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Development of an Integrated in-situ Remediation Technology

Draft Topical Report for Task #7.2 entitled, "Field Scale Studies" (January 10, 1996 - December 31, 1997)

Christopher J. Athmer, Sa V. Ho, B. Mason Hughes, P. Wayne Sheridan, and P. H. Brodsky (Monsanto Company) and

Andrew P. Shapiro and Joseph J. Salvo (General Electric Company), and

Dale S. Schultz, Richard C. Landis, Ron Griffith, and Stephen H. Shoemaker (DuPont)

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A. Executive Summary

Development of an Integrated in-situ Remediation Technology

DOE Contract Number: DE-AC05-96OR22459

Draft Topical Report for Task # 7.2 - "Field Scale Test"

(January 10, 1996 - December 31, 1997)

Authors:

Christopher Athmer, Sa V. Ho, B. Mason Hughes, P. Wayne Sheridan, and P. H. Brodsky (Monsanto Company) and

Andrew P. Shapiro and Joseph J. Salvo (General Electric Company), and

Dale S. Schultz, Richard C. Landis, Ron Griffith, and Stephen H. Shoemaker (DuPont)

Abstract

Contamination in low-permeability soils poses a significant technical challenge to in-situ remediation efforts. Poor accessibility to the contaminants and difficulty in delivery of treatment reagents have rendered existing in-situ treatments such as bioremediation, vapor extraction, and pump and treat rather ineffective when applied to low permeability soils present at many contaminated sites. The technology is an integrated in-situ treatment in which established geotechnical methods are used to install degradation zones directly in the contaminated soil and electro-osmosis is utilized to move the contaminants back and forth through those zones until the treatment is completed. The present Topical Report for Task #7.2 summarizes the Field Scale Test conducted by Monsanto Company, DuPont, and General Electric.

B. Acronyms and Abbreviations

DCE	Dichloroethylene
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	Department of Energy
DuPont	E. I. du Pont de Nemours & Co., Inc.
EPA	Environmental Protection Agency
GC	gas chromatography
GE	General Electric Company
LMES	Lockheed Martin Energy Systems
ROD	Record of Decision
RREL	Risk Reduction Engineering Laboratory
SWMU	Solid Waste Management Unit
TCE	trichloroethylene
VC	vinyl chloride

C. Units

C, °C	Celsius, degrees Celsius
cm	centimeters
d, D	days
deg	degrees
F, °F	Fahrenheit, degrees Fahrenheit
f, ft	feet
g	grams
gal, GAL	gallons
h, hr	hours
in	inches
k, K	thousand
kg	kilograms
l, L	liters
lb, lbs	pound(s)
m	meter
mg	milligrams
min	minutes
ml, mL	milliliters
mm	millimeters
ppb	parts per billion
ppm, ppmw	parts per million (by weight)
psi	pounds per square inch
µg	micrograms
µl, µL	microliters
"	inches
'	feet
#	pounds

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Statement of the Problem

Contamination in low permeability soils poses a significant technical challenge to *in-situ* remediation efforts. Poor accessibility to the contaminants and difficulty in delivery of treatment reagents have rendered existing *in-situ* treatments such as bioremediation, vapor extraction, and pump and treat, rather ineffective when applied to low-permeability soils present at many contaminated sites.

The Solution

The proposed technology combines electro-osmosis with treatment zones that are installed directly in the contaminated soils to form an integrated *in-situ* remedial process. Electro-osmosis is an established civil engineering technique and is well known for its effectiveness, utilizing very low power consumption, in moving water uniformly through low-permeability soils.

Conceptually, the integrated technology could treat organic and inorganic contamination, as well as mixed wastes. Once developed, the technology will have tremendous benefits over existing ones in many aspects including environmental impacts, cost effectiveness, waste generation, treatment flexibility, and breadth of applications.

Consortium Description

A Consortium has been formed consisting of Monsanto, E. I. du Pont de Nemours & Co., Inc. (DuPont), and General Electric (GE), with participation from the Environmental Protection Agency (EPA) Office of Research and Development, and the Department of Energy (DOE) Environmental Management Office of Science and Technology. The five members of this group are leaders in their represented technologies and hold significant patents and intellectual property which, in concert, may form an integrated solution for soil treatment. The figure on the cover page shows a schematic diagram of the various technologies and support services which the government/industry consortium has integrated for the development of an *in-situ* remediation technology.

Project History

To date, this project has been conducted in two parts: Phase I and Phase IIa. A Management Plan was originally prepared for Phase I of this project by Monsanto and submitted on November 30, 1994. That plan summarized the work plan which was developed in conjunction with DuPont, GE, EPA's Risk Reduction Engineering Laboratory (RREL), Lockheed Martin Energy Systems (LMES), and the Department of Energy. The DOE Gaseous Diffusion Plant in Paducah, Kentucky, was chosen as the site for the initial field tests. The specific contamination site selected at the Plant was Solid Waste Management Unit (SWMU) 91. For Phase I, the treatment cell selected to demonstrate the process measured 10 feet by 15 feet by 15 feet deep.

CDM Federal Programs Corporation was chosen to provide the on-site support of the field tests which were launched at the DOE site in November 1994. The Phase I experiment tested the combination of electro-osmosis and *in-situ* sorption in the treatment zones. Technology development was carried out under the present contract in Phases I and IIa by Monsanto, DuPont, and GE. These studies evaluated various degradation processes and their integration into the overall treatment scheme at bench and pilot scales.

Phase IIa was approved on January 18, 1996. For this phase, a significantly larger cell was selected, measuring 21 feet by 30 feet by 45 feet deep, and significant design changes were also implemented in the materials used to construct the electrodes and treatment zones. While Phase I was conducted to demonstrate the movement of TCE from the soil into the treatment zones, Phase IIa was conducted to demonstrate that Phase IIb (the full-scale remediation of the SWMU 91 site) would be successful. This latter phase included the use of zero-valent iron metal which degrades TCE to light hydrocarbons and chloride ions. In August of 1997, DOE advised that, based upon the performance of the *Lasagna*TM process during Phases I and IIa, *Lasagna*TM would be the preferred remedy given in the proposed Record of Decision (ROD). If signed, this ROD to be implemented in Phase IIb will be the first example of the use of *Lasagna*TM for the full-scale remediation of a TCE-contaminated clay site. ROD approval is expected in calendar-year 1998.

Technical Deliverables

Table E-1 summarizes the four topical reports which have been written to describe the results obtained from the Phase IIa research. This table also shows which organization is primarily responsible for the tasks and for preparing the topical reports. The present topical report summarizes Task #7.2.

Table E-1. List of Topical Reports and Responsible Company

Topical Report	Company
Task #3.1 - Emplacement Technology	DuPont
Tasks #3.2 - Modeling and Iron Dechlorination Studies	GE
Task #3.3 - <i>Lasagna</i> TM and Iron Dechlorination	Monsanto
Task #7.2 - Field Scale Test	Monsanto/DuPont/GE

Introduction

The *Lasagna*TM approach involves the synergistic combination of electrokinetics (EK) with treatment technologies. EK includes electro-osmosis (EO, transport of water) and electromigration (EM, transport of ions) induced by an applied dc electric field. EO has been used since the 1930s for dewatering clays, silts, and fine sands¹. Electrokinetics has recently received increasing attention as an *in-situ* method for remediating contaminated soils^{2, 3, 4, 5, 6, 7}. Contaminants in the soil are transported by EK to one of the electrodes for collection and further disposal. The mode of transport for organic contaminants is primarily through the EO flow from anode to cathode, whereas for metals and radionuclides the main mechanism for transport is ion migration under the electric field (EM). Depending upon their charge, ions can move to either electrode. Common heavy metals like lead and chromium are cationic (positively charged) when dissolved in water and move toward the cathode.

Advantages of electro-osmosis include (1) uniform water flow through heterogeneous soil, (2) a high degree of control of the flow direction, and (3) very low power consumption. As currently practiced, however, the technology is characterized by several limitations associated with electro-osmosis when applied to large-scale remedial applications. These include (1) long-term treatment duration (liquid flow rate induced by electro-osmosis is typically about 1 inch per day in clay soils), (2) the requirement for additional above-ground treatment, (3) unstable long-term operation resulting from soil drying and cracking, (4) inducement of a steep pH gradient in the soil bed, and (5) precipitation of metals and minerals near the cathode⁴⁻⁷. Recent efforts to mitigate the pH

¹ L. Casagrande, *BSCE*, 39:51-83 (1952).

² A. P. Shapiro, P. Renaud, and R. Probstein, "Preliminary Studies on the Removal of Chemical Species from Saturated Porous Media by Electroosmosis." In *Physicochemical Hydrodynamics*, Vol. 11, No. 5/6, pp. 785-802 (1989).

³ J. Hamed, Y. B. Acar, and R. J. Gale, *ASCE*, Vol. 112, pp. 241-271, February (1991).

⁴ C. J. Bruell and B. A. Segall, *J. Environ. Eng.*, Vol. 118, No. 1, pp 68-83, Jan/Feb 1992.

⁵ B. A. Segall, and C. J Bruell, *Environ. Eng.*, Vol. 118, No. 1, pp 84-100, Jan/Feb 1992.

⁶ Y. B. Acar, H. Li, and R. J. Gale, *ASCE*, Vol. 118, No. 11, pp. 1837-1852, November 1992.

⁷ A. P. Shapiro and R. F. Probstein, *Environ. Sci. Technol.* 27, pp. 283-291, 1993.

problem primarily involve conditioning the anode and cathode solutions through external water recirculating loops^{8, 9}.

The pH changes primarily result from water electrolysis as the predominant electrode reactions, generating acid at the anode and base at the cathode according to the following reactions:

where E_0 is the standard electrochemical potential.

The integrated *in-situ* treatment technology utilizes established geotechnical methods to emplace planar degradation or "treatment" zones directly in the contaminated soil, and electro-osmosis is utilized to transport the contaminants in water back and forth through these zones until the treatment is completed. Conceptually, the integrated technology could treat organic and inorganic contamination as well as mixed wastes. The process is termed "Lasagna" due to the many "layers" created by emplacement of the two electrodes and multiple treatment zones^{10, 11}.

The Phase I test (see Section E., Background, for project history) was a notable success, demonstrating, for the first time, scale-up of electrokinetics in conjunction with very high removal of TCE (~99%) from the contaminated soil. The Phase I experiment also demonstrated, for the first time, a strong possibility that Dense Non-Aqueous Phase Liquid (DNAPL) could be moved by the LasagnaTM process. The results were summarized in a report entitled "Development of an Integrated *in-situ* Remediation Technology, Tasks #12 and 13" prepared by Monsanto for the DOE under contract number DE-AR21-94MC31185¹².

⁸ R. Lageman "Electroreclamation - Applications in The Netherlands." *Environ. Sci. Technol.*, pp 2648-50, Vol. 27, No. 13, 1993.

⁹ Y. B. Acar and A. N. Alshawabkeh, "Principle of Electrokinetic Remediation" *Environ. Sci. Technol.*, pp 2638-47, Vol. 27, No. 13, 1993.

¹⁰ Sa V. Ho, P. Wayne Sheridan, Christopher J. Athmer, Michael A. Heitkamp, Joan M. Brackin, Deborah Weber, and Philip H. Brodsky, "Integrated in situ Soil Remediation Technology - The LasagnaTM Process." *Environ. Sci. Tech.*, vol 29., No. 10, 2528-2534 (1995).

¹¹ P. H. Brodsky and S. V. Ho, "In-Situ Remediation of Contaminated Soils," U.S. Patent 5,398,756, issued March 21, 1995.

¹² C. J. Athmer, S. V. Ho, B. M. Hughes, P. W. Sheridan, P. H. Brodsky, A. P. Shapiro, R. F. Thornton, J. J. Salvo, D. S. Schultz, R. C. Landis, R. Griffith, and S. H. Shoemaker, "Development of an Integrated *in-situ* Remediation Technology," Topical Report for Tasks 12 and 13, Report for DOE contract number DE-AR21-94MC31185, 1996.

The second phase, Phase IIa, (again, see Section E., Project History) represented a major step forward in terms of treating TCE *in situ* as well as extending the treatment to whatever depth necessary to clean up the Paducah site. Based on extensive data in the literature^{13, 14, 15, 16, 17, 18, 19, 20} and the consortium's studies, zero-valent iron in the form of iron filings was chosen as the reagent to degrade TCE. Issues related to TCE degradation in the *Lasagna*TM configuration included:

- effectiveness of iron filings in an electro-osmotic environment
- degradation by-products of TCE
- effectiveness of iron for degrading DNAPL TCE
- role of electrodes in TCE degradation

After sufficient laboratory and pilot testing, Phase IIa was begun to demonstrate the effectiveness of the technology for full-scale cleanup. For this phase, the two electrodes were 30 feet by 45 feet (deep) and were spaced 21 feet apart. Important issues addressed in this demonstration included:

¹³ T. Senzaki and Y. Kumagai, 1989. "Removal of Chlorinated Organic Compounds from Wastewater by Reduction Process: II. Treatment of Trichloroethylene with Powder. *Kogyo Yosui*. 369, 19-25.

¹⁴ R. W. Gillham, and S. F. O'Hannesin, 1994. *Ground Water* 32, 958-967.

¹⁵ R. W. Puls, R. M. Powell, and C. J. Paul, (1995). "In Situ Remediation of Ground Water Contaminated with Chromate and Chlorinated Solvents Using Zero Valent Iron: A Field Study," Natl. Meet. Amer. Chem. Soc., Div. Environ. Chem. 35, 788-791.

¹⁶ D. R. Burris, T. J. Campbell, and V. S. Manoranjan, (1995). "Sorption of Trichloroethylene and Tetrachloroethylene in a Batch Reactive Iron Water System." *Environ. Sci. Technol.* 29(11): 2850-2855.

¹⁷ A. L. Roberts, A. Totten, W. A. Arnold, D. R. Burris, and T.J. Campbell, (1996). "Reductive Elimination of Chlorinated Ethylenes by Zero Valent Metals." *Environ. Sci. Technol.* 30(8), 2654-2659.

¹⁸ T. L. Johnson, M. M. Scherer, and P. G. Tratnyek, (1996). "Kinetics of Halogenated Organic Compound Degradation by Iron Metal." *Environ. Sci. Technol.* 30(8): 2634-2640.

¹⁹ W. S. Orth and R. W. Gillham, (1996). "Dechlorination of Trichloroethene in Aqueous Solution Using Fe⁰." *Environ. Sci. Technol.*, 30:60-71.

²⁰ T. J. Campbell, D. R. Burris, A. L. Roberts, and J. R. Wells, (1997). "Trichloroethylene and Tetrachloroethylene Reduction in Metallic Iron-Water-Vapor Batch System." *Environ. Toxicol. Chem.* 16(4), 625-630.

- design and installation of electrodes and treatment zones to a depth of 45 feet
- electrical effects of voltage, current, power, soil conductivity, heating, etc.
- long-term operation of the process
- extent of soil cleanup as a function of treatment time
- cost of treatment

The treatment cost of the *Lasagna*TM technology, which has been targeted at \$50-100/yd³, is a very key issue in this demonstration. In addition, field data were also utilized to calibrate a mathematical model of the process developed in Phase I. Once the technology is successfully demonstrated and meets cost target, *Lasagna*TM could be scaled up to clean up the entire contaminated site at the Paducah Gaseous Diffusion Plant (PGDP) cylinder drop test area. This report summarizes the *Lasagna*TM Phase IIa field test.

Materials and Methods

Analytical Procedures for Soil and Carbon

Soil sampling was conducted by Oak Ridge National Laboratory (ORNL) under the direction of Lockheed Martin Energy Systems (LMES, then Martin Marietta Energy Systems). TCE was extracted from the soil with hexane. Soil analysis was performed at the site using a gas chromatograph equipped with an electron capture detector (GC-EC). Carbon sampling was performed by ORNL and ESC. Carbon analysis was also performed by ORNL. Details of the sampling and analytical protocols and methods are documented in the Phase I Report¹² or the Quality Assurance Project Plan for this test²¹.

Installation & Operation

Emplacement Method

The field test covered a soil section 21 feet long by 30 feet wide and approximately 45 feet deep. The installation was performed by Nilex Corporation of Englewood, Colorado under the direction of the consortium members DuPont and Monsanto. A specially designed mandrel/tremie tube system was used for introducing electrode and treatment zone materials. The mandrel was 20 inches wide by 2 inches thick (hollow) and approximately 55 feet long; it consisted of 4 tremie tubes measuring 2 inches by 5 inches welded together. The length of the mandrel allowed it to be driven 45 feet into the ground, at which point approximately 10 feet remained above ground. A crane and a vibratory hammer were used to move and drive the mandrel, which was mounted on a 60-foot mast tower. Materials

²¹ "Final Quality Assurance Project Plan (QAPP) for the Rapid Commercialization of an Integrated *in-situ* Remediation Technology," submitted to USDOE by Monsanto, March 3, 1997.

needed for each insertion were contained in a hopper fastened to the top end of the mandrel. The inserted materials were mixed in a cement mixer and were delivered to the mandrel system using a fork truck and cement bucket. All the materials were delivered to the site in bulk shipping bags that were filled with a convenient amount of material for mixing.

Once the grid was laid out for the installation of electrodes and treatment zones, the mandrel was positioned using the crane. The drives were overlapped by 5 inches (1 whole tremie) to assure longitudinal continuity of the electrode or treatment zone materials. Each zone was formed by sequentially making 24 drives, side by side 45 feet deep, along the 30-foot length of the unit, thereby creating a planar "curtain" of either electrode or treatment zone material (as applicable).

A conceptual drawing of the experiment installation at the Paducah plant is presented in Figure F-1.

Figure F-1. Conceptual Drawing of the Phase IIa Installation

Dimensions and Composition of Electrodes and Treatment Zones

The two 30- by 45-foot electrode zones consisted of 1 1/2-inch thick curtains of material, and the two zones were spaced 21 feet apart. The electrode material consisted of a dry mixture of 50/50 by volume Peerless iron filings and Loresco coke. This particular type of coke is commercially available and was specially designed as a backfill material for cathodic protection of buried metal systems such as pipes and tanks. The use of iron filings dictated that iron corrosion would be the predominant reaction at the anode instead of water electrolysis, thus minimizing acid (H^+) formation, which would reduce the effectiveness of electro-osmosis. Six steel rods (3/4" diameter, hot rolled) were inserted into the electrode materials of each electrode, approximately 5 feet apart, to a depth of 40 feet to effect uniform current distribution. The rods were connected in parallel to the main power cable, which was laid along the ground using cathodic-protection welding techniques. Current levels could be measured in each rod by measuring the difference in

current flow in the main cable before and after each steel rod. The steel rods served as the primary conductors and distributed the current throughout the anode and cathode materials. Tests performed after installation using a car battery connected to the outermost rods demonstrated an apparent electrode conductivity of 4.5 S/m. This was approximately 200 times higher than the soil conductivity.

Three treatment zones, each also 1 1/2 inches thick, were emplaced between the electrodes. The first treatment zone was emplaced 7 feet from the anode, the second 5 feet from the first, and the third 2 feet from the second. Treatment zone material consisted of Peerless iron filings (60% wt) suspended in wet kaolin clay, which formed a slurry that was poured down into the hollow mandrel to the 45-foot depth. The original design called for iron content of 8 vol% in clay, but excess water was needed in the clay slurry to make the viscosity high enough to allow it to pour down into the mandrel effectively. Unfortunately, when the mandrel was withdrawn, the resultant high viscosity allowed the slurry to spew up and out of the treatment zone "slot"; therefore, it was necessary to increase the consistency of the slurry to prevent loss of the minimum intended composition. Consequently, the actual volume of iron filings in the slurry was increased to 26 vol% (or 1.61 g Fe/cm³), which was more than 3 times the design level. Also, the clay slurry contained 50 wt% water, much higher than the saturation level of about 40% for kaolin clay. It was therefore anticipated that the overall material "bulk" in the treatment zones would shrink downward during the operation as a result of lateral water migration (due to electro-osmotic flow); however, since the 5 feet of gravel on the ground surface was not contaminated, no treatment zone was needed for this section, thus permitting the treatment material to shrink downward as much as 5 feet (i.e., to the top stratum of contaminated soil) without serious detriment. All materials chosen for electrodes and treatment zones are innocuous to the environment and are designed to remain in-place after the cleanup is completed. This is an important consideration in implementing the *Lasagna*TM technology to minimize both treatment costs and detrimental impact upon the environment.

Monitoring Probes

The voltage, temperature, water, and carbon monitoring systems were installed with the Nilex equipment using a 4-inch by 4-inch square tube tremie 50 feet long. The tremie was driven in the ground to the appropriate depth, the monitoring equipment was installed, and then the tremie was removed leaving the monitor in place. This was a no-waste and extremely fast method of installing piezometer and monitoring equipment. The carbon sock wells contained a 25-foot long sock filled with granular activated carbon. Initially, a plastic tie-wrap was fastened around the sock at 1-foot intervals to allow for discrete measurement of the TCE concentrations with depth; however, in addition, for the second generation socks, several short segments of the socks were filled with bentonite clay to much more effectively seal off any vertical TCE migration by hydraulic or gaseous diffusion, thus significantly improving the integrity of TCE measurements by depth. The bentonite seals were placed at about 12 and 18 feet deep. Figure F-2 shows the location of the installed monitoring equipment and piezometers.

Figure F-2. Location of Monitoring Points

Twelve thermocouples and six multi-depth voltage probes were installed in the unit. The thermocouples were installed at various depths and locations to monitor the temperature rise in the soil generated as a result of resistive heating. Each voltage probe allowed measurements of the voltage potential at vertical increments of 5 feet. A solar-powered data station, constructed by the Monsanto electronic shop, consisted of a digital thermometer and a multiposition switch for temperature measurements and a digital voltmeter with two multiposition switches for the voltage measurements. For voltage measurements, one switch allowed selection of a specific voltage probe and the other the desired depth.

Water Management System

The fluid circulation is presented in Figure F-1. Overflow "wells" installed in two of the cathode drives allowed the water which migrates to or "mounds" at the cathode to be transferred by horizontal pipes to a sump for reuse at the anode. Wells were also installed at the anode in two drives which were connected to the sump. This allowed the water from the sump to flow into these two wells and keep the anode moist.

To help keep the water handling systems from freezing, the horizontal pipes as well as the sump were installed below grade. The cathode side of the system was installed 4 ½ feet below grade and the anode piping 5 feet below grade to provide a downward gradient toward the anode. The 6-inch drop in water levels allowed measurement of the fluid flow rate as the water drained out of the cathode piping into the sump; this setup also prevented electrical shorting between anode and cathode through the water conduit. This direct recycling of water, cations, and high pH collected at the cathode back to the anode is one of the advantageous features of the *Lasagna*TM process.

Electrical System

Power to the test site was supplied with a diesel-run Olympian Power Generator CT-110 rated at 100 kw. A Rapid Power Technology model SCRA 410 C425 rectifier provided the DC power to the field unit. About 50 feet of heavy copper wire cable (0000 size) was used to connect the power rectifier to each electrode.

Soil Sampling

Five soil sampling locations were chosen based on the initial experimental design. These locations corresponded to the 5 piezometers installed (previously mentioned). Locations 2A-04 and 2A-05 were about 1 foot behind the last treatment zone (nearest the cathode). Location 2A-03 was between the 2-footspaced treatment zones. This location was designed to demonstrate the effect of closely spaced treatment zones in limiting "reverse" migration. The locations 2A-02 and 2A-01 provided for "upgradient" samples which should demonstrate limited changes during the first 6 months of operation. All soil sampling was conducted by ORNL. Soil samples were collected by taking 4-foot-long soil cores from the sampling hole. Each core was then sub-cored to attain soil samples at 1-foot intervals. TCE was extracted using hexane and analyzed on-site in a nearby laboratory trailer. More information on the soil sampling data and methods can be found in a related report.

Electro-osmotic Permeability Calculation: The electro-osmotic permeability can be calculated using the following equation:

$$Q = k_e \Delta E A$$

where Q = electro-osmosis volumetric flowrate (cm³/sec)

k_e = coefficient of electro-osmotic permeability (cm²/volt-sec)

ΔE = voltage gradient applied across the treatment cell (volt/cm)

A = cross-sectional area perpendicular to the direction of flow (cm²)

The electro-osmotic flow rate is thus proportional to the applied voltage gradient, and the electro-osmotic permeability has the units of velocity over field strength (cm/sec over volt/cm). The cross sectional area was 1.115×10^6 cm² for the Phase IIa test. Flow rate measurements were performed using a beaker and a stop watch. The flow of water from the cathode pipe into the sump was considered to be all cathode water. This assumption was considered valid since, when the power was shut off, the flow rate slowed down significantly and then stopped entirely. The flow rate measurements were normally not performed until several days after any significant rainfall.

Results and Discussion

Site & Soil Characteristics

The area at the Paducah Gaseous Diffusion Plant cylinder drop-test site is mostly clay with gravel and clay overburden and has been used as a truck road. The contaminant at this site is primarily trichloroethylene (TCE), the concentration of which ranges from below 1 mg/kg (ppm) to approximately 1,500 mg/kg. The vertical and lateral extent of the TCE plume at this site could be estimated from a number of soil and water samples taken over the years. With a soil density of 2 g/cc, 40% porosity and 20% moisture content, a soil concentration of 225 mg TCE/kg would result in pore water saturated with TCE (1100 mg/kg). Thus, a level of 1,500 ppm is definitely an indication of the presence of DNAPL in the area. Table F-1 lists the characteristics of the Paducah soil and Figure F-3 shows the calculated contour map of the highest TCE concentrations found in the soil.

Table F-1. Paducah Soil Characteristics

Soil Type:	Clay Loam
Sand Content:	22 Percent
Silt Content:	46 Percent
Clay Content:	32 Percent
Moisture Content:	15-18 Percent
Organic Carbon Content:	0.2 Percent
Cation Exchange Capacity:	13.4 meq/100 g
Porosity:	0.4
Bulk Density:	2.0 g/cc
Electroosmotic Conductivity	1.2×10^{-5} cm ² /v-sec
Hydraulic Conductivity (estimated)	1×10^{-7} cm/sec

Figure F-3. Highest TCE Concentrations Detected in Zones Shown (1- to 40-Foot Depth)

In preparation for the Phase IIa field test, nine soil borings were made to confirm the northern edge of the plume and to determine the baseline of TCE concentration in the test area. Soil samples were taken at 1-foot intervals to a depth of 40 feet. The TCE contamination appeared to taper off to below detection limits at about 30 to 35 feet deep. It was determined from the data to install the *Lasagna*TM system to a depth of 45 feet to ensure complete cleanup. The regional aquifer is approximately 60 feet below grade in this area.

Electrokinetic Effects

The field installation was accomplished during June, July, and August 1996. The experiment was started (power on) on August 18, 1996 and the power-on period lasted almost 1 year, until early August 1997. The system was shut down for 3 weeks in March, 1997 for soil sampling.

Initially, the voltage was set at 150 volts and 110 amps DC. The rectifier was originally configured to operate at 480 volts AC input; however, this configuration caused a large mismatch in the voltages, resulting in a large AC component (30%). This was undesirable because, while AC power contributes to heating up the soil, it does not induce electro-osmosis; therefore, any AC component results in lower efficiency. Consequently, the generator was changed on October 1, 1996 and the rectifier was modified to operate at 240 volts AC. This lowered the AC component to less than 5% of the total power. The voltage was then set to 200 volts and 200 amps DC. As the temperature rises, the electrical conductivity of the soil also increases; therefore, it is necessary to adjust for this at some point to prevent ultimate overheating; consequently, when the temperature reached approximately 80°C, the power was reduced to 120 volts and 120 amps DC and then adjusted to 150 to 180 volts. After 160 days of operation, the core temperature at the center of the treatment cell reached a maximum of 83°C. The average soil temperature (as compared to core temperature) increased from 18°C to a peak of 60°C between 5 and 6

months after power on, and then stabilized to approximately 50°C until the end of the test.

Temperature, voltage profiles, groundwater quality, and water flow rates were monitored for the duration of the experiment. The distance the water front traveled during the experiment was approximately 5.5 feet, resulting in 2 ½ pore volumes through the 2-foot-interval treatment zone. Figure F-4 shows the voltage and current data for the experiment as well as the pore water travel distance. The negative numbers signify reverse polarity. Figures 5 and 6 show the temperature trends at the 25-foot depth across the site and the temperature trends of the probes at the center of the unit. Temperature is very important in several respects. First, elevated temperatures increase the reaction rate of the degradation with iron filings. Second, and most importantly, the diffusion and dissolution rate of TCE in water increase with increasing temperature. It also happens that the viscosity of water decreases as the temperature increases. This enhancement is almost perfectly offset by the electrical conductivity increase due to increasing temperature; however, the prescribed adjustment - decreasing the applied voltage - has the undesirable effect of reducing the flow rate.

Figure F-4. Overall Voltage, Current, and Pore Water Travel Data

Figure F-5. Temperature Trends at 25 ft Depth

Figure F-6. Temperature Profile at Center of Test Site

Water flow-rates measured throughout the test period correlated well with the predicted flow rates based on the electro-osmotic permeability determined in the laboratory and the Phase I field test. The k_e calculated for the laboratory experiments and the Phase I field test was $1.2 \times 10^{-5} \text{ cm}^2/\text{volt-sec}$. Figure F-7 shows the measured and predicted flow rates, and the cumulative pore volumes of water passed through the system by electro-osmosis. Appendix A contains the spreadsheets of the recorded field data including temperatures, voltage, current, and flow rate. The water in the anode and cathode was monitored on a regular basis for TCE and chloride content and for pH and specific conductance. The cathode water (and the sump) quickly became alkaline, as expected. The pH at the cathode rose quickly to over 12 and the conductivity rose to over 15,000 $\mu\text{S}/\text{cm}$. The water quality at the anode was influenced strongly by the recirculating cathode fluid and therefore could not be accurately determined. The pH was about .5 to 2 pH units lower than at the cathode.

and the specific conductance was approximately 50 percent of cathode readings. In the laboratory and first field test, the pH at the anode remained approximately 6, while the specific conductance steadily increased. The dissolution of the iron at the anode and recycling of the cathode fluid was found to help stabilize the pH while the accumulation of anions, such as chloride and sulfate, caused the conductivity of the solution to raise steadily at the anode.

Figure F-7. Flow Rate Measured vs Predicted

Initially, voltage distribution in the soil between the two electrodes was reasonably uniform. After approximately 5 months of operation, however, the voltage profile at the anode began to deteriorate. An investigation revealed that the water distribution wells at the anode were filled with clay, thus preventing the return water from "re-wetting" the anode and the nearby soil regions. It is possible that soil intruded into the electrode area, causing a significant reduction in its hydraulic permeability. Once the electrode begins to dehydrate, the resistance increases along with temperature, causing yet more dehydration. During the March 1997 soil sampling, three new anode wells were installed in an attempt to remedy this condition. The soil samples obtained exhibited spots of very dry, reddish, "crusty" material and a quantity of wet, black, loose material. The exact composition of this material and its formation process was not conclusively determined. In any case, the unit did operate more effectively after adding the three new wells, but not as effectively as at the original start up. That operation was impaired was evidenced by the fact that the temperature at the anode gradually rose above that of all other areas of the unit, including the center core.

Overall, the electro-osmotic conductivity, pH, and conductivity trends, power requirements, temperature trends, and operational stability all were in agreement with laboratory results. It is believed that the dehydration encountered at the anode was due

primarily to an inefficient water distribution system, which failed to keep the anode sufficiently moist, as designed, for optimum current distribution. This is a key lesson learned from the test, and a more effective water distribution system will be incorporated in the design for the full-scale cleanup.

TCE Removal

In Phase IIa, the basic chemical reactions between Fe and TCE were utilized for degrading TCE in a thin treatment zone containing iron filings and clay. The dechlorination of TCE using zero-valent iron has been studied extensively by many research groups¹³⁻²⁰. The effectiveness of this approach has been demonstrated either as permeable reactive walls or packed bed reactors at many field sites^{22, 23, 24}. It is believed that the dechlorination goes through a step-by-step process in which one chlorine atom is removed each time:

where R stands for hydrocarbon. According to this mechanism, TCE dechlorination by-products would occur in the following order: dichloroethylene (DCE), vinyl chloride (VC), ethylene, and ethane. However, while ethylene and ethane are readily observed as reaction by-products, very little of the intermediates DCE and VC is typically detected, probably because they remain bound to the iron surface and undergo further dechlorination.

Dechlorination Rates and Design Criteria For Treatment Zones

The rate of TCE dechlorination was measured by GE researchers using the Paducah groundwater both in batch (stirred pot) and continuous (packed bed) mode. The basic rate constant determined from these measurement is $k = 0.08 \text{ ccH}_2\text{O/hr-g Fe}$, which for a packing density of 2.41 g Fe/cm^3 and 0.614 packing porosity translates into a first order rate constant of 0.31 hr^{-1} , or a half life of 2.2 hr at room temperature. The GE study also investigated the dechlorination of TCE daughter products, such as dichloroethylene (DCE)

²² R. E. Gillham, 1995. "Resurgence of Research Concerning Organic Transformations Enhanced by Zero-Valent Metals and Potential Application in Remediation of Contaminated Ground Water." Natl. Meet Amer. Chem. Soc., Div. Environ. Chem. 35, 691-694.

²³ R. W. Puls, R. M. Powell, and C. J. Paul, (1995). "In situ Remediation of Ground Water Contaminated with Chromate and Chlorinated Solvents Using Zero Valent Iron: A Field Study." Natl. Meet Amer. Chem. Soc., Div. Environ. Chem. 35, 788-791.

²⁴ C. L. Yamane, J. D. Gallinatti, F. S. Szerdy, T. A. Delfino, D. A. Hankins, and J. L. Vogan, 1995. "Installation of a Subsurface Groundwater Treatment Wall Composed of Granular Zero-Valent Iron." Natl. Meet Amer. Chem. Soc., Div. Environ. Chem. 35, 792-795.

and vinyl chloride (VC), which actually degrade more slowly than TCE: half life of 5.2 hr for c-DCE and of 3.3 hr for VC at 25°C. These data were utilized in the design of the treatment zones to ensure complete destruction of TCE as well as these daughter products, especially VC.

Key considerations in the design of the treatment zones for Phase IIa were:

- ease of installation
- sufficient residence time for complete destruction of TCE and its daughter products, especially VC
- optimum level of iron, balancing between cost and the need for excess iron to ensure performance (rate and stability)
- minimization of TCE loss through volatilization in the treatment zones.

At the targeted voltage gradient of 0.25 volt/cm, the velocity of water moving through the Paducah clay soil is approximately 0.32 cm/day. Calculations based on the GE rate data showed that a treatment zone thickness of 2 inches containing 100% iron much more than required for complete destruction of TCE and its daughter products. It was therefore decided to mix iron filings with an inert material. Sand and clay were the two obvious options considered. Clay was chosen because it offers the following advantages: higher stability in an electro-osmotic environment (better water retention), minimum TCE loss from volatilization, ease of installation as a slurry, and it provides a better medium for keeping the iron particles dispersed throughout the 45-foot depth.

The following table shows the estimated half life values for TCE, c-DCE and VC at 25, 40 and 60°C for an 8 vol% iron packing (0.5 gFe/cm³).

Temperature, C°	Half Life in hr		
	TCE	c-DCE	VC
25	10.7	25.3	16.2
40	3.5	8.2	5.2
60	2.4	5.5	3.6

Based on the above half-life values, the amount of TCE, c-DCE, and VC converted as a result of passing through each treatment zone can be estimated as follows, assuming plug flow for the liquid:

Temperature, C°	% Conversion per Pass		
	TCE	c-DCE	VC
25	100	99.83	100
40	100	100	100
60	100	100	100

For pore water containing 1,000 ppm TCE, 10 ppm c-DCE, and VC each entering a treatment zone, the amounts of these chemicals in the pore water exiting the treatment zone are shown in the following table in ppm.

Temperature, C°	Effluent Concentration in ppm per pass		
	TCE	c-DCE	VC
25	0.0003	0.0168	0.0005
40	0	0	0
60	0	0	0

Thus, the actual amount of iron in the treatment zones (26 vol% or 1.61 g Fe/cm³) was more than sufficient to destroy TCE and its daughter products to very low levels, theoretically in a single pass. Note that dechlorination of TCE and its daughter products was occurring between 40 and 60°C during most of the operation. Additionally, the design

assumed at least 2 pore volumes, i.e. each fluid element would pass through treatment zones twice.

Dechlorination Results from Water Samples

Water from the monitoring piezometers 2A-01, 2A-02, 2A-03, 2A-04, 2A-05, and the cathode was sampled on a periodic basis throughout the experiment. As can be seen in Figure F-8, the TCE concentration in well 2A-03 dropped from the initial value of 150 ppm to 15 ppm at the end of the test. Wells 2A-04 and 2A-05, which were emplaced behind the last treatment zone, showed different trends. Although the initial readings at both sampling locations were approximately 500-600 ppm, the TCE levels in 2A-05 remained high longer, while readings at the 2A-04 location declined steadily to about 160 ppm. It is unclear why location 2A-04 cleaned up as expected while 2A-05 was much slower to clean up. Piezometer 2A-01 became dry after November 5, 1996 until April 1997, after which the TCE levels could again be recorded, and the level dropped to below 30 ppm. Piezometers 2A-01 and 2A-02 became dry in July and August, 1997 and could not be sampled.

Figure F-8. Water TCE Concentration Trends

There is a strong possibility that some of the monitoring piezometers were contaminated with DNAPL. Some of the March water samples do not correlate well with the soil sampling. This is especially true for sample point 2A-05. The very high levels of TCE in the water (800 ppm) would surely indicate DNAPL in close proximity of the piezometer. The soil sampling, however, showed that TCE levels in the soil were well below DNAPL levels, even though a special effort was made to ensure DNAPL, if present, would be detected. To test the possibility of the piezometer 2A-05 contamination with DNAPL, in early June 1997, the well was purged several times, followed by sparging with helium for 72 hours. From that time on, the TCE levels in the pore water dropped steadily from approximately 700 to less than 200 ppm by early August, when the unit was shut down for final soil sampling.

Due to the strong evidence of DNAPL at various locations in the test plot, lab experiments were conducted to investigate the dechlorination of TCE. It was found that, as long as a minimal amount of water was present, the rate of TCE destruction for DNAPL would proceed at a rate comparable to that of TCE-saturated water. An unexpected outcome was the by-product distribution. For dissolved TCE, the products observed were primarily ethylene and ethane in equal amounts, with very little acetylene. When DNAPL was simulated, however, acetylene was determined to be the major dechlorination by-product, followed by ethylene, with very little ethane. This difference in by-product distribution provides an excellent indicator for determining TCE concentration levels in the field. The two reaction paths are shown in Appendix B as well as in the field results.

Water samples from various wells within the treatment cell and from a control well (MW 160) were taken six times during the test. The results are shown in Table F-2 and plotted in Figure F-9. It can be seen immediately that, throughout the test, samples from the control well showed high levels of TCE but non-detectable levels of the by-product gases ethylene, ethane, and acetylene. In contrast, all the samples from wells in the test zone showed high levels of the three by-product gases. For example, on Dec 13, 1996, the control sample showed 73 ppm TCE and none of the other gases, whereas well 2A-03 exhibited a comparable TCE level (78 ppm) but 144 ppb acetylene, 466 ppb ethane, and 223 ppb ethylene. The same is true for intermediate samples as well as for the final samples taken on June 6, 1997. It is thus clear that dechlorination of TCE was definitely occurring in the test zone, but not in the control area.

Table F-2. Water Sampling Results for Various Wells

Date	Sample ID	Concentration (ppb)					C ₂ Ratio
		Acetylene	Ethane	Ethylene	cis-DCE	TCE	
	<i>DNAPL TCE Degradation</i>	-	-	-	-	-	>10/0.2/1.0
	<i>Dissolved TCE Degradation</i>	-	-	-	-	-	<0.1/1.0/1.0
3-Dec	<i>Cathode 12/3/96</i>	426	38	168	NA	NA	2.5/0.2/1.0
3-Dec	<i>PZ-2A-02 12/3/96</i>	239	109	140	NA	NA	1.7/0.7/1.0
3-Dec	<i>PZ-2A-03 12/3/96</i>	149	405	177	NA	NA	0.8/2.3/1.0
3-Dec	<i>PZ-2A-04 12/3/96</i>	74	289	198	NA	NA	0.4/1.5/1.0
3-Dec	<i>PZ-2A-05 12/3/96</i>	15	385	113	NA	NA	0.1/3.4/1.0
13-Dec	<i>MW160(control) 12/13/96</i>	ND	ND	ND	ND	73,000	-
13-Dec	<i>PZ-2A-03 12/13/96</i>	144	466	223	ND	78,000	0.6/2.1/1.0
13-Dec	<i>PZ-2A-04 12/13/96</i>	61	262	153	ND	390,000	0.4/1.7/1.0
13-Dec	<i>PZ-2A-05 12/13/96</i>	33	379	165	ND	850,000	0.2/2.3/1.0
10-Jan	<i>PZ-2A-03 1/10/97</i>	143	211	184	NA	NA	0.8/1.1/1.0
10-Jan	<i>PZ-2A-04 1/10/97</i>	94	124	102	ND	200,000	0.9/1.2/1.0
10-Jan	<i>PZ-2A-05 1/10/97</i>	45	127	103	NA	NA	0.4/1.2/1.0
7-Mar	<i>PZ-2A-02 3/7/97</i>	147	ND	108			1.4/0.0/1.0
7-Mar	<i>PZ-2A-03 3/7/97</i>	ND	239	119			0.0/2.0/1.0
7-Mar	<i>PZ-2A-04 3/7/97</i>	57	85	70			0.8/1.2/1.0
7-Mar	<i>PZ-2A-05 3/7/97</i>	75	221	179			0.4/1.2/1.0
7-Mar	<i>Cathode 3/7/97</i>	184	105	221			0.8/0.5/1.0
30-Apr	<i>MW160(control) 4/30/97</i>	ND	ND	ND			-
30-Apr	<i>PZ-2A-03 4/30/97</i>	72	551	252			0.3/2.2/1.0
30-Apr	<i>PZ-2A-04 4/30/97</i>	74	334	92			0.8/3.6/1.0
30-Apr	<i>PZ-2A-05 4/30/97</i>	50	424	268			0.2/1.6/1.0
30-Apr	<i>Cathode 4/30/97</i>	127	ND	62			2.0/0.0/1.0
6-Jun	<i>MW160(control) 6/6/97</i>	ND	ND	ND		61,000	-
6-Jun	<i>PZ-2A-03 6/6/97</i>	59	629	311		45,000	0.2/2.0/1.0
6-Jun	<i>PZ-2A-04 6/6/97</i>	49	306	94		81,000	0.5/3.3/1.0
6-Jun	<i>PZ-2A-05 6/6/97</i>	49	720	297		490,000	0.2/2.4/1.0
6-Jun	<i>Cathode 6/6/97</i>	126	43	89		2,500	1.4/0.5/1.0
9-Jul	<i>MW160(control) 7/9/97</i>	ND	ND	ND		61,000	-
9-Jul	<i>PZ-2A-03 7/9/97</i>	58	816	385		47,000	0.2/2.1/1.0
9-Jul	<i>PZ-2A-04 7/9/97</i>	37	236	66		76,000	0.68/3.6/1.0
9-Jul	<i>PZ-2A-05 7/9/97</i>	91	763	290		280,000	0.3/2.6/1.0
9-Jul	<i>Cathode 7/9/97</i>	183	123	164		2,300	1.1/0.8/1.0

Figure F-9. C2 Degradation Products in Pore Water

Additionally, the pattern of by-product distribution, while varying widely, seemed very consistent with the combination of the two pathways previously discussed for TCE dechlorination. High levels of acetylene, which suggests dechlorination of DNAPL was dominating, accompanied intermediate levels of ethylene and much lower levels of ethane. In contrast, low levels of acetylene, which suggests dechlorination of dissolved TCE was dominating, accompanied much higher levels of ethane and intermediate to comparable levels of ethylene. It should be noted that high levels of the three by-product gases were also detected in the cathode water samples, indicating TCE dechlorination was occurring there as well. This is consistent with results from our laboratory studies.

Carbon Sock Data and Evidence of DNAPL Movement

The four carbon socks inserted in various soil regions (C-01, -02, -04 and -05 in Figure 2) in the test plot were intended to monitor the accumulated movement of TCE in the soil at periodic intervals. After the first 3 months of operation, the first set of carbon socks was recovered and analyzed for TCE and its main daughter products. The results for this first set are shown in Table F-3. Note that TCE distribution is consistent with soil sampling data showing high TCE contamination in the 15- to 25-foot depth regions. One intriguing aspect of these results was the very high levels of TCE found on the carbon. The simple calculation shown at the bottom of Table F-3 illustrates that, even if the soil pore water were 100% saturated with TCE, the amounts of TCE trapped on the carbon for all four socks from the 17- to 23-foot depth were many times higher than all the dissolved TCE in the pore water passing through. These results show clearly that the actual amounts of TCE in the soil were much higher than the average 50 ppm indicated by the pre-test soil sampling. More importantly, some form of DNAPL transport must have occurred to explain the carbon data. This is a significant result, since it suggests that the total treatment time could be significantly shorter than expected, based on TCE transport as dissolved in water. Data at the 4- and 5-month intervals shown in Table F-4 reveal even more accelerated accumulation of TCE on the carbon, probably a consequence of higher soil temperatures. Note that very high levels of TCE were recorded throughout all depths

during these periods, suggesting that vapor transport of TCE was an important factor in the apparent DNAPL-movement. It is possible that there could be several mechanisms for enhanced movement of DNAPL TCE in the soil due to increasing temperature: (1), enhanced dissolution rate, (2) EO-induced DNAPL movement due to lower viscosity, and (3) rapid distribution of TCE throughout the soil pore matrix via volatilization/vapor diffusion and re-absorption into the pore water.

Table F-3. First Carbon Sock Sampling Results

Carbon Socks First Sampling, November 13, 1996 Operation Time: 3 months				
Depth (ft)	TCE on Carbon (ppm)			
	C-01	C-02	C-04	C-05
4		83		2
5		52	20	7
6	12	55	18	19
7	17	77	80	36
8	16	22	26	20
9	28	83	26	18
10	23	5,265	52	23
11	69	9,306	33	27
12	2,064	6,562	11	65
13	6,937	5,595	11	161
14	9,465	8,199	80	369
15	14,714	24,392	115	816
16	29,704	41,436	100	2,715
17	81,420	105,190	1,747	3,441
18	116,989	136,687	54,230	9,029
19	118,259	154,094	31,377	24,221
20	126,433	169,319	53,571	18,591
21	102,790	150,946	41,457	70,617
22	116,964	81,176	17,900	94,812
23	130,106	103,850	140,714	139,821
Total TCE (g)	123	144	49	53

Calculations:
Carbon sock is 1.5 inches diameter, contains 144 grams wet carbon/ft.
Sock sectional area per foot in direction of flow = 116 cm².
At EO flow velocity of 0.8 cm/day, amount of water flowing into sock is equal to: 116 cm² x 0.8 cm/day x 0.4 (porosity) = 37.1
If water is saturated with TCE (1,100 mg/l), amount of TCE absorbed per foot of carbon sock for 3 months is:
1100 mg/l x 37.1 cm³/day x 0.001 l/cm³ x 90 days = 3.67 g TCE.
Average TCE loading on carbon for the 3 months time under saturated conditions = 3.67 g TCE / 144 g carbon = 25,500

TCE loadings on C-01 and C-02 from 17 to 23 ft are thus many times the saturation level, which suggests DNAPLs movement.

Table F-4. Carbon Sock Sampling Data for Second and Third Events

TCE on Carbon (ppm)					
Second Sampling, Dec 13, 1996 Operation Time : 4 months Carbon Sock Time : 1 month			Third Sampling, Jan 09, 1997 Operation Time : 5 months Carbon Sock Time		
			2 months		1 month
Depth (ft)	C-02	C-05	C-01	C-04	C-05
1	405,541			1,632	124,667
2	394,541		61,675	481	87,697
3	411,029	69	46,871	268	86,942
4	429,261	43	32,936	272	34,281
5	389,354	56	22,815	846	15,828
6	403,701	32	19,093	7,491	Bentonite
7	303,303	59	15,708	12,821	809
8	296,435	98	11,941	1,560	569
9	212,292	126	10,568	7,111	1,205
10	242,627	176	12,053	6,948	3,915
11	257,343	86	15,316	7,134	4,522
12	140,342	285	20,949	4,829	Bentonite
13	259,092	440	31,085	8,346	Bentonite
14	293,527	436	64,185	6,469	3,500
15	262,147	226	100,286	17,723	1,251
16	266,120	686	149,777	10,573	3,950
17	225,826	878	164,884	22,929	10,707
18	269,942	1,235	183,357	32,704	13,815
19	262,363	1,522	237,793	50,202	40,957
20	262,561	4,099	207,050	49,155	128,510
21	261,774	11,487	241,157	72,523	18,521
22	227,243	17,844		58,740	71,479
23	252,027	51,789		30,422	
24	286,678	61,624		55,553	
				53,131	
Total TCE (g)	631	14	148	47	39

With the carbon samples and piezometers indicating very high levels of TCE, a large amount of DNAPL was probably present in the southern portion of the experiment plot. The initial soil sampling did confirm the presence of DNAPL but not at the levels indicated by the carbon samples. The carbon sock data are graphically summarized in Figure F-10 and shown in more detail in Appendix C.

Figure F-10. TCE Amounts in Carbon Sock Monitors

Soil Data and TCE Removal Estimates

While the water data and dechlorination results were interesting, the decisive factor in determining whether the *Lasagna*TM process was successful in cleaning up the plot rested upon actual soil samples. The site operators and the State of Kentucky had negotiated a clean up target of 5.7 mg of TCE per kg of soil (ppm). This level was based on assessment modeling of the groundwater reaching the fence line. *Lasagna*TM would be considered successful if the average of the soil samples was less than 5.7 mg/kg. The soil sampling procedure called for at least 5 sample locations and soil samples taken at 1-foot intervals in the bore holes from 5 to 40 feet deep, as described in the experimental section.

The soil sampling results of the three soil sampling events - pre-test, mid-test, and post-test - are summarized in Table F-5. The pre-test soil sampling was performed in March, 1996. The data in Table F-5 show that the TCE concentrations in the soil ranged from non-detected to approximately 360 mg/kg (ppm) for any single soil sample. Sample point 2A-03 had the highest average TCE concentration (50 mg/kg), followed by 2A-02, 2A-05, 2A-04 and 2A-01. This soil sampling event shows there was DNAPL in the area of 2A-03, 2A-04 and 2A-05. More detailed soil data are included in Appendix D.

Table F-5. Soil Sampling Results

Sample Point		Mar-96	Mar-97	Aug-97	Removal	Number of Pore Volumes
2A-01	Min	nd		nd		
	Max	125		10.6		
	Avg	18.4		0.886	95.2%	1
2A-02	Min	.106	nd	nd		
	Max	148	1503	106		
	Avg	42.1	89.6	23.9	43.2%	<1
2A-03	Min	nd	nd	nd		
	Max	309	27.4	1.48		
	Avg	50.8	2.20	0.150	99.7%	2+
2A-04	Min	nd	nd	nd		
	Max	152	65.8	47.9		
	Avg	33.6	12.9	9.46	71.8%	<1
2A-05	Min	.188	.050	nd		
	Max	123	116	64.4		
	Avg	31.4	16.4	9.19	70.7%	<1

Results of the mid-test soil sampling conducted in early March, 1997, after 6 months of operation, were encouraging. The sampling was modified slightly to include samples at all soil strata interfaces as well as the 1-foot intervals. The purpose of this intermediate sampling event was to determine whether the LasagnaTM process was effective and whether DNAPL was still present. The soil samples near 2A-03, which was located between the 2-foot spaced treatment zones, indicated 95% removal of TCE. Since 2A-03 had the highest average pre-test TCE levels, the process was clearly effective, even with the presence of DNAPL. Soil samples near 2A-04 showed a 60% cleanup while the 2A-05 samples showed 50% cleanup. It is possible that some reverse movement of TCE in areas of high concentrations may have slowed the apparent clean-up of areas 2A-04 and 2A-05. The soil samples near 2A-02, which is an upstream location, showed very high amounts of TCE.

The post-test samples taken in August, 1997, show a continued decline in the soil TCE concentrations. Most impressively, sample 2A-03 dropped to an average of less than 0.2 ppm with the highest single sample measuring 1.5 ppm. Sample points 2A-04 and 2A-05 had average TCE concentrations above the 5.7 ppm target but showed steady progress with approximately 70% removal. Sample point 2A-01 showed excellent clean up with 95% removal and an average soil TCE concentration of less than 1 ppm. The upgradient sample point, 2A-02 has cleaned up slightly, but the results over the three sampling events are erratic. While the results from sample point 2A-02 are inclusive, its upgradient location suggests it is unlikely that any significant TCE removal has occurred, because the "clean front" of pore water would not yet have reached this location according to flow rate

measurements and electro-osmotic permeability calculations. The soil sample results for the five locations are presented in Figures F-11 - F-15.

Figure F-11. Soil TCE Concentrations for Sample Point 2A-01

Figure F-12. Soil TCE Concentrations for Sample Point 2A-02

Figure F-13. Soil TCE Concentrations for Sample Point 2A-03

Figure F-14. Soil TCE Concentrations for Sample Point 2A-04

Figure F-15. Soil TCE Concentrations for Sample Point 2A-05

Volatilization Testing

Since the soil was heated to an average temperature of 60°C (>80°C at the center core) by the end of the field test, there was concern that an unknown percentage of the TCE was possibly being volatilized into the surrounding atmosphere instead of being dechlorinated by electro-osmosis, thus causing a health hazard and leading to an erroneous conclusion on the effectiveness of the technology for TCE cleanup. To address this concern, emissions were monitored twice during the test using an EPA-certified flux chamber method, the first time about half way into the test and the second near the end when the soil temperature was the highest. The flux chamber method is the most commonly used air sampling procedure to determine gaseous emissions from landfills and impoundments. No significant TCE emissions, including its daughter products, were detected. The cold surfaces of the 4-foot gravel layer and a layer of treatment zone materials spread above the gravel may have resulted in condensation of any TCE emissions and thus helped contain them. The flux chamber data is presented in Appendix E.

Conclusions

Based upon these results, it is concluded that the *Lasagna*TM technology has demonstrated the capability to effectively dechlorinate TCE contamination in situ, including DNAPL concentrations, in low-permeable soil to a depth of 45 feet. An existing emplacement method with a hollow mandrel was effectively adapted for installing electrodes and treatment zones in thin layers through stiff clay soil without generating solid waste. The electrokinetic aspects of the field demonstration, such as water flow rate, voltage, and current distribution, power consumption, and extent of temperature rise and temperature profile in the soil correlate well with the pilot and laboratory experiments. These results were also in good agreement with a mathematical model developed from Phase I. Inexpensive, innocuous, and easily handled materials such as granular coke and iron filings were found to be effective for forming electrodes and treatment zones. This was the first time that iron filings mixed with clay to form a slurry has been shown to be effective for degrading TCE in an electrokinetic environment. There are strong indications that some of the TCE could have been transported and degraded in the DNAPL form. Soil samples taken at several key locations and down to the 45-foot depth indicated that two pore volumes of electro-osmotic flow between the adjacent treatment zones were sufficient to reduce TCE contamination levels to below the cleanup target of 5.7 ppm, even in regions containing DNAPL. The overall removal efficiency obtained was in the range of 95% for 1 pore volume to over 99% for 2.6 pore volumes. Implemented for the first time under actual field conditions and with the unexpected complications of much higher than expected DNAPL levels and complex hydrogeology in the subsurface, the *Lasagna*TM process has demonstrated its robustness and flexibility in cleaning up TCE-contaminated soil *in situ*.

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Appendix A. Field Data Electrokinetic Data Spreadsheets

Temperatures													
Temperature Trends													
Location	Elapsed Time	C-25'	C-50'	C-45'	C-5'	S-25'	E-25'	Ne-25'	Nw-25'	Control25'	Control5'	Surface	Ambient
TC #	Time	1	2	3	4	5	6	7	8	9	10	11	12
Date & Time (days)													Center Aver. frm 5-45'
8/9/96 11:30		15.4	14.7	14.9	25.4		15.5	15.8	15.1	14.6	26.3	28.2	18.6
8/12/96 14:00	0	14.9	14.2	14.4	22.9		15.0	15.5	14.8	14.3	25.7	25.8	17.4
8/13/96 13:50	0	14.8	14.1	14.3	23.2		15.3	15.9	15.1	14.7	25.8	26.0	17.4
8/14/96 12:10	0	17.4	17.3	17.8	26.3		18.3	19.0	18.0	17.2	27.9	28.2	20.5
8/15/96 8:30	0.85	15.6	14.4	14.7	23.5		15.8	16.2	15.8	14.3	25.2	27.5	17.9
8/16/96 8:30	1.85	16.0	14.2	14.5	24.0		16.3	16.9	16.4	14.1	25.0	26.8	18.2
8/19/96 9:17	4.88	17.6	14.2	15.0	26.2		17.6	19.3	18.4	14.1	25.4	28.9	19.6
8/20/96 9:43	5.90	18.9	15.2	27.8	28.0		18.7	20.4	19.5	14.9	26.2	30.0	24.9
8/21/96 11:00	6.95	18.4	14.3	15.4	27.5		18.4	20.1	19.0	14.1	25.6	29.4	20.4
8/21/96 14:20	7.09	18.1	14.1	15.2	27.3		18.4	19.0	20.0	14.1	25.6	29.4	20.2
8/22/96 10:00	7.91	19.1	14.4	15.6	28.0		18.9	19.2	20.2	14.2	25.8	30.2	20.9
8/23/96 10:00	8.91	19.4	14.6	15.9	28.7		19.0	19.6	20.8	14.4	26.2	30.6	21.3
8/26/96 9:00	11.87	20.9	15.1	16.7	30.4		21.2	20.7	22.0	14.7	26.7	31.0	22.7
8/27/96 10:15	12.92	21.5	15.7	17.4	31.5		21.1	21.4	22.8	15.4	27.6	30.9	23.5
8/28/96 13:30	14.06	21.4	15.4	17.1	31.5	-1.4	21.0	21.2	22.9	15.0	26.9	29.8	23.3
8/29/96 9:00	14.87	22.3	16.1	17.8	32.3		21.8	21.8	23.4	15.6	27.1	30.8	24.1
9/4/96 10:30	20.93	24.1	16.5	18.8	34.1	-0.8	23.2	23.2	23.9	16.0	26.6	29.5	25.7
9/5/96 13:48	22.07	23.9	17.7	20.0	35.4	-1.5	25.1	24.6	25.4	17.4	27.9	30.6	26.4
9/6/96 10:30	22.93	27.2	19.7	21.9	36.4	0.6	26.4	25.9	26.9	19.1	28.8	31.8	28.5
9/9/96 13:25	26.05	28.0	19.8	22.2	36.9	0.6	27.5	26.8	27.8	19.4	28.8	31.8	29.0
9/11/96 8:17	27.84	28.4	19.9	22.4	37.3	0.6	27.5	26.4	28.3	18.7	27.6	31.2	29.4
9/12/96 8:20	28.84	28.5	19.7	22.3	37.2	0.6	27.6	26.8	27.9	19.1	27.8	33.6	29.3
9/13/96 12:42	30.02	28.7	19.7	22.3	37.3	0.6	27.4	26.6	27.8	18.7	27.3	31.4	29.4
9/18/96 8:25	34.84	29.7	19.7	22.4	37.1	0.0	28.8	27.2	28.3	18.7	24.5	28.0	29.7
9/19/96 8:40	35.85	28.6	18.1	21.1	35.9	0.0	27.4	26.2	27.4	17.2	22.6	27.0	28.5
9/20/96 8:00	36.83	29.1	18.3	21.4	36.3	0.0	27.9	26.6	28.0	17.3	22.4	27.8	28.9
9/23/96 8:45	39.86	29.9	17.9	21.3	36.2		28.7	27.4	28.7	16.9	21.6	27.2	29.1
9/24/96 8:40	40.85	32.1	20.0	23.4	38.5		30.8	29.6	31.0	18.9	23.5	28.8	31.3
9/25/96 12:45	42.02	31.0	18.5	22.0	37.2		29.4	28.2	29.5	17.3	21.6	25.7	30.1
9/26/96 8:20	42.84	31.7	18.9	22.4	37.7		30.3	28.8	30.2	17.6	21.7	27.1	30.6
9/27/96 8:40	43.85	34.0	21.1	24.7	40.2		32.7	31.5	33.0	20.1	24.0	28.4	33.0
10/1/96 9:00	47.87	34.1	19.6	23.5	38.8		32.7	30.5	32.2	18.3	20.6	26.5	32.1
10/1/96 13:30	48.06	33.3	19.2	23.2	38.2		31.6	30.0	31.6	17.8	20.2	25.7	31.6
10/2/96 10:42	48.94	33.8	20.3	24.2	38.7		32.7	31.4	33.1	19.2	21.4	27.4	32.2
10/3/96 8:00	49.83	35.7	21.1	24.9	39.7	0.0	35.4	32.4	34.1	19.5	21.9	28.4	33.4
10/4/96 9:30	50.89	36.3	20.8	25.0	40.2	0.0	35.6	32.9	34.7	19.3	21.6	27.0	33.8
10/7/96 8:15	53.84	38.1	21.0	25.6	41.9	-0.7	37.4	34.9	35.8	19.5	21.2	29.0	35.2
10/8/96 8:15	54.84	39.2	21.5	26.1	42.8	0.0	38.2	35.5	36.3	19.7	21.4	29.4	36.0
10/9/96 9:20	55.88	39.6	21.2	25.9	43.0	0.0	38.4	35.7	36.3	19.3	20.6	26.7	36.2
10/10/96 10:05	56.91	40.7	21.6	26.6	44.1		39.6	36.5	37.1	19.7	20.4	27.1	37.1
10/11/96 11:20	57.97	41.5	22.1	27.2	44.9	0.0	40.2	37.2	37.8	20.2	20.4	26.3	37.9
10/15/96 8:30	61.85	43.2	22.2	27.6	45.4	0.0	41.5	37.6	38.5	20.5	20.2	30.5	38.7
10/16/96 9:20	62.88	43.8	22.5	28.0	45.6	0.0	41.8	37.7	38.7	20.3	20.3	30.0	39.1
10/17/96 10:11	63.92	44.8	22.6	28.1	45.8	0.0	43.1	37.8	39.5	20.2	20.2	29.9	39.6
10/18/96 9:43	64.90	45.4	23.3	28.9	46.8	0.0	43.4	39.1	39.9	21.2	21.4	29.1	40.4
10/21/96 9:00	67.87	46.4	23.2	28.9	46.4	0.0	45.5	39.8	40.5	20.8	19.5	26.6	40.6
10/22/96 8:30	68.85	46.8	23.1	28.9	46.4	0.0	44.6	40.0	40.6	20.7	19.2	26.3	40.7
10/23/96 7:40	69.81	47.8	23.5	29.5	46.7	0.0	45.8	40.1	40.7	21.1	19.4	24.2	41.3
10/24/96 13:50	71.07	47.7	23.5	29.6	46.4	0.0	44.8	40.6	41.2	21.2	18.9	24.2	41.2
10/29/96 9:10	75.88	49.6	23.3	29.7	45.8		48.3	41.3	42.1	20.8	18.1	25.1	41.7
10/30/96 10:07	76.91	51.2	24.5	30.8	47.1		49.5	42.5	43.8	21.8	19.6	26.4	43.0
10/31/96 14:20	78.09	51.8	24.5	31.2	47.2	0.0	50.1	43.0	44.2	22.1	19.9	26.0	43.4
11/1/96 14:41	79.10	51.8	24.5	31.0	47.0	0.0	49.6	42.8	44.1	21.8	18.0	24.6	43.3
11/4/96 8:05	81.83	52.5	24.2	30.8	46.5	0.0	50.3	42.8	44.2	21.3	16.1	22.2	43.3
11/5/96 8:05	82.83	53.0	24.5	31.2	46.8		50.5	43.6	44.8	21.6	15.9	23.1	43.7
11/6/96 9:45	83.90	53.1	24.5	31.4	46.6	0.0	50.3	43.6	44.3	21.7	16.1	23.8	43.7
11/8/96 13:12	86.04	55.4	26.0	33.0	47.9	0.0	52.4	45.6	45.3	23.2	17.8	21.5	45.4
11/11/96 9:45	88.90	55.8	25.2	32.2	46.8	0.0	53.5	45.3	44.5	22.4	15.0	18.4	44.9
11/12/96 8:35	89.85	56.4	25.5	32.6	46.8		54.0	45.6	44.6	22.4	14.3	17.9	45.3
11/13/96 8:25	90.84	57.4	26.0	33.2	47.1		55.0	46.8	45.1	22.9	14.4	18.2	45.9
11/14/96 8:45	91.86	57.4	25.8	33.0	46.4		54.6	46.1	45.0	22.8	13.8	16.8	45.6
11/18/96 9:15	95.88	59.2	26.1	33.5	46.4		56.2	47.6	46.6	23.1	13.8	18.9	46.4
11/20/96 15:10	98.13	59.9	26.4	33.8	47.1		56.5	48.0	48.1	23.4	14.1	19.2	46.9
11/21/96 8:07	98.83	60.3	26.4	33.8	47.2		57.2	48.2	48.4	23.3	13.8	19.5	47.1
11/21/96 14:20	99.09	60.7	26.8	34.3	47.6		57.5	48.5	48.9	23.8	14.2	19.6	47.5
11/22/96 8:38	99.85	61.6	27.5	34.9	48.2		58.2	49.4	49.6	24.5	14.7	18.7	48.2
11/25/96 13:20	103.05	62.4	27.1	34.6	48.2		58.8	49.8	50.1	24.1	13.8	17.9	48.4
11/26/96 8:25	103.84	62.7	27.3	34.8	48.1		59.2	49.8	50.4	24.2	13.6	16.2	48.5
11/27/96 13:30	105.06	62.7	27.3	34.9	47.8		58.6	49.4	50.7	24.5	13.2	15.3	48.5
12/2/96 12:20	110.01	64.2	27.2	34.8	48.0		60.0	50.6	51.6	24.3	12.5	17.5	49.0
12/3/96 8:10	110.83	65.2	27.7	35.2	48.6		61.6	51.6	52.2	24.5	12.4	18.1	49.7
12/5/96 11:40	112.98	65.0	27.0	34.7	48.4		61.2	51.0	52.0	24.3	11.4	17.6	49.4
12/9/96 10:40	116.94	66.7	27.7	35.4	49.8		62.6	52.1	53.6	25.2	11.9	18.2	50.6
12/9/96 12:00	116.99	67.8	29.3	37.0	51.3		63.1	53.3	55.1	26.8	13.6	19.8	52.0

A. Field Data Electrokinetic Data Spreadsheets (Cont'd)

Temperatures														
Temperature Trends (cont'd)														
Location	Elapsed	C-25'	C-50'	C-45'	C-5'	S-25'	E-25'	Ne-25'	Nw-25'	Control25'	Control5'	Surface	Ambient	Center Aver.
TC #	Time	1	2	3	4	5	6	7	8	9	10	11	12	frm 5-45'
Date & Time (days)														
12/10/96 10:20	117.92	67.1	28.0	35.7	49.9		62.9	52.2	53.7	25.0	11.4	18.3	7.5	50.9
12/12/96 11:23	119.97	67.9	28.4	36.1	51.1		63.3	53.2	54.8	25.9	13.3	20.9	4.0	51.7
12/13/96 8:10	120.83	68.2	28.4	36.1	50.7		63.8	53.2	54.8	25.7	13.3	20.1	0.1	51.7
12/13/96 9:50	120.90													
Polarity Reversal														
12/16/96 11:50	123.99	68.7	28.6	36.4	50.9		63.8	52.5	55.1	26.0	13.2	16.8	-2.7	52.0
12/18/96 10:30	125.93	69.6	29.3	37.2	53.2		65.1	53.2	55.9	26.7	12.2	15.1	-7.5	53.3
12/19/96 8:00	126.83	68.6	28.2	35.9	51.8		64.1	52.0	54.8	25.8	10.6	14.2	-12.3	52.1
12/19/96 14:30	127.10													
Polarity Normal														
12/19/96 14:30	127.10	70.8	30.5	38.1	53.4		65.8	53.8	56.9	27.9	12.5	15.8	-8.3	54.1
12/20/96 15:36	128.14	69.8	29.2	36.8	50.2		65.2	52.8	55.8	26.8	11.3	14.8	-6.1	52.3
12/23/96 12:10	131.00	71.2	29.2	37.1	49.9		66.1	53.2	56.3	26.6	9.8	18.5	12.4	52.7
12/26/96 9:10	133.88	72.2	29.2	37.2	50.5		67.2	54.4	56.6	27.2	10.5	16.7	-1.9	53.3
12/30/96 9:30	137.89	73.4	29.6	37.5	51.8		68.5	55.2	57.7	27.8	12.6	20.7	0.0	54.2
12/31/96 7:35	138.81	74.1	30.3	38.2	52.9		62.9	55.8	58.6	28.6	13.6	22.1	5.7	55.1
12/31/96 9:10	138.88	74.6	31.3	39.3	54.0		68.7	55.9	59.4	29.4	14.4	22.0	7.1	56.0
1/3/97 10:20	141.92	75.8	31.2	39.2	54.7		71.1	57.2	59.4	29.2	14.9	24.7	13.2	56.6
1/7/97 9:40	145.90	76.8	31.5	39.5	56.3		72.3	57.8	59.8	29.6	15.9	21.4	-3.0	57.5
1/9/97 9:25	147.89	75.8	32.6	40.5	57.7		74.0	59.3	61.0	31.2	15.4	20.1	-3.5	58.0
1/16/97 8:30	154.85	77.4	31.0	39.3	55.3		73.0	58.2	59.9	29.9	9.2	15.0	-8.6	57.3
1/21/97 8:05	159.83	83.3	31.8	41.2	57.7		78.6	62.5	64.2	31.3	7.2	17.6	9.8	60.7
1/22/97 8:00	160.83	83.2	32.2	41.2	57.7	Membrane	79.0	62.0	64.4	31.4	3.0	19.0	9.3	60.5
1/29/97 8:00	167.83	83.8	33.9	42.6	56.7		78.0	61.4	64.8	32.8	11.1	15.6	-5.8	61.0
2/6/97 8:00	175.83	82.1	34.0	42.1	54.2	83.5	76.3	61.1	64.3	33.8	13.1	19.4	2.2	59.5
2/14/97 8:00	183.83	78.5	32.9	40.8	51.0		73.4	58.1	62.2	33.0	10.9	16.0	2.6	56.8
2/18/97 8:15	187.84	77.3	32.7	39.8	48.7	79.0	71.2	58.2	61.4	32.6	10.7	17.3	11.1	55.3
2/25/97 12:30	195.01	77.0	33.6	40.8	49.2	76.7	71.2	56.2	61.6	33.6	14.1	19.8	12.4	55.7
2/26/97 9:00	195.87	75.3	32.6	39.9	48.4	75.9	70.6	56.0	60.6	32.9	13.8	20.3	10.5	54.5
3/4/97 7:25	201.80	72.8	32.4	39.7	44.7	71.0	68.1	53.8	58.6	33.1	15.2	17.3	10.2	52.4
3/5/97 9:00	202.87	73.6	33.6	40.2	45.3	70.3	68.3	54.4	59.0	33.7	16.3	20.8	9.2	53.0
3/7/97 7:25	204.80	71.8	32.6	39.5	43.9	68.9	66.3	53.1	57.4	33.2	14.8	18.3	6.4	51.7
3/12/97 10:00	209.91	69.1	31.9	38.6	41.5	66.2	64.2	51.6	55.7	32.9	15.3	20.5	9.9	49.7
3/17/97 14:20	215.09	68.2	32.4	38.4	40.2	63.4	63.0	50.7	54.2	32.5	15.0	17.4	11.0	48.9
3/18/97 8:30	215.85	68.5	32.6	38.2	39.9	63.2	61.7	50.1	53.7	32.6	14.8	17.4	15.1	48.9
3/18/97 9:55	215.91													
Polarity Reversal														
3/18/97 9:55	215.91	69.2	32.6	38.9	40.0	63.1	65.2	52.6	54.4	32.7	14.8	17.2	17.2	49.4
3/19/97 12:00	216.99	68.7	33.0	39.6	41.1	62.9	63.4	53.1	54.4	33.5	15.5	17.2	11.0	49.8
3/21/97 14:00	219.08	66.4	32.0	37.8	39.8	60.4	62.3	51.1	52.6	32.5	15.3	19.5	26.0	48.0
3/24/97 13:50	222.07	65.8	31.8	38.2	39.2	60.0	62.7	51.3	53.2	33.0	16.6	21.0	22.0	47.7
3/26/97 10:00	223.91	67.2	32.2	39.0	40.6	61.1	63.2	52.2	54.4	32.5	17.4	19.4	12.0	48.9
3/28/97 8:15	225.84	66.4	31.7	38.8	40.3	60.1	63.4	52.3	52.8	32.0	16.9	21.7	19.8	48.5
3/31/97 12:30	229.01	65.5	33.1	38.2	41.6	60.2	62.7	51.4	53.7	32.9	18.7	20.5	9.4	48.4
3/31/97 14:30	229.10													
Polarity Normal														
3/31/97 14:30	229.10	66.6	33.1	39.1	42.2	61.5	62.4	50.8	54.9	32.7	18.3	20.2	15.1	49.3
4/1/97 8:20	229.84	65.5	32.0	38.1	41.1	60.3	60.3	51.0	53.6	32.4	17.8	20.8	11.0	48.2
4/4/97 8:00	232.83	66.0	31.7	38.6	42.1	61.2	62.7	50.8	53.9	32.4	18.6	24.7	16.9	48.9
4/5/97 18:00	234.24													
Power off for unknown reason														
4/9/97 13:00	238.03													
Power back on														
4/10/97 9:30	238.89	64.3	32.4	38.0	42.1	59.2	60.4	49.4	53.1	32.1	18.9	20.3	5.0	48.1
4/17/97 8:40	245.85	63.7	31.7	37.5	43.2	60.6	59.6	49.8	53.2	32.3	19.5	22.6	4.8	48.1
4/23/97 14:20	252.09	62.7	32.3	36.7	44.6	61.0	58.7	49.6	53.1	32.2	19.7	23.0	16.5	48.0
4/25/97 12:40	254.02	61.7	31.7	36.7	44.9	61.4	58.1	48.5	53.6	32.3	19.9	24.9	21.0	47.8
4/25/97 13:15	254.05	61.7	31.7	36.7	44.9	61.4	58.1	48.5	53.6	32.3	19.9	24.9	21.0	47.8
4/28/97 14:45	257.11	63.7	32.1	37.7	46.9	62.3	60.5	51.5	54.2	32.4	20.7	23.2	19.9	49.4
5/1/97 12:00	259.99	62.9	31.7	38.0	47.3	62.5	60.2	50.6	53.8	32.2	21.4	26.4	17.1	49.4
5/7/97 9:40	265.90	62.5	31.2	37.2	48.1	62.3	59.7	50.1	53.8	31.8	21.8	27.6	19.8	49.3
5/13/97 8:35	271.85	62.1	31.7	37.1	50.0	63.0	60.0	50.0	54.0	32.2	23.9	29.3	15.3	49.7
5/20/97 13:50	279.07	62.1	31.9	37.7	52.0	63.9	59.2	50.2	54.8	31.8	26.2	30.0	21.5	50.6
5/21/97 13:30	280.06	62.2	32.1	37.6	52.5	64.9	59.2	49.4	55.0	32.9	26.4	31.0	21.3	50.8
5/27/97 12:00	285.99	60.2	31.7	35.5	52.5	64.0	56.3	49.2	53.6	32.0	27.0	32.9	18.5	49.4
5/28/97 14:35	287.10	59.3	31.1	35.9	52.2	64.4	54.7	46.5	53.5	32.0	27.1	31.1	23.8	49.1
6/2/97 9:45	291.90	59.4	31.4	35.5	53.3	65.9	56.2	48.9	57.8	32.3	25.9	27.7	18.9	49.4
6/6/97 9:15	295.88	59.0	31.0	36.0	54.0	67.0	55.0	48.0	57.0	32.0	26.0	31.0	20.0	49.7
6/10/97 8:00	299.83	59.7	31.3	35.6	55.2	68.0	56.6	49.3	59.3	32.2	26.7	32.8	19.1	50.2
6/16/97 9:00	305.87	59.0	31.0	35.0	55.0	69.0	56.0	48.0	58.0	32.0	28.0	34.0	23.0	49.7
6/20/97 9:45	309.90	61.6	30.9	37.1	56.6	72.9	58.5	49.1	61.0	32.0	29.2	36.0	28.9	51.8
6/26/97 8:55	315.86	59.0	31.0	36.0	56.0	68.0	55.0	48.0	62.0	32.0	32.0	40.0	24.0	50.3
6/30/97 8:20	319.84	57.8	30.8	34.7	56.2	67.1	54.1	47.0	61.0	32.5	32.8	38.7	24.7	49.6
7/16/97 10:50	335.94	58.7	30.8	35.8	56.2	65.2	56.2	47.5	62.5	33.0	35.3	40.6	32.7	50.2
7/30/97 10:20	349.92	58.0	30.6	35.5	57.1	65.1	54.3	46.7	63.8	39.5	38.7	40.4	33.9	50.2
8/6/97 7:27	356.80	56.5	30.3	34.7	55.8	62.4	53.4	46.0	63.6	33.8	38.0	41.6	16.6	49.0

A. Field Data Electrokinetic Data Spreadsheets (Cont'd)

Voltage Data (25ft depth)										Voltages		2' zone = 61 cm										Measured Flow Rate (l/hr)
Probe #	Elapsed Time (days)	Actual Run Time (days)	1.0 Center	2.0 North	3.0 South	4.0 East	5.0 West	6.0 W-Control	Overall Voltage (Volts)	Current (Amps)	Cummulative Power kw-hr	Estimated Flow (l/hr)	Estimated Travel (cm/day)	Cumulative Travel (cm)	Ave. Soil Conductivity (S/M)	Distance Traveled in inches	# Pore Volume 2' zone					
Location																						
Date & Time	(days)	(days)			(volts)				(Volts)	(Amps)		(l/hr)	(cm/day)	(cm)	(S/M)							
8/9/96 11:30			104.2	104.0	103.7	5.0	103.9	145.5	160													
8/12/96 14:00	0.0		99.4	99.2	98.8	5.0	98.7	138.2	150													
8/13/96 13:50	0.0		86.3	86.4	86.3	5.2	141.5	147.2	160	142					0.051							
8/14/96 12:10	0.0	0.0	72.1	87.6	91.8	5.0	137.8	143.5	158	136			11.3	0.61	0.6	0.049	0					
8/15/96 8:30	0.85	0.85	70.2	84.4	88.7	4.8	133.2	138.3	153	132		424	10.9	0.59	1.1	0.050	#N/A					
8/16/96 8:30	1.8	1.85	80.0	95.9	100.9	5.5	151.4	156.9	170	146		963	12.1	0.65	1.8	0.049	#N/A					
8/19/96 9:17	4.9	4.88	78.8	93.3	99.0	6.2	148.1	153.2	168	145		2,752	12.0	0.65	3.7	0.049	#N/A					
8/20/96 9:43	5.9	5.90	74.6	85.6	88.2	5.4	131.9	137.0	150	129		3,284	10.7	0.58	4.3	0.049	#N/A					
8/21/96 11:00	7.0	6.95	69.6	82.5	87.1	5.5	130.7	136.0	150	129		3,774	10.7	0.58	4.9	0.049	#N/A					
8/21/96 14:20	7.1	7.09	68.4	81.5	86.5	5.6	130.0	135.5	148	127		3,837	10.6	0.57	5.0	0.049	#N/A					
8/22/96 10:00	7.9	7.91	64.8	76.7	81.1	5.1	122.1	127.1	147	129		4,209	10.7	0.58	5.5	0.050	#N/A					
8/23/96 10:00	8.9	8.91	66.9	79.5	84.1	5.4	126.1	131.2	146	130		4,665	10.8	0.58	6.0	0.051	Update 11					
8/26/96 9:00	11.9	11.87	61.6	73.0	77.2	5.0	116.0	120.9	138	123		5,940	10.2	0.55	7.7	0.051	#N/A					
8/27/96 10:15	12.9	12.92	61.1	71.9	75.2	4.9	113.4	118.1	133	118		6,352	9.8	0.53	8.2	0.051	Length = 2					
8/28/96 13:30	14.1	14.06	65.1	77.0	81.1	5.7	122.0	127.2	138	125		6,801	10.4	0.56	8.9	0.052	Width = 30					
8/29/96 9:00	14.9	14.87							136	123		7,132	10.2	0.55	9.3	0.052	Depth = 40					
9/4/96 10:30	20.9	20.93							132	119		9,494	9.9	0.53	12.5	0.052	#N/A					
9/5/96 13:48	22.1	22.07							136	123		9,938	10.2	0.55	13.2	0.052	reference					
9/6/96 10:30	22.9	22.93	61.3	72.9	76.9	5.0	117.0	123.0	140	127		10,295	10.5	0.57	13.6	0.052	#N/A					
9/9/96 13:25	26.1	26.05	65.1	76.7	80.6	5.2	122.4	128.5	140	127		11,627	10.5	0.57	15.4	0.052	#N/A					
9/11/96 8:17	27.8	27.84	60.0	70.2	74.1	4.8	112.3	118.1	130	127		12,362	10.5	0.57	16.4	0.056	#N/A					
9/12/96 8:20	28.8	28.84	59.2	68.9	72.5	4.7	109.4	115.6	130	127		12,759	10.5	0.57	17.0	0.056	#N/A					
9/13/96 12:42	30.0	30.02	62.9	73.6	78.1	5.2	117.8	124.6	140	132		13,255	10.9	0.59	17.7	0.054	#N/A					
9/18/96 8:25	34.8	34.84	57.2	67.0	70.8	4.6	105.9	112.4	128	122		15,224	10.1	0.54	20.3	0.055	#N/A					
9/19/96 8:40	35.9	35.85	72.3	84.5	89.7	5.2	134.0	142.2	160	160		15,716	13.3	0.71	21.0	0.057	#N/A					
9/20/96 8:00	36.8	36.83	72.9	84.3	89.8	5.3	133.7	142.0	160	160		16,314	13.3	0.71	21.7	0.057	8.6					
9/23/96 8:45	39.9	39.86	72.9	84.4	89.7	5.3	133.3	142.3	160	158		18,165	13.1	0.71	23.9	0.057	9.4					
9/24/96 8:40	40.9	40.85	73.4	84.1	89.7	5.4	133.2	142.3	160	158		18,769	13.1	0.71	24.6	0.057	9.7					
9/25/96 12:45	42.0	42.02	73.6	84.5	90.0	5.6	133.6	142.5	160	159		19,481	13.2	0.71	25.4	0.057	10.0					
9/26/96 8:20	42.8	42.84	73.5	84.3	89.9	5.7	133.3	142.4	160	159		19,980	13.2	0.71	26.0	0.057	10.2					
9/27/96 8:40	43.9	43.85	73.5	83.8	89.2	5.6	132.3	141.8	160	159		20,599	13.2	0.71	26.7	0.057	10.5					
10/1/96 9:00	47.9	47.87	73.7	83.6	88.6	6.3	131.4	141.2	158	148		22,950	12.3	0.66	29.4	0.054	11.6					
10/1/96 13:30	48.1	47.87	94.0	107.0	112.0	7.0	167.0	180.0	200	207		23,093	17.2	0.92	29.5	0.059	11.6					
10/2/96 10:42	48.9	48.75	92.7	105.4	112.6	7.9	165.4	180.6	200	207		23,970	17.2	0.92	30.3	0.059	11.9					
10/3/96 8:00	49.8	49.64	96.5	108.6	114.6	8.1	171.2	184.4	200	209		24,856	17.3	0.93	31.2	0.060	12.3					
10/4/96 9:30	50.9	50.70	96.6	108.4	114.4	8.4	170.5	184.0	200	211		25,927	17.5	0.94	32.2	0.061	12.7					
10/7/96 8:15	53.8	53.65	96.1	106.9	112.2	8.1	167.6	181.8	200	217		28,956	18.0	0.97	35.0	0.062	13.8					
10/8/96 8:15	54.8	54.65	95.8	106.6	111.8	8.5	167.7	181.5	200	217		29,987	18.0	0.97	36.0	0.062	14.2					
10/9/96 9:20	55.9	55.69	96.3	106.1	111.3	8.6	166.5	181.6	200	215		31,081	17.8	0.96	37.0	0.062	14.6					
10/10/96 10:05	56.9	56.73	96.2	106.2	111.4	8.5	166.6	181.5	200	217		32,150	18.0	0.97	38.0	0.062	15.0					
10/11/96 11:20	58.0	57.78	96.3	105.6	111.5	8.6	165.5	181.0	200	218		33,248	18.1	0.97	39.0	0.063	15.4					
10/15/96 8:30	61.6	61.66	86.6	94.6	99.2	7.9	147.1	161.9	181	200		36,958	16.8	0.89	42.5	0.063	16.7					
10/16/96 9:20	62.9	62.69	82.8	89.8	94.7	7.8	141.1	155.0	175	187		37,613	15.5	0.83	43.3	0.061	17.1					
10/17/96 10:11	63.9	63.73	86.5	93.7	98.9	8.2	147.2	167.2	180	195		38,658	16.2	0.87	44.2	0.062	17.4					
10/18/96 9:43	64.9	64.71	80.7	86.8	92.4	7.7	136.3	149.8	170	184		39,436	15.3	0.82	45.1	0.062	17.7					
10/21/96 9:00	67.9	67.68	85.8	92.4	98.2	8.4	142.2	157.2	179	197		41,806	16.3	0.88	47.7	0.063	18.8					
10/22/96 8:30	68.8	68.66	85.4	91.9	97.3	8.6	143.0	158.2	180	198		42,639	16.4	0.88	48.5	0.063	19.1					
10/23/96 7:40	69.8	69.63	77.2	82.5	88.9	7.7	128.3	141.5	160	180		43,383	14.9	0.80	49.3	0.065	19.4					
10/24/96 13:50	71.1	70.88	89.0	94.9	103.0	9.0	147.7	163.3	180	206		44,373	17.1	0.92	50.5	0.066	19.9					
10/29/96 9:10	75.9	75.69	81.2	86.5	100.6	8.5	132.2	145.8	161	190		48,266	15.8	0.85	54.5	0.068	21.5					
10/30/96 10:07	76.9	76.73	81.5	86.8	94.8	8.4	133.2	145.8	161	190		49,030	15.8	0.85	55.4	0.068	21.8					
10/31/96 14:20	78.1	77.90	79.7	84.7	92.5	8.4	129.0	141.7	159	187		49,881	15.5	0.83	56.4	0.068	22.2					
11/1/96 14:41	79.1	78.92	78.8	83.6	91.3	8.3	127.8	140.1	155	186		50,594	15.4	0.83	57.2	0.069	22.5					
11/4/96 8:05	81.8	81.64	78.9	85.0	87.9	8.4	128.5	141.4	160	183		52,494	15.2	0.82	59.5	0.066	23.4					
11/5/96 8:05	82.8	82.45	85.5	91.5	94.9	9.2	139.1	153.2	170	197		53,246	16.3	0.88	60.3	0.067	23.8					
11/6/96 9:45	83.9	83.52	84.0	88.2	93.5	9.0	137.6	151.4	170	188		54,086	15.6	0.84	61.2	0.063	24.1					
11/8/96 13:12	86.0	85.67	81.4	87.1	91.5	9.0	134.6	148.2	170	190		55,739	15.8	0.85	63.1	0.064	24.8					
11/11/96 9:45	88.9	88.52	78.1	84.8	81.8	8.7	128.2	141.2	165	180		57,864	14.9	0.80	65.4	0.063	25.7					
11/12/96 8:35	89.9	89.48	83.4	89.9	88.4	9.3	136.8	150.4	170	186		58,564	15.4	0.83	66.1	0.063	26.0					
11/13/96 8:25	90.8	90.22	90.0	97.5	95.4	10.2	148.4	162.8	185	200		59,380	16.6	0.89	67.0	0.062	26.4					
11/14/96 8:45	91.9	91.23	84.9	91.7	89.7	9.7	139.0	152.8	180	193		60,253	16.0	0.86	67.9	0.062	2					

A. Field Data Electrokinetic Data Spreadsheets (Cont'd)

Voltage Data (25ft depth)																		
Probe #	Elapsed Time	Actual Run Time	1.0 Center	2.0 North	3.0 South	4.0 East	5.0 West	6.0 W-Control	Overall Voltage	Cumulative Current	Estimated Power	Estimated Flow	Estimated Travel	Estimated Cumulative Travel	Ave. Soil Conductivity	Distance Traveled	# Pore Volume	Measured Flow Rate
Date & Time	(days)	(days)			(volts)				(Volts)	(Amps)	kw-hr	(Vhr)	(cm/day)	(cm)	(S/M)	in inches	2' zone	(Uhr)
12/20/96 15:36	128.1	127.18	81.0	82.2	86.0	11.6	127.8	132.5	180	190	87,842	15.8	0.85	88.4	0.061	34.8	1.45	9.9
(Note: On 12/20/96, system was off for 3 hrs, on for 1.5 hr before voltage and flow was measured)																		
12/23/96 12:10	131.0	129.91	78.6	80.0	83.9	13.2	121.8	127.8	180	185	90,156	15.3	0.83	90.7	0.059	35.7	1.49	12.0
12/26/96 9:10	133.9	132.78	75.5	77.2	80.8	13.0	116.2	122.8	180	180	92,423	14.9	0.80	93.0	0.057	36.6	1.53	14.3
12/30/96 9:30	137.9	136.80	75.1	77.0	80.3	13.0	115.0	122.0	180	180	95,544	14.9	0.80	96.3	0.057	37.9	1.58	13.5
12/31/96 7:35	138.8	137.72	80.2	80.0	91.6	13.5	121.0	128.5	180	196	96,291	16.3	0.87	97.1	0.062	38.2	1.59	
1/3/97 9:10	138.9	137.78	80.2	80.0	91.6	13.5	121.0	128.5	180	196	96,347	16.3	0.87	97.1	0.062	38.2	1.59	13.5
1/3/97 10:20	141.9	140.83	80.1	79.6	91.9	13.9	120.1	127.7	180	188	98,876	15.6	0.84	99.7	0.060	39.2	1.64	13.8
1/7/97 9:40	145.9	144.81	70.7	70.0	81.4	13.0	105.9	112.8	180	170	101,777	14.1	0.76	102.7	0.061	40.4	1.68	12.0
1/9/97 9:25	147.9	146.80	75.4	74.4	87.0	14.0	112.4	119.9	172	181	103,168	15.0	0.81	104.3	0.060	41.1	1.71	15.9
1/16/97 8:30	154.8	153.78	73.1	74.8	79.4	14.3	111.0	118.9	180	175	108,402	14.5	0.78	109.7	0.056	43.2	1.80	13.5
1/21/97 8:05	159.8	158.74	71.7	73.5	78.2	14.1	109.5	117.4	180	171	112,126	14.2	0.76	113.5	0.055	44.7	1.86	14.5
1/29/97 8:00	169.8	168.74	46.3	47.5	50.1	9.5	69.8	75.2	120	112	112,634	9.3	0.50	114.0	0.054	44.9	1.87	
1/29/97 8:00	167.8	166.74	45.2	46.5	49.2	8.7	67.3	72.7	120	109	114,861	9.0	0.49	117.4	0.052	46.2	1.93	10.0
2/6/97 8:00	175.8	174.74	41.2	42.5	46.4	7.6	57.5	62.2	120	96	117,223	8.0	0.43	120.9	0.046	47.6	1.98	6.9
2/14/97 8:00	183.9	182.74	40.3	41.5	45.0	7.0	56.3	60.9	120	93.5	119,406	7.8	0.42	124.2	0.045	48.9	2.04	7.8
2/18/97 8:15	187.8	186.75	39.2	40.8	43.5	6.9	54.9	59.3	120	85	120,437	7.0	0.38	125.7	0.041	49.5	2.06	4.8
2/25/97 12:30	195.0	193.92	37.0	38.9	41.2	6.7	51.5	56.0	120	83	122,173	6.9	0.37	128.4	0.040	50.5	2.11	4.4
3/2/97 8:00	198.9	197.8	POWER OFF							0	122,377	0.0	0.00	128.4		50.5	2.11	
3/4/97 7:25	201.8	194.78	0.0	0.0	0.0	0.0	0.0	0.0	0	0	122,377	0.0	0.00	128.4		50.5	2.11	
3/5/97 9:00	202.9	194.78	0.0	0.0	0.0	0.0	0.0	0.0	0	0	122,377	0.0	0.00	128.4		50.5	2.11	
3/7/97 7:25	204.8	194.78	0.0	0.0	0.0	0.0	0.0	0.0	0	0	122,377	0.0	0.00	128.4		50.5	2.11	
3/12/97 10:00	209.9	194.78	0.0	0.0	0.0	0.0	0.0	0.0	0	0	122,377	0.0	0.00	128.4		50.5	2.11	0.0
3/17/97 11:20	215.1	194.78	40.4	41.2	44.6	6.8	59.5	61.3	120	87	122,377	7.2	0.40	128.4	0.042	50.5	2.11	
3/18/97 8:30	215.8	195.53	41.8	42.7	46.0	7.4	60.7	62.4	120	83	122,563	6.9	0.37	128.7	0.040	50.7	2.11	4.8
3/18/97 9:55	215.9	195.53	41.2	42.2	46.1	6.7	61.1	62.3	120	91	122,577	7.5	0.40	128.7	0.044	50.7	2.11	
3/19/97 12:00	217.0	196.62	40.9	42.7	46.2	7.4	60.3	62.4	120	87.5	122,856	7.3	0.39	128.2	0.042	50.5	2.10	
3/21/97 14:00	219.1	198.70	41.5	43.2	46.6	8.2	60.5	62.2	120	86.3	123,378	7.2	0.39	127.4	0.041	50.2	2.09	
3/24/97 13:50	222.1	201.70	42.2	43.8	47.6	9.2	60.8	62.3	120	87.1	124,125	7.2	0.39	126.3	0.042	49.7	2.07	
3/26/97 10:00	223.9	203.54	41.8	43.8	47.2	10.0	60.6	62.0	120	84	124,578	7.0	0.37	125.6	0.040	49.4	2.06	
3/28/97 8:15	225.8	205.47	42.0	43.8	50.9	10.7	62.2	61.6	120	86.3	125,051	7.2	0.39	124.8	0.041	49.2	2.05	
3/31/97 12:30	229.0	208.64	42.8	44.7	47.4	4.6	65.3	61.9	120	83.6	125,828	6.9	0.37	123.7	0.040	48.7	2.03	
3/31/97 14:30	229.1	208.64	52.9	55.5	59.8	0.9	76.0	78.6	150	116	125,829	9.6	0.50	123.7	0.044	48.7	2.03	
4/1/97 8:20	229.8	209.39	52.2	53.9	59.0	9.3	76.3	77.8	150	116.5	126,140	9.7	0.52	124.0	0.045	48.8	2.03	
4/4/97 8:00	232.8	212.37	52.4	54.4	58.6	8.3	77.2	78.2	150	116.9	127,394	9.7	0.52	125.6	0.045	49.5	2.06	5.0
4/5/97 18:00	234.2	213.79																
4/9/97 13:00	238.0	213.79																
4/10/97 9:30	238.9	214.84	49.7	52.2	55.3	7.8	71.8	74.3	150	110	127,973	9.1	0.49	126.3	0.042	49.7	2.07	7.0
4/17/97 8:40	245.9	221.61	48.5	50.4	54.4	7.7	68.5	71.3	150	100	129,352	8.3	0.45	129.4	0.038	50.9	2.12	7.0
4/23/97 14:20	252.1	227.84	46.0	48.4	50.8	8.6	64.9	67.3	150	82	130,474	6.8	0.37	131.7	0.031	51.8	2.16	8.5
4/25/97 12:40	254.0	229.77	45.0	50.9	54.9	9.0	63.6	66.4	150	74	131,142	6.1	0.33	132.3	0.028	52.1	2.17	6.1
4/25/97 13:15	254.0	229.80	65.0	68.7	71.8	12.2	92.6	97.2	210	115	131,151	9.5	0.51	132.3	0.031	52.1	2.17	
4/28/97 14:45	257.1	232.86	64.6	67.7	72.6	12.9	91.8	96.8	210	130	132,671	10.8	0.58	134.1	0.036	52.8	2.20	12.0
5/1/97 12:00	260.0	235.75	56.0	57.9	61.3	10.6	78.6	82.5	175	120	134,031	10.0	0.54	135.7	0.039	53.4	2.23	8.6
5/7/97 9:40	265.9	241.65	50.1	53.1	56.6	10.8	70.0	74.5	175	109	136,944	9.0	0.49	138.5	0.036	54.5	2.27	7.1
5/13/97 8:35	271.9	247.60	46.8	50.2	52.0	11.0	66.0	70.0	175	102	139,933	8.5	0.46	141.2	0.033	55.6	2.32	8.7
5/20/97 13:50	279.1	254.82	43.1	46.3	48.1	10.4	60.9	64.5	175	89	143,298	7.4	0.40	144.1	0.029	56.7	2.36	7.8
5/21/97 13:30	280.1	255.81	44.6	48.0	50.7	10.7	63.2	67.2	175	98	143,708	8.1	0.44	144.5	0.032	56.9	2.37	
5/27/97 12:00	286.0	261.75	44.9	47.6	51.0	10.6	63.6	67.6	175	96.8	146,202	8.0	0.43	147.1	0.032	57.9	2.41	6.3
5/28/97 14:35	287.1	261.75	60.0	66.0	69.0	14.0	85.0	90.0	175	138	146,634	11.4	0.62	147.8	0.045	58.2	2.42	
6/2/97 8:45	291.9	266.55	54.0	58.0	62.0	13.0	76.0	80.0	175	119	149,012	9.9	0.53	150.3	0.039	59.2	2.47	11.8
6/6/97 9:15	295.9	270.52	51.0	51.0	60.0	12.0	73.0	78.0	175	112	150,815	9.3	0.50	152.3	0.037	60.0	2.50	8.2
6/10/97 8:00	299.8	274.47	50.0	54.0	57.0	12.0	70.0	74.0	175	111	152,888	9.2	0.50	154.3	0.036	60.7	2.53	10.2
6/16/97 9:00	305.9	280.51	47.0	48.0	53.0	12.0	66.0	70.0	175	103	155,806	8.5	0.46	157.1	0.034	61.8	2.58	6.2
6/26/97 8:45	309.9	284.55	58.0	62.0	69.0	14.0	82.0	87.0	175	132	157,626	10.9	0.59	159.4	0.043	62.8	2.62	1.4
6/26/97 8:55	315.9	290.51	39.0	42.0	43.0	10.0	55.0	59.0	175	85	160,670	7.0	0.38	161.7	0.028	63.7	2.65	5.2
6/30/97 8:20	319.8	294.49	37.0	43.0	42.0	9.9	52.0	57.0	175	81	162,240	6.7	0.36	163.1	0.027	64.2	2.68	4.5
7/16/97 10:50	335.9	310.59	33.0	37.0	36.0	8.7	47.0	50.0	175	64	169,443	5.3	0.29	167.7	0.021	66.0	2.75	3.8
7/30/97 10:20	349.9	324.57	31.0	35.0	34.0	8.0	44.0	48.0	175	61	173,817	5.1	0.27	171.5	0.020	67.5	2.81	3.1
8/6/97 7:27	356.8	331.45	30.0	34.0	33.0	8.0	42.0	46.0	180	58	175,898	4.8	0.26	173.3	0.018	68.2	2.84	3.9

CDM WESTON

Appendix B. Water Sampling Analysis and Summary Spreadsheets

Well ID	Method	LAB	Date	Vial ID	CDMFPC			Weston			LMUS			Customer Sample #	Old CDMFPC	
					VC	DCE (ug/L)	TCE-CDM	VC	DCE (ug/L)	TCE-Weston	VC	DCE (ug/L)	TCE-LMUS		Conc	
PZ-2A-01	P&T		8/8/96	PZ-2A-01(8/8)	4	ND	168,085	ND	ND	150,000	ND	ND	240,000	513, 511, 512		
PZ-2A-02	P&T		8/8/96	PZ-2A-02(8/8)	23	163	40,472	NA	NA	NA	NA	NA	NA	508		
PZ-2A-03	P&T		8/8/96	PZ-2A-03-A1(8/8)	43	1,960	57,240	NA	NA	NA	NA	NA	NA	507		
PZ-2A-04	P&T		8/8/96	PZ-2A-04-A1(8/8)		1,112	260,000	ND	ND	340,000	NA	NA	NA	509, 510		
PZ-2A-05	P&T		8/8/96	PZ-2A-05-A1(8/8)	25	850	460,000	NA	NA	NA	ND	ND	700,000	505, 506		
PZ-2A-01	P&T		8/12/96	PZ-2A-01(8/12)	63	ND	99,113	ND	ND	300,000	NA	NA	NA	516, 518, 517		
PZ-2A-02	P&T		8/12/96	PZ-2A-02(8/12)	105	1,891	335,175	NA	NA	NA	NA	NA	NA	523		
PZ-2A-03	P&T		8/12/96	PZ-2A-03-A1(8/12)	51	109	68,456	NA	NA	NA	NA	NA	NA	522		
PZ-2A-04	P&T		8/12/96	PZ-2A-04-A1(8/12)	45	57	185,224	ND	ND	430,000	NA	NA	NA	519, 520		
PZ-2A-05	P&T		8/12/96	PZ-2A-05-A1(8/12)	3	366	102,108	NA	NA	NA	NA	NA	NA	521		
PZ-2A-01	P&T		8/27/96	PZ-2A-01(8/27)	4	106	28,000	ND	ND	420,000	NA	NA	NA	527, 529, 528		
PZ-2A-02	P&T		8/27/96	PZ-2A-02(8/27)	69	1,300	790,000	NA	NA	NA	NA	NA	NA	534		
PZ-2A-03	P&T		8/27/96	PZ-2A-03-A1(8/27)	74	5,300	300,000	NA	NA	NA	NA	NA	NA	533		
PZ-2A-04	P&T		8/27/96	PZ-2A-04-A1(8/27)	0	2,200	480,000	ND	ND	410,000	NA	NA	NA	530, 531		
PZ-2A-05	P&T		8/27/96	PZ-2A-05-A1(8/27)	32	2,200	770,000	NA	NA	NA	NA	NA	NA	532		
MW-160(8/27/96)	P&T		8/27/96	MW-160(8/27/96)	ND	218	60,000	ND	ND	36,000	NA	NA	NA	535, 537, 538		
PZ-2A-01	P&T		9/10/96	PZ-2A-01-A1(9/10)	ND	690	48,000	NA	NA	NA	NA	NA	NA			
PZ-2A-01	P&T		9/10/96	PZ-2A-01-A2(9/10)	ND	460	49,000	NA	NA	NA	NA	NA	NA			
PZ-2A-02	P&T		9/10/96	PZ-2A-02-A1(9/10)	ND	1,800	130,000	NA	NA	NA	NA	NA	NA	550-A1		
PZ-2A-02	P&T		9/10/96	PZ-2A-02-A2(9/10)	NA	NA	NA	NA	NA	NA	NA	NA	NA	550-A2		
PZ-2A-02	P&T		9/10/96	PZ-2A-02-B1(9/10)	ND	876	NA	NA	NA	NA	NA	NA	NA	550-B1		
PZ-2A-03	P&T		9/10/96	PZ-2A-03-A1(9/10)	1,300	6,000	190,000	NA	NA	NA	ND	ND	260,000	548-A1, 549-A1		
PZ-2A-03	P&T		9/10/96	PZ-2A-03-A2(9/10)	ND	5,400	180,000	NA	NA	NA	ND	ND	230,000	548-A2, 549-A2		
PZ-2A-03	P&T		9/10/96	PZ-2A-03-B1(9/10)	NA	NA	NA	NA	NA	NA	ND	ND	260,000	549-B1		
PZ-2A-03	P&T		9/10/96	PZ-2A-03-B2(9/10)	NA	NA	NA	NA	NA	NA	ND	ND	220,000	549-B2		
PZ-2A-04	P&T		9/10/96	PZ-2A-04-A1(9/10)	17	1,700	ND	ND	ND	400,000	ND	ND	570,000	542-A1, 544-A1		
PZ-2A-04	P&T		9/10/96	PZ-2A-04-A2(9/10)	ND	1,700	510,000	NA	NA	NA	ND	ND	570,000	542-A2, 544-A2		
PZ-2A-04	P&T		9/10/96	PZ-2A-04-B1(9/10)	ND	2,300	NA	NA	NA	NA	ND	ND	580,000	542-B1, 544-B1		
PZ-2A-04	P&T		9/10/96	PZ-2A-04-B2(9/10)	ND	1,500	710,000	NA	NA	NA	ND	ND	570,000	542-B2, 544-B2		
PZ-2A-05	P&T		9/10/96	PZ-2A-05-A1(9/10)	28	2,300	410,000	ND	ND	260,000	ND	ND	410,000	545-A1, 547-A1		
PZ-2A-05	P&T		9/10/96	PZ-2A-05-A2(9/10)	ND	2,900	380,000	NA	NA	NA	ND	ND	370,000	545-A2, 547-A2		
PZ-2A-05	P&T		9/10/96	PZ-2A-05-B1(9/10)	ND	1,100	460,000	NA	NA	NA	ND	ND	370,000	545-B1, 547-B1		
PZ-2A-05	P&T		9/10/96	PZ-2A-05-B2(9/10)	ND	1,200	390,000	NA	NA	NA	ND	ND	370,000	545-B2, 547-B2		
PZ-2A-01	P&T		9/24/96	PZ-2A-01-A1(9/24)	ND	5,400	91,000	NA	NA	NA	NA	NA	NA	554	554	
PZ-2A-01	P&T		9/24/96	PZ-2A-01-A2(9/24)	ND	2,100	98,000	NA	NA	NA	NA	NA	NA	554		
PZ-2A-01	P&T		9/24/96	PZ-2A-01-A3(9/24)	ND	8,300	140,000	NA	NA	NA	NA	NA	NA			
PZ-2A-02	P&T		9/24/96	PZ-2A-02(9/24)	ND	ND	110,000	NA	NA	NA	NA	NA	NA	555	555	
PZ-2A-03	P&T		9/24/96	PZ-2A-03(9/24)	39	6,800	110,000	ND	ND	110,000	NA	NA	NA	558		
PZ-2A-04	P&T		9/24/96	PZ-2A-04-A1(9/24)	ND	3,200	470,000	ND	ND	550,000	ND	50,000	530,000	559		
PZ-2A-04	P&T		9/24/96	PZ-2A-04-A2(9/24)	ND	1,900	460,000	NA	NA	NA	NA	NA	NA	559	558	
PZ-2A-04	P&T		9/24/96	PZ-2A-04-A3(9/24)	3,000	3,700	440,000	NA	NA	NA	NA	NA	NA	559		
PZ-2A-05	P&T		9/24/96	PZ-2A-05(9/24)	ND	ND	180,000	NA	NA	NA	NA	NA	NA	561	559	
PZ-2A-02	P&T		11/13/96	PZ-2A-02(11/13)	33	NA	50,000	NA	NA	NA	NA	NA	NA	577		
PZ-2A-03	P&T		11/13/96	PZ-2A-03-A1(11/13)	ND	1,700	130,000	NA	NA	NA	NA	NA	NA	575		
PZ-2A-03	P&T		11/13/96	PZ-2A-03-A2(11/13)	ND	4,800	83,000	NA	NA	NA	NA	NA	NA	576		

CDM WESTON

Well ID	Method	LAB	Date	Yield	CDMFPC		ICE-CDM	Weston			LMUS			Customer Sample #	Old CDMFPC Cont
					VC	DCE (ug/L)		VC	DCE	ICE-Weston (ug/L)	VC	DCE	ICE-LMUS (ug/L)		
PZ-2A-04	P&T		11/13/96	PZ-2A-04(11/13)	11	3,000	200,000	ND	ND		260,000	NA	NA	310,000	570, 571, 572
PZ-2A-05	P&T		11/13/96	PZ-2A-05(11/13)	NA	3,700	530,000	ND	ND		640,000	NA	NA	NA	573, 574
PZ-2A-02	P&T		12/12/96	PZ-2A-02(12/12)	81	830	410,000	NA	NA	NA	NA	NA	NA	NA	577
PZ-2A-03	P&T		12/12/96	PZ-2A-03(12/12)	119	1,030	59,000	NA	NA	NA	NA	0	0	78,000	575
PZ-2A-04	P&T		12/12/96	PZ-2A-04(12/12)	43	900	220,000	0	0	0	310,000	NA	0	390,000	576
PZ-2A-05	P&T		12/12/96	PZ-2A-05(12/12)	75	2,130	490,000	0	0	0	470,000	NA	0	850,000	570
PZ-2A-03	P&T		1/10/97	PZ-2A-03(1/10)	4	1,200	81,000	NA	NA	NA	NA	NA	NA	NA	573
PZ-2A-04	P&T		1/10/97	PZ-2A-04(1/10)	29	700	160,000	0	0	0	170,000	NA	0	200,000	
PZ-2A-05	P&T		1/10/97	PZ-2A-05(1/10)	8	2,600	710,000	0	0	0	730,000	NA	NA	NA	
PZ-2A-03	P&T		2/12/97	PZ-2A-03(2/12)	29	660	33,000	NA	NA	NA	ND	ND	ND	13,000	
PZ-2A-05	P&T		2/12/97	PZ-2A-05(2/12)	15	2,200	950,000	0	0	0	550,000	ND	ND	750,000	
PZ-2A-02	P&T		2/12/97	PZ-2A-02(2/12)	50	1,100	710,000	NA	NA	NA	ND	ND	ND	730,000	
PZ-2A-04	P&T		2/12/97	PZ-2A-04(2/12)	39	630	140,000	0	0	0	5,800	ND	ND	140,000	
PZ-2A-02	P&T		3/7/97	PZ-2A-02(3/07)	26	1,700	160,000	NA	NA	NA	NA	NA	NA	NA	
PZ-2A-03	P&T		3/7/97	PZ-2A-03(3/07)	73	640	35,000	NA	NA	NA	NA	NA	NA	NA	
PZ-2A-04	P&T		3/7/97	PZ-2A-04(3/07)	75	1,400	120,000	NA	NA	NA	NA	NA	NA	NA	
PZ-2A-04	P&T		3/7/97	PZ-2A-04(3/07)	72	1,200	150,000	NA	NA	NA	NA	NA	NA	NA	
PZ-2A-05	P&T		3/7/97	PZ-2A-05(3/07)	77	2,500	590,000	NA	NA	NA	NA	NA	NA	NA	
PZ-2A-03	P&T		4/30/97	PZ-2A-03(4/30)	14	1,800	22,000	0	0	0	39,000	NA	NA	NA	
PZ-2A-04	P&T		4/30/97	PZ-2A-04(4/30)	4	810	42,000	0	0	0	80,000	NA	NA	NA	
PZ-2A-05	P&T		4/30/97	PZ-2A-05(4/30)	21	1,300	101,000	NA	NA	NA	NA	NA	NA	NA	
Cathode SE	P&T		6/6/97	Cathode SE(6/6)		400	10,000	ND	ND		2,500	0	0	1,400	
MW-160	P&T		6/6/97	MW-160(6/6)		19	83,000	ND	ND		61,000	0	0	50,000	
PZ-2A-03	P&T		6/6/97	PZ-2A-03(6/6)	7	1,800	94,000	ND	ND		45,000	0	0	39,000	
PZ-2A-04	P&T		6/6/97	PZ-2A-04(6/6)		450	160,000	ND	ND		81,000	0	0	85,000	
PZ-2A-05	P&T		6/6/97	PZ-2A-05(6/6)	10	2,700	700,000	ND	ND		490,000	0	0	360,000	
Cathode SE	P&T		7/9/97	Cathode SE(7/9)		710	18,000	0	270		1,700	ND	ND	2,300	
MW-160	P&T		7/9/97	MW-160(7/9)		18	90,000	0	0		51,000	ND	ND	61,000	
PZ-2A-03	P&T		7/9/97	PZ-2A-03(7/9)	5	1,900	94,000	0	0		33,000	ND	ND	47,000	
PZ-2A-04	P&T		7/9/97	PZ-2A-04(7/9)	4	560	109,000	0	0		63,000	ND	ND	76,000	
PZ-2A-05	P&T		7/9/97	PZ-2A-05(7/9)	11	1,300	15,000	0	0		230,000	ND	ND	280,000	
			8/7/97	Cathode SE(8/7)				0	65		230				
			8/7/97	MW-160(8/7)				0	0		42,000				
			8/7/97	PZ-2A-03(8/7)				0	0		26,000				
			8/7/97	PZ-2A-04(8/7)				0	0		32,000				
			8/7/97	PZ-2A-05(8/7)				0	0		170,000				

B-2

TCE

Monsanto informal data																		
TCE analysis trends			Results in mg/l (ppm)															
Well #	10/15/96	10/22/96	11/5/96	11/21/96	11/25/96	12/3/96	12/31/96	1/22/97	1/29/97	2/6/97	2/18/97	(+/-) 3/31/97	4/29/97	5/13/97	5/21/97	6/10/97	7/9/97	8/7/97
2A-01	180	201	192									38	nd	38	15	30		
2A-02				600	746	677	686	414	257	656	679	109	157	302	122	250		
2A-03	155	109	109	68	78	82	105	13	14	11	15	3	39	48	39	46	33	26
2A-04	521	554	557	441	471	450	362	195	204	179	162	75	66	77	78	81	63	32
2A-05	534	698	572	678	785	769	725	786	862	759	794	638	541	565	659	591	230	170
Cathode	6	10	7	2	<1	8	8	7	3	9	6		2	5	3	2	1.7	0.23
Sump			nd		nd	<1	7	2	3	6	3	3	nd	3	nd	2		
Anode			nd		nd	<1	6	2	3	1	1		nd	nd	nd	nd		
C-01				38.5														
C-02				788.5														
C-04				148.5														
C-05				302.5														

chloride

Monsanto informal data																		
Chloride analysis trends			Results in mg/l (ppm)															
Well #	10/15/96	10/22/96	11/5/96	11/21/96	11/25/96	12/3/96	12/31/96	1/22/97	1/29/97	2/6/97	2/18/97	(+/-) 3/31/97	4/29/97	5/13/97	5/21/97	6/10/97		
2A-01	133	110	14									45	15	4	4	2		
2A-02				87	85	63	212	372	337	495	575	822	314	333	340	199		
2A-03	69	56	49	35	37	30	31	14	7	19	8	16	16	19	17	13		
2A-04	18	14	13	7	9	7	6	6	4	13	26	7	9	12	14	11		
2A-05	21	25	16	7	9	7	5	13	5	9	5	68	10	6	4	3		
Cathode		148	113	49	93	83	53	82	14	73	69	50	15	9	13	9		
Sump			46	46	40	40	39	30	28	33	23	51	50	36	21	11		
Anode			32	43	35	32	34	141	25	28	24	22	138	1	259	192		
C-01				167														
C-02				652														
C-04				12														
C-05				8														

pH

Monsanto informal data																
pH analysis trends																
Well #	10/15/96	10/22/96	11/5/96	11/21/96	11/25/96	12/3/96	12/31/96	1/22/97	1/29/97	2/6/97	2/18/97	(+/-) 3/31/97	4/29/97	5/13/97	5/21/97	6/10/97
2A-01	6.44	6.33	6.29									6.75	6.47	7.33	7.42	7.94
2A-02				6.55	6.74	6.57	6.58	6.24	6.29	6.27	6.12	6.24	6.53	6.47	6.35	6.56
2A-03	7.10	6.90	6.62	6.97	6.82	7.21	6.82	6.74	6.96	6.76	7.60	6.35	6.26	8.22	7.75	7.09
2A-04	6.90	6.70	6.60	6.67	6.59	6.51	6.42	6.08	6.26	6.28	6.47	6.55	6.42	6.39	6.42	6.27
2A-05	7.00	7.08	7.04	6.91	6.98	6.99	6.62	6.20	6.22	5.64	6.35	6.51	6.03	6.41	6.6	6.13
Cathode	12.38	12.25	12.37	12.53	12.58	12.40	12.39	12.48	12.47	12.48	12.49	10.42	11.96	12.04	12.06	12.28
Sump			12.25	11.84	11.95	11.80	12.13	11.25	11.66	11.56	11.74	10.44	11.88	11.95	11.8	12.32
Anode			11.86	10.98	10.16	9.86	10.62	6.57	10.80	11.44	11.49	12.22	8.22	8.34	5.32	7.07
C-01				6.83												
C-02				6.43												
C-04				6.07												
C-05				6.41												

COND

Monsanto informal data																
Specific Conductance analysis trends Results in uS/cm																
Well #	10/15/96	10/22/96	11/5/96	11/21/96	11/25/96	12/3/96	12/31/96	1/22/97	1/29/97	2/6/97	2/18/97	(+/-) 3/31/97	4/29/97	5/13/97	5/21/97	6/10/97
2A-01	612	608	406									710	293	202	110	54
2A-02				497	532	570	1080	1261	1400	1501	1650	2840	1132	1115	1338	775
2A-03	308	303	278	225	230	214	210	211	201	209	186	305	163	150	144	108
2A-04	417	530	565	476	531	630	350	279	219	411	797	181	283	498	545	280
2A-05	235	362	349	265	248	241	125	135	103	111	105	408	128	169	219	89
Cathode	18,040		18,500	18,180	15,210	14,200	15,800	18,050	13,700	14,150	14,810	1,150	8300	7400	8800	9420
Sump			10,340	3,390	3,850	4,610	8,750	2,710	3,530	3,707	4,060	1,225	5800	156	7100	8660
Anode			4,080	1,350	1,510	2,670	3,380	1,770	2,720	2,600	3,050	9,210	170	6950	1023	1380
C-01				783												
C-02				2260												
C-04				208												
C-05				230												

C2 Data

Concentration (ppb)

Date	Sample ID	Acetylene	Ethane	Ethylene	cis-DCE	TCE	C ₂ Ratio
	DNAPL TCE Degradation	-	-	-	-	-	>10/0.2/1.0
	Dissolved TCE Degradation	-	-	-	-	-	<0.1/1.0/1.0
3-Dec	Cathode 12/3/96	426	38	168	NA	NA	2.5/0.2/1.0
3-Dec	PZ-2A-02 12/3/96	239	109	140	NA	NA	1.7/0.7/1.0
3-Dec	PZ-2A-03 12/3/96	149	405	177	NA	NA	0.8/2.3/1.0
3-Dec	PZ-2A-04 12/3/96	74	289	198	NA	NA	0.4/1.5/1.0
3-Dec	PZ-2A-05 12/3/96	15	385	113	NA	NA	0.1/3.4/1.0
13-Dec	MW160(control) 12/13/96	ND	ND	ND	ND	73,000	-
13-Dec	PZ-2A-03 12/13/96	144	466	223	ND	78,000	0.6/2.1/1.0
13-Dec	PZ-2A-04 12/13/96	61	262	153	ND	390,000	0.4/1.7/1.0
13-Dec	PZ-2A-05 12/13/96	33	379	165	ND	850,000	0.2/2.3/1.0
10-Jan	PZ-2A-03 1/10/97	143	211	184	NA	NA	0.8/1.1/1.0
10-Jan	PZ-2A-04 1/10/97	94	124	102	ND	200,000	0.9/1.2/1.0
10-Jan	PZ-2A-05 1/10/97	45	127	103	NA	NA	0.4/1.2/1.0
7-Mar	PZ-2A-02 3/7/97	147	ND	108			1.4/0.0/1.0
7-Mar	PZ-2A-03 3/7/97	ND	239	119			0.0/2.0/1.0
7-Mar	PZ-2A-04 3/7/97	57	85	70			0.8/1.2/1.0
7-Mar	PZ-2A-05 3/7/97	75	221	179			0.4/1.2/1.0
7-Mar	Cathode 3/7/97	184	105	221			0.8/0.5/1.0
30-Apr	MW160(control) 4/30/97	ND	ND	ND			-
30-Apr	PZ-2A-03 4/30/97	72	551	252			0.3/2.2/1.0
30-Apr	PZ-2A-04 4/30/97	74	334	92			0.8/3.6/1.0
30-Apr	PZ-2A-05 4/30/97	50	424	268			0.2/1.6/1.0
30-Apr	Cathode 4/30/97	127	ND	62			2.0/0.0/1.0

C2 Data

Appendix C. Carbon Sock Data Spreadsheets

8/13/96

Carbon Sock #01

	TCE Conc. Carbon (mg/kg) 13-Nov-96	TCE Conc. Carbon (mg/kg) 9-Jan-97	TCE Conc. Carbon (mg/kg) 24-Feb-97	Power Off TCE Conc. Carbon (mg/kg) 11-Mar-97	TCE Conc. Carbon (mg/kg) 10-June-97	TCE Conc. Carbon (mg/kg) 3-Aug-97
Days	92	149	195	210	301	355
Delta Days	92	57	46	15	91	54
Depth						
0	12				4	
1	17		43,658	1	4	729
2	16	61,675	49,134	0	11	1,058
3	28	46,871	39,179	0	85	2,396
4	23	32,936	26,973	0	430	2,102
5	69	22,815	20,210	0	636	1,283
6	2,064	19,093	15,229	1	758	684
7	6,937	15,708	9,282	3	214	542
8	9,465	11,941	5,633	112	77	353
9	14,714	10,568	25,181	1,367		320
10	29,704	12,053				
11	81,420	15,316	291		512	
12	116,989	20,949	9,422	11	1,132	1,454
13	118,259	31,085	18,902	4	67	3,826
14	126,433	64,185	26,561	4	266	5,203
15	102,790	100,286	5,373	6	306	7,698
16	116,964	149,777		4		4,307
17	130,106	164,884	4,868			
18		183,357	9,571		998	
19		237,793	60,320	269	10,784	4,022
20		207,050	90,009	981	19,608	5,451
21		241,157	38,370	12,262	9,523	36,913
22			20,952	16,431	4,192	152,025
23			194	9,717	34,875	51,636
24				5,462	1,555	56,652
25				9,566		44,377
Total	856,011	1,649,499	519,311	66,201	86,039	383,032
Segment Wt (g)	144	90	60	60	60	60
Total TCE (g)	123	148	31	3.4	5.2	23
Rate (mg/day)	1,340	2,604	677	225	57	426

8/13/96

Carbon Sock #02

	TCE Conc. Carbon (ppm) 13-Nov-96	TCE Conc. Carbon (mg/kg) 16-Dec-96
Days	92	125
Delta Days	92	33
Depth		
0	83	
1	52	405,541
2	55	394,541
3	77	411,029
4	22	429,261
5	83	389,354
6	5,265	403,701
7	9,306	303,303
8	6,562	296,435
9	5,595	212,292
10	8,199	242,627
11	24,392	257,343
12	41,436	140,342
13	105,190	259,092
14	136,687	293,527
15	154,094	262,147
16	169,319	266,120
17	150,946	225,826
18	81,176	269,942
19	103,850	262,363
20		262,561
21		261,774
22		227,243
23		252,027
24		286,678
25		
Total	1,002,389	7,015,068
Segment Wt (g)	144	90
Total TCE (g)	144	631
Rate (mg/day)	1,569	19,132

8/13/96

Carbon Sock #04

	TCE Conc. Carbon (ppm) 13-Nov-96	TCE Conc. Carbon (mg/kg) 9-Jan-97	TCE Conc. Carbon (mg/kg) 24-Feb-97	Power Off TCE Conc. Carbon (mg/kg) 11-Mar-97	TCE Conc. Carbon (mg/kg) 10-June-97	TCE Conc. Carbon (mg/kg) 3-Aug-97
Days	92	149	195	210	301	355
Delta Days	92	57	46	15	91	54
Depth						
0	20		2,435	645	239	
1	18	1,632	2,197	0	6	6
2	80	481	773	1	2	2
3	26	268	2,046	1	6	3
4	26	272	4,457	3	2	3
5	52	846	1,287	3	4	3
6	33	7,491	1,166	2	5	2
7	11	12,821	3,895	3	5	
8	11	1,560	5,803	5	4	
9	80	7,111				3
10	115	6,948				3
11	100	7,134	1,639	2,126	4	13
12	1,747	4,829	339	134	1	10
13	54,230	8,346	795	152	2	9
14	31,377	6,469	1,960		2	
15	53,571	17,723	1,871		2	
16	41,457	10,573				7
17	17,900	22,929	6,138	3,438		1
18	140,714	32,704	9,200	407	279	7
19		50,202	16,892	401	5,160	51
20		49,155	28,756	1,628	816	938
21		72,523	34,122	1,281	114	606
22		58,740	33,212	1,195	98	2,244
23		30,422	33,699	1,879	532	
24		55,553		4,842	3,097	
25		53,131				
Total	341,569	519,865	192,681	18,145	10,379	3,912
Segment Wt (g)	144	90	60	60	60	60
Total TCE (g)	49	47	12	1.1	0.62	0.23
Rate (mg/day)	535	821	251	73	7	4

8/13/96

Carbon Sock #05

	TCE Conc. Carbon (ppm) 13-Nov-96	TCE Conc. Carbon (mg/kg) 13-Dec-96	TCE Conc. Carbon (mg/kg) 9-Jan-97	TCE Conc. Carbon (mg/kg) 24-Feb-97	Power Off TCE Conc. Carbon (mg/kg) 11-Mar-97	TCE Conc. Carbon (mg/kg) 10-June-97	TCE Conc. Carbon (mg/kg) 3-Aug-97
Days	92	122	149	195	210	301	355
Delta Days	92	30	27	46	15	91	54
Depth							
0	2	69			103	90	
1	7	43	124,667	2	317	1,321	
2	19	56	87,697	38	206	994	30,961
3	36	32	86,942	30	220	660	28,451
4	20	59	34,281	37	66	907	24,715
5	18	98	15,828	64	33	387	27,524
6	23	126		125	10	267	274,858
7	27	176	809	2,916	13	328	177,790
8	65	86	569	2,788	6	244	211,145
9	161	285	1,205				121,424
10	369	440	3,915				
11	816	436	4,522	1,695	58	81	
12	2,715	226		1,543	20	19	64,525
13	3,441	686		3,053	13	13	75,933
14	9,029	878	3,500	3,967	9	27	104,404
15	24,221	1,235	1,251	4,202	14	51	77,080
16	18,591	1,522	3,950				118,125
17	70,617	4,099	10,707	3,173	4,371		
18	94,812	11,487	13,815	5,599	185	1,836	
19	139,821	17,844	40,957	9,635	1,584	7,278	14,279
20		51,789	128,510	2,357	1,076	11,964	16,381
21		61,624	18,521	2,089	2,118	20,684	22,256
22			71,479	1,147	3,983	67,463	18,573
23				8,738	4,872	27,043	33,827
24						19,812	29,146
25							20,094
Total	364,810	153,296	653,124	53,198	19,261	161,471	1,491,491
Segment Wt (g)	144	90	60	60	60	60	60
Total TCE (g)	53	14	39	3.2	1.2	10	89
Rate (mg/day)	571	460	1,451	69	77	106	1,657

SUMMARY

Depth	L2A-01 29-Feb-96	L2A-01FS 11-Aug-97
4	43	630
5	56	
6	71	457
7	42	81
8	38	228
9	40	269
10	24	140
11	16	32
		9
13	4	0
14	7	0
15	13	0
		0
17	0	0
18	1	12
19	2	12
20	14	145
21	63	29
22	800	3,194
23	1,020	10,588
24	13,693	7,280
25	85,830	903
26	113,043	1,360
27	124,915	477
28		730
29		138
30	70,189	155
31	46,645	1,701
32	21,085	1,517
33	11,922	277
34	11,134	605
35	13,518	55
36		0
37		0
38		0
39		0
40		

Min	0	0
Max	124,915	10,588
Avg	18,365	886

Depth	L2A-02 3-Mar-96	L2A-02AP 7-Mar-97	L2A-02FS 12-Aug-97
4			46
5	106	152	469
6	1,533	0	1,715
7	8,577	90	688
8	16,992	7	209
9	17,530	7	333
10	37,330	0	118
11	49,007	0	139
12	38,794	26	430
13	96,064	24	1,667
14	27,183	96	5,720
15	39,888	66	355
16	39,934	4,636	7,663
17		46,793	1,524
18	52,930	88,692	2,507
19	43,303	1,503,925	12,075
20	118,250	432,994	8,761
21	50,131	254,148	100,664
22	34,220	162,274	12,504
23	41,380	93,904	85,577
24	148,159	68,044	77,618
25	99,561	44,565	50,897
26	57,014	91,224	31,200
27	56,319		68,606
28	697	51,445	41,537
29	21,669	55,494	49,956
30	42,455	41,630	73,449
31	30,741	2,462	56,976
32	4,067	3,757	44,866
33	4,806		106,228
34		3,108	30,106
35		3,673	10,912
36		1,131	0
37		1,638	0
38		1,234	0
39		996	0
40			0

Min	106	0	0
Max	148,159	1,503,925	106,228
Avg	42,094	89,643	23,933

Depth	L2A-03 3-Mar-96	L2A-03P 7-Mar-97	L2A-03FS 9-Aug-97
4	0		0
5	507	18	0
6	390	94	0
7	782	279	0
8	728	289	0
		100	8
10	937	75	9
11	5,162	75	11
12	2,341	69	47
13	4,009	21	22
14	2,182	30	0
15	2,638	3	0
16		24	0
17		131	61
18	17,684	84	40
19	31,909	2,306	1,241
20	308,686	3,448	71
21		2,915	60
22		1,145	0
23	218,566	27,401	414
24	250,465	18,576	1,480
25	199,155	7,444	1,297
26	101,415	3,047	609
27	64,480	344	0
28	63,874	61	0
29	101,501	11	0
30	71,074	1	0
31	57,048	3	0
32	13,571	1	0
33	11,269	0	0
34	17,246	31	0
35	11,470	58	12
36	4,834		0
37	2,739		0
38	4,004		0
39	4,143		0
40			

Min	0	0	0
Max	308,686	27,401	1,480
Avg	50,800	2,186	150

SUMMARY

	L2A-04	L2A-04P	L2A-04AFS
Depth	2-Mar-96	6-Mar-97	10-Aug-97
4			12
5	8	4,412	193
6	41	3,066	1,726
7	50	3,576	989
8	120	920	338
9	109	4,215	179
10	91	1,805	128
11	996	508	18
12	772	44	0
13	913	66	0
14	900	99	0
15	824	216	0
16	891	492	0
17		4,641	523
18	4,114	6,666	1,436
19	40,232	10,658	302
20	48,589	19,042	229
21	23,166		7,811
22	59,951		2,212
23	32,322	65,819	17,991
24	16,124	12,236	35,965
25	136,417	6,663	23,993
26	94,367	17,915	34,170
27	152,025	56,332	38,077
28	102,196	38,637	412
29		63,976	7,126
30	43,639	23,126	47,912
31	129,399	50,362	43,477
32	129,332	17,882	34,178
33	63,678	8,009	8,987
34	48,924	9,377	14,053
35	7,139	6,008	8,158
36	0	209	7,232
37	0	615	1,306
38	0	0	936
39	444	1,796	336
40	3,086	708	

Min	0	0	0
Max	152,025	65,819	47,912
Avg	33,555	12,944	9,456

	L2A-05	L2A-05P	L2A-05FS
Depth	4-Mar-96	6-Mar-97	11-Aug-97
		50	0
6	188	324	3,997
7	327	453	7,232
8	360	2,170	703
9	331	1,520	147
10	516	496	249
11	1,080	819	188
12	1,979	1,043	99
13		234	43
14	1,607	673	78
15	3,106	1,016	2,559
16	7,539	1,721	3,067
17		288	2,576
18	35,113	6,969	5,510
19	106,311	81,757	12,390
20	70,016	60,716	64,401
21		43,916	6,665
22	66,432	116,410	17,205
23	95,270	89,898	29,410
24	123,366	51,849	36,105
25	65,100	40,926	19,610
26	73,267	26,528	15,072
27	108,905	18,755	1,109
28	88,592	14,886	2,946
29		8,357	12,579
30		10,216	24,167
31		15,353	22,770
32		309	5,055
33	4,350	1,601	22,143
34	12,271	1,994	2,050
35	1,870	2,253	3,916
36	6,586	1,879	4,583
37	2,297	1,292	1,016
38	1,816	159	582
39	647	144	365
40	427	273	232
41		149	

Min	188	50	0
Max	123,366	116,410	64,401
Avg	31,417	16,416	9,189

Appendix E. Summary of Flux Chamber Results

Dec-97

<u>Sample ID</u>	<u>Description</u>	<u>Micrograms/tube</u>	<u>% Recovery</u>
FC-1 Front	12 liters from FC	<14	
FC-2 Front	12 liters from FC	<14	
FC-3 Front	12 liters from FC	<14	
FC-4 Front	12 liters from FC	<14	
FC-5 Front	12 liters from FC	<14	
FC-6 Front	12 liters from FC	<14	
FC-7 Front	12 liters from FC	<14	
FC-8 Front	12 liters from FC	<14	
FC-9 Front	12 liters from FC	<14	
FC-10 Front	12 liters from FC	<14	
FC-11 Front	12 liters from FC	<14	
FC-12 Front	12 liters from FC	<14	
FC-13A	100 ug spiked tube	70	
FC-13B	100 ug spiked tube	75	
FC-13C Front	12 liters from FC	<14	
FC-13D	Blank Tube	<14	
BLK	Blank Tube	<14	
BLK BS	Recovery Study		73%

Feb-98

<u>Sample ID</u>	<u>Description</u>	<u>Micrograms/tube</u>	<u>% Recovery</u>
FC-1 Front	12 liters from FC	<14	
FC-2 Front	12 liters from FC	<14	
FC-3 Front	12 liters from FC	<14	
FC-4 Front	12 liters from FC	<14	
FC-5 Front	12 liters from FC	<14	
FC-6 Front	12 liters from FC	<14	
FC-7 Front	12 liters from FC	<14	
FC-7 Back	12 liters from FC	<14	
FC-8 Front	12 liters from FC	<14	
FC-9 Front	12 liters from FC	<14	
FC-10 Front	12 liters from FC	<14	
FC-11 Front	12 liters from FC	<14	
FC-12 Front	12 liters from FC	<14	
FC-13A	Field Blank	<14	
FC-13B	Trip Blank	18	
FC-13C Front	100 ug spiked tube	<14	0%
FC-13D	100 ug spiked tube	<14	0%
BLK	Blank Tube	<14	
BLK BS	Recovery Study		107%
BLK BSD	Recovery Study		107%
BLK	Blank Tube	<14	
BLK BS	Recovery Study		84%
BLK BSD	Recovery Study		80%