

APPENDIX B

**ANAEROBIC BIODEGRADATION
TREATABILITY STUDY REPORT**

Draft

**Anaerobic Biodegradation Treatability Study Report
Former Chemical Laundry and Motor Pool Area 1500
Parcel 94(7)**

**Fort McClellan
Calhoun County, Alabama**

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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 parcels at FTMC under the management of the U.S. Army Corps of Engineers-Mobile District. The Corps 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 in site groundwater. In addition, the maximum detected concentration of chlorobenzene exceeded its maximum contaminant level. Based on the results of the RI, further investigation of the groundwater contamination at Parcel 94(7) was recommended. In April 2002, contaminated site soil and groundwater were collected to conduct a laboratory treatability study to investigate the potential for intrinsic and enhanced biodegradation of chlorinated solvents in the residuum water-bearing zone at Parcel 94(7). The objective of this investigation was to evaluate the effect of lactate for stimulating reductive dechlorination of TCE, VC, and chlorobenzene by naturally occurring microbes. The rate of dechlorination by indigenous microorganisms at the site and other factors that may affect performance of the technology during pilot or full-scale implementation were determined. A feasibility study was initiated to screen remedial action technologies and process options for groundwater remedial alternatives. The results from this treatability study will be incorporated into the feasibility study report.

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 summary, the geology at Parcel 94(7) is characterized as clayey silt and
4 silty sand residuum overlying fractured, weathered limestone and interbedded weathered shale.
5 The depth to bedrock ranges from 6 to 50 feet 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 0.14 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 0.03 ft/day in bedrock (IT, 2002).

2.0 Technology Description

Most naturally occurring chemicals and many anthropogenic chemicals can be biodegraded under either aerobic (with oxygen) or anaerobic (without oxygen) conditions. Chlorinated solvents, such as the chemicals of concern (COC) identified at Parcel 94(7), are biodegradable under anaerobic conditions, provided that suitable conditions exist at the site, including an appropriate oxidation-reduction potential and availability of a readily biodegradable carbon source to provide electrons for reductive dechlorination. The site conditions dictate the rate and completeness of the biodegradation reactions. Biodegradation may not occur at some sites due to toxicity associated with high concentrations of contaminants, competition with other biological reactions, or the lack of a suitably adapted indigenous microbial population. The biological reactions, conditions necessary to support biodegradation, and steps required to enhance in situ reductive dechlorination are discussed.

2.1 Anaerobic Biodegradation

In general, aerobic degradation of TCE does not occur under natural conditions because it is such a highly oxidized compound. Instead, TCE can be degraded under anaerobic conditions via pathways that result in the sequential dechlorination of TCE to cis-1,2-dichloroethene (DCE), to VC, and, ultimately, to ethene or ethane. However, under less-than-ideal circumstances where geochemical conditions are unfavorable for complete reductive dechlorination, incomplete conversion of the parent compound can occur, resulting in an accumulation of the daughter products cis-1,2-DCE and VC. Biodegradation may continue to occur, however, because cis-1,2-DCE and VC can be mineralized to carbon dioxide and water under aerobic, nitrate-reducing, or iron-reducing conditions. Thus, by providing a sufficient supply of an electron donor (i.e., carbon source) and appropriate oxidation-reduction potential conditions (i.e., rendering the environment more anaerobic), the microbial community can be stimulated to effect complete dechlorination of TCE to ethene.

Reductive dechlorination requires the presence of a biodegradable organic substrate, since the chlorinated hydrocarbons are not used as a carbon and energy (food) source by the anaerobic microbes responsible for reductive dechlorination. Instead, the chlorinated ethenes are used as respiratory substrates, or electron acceptors, during metabolism. Because it depends on an organic carbon source, reductive dechlorination does not occur in groundwater lacking a natural or anthropogenic source of biodegradable organic carbon.

Reductive dechlorination may occur by either of two distinct processes. Co-metabolic reductive dechlorination is a relatively slow process whereby chlorinated ethenes are gratuitously degraded

1 during the anaerobic biodegradation of other organic compounds under sulfate-reducing or
2 methanogenic conditions. Halorespiration is a much more rapid form of reductive dechlorination
3 in which the organic carbon is biodegraded to yield hydrogen. The hydrogen is then used by a
4 halorespiring microorganism that converts hydrogen and carbon dioxide to biomass using the
5 chlorinated ethenes as the electron acceptors (respiratory substrates) in the process.

6
7 Supplying a biodegradable organic compound to the groundwater can often stimulate reductive
8 dechlorination. Lactate, molasses, hydrogen releasing compound (HRCTM), and a variety of
9 other readily degradable materials can be used as a carbon source to stimulate reductive
10 dechlorination. The application of a carbon source requires the direct injection of a dilute
11 aqueous solution of the carbon source (usually one to two percent by weight) into the aquifer or
12 injection of concentrated materials (e.g., HRC). This can be accomplished using a batch delivery
13 system or by continuous injection. Extraction wells are often used to facilitate the movement of
14 soluble carbon sources. Poorly soluble or concentrated materials such as HRC are typically
15 injected directly into the aquifer and allowed to diffuse into the groundwater. This passive
16 distribution method requires much closer spacing of the injection points than injection/extraction
17 systems, but water treatment is eliminated and there is no operation and maintenance associated
18 with the application, other than monitoring and perhaps additional periodic deliveries of the
19 material. Inorganic nutrients such as ammonia and phosphate may also be required in a nutrient-
20 deficient aquifer. These can be added as soluble salts mixed with the organic carbon substrate.

21 22 **2.2 Technology Application**

23 This treatability study was designed to evaluate the potential for successfully stimulating the
24 anaerobic reductive dechlorination of chlorobenzene, TCE, cis-1,2-DCE, and VC. Lactate and
25 HRC were tested for their ability to support reductive dechlorination. These products were
26 chosen based on proven potential to stimulate reductive dechlorination at other sites, price, and
27 chemical characteristics. Sodium lactate is readily soluble in water and can be easily injected as
28 a dilute solution. The injection of sodium lactate would likely be coupled with extraction of
29 groundwater at extraction wells to draw the injected substrate through the contaminated portion
30 of the aquifer. The number and location of injection and extraction wells would be configured
31 based on contaminant concentrations, clean-up goals, and aquifer properties.

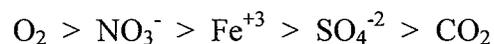
32
33 HRC is a proprietary chemical manufactured by Regenesi Bioremediation Products, Inc. It
34 enhances the growth and activity of indigenous microorganisms, including anaerobic reductive
35 dechlorinating microbes, by slowly releasing hydrogen to the aquifer. The enhanced activity
36 often results in the accelerated biodegradation of chlorinated solvents. Since its introduction in
37 1997, HRC has been shown to achieve rapid in situ degradation of chlorinated volatile organic

1 compounds without the costs and disruption associated with complex engineered remediation
2 systems and without the ongoing cost and liability of natural attenuation approaches.

3
4 HRC is an environmentally safe, food-grade, glycerol polylactate ester that is slowly metabolized
5 to a lactic acid complex after introduction to the aquifer. HRC is injected as a highly viscous
6 liquid under pressure directly into the subsurface through direct-push points or boreholes. The
7 locations of injection points would be configured based on contaminant concentrations, clean-up
8 goals, and aquifer properties. Because HRC does not flow readily into the aquifer matrix,
9 injection points may be spaced relatively close together, to allow advective and diffusive
10 transport of the hydrolyzed product throughout the treatment area.

11 12 **2.3 Geomicrobiology**

13 Biological monitoring parameters are indicators of microbiological activity. Microbial
14 respiration is the biochemical process that leads to the oxidation of reduced organic carbon.
15 Actively respiring microorganisms alter their environment. The effects of microbial respiration
16 are observed by tracking the concentrations of respiratory substrates and products within the
17 microcosms. Frequently encountered respiratory substrates include oxygen (O₂), nitrate (NO₃⁻),
18 ferric iron (Fe⁺³), sulfate (SO₄⁻²), and carbon dioxide (CO₂). Respiratory substrates are used
19 preferentially based on the amount of energy that can be derived from each of them. Respiratory
20 substrates are used in the following order:



22
23
24 Reductive dechlorination of TCE and other chlorinated solvents appears to occur only under
25 extremely anaerobic, highly reduced conditions, such as sulfate-reducing conditions and
26 methanogenic conditions. Sulfate reduction and methanogenesis are inhibited until O₂, NO₃⁻,
27 and Fe⁺³ have been depleted. Sulfate reduction provides more energy to microorganisms than
28 methanogenesis, so that sulfate reducers out-compete methanogens and dominate the microbial
29 population as long as sulfate is abundant. Sulfate reducers may dechlorinate TCE; however, they
30 are not known to dechlorinate cis-1,2-DCE or VC. Under methanogenic conditions, TCE, cis-
31 1,2-DCE, and VC are all dechlorinated. Tracking the concentrations of respiratory substrates
32 and products in the microcosms can provide qualitative evidence of the occurrence of reductive
33 dechlorination. Expected changes in microcosms with microbial activity include a decrease in
34 concentrations of dissolved oxygen (DO) and consumption of anaerobic respiratory substrates
35 such as nitrate and sulfate. Similarly, increases in the concentrations of the products of
36 anaerobic respiration, ferrous iron (Fe⁺²) and methane, are anticipated.

3.0 Methods

A laboratory investigation was conducted to evaluate the biological dechlorination potential of the indigenous microbes at the site. Soil and groundwater samples were collected from the impacted bedrock at Parcel 94(7) and were used to establish the microcosms for the treatability study. The investigation was designed to determine the biodegradability of the site COCs, TCE, chlorobenzene, and VC, by naturally occurring bacteria. The objectives of the investigation were met by measuring the rate of biodegradation, the persistence of biodegradation products, and evaluating the effect of adding an easy-to-degrade carbon source to the impacted medium.

3.1 Microcosm Preparation

Anaerobic biodegradation of the chlorinated solvents was evaluated in 40-milliliter capacity volatile organic analysis glass vials. Approximately 3 gallons of groundwater from monitoring well FTA-94-MW11 and 2 kilograms of soil from a soil boring near the same monitoring well were collected for the treatability study. The soil was collected from two different depths, 24 to 28 ft bgs and 28 to 30 ft bgs. The two soil samples were composited in the laboratory prior to establishing the microcosms. Ten-gram aliquots of composited soil and approximately 30 milliliters of groundwater were placed in each vial (filled to capacity, leaving no remaining headspace). The groundwater sample used to establish the microcosms did not contain adequate concentrations of chlorobenzene or TCE and its degradation products to enable tracking the contaminants throughout the study. Therefore, the vials were spiked with the parent compounds TCE and chlorobenzene to yield concentrations of 3 milligrams per liter (mg/L) and 1 mg/L, respectively. Except for the inhibited control group discussed below, the vials were incubated upside-down at room temperature in an anaerobic glove box. Five treatments were established to allow for sacrificial triplicate analysis over five time points. A total of 75 individual vials were prepared for the treatability study. The time points for analysis were selected to track the activity in the microcosms and determine if biodegradation was reducing the contaminant levels. The following time points were selected: baseline, 2 weeks, 4 weeks, 8 weeks, and 12 weeks. This experimental design eliminated the error associated with trying to reproducibly sample the same container over time, which is problematic with volatile compounds.

As shown in Table 3-1, an inhibited control, an untreated control, an HRC-amended treatment, and two lactate-amended treatments were established. The inhibited control was established by storing the vials in a refrigerator at 4 degrees Celsius to inhibit microbial activity. Any changes in concentrations of volatile organic compounds in this treatment were attributed to experimental error and physical loss. The untreated control simulates the occurrence of natural biodegradation in the absence of any amendment or stimulation. The HRC treatment vials were amended with

Table 3-1

**Summary of Treatment Conditions
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama**

Treatment	Conditions
Inhibited Control	Soil and groundwater slurry, stored at 4°C
Unamended Control	Soil and groundwater slurry
500 mg/L Lactate Amended	Soil and groundwater slurry amended with 500 mg/L total carbon as Lactate, and 250 ppm Restore 375®
2,000 mg/L Lactate Amended	Soil and groundwater slurry amended with 2,000 mg/L total carbon as Lactate, and 500 ppm Restore 375
HRC™ Amended	Soil and groundwater slurry amended with 1,100 mg/L carbon as HRC™, and 580 mg/L Restore 735

°C - Degrees Celsius.
mg/L - Milligrams per liter.
ppm - Parts per million.

1 1,100 mg/L organic carbon as HRC and 500 mg/L RESTORE 375[®], a microbial nutrient
2 formulation designed for application in groundwater. One of the lactate treatments was amended
3 with 2,000 mg/L organic carbon as sodium lactate and 1,000 mg/L RESTORE 375. The other
4 lactate treatment was amended with 500 mg/L organic carbon as sodium lactate and 250 mg/L
5 RESTORE 375. Two lactate treatments were established to evaluate the effect of varying the
6 lactate concentration on the biodegradation of the COCs.

7
8 RESTORE 375 contains ammonium chloride and sodium phosphate salts pH buffered to pH 7.0.
9 In addition to supplying inorganic nutrients, RESTORE 375 also buffers the pH of the
10 groundwater and soil. This is a potentially valuable benefit, since biodegradation can be
11 inhibited if the pH of the groundwater is not in the range of 5 to 9. The optimal pH range for
12 biodegradation is 6 to 8. During the biodegradation of organic carbon, volatile fatty acids are
13 produced that can reduce the pH of the groundwater to a level that may reduce degradation rates
14 or even prevent biodegradation; thus, the buffering capacity of the RESTORE 375 solution is
15 highly beneficial for biodegradative processes.

16
17 Each treatment and the two controls were analyzed for TCE, cis-1,2-DCE, trans-1,2-DCE, VC,
18 chlorobenzene, methane, ethane, ethene, total organic carbon (TOC), ortho-phosphate, ammonia,
19 pH, nitrate, nitrite, sulfate, chloride, and DO. The analyses were conducted at the beginning of
20 the treatability study and after 2, 4, 8, and 12 weeks of incubation. All analyses, with the
21 exception of pH, ammonia, ortho-phosphate, and DO, were conducted in triplicate.

22 23 **3.2 Analytical Methods**

24 All analyses were conducted by Shaw Environmental's Technology Development Laboratory.
25 The analytical methods used for the investigation are summarized in Table 3-2 and are described
26 as follows:

- 27
28 • **Chlorinated Solvent Analysis.** Chlorinated ethenes and chlorobenzene were
29 detected by gas chromatography equipped with a flame ionization detector using a
30 modification of SW-846 Method 8015B.
- 31
32 • **Methane, Ethene, and Ethane Analysis.** Methane, ethene, and ethane were
33 analyzed by gas chromatography with a flame ionization detector using a
34 modification of Method RSK-175. Methane is a metabolic by-product of
35 anaerobic microbial respiration; detection of methane indicates that conditions are
36 suitable for the reductive dechlorination of TCE and its intermediates. Ethene is
37 the product of the complete dechlorination of TCE. Ethane is the biological
38 breakdown product of ethene.

Table 3-2

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

Lab Parameter	Method	Application
Chlorinated Ethenes (Volatile Organic Compounds)	SW-846 Method 8015B	Used to quantify TCE and intermediates and provide evidence for biodegradation.
Methane, Ethane, Ethene	RSK 175, EPA Draft Method	Increased concentrations of methane indicate the occurrence of methanogenesis, a form of microbial respiration that will support the reductive dechlorination of TCE and its daughter products.
pH	Standard Methods for Analysis of Water and Wastewater, 18 th Ed 4500-H+ or EPA Method 150.1	The preferred pH for biodegradation ranges from pH 6 to 8. Biological activity will generally continue between a range of 5 to 9 but outside this range, activity may be inhibited.
Total Organic Carbon	Standard Methods for the Analysis of Water and Wastewater, 18 th Ed. 5310 B	Provides carbon and energy to sustain microbial activity. TOC is especially important for the biodegradation of compounds that are not directly used as a carbon and energy source for microbial growth, such as TCE.
Ammonia	Standard Methods for the Analysis of Water and Wastewater, 18 th Ed. 4500-NH ₃ F	Used to indicate nutrient deficiencies, and the disappearance of nutrients added to selected microcosms.
Phosphate	Standard Methods for Analysis of Water and Wastewater, 18 th Ed 4500-P E or EPA Method 300	Used to indicate nutrient deficiencies, and the disappearance of nutrients added to selected microcosms.
Nitrate, Nitrite, Sulfate, Chloride	SW-846 Method 300	Used to indicate nutrient presence required for microbial activity. Chloride level used to measure appearance of chloride as evidence of reductive dechlorination.
Dissolved Oxygen	Standard Methods for Analysis of Water and Wastewater, 18 th Ed 4500-O G	Determines whether a microcosm is aerobic or anaerobic.

- 1 • **Dissolved Oxygen.** DO was tested in the treatment vessels using a galvanic
2 detector. Very low DO concentrations were expected in the treatment vessels
3 undergoing reductive dechlorination. For each set of triplicates, the DO of one
4 sample was measured at each time point.
5
- 6 • **Anions (Nitrate, Nitrite, Sulfate, Chloride).** Anions were analyzed using
7 SW-846 Method 300. Nitrate, nitrite, and sulfate are measured to indicate the
8 presence of electron acceptors. An increase in chloride levels would be interpreted
9 as evidence of reductive dechlorination.
10
- 11 • **pH Analysis.** For each set of triplicates, the pH of one sample was measured at
12 each time point.
13
- 14 • **Total Organic Carbon.** TOC was analyzed by the combustion-infrared
15 detection method (Standard Methods for the Analysis of Water and Wastewater,
16 Method 5310B).
17
- 18 • **Ortho-Phosphate.** Ortho-phosphate was supplied to the microcosms that were
19 amended with a carbon source, using the microbial nutrient blend RESTORE 375.
20 The concentration of phosphate was quantified using Standard Method 4500-P E.
21
- 22 • **Ammonia.** Ammonia was supplied to the microcosms that were amended with a
23 carbon source, using the microbial nutrient blend RESTORE 375. Ammonia was
24 measured using Standard Method 4500-NH₃F.
25

26 **3.3 Degradation Rate Constants**

27 The data produced from the various microcosms were evaluated for trends that indicate intrinsic
28 bioremediation via reductive dechlorination. Biodegradation rate constants were determined
29 assuming first-order kinetics and using an equation of the form:

$$30 \quad C_0 = C_i e^{-kt}$$

31 where:
32

33 C_0 = The final measured concentration of a given contaminant in mg/L
34

35 C_i = The initial measured concentration in mg/L
36

37 t = Time between initial and final measurement (weeks)
38

39 k = Degradation rate constant (per week).

40 From the biodegradation rate constant, the half-life of a contaminant was calculated using the
41 following equation:
42

$$43 \quad t_{1/2} = (\ln 2) / k$$

1 where:

2

3 $t_{1/2}$ = Contaminant half-life, the time required for the concentration of the contaminant to
4 decrease by one-half (weeks).

5

6

4.0 Results

The treatability study demonstrated that naturally occurring bacteria at the site are capable of limited biodegradation of TCE under lactate and nutrient amended conditions. Under natural conditions, a decrease in the concentration of chlorobenzene was observed, indicating possible biodegradation. The addition of HRC as the carbon source did not promote reductive dechlorination of TCE. The following sections present the detailed results of the enhanced anaerobic biodegradation treatability study.

4.1 Inhibited Control Microcosms

The inhibited control microcosms were established to measure the loss of chlorinated solvents due to physical processes and experimental error. Table 4-1 and Figure 4-1 presents the results of the inhibited control microcosms. TCE in the inhibited microcosms decreased slightly over the duration of the 12-week study. The absence of any cis-1,2-DCE, VC, ethene, or ethane demonstrates that reductive dechlorination did not occur in the inhibited microcosms. In addition, the low levels of methane and the constant levels of sulfate and chloride over the course of the 12-week study indicate that the temperature-inhibited microcosms effectively suppressed microbial activity. Chlorobenzene concentrations decreased from an initial concentration of 0.938 mg/L to 0.660 mg/L. The inhibited microcosms provided a baseline against which the remaining microcosms were compared. Observed differences between the inhibited microcosms and the remainder of the microcosms were attributed to biological activity.

4.2 Unamended Control Treatment

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

Table 4-1

**Inhibited Control Treatment Results
Anaerobic Biodegradation Treatability Study
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	2.36	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 4-1

Inhibited Control Data Graph
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry & Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama

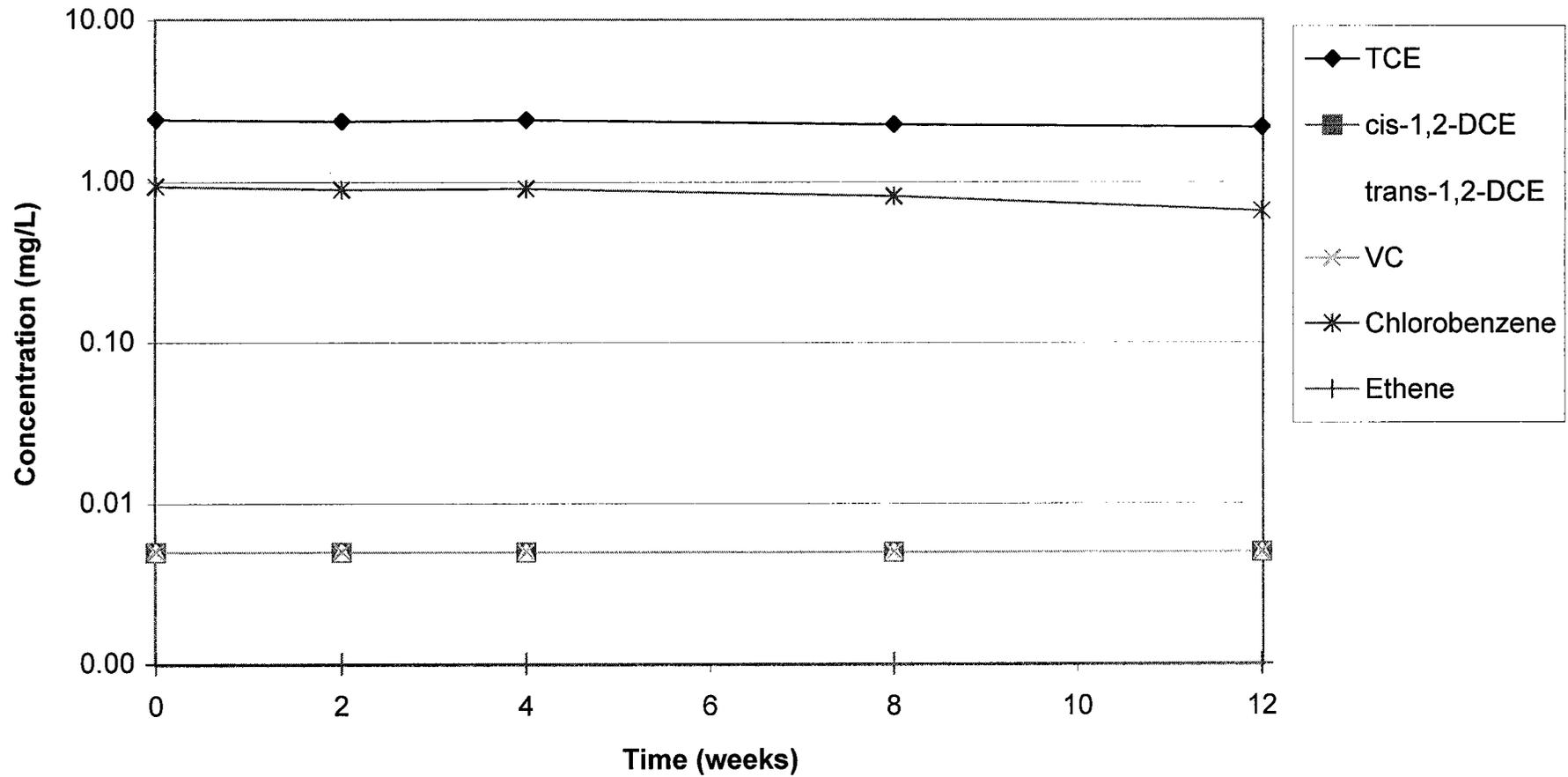


Table 4-2

**Unamended Control Treatment Results
Anaerobic Biodegradation Treatability Study
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

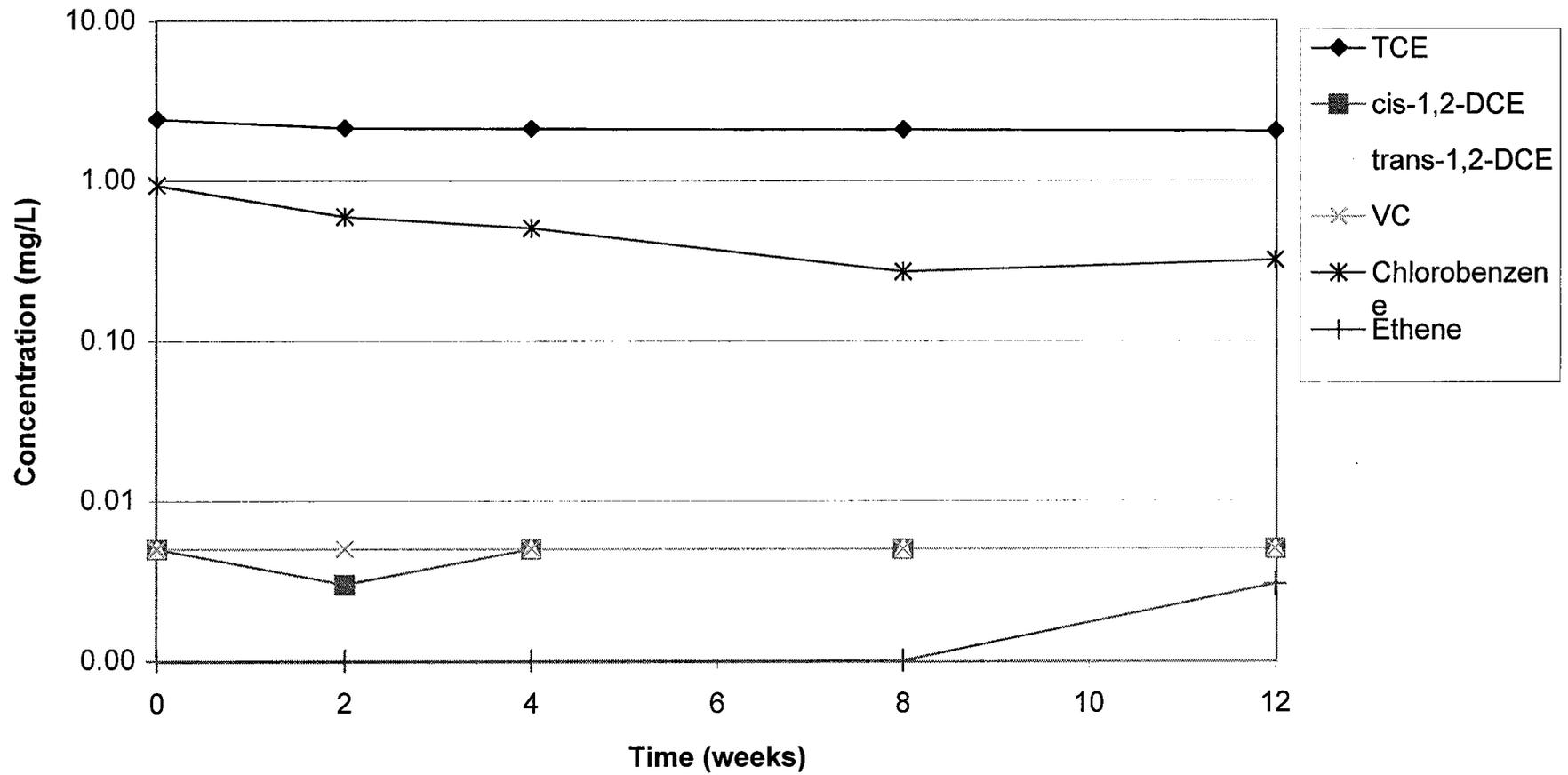
NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

Figure 4-2

Unamended Control Data Graph
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry & Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama



1
2 The decrease in chlorobenzene concentrations from an initial concentration of 0.929 mg/L to
3 0.317 mg/L indicates that chlorobenzene degraded in the unamended microcosms. An
4 evaluation of the DO results indicates that elevated DO concentrations existed at the start of
5 incubation and decreased to anaerobic levels over the duration of the investigation.
6 Chlorobenzene is amenable to aerobic biodegradation through metabolic oxidation in the
7 presence of dissolved oxygen. The decrease in chlorobenzene concentrations is attributed to the
8 aerobic biodegradation of chlorobenzene. The DO was inadvertently introduced into the
9 microcosms during experimental set up. Therefore, the observed aerobic biodegradation of
10 chlorobenzene will not occur under current field conditions without the addition of DO.

11 12 **4.3 500 mg/L Lactate-Amended Treatment**

13 The addition of 500 mg/L carbon to the microcosms in the form of sodium lactate slightly
14 induced the anaerobic biodegradation of TCE. Table 4-3 and Figure 4-3 present the results of
15 the 500 mg/L lactate treatment. TCE decreased from an initial level of 2.05 mg/L to 1.51 mg/L
16 following 12 weeks of incubation. The concentrations of cis-1,2-DCE increased slightly from
17 nondetect levels to 0.009 mg/L in week twelve. This indicates that the decrease in TCE
18 concentrations was the result of reductive dechlorination. The lack of VC production was
19 evidence that the complete reductive dechlorination of TCE did not occur in the 500 mg/L
20 lactate-amended treatments over the allotted 12-week period.

21
22 TOC, supplemented by lactate, was present at high levels throughout the treatment period and
23 contained enough biodegradable carbon to support microbial activity. Ammonia and phosphate
24 levels decreased to nondetect levels after week eight, which possibly inhibited the
25 biodegradation. The pH remained near neutral throughout the treatment period. The pH was
26 within the optimal range for microbial activity. The DO concentration decreased from 6 mg/L to
27 nondetect levels within the first four weeks of incubation, indicating the anaerobic conditions
28 were quickly achieved in the microcosms. The concentration of sulfate decreased from 11 mg/L
29 to <0.5 mg/L by week four, with the bulk of the sulfate being reduced within the first two weeks
30 of incubation. The sharp drop in sulfate concentrations indicates that sulfate-reducing conditions
31 were rapidly established in the microcosms. Following the consumption of sulfate, methane and
32 ethene production was increased, indicating that conditions were favorable for anaerobic
33 microbial processes. Reductive dechlorination results in the release of chloride ion. Chloride
34 concentrations increased slightly over the course of the investigation, indicating that minimal
35 reductive dechlorination has occurred.

Table 4-3

**500 mg/L Lactate-Amended Treatment Results
Anaerobic Biodegradation Treatability Study
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)	2.05	1.92	1.86	1.65	1.51
cis-1,2- DCE (mg/L)	0.005 U	0.005 U	0.003 J	0.006	0.009
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)	0.859	0.711	0.728	0.608	0.513
Methane (mg/L)	0.001U	0.006	0.089	0.022	0.360
Ethene (mg/L)	0.001 U	0.001 U	0.001	0.005	0.010
Ethane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.001 U
TOC (mg/L)	170	160	200	170	160
pH (S.U.)	6.9	7.0	7.0	6.7	7.0
Ortho-phosphate (mg/L)	1.3	0.5 U	1.2	0.5 U	0.5 U
Ammonia (mg/L)	2.9	2.6	5.4	1.0 U	1.0 U
DO (mg/L)	10	4	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	5.1	0.5 U	0.5 U	0.50 U
Chloride (mg/L)	28	29	32	30	32

Notes:

mg/L - milligrams per liter

S.U. - Standard Units

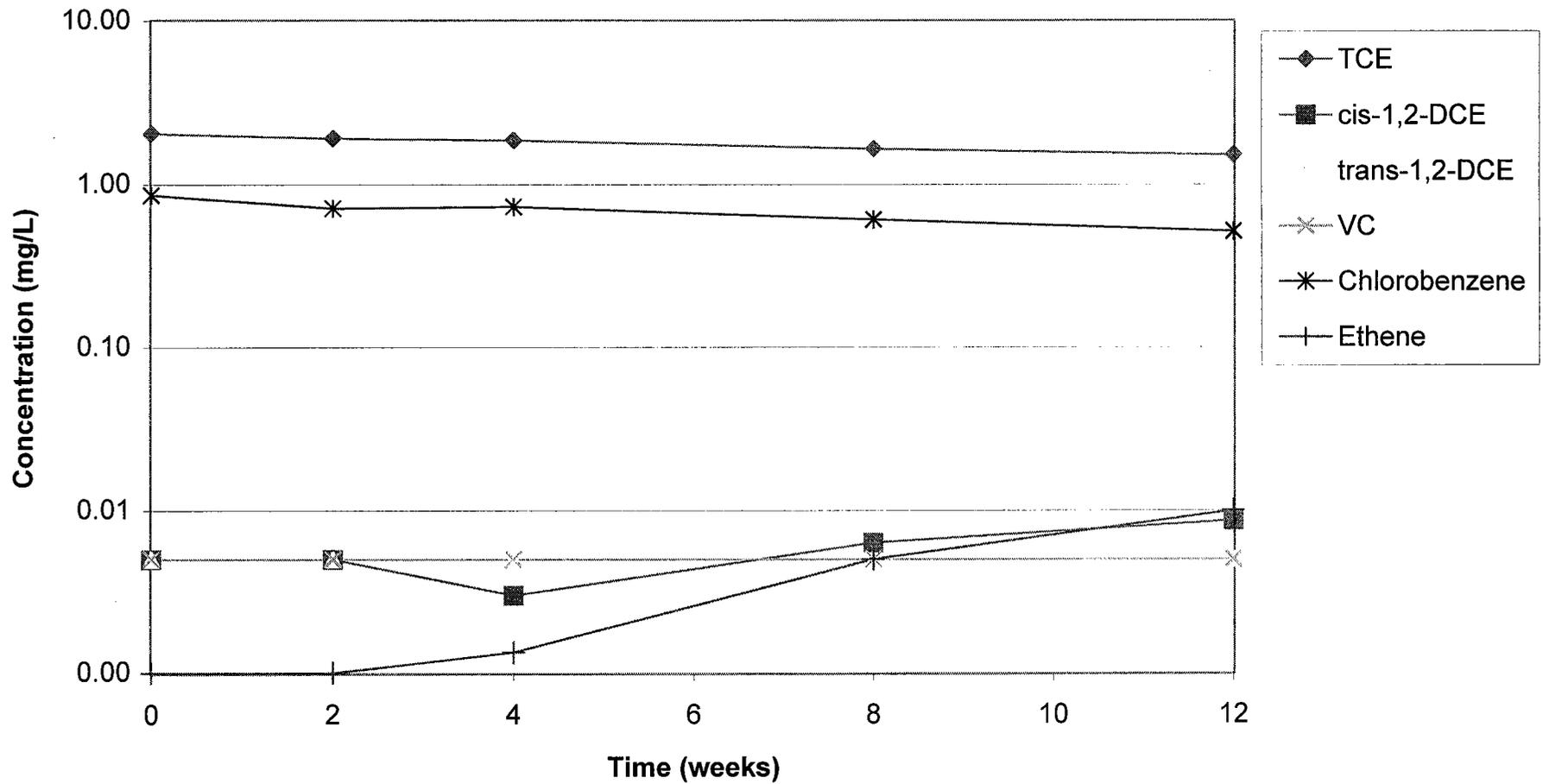
NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

Figure 4-3

500 mg/L Lactate Amended Data Graph
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry & Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama



1 The concentrations of chlorobenzene decreased from an initial level of 0.859 mg/L to 0.513
2 mg/L following 12 weeks of incubation, a change comparable to the level of decrease observed
3 in the inhibited control. Enhanced anaerobic conditions did not stimulate the biodegradation of
4 chlorobenzene. The results obtained from the 500 mg/L lactate-amended treatment were
5 favorable for inducing the reductive dechlorination of TCE. However, the complete reductive
6 dechlorination of TCE to ethene did not occur over the 12-week incubation period.

8 **4.4 2,000 mg/L Lactate-Amended Treatment**

9 The addition of 2,000 mg/L carbon in the form of sodium lactate induced the anaerobic
10 biodegradation of TCE. Table 4-4 and Figure 4-4 present the results of this treatment. TCE
11 decreased from an initial concentration of 2.35 mg/L to 1.76 mg/L following 12 weeks of
12 incubation. The level of decrease in TCE concentrations was similar to that observed in the 500
13 mg/L lactate treatment. The concentrations of cis-1,2-DCE increased from nondetect levels to
14 0.025 mg/L in week twelve, indicating more cis-1,2-DCE production compared to the 500 mg/L
15 lactate-amended treatment. The decrease in TCE concentrations coupled with an increase in cis-
16 1,2-DCE concentrations indicates that reductive dechlorination occurred in the 2,000 mg/L
17 lactate-amended treatments. The lack of VC production was evidence that the complete
18 reductive dechlorination of TCE did not occur in the 2,000 mg/L lactate-amended treatments
19 over the 12-week incubation period.

20
21 TOC, supplemented by lactate, was present at high levels throughout the treatment period and
22 contained enough biodegradable carbon to support microbial activity. Ammonia and phosphate
23 were present at high levels, and the pH remained near neutral throughout the treatment period.
24 Therefore, sufficient nutrients were available and the pH was within the optimal range for
25 microbial activity. The DO concentration decreased from 4 mg/L to nondetect levels within the
26 first four weeks of incubation. The concentration of sulfate decreased from 12 mg/L to <0.5
27 mg/L by week four, with the bulk of the sulfate being reduced within the first two weeks of
28 incubation. The sharp drop in sulfate concentrations indicates that sulfate-reducing conditions
29 were rapidly established in the microcosms. Following the consumption of sulfate, a large
30 increase in methane levels was observed, indicating conditions were favorable for anaerobic
31 microbial processes. The increase in methane concentrations was substantially higher than the
32 increase observed in the 500 mg/L lactate-amended treatment. Chloride concentrations slightly
33 increased throughout the study, indicating the occurrence of minimal reductive dechlorination.

34
35 Chlorobenzene concentrations decreased from an initial level of 0.942 mg/L to 0.589 mg/L
36 following 12 weeks of incubation, a change comparable to the level of decrease observed in the
37 inhibited control. Enhanced anaerobic conditions did not stimulate the biodegradation of

Table 4-4

**2,000 mg/L Lactate-Amended Treatment Results
Anaerobic Biodegradation Treatability Study
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)	2.35	1.99	2.03	1.81	1.76
cis-1,2- DCE (mg/L)	0.005 U	0.005 U	0.005 J	0.010	0.025
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 J
Chlorobenzene (mg/L)	0.942	0.796	0.800	0.686	0.589
Methane (mg/L)	0.001 U	0.001 J	0.084	1.22	65.7
Ethene (mg/L)	0.001 U	0.001 U	0.002	0.005	0.010
Ethane (mg/L)	0.001 U	0.001 U	0.001 U	0.001 U	0.004
TOC (mg/L)	600	580	580	560	600
pH (S.U.)	6.9	6.8	6.8	7.5	6.9
Ortho-phosphate (mg/L)	0.5 U	0.86	2.1	1.3	1.5
Ammonia (mg/L)	18	18	19	4.2	4.5
DO (mg/L)	10	3	1	1	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)	12	8.7	0.5 U	0.5 U	0.5 U
Chloride (mg/L)	99	97	120	110	100

Notes:

mg/L - milligrams per liter

S.U. - Standard Units

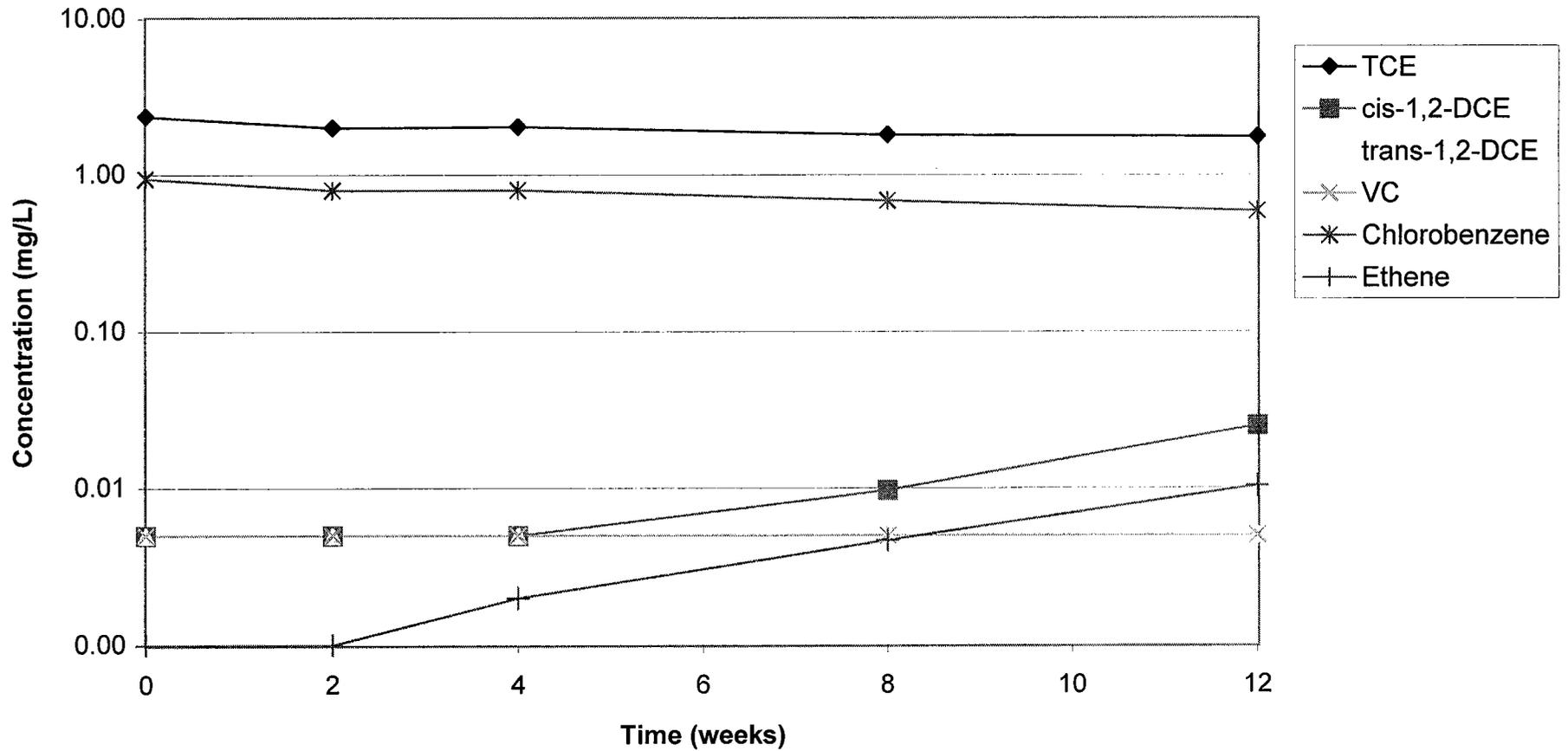
NA - Not Analyzed

U - Analyte not detected or below method detection limits

J - Estimated value, average below method detection limits

Figure 4-4

2,000 mg/L Lactate Amended Data Graph
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry & Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama



1 chlorobenzene. The results obtained from the 2,000 mg/L lactate-amended treatment were more
2 favorable for inducing the reductive dechlorination of TCE when compared to the 500 mg/L
3 lactate-amended treatment. However, the complete reductive dechlorination of TCE to ethene
4 did not occur over the 12-week incubation period.
5

6 **4.5 HRC-Amended Treatment**

7 The addition of 1,100 mg/L carbon in the form of HRC did not induce the anaerobic
8 biodegradation of TCE. Table 4-5 and Figure 4-5 present the results of this treatment. A slight
9 decrease in TCE concentrations comparable to the decrease observed in the inhibited control
10 indicates that TCE did not undergo reductive dechlorination in the HRC-amended treatments.
11 The absence of any cis-1,2-DCE and VC is further evidence that the slight decrease in TCE
12 concentrations was not the result of reductive dechlorination. In addition, the low levels of
13 methane and the constant levels of sulfate and chloride over the course of the 12-week study are
14 further evidence of the lack of reductive dechlorination.
15

16 Chlorobenzene concentrations decreased from an initial level of 0.955 mg/L to 0.615 mg/L
17 following 12 weeks of incubation, a change comparable to the level of decrease observed in the
18 inhibited control. The addition of HRC did not stimulate the biodegradation of chlorobenzene.
19 The results obtained from the HRC-amended treatment were not favorable for inducing the
20 reductive dechlorination of TCE.
21

22 **4.6 Degradation Rate Constants**

23 The degradation rate constant of TCE was calculated for each treatment assuming first-order
24 kinetics as presented in Section 3.3. Table 4-6 summarizes the degradation rate constants and
25 the half-life of TCE degradation in each of the five treatments. The results indicate similar
26 degradation rate constants in the inhibited control, unamended control, and the HRC-amended
27 treatment. The slight decrease in TCE concentrations in those treatments was attributed to
28 physical losses and not to reductive dechlorination. The degradation rate constant in the three
29 treatments averaged 0.011 per week, which corresponds to an average half-life of 61 weeks. The
30 lactate-amended treatments exhibited a decrease in TCE concentrations that was attributed to
31 reductive dechlorination. The TCE biodegradation rate constants in the two lactate-amended
32 treatments averaged 0.024 per week, which corresponds to a half-life of 30 weeks. Correcting
33 for the physical losses of TCE quantified in the inhibited control, the adjusted TCE
34 biodegradation rate constant under lactate-amended conditions equals 0.013 per week, which
35 corresponds to a half-life of 53 weeks. The half-life of 53 weeks represents the time required for
36 the concentrations of TCE to decrease by one-half, resulting in the accumulation of cis-1,2-DCE.
37 A degradation constant could not be calculated for cis-1,2-DCE because the compound did not
38 degrade over the 12-week incubation period.

Table 4-5

HRC™-Amended Treatment Results
Anaerobic Biodegradation Treatability Study
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)	2.46	2.16	2.01	1.93	2.04
cis-1,2- DCE (mg/L)	0.005 U	0.006	0.006	0.003 J	0.008
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	0.010
Chlorobenzene (mg/L)	0.955	0.780	0.744	0.698	0.615
Methane (mg/L)	0.001U	0.007	0.010	0.008	0.015
Ethene (mg/L)	0.001 U	0.001 U	0.001 U	0.001 J	0.002
Ethane (mg/L)	0.001 U	0.001 U	0.001 J	0.001 U	0.002
TOC (mg/L)	1600	820	1100	960	1300
pH (S.U.)	6.0	6.1	6.0	6.2	6.1
Ortho-phosphate (mg/L)	46	36	27	22	16
Ammonia (mg/L)	36	39	54	34	41
DO (mg/L)	11	3	1	1	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)	12	12	7.3	1.7	14
Chloride (mg/L)	170	150	170	170	180

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

HRC™ Amended Treatment Data Graph
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry & Motor Pool Area 1500,
Parcel 94(7)
Fort McClellan, Calhoun County, Alabama

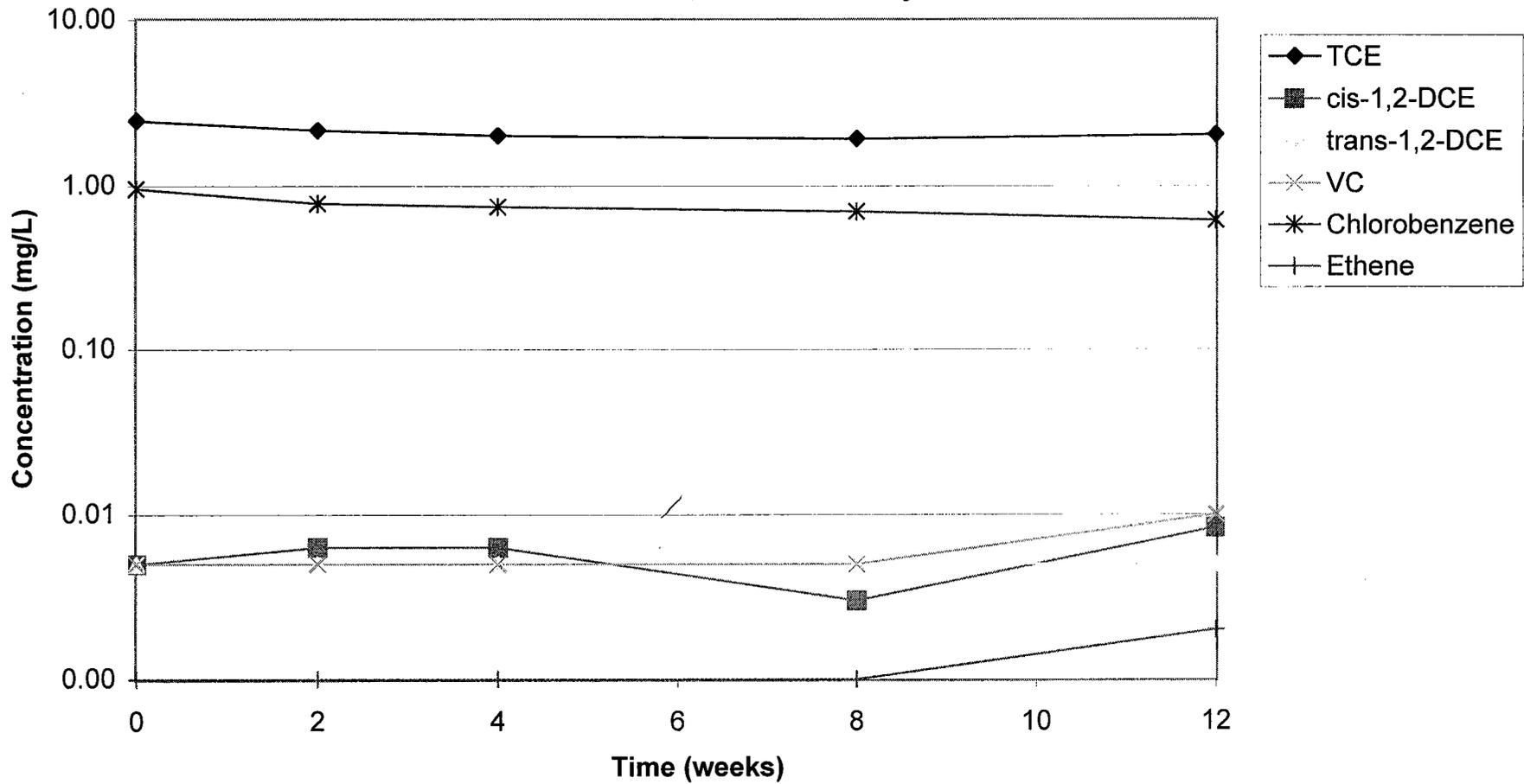


Table 4-6

**TCE Degradation Rate Constants
Anaerobic Biodegradation Treatability Study
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama**

Treatment	TCE Biodegradation Rate Constant (per week)	TCE Half-life (weeks)	TCE Half-life (years)
Unamended Control	0.011	65	1.25
Inhibited Control	0.009	75	1.45
HRC™ Amended	0.014	49	0.95
500 mg/L Lactate Amended	0.025	28	0.53
2,000 mg/L Lactate Amended	0.022	32	0.62

5.0 Conclusions and Recommendations

The laboratory evaluation provided evidence that native microbes in the bedrock at aquifer Parcel 94(7) are capable of limited reductive dechlorination of TCE under enhanced conditions. Specific conclusions from the evaluation are summarized:

- The temperature-inhibited microcosms effectively suppressed microbial activity and provided a baseline against which the remaining microcosms were compared.
- Biodegradation of chlorinated ethenes was not observed in the unamended treatment, indicating that current field conditions are not suitable for reductive dechlorination. The lack of reductive dechlorination was attributed to nondetect TOC concentrations, elevated sulfate concentrations, and the lack of nutrients.
- The addition of lactate at concentrations of 500 mg/L and 2,000 mg/L induced limited reductive dechlorination of TCE. Sulfate reduction occurred rapidly, followed by methanogenesis and the limited production of cis-1,2-DCE. The results obtained from the 2,000 mg/L lactate-amended treatment were more favorable for inducing the reductive dechlorination of TCE when compared to the 500 mg/L lactate-amended treatment. However, the complete reductive dechlorination of TCE to ethene did not occur over the 12-week incubation period.
- The half-life for TCE dechlorination to cis-1,2-DCE in the lactate-amended treatments averaged 53 weeks (corrected for physical losses of TCE quantified in the inhibited control). The half-life of 53 weeks represents the time required for the concentrations of TCE to decrease by one-half, resulting in the accumulation of cis-1,2-DCE.
- The addition of HRC did not induce reductive dechlorination of the chlorinated ethenes. Sulfate reduction and methanogenesis were not observed.
- The biodegradation of chlorobenzene was not induced under enhanced anaerobic conditions. However, the biodegradation of chlorobenzene was observed in the unamended control under aerobic conditions. DO was inadvertently introduced into the microcosms during experimental set up. Therefore, the observed aerobic biodegradation of chlorobenzene will not occur under current field conditions without the addition of DO.

Enhanced anaerobic biodegradation through lactate or HRC addition is not recommended for this site. The dechlorination of TCE to cis-1,2-DCE was extremely slow, with an average half-life of 53 weeks. The complete reductive dechlorination of TCE to the desirable end product ethene was not observed during the treatability study. Therefore, enhanced anaerobic biodegradation is not recommended as a treatment technology for the bedrock zone at Parcel 94(7).

6.0 References

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.

APPENDIX C
BACKUP CALCULATIONS
FOR ALTERNATIVE 3

Drawdown Simulation

FTA-94 Mean for MW-11 and MW-12

6" well to 110 ft with 60 ft screen

Aquifer Horizontal Conductivity	1.077 gpd/ft ²
Aquifer Vertical Conductivity	0.108 gpd/ft ²
Aquifer Thickness	85 feet
Artesian Storativity	0.005
Water Table Storativity	0.02
Effective Radius	0.25 feet
Top of Aquifer	0 feet
Base of Aquifer	85 feet
Initial Water Level	0 feet
Infinite Aquifer System	

Notes:

Hydraulic conductivity from mean of slug tests. Initial estimates should be confirmed by conducting well capacity tests in pilot test wells before designing full scale system. Water Column modeled from 780 to 695 ft msl.

Well specification

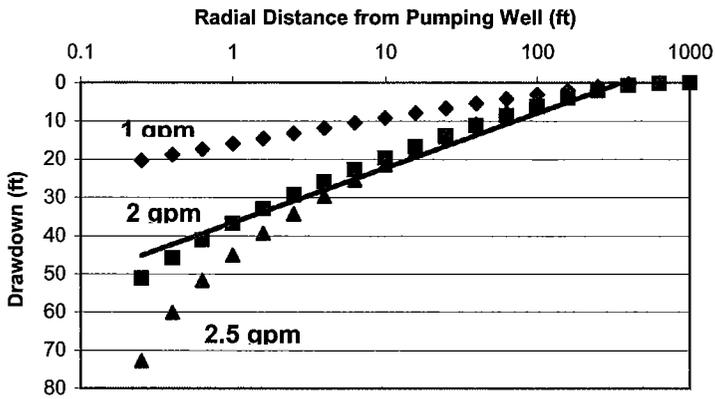
Total depth 110 ft well bottom at 698 msl
Screen bottom 60 feet of well (50 to 110 ft bgs)
water level will enter screen, some cascading will occur

Time (min)	Discharge - Time - Drawdown		
	1 gpm	2 gpm	2.5 gpm
0.14	0.1	0.19	0.24
0.23	0.15	0.3	0.38
0.36	0.23	0.47	0.59
0.57	0.37	0.73	0.91
0.91	0.56	1.13	1.41
1.44	0.86	1.73	2.16
2.28	1.3	2.6	3.26
3.62	1.92	3.85	4.82
5.73	2.76	5.55	6.95
9.09	3.85	7.75	9.73
14.4	5.14	10.42	13.12
22.82	6.57	13.44	16.99
36.17	8.01	16.57	21.11
57.33	9.34	19.61	25.19
90.86	10.51	22.39	29.06
144	11.51	24.89	32.63
228.22	12.39	27.14	35.96
361.71	13.2	29.25	39.16
573.27	13.96	31.27	42.34
908.58	14.7	33.28	45.58
1440	15.43	35.29	48.98
2282.25	16.14	37.32	52.61
3617.12	16.84	39.39	56.57
5732.74	17.53	41.49	61
9085.79	18.2	43.62	66.17
14400	18.84	45.75	72.73
22822.47	19.46	47.88	
36171.17	20.04	49.97	
43200	20.35	51.16	
Total simulation time	43200 min		

Discharge - Distance - Drawdown

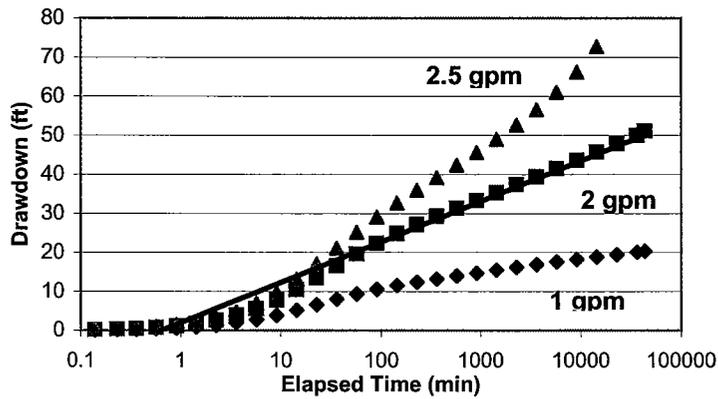
Discharge	r (ft)		s (ft)		
	1 gpm	2 gpm	2 gpm	2.5 gpm	
0.25	20.35	51.16	72.73		
0.4	18.85	45.8	60.04		
0.63	17.39	41.08	51.69		
1	15.95	36.83	45.03		
1.58	14.55	32.92	39.32		
2.5	13.17	29.28	34.24		
3.96	11.82	25.87	29.63		
6.28	10.49	22.65	25.38		
9.95	9.19	19.58	21.41		
15.77	7.91	16.65	17.68		
25	6.65	13.85	14.16		
39.62	5.42	11.17	10.84		
62.8	4.21	8.6	7.75		
99.53	3.05	6.18	4.94		100 foot spacing
157.74	1.97	3.95	2.58		
250	1.04	2.07	0.94		
396.22	0.38	0.74	0.19		
627.97	0.07	0.14	0.02		
995.27	0.01	0.01			

□



2.5 gpm will produce excessive long-term drawdown
 Both 1 and 2 gpm produce sustainable long-term drawdown.
 Recommended pumping rate 2 gpm

Minimum drawdown at midpoint between 2 wells spaced 100 feet apart 24.43



Center pumping system near FTA-94-MW-11.
 Use 7 wells, on a block centered pattern with 100 foot spacing to produce a minimum 24 foot drawdown with in the well system
 Use wells 1 and 2 to capture to 0.10 mg/L
 Add wells 3 and 5 to capture to 0.01 mg/L
 Add wells 4, 5, and 8 to capture to 0.001 mg/l

**Time Required to Reduce VOC Concentration to 100 ug/L via Groundwater Extraction
Former Chemical Laundry and Motor Pool Area 1500, Parcel 94(7)
Fort McClellan, Calhoun County, Alabama**

(Page 1 of 1)

$$PV = -R \cdot \ln(C_{vocf}/C_{voci}) \text{ (per batch-flush method of Zheng*)}$$

PV = Number of pore volumes

R = Retardation Factor

C_{vocf} = Final concentration of VOCs in groundwater

C_{voci} = Initial concentration of VOCs in groundwater

R = 40.9128 maximum retardation factor for the COCs per Table 5-3 of RI

C_{vocf} = 100 ppb - assuming monitored natural attenuation for this VOC concentration and lower

C_{voci} = 445 ppb - maximum detected concentration at Parcel 94(7)

$$PV = 61.07889$$

Volume of water per pore volume = Area of plume within 0.100 ppm isopleth *

Average thickness of plume within 0.100 ppm isopleth * Porosity

Area of plume within 0.100 ppm isopleth =	22500 square feet	(per Figures 4-10 and 4-11 of RI)
Average thickness of plume within 0.100 ppm isopleth =	48.35 feet	(per Figures 5-1 and 5-2 of RI)
Porosity =	0.2	(per Table 5-3 of RI)

$$\text{Volume of water per pore volume} = 1.6276E+06 \text{ gallons}$$

Time required for cleanup with groundwater extraction remedial technology = PV * Volume of water per pore volume / extraction rate

Extraction rate = 10 gpm (assuming 5 extraction wells at 2 gpm per well)

Time required for cleanup with groundwater extraction remedial technology = **18.91 years**

*: Zhang, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of ground-water remedial alternatives at a Superfund site, *Ground Water*, 29(6):838-848.