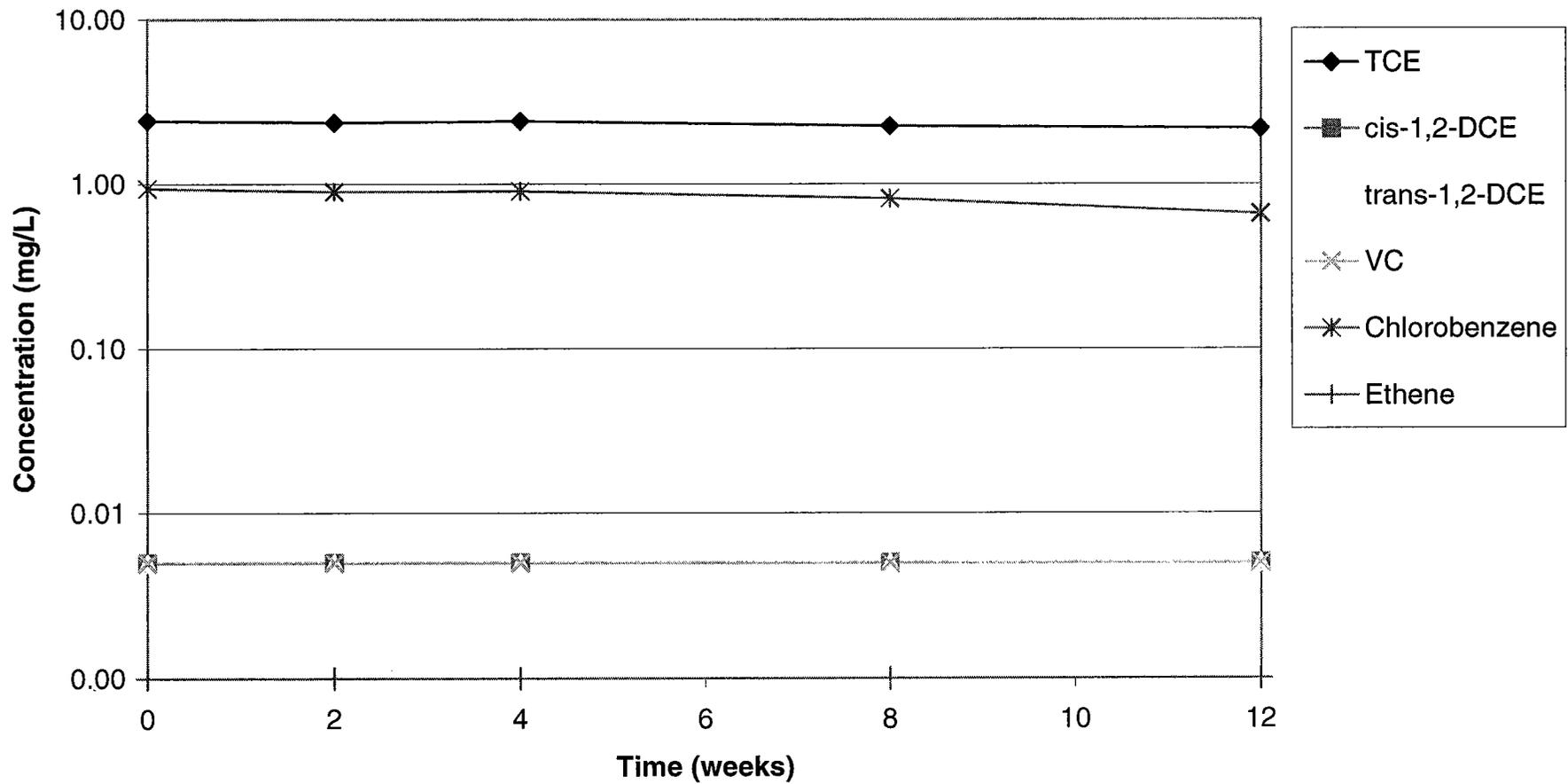
S.U. - Standard Units

NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

**Figure 4-2**  
**Inhibited Microcosm Data Graphs**  
**Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)**  
**Ft. McClellan, Calhoun County, Alabama**



1 reductive dechlorination did not occur in the inhibited microcosms. In addition, the low levels of  
2 methane and the constant levels of sulfate and chloride over the course of the 12-week study  
3 indicate that the temperature-inhibited microcosms effectively suppressed microbial activity.  
4 Chlorobenzene concentrations decreased from an initial concentration of 0.938 mg/L (spiked  
5 concentration) to 0.660 mg/L. The inhibited microcosms provided a baseline against which the  
6 unamended microcosms were compared. Differences in VOC concentrations and other  
7 parameters between the inhibited microcosms and the unamended microcosms were attributed to  
8 biological activity.

#### 9 10 **4.3.2 Unamended Control Microcosms**

11 Unamended soil and groundwater microcosms were established to evaluate the anaerobic  
12 biodegradation of the COCs at Parcel 94(7) that could occur in situ under current field  
13 conditions. Table 4-9 and Figure 4-3 present the results of the unamended microcosms. The  
14 results indicate that the concentration of TCE did not decrease over the duration of the 12-week  
15 study. The lack of production of cis-1,2-DCE and VC and the constant concentrations of sulfate  
16 and chloride throughout the 12-week study are further evidence of the lack of anaerobic  
17 microbial activity. Regardless of the electron acceptor used, organic carbon is required as a  
18 source of reduced carbon and energy to sustain microbial activity. TOC concentrations greater  
19 than 20 mg/L are considered adequate to support microbial activity. The lack of reductive  
20 dechlorination in the unamended microcosms can be attributed to elevated DO levels,  
21 insufficient TOC levels, and elevated sulfate concentrations. The system also appears to be  
22 nutrient limited, as indicated by the low to nondetect levels of ortho-phosphate and ammonia.  
23 The results obtained from the unamended microcosms indicate that current field conditions are  
24 not favorable for reductive dechlorination of TCE to occur at Parcel 94(7).

25  
26 Chlorobenzene concentrations decreased from an initial concentration of 0.929 mg/L to 0.317  
27 mg/L following 12 weeks of incubation. The decrease in concentrations indicates that  
28 chlorobenzene degraded in the unamended microcosms. An evaluation of the baseline data  
29 indicates that elevated DO concentrations existed at the start of incubation and decreased to  
30 anaerobic levels over the duration of the investigation. Chlorobenzene is amenable to aerobic  
31 biodegradation through metabolic oxidation in the presence of dissolved oxygen. The decrease  
32 in chlorobenzene concentrations is attributed to its aerobic biodegradation. The half-life for  
33 chlorobenzene degradation was calculated at 7 weeks (49 days), which is more rapid than the  
34 half-lives reported for chlorobenzene in the scientific literature.

**Table 4-9**

**Unamended Microcosm Results  
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)  
Fort McClellan, Calhoun County, Alabama**

Analyte	Sampling Points				
	Initial	Week 2	Week 4	Week 8	Week 12
TCE (mg/L)	2.42	2.13	2.12	2.09	2.05
cis-1,2- DCE (mg/L)	0.005 U	0.003 J	0.005 U	0.005 U	0.005 J
trans-1,2-DCE (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
VC (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
Chlorobenzene (mg/L)	0.929	0.590	0.500	0.269	0.317
Methane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.002
Ethene (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.003
Ethane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.001 U
TOC (mg/L)	1.0 U	1.0 U	1.0 U	1.0 U	19
pH (S.U.)	6.6	6.9	7.1	6.7	7.1
Ortho-phosphate (mg/L)	0.5 U	0.5 U	0.96	0.5 U	0.5 U
Ammonia (mg/L)	1.0 U	1.0 U	1.0 U	1.0 U	1.0 U
DO (mg/L)	11	6.0	2.0	2.0	NA
Nitrate (mg/L)	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Nitrite (mg/L)	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Sulfate (mg/L)	11	11	12	12	12
Chloride (mg/L)	3.5	3.5	3.6	4.0	4.1

**Notes:**

mg/L - milligrams per liter

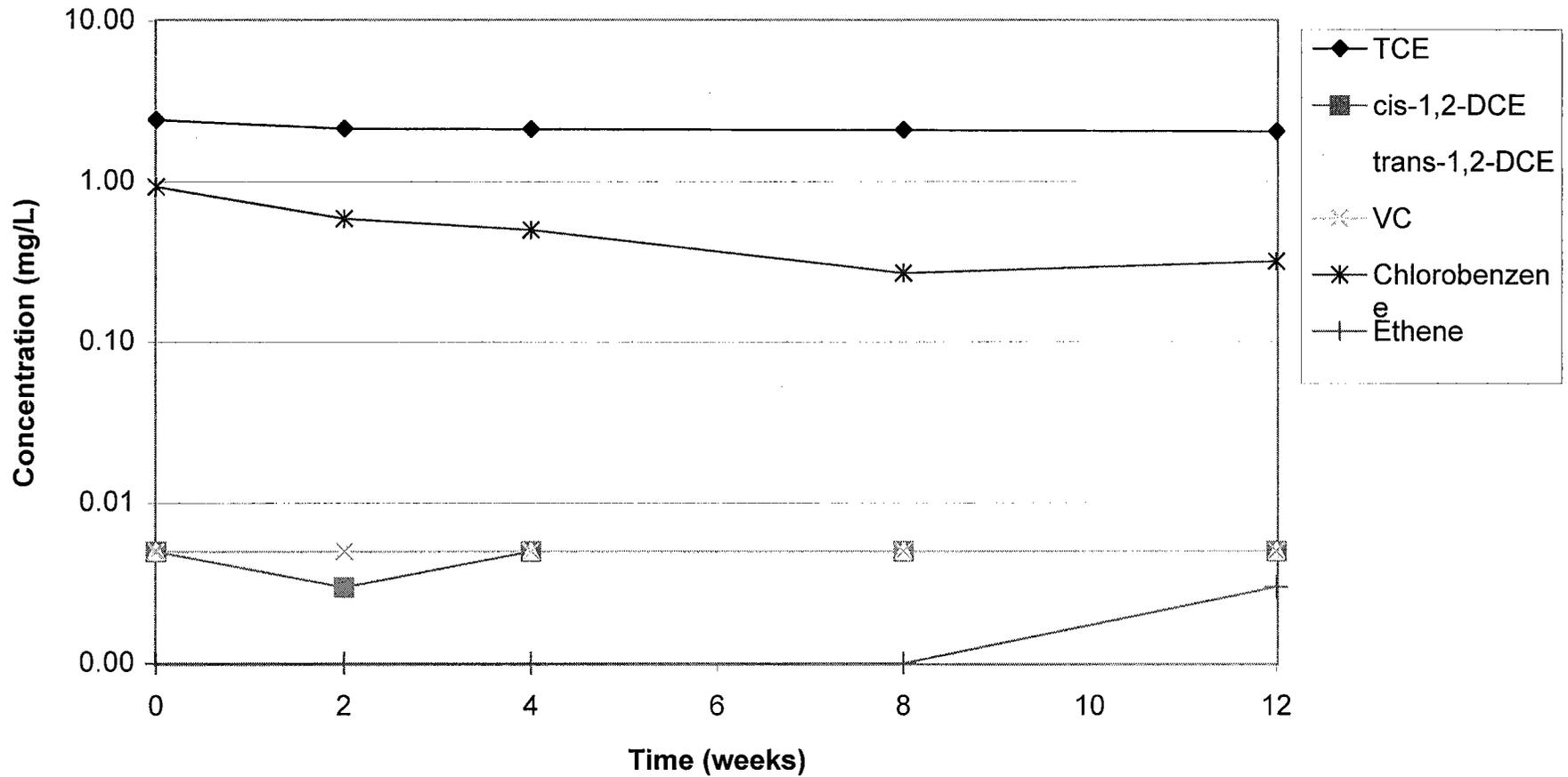
S.U. - Standard Units

NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

**Figure 4-3**  
**Unamended Microcosm Data Graphs**  
**Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)**  
**Fort McClellan, Calhoun County, Alabama**



1 The results obtained from the microcosms indicate that conditions are favorable for the aerobic  
2 biodegradation of chlorobenzene but are not favorable for the reductive dechlorination of  
3 chlorinated ethenes. In general, the results from the microcosms confirm the observations  
4 obtained from the first two lines of evidence of the natural attenuation evaluation at Parcel 94(7).

## 5.0 Conclusions and Recommendations

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The *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (EPA, 1998) was used in investigating the effects of natural attenuation on groundwater contaminants at Parcel 94(7). The field and laboratory investigations provided evidence suggesting site conditions are not favorable for the anaerobic biodegradation of TCE and its daughter products via reductive dechlorination. The lack of reductive dechlorination was attributed to elevated DO concentrations, high ORP readings, the absence (nondetect concentrations) of TOC, and the lack of sufficient nutrients. Although a decreasing trend was observed, the concentration of TCE in the residuum water-bearing zone remains above the MCL. The decrease in TCE concentrations is likely due to natural attenuation mechanisms such as dilution, dispersion, sorption, and possibly aerobic biodegradation. Site evidence indicates that intrinsic aerobic biodegradation via metabolic oxidation has decreased the concentrations of cis-1,2-DCE, VC, and chlorobenzene in the residuum water-bearing zone to nondetect levels for VC and chlorobenzene and to concentrations below the MCL for cis-1,2-DCE. Continued monitoring for VOCs and natural attenuation parameters is recommended for the residuum water-bearing zone at Parcel 94(7) in order to confirm the observed concentration trends.

In the bedrock water-bearing zone, conditions are favorable for the aerobic biodegradation of cis-1,2-DCE, VC, and chlorobenzene but unfavorable for the biodegradation of TCE. Concentration trends for the COCs in the bedrock water-bearing zone could not be determined from the available data. As such, continued monitoring for VOCs and natural attenuation parameters is recommended for the bedrock water-bearing zone at Parcel 94(7) in order to identify concentration trends, calculate attenuation rates (if applicable), and determine if aerobic biodegradation is decreasing the concentrations of cis-1,2-DCE, VC, and chlorobenzene.

## 6.0 References

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Bear, J., 1979, *Hydraulics of Groundwater*, McGraw-Hill, New York.

Biomedical and Environmental Information Analysis, 1989, *The Installation Restoration Program Toxicology Guide, Vol. 1*, Harry G. Armstrong Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson, Air Force Base, OH. DOE Interagency Agreement No. 1891-A076-A1.

Bouwer, E. J., 1994, "Bioremediation of Chlorinated Solvents using Alternative Electron Acceptors," *Handbook of Bioremediation*, Norris, R. D., R. E. Hinchee, R. Brown, P. L. McCarty, L. Semprini, J. T. Wilson, D. H. Kampbell, M. Reinhard, E. J. Bouwer, R. C. Borden, T. M. Vogel, J. M. Thomas, and C. H. Ward, eds., Lewis Publishers, Boca Raton.

Buscheck, T. E., and C. M. Alcantar, 1995, "Regression Techniques and Analytical solutions to Demonstrate Intrinsic Bioremediation," *Intrinsic Bioremediation*, R. E. Hinchee, J. T. Wilson, and D. C. Downey, eds., Battelle Press, Columbus.

Fiorenza, S., E. L. Hockman, Jr., S. Szojka, R. M. Woeller, and J. W. Wigger, 1994, "Natural Anaerobic Degradation of Chlorinated Solvents at a Canadian Manufacturing Plant," *Bioremediation of Chlorinated and Polycyclic Aromatic Hydrocarbon Compounds*, R. E. Hinchee, A. Leeson, L. Semprini, and S. K. Ong, eds., Lewis Publishers, Boca Raton.

Howard, P., R. Boethling, W. Jarvis, W. Meylan, and E. Michalenko, 1991, *Handbook of Environmental Degradation Rates*, Lewis Publishers.

IT Corporation (IT), 2002, *Draft Remedial Investigation Report, Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7), Fort McClellan, Calhoun County, Alabama*, May.

McCarty, P. L., and L. Semprini, 1994, "Ground-water Treatment of Chlorinated Solvents," *Handbook of Bioremediation*, R. D. Norris, R. E. Hinchee, R. Brown, P. L. McCarty, L. Semprini, J. T. Wilson, D. H. Kampbell, M. Reinhard, E. J. Bouwer, R. C. Borden, T. M. Vogel, J. M. Thomas, and C. H. Ward, eds., Lewis Publishers, Boca Raton.

Mertens, J. A., 1993, "Dichloroethylene," *Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed*, John Wiley and Sons, Inc., New York.

Mohn, W. W., and J. M. Tiedje, 1992, "Microbial Reductive Dehalogenation," *Microbiological Reviews*, 56(3): 482-507.

U.S. Environmental Protection Agency (EPA), 1998, *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*, U.S. EPA/600/R-98/128, Wiedemeier, T. H., M. A. Swanson, D. E. Moutoux, E. K. Gordon, J. T. Wilson, B. H. Wilson, D. H. Kampbell, P. E. Haas, R. N. Miller, J. E. Hansen, and F. H. Chapelle, Cincinnati, Ohio.

- 1 Vogel, T. M., and P. L. McCarty, 1987, "Abiotic and Biotic Transformations of 1,1,1-  
2 trichloroethane under methanogenic conditions," *Environmental Science and Technology*,  
3 21(12): 1208-1213.  
4
- 5 Young, L. Y., and C. E. Cerniglia, 1995, "Microbial Transformation and Degradation of Toxic  
6 Organic Chemicals," John Wiley and Sons, Inc., New York.