

APPENDIX A

NATURAL ATTENUATION EVALUATION

Draft

**Natural Attenuation Evaluation
Small Weapons Repair Shop, Parcel 66(7)**

**Fort McClellan
Calhoun County, Alabama**

Prepared for:

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Table of Contents

	Page
List of Tables	ii
List of Figures	ii
List of Abbreviations and Acronyms	iii
1.0 Introduction	1-1
1.1 Site Description and History	1-1
1.2 Summary of Geology and Hydrogeology	1-2
2.0 Natural Attenuation	2-1
2.1 Natural Attenuation Lines of Evidence	2-1
2.2 Anaerobic Reductive Dechlorination	2-2
2.3 Geomicrobiology	2-3
3.0 Natural Attenuation Evaluation Methods	3-1
3.1 Groundwater Analysis	3-1
3.2 Microcosms	3-2
3.3 Data Evaluation Procedures	3-3
4.0 Results	4-1
4.1 First Line of Evidence: Occurrence of Chlorinated Solvents and Biodegradation Products	4-1
4.1.1 Residuum Water-Bearing Zone	4-1
4.1.2 Bedrock Water-Bearing Zone	4-2
4.1.3 cis- to Total 1,2-DCE Ratio	4-3
4.1.4 Attenuation and Biodegradation Rates	4-3
4.2 Second Line of Evidence: Changes in Groundwater Geochemical Parameters	4-4
4.2.1 Residuum Water-Bearing Zone	4-4
4.2.2 Bedrock Water-Bearing Zone	4-7
4.2.3 EPA Screening Procedure	4-9
4.3 Third Line of Evidence: Controlled Microcosm Studies	4-9
5.0 Conclusions and Recommendations	5-1
6.0 References	6-1

List of Tables

Table	Title	Follows Page
3-1	Groundwater Analytical Methods	3-1
4-1	Analytical Summary of VOC Results	4-1
4-2	cis-1,2-DCE to Total 1,2-DCE Ratio	4-3
4-3	Monitored Natural Attenuation Cleanup Time Estimates	4-4
4-4	Natural Attenuation Parameters – Field Measurements	4-4
4-5	Natural Attenuation Parameters – Laboratory Measurements	4-4
4-6	EPA Screening Procedure for Evidence of Natural Attenuation	4-9
4-7	Inhibited Microcosm Results	4-9
4-8	Unamended Microcosm Results	4-10

List of Figures

Figure	Title	Follows Page
1-1	Site Location Map	1-1
2-1	Pathways for Anaerobic Degradation of Chlorinated Aliphatic Hydrocarbons	2-3
3-1	Sample Location Map	3-1
4-1	TCE Attenuation and Biodegradation Rate Calculations	4-3
4-2	cis-1,2-DCE Attenuation and Biodegradation Rate Calculations	4-3
4-3	1,1-DCE Attenuation and Biodegradation Rate Calculations	4-3
4-4	Inhibited Microcosm Data Graphs	4-9
4-5	Unamended Microcosm Data Graphs	4-10

List of Abbreviations and Acronyms

bgs	below ground surface
CaCO ₃	calcium carbonate
CO ₂	carbon dioxide
COPC	chemicals of potential concern
DCA	dichloroethane
DCE	dichloroethene
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
Fe ⁺³	ferric iron
Fe ⁺²	ferrous iron
f _{oc}	fraction organic carbon
ft	feet
ft/day	feet per day
ft/yr	feet per year
FTMC	Fort McClellan
g	grams
IT	IT Corporation
K _d	soil-water distribution coefficient
K _{oc}	organic carbon partitioning coefficient
MCL	maximum contaminant level
µg/L	micrograms per liter
mg	milligram
mg/L	milligrams per liter
mL	milliliter
mV	millivolts
NO ₃ ⁻	nitrate
O ₂	oxygen
ORP	oxidation-reduction potential
R	retardation factor
RI	remedial investigation
SO ₄ ⁻²	sulfate
TCA	trichloroethane
TCE	trichloroethene

List of Abbreviations and Acronyms (Continued) _____

TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
VC	vinyl chloride
VOC	volatile organic compounds

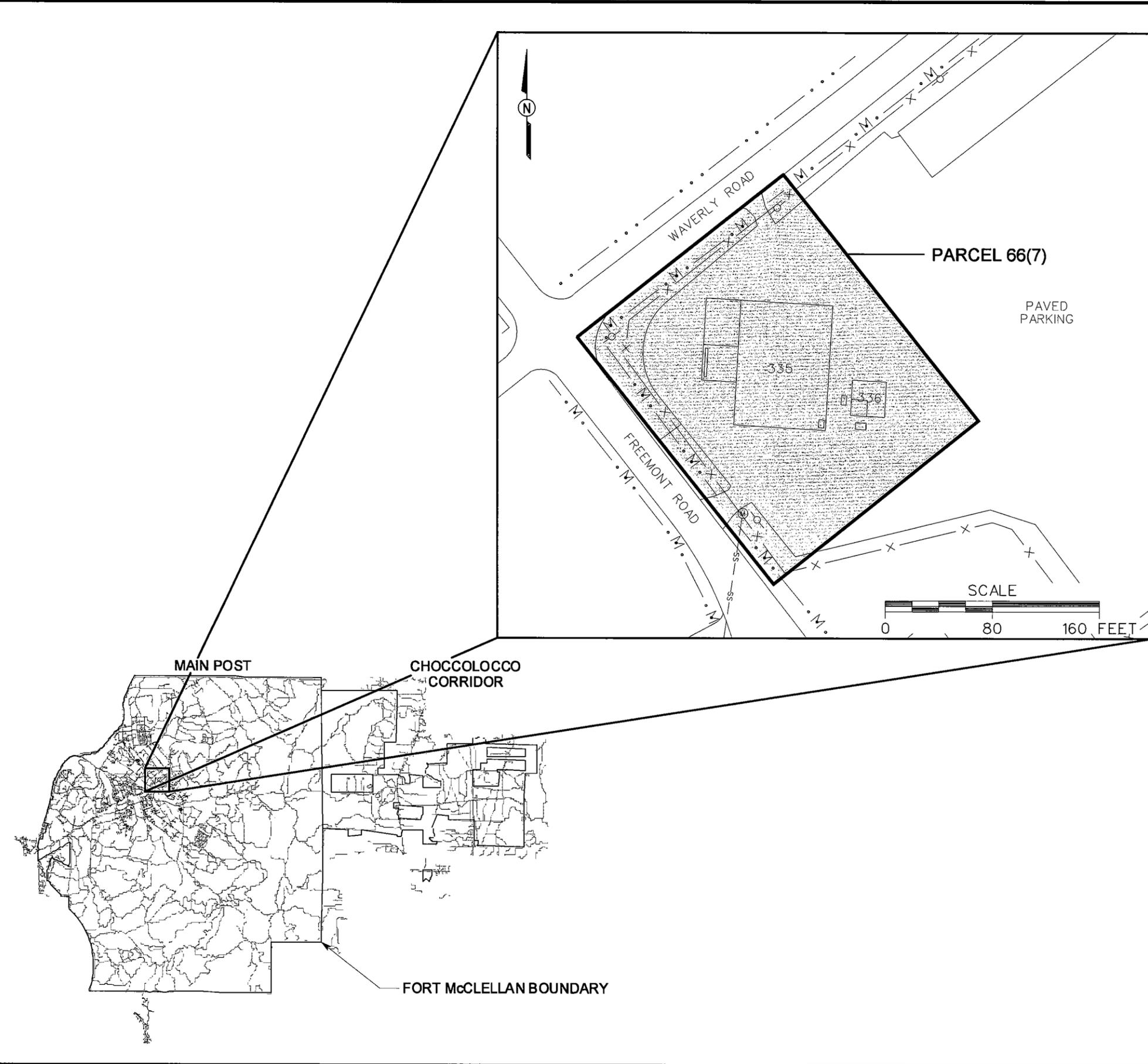
1.0 Introduction

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 Small Weapons Repair Shop, Parcel 66(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 the following five chlorinated volatile organic compounds (VOC) as chemicals of potential concern (COPC) in groundwater at Parcel 66(7): 1,1-dichloroethene (DCE), 1,2-dichloroethane (DCA), cis-1,2-DCE, trichloroethene (TCE), and vinyl chloride (VC). Based on the results of the RI, further investigation of the groundwater contamination at Parcel 66(7) was recommended. In April 2002, additional groundwater samples were collected from select wells at the site and analyzed for VOCs 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 66(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 66(7) is located in the central portion of the Main Post at FTMC at the intersection of Waverly Road and Freemont Road (Figure 1-1). Buildings 335 and 336 are located within the site boundary. In the Small Weapons Repair Shop located in Building 335, weapons brought for repair were degreased with 1,1,1-trichloroethane (TCA) in a vapor degreaser and stripped with a caustic solution (IT, 2002). An alternate description of weapons refinishing activities states that TCE was used for the initial step as a degreasing agent for small weapons parts (FTMC, 1985). According to this alternate description, a 110-gallon vat of heated TCE was used for a 10 to 15 minute period to degrease parts. Typically, the vat contents would be pumped into drums for disposal. However, the potential existed for the contents of the vat to discharge directly to the ground surface outside the building.

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	UNIMPROVED ROADS AND PARKING
	PAVED ROADS AND PARKING
	BUILDING
	PARCEL BOUNDARY
	SURFACE DRAINAGE / CREEK
	MANMADE SURFACE DRAINAGE FEATURE
	FENCE
	UTILITY POLE
	SANITARY SEWER LINE
	MANHOLE

FIGURE 1-1
SITE LOCATION MAP
SMALL WEAPONS REPAIR SHOP
PARCEL 66(7)

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



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 summary, the geologic data collected at Parcel 66(7) show that the upper
4 portion of the residuum consists of brown to brownish gray to yellowish orange silty clay and
5 clay, with occasional intervals of highly weathered shale. This sequence extends from the
6 ground surface to a depth of approximately 10 to 13 feet below ground surface (bgs). Underlying
7 this interval, and included as residuum, is a variable thickness of highly weathered, light gray to
8 black shale that extends to a maximum depth of approximately 30 feet bgs. Underlying the
9 residuum is bedrock consisting of moderately hard, slightly weathered, fractured, dark gray to
10 black shale.

11
12 Groundwater flow across the area appears to be influenced by a topographic high located to the
13 west of the site that has created a local groundwater divide in the vicinity of Parcel 66(7). In the
14 residuum water-bearing zone, the axis of a groundwater divide is located just to the west of
15 Building 335. Groundwater flow in the northern portion of the site is to the north, while
16 groundwater flow in the southwestern part of the parcel is to the south. The groundwater flow in
17 the bedrock water-bearing zone is similar to the groundwater flow regime in the residuum water-
18 bearing zone (IT, 2002).

19
20 The horizontal hydraulic gradients of the residuum and bedrock water-bearing zones are low,
21 indicating a relatively flat water table. The horizontal hydraulic gradients are approximately 0.01
22 feet per foot for both the residuum and the bedrock water-bearing zones. The geometric means
23 of hydraulic conductivity values are 0.07 feet per day (ft/day) for the residuum and 0.09 ft/day
24 for the bedrock. Using estimated porosities of 30 percent for the residuum and 15 percent for the
25 bedrock, the groundwater flow velocities were calculated at approximately 0.0022 ft/day for the
26 residuum and 0.0078 ft/day for the bedrock. These groundwater velocities were used in
27 determining the degradation rates of the COPCs at Parcel 66(7).

2.0 Natural Attenuation

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 (Wiedemeier et al., 1998). The 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.*
- 3) *Data from field or microcosm studies (conducted in or with actual contaminated site media) which directly demonstrate the occurrence of a particular natural*

1 *attenuation process at the site and its ability to degrade the contaminants of*
2 *concern.*
3

4 The first and most direct approach to quantifying the influence of intrinsic biodegradation is the
5 observation of decreased concentrations of target contaminants and increased levels of
6 dechlorinated products over time. Under anaerobic conditions, TCE is reductively dechlorinated,
7 yielding, in succession, cis-1,2-DCE, VC, and finally ethene. Direct observation of this
8 progression of events in groundwater is a strong, positive indicator of intrinsic biodegradation.
9 The second line of evidence involves biologically mediated changes in groundwater chemistry,
10 including concentration reduction in respiratory substrates, concentration increases in respiratory
11 products, and changes in other groundwater parameters such as pH, dissolved chloride, and
12 oxidation-reduction potential (ORP). The third line of evidence comes from microcosm studies
13 where the biodegradability of the chlorinated aliphatic hydrocarbons is demonstrated using actual
14 contaminated site media under conditions that mimic those found in the subsurface at the site.
15 All three lines of evidence were investigated to evaluate the occurrence of natural attenuation at
16 Parcel 66(7).

17

18 **2.2 Anaerobic Reductive Dechlorination**

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

27

28 The human health risk assessment for Parcel 66(7) (IT, 2002) resulted in the selection of the
29 following five chlorinated VOCs as COPCs in groundwater: 1,1-DCE, 1,2-DCA, cis-1,2-DCE,
30 TCE, and VC. The transformation of TCE under anaerobic conditions proceeds by sequential
31 reductive dechlorination to cis-1,2-DCE, VC, and ultimately the innocuous end product ethene.
32 Therefore, the presence of the daughter products cis-1,2-DCE and VC at Parcel 66(7) is likely a
33 result of the reductive dechlorination of TCE. Although not selected as a COPC, 1,1,1-TCA was
34 detected in the residuum water-bearing zone at Parcel 66(7). Abiotic transformation of 1,1,1-
35 TCA results in the formation of the COPC 1,1-DCE and acetic acid (Vogel and McCarty, 1987).
36 Biotic transformation of 1,1,1-TCA under anaerobic conditions results in the formation of 1,1-

1 DCA (detected but not a COPC), which can be further transformed into chloroethane. The
2 COPC 1,2-DCA may be biologically transformed into chloroethane. Once chloroethane is
3 formed, it rapidly degrades abiotically to ethanol. Figure 2-1 presents published pathways for the
4 anaerobic degradation of chlorinated aliphatic compounds including the five COPCs at Parcel
5 66(7).

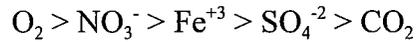
6
7 There is a decreased potential for less-chlorinated aliphatic hydrocarbons to act as electron
8 acceptors and undergo further reductive dechlorination, often resulting in the transient
9 accumulation of DCE and VC. This phenomenon may be due to the increase in Gibb's free
10 energy value of the chlorine-to-carbon bonds as the number of chlorine atoms on the molecule
11 decreases. Thus, more energy may be required to remove the last chlorine atom from a
12 chlorinated ethene than was required for the first. The increased energy requirement would also
13 cause the reaction to be slower. A common observation is that TCE is reductively dechlorinated
14 under relatively mild reducing conditions, whereas DCE and VC require increasingly stronger
15 reducing conditions to be dechlorinated (Mohn and Tiedje, 1992). However, under aerobic and
16 some anaerobic conditions the less-chlorinated aliphatic hydrocarbons like VC can be used as the
17 primary substrate in biologically mediated oxidation-reduction reactions (McCarty and Semprini,
18 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon
19 from the degraded chlorinated aliphatic hydrocarbon.

20
21 Because 1,2-DCE is a common solvent and may have been spilled along with TCE, determining
22 that the DCE is derived from reductive dechlorination can be a critical factor supporting the
23 occurrence of natural attenuation. Solvent manufacturing processes yield approximately the
24 same amounts of cis-1,2-DCE and trans-1,2-DCE, which may then be fractionated by distillation
25 (Biomedical and Environmental Information Analysis, 1989; Mertens, 1993). However,
26 microbial dechlorination usually yields 10 to 100 times more of the cis- isomer than the trans-
27 isomer (Bouwer, 1994; Wiedemeier et al., 1998; Fiorenza et al., 1994). The microbiological
28 preference for producing cis-1,2-DCE may have to do with steric hindrances or enzyme active
29 site configurations that favor removal of the chlorine atom located in the trans- position relative
30 to the chlorine on the other carbon atom of TCE.

31 32 **2.3 Geomicrobiology**

33 Biological monitoring parameters are indicators of microbiological activity in the subsurface.
34 Microbial respiration is the biochemical process that leads to the oxidation of reduced organic
35 carbon. Actively respiring microorganisms alter their environment. The effects of microbial
36 respiration are observed in situ by comparing the concentrations of respiratory substrates within

1 and outside the contaminated area. Frequently encountered respiratory substrates include oxygen
2 (O_2), nitrate (NO_3^-), ferric iron (Fe^{+3}), sulfate (SO_4^{-2}), and carbon dioxide (CO_2). Respiratory
3 substrates are used preferentially based on the amount of energy that can be derived from each of
4 them. Respiratory substrates are used in the following order:



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

23 As discussed above, intrinsic biodegradation results in changes in the concentrations of microbial
24 respiratory substrates and products. Expected changes in aerobic aquifers include depressed
25 concentrations of DO and a change in ORP from positive to negative values within and
26 downgradient of the contaminated plume. Anaerobic respiratory substrates, such as nitrate and
27 sulfate, should trend toward lower concentrations in groundwater located within and
28 downgradient of the contaminated plume. Similarly, increases in the concentrations of the
29 products of anaerobic respiration, Fe^{+2} and methane, are often apparent.

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

35 The reductive dechlorination of chlorinated solvents releases chloride into groundwater. In areas
36 where the groundwater has a very low background chloride concentration, an elevation in

1 chloride concentration may be observed as a result of reductive dechlorination. However, in
2 most cases the slight contribution of chloride to groundwater through reductive dechlorination
3 will not be obvious.

3.0 Natural Attenuation Evaluation Methods

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 66(7). In addition, microcosms were established using site soil and groundwater to monitor the degradation of the COPCs under controlled laboratory conditions.

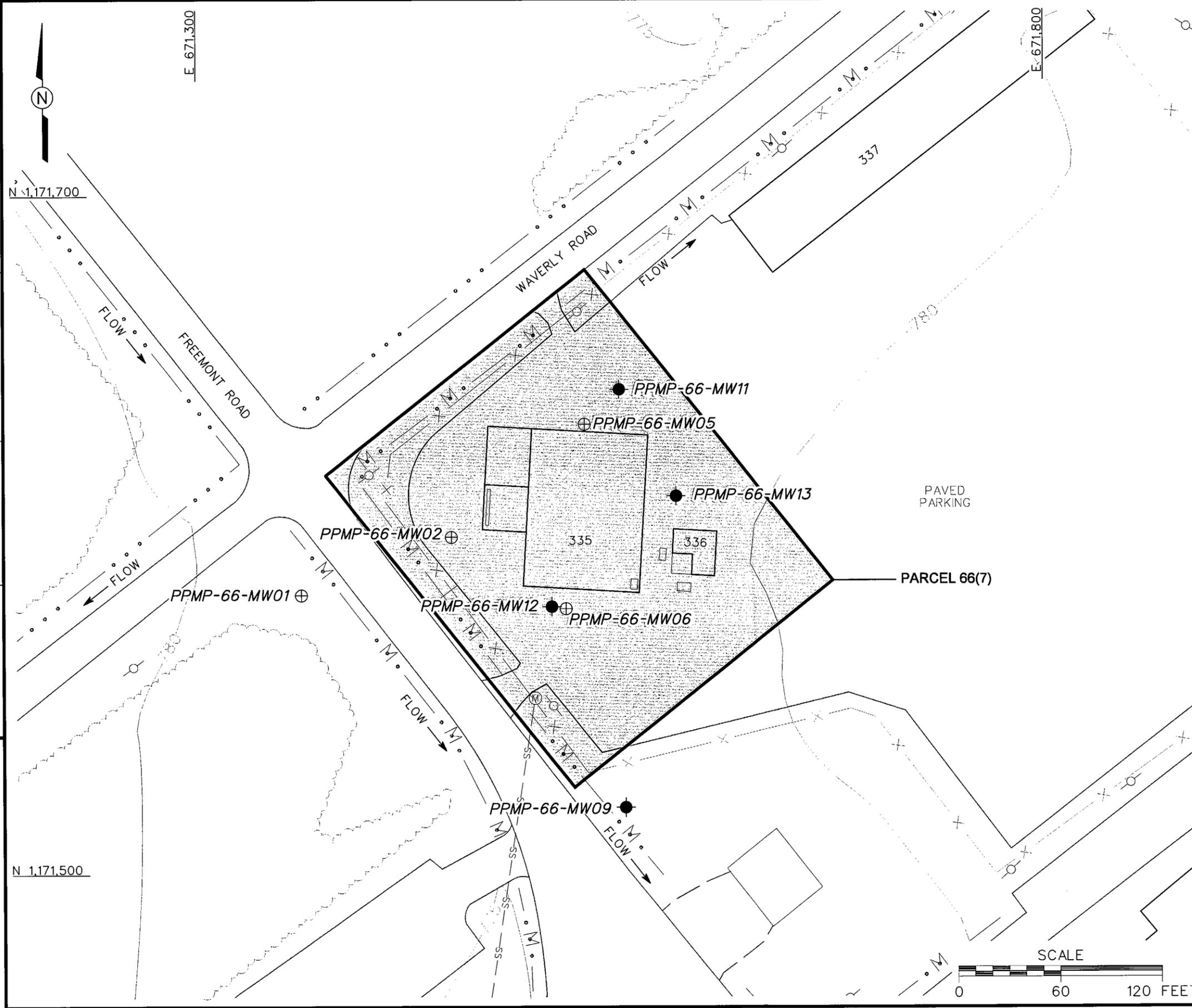
In April 2002, groundwater samples were collected from several monitoring wells at Parcel 66(7). The following four monitoring wells screened in the residuum water-bearing zone were sampled: PPMP-66-MW01, PPMP-66-MW02, PPMP-66-MW05, and PPMP-66-MW06. Data obtained from PPMP-66-MW01 were used as background values, since the well is not impacted with VOCs and is located upgradient of the contaminant plume. To evaluate the occurrence of natural attenuation in the bedrock water-bearing zone at Parcel 66(7), the following four monitoring wells were sampled: PPMP-66-MW09, PPMP-66-MW11, PPMP-66-MW12, and PPMP-66-MW13. Data obtained from PPMP-66-MW09 were used as background values, since the well is not impacted with VOCs and is located cross-gradient of the contaminant plume. The locations of the monitoring wells sampled for evidence of natural attenuation is presented in Figure 3-1. The following sections describe the analytical and data evaluation methods used in evaluating natural attenuation at Parcel 66(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⁺²
- ORP
- pH
- Conductivity
- Temperature
- DO
- Turbidity.

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- LEGEND**
- UNIMPROVED ROADS AND PARKING
 - PAVED ROADS AND PARKING
 - BUILDING
 - TOPOGRAPHIC CONTOURS (CONTOUR INTERVAL - 5 FOOT)
 - TREES / TREELINE
 - PARCEL BOUNDARY
 - CULVERT WITH HEADWALL
 - SURFACE DRAINAGE / CREEK
 - MANMADE SURFACE DRAINAGE FEATURE
 - FLOW SURFACE WATER FLOW DIRECTION
 - FENCE
 - UTILITY POLE
 - SANITARY SEWER LINE
 - MANHOLE
 - BEDROCK MONITORING WELL AND GROUNDWATER SAMPLE LOCATION
 - RESIDUUM MONITORING WELL AND GROUNDWATER SAMPLE LOCATION
 - GROUNDWATER, SURFACE AND SUBSURFACE SOIL SAMPLE LOCATION

NOTE:

1. THE WELLS SHOWN ON THIS FIGURE WERE SAMPLED IN APRIL 2002 FOR VOCs AND NATURAL ATTENUATION PARAMETERS.

FIGURE 3-1
SAMPLE LOCATION MAP
SMALL WEAPONS REPAIR SHOP
PARCEL 66(7)

U. S. ARMY CORPS OF ENGINEERS
 MOBILE DISTRICT
 FORT McCLELLAN
 CALHOUN COUNTY, ALABAMA
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Table 3-1

**Groundwater Analytical Methods
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Parameter	Method
Field Measurements	
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
Fixed Laboratory Measurements (including microcosm analysis)	
VOCs	SW-846, Method 8021
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)
Ammonia Nitrogen	Standard Methods for the Analysis of Water and Wastewater, 18th Ed. 4500-NH ₃ F
Phosphate	Standard Methods for Analysis of Water and Wastewater; 18th Ed 4500-P E or EPA Method 300

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 gas)
- 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 PPMP-66-MW06 and two kilograms of soil from a soil boring near PPMP-66-
18 MW06 were collected for the microcosms setup. The groundwater and soil samples were
19 composited separately to achieve a homogeneous mixture for each. Ten-gram (g) aliquots of
20 composited soil were placed in 40 milliliter (mL) volatile organic analysis vials. The vials were
21 then filled with composited groundwater, leaving no headspace. Fifteen microcosms were
22 established to allow for triplicate analysis over five time points. Fifteen additional microcosms
23 were established and stored in a refrigerator set at 4 degrees Celsius to inhibit microbial activity.

24 The inhibited microcosms served as controls for the experiment to account for losses of
25 contaminants due to laboratory procedures and sample handling activities. Both sets of
26 microcosms were analyzed concurrently using the same methods. The time points for analysis
27 (baseline, 2 weeks, 4 weeks, 8 weeks, and 12 weeks) were selected to track the activity in the
28 microcosms and determine if biodegradation was reducing the contaminant levels over the
29 duration of the incubation. Three microcosms from each treatment were sacrificed at each time
30 point, and the aqueous phase was analyzed for VOCs, DO, pH, ammonia, phosphate, TOC,
31 nitrate, nitrite, sulfate, chloride, methane, ethane, and ethene. The methods used for the analyses
32 are listed in Table 3-1.

33
34 As part of a treatability study, other microcosms were established using Parcel 66(7) soil and
35 groundwater to evaluate the enhanced biodegradation of the COPCs in the presence of various
36 organic carbon sources. A description of the results of the treatability study is beyond the scope

1 of the natural attenuation evaluation and will be presented separately in a treatability study
2 report.

3 4 **3.3 Data Evaluation Procedures**

5 The data produced from the various analytical methods were evaluated for trends that indicate
6 intrinsic bioremediation via reductive dechlorination. In addition, attenuation and
7 biodegradation rate constants were calculated using the equation of Buscheck and Alcantar
8 (1995). Chlorinated compound concentrations were first evaluated as a function of distance
9 migrated using a first-order decay equation of the form:

$$10 \qquad C_d = C_o e^{-kd}$$

11
12
13 where:

C_d - the chlorinated compound concentration at distance "d"

C_o - the initial chlorinated compound concentration at
distance "zero"

d - distance between the initial sampling point (distance "zero")
and the downgradient sampling point (ft)

k - attenuation rate constant (per foot)

14
15
16
17
18
19
20 The Buscheck and Alcantar analysis applies the one-dimensional steady-state analytical solution
21 for the advection-dispersion equation presented by Bear (1979) to the rate of change per distance
22 migrated. This part of the analysis adjusts the concentration change per distance migrated to
23 accommodate dispersion, advection, and sorption. The biodegradation rate constants were
24 calculated using the following equation:

$$25 \qquad \lambda = (v_c/4\alpha_x)([1+2\alpha_x(k/v_x)]^2 - 1)$$

26
27
28 where:

λ - biodegradation rate constant (per year)

v_c - contaminant velocity (ft/year)

v_x - linear groundwater velocity (ft/year)

α_x - longitudinal dispersivity (ft)

k - attenuation rate constant (per foot)

29
30
31
32
33
34 The plume was assumed to be at steady state. The analytical solution includes advection,
35 dispersion, sorption, and decay. The longitudinal dispersivity, α_x , was assumed to be 5 percent
36 of the flow field. The flow field is the distance separating the two furthest wells in the flow

1 vector. The distribution coefficients were calculated using the following equation, assuming 0.1
2 percent fraction organic carbon, f_{oc} , in the aquifer soil matrix and values for the organic carbon
3 partitioning coefficients, K_{oc} , from the scientific literature. With these f_{oc} and K_{oc} values, the soil-
4 water distribution coefficients, K_d , for the chlorinated aliphatic hydrocarbons were calculated
5 using the following equation:

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

6
7
8
9 The retardation factor (R) for each chlorinated aliphatic hydrocarbon was calculated using the
10 following equation:

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

11
12
13
14 where: R - retardation factor
15 ρ_b - soil bulk density
16 K_d - soil-water distribution coefficient
17 n - porosity
18

19 The contaminant velocities were calculated using the following equation:

$$v_c = v_x / R$$

20
21
22
23 A biodegradation half-life was calculated for each chemical by the following equation:

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

24
25
26
27 where: $t_{1/2}$ - half-life (years)
28 λ - 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 reductive dechlorination of chlorinated solvents. The combined evidence generated from several different aspects of this evaluation was evaluated for the occurrence of natural attenuation by the process of reductive dechlorination in the residuum and bedrock water-bearing zones beneath Parcel 66(7). 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. The following four wells were sampled in the residuum water-bearing zone: PPMP-66-MW01, PPMP-66-MW02, PPMP-66-MW05, and PPMP-66-MW06 (Figure 3-1). TCE was detected in PPMP-66-MW06 and PPMP-66-MW02 at concentrations of 14,000 micrograms per liter ($\mu\text{g/L}$) and 24 $\mu\text{g/L}$, respectively, both of which exceed the maximum contaminant level (MCL) of 5 $\mu\text{g/L}$. The TCE concentration detected in PPMP-66-MW06 is the highest concentration on site and constitutes the hot spot of the plume. The TCE reductive dechlorination daughter product, cis-1,2-DCE, was detected in PPMP-66-MW06 and PPMP-66-MW02 at concentrations of 720 $\mu\text{g/L}$ and 8.8 $\mu\text{g/L}$, respectively. The cis-1,2-DCE concentration in PPMP-66-MW06 exceeded its MCL of 70 $\mu\text{g/L}$. 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 also detected in PPMP-66-MW06 and PPMP-66-MW02. The concentrations of VC were 3.5 $\mu\text{g/L}$ in PPMP-66-MW06 and 67 $\mu\text{g/L}$ in PPMP-66-MW02, both of which exceeded the MCL of 2 $\mu\text{g/L}$. The collocation of the cis-1,2-DCE and VC detections is evidence that reductive dechlorination has occurred at the site. Ethene, the desired end product of the reductive dechlorination of TCE, was detected in PPMP-66-MW02 at a

Table 4-1

**Analytical Summary of VOC Results
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

(Page 1 of 2)

LOCATION_CODE			PPMP-66-MW01		PPMP-66-MW02		PPMP-66-MW05		PPMP-66-MW06	
SAMPLE_NO			ZC3010		ZC3011		ZC3012		ZC3013	
SAMPLE_DATE			4/11/02		4/24/02		4/22/02		4/25/02	
START_DEPTH			9		9		9.3		8.5	
END_DEPTH			24		24		29.3		28.5	
Chemical	Units	MCL	Result	Qual	Result	Qual	Result	Qual	Result	Qual
1,1,1-Trichloroethane	ug/L	200	1	U	5	U	1	U	50	J
1,1-Dichloroethane	ug/L	-	1	U	4.1	J	1	U	110	
1,1-Dichloroethene	ug/L	7	1	U	9.1		1	U	360	
1,2-Dichloroethane	ug/L	5	1	U	5	U	1	U	0.86	J
Chloroethane	ug/L	-	1	U	3.9	J	1	U	1	U
cis-1,2-Dichloroethene	ug/L	70	1	U	8.8		1	U	720	
Methylene chloride	ug/L	5	2	U	10	U	0.58	J	2	U
Toluene	ug/L	1000	1	U	5	U	1	U	4	
trans-1,2-Dichloroethene	ug/L	100	1	U	5.7		1	U	31	
Trichloroethene	ug/L	5	1	U	24		1	U	14000	
Vinyl chloride	ug/L	2	1	U	67		1	U	3.5	
Ethene	ug/L	-	1	U	37		1	U	1	

Table 4-1

**Analytical Summary of VOC Results
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

(Page 2 of 2)

LOCATION_CODE			PPMP-66-MW09		PPMP-66-MW11		PPMP-66-MW12		PPMP-66-MW13	
SAMPLE_NO			ZC3014		ZC3015		ZC3016		ZC3017	
SAMPLE_DATE			4/15/02		4/17/02		4/26/02		4/24/02	
START_DEPTH			52		63		64.2		61.6	
END_DEPTH			72		83		74.2		71.6	
Chemical	Units	MCL	Result	Qual	Result	Qual	Result	Qual	Result	Qual
1,1,1-Trichloroethane	ug/L	200	1	U	1	U	1	U	1	U
1,1-Dichloroethane	ug/L	-	1	U	1	U	1	U	1	U
1,1-Dichloroethene	ug/L	7	1	U	1	U	1	U	1	U
1,2-Dichloroethane	ug/L	5	1	U	1	U	1	U	1	U
Chloroethane	ug/L	-	1	U	1	U	1	U	1	U
cis-1,2-Dichloroethene	ug/L	70	1	U	1	U	1	U	1	U
Methylene chloride	ug/L	5	2	U	0.55	J	0.28	J	2	U
Toluene	ug/L	1000	1	U	0.46	J	1	U	1	U
trans-1,2-Dichloroethene	ug/L	100	1	U	1	U	1	U	1	U
Trichloroethene	ug/L	5	1	U	1	U	1	U	1	U
Vinyl chloride	ug/L	2	1	U	1	U	1	U	1	U
Ethene	ug/L	-	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

Residuum Wells - MW-01, MW-02, MW-05, and MW-06

Bedrock Wells - MW-09, MW-11, MW-12, and MW-13

1 concentration of 37 µg/L. Ethane, the degradation product of ethene, was detected in PPMP-66-
2 MW02 and PPMP-66-MW06 at a concentration of 2 µg/L in each well. The detection of ethene
3 and ethane is evidence of the complete reductive dechlorination of TCE.
4

5 The chlorinated compound 1,1-DCE, an abiotic degradation product of 1,1,1-TCA, was detected
6 at 360 µg/L in PPMP-66-MW06 and 9.1 µg/L in PPMP-66-MW02. Both concentrations
7 exceeded the 1,1-DCE MCL of 7 µg/L. 1,1-DCE further degrades to VC through reductive
8 dechlorination. The groundwater samples with a detection of 1,1-DCE also contained VC.
9 However, since both cis-1,2-DCE and 1,1-DCE degrade to VC, the VC formed as a result of 1,1-
10 DCE degradation versus that formed from the degradation of cis-1,2-DCE could not be
11 distinguished. The remaining chlorinated aliphatic hydrocarbons in the residuum water-bearing
12 zone, 1,1,1-TCA, 1,1-DCA, 1,2-DCA, methylene chloride, and trans-1,2-DCE, were detected at
13 concentrations below their respective MCLs and were not identified in the risk assessment as
14 COPCs.
15

16 Although the VOC results indicate that reductive dechlorination has occurred, the concentration
17 of TCE in PPMP-66-MW06 remains five orders of magnitude greater than the MCL. Due to the
18 lack of historical VOC data, it is not possible to determine if the concentrations of TCE and its
19 degradation products are increasing or decreasing in the residuum water-bearing zone near the
20 plume hot spot. Therefore, in accordance with the protocol of the U.S. Environmental Protection
21 Agency (EPA) for evaluating natural attenuation of chlorinated solvents in groundwater
22 (Wiedemeier et al., 1998), the second and third lines of evidence listed in Section 2.1 were
23 evaluated to demonstrate the efficacy of natural attenuation at Parcel 66(7).
24

25 **4.1.2 Bedrock Water-Bearing Zone**

26 A summary of the VOC analytical data obtained from groundwater samples collected during the
27 April 2002 sampling event is presented in Table 4-1. The following four wells were sampled in
28 the bedrock water-bearing zone: PPMP-66-MW09, PPMP-66-MW11, PPMP-66-MW12, and
29 PPMP-66-MW13. With the exception of estimated detections for methylene chloride and
30 toluene, no other VOCs were detected in the bedrock water-bearing zone. The bedrock VOC
31 data suggest that chlorinated solvents present in the residuum have not migrated downward into
32 the bedrock. The semi-confining conditions observed between the residuum and the bedrock
33 during the RI activities support this conclusion (IT, 2002). The only historical detection of
34 chlorinated aliphatic hydrocarbons in the bedrock water-bearing zone was an estimated TCE
35 concentration of 2.3 µg/L detected in PPMP-66-MW13 during the March 2001 RI sampling

1 event (IT, 2002). The lack of TCE in PPMP-66-MW13 during the April 2002 sampling event
2 suggests that either TCE degraded or the 2001 result was an analytical anomaly. No
3 dechlorination products were detected in PPMP-66-MW13 nor in any other monitoring wells
4 screened in the bedrock water-bearing zone.

6 **4.1.3 *cis-* to Total 1,2-DCE Ratio**

7 Biologically mediated reductive dechlorination of TCE favors the formation of *cis*-1,2-DCE to
8 such an extent that less than 20 percent of the total 1,2-DCE will be *trans*-1,2-DCE. The ratio of
9 *cis-* to total 1,2-DCE was calculated for each sampled residuum monitoring well, as presented in
10 Table 4-2. Of the two locations where 1,2-DCE was detected, *cis*-1,2-DCE accounted for 61
11 percent of the total 1,2-DCE in PPMP-66-MW02 and 96 percent in PPMP-66-MW06. These
12 results strongly suggest that the presence of *cis*-1,2-DCE and *trans*-1,2-DCE in the residuum
13 water-bearing zone at Parcel 66(7) is due to the reductive dechlorination of TCE.

15 **4.1.4 *Attenuation and Biodegradation Rates***

16 Attenuation and biodegradation rate constants were calculated for TCE, *cis*-1,2-DCE, and 1,1-
17 DCE using concentrations detected in monitoring wells screened in the residuum water-bearing
18 zone along a downgradient flowpath. The flow vector that most closely matches groundwater
19 flow direction and represents the plume migration includes PPMP-66-MW06, PPMP-66-MW02,
20 and PPMP-66-MW15. Due to the groundwater divide in the residuum water-bearing zone, the
21 selected flow vector deviates slightly from the direction of observed groundwater flow. The
22 horizontal groundwater flow velocity in the residuum water-bearing zone was calculated at
23 0.0022 ft/day, which corresponds to 0.85 ft per year. The calculation of degradation rate
24 constants was not performed for the bedrock water-bearing zone, due to the lack of
25 contamination.

26
27 The attenuation and biodegradation rate constants for TCE, *cis*-1,2-DCE, and 1,1-DCE are
28 presented in Figures 4-1, 4-2, and 4-3, respectively. The calculated attenuation half-life for TCE
29 is 9.7 years, with a biodegradation half-life of 10.4 years. Biodegradation or mechanisms other
30 than dispersion and adsorption accounted for approximately 94 percent of the total TCE
31 attenuation. The calculated biodegradation half-life for TCE is very slow compared to values
32 reported in scientific literature. The biodegradation half-lives for *cis*-1,2-DCE and 1,1-DCE are
33 15.2 and 17.6 years, respectively. The site-specific biodegradation half-lives for the DCE
34 compounds are longer than the half-life of TCE because more highly chlorinated compounds
35 degrade more rapidly under anaerobic conditions (Wiedemeier et al., 1998). Using the site-
36 specific attenuation rates the estimated cleanup time was calculated assuming first-order

Table 4-2

**Cis-1,2-DCE to Total 1,2-DCE Ratio
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

LOCATION_CODE		PPMP-66-MW01		PPMP-66-MW02		PPMP-66-MW05		PPMP-66-MW06	
SAMPLE_NO		ZC3010		ZC3011		ZC3012		ZC3013	
SAMPLE_DATE		4/11/02		4/24/02		4/22/02		4/25/02	
START_DEPTH		9		9		9.3		8.5	
END_DEPTH		24		24		29.3		28.5	
Chemical	Units	Result	Qual	Result	Qual	Result	Qual	Result	Qual
cis-1,2-DCE	ug/L	1	U	8.8		1	U	720	
trans-1,2-DCE	ug/L	1	U	5.7		1	U	31	
Total 1,2-DCE	ug/L	1	U	14.5		1	U	751	
Ratio of cis-1,2-DCE to Total 1,2-DCE	%	NA		61%		NA		96%	

Qual - Laboratory qualifier

ug/L - micrograms per liter

% - percent

U - Analyte was not detected or below method detection limits

Figure 4-1

TCE Attenuation and Biodegradation Rate Calculations
Small Weapons Repair Shop, Parcel 66(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.

Residuum	Slope of exponential regression versus distance (k/v_x)		
MW Location	PPMP-66-MW06	PPMP-66-MW02	PPMP-66-MW15
Feet Downgradient	0.0	80	113
Concentration (ug/L)	14000	24	1
Hydraulic Conductivity	0.07 ft/day		
Groundwater Gradient	0.01 ft/ft		
Porosity	0.3 porosity		
Average groundwater velocity, v_x =	0.002 ft/day 0.85 ft/year		

Slope R^2
 -0.0839 0.9977

TCE	
λ =	$(v_x/4\alpha_x) ([1+2\alpha_x(k/v_x)]^2 - 1)$
α_x =	5 % of flow field (distance separating two furthest wells) 5.625 ft
f_{oc} =	0.001
K_{oc} =	107 L/kg
K_d =	$K_{oc}f_{oc}$ 0.107 L/kg
ρ_b =	1.6 kg/L
n =	0.3
R =	$1 + (\rho_b K_d/n)$ 1.571
v_c =	v_x/R 0.5422 ft/year

Intrinsic Biodegradation	
$(v_x/4\alpha_x)$ =	0.0241 /yr
(k/v_x) =	0.0839 /ft
$[1+2\alpha_x(k/v_x)]$	1.9439
λ =	0.0670 /year
Half-life	10.4 years

Natural Attenuation	
k =	0.0715 /year
half-life =	9.70 years
λ/k =	94%

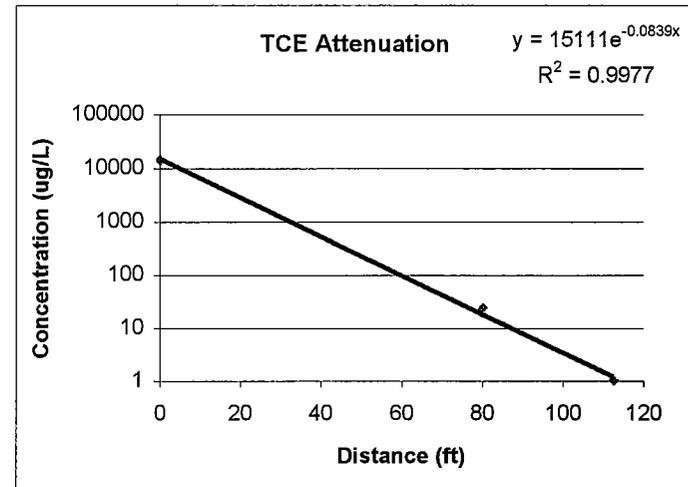


Figure 4-2

**Cis-1,2-DCE Attenuation and Biodegradation Rate Calculations
Small Weapons Repair Shop, Parcel 66(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.

Residuum Slope of exponential regression versus distance (k/v_x)

MW Location	PPMP-66-MW06	PPMP-66-MW02	PPMP-66-MW15
Feet Downgradient	0.0	80	113
Concentration (ug/L)	720	8.8	1

Slope	R ²
-0.0578	0.9979

Hydraulic Conductivity	0.07 ft/day
Groundwater Gradient	0.01 ft/ft
Porosity	0.3 porosity
Average groundwater velocity, v_x =	0.002 ft/day 0.85 ft/year

cis-1,2-DCE

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

α_x = 5 % of flow field (distance separating two furthest wells)
5.625 ft

f_{oc} = 0.001

K_{oc} = 80 L/kg

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

0.08 L/kg

ρ_b = 1.6 kg/L

n = 0.3

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

1.427

$v_c = v_x/R$

0.5970 ft/year

Intrinsic Biodegradation

$(v_x/4\alpha_x) = 0.0265$ /yr

$(k/v_x) = 0.0578$ /ft

$[1+2\alpha_x(k/v_x)] = 1.6503$

$\lambda = 0.0457$ /year

Half-life = 15.2 years

Natural Attenuation

$k = 0.0492$ /year

half-life = 14.08 years

$\lambda/k = 93\%$

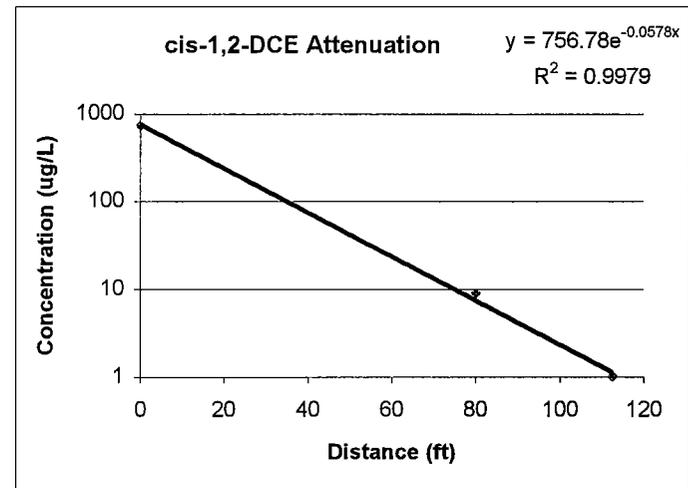


Figure 4-3

**1,1-DCE Attenuation and Biodegradation Rate Calculations
Small Weapons Repair Shop, Parcel 66(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.

Residuum	Slope of exponential regression versus distance (k/v_x)		
MW Location	PPMP-66-MW06	PPMP-66-MW02	PPMP-66-MW15
Feet Downgradient	0.0	80	113
Concentration (ug/L)	360	9.1	1
Hydraulic Conductivity	0.07 ft/day		
Groundwater Gradient	0.01 ft/ft		
Porosity	0.3 porosity		
Average groundwater velocity, v_x =	0.002 ft/day		
	0.85 ft/year		

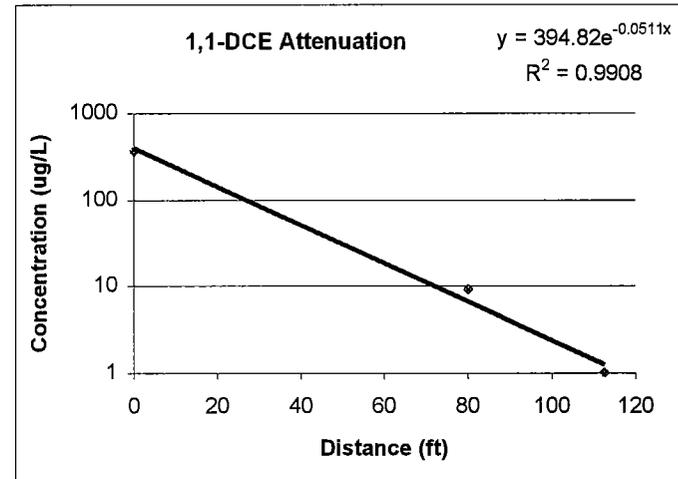
Slope R^2
-0.0511 0.9908

1,1-DCE

λ =	$(v_x/4\alpha_x) ([1+2\alpha_x(k/v_x)]^2 - 1)$
α_x =	5 % of flow field (distance separating two furthest wells) 5.625 ft
f_{oc} =	0.001
K_{oc} =	80 L/kg
K_d =	$K_{oc}f_{oc}$ 0.08 L/kg
ρ_b =	1.6 kg/L
n =	0.3
R =	$1 + (\rho_b K_d/n)$ 1.427
v_c =	v_x/R 0.5970 ft/year

Intrinsic Biodegradation	
$(v_x/4\alpha_x)$ =	0.0265 /yr
(k/v_x) =	0.0511 /ft
$[1+2\alpha_x(k/v_x)]$	1.5749
λ =	0.0393 /year
Half-life	17.6 years

Natural Attenuation	
k =	0.0435 /year
half-life =	15.93 years
λ/k =	90%



1 degradation kinetics. Table 4-3 summarizes the attenuation and biodegradation rate constants
2 and estimates the cleanup time calculated from those rates. The estimated cleanup time using
3 natural attenuation as the remedial alternative would be in excess of 100 years. The actual
4 cleanup time would be longer, due to the formation of VC as a daughter product of TCE, cis-1,2-
5 DCE, and 1,1-DCE reductive dechlorination. In addition, the attenuation rates may decrease
6 with time due to changes in geochemical and microbiological conditions at the site. For
7 example, the complete consumption of bioavailable natural organic carbon would decrease the
8 biodegradation rates because reductive dechlorination does not occur without the presence of a
9 carbon and energy source. Therefore, monitored natural attenuation would not achieve the
10 groundwater MCLs in a reasonable time frame.

11 **4.2 Second Line of Evidence: Changes in Groundwater Geochemical Parameters**

12 Groundwater geochemical parameters were analyzed in groundwater samples collected during
13 the April 2002 sampling event. A summary of analytical data obtained from the field
14 measurements are provided in Table 4-4, and analytical data obtained from the laboratory
15 measurements are provided in Table 4-5. The geochemical data sets obtained from PPMP-66-
16 MW01 and PPMP-66-MW09 were used as background sets for the residuum and bedrock water-
17 bearing zones, respectively. PPMP-66-MW01 was selected as the background well for the
18 residuum water-bearing zone because it is not impacted with chlorinated solvents and is located
19 upgradient of the contaminated groundwater (Figure 3-1). For the bedrock water-bearing zone,
20 PPMP-66-MW09 was used as the background well since it is not impacted with chlorinated
21 solvents and is located hydraulically cross-gradient of the contaminated groundwater in the
22 residuum water-bearing zone (Figure 3-1). The effects of microbial respiration are observed in
23 situ by comparing the concentrations of respiratory substrates within the contaminated area with
24 the concentrations in the background wells. To avoid confusing the results from the residuum
25 with those from the bedrock, the discussion of changes in geochemical parameters is presented
26 separately for each water-bearing zone.

27 **4.2.1 Residuum Water-Bearing Zone**

28
29 As discussed in Section 2.1, respiratory substrates are used preferentially based on the amount of
30 energy that can be derived from each of them. Respiratory substrates are used in the following
31 order:
32

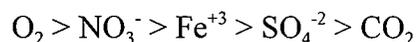


Table 4-3

**Monitored Natural Attenuation Cleanup Time Estimates
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Clahoun County, Alabama**

Chemical	Biodegradation Rate Constant (year ⁻¹)	Biodegradation Half-life (years)	Attenuation Rate Constant (year ⁻¹)	Attenuation Half-life (years)	Percentage of Biodegradation (%)	Maximum Concentration (ug/L)	MCL (ug/L)	Estimated Cleanup Time (years)
TCE	0.067	10.4	0.071	9.7	94%	14000	5	111
cis-1,2-DCE	0.046	15.2	0.049	14.1	93%	720	70	47
1,1-DCE	0.039	17.6	0.044	15.9	90%	360	7	91

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 site-specific attenuation rate, and first order degradation kinetics.
- 2) The actual cleanup time would be higher due to the formation of vinyl chloride as a daughter product of TCE, cis-1,2-DCE, and 1,1-DCE.
- 3) The attenuation rates may decrease with time due to changes in geochemical and microbiological conditions at the site. For example, the complete consumption of bioavailable natural organic carbon would decrease the biodegradation rates because reductive dechlorination does not occur without the presence of a carbon and energy source.

Table 4-4

**Natural Attenuation Parameters - Field Measurements
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Monitoring Well	DO mg/L	ORP mV	pH S.U.	Temperature C	Fe⁺² mg/L	Conductivity mS/cm	Turbidity NTU
Residuum							
PPMP-66-MW01 ^a	0.46	38	6.96	15.7	0.38	3.5	1.14
PPMP-66-MW02	0.0	-71	7.13	21.7	1.13	2.15	1.13
PPMP-66-MW05	0.41	-94	7.39	16.9	0.5	0.724	0.7
PPMP-66-MW06	0.0	-131	7.42	22.3	0.36	0.837	0.99
Bedrock							
PPMP-66-MW09 ^b	1.76	-42	7.14	24.8	1.52	2.7	1.1
PPMP-66-MW11	5.6	184	7.1	21.9	0.05	2.26	18.7
PPMP-66-MW12	0.95	-84	7.19	17.4	0.68	2.48	6.7
PPMP-66-MW13	2.86	-51	7.07	25.6	0.62	2.75	1.8

DO - dissolved oxygen
 ORP - oxidation-reduction potential
 S.U. - Standard Units
 C - degrees celsius
 Fe⁺² - ferrous iron
 mg/L - milligrams per liter
 mV - milliVolts
 mS/cm - milliSiemens per centimeter
 NTU - Nephelometric Turbidity Units

Notes:

^a PPMP-66-MW01 screened in the residuum was selected as a background well because it is not impacted with chlorinated solvents and is located cross-gradient of the contaminated groundwater.

^b PPMP-66-MW09 screened in the bedrock aquifer was selected as a background well because it is not impacted with chlorinated solvents and is located upgradient of the contaminated groundwater.

Table 4-5

**Natural Attenuation Parameters - Laboratory Measurements
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Sample Number	Monitoring Well	TOC mg/L	pH S.U.	Alkalinity mg CaCO ₃ /L	Chloride mg/L	Nitrite mg/L	Nitrate mg/L	Sulfate mg/L	Methane mg/L	Ethene mg/L	Ethane mg/L
Residuum											
ZC3010	PPMP-66-MW01 ^a	1.0U	6.7	355	30	0.5U	0.5U	1700	0.008	0.001U	0.001U
ZC3011	PPMP-66-MW02	1.0U	6.3	453	31	0.5U	0.5U	630	0.026	0.037	0.002
ZC3012	PPMP-66-MW05	1.0U	6.8	345	35	0.5U	0.5U	82	0.025	0.001U	0.001U
ZC3013	PPMP-66-MW06	1.0U	6.8	345	7.8	0.5U	0.5U	150	0.485	0.001	0.002
Bedrock											
ZC3014	PPMP-66-MW09 ^b	1.0U	6.8	358	30	0.5U	0.5U	1100	0.005	0.001U	0.001U
ZC3015	PPMP-66-MW11	1.0U	7.0	235	36	0.5U	0.5U	990	0.008	0.001U	0.001U
ZC3016	PPMP-66-MW12	1.0U	6.9	265	44	0.5U	0.5U	2700	0.018	0.001U	0.001U
ZC3017	PPMP-66-MW13	1.0U	6.8	315	51	0.5U	0.5U	1600	0.008	0.001U	0.001U

TOC - Total Organic Carbon

S.U. - Standard Units

mg CaCO₃/L - milligrams calcium carbonate per liter

mg/L - milligram per liter

U - Analyte was not detected or below method detection limits

Notes:

^a PPMP-66-MW01 screened in the residuum was selected as a background well because it is not impacted with chlorinated solvents and is located cross-gradient of the contaminated groundwater.

^b PPMP-66-MW09 screened in the bedrock aquifer was selected as a background well because it is not impacted with chlorinated solvents and is located upgradient of the contaminated groundwater.

1 The following discussion evaluates the respiratory processes that have occurred or are currently
2 occurring in the residuum water-bearing zone beneath Parcel 66(7) and relates the findings to the
3 occurrence of reductive dechlorination.

4
5 The preferred terminal electron acceptor during microbial respiration is O_2 . The DO
6 concentration was measured in the field using a low-flow method to minimize aeration of the
7 groundwater sample. The DO results in the residuum monitoring wells ranged from 0.0
8 (nondetect) to 0.41 milligrams per liter (mg/L), with a background concentration of 0.46 mg/L in
9 PPMP-66-MW01 (Table 4-4). These DO results indicate that anaerobic conditions prevail in the
10 residuum water-bearing zone. The lowest DO readings (nondetect) were obtained in PPMP-66-
11 MW02 and PPMP-66-MW-06, which are both impacted with chlorinated solvents, indicating
12 that the DO has been completely depleted in the areas with contamination. The ORP ranged
13 from -71 to -131 millivolts (mV), with a background value of +38 mV (Table 4-4). The lower
14 ORP readings in the impacted monitoring wells are likely a result of increased biological activity
15 resulting from contaminant degradation. The ORP readings indicate anaerobic reducing
16 conditions in the residuum water-bearing zone, which correlates with the interpretation of the DO
17 readings. The complete reductive dechlorination of chlorinated solvents only proceeds under
18 extreme anaerobic conditions.

19
20 Following O_2 , microorganisms preferentially use NO_3^- as a terminal electron acceptor. Table 4-5
21 indicates that NO_3^- (nitrate) was not detected in any of the groundwater samples collected from
22 the residuum monitoring wells, including the background well PPMP-66-MW01. Nitrate
23 reduction, which is thermodynamically favorable over reductive dechlorination, is not a likely
24 mode of microbial respiration in the residuum water-bearing zone.

25
26 Iron reduction is a common part of anaerobic microbial metabolism in groundwater. Ferric iron
27 (Fe^{+3}) is reduced to ferrous iron (Fe^{+2}) during microbial respiration. This process results in an
28 accumulation of soluble Fe^{+2} in the groundwater where iron-reducing bacteria are active or have
29 been active. Highly chlorinated compounds like TCE can undergo reductive dechlorination
30 under iron-reducing conditions. However, lesser-chlorinated compounds like DCE and VC do
31 not typically undergo reductive dechlorination under iron-reducing conditions. Concentrations
32 of Fe^{+2} above 1 mg/L generally indicate iron-reducing conditions. Table 4-4 presents the Fe^{+2}
33 concentrations in residuum monitoring wells. There is no significant difference between the Fe^{+2}
34 concentration in the background well and those in the impacted wells. The concentration of Fe^{+2}
35 slightly exceeded 1 mg/L in PPMP-66-MW02 (1.13 mg/L); however, the remainder of the wells
36 indicate that iron reduction has not occurred to a great extent in the residuum water-bearing zone.

1
2 Reductive dechlorination of highly chlorinated compounds (TCE and TCA) actively occurs
3 under sulfate-reducing conditions, but the reductive dechlorination of DCE and VC is unlikely to
4 occur under the same conditions. Sulfate-reducing conditions are favored when other electron
5 acceptors such as O_2 , NO_3^- , and Fe^{+3} are depleted. Active sulfate reduction is often indicated by a
6 depletion of sulfate in groundwater and a possible increase in sulfide. Concentrations of sulfate
7 greater than 20 mg/L may cause competitive exclusion of reductive dechlorination (Wiedemeier
8 et al., 1998). Table 4-5 indicates that the sulfate concentrations in the residuum monitoring wells
9 ranged from 82 to 630 mg/L, with a background concentration of 1,700 mg/L in PPMP-66-
10 MW01. The lower sulfate concentrations in the impacted groundwater indicate that sulfate
11 reduction has occurred. However, the concentrations of sulfate remain above 20 mg/L, which
12 indicates that sulfate reduction will likely interfere with reductive dechlorination of DCE and VC
13 in the residuum water-bearing zone.

14
15 Dissolved methane is a good indicator of methanogenic anaerobic conditions with CO_2 being the
16 terminal electron acceptor. Methanogenic conditions favor the complete reductive dechlorination
17 of chlorinated compounds like TCE, DCE, DCA, and VC to desired end products like ethene and
18 ethane. Methane concentrations in the residuum monitoring wells ranged from 0.025 to 0.485
19 mg/L, with a background concentration of 0.008 mg/L in PPMP-66-MW01. The elevated
20 concentrations of methane detected in the impacted groundwater compared to the low methane
21 concentration detected in the background well is evidence that methanogenesis has occurred in
22 portions of the residuum water-bearing zone. The occurrence of methanogenesis in portions of
23 the residuum water-bearing zone indicates that conditions may be suitable for the complete
24 reductive dechlorination of chlorinated aliphatic hydrocarbons.

25
26 Reductive dechlorination releases chloride ions into the groundwater. The chloride
27 concentrations in the residuum monitoring wells ranged from 7.8 to 35 mg/L, with a background
28 concentration of 30 mg/L in PPMP-66-MW01. The chloride concentrations do not provide
29 supportive evidence of reductive dechlorination in the impacted residuum water-bearing zone at
30 Parcel 66(7).

31
32 Regardless of the electron acceptor being used, organic carbon is a required source of reduced
33 carbon and energy to sustain microbial activity. TOC concentrations greater than 20 mg/L are
34 considered adequate to support microbial activity. Analysis of groundwater samples collected
35 from residuum monitoring wells did not detect TOC in any of the samples (detection limit of 1.0

1 mg/L). Therefore, TOC concentrations in the residuum water-bearing zone at Parcel 66(7) do
2 not provide carbon and energy sources to support reductive dechlorination.

3
4 The alkalinity measured in the background well PPMP-66-MW01 was 355 milligrams calcium
5 carbonate per liter (mg CaCO₃/L). Alkalinity values in the impacted wells ranged from 345 to
6 453 mg CaCO₃/L. There was no observed difference in the alkalinity across the site. Therefore,
7 alkalinity concentrations do not provide any evidence of microbial activity. The optimum pH
8 range for microbial activity is between 6 and 8 standard units. Results of the field (Table 4-4)
9 and laboratory (Table 4-5) pH measurements indicate that the pH in the residuum monitoring
10 wells is within the optimum range for microbial activity. Therefore, the groundwater pH is not
11 expected to inhibit biodegradation in the residuum water-bearing zone at Parcel 66(7).

12
13 The qualitative assessment of the respiratory substrates and products detected in the residuum
14 monitoring wells presents limited evidence that intrinsic biodegradation via reductive
15 dechlorination is occurring at the site. The nondetect TOC levels and elevated sulfate
16 concentrations suggest conditions are not suitable for reductive dechlorination to occur.
17 Therefore, the site does not appear to be suited for the application of natural attenuation for
18 groundwater restoration.

19 20 **4.2.2 Bedrock Water-Bearing Zone**

21 The following discussion evaluates the respiratory processes that have occurred or are currently
22 occurring in the bedrock water-bearing zone beneath Parcel 66(7). Since the detection of
23 contaminants in the bedrock monitoring wells was limited to estimated concentrations of
24 methylene chloride and toluene, no measurable differences in geochemical parameters were
25 anticipated in the various bedrock monitoring wells.

26
27 The preferred terminal electron acceptor during microbial respiration is O₂. The DO
28 concentration was measured in the field using a low-flow method to minimize aeration of the
29 groundwater samples. The DO results in the bedrock monitoring wells ranged from 0.95 to 5.6
30 mg/L, with a background concentration of 1.76 mg/L in PPMP-66-MW09 (Table 4-4). The DO
31 results indicate that aerobic conditions prevail in the bedrock water-bearing zone, which confirms
32 the lack of biodegradative microbial activity due to the pristine aquifer conditions. The ORP
33 ranged from -42 to +184 mV, with a background value of -42 mV (Table 4-4). ORP readings
34 above 50 mV are generally indicative of aerobic conditions. The ORP readings in the bedrock
35 water-bearing zone correlate with the interpretation of the DO readings.

1 Following O₂, microorganisms preferentially use NO₃⁻ as a terminal electron acceptor. Table 4-5
2 indicates that NO₃⁻ was not detected in any of the groundwater samples collected from the
3 bedrock monitoring wells, including the background well PPMP-66-MW09. This indicates that
4 nitrate reduction is not a likely mode of microbial respiration in the bedrock water-bearing zone.
5

6 Concentrations of Fe⁺² above 1 mg/L generally indicate iron-reducing conditions. Table 4-4
7 presents the Fe⁺² concentrations in the bedrock monitoring wells. There is no significant
8 difference in the Fe⁺² concentrations detected in the bedrock monitoring wells. The
9 concentration of Fe⁺² slightly exceeded 1 mg/L in the background well PPMP-66-MW09 (1.52
10 mg/L); however, the remainder of the wells indicate that iron reduction has not occurred to a
11 great extent in the bedrock water-bearing zone.
12

13 Active sulfate reduction is often indicated by a depletion of sulfate in groundwater and a possible
14 increase in sulfide. Concentrations of sulfate greater than 20 mg/L may cause competitive
15 exclusion of reductive dechlorination (Wiedemeier et al., 1998). Table 4-5 indicates that the
16 sulfate concentrations in the bedrock monitoring wells ranged from 990 to 2,700 mg/L, with a
17 background concentration of 1,100 mg/L in PPMP-66-MW09. The elevated sulfate
18 concentrations indicate that sulfate reduction would likely interfere with reductive dechlorination
19 in case of future migration of chlorinated solvents into the bedrock water-bearing zone.
20

21 Methane concentrations ranged from 0.005 to 0.018 mg/L, with a background concentration of
22 0.005 mg/L in PPMP-66-MW09. The low concentrations of methane are further evidence that
23 only limited anaerobic biological activity may have occurred in the bedrock water-bearing zone.
24

25 The chloride concentrations in the bedrock water-bearing zone ranged from 30 to 51 mg/L, with
26 a background concentration of 30 mg/L in PPMP-66-MW09. There is no variation in the
27 chloride concentrations. Therefore, chloride concentrations do not provide evidence of reductive
28 dechlorination in the bedrock water-bearing zone.
29

30 Organic carbon is a required source of reduced carbon and energy to sustain microbial activity.
31 TOC concentrations greater than 20 mg/L are considered adequate to support microbial activity.
32 Analysis of bedrock groundwater did not detect TOC in any of the collected samples (detection
33 limit of 1.0 mg/L). Therefore, TOC concentrations in the bedrock water-bearing zone at Parcel
34 66(7) do not provide enough carbon and energy sources to support reductive dechlorination.
35

1 The qualitative assessment of the respiratory substrates and products detected in the bedrock
2 water-bearing zone presents no evidence of biodegradative microbial activity. If contamination
3 does reach the bedrock water-bearing zone at some point in the future, the lack of TOC and the
4 elevated sulfate concentrations suggest that conditions would not be suitable for reductive
5 dechlorination to occur.

7 **4.2.3 EPA Screening Procedure**

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

17
18 The screening was limited to the residuum water-bearing zone, since the bedrock does not
19 contain any significant levels of contamination. The results of the screening are presented in
20 Table 4-6. The weighted scores for the residuum monitoring wells ranged from 6 to 12, with a
21 background score of 6 for PPMP-66-MW01. This range indicates limited evidence that reductive
22 dechlorination is occurring and confirms the results obtained from evaluating the first line of
23 evidence. The conditions in the residuum water-bearing zone at Parcel 66(7) are not suitable for
24 reductive dechlorination to achieve groundwater restoration.

26 **4.3 Third Line of Evidence: Controlled Microcosm Studies**

27 Microcosms were established to monitor the degradation of the contaminants under controlled
28 laboratory conditions. The experimental setup consisted of unamended microcosms and
29 temperature inhibited microcosms as described in Section 3.2. The inhibited microcosms were
30 set up to account for contaminant losses due to physical processes and experimental error. Table
31 4-7 and Figure 4-4 present the results of the inhibited microcosms. The concentrations of TCE in
32 the inhibited microcosms decreased from 1.29 mg/L to 0.732 mg/L over the duration of the 12-
33 week study. This indicates that physical losses of TCE through experimental error were not well
34 controlled during the study. The relatively constant levels of DCE (slight decrease) and the
35 absence of any VC, ethene, or ethane demonstrate that reductive dechlorination was not
36 occurring in the inhibited microcosms. In addition, the low levels of methane and the constant

Table 4-6

EPA Screening Procedure for Evidence of Natural Attenuation
 Small Weapons Repair Shop, Parcel 66(7)
 Fort McClellan, Calhoun County, Alabama

Chemical and Geochemical Parameters

Monitoring Well	pH (S. U.)	Temperature (Degrees C)	Dissolved Oxygen (mg/L)	ORP (mV)	TOC (mg/L)	Fe ⁺² (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Alkalinity (mg/CaCO ₃)	Total Methane (mg/L)	Total Ethene (mg/L)	Total Ethane (mg/L)	cis-1,2-DCE (µg/L)	Total 1,2-DCE (µg/L)	% cis-1,2-DCE
PPMP-66-MW01*	6.7	15.7	0.46	38	1 U	0.38	1700	NA	30	0.5 U	355	0.008	0.001 U	0.001 U	1 U	1 U	-
PPMP-66-MW02	6.3	21.7	0.00	-71	1 U	1.13	630	NA	31	0.5 U	453	0.026	0.037	0.002	8.8	14.5	61%
PPMP-66-MW05	6.8	16.9	0.41	-94	1 U	0.5	82	NA	35	0.5 U	345	0.025	0.001 U	0.001 U	1 U	1 U	-
PPMP-66-MW06	6.8	22.3	0.00	-131	1 U	0.36	150	NA	7.8	0.5 U	345	0.485	0.001	0.002	720	751	96%

Weighted Scores

Monitoring Well	pH	Temperature	Dissolved Oxygen	ORP	TOC	Fe ⁺²	Sulfate	Sulfide	Chloride	Nitrate	Alkalinity	Total Methane	Total Ethene	Total Ethane	% cis-1,2-DCE	Score
PPMP-66-MW01*	0	0	3	1	0	0	0	0	0	2	0	0	0	0	0	6
PPMP-66-MW02	0	1	3	1	0	3	0	0	0	2	0	0	2	0	0	12
PPMP-66-MW05	0	0	3	1	0	0	0	0	0	2	0	0	0	0	0	6
PPMP-66-MW06	0	1	3	2	0	0	0	0	0	2	0	0	0	0	2	10

Total Scores

MW	Score	Classification
PPMP-66-MW01*	6	Limited Evidence
PPMP-66-MW02	12	Limited Evidence
PPMP-66-MW05	6	Limited Evidence
PPMP-66-MW06	10	Limited Evidence

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

* PPMP-66-MW01 screened in the residuum was selected as a background well because it is not impacted with chlorinated solvents and is located cross-gradient 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⁺² - ferrous iron

mg CaCO₃/L - milligrams calcium carbonate per liter

U - Analyte was not detected or below method detection limits

µg/L - micrograms per liter

Table 4-7

**Inhibited Microcosms Results
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Analyte	Sampling Points				
	Initial	Week 2	Week 4	Week 8	Week 12
TCE (mg/L)	1.29	0.970	0.924	0.648	0.732
<i>cis</i> -1,2- DCE (mg/L)	0.453	0.384	0.375	0.337	0.376
<i>trans</i> -1,2-DCE (mg/L)	0.007	0.006	0.006	0.004 J	0.005 U
VC (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
1,1-DCE (mg/L)	0.077	0.070	0.069	0.057	0.067
1,2-DCA (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
Methane (mg/L)	0.043	0.054	0.107	0.095	0.046
Ethene (mg/L)	0.001 U	0.001	0.003	0.005	0.006
Ethane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.001 U
TOC (mg/L)	1.0 U	1.3	12	1.4	3.3
pH (S.U.)	8.0	8.4	8.4	8.3	8.4
Ortho-phosphate (mg/L)	0.5 U	0.5 U	0.5	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)	3	3	NA	NA	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	0.53	0.5 U	0.5 U
Sulfate (mg/L)	180	190	150	210	170
Chloride (mg/L)	8.5	8.6	8.1	8.6	8.0

Notes:

mg/L - milligrams per liter

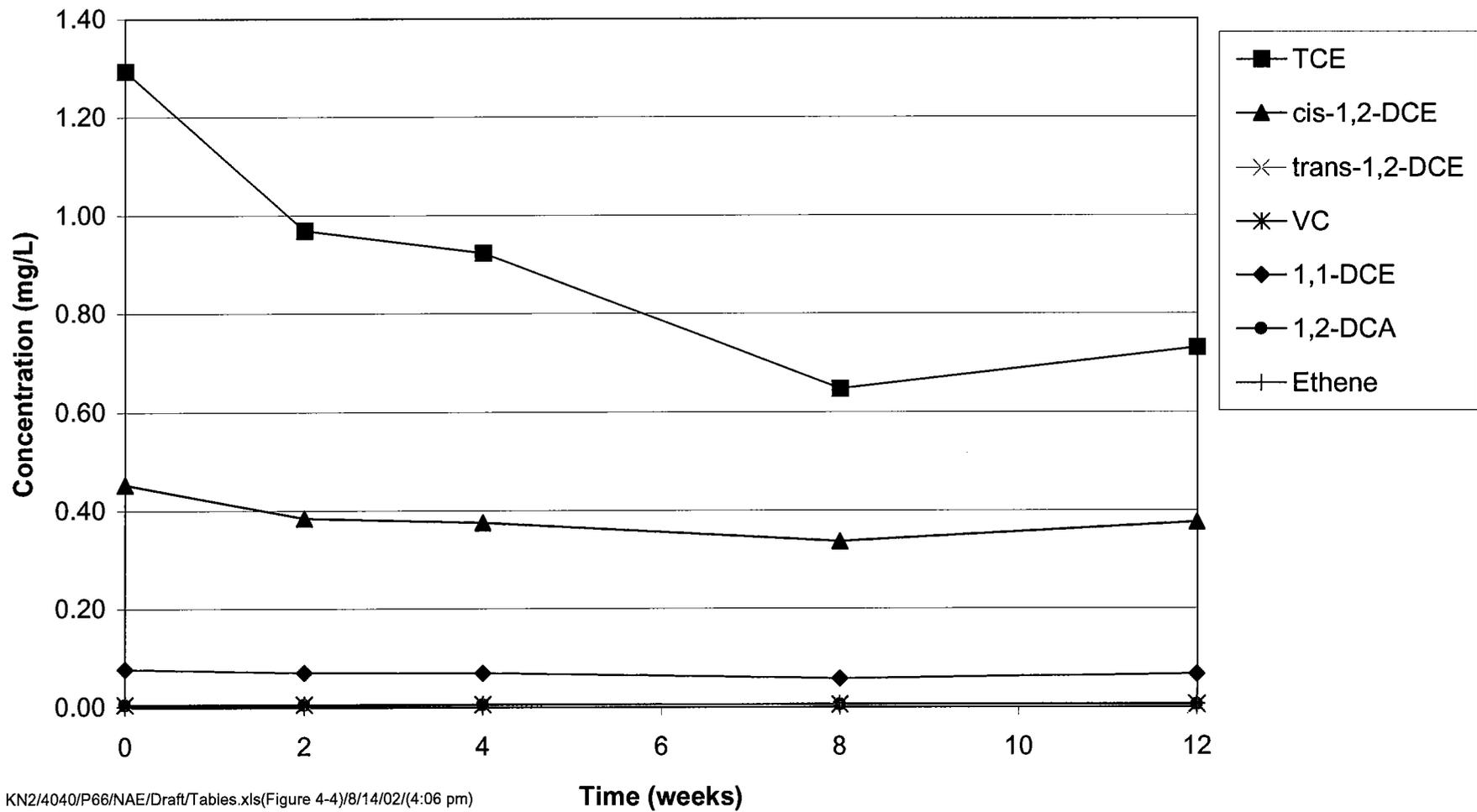
S.U. - Standard Units

NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

Figure 4-4
Inhibited Microcosms Data Graphs
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama



1 levels of sulfate and chloride over the course of the 12-week study indicate that the temperature-
2 inhibited microcosms effectively suppressed microbial activity. The inhibited microcosms
3 provided a baseline against which the unamended microcosms were compared. Differences in
4 VOC concentrations and the other parameters between inhibited microcosms and the unamended
5 microcosms were attributed to biological activity.
6

7 The unamended soil and groundwater microcosms were used to evaluate the reductive
8 dechlorination of TCE that could occur in situ under current field conditions. Table 4-8 and
9 Figure 4-5 present the results of the unamended microcosms. The results indicate that the
10 concentration of TCE decreased from 1.23 mg/L to 0.631 mg/L, a level of decrease that is similar
11 to the change in TCE concentrations observed in the inhibited control. The concentrations of
12 DCE remained relatively unchanged (slight decrease), which is evidence that TCE did not
13 degrade to cis-1,2-DCE in the unamended microcosms. Further evidence for the lack of
14 reductive dechlorination is lack of VC detections and the constant concentrations of methane,
15 sulfate, and chloride throughout the 12-week study. The results obtained from the unamended
16 microcosms mirrored the results obtained from the inhibited microcosms. The lack of reductive
17 dechlorination in the unamended microcosms can be attributed to insufficient TOC levels and
18 elevated sulfate concentrations. The system also appears to be nutrient limited, as indicated by
19 the nondetect levels of ortho-phosphate and ammonia. The results obtained from the microcosms
20 indicate that conditions are not suitable for reductive dechlorination and confirm the observations
21 obtained from the first two lines of evidence of the natural attenuation evaluation at Parcel 66(7).

Table 4-8

**Unamended Microcosms Results
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama**

Analyte	Sampling Points				
	Initial	Week 2	Week 4	Week 8	Week 12
TCE (mg/L)	1.23	0.96	0.790	0.526	0.631
<i>cis</i> -1,2- DCE (mg/L)	0.440	0.412	0.370	0.319	0.346
<i>trans</i> -1,2-DCE (mg/L)	0.007	0.006	0.008	0.004 J	0.004 J
VC (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
1,1-DCE (mg/L)	0.073 U	0.066	0.065	0.053	0.055
1,2-DCA (mg/L)	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U
Methane (mg/L)	0.031	0.069	0.087	0.068	0.042
Ethene (mg/L)	0.001 U	0.005	0.011	0.017	0.014
Ethane (mg/L)	0.001 U	0.001 U	0.001 U	0.004	0.001
TOC (mg/L)	1.0 U	1.0 U	2.4	28	2.6
pH (S.U.)	8.6	8.6	8.5	8.3	8.3
Ortho-phosphate (mg/L)	0.5 U	0.5 U	0.6	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)	2	1	NA	NA	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)	180	190	220	200	190
Chloride (mg/L)	8.6	8.8	8.4	8.8	8.2

Notes:

mg/L - milligrams per liter

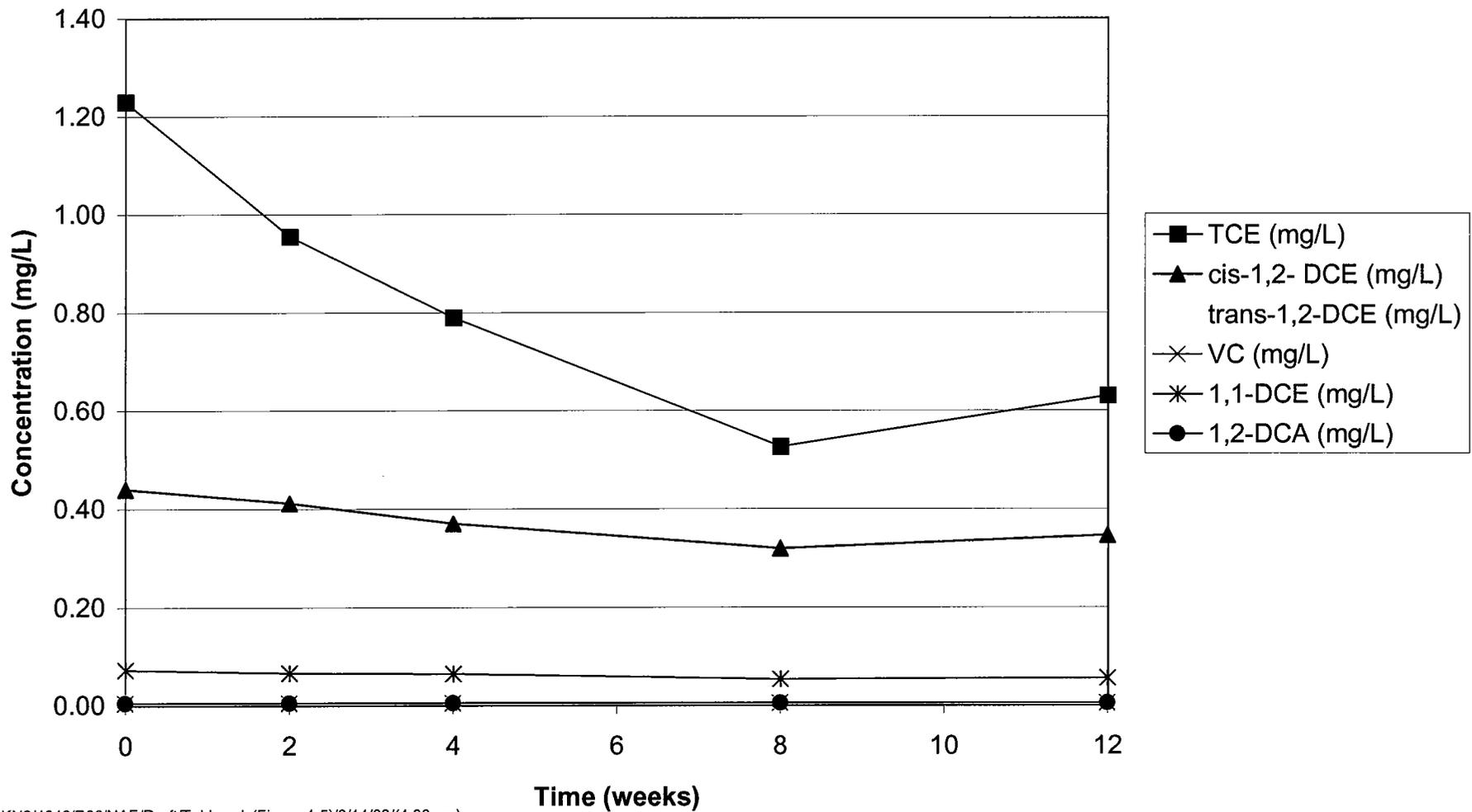
S.U. - Standard Units

NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

Figure 4-5
Unamended Microcosms Data Graphs
Small Weapons Repair Shop, Parcel 66(7)
Fort McClellan, Calhoun County, Alabama



1 **5.0 Conclusions and Recommendations**

2
3 Using the evaluation approaches advanced by EPA (Wiedemeier et al., 1998), evidence from the
4 site indicates that naturally occurring intrinsic biodegradation is making a limited contribution to
5 the restoration of the residuum water-bearing zone. The concentrations of chlorinated aliphatic
6 hydrocarbons in the bedrock water-bearing zone do not warrant remediation. The field and
7 laboratory investigations into the biodegradation of chlorinated aliphatic hydrocarbons provided
8 several different pieces of evidence suggesting that very limited reductive dechlorination of TCE
9 and its daughter products is taking place and that the bulk of TCE-contaminated groundwater
10 remains unaffected.

11
12 The lack of reductive dechlorination in the residuum water-bearing zone can be attributed to
13 nondetect concentrations of naturally occurring TOC, elevated levels of sulfate, and the lack of
14 sufficient nutrients. Degradation rate constants, EPA screening procedure, and controlled
15 microcosm studies all point towards the lack of reductive dechlorination in the residuum water-
16 bearing zone at Parcel 66(7). Therefore, natural attenuation is not recommended as a process
17 option for the restoration of the residuum water-bearing zone at Parcel 66(7).

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