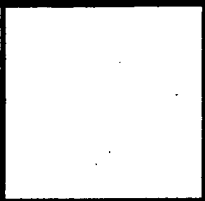


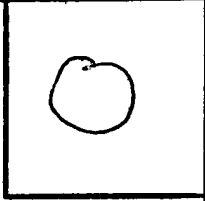
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FINAL

**TREATABILITY STUDY IN SUPPORT OF
THE INTRINSIC REMEDIATION OPTION AT
THE CHRISTMAS TREE FIRE TRAINING AREA**

at

**WESTOVER AIR RESERVE BASE
CHICOPEE, MASSACHUSETTS**

JANUARY 1997

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS**

and

**439TH SPTG/CEV
WESTOVER AIR RESERVE BASE
CHICOPEE, MASSACHUSETTS**

Prepared by:

**PARSONS ENGINEERING SCIENCE, INC.
1700 BROADWAY, SUITE 900
DENVER, COLORADO 80290**

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFCEE	Air Force Center for Environmental Excellence
ARB	Air Reserve Base
bgs	below ground surface
BTEX	Benzene, toluene, ethylbenzene, and xylene
CAH	chlorinated aliphatic hydrocarbon
CO ₂	carbon dioxide
DCE	dichloroethene
DO	dissolved oxygen
ES	Engineering-Science, Inc.
Fe ²	ferrous iron
Fe ³	ferric iron hydroxide
ft/day	feet per day
ft/ft	foot per foot
ff ² /day	square feet per day
ft/yr	feet per year
FTA	Fire Training Area
GC/MS	gas chromatography/mass spectrometry
HDPE	high density polyethylene
IRP	Installation Restoration Program
LTM	long-term monitoring
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
mV	millivolt
N	nitrogen
NAPL	non-aqueous phase liquid
NRMRL	National Risk Management Research Laboratory
Parsons ES	Parsons Engineering Science, Inc.
POC	point of compliance
QC	quality control
redox	oxidation reduction
RI	Remediation Investigation
SAC	Strategic Air Command
SVOC	semivolatile organic compound
TCE	trichloroethene
TEMB	tetramethylbenzene
TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TS	Treatability Study
USEPA	U.S. Environmental Protection Agency
USGS	United States Geologic Survey
VOC	volatile organic compound

EXECUTIVE SUMMARY

This report presents the results of a treatability study (TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at the Christmas Tree Fire Training Area (FT-03), Westover Air Reserve Base, Massachusetts to evaluate the use of intrinsic remediation with long-term monitoring (LTM) as a remedial option for dissolved fuel-hydrocarbons in the shallow groundwater. A bioventing system currently is in operation at the site for the remediation of soil contamination. There is no evidence of mobile, light, non-aqueous phase liquid at the site. Therefore, this study focused on the impact of dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) on the shallow groundwater system at the site. Dissolved chlorinated solvents also are present in the shallow groundwater; therefore, their impact on groundwater is presented as well. Site history and the results of soil and groundwater investigations conducted previously also are summarized in this report.

Comparison of BTEX, chlorinated solvent, electron acceptor, and biodegradation byproduct isopleth maps for both May 1995 and July 1996 sampling events at FT-03 provides strong qualitative geochemical evidence of biodegradation of both BTEX and chlorinated solvent compounds. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons has occurred at the site via aerobic respiration and the anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. In addition, the ratio of TCE to the daughter product cis-1,2-DCE suggests that chlorinated solvents in the groundwater are being degraded through reductive dechlorination. Furthermore, the significant decrease in both dissolved fuel hydrocarbon and chlorinated solvent concentrations suggest that bioventing operations at FT-03 have had only a positive effect on groundwater remediation. Since May 1995, bioventing operations, in conjunction with natural attenuation processes, have helped to decrease the size of the dissolved BTEX plume from 5.7 acres to 2/3 of an acre and to reduce the concentration of BTEX compounds in the groundwater throughout the site an average of 97 percent.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the source areas to potential receptors. In particular, this component focused on the contaminant fate and transport of the dissolved BTEX plume. To help simulate the effects of biodegradation and dispersion on the BTEX plume, three conservative analytical models were used to estimate the fate of dissolved BTEX movement through the shallow groundwater. Input parameters for the models were obtained from previous site characterization data, supplemented with data collected by Parsons ES. Model parameters that were not measured at the site were estimated using reasonable literature values.

The results of this study suggest that natural attenuation of BTEX and chlorinated solvent compounds is occurring at FT-03. In May 1995, with the exception of monitoring well TF-2A, dissolved groundwater BTEX concentrations were below the state and federal regulatory guidelines. TCE was detected at a concentration above the federal groundwater standard at monitoring well TF-14. However, the remaining chlorinated solvents at the site were below regulatory guidelines, or not detected. In July 1996, all detected BTEX and chlorinated solvent concentrations were below both the state and federal regulatory

guidelines. The estimated rates of biodegradation, when coupled with sorption, dispersion, and dilution, should be sufficient to maintain dissolved BTEX and chlorinated solvent concentrations at levels below current regulatory guidelines. Given the observed retreat of the dissolved BTEX and chlorinated solvent plumes, intrinsic remediation and LTM is a viable remedial option for BTEX-impacted groundwater at the site. The Air Force therefore recommends implementation of intrinsic remediation with LTM for BTEX and chlorinated solvent-impacted groundwater at the site. Analytical modeling results suggest significant decreases in the source concentration and plume extent due to natural attenuation processes. Furthermore, the current operation of a bioventing soil remediation system has increased source decay rates in the vadose zone soils and reduced the groundwater contaminant source. Institutional controls such as restrictions on shallow groundwater use would prevent completion of pathways while site remediation is in progress.

To continue to verify the results of the analytical modeling effort, and to ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, a LTM plan was developed on the basis of the 1995 groundwater results and analytical models. The Air Force recommends using 5 LTM wells and 3 point-of-compliance wells to monitor the long-term migration and degradation of the dissolved BTEX plume. In addition to analyses used to verify the effectiveness of intrinsic remediation, the groundwater samples should be analyzed for BTEX compounds by US Environmental Protection Agency (USEPA) Method SW8020 and chlorinated solvents by USEPA Method SW8010. On the basis of 1996 groundwater sampling results, it may be possible to reduce the number of wells included in the LTM plan as well as the duration of annual monitoring. If dissolved BTEX or chlorinated solvent concentrations in groundwater collected from the POC wells exceed regulatory criteria, additional evaluation or corrective action may be necessary at this site.

SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. (Parsons ES), formerly Engineering Science, Inc. (ES), and presents the results of a treatability study (TS) conducted to evaluate the use of intrinsic remediation for remediation of fuel-hydrocarbon- and chlorinated-solvent-contaminated groundwater at the Christmas Tree Fire Training Area (FT-03) at Westover Air Reserve Base (ARB), Chicopee, Massachusetts (the Base). As used throughout this report, the term "intrinsic remediation" refers to a management strategy that relies on natural attenuation mechanisms to control exposure to risks associated with contaminants in the subsurface. "Natural attenuation" refers to the actual processes (e.g., biodegradation, sorption, and dispersion) that facilitate intrinsic remediation.

Intrinsic remediation is an innovative remedial approach that relies on natural attenuation to remediate contaminants dissolved in groundwater. Mechanisms for natural attenuation of benzene, toluene, ethylbenzene, and xylenes (BTEX) include biodegradation, advection, dispersion, dilution from recharge, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of intrinsic remediation can vary markedly from site to site depending on governing physical and chemical processes.

The main emphasis of the work described herein was to evaluate if natural attenuation mechanisms would be sufficient to reduce concentrations of dissolved fuel-related compounds in groundwater to levels that meet federal and state groundwater protection standards. The potential for these mechanisms to effectively reduce the concentrations of chlorinated solvents at the site, which is ancillary to the scope of this program, also was qualitatively considered. This study is not intended to be a contaminant assessment report, a remedial action options evaluation, or a remedial action plan; rather, it is provided for the use of the Base and its prime environmental contractor(s) as information to be used for future decision making regarding this site.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers from the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division, was retained by the United States Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization and data analysis to evaluate the scientific

defensibility of intrinsic remediation with long-term monitoring (LTM) as a remedial option for contaminated groundwater at FT-03.

There were two primary objectives of this project:

- Determine whether natural attenuation processes for fuel hydrocarbons and chlorinated solvents are occurring in groundwater at the site, and if so,
- Investigate if these processes are sufficient to minimize the expansion of the contaminant plume using analytical models to ensure that federal and state groundwater protection standards will be met at a downgradient point of compliance (POC).

These objectives were accomplished by:

- Reviewing previously reported hydrogeologic and soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of groundwater contamination;
- Collecting geochemical data in support of intrinsic remediation;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Evaluating site-specific data to determine whether natural processes of contaminant attenuation and destruction are occurring in groundwater at the site;
- Using analytical models to simulate the fate and transport of fuel hydrocarbons in groundwater;
- Determining if natural processes are sufficient to minimize BTEX plume expansion so that groundwater quality standards can be met at a downgradient POC; and
- Providing a LTM plan that includes LTM and POC well locations and a sampling and analysis plan.

Site characterization activities, performed in May 1995, in support of intrinsic remediation included sampling and analysis of groundwater from monitoring wells, static groundwater level measurement, and aquifer slug testing. Five new monitoring wells were installed under a separate contract before the start of the intrinsic remediation demonstration. Additional groundwater sampling was conducted in July 1996, to supplement data collected in May 1995 and to confirm dissolved BTEX contamination in deep wells at the site.

Much of the hydrogeological and groundwater chemical data necessary to evaluate the intrinsic remediation option were available from previous investigations conducted at this site, at other sites with similar characteristics, or in technical literature. The

field work conducted under this program was oriented toward collecting supplementary hydrogeological and chemical data necessary to document and model the effectiveness of intrinsic remediation with LTM for fuel-hydrocarbon-contaminated groundwater.

Site-specific data were used to develop analytical models of groundwater flow and solute transport. The analytical models were used to simulate the movement of dissolved BTEX in the shallow saturated zone. Model results were used to help assess the potential for completion of receptor exposure pathways involving groundwater and to identify whether intrinsic remediation with LTM is an appropriate and defensible remedial option for contaminated groundwater at site FT-03. Site-specific data also were used to evaluate the potential fate and transport of trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride in the presence of fuel hydrocarbons. Potential biological degradation of these chlorinated solvents via reductive dechlorination was addressed qualitatively.

This report contains eight sections, including this introduction, and three appendices. Section 2 summarizes the site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the analytical models used and the design of the conceptual model for the site, lists model assumptions and input parameters, and describes sensitivity analysis, model output, and the results of the modeling. Section 6 presents the LTM plan for the site. Section 7 presents the conclusions of this work and provides recommendations for further work at the site. Section 8 lists the references used to develop this document. Appendix A contains monitoring well installation logs, groundwater sample forms, and slug test results. Appendix B presents soil and groundwater analytical results. Appendix C contains calculations and model output parameters in hardcopy format.

1.2 FACILITY BACKGROUND

The Base, located in south-central Massachusetts, covers nearly 2,400 acres in the northeastern portion of the city of Chicopee, within the Connecticut River Valley (Figure 1.1). The Base is in close proximity to Interstate 90 (the Massachusetts Turnpike) and Interstate 91 (a major north-south route), and is 90 miles west of Boston. Westover ARB is in Hampden County, and the land uses around the Base are a mix of rural, residential, recreational, and industrial/commercial development.

The Base became operational in April 1940, and served as a training center for the 359th Fighter Group until 1945. After World War II, the Base served the Air Transport Command, which in 1948 became the Military Air Transport Services. From 1956 to 1974, the Base was used by Strategic Air Command (SAC) crews operating B-52s. Westover's 99th Bomb Wing was the primary SAC unit flying missions in the Vietnam War. The Air Force Reserve came to Westover in 1965, and in 1974 the Base was deactivated to become an Air Force Reserve Base. Westover's world-wide mission increased with the arrival of 16 C-5As in 1987. Currently the Base is the nation's largest Air Force Reserve Base and is operated by a work force of 1,200 civilians, including 533 Air Reserve technicians. More than 4,000 reservists from all military branches throughout the northeastern United States serve at Westover ARB.

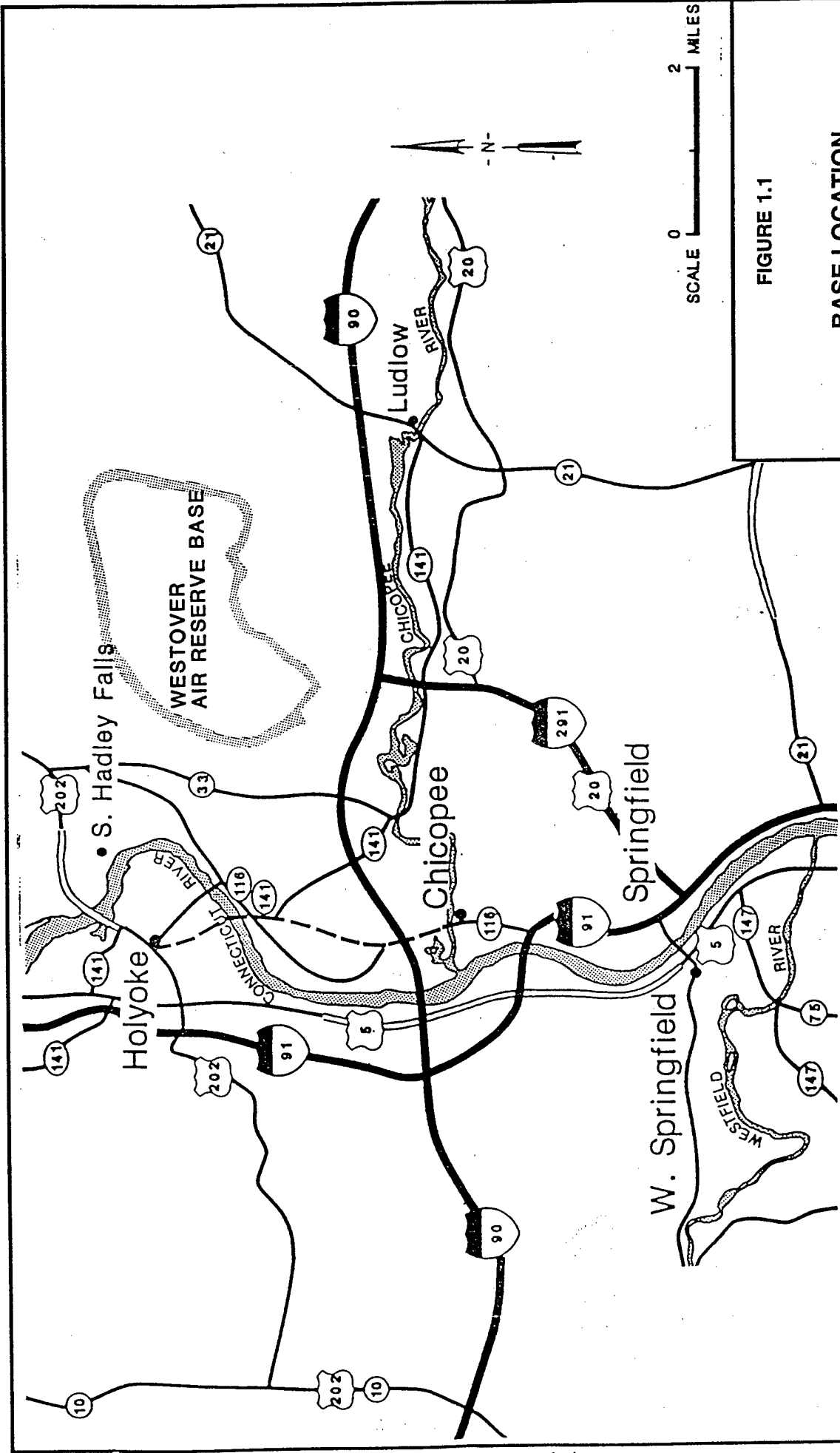


FIGURE 1.1

BASE LOCATION

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

Sources: ES, 1988.

Site FT-03 is located in the southwestern portion of the Base, approximately 125 feet north of the southern Base boundary (Figure 1.2). Chicopee Memorial State Park lies south of the Base boundary, and Chicopee Reservoir, located within the park, is approximately 0.4 mile southeast of FT-03. Building 7400, a helicopter hangar and maintenance facility, lies northeast of FT-03. The southwestern terminus of the runway lies due east of the site. Site FT-03 was used from 1940 to 1964, for fire training exercises in which unknown volumes of waste fuels and solvents were released at the site.

The only active fuel handling at the site is the transfer of JP-4 through a buried 8-inch fuel supply line, located in the northern portion of the site (ES, 1988) (Figure 1.3). Until recently, a portion of the site was used as a parking area for trucks and troop transports (O'Brien and Gere Engineers, Inc., 1993). Site FT-03 is covered by sparsely vegetated sandy, gravelly soil with no visible evidence of the former fire training area or fuel hydrocarbon contamination.

A series of investigations have undertaken characterization of site FT-03 using numerous techniques. In 1986, ES (1986 and 1988) installed monitoring wells TF-1 through TF-6, TF-1A, and TF-2A, obtained water level measurements, and drilled and sampled three shallow test borings to depths of 15 feet below ground surface (bgs). ES also performed a series of soil electrical resistivity surveys. UNC Geotech (1991) installed two additional wells, collected soil samples for laboratory analysis from 19 soil boreholes, and conducted a toluene soil gas survey. In 1993, 13 additional soil boreholes were sampled, and one well was constructed by O'Brien and Gere Engineers, Inc. (1993).

Results of the past investigations have identified petroleum hydrocarbon and chlorinated solvent contamination in site environmental samples. Soil contamination was identified in the former burn area to depths of up to 10 feet bgs. In May 1995, O'Brien and Gere Engineers, Inc. began operation of a full-scale bioventing system.

Groundwater contamination has been detected in the vicinity and downgradient of the burn area at Site FT-03. Engineered solutions to remediate groundwater have not been implemented at this site.

Results of the soil and groundwater investigations at the site have been documented in the Ground Water Monitoring Report for Site FT-03 "Christmas Tree" Fire Training Area (O'Brien and Gere, 1995); Supplemental Remedial Investigation/Feasibility Study Report (O'Brien and Gere, 1994); Installation Restoration Program (IRP) Work Plan (O'Brien and Gere, 1993); Final Remedial Investigation (RI) Report (UNC Geotech, 1991); IRP Phase II-Confirmation/Quantification Stage 2 Report (ES, 1988); Final Report, Phase II-Problem Confirmation Study (Weston, 1984); and IRP Records Search (CH2M Hill, 1982). The site-specific data presented in Sections 3, 4, and 5 are based on a review of these documents and on data collected by Parsons ES under this program.

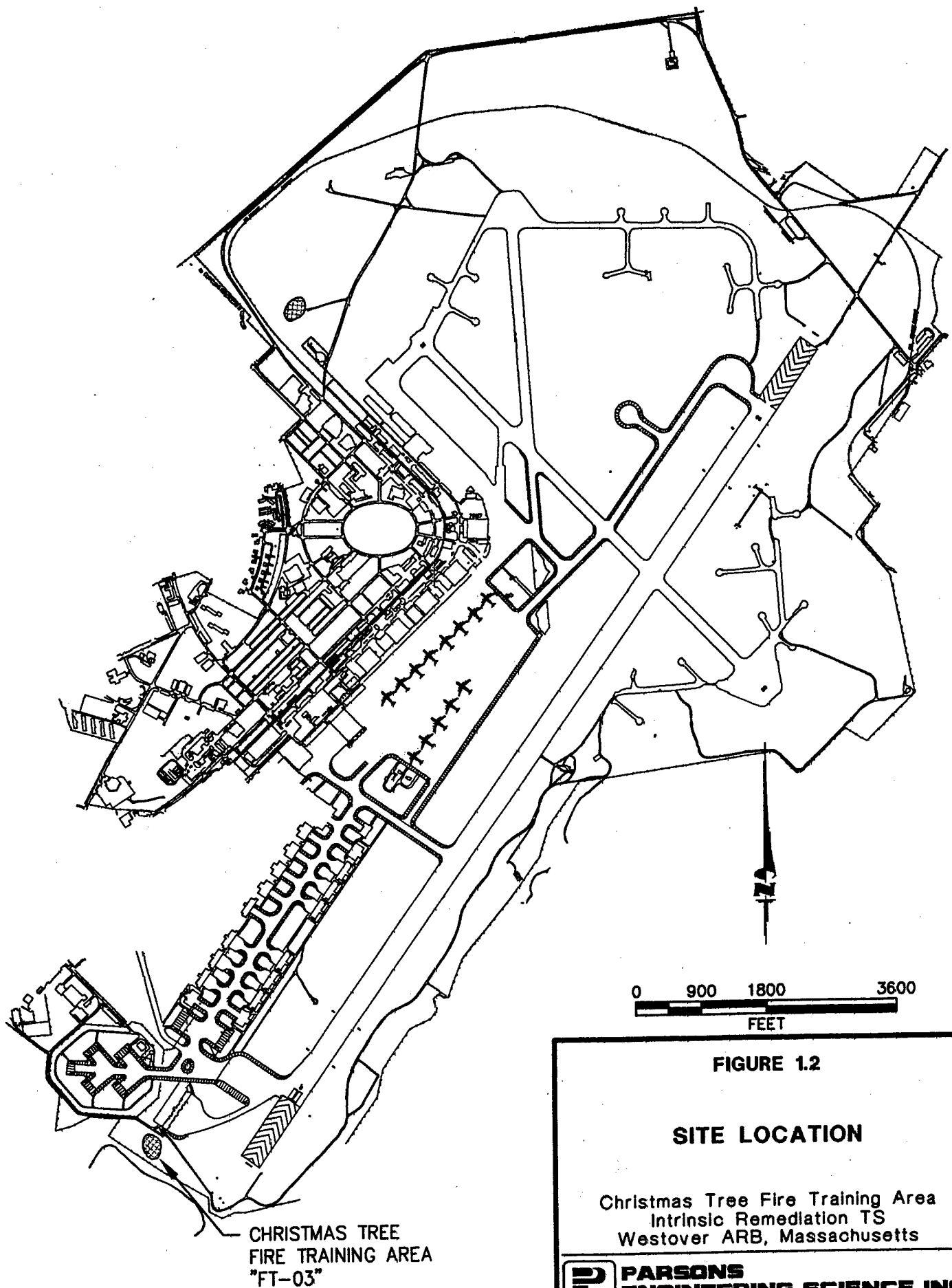


FIGURE 1.2

SITE LOCATION

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts



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Denver, Colorado

Source: Westover ARB, 1993

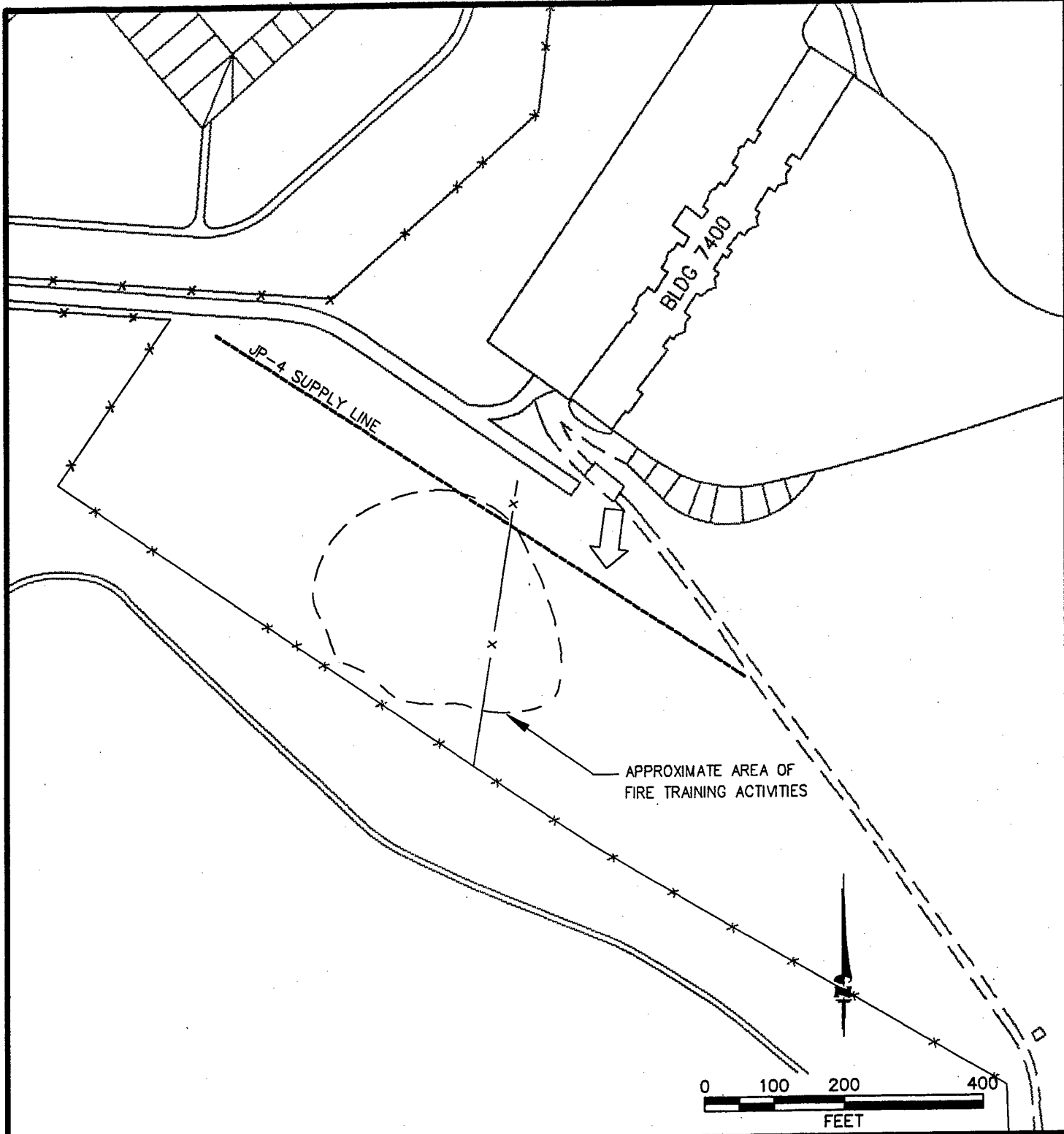


FIGURE 1.3

FT-03 LAYOUT

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts



**PARSONS
 ENGINEERING SCIENCE, INC.**

Denver, Colorado

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES personnel to collect site-specific data at FT-03, the Christmas Tree Fire Training Area, Westover ARB, Massachusetts. To meet the requirements of the intrinsic remediation demonstration, additional data were required to evaluate aquifer properties, soil sorption, and the extent of groundwater contamination. Immediately prior to site characterization, the Base had five additional monitoring wells installed and developed at the site. A soil sample was collected from the screened interval of each monitoring well and analyzed for total organic carbon (TOC). Site characterization activities for this TS involved the collection and analysis of groundwater samples from the 5 newly installed and 10 of the 11 previously installed monitoring wells, measurement of groundwater levels, and performance of aquifer slug tests. Groundwater samples collected at the 15 wells were analyzed for the parameters listed in Table 2.1. Previously collected data and data collected under this program were integrated to develop the conceptual site model and to aid interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

The following sections describe the procedures that were followed when collecting site-specific data in May 1995 and July 1996. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1995).

2.1 MONITORING WELL INSTALLATION

Five monitoring wells were installed and developed by Environmental Products and Services, Inc. under a separate Base contract during the week of May 15, 1995. These monitoring wells were installed to help characterize the shallow groundwater flow system and the extent of groundwater contamination. This characterization information was used in this TS to narrow the variable constraints of the analytical models and to support the demonstration of intrinsic remediation. A copy of the well installation summary report is provided in Appendix A. Figure 2.1 shows the locations of all site wells; the new wells are identified as TF-12 through TF-16. Construction details of all site wells are summarized in Table 2.2.

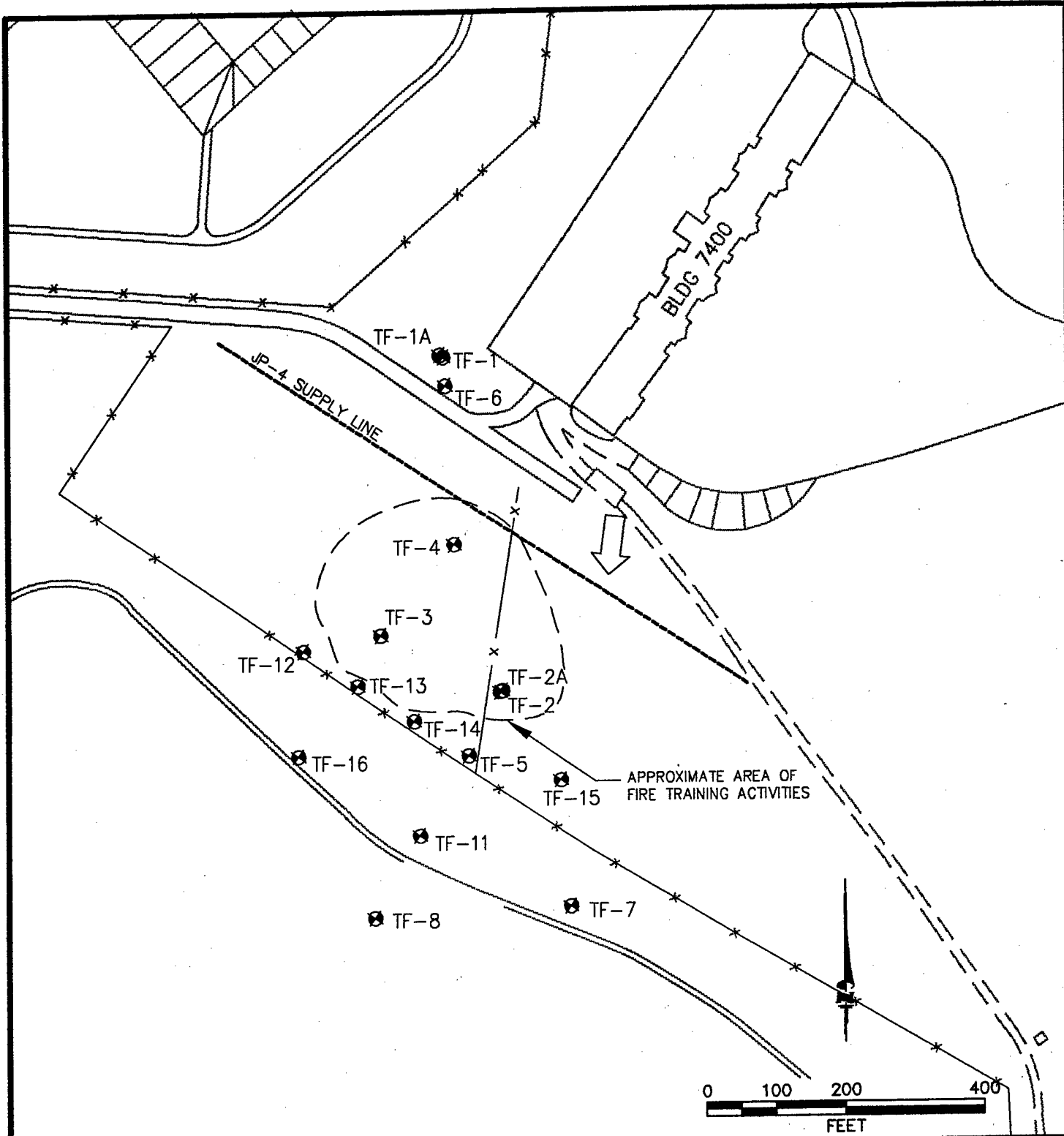
2.2 GROUNDWATER SAMPLING

Groundwater samples were collected at the 5 newly installed wells and 10 of the 11 previously installed monitoring wells on May 17 through 19, 1995 (Figure 2.1). Monitoring Well TF-6 was not sampled because the screen interval penetrates the entire aquifer, and therefore would not produce representative groundwater samples.

TABLE 2.1
SUMMARY OF GROUNDWATER ANALYSES
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Analyte	Method	Field (F) or Fixed-Base Laboratory (L)
Total Iron	Colorimetric, HACH Method 8008	F
Ferrous Iron (Fe ²⁺)	Colorimetric, HACH Method 8146	F
Ferric Iron (Fe ³⁺)	Difference between total and ferrous iron	F
Manganese	Colorimetric, HACH Method 8034	F
Reduction/Oxidation Potential	Direct reading meter	F
Oxygen	Direct reading meter	F
pH	Direct reading meter	F
Conductivity	Direct reading meter	F
Temperature	Direct reading meter	F
Carbon Dioxide	Titrimetric, HACH Method 1436-01	F
Alkalinity (Carbonate [CO ₃ ²⁻] and Bicarbonate [HCO ₃ ⁻])	F = Titrimetric, HACH Method 8221	F
Nitrate + Nitrite	EPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-147 ^{a/}	L
Dissolved Organic Carbon	RSKSOP-102	L
Volatile Organic Compounds (VOCs)	RSKSOP-148	L
Fuel Carbon	RSKSOP-133	L
BTEX	RSKSOP-133	L

^{a/} RSKSOP - Robert S. Kerr Standard Operating Procedure performed by the USEPA National Risk Management Research Laboratory (formerly the Robert S. Kerr Environmental Research Laboratory).



LEGEND

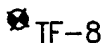
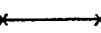
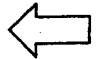
- 
TF-8
MONITORING WELL
- 
FENCE
- 
GROUNDWATER FLOW DIRECTION

FIGURE 2.1

MONITORING WELL LOCATIONS

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

TABLE 2.2
SUMMARY OF GROUNDWATER MONITORING
WELL INSTALLATION DATA
 Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Identification	Northing	Easting	Completion Date	Completion Depth (feet bgs) ^{b/}	Borehole Diameter (inches)	Casing Diameter (inches)	Slot Size (inches)	Screen Interval (feet bgs)	Approximate Land Surface (feet msl) ^{d/}	Elevation Top of PVC ^{a/} (feet msl)
TF-1	7667.34	8776.84	12/29/86	89.0	8.0	2.0	0.020	74.0-89.0	235.77	238.73
TF-1 A	7666.97	8771.08	12/9/86	50.0	8.0	2.0	0.020	35.0-50.0	235.68	238.23
TF-2	7319.66	9114.78	1/5/87	83.5	8.0	2.0	0.020	68.5-83.5	233.09	236.31
TF-2 A	7322.86	9116.93	12/11/87	52.0	8.0	2.0	0.020	37.0-52.0	233.05	235.41
TF-3	7456.41	8941.12	12/16/86	52.0	8.0	2.0	0.020	37.0-52.0	236.07	238.34
TF-4	7289.82	8926.77	12/18/86	52.0	8.0	2.0	0.020	37.0-52.0	233.80	236.05
TF-5	7218.34	9130.02	NA ^{d/}	55.0	8.0	2.0	NA	35.0-50.0	231.91	234.03
TF-6	7635.29	8802.61	NA	90.0	8.0	2.0	NA	34.5-77.0	236.32	236.96
TF-7	7121.02	9375.21	NA	58.0	8.0	2.0	NA	38.8-53.8	231.63	234.39
TF-8	6949.21	9150.87	NA	57.0	8.0	2.0	NA	38.7-53.7	231.27	233.62
TF-11	7084.33	9139.09	NA	NA	8.0	2.0	NA	NA	231.07	233.66
TF-12	7208.11	8847.25	5/15/95	45.0	8.0	2.0	0.010	35.0-45.0	232.53	235.07
TF-13	7211.51	8940.77	5/15/95	45.0	8.0	2.0	0.010	35.0-45.0	231.83	234.59
TF-14	7215.51	9037.21	5/15/95	45.0	8.0	2.0	0.010	35.0-45.0	231.67	234.01
TF-15	7262.74	9259.68	5/15/95	50.0	8.0	2.0	0.010	40.0-50.0	234.01	236.96
TF-16	7079.89	8926.94	5/18/95	50.0	8.0	2.0	0.010	40.0-50.0	231.91	234.80

^{a/} PVC = polyvinyl chloride.

^{b/} bgs = below ground surface.

^{c/} msl = above mean sea level.

^{d/} NA = data not available.

Monitoring wells TF-1 through TF-16, except TF-6, also were sampled in July 1996. Groundwater sampling forms, provided in Appendix A, were used to document the specific details of the sampling event for each well. In addition to the sampling events conducted under this program, ES (1988), UNC Geotech (1991), and O'Brien and Gere (1994) have conducted groundwater sampling events at the site.

This section describes the procedures used for collecting groundwater samples. To maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Parsons ES, 1995) and summarized in the following sections were followed.

2.2.1 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) before arriving in the field. Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination from improperly cleaned equipment; therefore, pumps and water level indicators were thoroughly cleaned before and after field use and between uses at different sampling locations.

2.2.1.1 Equipment Decontamination

All portions of sampling and test equipment that contacted the samples were thoroughly cleaned before use. The purging pump, pump tubing, and water level indicator were the only reusable pieces of equipment that came in contact with groundwater samples or were used in the wells. The following protocol was used to clean the Grundfos Redi-Flo 2[®] pump, Envirotech[®] ES-60 two-stage pump, and water level indicator that contacted the groundwater or were lowered downhole:

- Flushed and rinsed with potable water;
- Rinsed with isopropyl alcohol (external surfaces only);
- Rinsed with distilled or deionized water (external surfaces only); and
- Air dried before use.

Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form.

2.2.1.2 Equipment Calibration

Field analytical equipment was calibrated according to the manufacturers' specifications before field use, and as required. Because the majority of physical and chemical analyses were performed by USEPA/NRMRL personnel, this requirement applied specifically to direct-reading meters used for onsite chemical measurements of pH and dissolved oxygen (DO).

2.2.1.3 Preparation of Location

Before proceeding with sampling, the area around the well was cleared of foreign materials, such as brush, rocks, and debris to prevent sampling equipment from inadvertently contacting the debris. Location preparation also included an inspection of the integrity of the well. At this time, any irregularities involving the protective cover, cap, lock, external surface seal, internal surface seal, well identification, well datum, and pad were noted.

2.2.1.4 Water Level and Total Depth Measurements

Before removing any water from the well, the static water level was measured. An electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. After measurement of the static water level, the water level probe was lowered to the bottom of the well for measurement of total well depth (recorded to the nearest 0.01 foot). From these measurements, the volume of water to be purged from the wells was calculated.

2.2.2 Well Purging and Sample Collection

Well purging consisted of removing at least three casing volumes of water with a Grundfos Redi-Flo 2[®] pump (1995) or Envirotech[®] ES-60 two-stage pump (1996) prior to sample collection. Once three casing volumes of water were removed from the well, purging continued until the pH, temperature, and DO concentrations had stabilized.

Within 24 hours of the purge, a dedicated, disposable high-density polyethylene (HDPE) bailer was used to extract groundwater samples from the well. The bailer was lowered on a disposable polypropylene rope until completely submerged. Both lowering and raising were performed slowly to avoid unnecessary splashing and volatilization of contaminants. The samples were transferred directly into the appropriate sample containers. The water was carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample bottles for BTEX, trimethylbenzenes (TMBs), tetramethylbenzenes (TEMBs), and volatile organic compounds (VOCs) were filled so that there were no headspace or air bubbles within the container.

2.2.3 Onsite Chemical Parameter Measurement

Measurement of DO, pH, and temperature was performed at the well at the time of sample collection. All other field parameters were measured onsite by USEPA/NRMRL personnel at their mobile laboratory immediately following sample collection.

2.2.3.1 Dissolved Oxygen Measurements

DO measurements were taken using an Orion[®] model 840 DO meter in a flow-through cell at the outlet of the purge pump. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

2.2.3.2 pH and Temperature Measurements

Because the pH and temperature of groundwater can change significantly within a short time following sample acquisition, these parameters were measured at the time of sample collection, in the same flow-through cell used for DO measurements. The measured values were recorded on the groundwater sampling record.

2.2.4 Sample Handling

2.2.4.1 Sample Preservation

The USEPA/NRMRL personnel provided appropriately preserved sample bottles. Samples were delivered to the onsite USEPA mobile laboratory within minutes of sample collection. As the temperatures were cool and the samples were delivered to the mobile laboratory within minutes of sample collection, ice was not used to cool the samples during transport to the USEPA mobile laboratory. Samples for those analyses not performed by the mobile laboratory were preserved and shipped by the USEPA field personnel to the NRMRL in Ada, Oklahoma for analysis.

2.2.4.2 Sample Containers and Labels

Sample containers and appropriate container lids were provided by the analytical laboratory. The sample containers were filled as described in Section 2.2.2, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sampling date;
- Sampling time;
- Requested analyses;
- Preservatives added; and,
- Sample collector's initials.

2.2.4.3 Sample Shipment

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory. The samples were packaged to prevent leakage or vaporization from their container, and the samples were cushioned to avoid breakage.

Sample shipment to the NRMRL in Oklahoma and associated chain-of-custody documentation was the responsibility of the USEPA/NRMRL field personnel.

2.3 AQUIFER TESTING

Slug tests were conducted at two monitoring well locations to estimate the hydraulic conductivity of the shallow saturated zone at FT-03. Slug tests are single-well hydraulic tests used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft²/day). Slug testing can be performed using either a rising head or a falling head test. Both rising head and falling head tests were used at this site. The tests were performed in monitoring wells TF-8 and TF-16 (Figure 2.1). Detailed slug testing procedures are presented in the *Technical Protocol for Implementing the Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (Wiedemeier *et al.*, 1995), hereafter referred to as the Technical Protocol document.

Data obtained during slug testing were analyzed using AQTESOLV[®] software and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3.2.2 and Appendix A.

2.4 SURVEYING

After completion of field work, all 16 monitoring well locations and elevations were surveyed by Huntley and Associates of Chicopee, Massachusetts. The horizontal locations were measured relative to existing survey control points. The elevations of the ground surface adjacent to the well casing and the measurement datum (top of the PVC well casing) were measured relative to mean sea level (msl). Horizontal locations were surveyed to the nearest 0.1 foot. Datum and ground surface elevations were surveyed to the nearest 0.01 foot.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

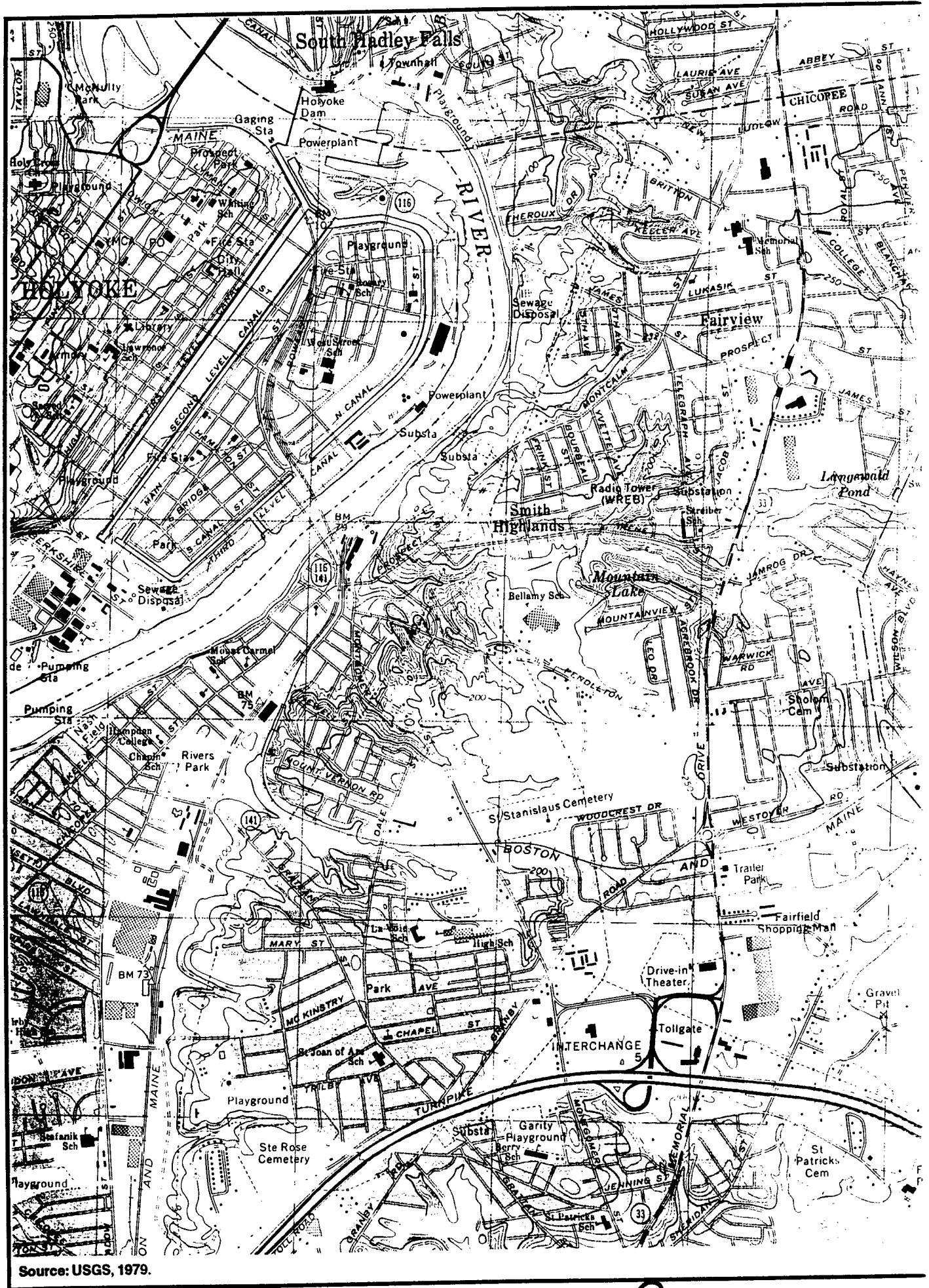
This section describes the physical characteristics of site FT-03 as determined from data collected by Parsons ES in May 1995 and July 1996, and in conjunction with data documented in previous reports on Westover ARB. Investigative techniques used by Parsons ES to determine the physical characteristics of the site are discussed in Section 2.

3.1 SURFACE FEATURES

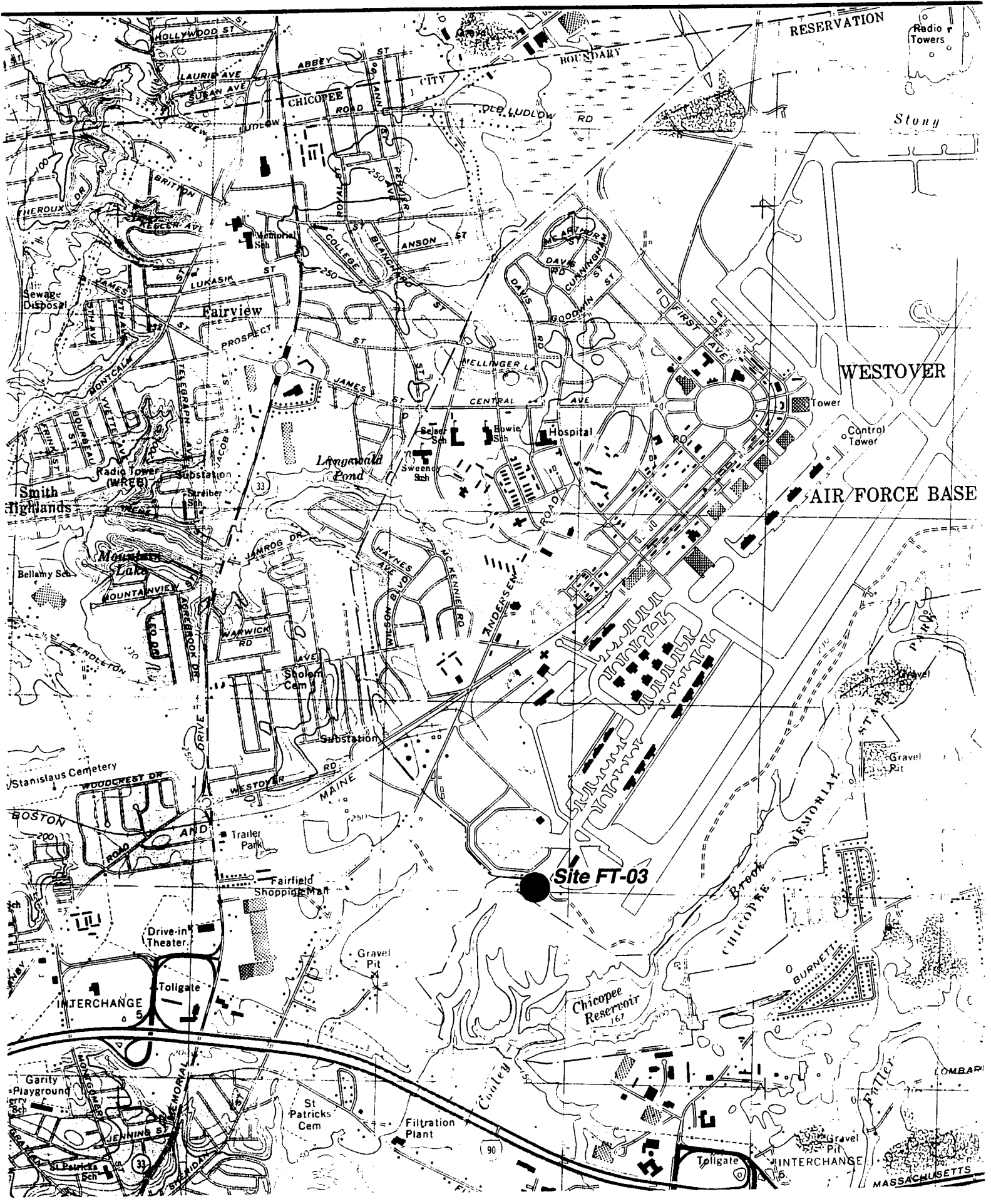
3.1.1 Topography and Surface Water Hydrology

Westover ARB is located within the Connecticut River Valley Lowland Subdivision of the New England Upland Physiographic Province, which is part of the Northern Appalachian Mountain System. The area surrounding the Base includes nearly level flood plains, level to gently sloping terraces along the Connecticut River, and several large intrusive dikes that rise several hundred feet above the valley floor. Regional elevations range from 50 feet above msl at the Connecticut River to 1,200 feet msl to the north of the Base at Mount Tom. A topographic map of the Base and the surrounding area is presented on Figure 3.1. The FT-03 site lies at an elevation of approximately 230 feet above msl and is characterized by gentle slopes, developed on fluvial sands. Chicopee Memorial State Park, immediately south of site FT-03, has undeveloped moderate to steep slopes.

Major surface water features in the area include the Connecticut River, located approximately 2 miles west of the Base, and the Chicopee River, located approximately 1 mile south of the Base boundary. The Base is drained by three smaller drainages: Stony Brook in the north, Willamansett Brook to the west, and Cooley Brook along the southeastern boundary of the Base (Figure 3.1). Langewald Pond and Mountain Lake, west of the Base, receive water from Willamansett Brook. Stony Brook receives runoff, mainly through storm drains, from the northern portion of the Base. Cooley Brook receives runoff from most of the industrial operations, flight line hangars, and runways via storm sewers, culverts, and ditches. Oil/water separators have been constructed along Cooley Brook to filter storm runoff before discharge into the Brook (O'Brien and Gere, 1993). Cooley Brook supplies water to Chicopee Reservoir and the Chicopee River. Surface water overland flow in the vicinity of FT-03 is south-southwest into the Cooley Brook watershed.



Source: USGS, 1979.



Site FT-03

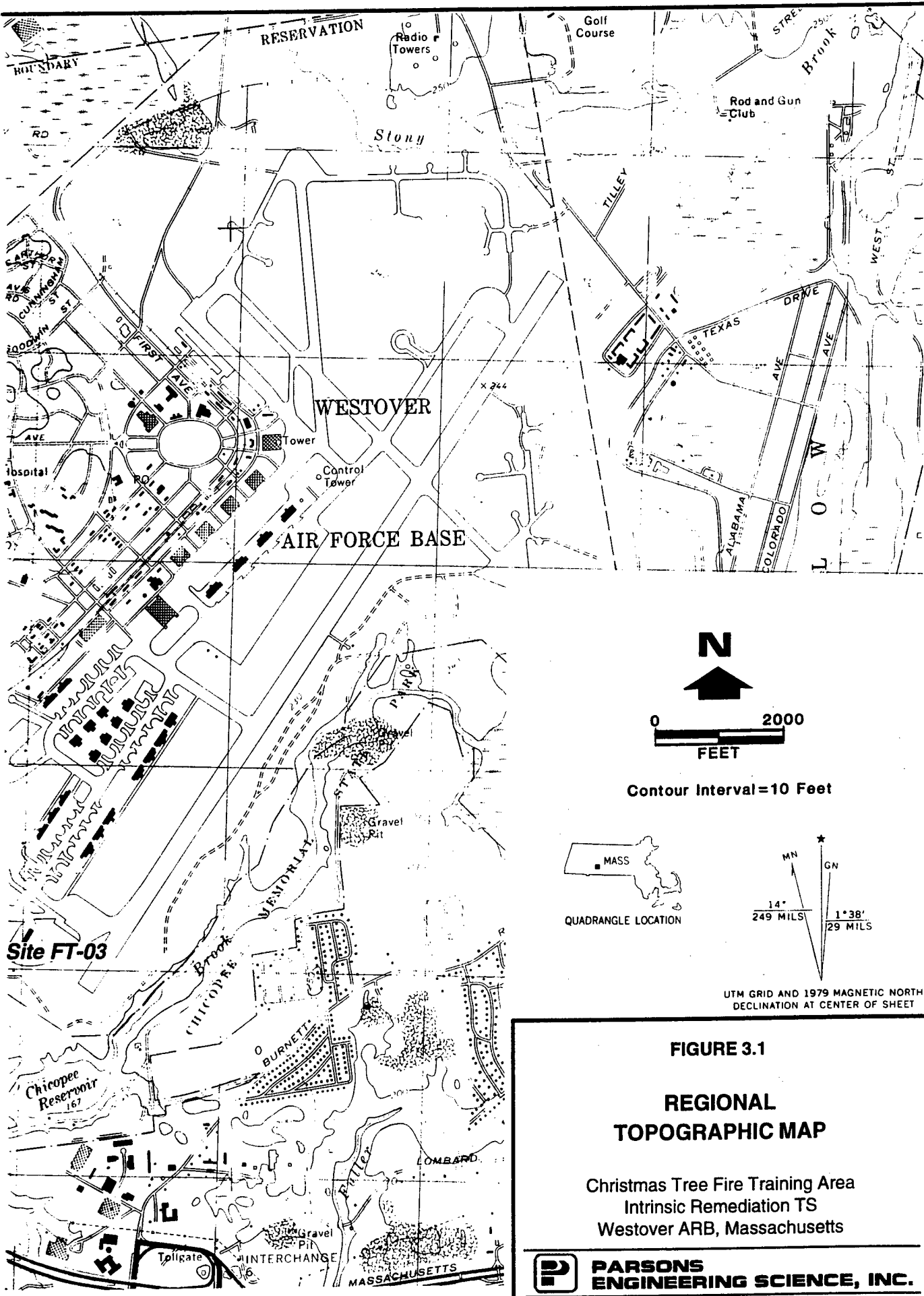


FIGURE 3.1

REGIONAL TOPOGRAPHIC MAP

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

3.1.2 Manmade Features

FT-03 is located immediately south of the Westover ARB flight operations area. Manmade features at the site include an underground 8-inch JP-4 supply line, a gravel road, a flightline fence that bisects the site, and a Base boundary fence (Figure 1.3). An operational bioventing system, installed by O'Brien and Gere (1995), also is present at the site. At the boundaries of the site lie Building 7400, the Base perimeter road, and the Base boundary. A service road for Chicopee Memorial State Park is located approximately 100 to 150 feet south of the Base boundary. Other significant nearby manmade constructions include the runway, located approximately 1,000 feet east of the site, and Chicopee Reservoir, located approximately 2,000 feet southeast of the site.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Regionally, the central Massachusetts bedrock geology consists of a variety of Precambrian and early Paleozoic crystalline rocks known as the Grenville crystallines (ES, 1988). These rocks are most evident as the Adirondack Mountains to the west of the Base. The crystalline rocks underwent periods of folding, faulting, metamorphism, and intrusion during the Taconic (Ordovician) and Acadian (Devonian) orogenies. The resulting stresses from these orogenies produced extensive folding and faulting during the Mesozoic. Additional folding and rifting occurred in the early Jurassic periods, and a series of north-south trending fault structures were formed. Unconformably overlying the crystallines are Triassic "redbeds" consisting of arkosic sandstone, conglomerates, siltstones, and occasional gray shales. The Triassic rocks in the Westover ARB area are reddish-brown arkosic sand and siltstones of the Portland Formation. Uplift and erosion of the Triassic formations resulted in an unconformity between the Portland Formation and overlying Pleistocene glacial sediments.

The Pleistocene glacial advance reshaped the landscape and deposited poorly sorted gravel, sand, silt, and clay mixtures as moraines and till sheets. During the glacial retreat, melt waters impounded by glacial deposits and existing topography formed several large glacial lakes. The largest of the Pleistocene lakes in the region was glacial Lake Hitchcock, which extended from Hartford, Connecticut to Lyme, New Hampshire. The lake was as much as 250 feet deep in the Chicopee area (Thomas, 1987). The resulting sedimentation deposited thick, gray, varved lacustrine clays with silt and fine sand laminations. Overlying the lacustrine sediments are fine to coarse sands with traces of gravel and silt that were deposited as deltaic outwash deposits as glacial Lake Hitchcock drained and filled with sediment.

The regional hydrogeology of the Westover ARB area consists of three major hydrogeologic units. An aquitard composed of lacustrine deposits and till separates the shallow deltaic outwash aquifer from the underlying Triassic bedrock aquifer. Both aquifers are used to a limited extent for industrial, municipal, and domestic purposes. The glacial outwash aquifer ranges in thickness from 25 to 85 feet in the area of the Base, and is recharged by infiltration from rain and melting snow (O'Brien and Gere, 1993). Depth to groundwater is generally 5 to 40 feet bgs and is influenced by surface topographic features. Basewide hydraulic conductivities in the shallow aquifer average 13 feet per day (ft/day) and range from 2.2 to 33 ft/day.

3.3 SITE GEOLOGY AND HYDROGEOLOGY

Characterization of the shallow aquifer system at FT-03 has been the objective of several investigations. A site visit was conducted by CH2M Hill in 1981 to collect information for a Phase I, IRP Records Search. In 1984, Weston Environmental performed an investigation for a Phase II Confirmation Study. Subsequent investigations by ES (1988), UNC Geotech (1991), and O'Brien and Gere (1994) involved the installation of 11 monitoring wells, soil and soil gas sampling, and geophysical surveys. A bioventing soil remediation system is also currently being operated by O'Brien and Gere. As part of the current TS investigation, five additional monitoring wells were installed.

3.3.1 Lithology and Stratigraphic Relationships

The shallowest sediments at FT-03 consist of light-colored, fine to medium sands that range in thickness from 0 to 20 feet and were classified during a previous investigation as disturbed Base fill (ES, 1988). Underlying the surficial soils is a 10- to 40-foot-thick, well-sorted, interbedded sand and sandy gravel, with some clean coarse gravel seams. Below the sand and gravel are layers of fine sand and silty sand. The water table is present in these sands at 40 to 45 feet bgs. At approximately 80 feet bgs, lacustrine varved silts and clays are present (O'Brien and Gere, 1994). These sediments are up to 40 feet thick and consist of silts and clays that form an aquitard. Underlying the aquitard unit are the thin glacial till and Triassic bedrock units present throughout the Chicopee region.

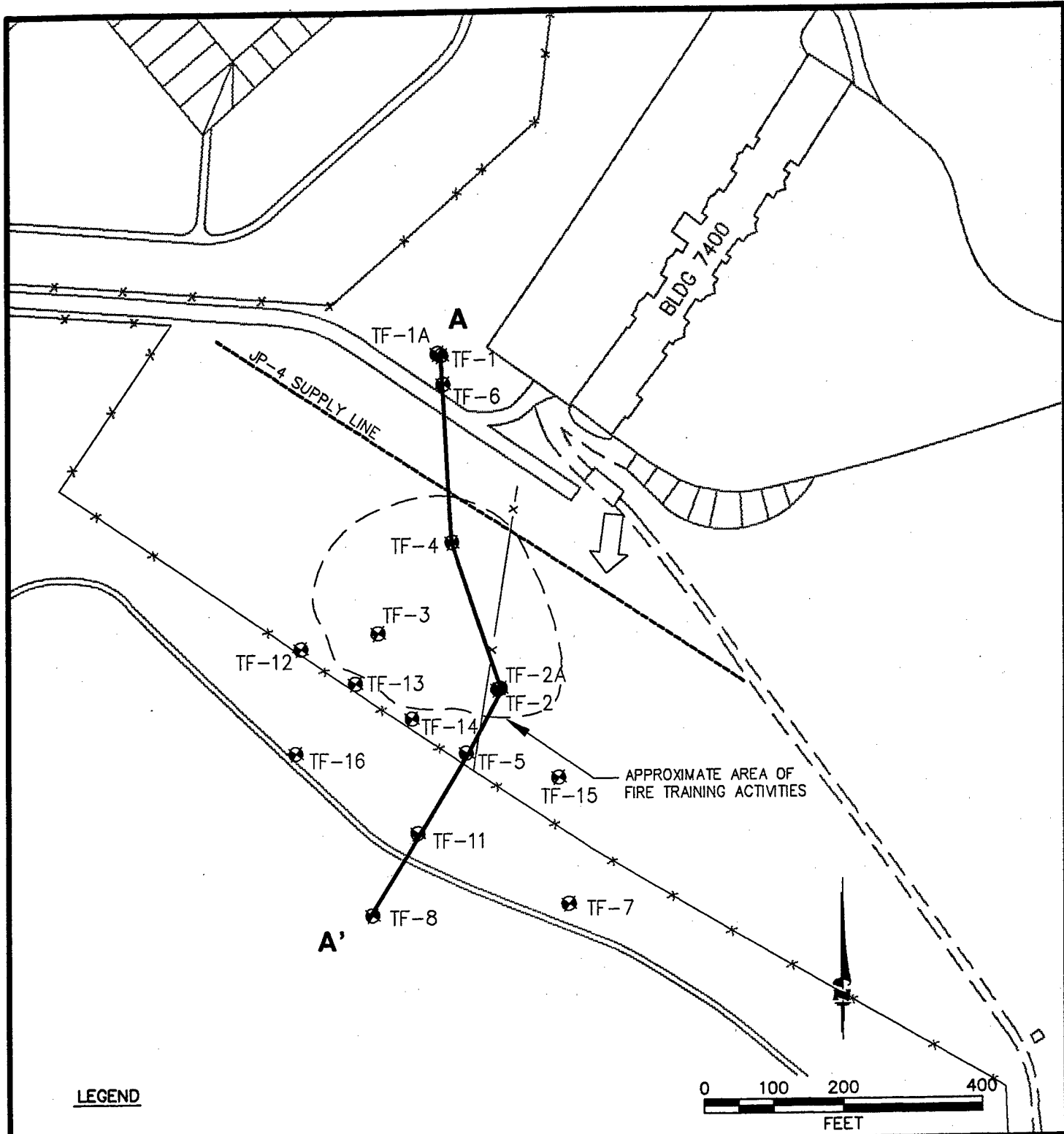
To illustrate these stratigraphic relationships, a hydrogeologic section has been developed from subsurface data derived from logs of previously installed monitoring wells. Figure 3.2 shows the location of this section. Figure 3.3 presents hydrogeologic section A-A', which is approximately parallel to the direction of groundwater flow.

3.3.2 Groundwater Hydraulics

3.3.2.1 Flow Direction and Gradient

Groundwater is located approximately 40 to 45 feet bgs, and the flow direction is to the south (Figure 3.4). Previously, the hydraulic gradient was estimated at 0.07 foot per foot (ft/ft) using few monitoring wells. However, Parsons ES and O'Brien and Gere (1994) groundwater elevation data suggest a less steep gradient of 0.01 ft/ft. A summary of historical groundwater measurements is presented in Table 3.1.

Evidence suggests that significant vertical flow gradients within the shallow aquifer are not present at this site. Two monitoring well clusters had shallow wells screened across the water table and deep wells screened at least 35 feet below the water table. Vertical gradients were computed at 0.012 ft/ft downward at TF-2 and -2A, and 0.0021 ft/ft upward at TF-1 and -1A from 1994 groundwater elevations. Nearly identical vertical gradients were estimated from 1996 groundwater elevations. As these gradients are small relative to the horizontal gradient and in opposing directions, the vertical gradients across the site are considered to be negligible.



LEGEND




-  MONITORING WELL LOCATION
- A — A'** HYDROGEOLOGIC SECTION LOCATION
-  GROUNDWATER FLOW DIRECTION
-  FENCE

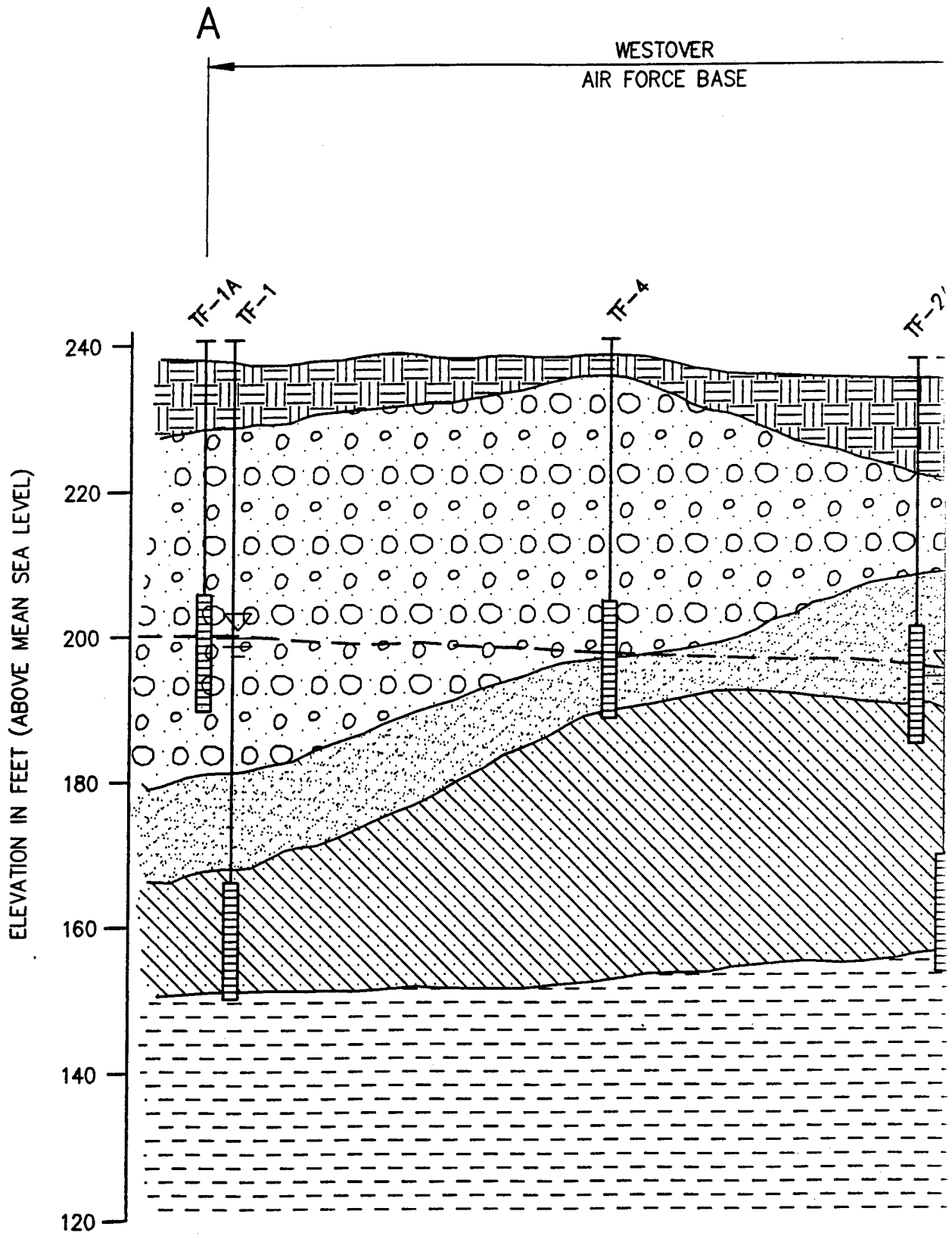


FIGURE 3.2

HYDROGEOLOGIC SECTION LOCATION

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

 **PARSONS ENGINEERING SCIENCE, INC.**
Denver, Colorado



Source: O'Brien and Gere, 1994.

L:\45028\DRAWNGS\95DN1283, 01/24/97 at 14:14

WESTOVER
AIR FORCE BASE

CHICOPEE
STATE FOREST

A'

FENCELINE

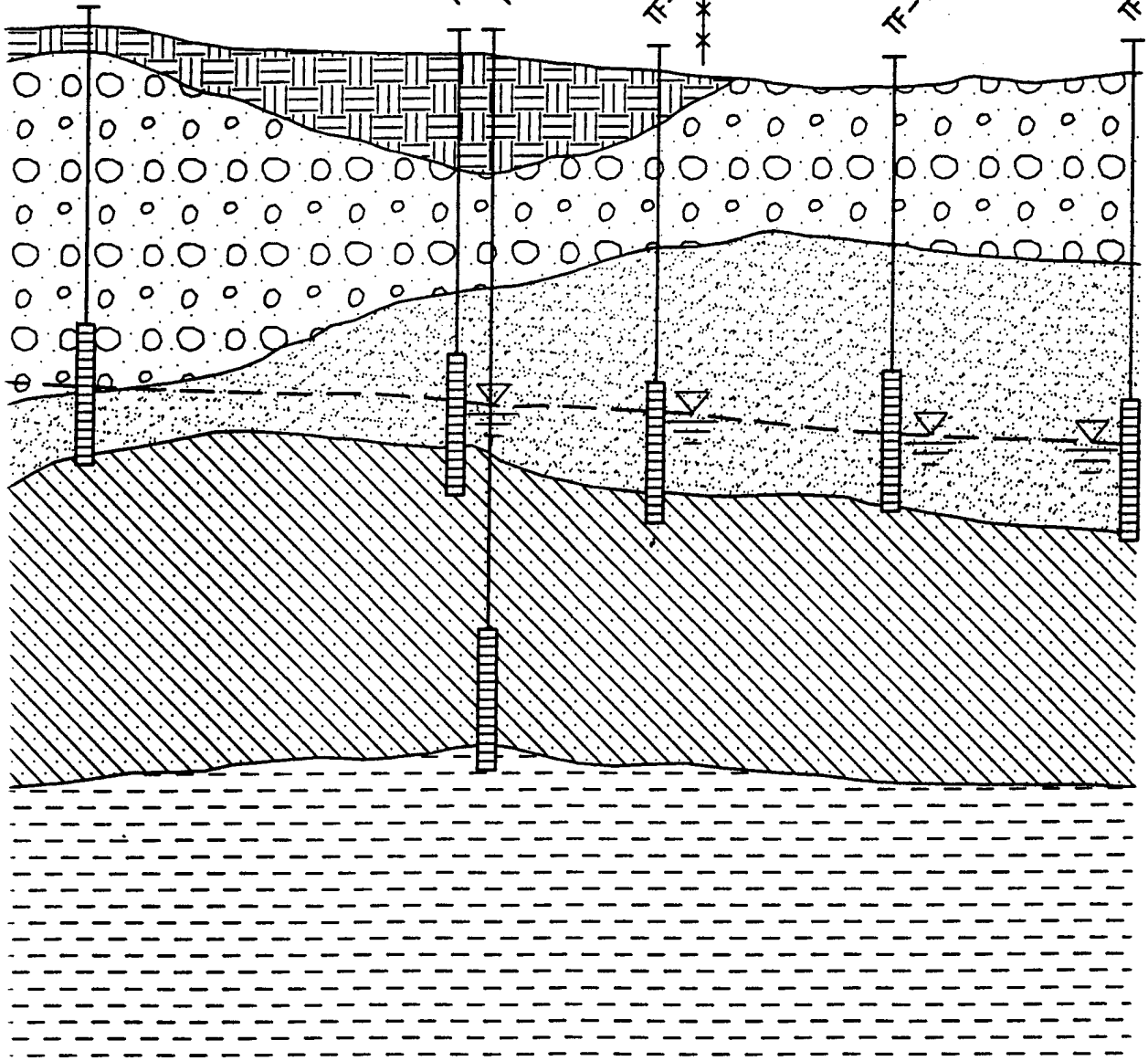
TF-4

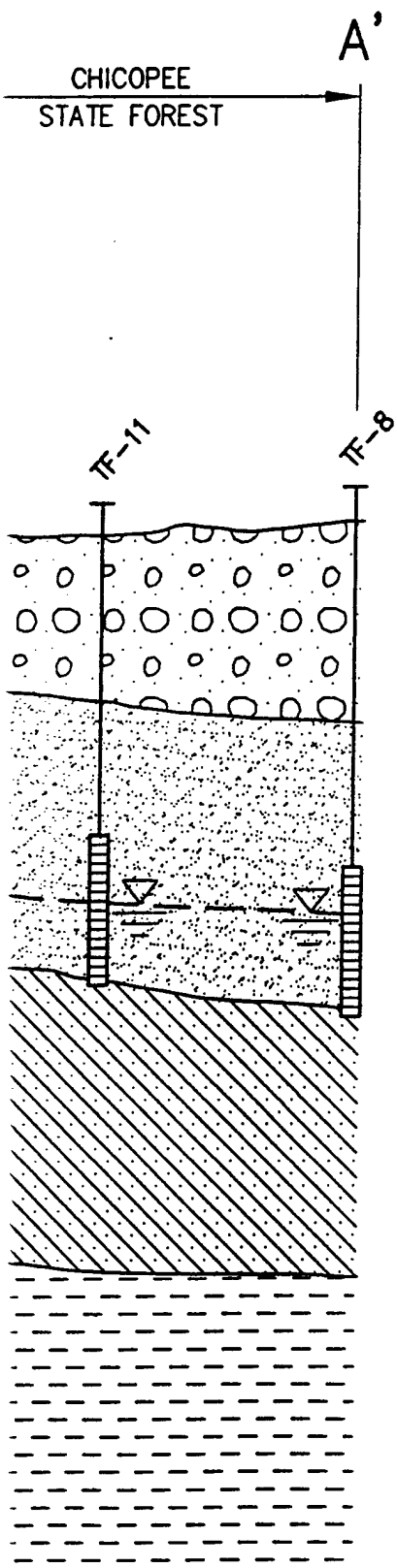
TF-2A
TF-2

TF-5

TF-11

TF-8





LEGEND



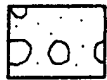
WATER TABLE - 5/95



SCREENED INTERVAL



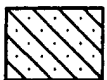
BASE FILL



SAND AND GRAVEL



FINE SAND



FINE SILTY SAND



VARVED SILT, CLAY, AND SAND
LACUSTRINE DEPOSITS



Approximate Horizontal Scale in Feet
Vertical Exaggeration = 5X

FIGURE 3.3

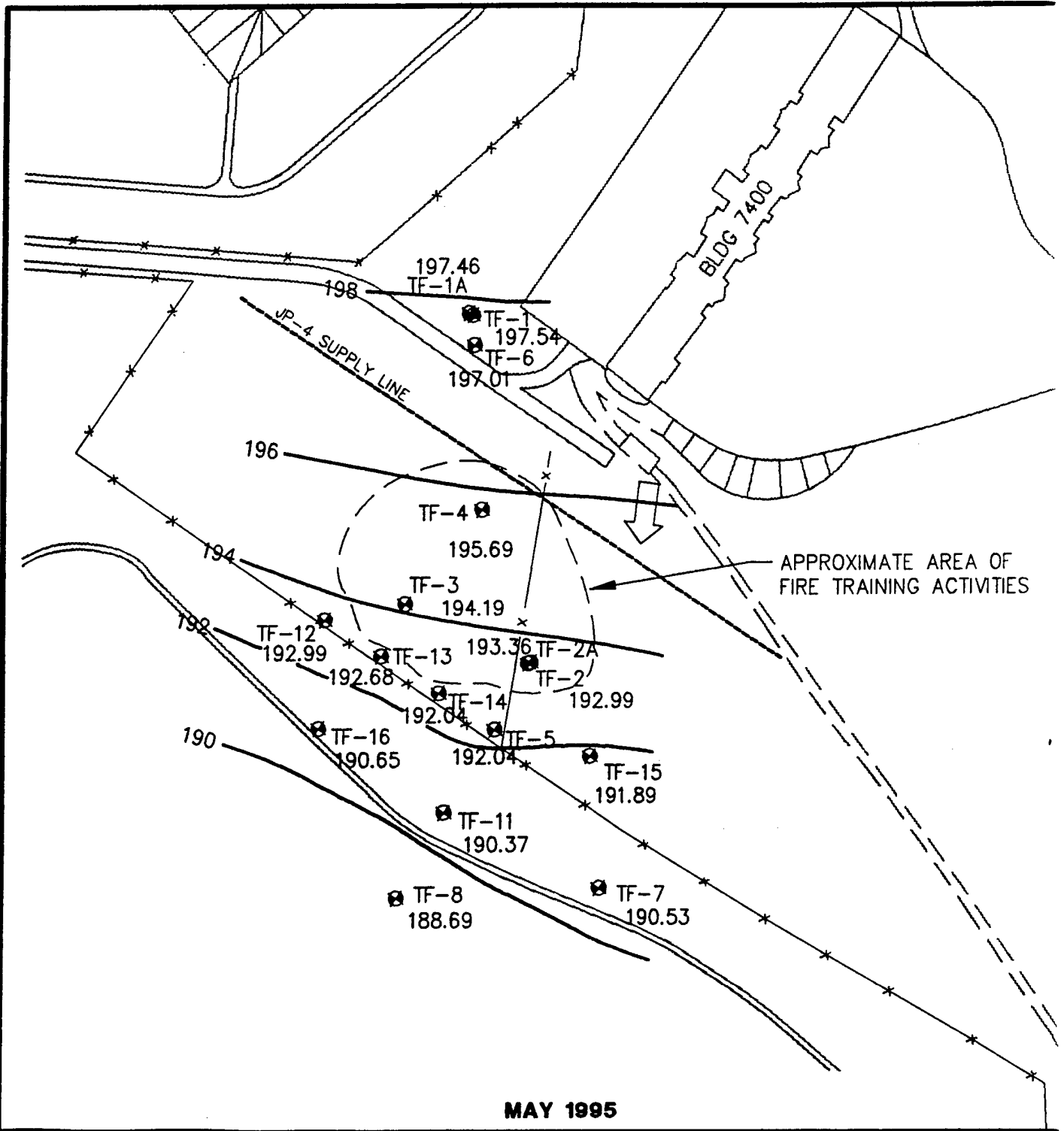
HYDROGEOLOGIC SECTION A-A'

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts


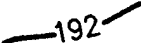




**PARSONS
ENGINEERING SCIENCE, INC.**

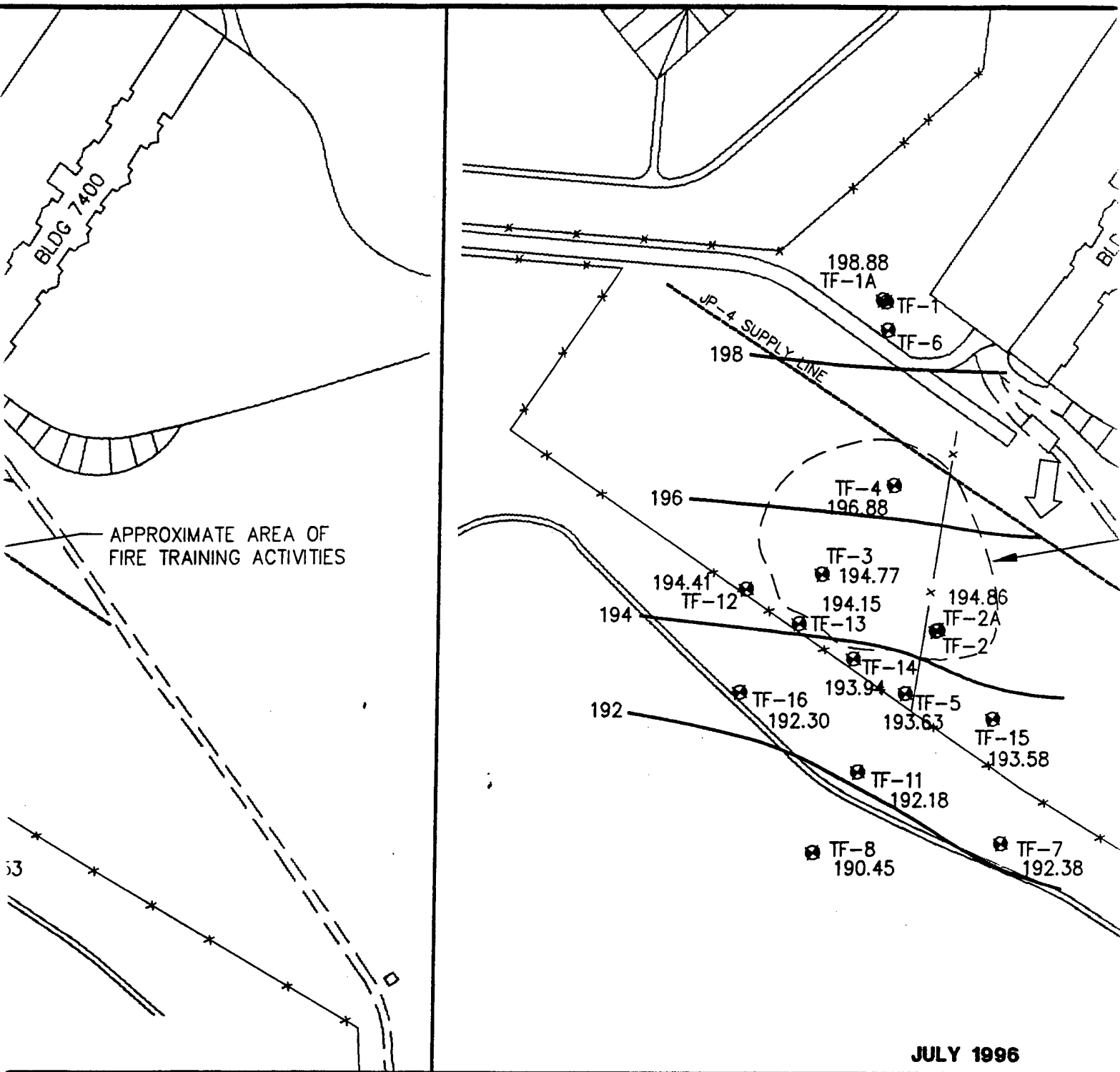
Denver, Colorado



LEGEND

- 
TF-8
 188.69 **MONITORING WELL LOCATION WITH GROUNDWATER ELEVATION (FT MSL)**
- 
192 **LINE OF EQUAL GROUNDWATER ELEVATION (FT MSL)**
- 
GROUNDWATER FLOW DIRECTION
- 
FENCE

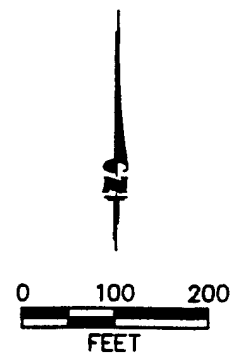
NOTE: IN MAY 1995, G
 OVER A 9-DAY
 SURVEY WAS NO
 RESTRICTED SITE



JULY 1996

GROUNDWATER

NOTE: IN MAY 1995, GROUNDWATER ELEVATIONS WERE MEASURED OVER A 9-DAY PERIOD. A FINAL WATER LEVEL SURVEY WAS NOT CONDUCTED DUE TO RESTRICTED SITE ACCESS.

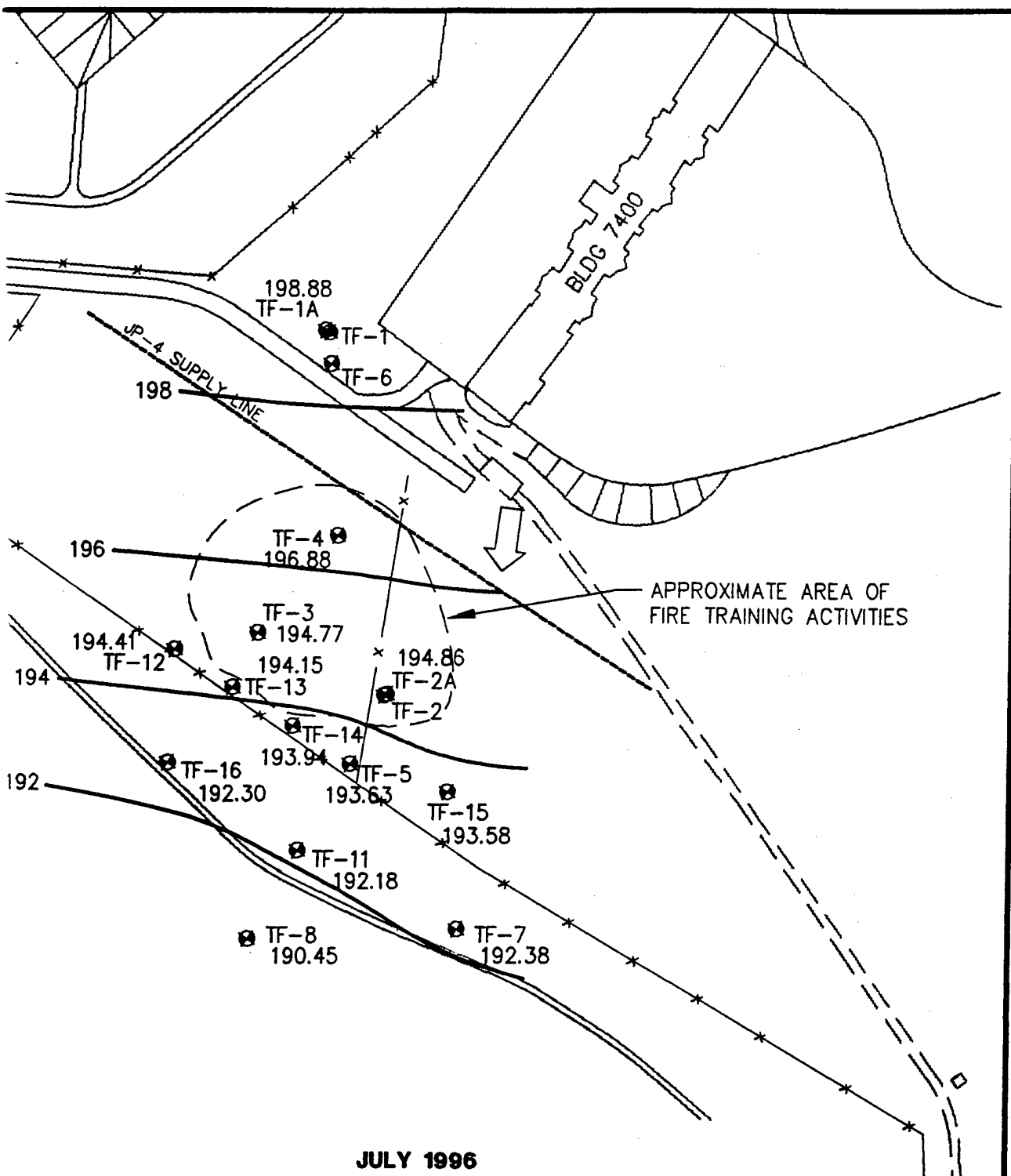


GF

Ch

V





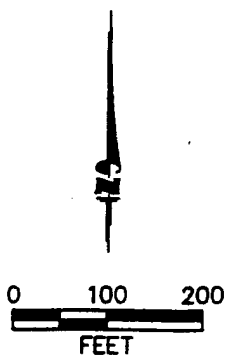
JULY 1996

FIGURE 3.4

GROUNDWATER ELEVATIONS

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

WERE MEASURED
 LEVEL



PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

TABLE 3.1
SUMMARY OF GROUNDWATER ELEVATION MEASUREMENTS
 Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Well Identification	Measurement Date	Screen Interval (ft bgs) ^{a/}	Depth to Water (ft btoc) ^{b/}	Groundwater Elevation (ft msl) ^{c/}
TF-1	1/23/87	74.0-89.0	42.26	196.38
	3/5/87		42.51	196.13
	4/21/87		41.63	197.01
	10/30/88		42.30	196.34
	5/11/95		41.19	197.54
	7/16/96		39.76	198.97
	TF-1 A		1/23/87	35.0-50.0
3/5/87		41.98	196.16	
4/21/87		41.03	197.11	
10/30/88		41.58	196.56	
12/94		40.97	197.18	
5/11/95		40.77	197.46	
7/16/96		39.35	198.88	
TF-2	1/23/87	68.5-83.5	44.74	191.40
	3/5/87		44.92	191.22
	4/21/87		44.02	192.12
	10/30/88		44.49	191.65
	12/94		43.82	192.44
	5/11/95		43.32	192.99
	7/16/96		41.84	194.47
TF-2 A	1/23/87	37.0-52.0	43.27	191.97
	3/5/87		43.56	191.68
	4/21/87		42.53	192.71
	10/30/88		43.15	192.09
	12/94		42.55	192.82
	5/11/95		42.05	193.36
	7/16/96		40.55	194.86
TF-3	1/23/87	37.0-52.0	43.14	192.73
	3/5/87		43.35	192.52
	4/21/87		42.64	193.23
	10/30/88		42.91	192.96
	12/94		43.02	192.80
	5/11/95		41.86	194.19
	7/16/96		41.28	194.77
TF-4	1/23/87	37.0-52.0	43.81	194.41
	3/5/87		43.98	194.24
	4/21/87		43.33	194.89
	10/30/88		43.65	194.57
	5/11/95		42.65	195.69
	7/16/96		41.46	196.88

TABLE 3.1 (Concluded)
SUMMARY OF GROUNDWATER MEASUREMENTS
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Well Identification	Measurement Date	Screen Interval (ft bgs) ^{a/}	Depth to Water (ft btoc) ^{b/}	Groundwater Elevation (ft msl) ^{c/}
TF-5	12/94	35.0-50.0	42.57	191.40
	5/11/95		41.99	192.04
	7/16/96		40.40	193.63
TF-6	5/11/95	34.5-77.0	39.95	197.01
TF-7	10/30/88	38.8-53.8	43.25	190.97
	12/94		44.42	189.94
	5/11/95		43.75	190.64
	5/20/95		43.86	190.53
TF-8	7/16/96	38.7-53.7	42.01	192.38
	10/30/88		44.19	189.27
	12/94		45.91	187.67
	5/11/95		44.77	188.85
	5/20/95		44.93	188.69
TF-11	7/16/96	NA ^{d/}	43.17	190.45
	12/94		43.94	189.59
	5/11/95		43.17	190.49
	5/20/95		43.29	190.37
TF-12	7/16/96	35.0-45.0	41.48	192.18
	5/18/95		42.08	192.99
TF-13	7/16/96	35.0-45.0	40.66	194.41
	5/18/95		41.91	192.68
TF-14	7/16/96	35.0-45.0	40.44	194.15
	5/18/95		41.97	192.04
TF-15	7/16/96	40.0-50.0	40.27	193.74
	5/18/95		45.07	191.89
TF-16	7/16/96	40.0-50.0	43.38	193.58
	5/20/95		44.15	190.65
	7/16/96		42.50	192.30

Note: A complete round of measurements could not be collected on 5/20/95 due to restricted site access.

Source: ES, 1988.

- a/ ft bgs = feet below ground surface.
- b/ ft btoc = feet below top of well casing.
- c/ ft msl = feet above mean sea level.
- d/ NA = data not available.

3.3.2.2 Hydraulic Conductivity

Parsons ES estimated the hydraulic conductivity at wells TF-8 and TF-16 using falling/rising head slug tests and the methods of Bouwer and Rice (1976) as described by Wiedemeier *et al.* (1995). The results of these slug tests are summarized in Table 3.2. The average hydraulic conductivity of the sands at the water table as determined from these tests is 3.45 ft/day. On the basis of measurements at wells TF-1 and TF-2 (Table 2.2), UNC Geotech (1991) estimated the hydraulic conductivities of the deeper portions of the aquifer to range from 3.4 to 12 ft/day.

TABLE 3.2
1995 SLUG TEST RESULTS
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Well	Hydraulic Conductivity (feet/minute)	hydraulic Conductivity (feet per day)
FT-8	0.00236	3.41
FT-16	0.00242	3.50
Average	0.0024	3.45

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil comprising the shallow saturated zone were used. Walton (1988) gives ranges of effective porosity for sand of 0.1 to 0.35. Contrasts in the classification of the aquifer matrix between previous investigations have ranged from fine to coarse sand. Because the presence of fines tends to decrease the effective porosity, and because lower effective porosity results in higher computed advective groundwater velocities, an effective porosity of 0.2 was assumed for this project. This is a conservative value because a higher calculated groundwater velocity results in a faster rate of contaminant plume migration.

3.3.2.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$v = \frac{K dH}{n_e dL}$$

Where: \bar{v} = Average advective groundwater velocity (seepage velocity) [L/T]
K = Hydraulic conductivity [L/T] (3.45 ft/day)
dH/dL = Gradient [L/L] (0.01 ft/ft)
 n_e = Effective porosity (0.2).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at the site in May 1995, was estimated to be 0.173 ft/day, or approximately 63.0 feet per year.

3.3.2.5 Preferential Flow Paths

A single buried JP-4 supply line is known to cross the site upgradient from the former fire training pit (i.e., source area). Past investigations have concluded that localized contamination has originated from the fuel line. Furthermore, the relatively steep gradient (0.01 ft/ft) and depth of the groundwater table across the site (40 to 45 feet bgs) may prevent anthropogenic features from affecting preferential groundwater flow paths. Natural preferential flow pathways were not identified, although the top of silty sand unit is relatively high in the vicinity of monitoring well TF-14, and may limit groundwater flow through this area.

3.3.3 Groundwater Use

Groundwater in the Westover ARB region is used for public water supply and industrial use. ES (1988) reported that groundwater supply wells penetrate into the Triassic bedrock aquifer. One nonpotable well, located on the Base approximately 4,000 feet north (upgradient) of the site, is currently operational. All remaining wells at or near the Base have been abandoned in favor of municipal water provided from surface water supplies by the city of Chicopee.

3.4 CLIMATE

The climate in south-central Massachusetts is typified by cold winters and moderately warm summers. The temperatures range from a mean high of 83 degrees Fahrenheit (°F) in July to a mean low of 16°F in January. Precipitation averages 42 inches per year, with the maximum precipitation typically occurring during the months of July through September. May is usually the driest month, with a mean precipitation total of 2.8 inches. The mean annual wind speed is 6 knots from the south.

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCES OF CONTAMINATION

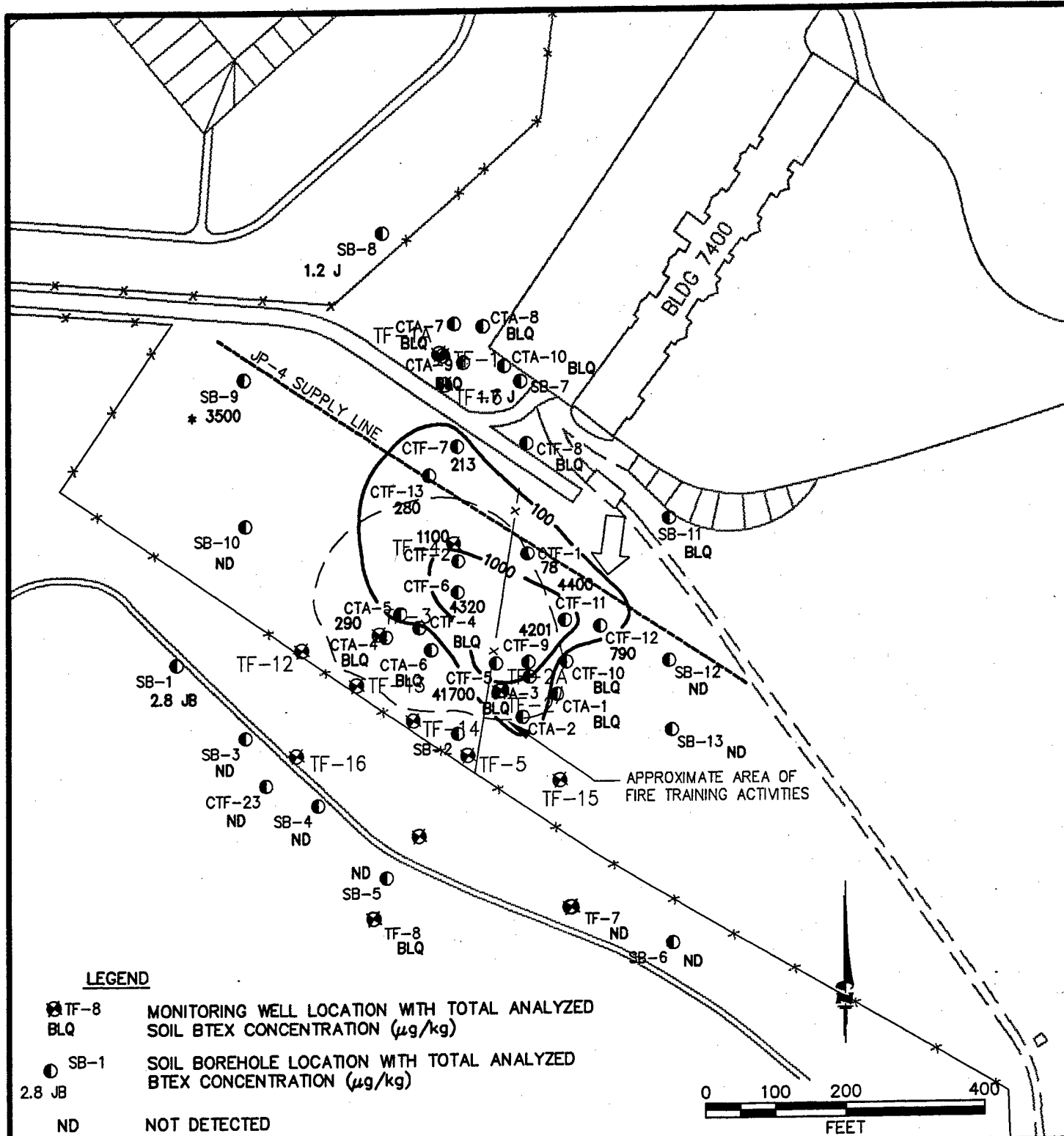
The discharge of waste fuels and solvents during fire training exercises from 1940 through 1964 has been identified as the source of environmental contamination at FT-03. As no liners or other containment devices were used within the burn pit, a portion of the unburned waste fuels and solvents likely percolated into the soils and the groundwater following each training exercise. However, neither the frequency of training exercises nor the volume of waste fuels and solvents used during exercises is known. Full-scale remediation of vadose zone soils contaminated with residual petroleum commenced in May 1995, with the installation and operation of a full-scale bioventing system. With the exception of the bioventing system, there is no visible evidence at the site of the former fire training activities and the associated contamination.

4.2 SOIL CHEMISTRY

Site soils have been characterized in previous investigations by ES (1988), UNC Geotech (1991), and O'Brien & Gere (1994). Borehole locations are presented on Figure 4.1. As part of the initial site characterization, ES (1988) analyzed soil samples from three boreholes for VOCs (including BTEX and chlorinated solvents) and petroleum hydrocarbons. To continue the delineation of the lateral and vertical extent of contamination, UNC Geotech (1991) analyzed 57 soil samples from 24 boreholes for BTEX, oil and grease, and total chromatographable petroleum hydrocarbons (in the range of C8 through C32). Results of the UNC Geotech soils investigation are summarized in Table 4.1. O'Brien and Gere (1994) expanded the UNC Geotech investigation with an additional 27 soil samples collected from 13 boreholes. Samples were analyzed for VOCs, semivolatile organic compounds (SVOCs), and total petroleum hydrocarbons (TPH). Results of the O'Brien and Gere soil investigation are summarized in Table 4.2.

4.2.1 Soil BTEX and Petroleum Hydrocarbon Contamination

Historically, elevated BTEX concentrations have been detected in soil samples collected from the main burn area. The highest detected total BTEX concentration was 41,700 micrograms per kilogram ($\mu\text{g}/\text{kg}$) in the soil sample collected from borehole CTF-5 at 5 feet bgs. The second highest BTEX concentration (4,510 $\mu\text{g}/\text{kg}$) was detected in the sample from 15 feet bgs in the same borehole. This sample also represents the deepest detected BTEX concentration at the site. A 20-foot sample with



LEGEND

- TF-8
 BLQ MONITORING WELL LOCATION WITH TOTAL ANALYZED SOIL BTEX CONCENTRATION ($\mu\text{g}/\text{kg}$)
- SB-1
 2.8 JB SOIL BOREHOLE LOCATION WITH TOTAL ANALYZED BTEX CONCENTRATION ($\mu\text{g}/\text{kg}$)
- ND NOT DETECTED
- JB SAMPLE RESULT IS APPROXIMATE AND MAY REFLECT BLANK CONTAMINATION
- BLQ BELOW LEVEL OF QUANTITATION
- 100
 EXTENT OF BTEX-CONTAMINATED SOIL ($\mu\text{g}/\text{kg}$) (DASHED WHERE INFERRED)
- GROUNDWATER FLOW DIRECTION
- FENCE
- * CONTAMINATION ASSOCIATED WITH JP-4 SUPPLY LINE AND THEREFORE ELIMINATED FROM CONTOURED REGION.



FIGURE 4.1

**CONTOUR MAP OF
TOTAL ANALYZED SOIL BTEX**

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Sources: O'Brien & Gere, 1994; UNC Geotech, 1991.

TABLE 4.1
SOIL ANALYTICAL RESULTS
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Location	Sample Depth (ft bgs) ^d	Benezene (µg/kg) ^b	Toluene (µg/kg)	Ethyl-benzene (µg/kg)	Total Xylenes (µg/kg)	Total BTEX (µg/kg)	Oil and Grease (mg/kg) ^d	Total Chromatographable Hydrocarbons (µg/kg)
CTF-1	0	BLQ ^d	78	BLQ	BLQ	78	1000	120000
CTF-2	0	BLQ	270	530	BLQ	800	13000	3000000
	5	BLQ	BLQ	BLQ	1100	1100	3900	1500000
	10	BLQ	BLQ	BLQ	BLQ	BLQ	120	170000
	15	BLQ	BLQ	BLQ	BLQ	BLQ	65	BLQ
CTF-3	0	BLQ	BLQ	BLQ	BLQ	BLQ	7200	3200000
CTF4	0	BLQ	BLQ	BLQ	BLQ	BLQ	91	BLQ
	5	BLQ	BLQ	BLQ	BLQ	BLQ	310	9200
CTF-5	0	BLQ	BLQ	BLQ	BLQ	BLQ	640	31000
	5	BLQ	BLQ	5700	36000	41700	4700	1300000
	10	BLQ	BLQ	440	3000	3440	1300	57000
	15	BLQ	BLQ	610	3900	4510	640	49000
	20	BLQ	BLQ	BLQ	BLQ	BLQ	19	31000
CTF-6	0	BLQ	BLQ	520	3800	4320	3000	2100000
	7	BLQ	130	BLQ	1800	1930	3700	3000000
	10	74	50	190	380	694	130	320000
CTF-7	0	BLQ	53	BLQ	160	213	97	6500
	5	BLQ	BLQ	BLQ	BLQ	BLQ	10	BLQ
	10	BLQ	BLQ	BLQ	BLQ	BLQ	68	2100
CTF-8	0	BLQ	BLQ	BLQ	BLQ	BLQ	37	BLQ
	5	BLQ	BLQ	BLQ	BLQ	BLQ	56	12000
	10	BLQ	BLQ	BLQ	BLQ	BLQ	5	BLQ
CTF-9	0	BLQ	BLQ	240	980	1220	1800	2800000
	5	61	530	410	3200	4201	2300	1600000
	10	BLQ	BLQ	BLQ	BLQ	BLQ	180	14000
CTF-10	0	BLQ	BLQ	BLQ	BLQ	BLQ	190	19000
	5	BLQ	BLQ	BLQ	BLQ	BLQ	16	4000
	10	BLQ	BLQ	BLQ	BLQ	BLQ	6	BLQ
CTF-11	0	BLQ	BLQ	BLQ	BLQ	BLQ	18	BLQ
	5	BLQ	BLQ	900	3500	4400	19	23000
	10	BLQ	BLQ	90	290	380	7	BLQ
CTF-12	0	BLQ	BLQ	BLQ	BLQ	BLQ	99	150000
	7	BLQ	360	160	270	790	29	8100
	10	BLQ	BLQ	BLQ	BLQ	BLQ	13	BLQ
CTF-13	0	BLQ	150	BLQ	130	280	155	5200
	5	BLQ	BLQ	BLQ	BLQ	BLQ	300	3800
	10	BLQ	66	BLQ	BLQ	66	24	BLQ
CTF-23	20	ND ^d	ND	BLQ	ND	ND	100	ND

TABLE 4.1 (Concluded)
SOIL ANALYTICAL RESULTS
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Location	Sample Depth (ft bgs) ^{a/}	Benezene (µg/kg) ^{b/}	Toluene (µg/kg)	Ethylbenzene (µg/kg)	Total Xylenes (µg/kg)	Total BTEX (µg/kg)	Oil and Grease (mg/kg) ^{c/}	Total Chromatographable Hydrocarbons (µg/kg)
CTA-1	3	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	8600
CTA-2	0	BLQ	BLQ	BLQ	BLQ	BLQ	160	9800
	3	BLQ	BLQ	BLQ	380	380	BLQ	BLQ
CTA-3	0	BLQ	BLQ	BLQ	BLQ	BLQ	3130	740000
CTA-4	0	BLQ	BLQ	BLQ	BLQ	BLQ	180	7500
CTA-5	0	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	2200
	3	BLQ	160	BLQ	BLQ	BLQ	170	95000
	5	BLQ	170	BLQ	120	290	2110	650000
CTA-6	0	BLQ	BLQ	BLQ	BLQ	BLQ	60	BLQ
CTA-7	0	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	2400
	5	BLQ	BLQ	BLQ	BLQ	BLQ	90	BLQ
CTA-9	0	BLQ	BLQ	BLQ	BLQ	BLQ	110	BLQ
CTA-10	0	BLQ	BLQ	BLQ	BLQ	BLQ	50	2500
TF-7	0	BLQ	BLQ	ND	ND	ND	ND	25000
	5	BLQ	BLQ	ND	ND	ND	100	ND
	10	BLQ	59	ND	ND	59	100	ND
TF-8	0	BLQ	BLQ	BLQ	BLQ	BLQ	100	4800
	5	BLQ	BLQ	BLQ	BLQ	BLQ	ND	7100
	10	BLQ	BLQ	BLQ	BLQ	BLQ	100	ND

Source: UNC Geotech, 1991.

a/ ft bgs = feet below ground surface.

b/ µg/kg = micrograms per kilogram.

c/ mg/kg = milligrams per kilogram.

d/ BLQ = Below level of quantitation.

e/ ND = Not detected.

TABLE 4.2
SOIL ANALYTICAL DATA
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Identification	Depth (feet bgs)	Benzene (µg/kg)	Toluene (µg/kg)	Ethylbenzene (µg/kg)	Xylenes (µg/kg)	BTEX (µg/kg)	TCE ^a (µg/kg)	Tetrachloroethene (µg/kg)	1,2-DCE ^b (µg/kg)	TPH ^c (mg/kg)
SB-1	0-2	1.2 JB ^d	ND ^e	ND	1.6 JB	2.8 JB	ND	2.7 JB	1.2 JB	9.8 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	6.6 JB
SB-2	0-2	ND	ND	ND	ND	ND	ND	ND	ND	16 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	3.5 JB
SB-3	0-2	ND	ND	ND	ND	ND	ND	ND	ND	6.4 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	6.6 JB
SB-4	0-2	ND	ND	ND	ND	ND	ND	ND	ND	6.4 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	6.1 JB
SB-5	0-2	ND	ND	ND	ND	ND	ND	ND	ND	4.4 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	2.6 JB
SB-6	0-2	ND	ND	ND	ND	ND	ND	ND	ND	4.2 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	3.4 JB
SB-7	0-2	ND	0.6 J ^f	ND	ND	ND	ND	ND	ND	87
	18-20	ND	ND	ND	1.1 J	1.7 J	ND	ND	ND	5.8 JB
SB-8	0-2	ND	ND	ND	ND	ND	ND	ND	ND	18 JB
	18-20	ND	1.2 J	ND	ND	1.2 J	ND	ND	ND	7.3 JB
SB-9	0-2	ND	ND	ND	ND	ND	ND	ND	ND	5.7 JB
	8-10	ND	ND	ND	3500.0	3500.0	ND	ND	ND	1300
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	27 JB
SB-10	0-2	ND	ND	ND	ND	ND	ND	ND	ND	5.8 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	6.1 JB
SB-11	0-2	ND	ND	ND	ND	ND	ND	ND	ND	64
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	15 JB
SB-12	0-2	ND	ND	ND	ND	ND	ND	ND	ND	87
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	13 JB
SB-13	0-2	ND	ND	ND	ND	ND	ND	ND	ND	28 JB
	18-20	ND	ND	ND	ND	ND	ND	ND	ND	9.9 JB

Source: O'Brien and Gere, 1994.

^a TCE = Trichloroethene; µg/kg = micrograms per kilogram.

^b 1,2 - DCE = 1,2 - dichloroethene.

^c TPH = Total petroleum hydrocarbons; mg/kg = milligrams per kilogram.

^d JB = Sample result is approximate and may reflect blank contamination.

^e ND = Not detected.

^f J = Result is detected below the reporting limit or is an estimated concentration.

a total BTEX concentration below the level of quantitation defines the vertical extent of contamination at borehole CTF-5.

Total BTEX concentrations above 1,000 µg/kg were also observed in soil samples collected from boreholes SB-9 and CTF-2, -6, -9, and -11. The contamination detected in borehole SB-9 is believed to be associated with the buried JP-4 fuel line northwest of the former fire training area (O'Brien and Gere, 1994). The remaining four boreholes in conjunction with borehole CTF-5 fall within the areal extent of the burn area for the former fire training exercises, as represented by the 1,000-µg/kg contour on Figure 4.1. The total area of impacted soils is approximated by the 100-µg/kg contour on Figure 4.1. Boreholes CTF-1 and CTA-3 have been included in the contoured areas despite low total BTEX concentrations. In both instances, the only analyzed soil sample was collected from surface soils, where volatilization of BTEX compounds is likely to have occurred. Each sample from these two boreholes also had an oil and grease concentration of at least 1,000 milligrams per kilogram (mg/kg).

With the exception of borehole CTF-5 as described above, the majority of BTEX contamination was detected in the top 10 feet of soil. Furthermore, over 84 percent of all detected BTEX mass in soil samples has consisted of xylenes. These two conditions result from the type and time frame of the fuel release. Fuel constituents are concentrated in shallow soils because fuels were released at the site surface resulting from fire training exercises. As unburned fuels percolated into the ground, fuel constituents sorbed to the organic carbon in the soil, with the highest BTEX concentrations sorbing to the shallower soils. Among BTEX compounds, ethylbenzene and xylenes are the least volatile and have the strongest sorption coefficients (Wiedemeier *et al.*, 1995); therefore, they are the least mobile and most likely to sorb to shallow soils. Because the fire training exercises were conducted 30 years ago, the more mobile, volatile, and soluble constituents (benzene and toluene) have been preferentially removed from the site through the percolation of rainwater and the migration of soil gas. High xylenes concentrations are also the result of initial concentrations in the source fuel. Over 50 percent of the BTEX in fresh JP-4 consists of xylenes. This percentage would be expected to increase with the preferential removal of benzene and toluene, which comprise 11 and 30 percent of BTEX in fresh JP-4, respectively (Arthur D. Little, 1987).

The presence of BTEX compounds in shallow soils at FT-03 prompted the Base to implement a bioventing soil remediation system in May 1995. To date no additional soil samples have been collected to determine the effectiveness of the system. However, the decrease of groundwater contamination between May 1995 and July 1996 suggests that bioventing at the site has significantly increased aerobic biodegradation processes in soils, resulting in a reduction in the mass of BTEX entering the groundwater.

Elevated concentrations of oil and grease and total chromatographable hydrocarbons correlate strongly with elevated concentrations of total BTEX. Concentrations of oil and grease in excess of 2,000 mg/kg were detected in soil samples collected from boreholes CTF-2, -3, -5, -6, and -9 and CTA-3, and -5 (Table 4.1). Five of these boreholes are included in the total BTEX contour of 1,000 µg/kg on Figure 4.1. It is suspected that borehole CTF-3 also lies within the 1,000-µg/kg BTEX contour; however, the location of this borehole could not be established accurately from past

reports. Similarly, concentrations of total chromatographables in excess of 1,000 mg/kg were detected in soil samples from boreholes CTF-2, -3, -5, -6, and -9. Four of these boreholes were included in and one is suspected to lie within the total BTEX contour of 1,000 $\mu\text{g}/\text{kg}$ on Figure 4.1.

4.2.2 Soil Chlorinated Solvent Contamination

Twenty-seven soil samples were collected at FT-03 and analyzed for chlorinated solvents by O'Brien and Gere (1994). The only detections of chlorinated solvents were below 3 $\mu\text{g}/\text{kg}$ (Table 4.2) and were also detected in an associated blank at similar concentrations. None of the 27 samples, however, was collected from the suspected area of the former burn pit or the area of impacted soil as defined by the 1,000- or 100- $\mu\text{g}/\text{kg}$ total BTEX concentration contours shown on Figure 4.1. It is unknown whether chlorinated solvents are present in source area soils.

4.2.3 Total Organic Carbon

TOC concentrations are used to estimate the amount of organic matter sorbed on soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption results in retardation of the contaminant plume migration relative to the average advective groundwater velocity.

Five samples for TOC analysis were collected by the Base drilling subcontractor in 1995. The samples were taken at the groundwater interface and used in the computation of contaminant retardation as a result of sorption. All TOC concentrations were below the method detection limit of 1 mg/kg. TOC data are presented in Appendix B.

4.3 GROUNDWATER CHEMISTRY

Three lines of evidence can be used to document the occurrence of natural attenuation: (1) geochemical evidence; (2) documented loss of contaminant mass at the field scale; and (3) laboratory microcosm studies. The first two lines of evidence (geochemical evidence and documented loss of contaminants) are used herein to support the occurrence of natural attenuation, as described in the following sections. Because these two lines of evidence strongly suggest that natural attenuation is occurring at this site, laboratory microcosm studies were not deemed necessary.

4.3.1 Dissolved Hydrocarbon and Chlorinated Solvent Contamination

As a part of previous site investigations, groundwater samples were collected on six occasions between 1986 and 1994. The highest BTEX and chlorinated solvent concentrations have consistently been detected in groundwater samples from TF-2A, with the highest total BTEX concentration [2,820 micrograms per liter ($\mu\text{g}/\text{L}$)] and the highest total chlorinated solvent concentration (130 $\mu\text{g}/\text{L}$ of 1,2-DCE) both detected in 1988 (ES, 1988). Dissolved concentrations of BTEX and chlorinated solvents have been detected in groundwater samples from all three wells located downgradient from well TF-2A (TF-5, TF-8, and TF-11). Typically, total BTEX concentrations at TF-2A

have exceeded concentrations in samples from other site wells by at least an order of magnitude. Differences in chlorinated solvent concentrations are typically just under one order of magnitude. Furthermore, at TF-2A, groundwater BTEX concentrations have decreased by almost 1,200 µg/L since 1989, and 1,2-DCE groundwater concentrations at TF-2A also have decreased by approximately 100 µg/L.

Groundwater samples collected in May 1995 and July 1996, by Parsons ES personnel at the previously sampled and newly installed monitoring wells confirmed these historical observations. Tables 4.3 and 4.4 summarize groundwater contaminant data for the 1995 and 1996 samples. Analytical results from the 1995 TS investigation and July 1996 sampling event are discussed in the following subsections.

4.3.1.1 Dissolved BTEX Contamination

The areal distributions of total dissolved BTEX in groundwater for May 1995 and July 1996 are presented on Figure 4.2. Where nested monitoring wells are present, isopleths are drawn using the concentration detected at the well screened across the water table. In May 1995, the main body of the plume is centered beneath the southern portion of the approximate area of fire training activities, with decreasing BTEX concentrations spreading downgradient to the south and south-southwest. The 100-µg/L BTEX isopleth depicts a division of the plume. This division likely results from the geologic high in a zone of lower hydraulic conductivity near well TF-14. As defined by the estimated position of the 10-µg/L isopleth, the BTEX plume is approximately 630 feet long and 580 feet wide with an approximate area of 249,600 square feet, or approximately 5.7 acres.

Well TF-2A is located at the center of the observed BTEX plumes. In May 1995, the groundwater sample collected at this location contained both the maximum observed total BTEX concentration of 1,657 µg/L and the maximum observed benzene concentration of 5 µg/L. In 1989, BTEX concentrations were 2,690 µg/L and the benzene concentration was 6.7 µg/L. BTEX concentrations at the three wells immediately downgradient of TF-2A ranged from 60 to 124 µg/L with benzene concentrations of 1.7 to 3.7 µg/L (Table 4.3). Elsewhere, the total BTEX concentrations in shallow wells ranged from 14 µg/L to 88 µg/L, with benzene concentrations from below the quantitation limit to 3.5 µg/L. BTEX compounds were not detected above quantitation limits in groundwater samples collected at TF-1A, TF-4, and TF-15. The decreasing BTEX concentrations within the source area at monitoring well TF-2A provide evidence that BTEX mass is being removed through natural attenuation processes.

July 1996 data suggest that the rate of dissolved BTEX attenuation is increasing. The observed dissolved BTEX plume in July 1996 is approximately 200 feet long by 150 feet wide, covering an area of about 30,000 square feet (2/3 of an acre). Only sampling locations TF-2A, 468.9 µg/L, and TF-5, 1.2 µg/L, had detectable concentrations of dissolved total BTEX. These observed concentrations represent 72 percent and 97 percent decreases in total dissolved BTEX concentrations in TF-2A and TF-5, respectively, since the May 1995 TS investigation. On a percentage basis, the magnitude of these decreases are approximately twice those observed for the entire 6 years between 1989 and 1995. At all remaining locations where dissolved BTEX was detected in 1995, the 1996 results represent a 100 percent decrease. Because the only

TABLE 4.3
GROUNDWATER QUALITY DATA
FOR BTEX, TMB, AND TMB COMPOUNDS
 Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Sample ID	Date Sampled	Benzene (µg/L) ^{a/}	Toluene (µg/L)	Ethyl-Benzene (µg/L)	p-Xylenes (µg/L)	m-Xylenes (µg/L)	o-Xylenes (µg/L)	Total BTEX (µg/L)	Fuel Carbon (mg/L)	1,3,5-	1,2,4-	1,2,3-	1,2,4,5	1,2,3,5	
										TMB ^{c/} (mg/L)	TMB (mg/L)	TMB (mg/L)	TEMB ^{d/} (mg/L)	TEMB (mg/L)	
TF-1	5/17/95	14.51	57.17	13.86	9.84	23.74	17.74	136.86	154.40	3.05	10.83	3.80	<1.0	1.18	ND
TF-1	7/16/96	<1.0	ND ^{b/}	ND	ND	ND	ND	<1.0	<1.0	ND	ND	ND	NA	NA	NA
TF-1 A	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TF-1 A	7/16/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-2	5/18/95	7.84	39.38	11.52	9.22	21.00	14.58	103.54	156.00	3.67	14.04	4.89	1.30	1.69	1.17
TF-2	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-2 A	5/18/95	5.01	184.60	378.61	255.13	559.53	273.67	1656.55	2580.00	87.43	280.06	92.38	10.08	15.67	17.36
TF-2 A	7/18/96	<1.0	18.2	116	97.2	58.5	179	468.90	1040	55.8	86.3	60.4	NA	NA	NA
TF-3	5/18/95	1.89	20.17	6.10	4.48	10.97	7.35	50.96	56.78	1.69	5.21	1.83	ND	ND	ND
TF-3	7/16/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-4	5/18/95	ND	<1.0	ND	ND	<1.0	ND	<2.0	<1.0	ND	ND	ND	ND	ND	ND
TF-4	7/16/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-5	5/18/95	2.29	19.39	45.65	31.01	15.59	9.18	123.11	320.60	2.71	46.80	3.94	3.21	3.87	6.29
TF-5	7/16/96	<1.0	<1.0	1.2	ND	ND	ND	1.20	16.4	<1.0	ND	0.9	NA	NA	NA
TF-7	5/19/95	<1.0	4.54	1.87	1.53	3.45	2.45	13.84	20.31	1.15	3.03	1.29	ND	ND	ND
TF-7	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-8	5/19/95	<1.0	5.81	2.12	1.60	3.73	2.64	15.90	20.99	1.12	2.79	1.11	ND	ND	ND
TF-8	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-11	5/19/95	1.99	11.58	39.75	10.14	8.37	5.07	76.90	301.10	1.45	12.95	3.05	4.35	3.53	8.39
TF-11	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-12	5/18/95	<1.0	8.84	2.89	2.37	5.77	3.90	23.77	29.73	1.22	3.38	1.21	ND	ND	ND
TF-12	7/16/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-13	5/18/95	3.71	42.29	16.54	12.28	29.36	19.92	124.10	160.90	4.46	17.32	5.39	0.96	1.55	ND
TF-13	7/16/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-14	5/18/95	1.69	20.34	8.18	6.20	14.56	9.44	60.41	80.58	2.52	9.26	2.95	ND	1	ND
TF-14	7/16/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-15	5/18/95	ND	<1.0	ND	ND	ND	ND	<1.0	<1.0	ND	ND	ND	ND	ND	ND
TF-15	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
TF-16	5/19/95	3.46	32.79	11.27	8.10	19.51	13.23	88.36	105.30	2.75	10.14	3.23	ND	0.89	ND
TF-16	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA

^{a/} µg/L = micrograms per liter.

^{b/} ND = not detected.

^{c/} TMB = trimethylbenzene.

^{d/} TEMB = tetramethylbenzene.

TABLE 4.4
 CONCENTRATION DATA FOR CHLORINATED VOLATILE ORGANIC COMPOUNDS
 IN GROUNDWATER

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Sample ID	Date Sampled	PCE ^{a/} (µg/L) ^{d/}	TCE ^{b/} (µg/L)	Trans-		Ethene (mg/L)	Ethane (mg/L)
				1,1-DCE ^{c/} (µg/L)	1,2-DCE (µg/L)		
				Cis-	Vinyl		
				1,2-DCE (µg/L)	Chloride (µg/L)		
TF-1	5/19/95	ND ^{e/}	ND	ND	ND	ND	ND
TF-1	7/16/96	ND	ND	ND	ND	ND	ND
TF-1 A	5/19/95	ND	ND	ND	ND	ND	ND
TF-1 A	7/16/96	BLQ	ND	ND	ND	ND	ND
TF-2	5/19/95	BLQ ^{f/}	ND	ND	ND	ND	ND
TF-2	7/18/96	ND	ND	ND	ND	ND	ND
TF-2 A	5/19/95	ND	ND	ND	31.9	ND	ND
TF-2 A	7/18/96	ND	ND	ND	ND	ND	ND
TF-3	5/19/95	BLQ	BLQ	ND	ND	ND	ND
TF-3	7/16/96	1.5	1.4	ND	1.8	ND	ND
TF-4	5/19/95	ND	BLQ	ND	ND	ND	ND
TF-4	7/16/96	ND	ND	ND	ND	ND	ND
TF-5	5/19/95	BLQ	ND	ND	3.9	ND	ND
TF-5	7/16/96	BLQ	ND	ND	BLQ	ND	ND
TF-7	5/19/95	ND	BLQ	ND	ND	ND	ND
TF-7	7/17/96	ND	BLQ	ND	ND	ND	ND
TF-8	5/19/95	ND	1.8	ND	BLQ	ND	ND
TF-8	7/17/96	ND	BLQ	ND	1.0	ND	ND
TF-11	5/19/95	ND	ND	ND	12.8	ND	ND
TF-11	7/17/96	BLQ	ND	ND	3.4	ND	ND
TF-12	5/19/95	ND	ND	ND	ND	ND	ND
TF-12	7/16/96	ND	ND	ND	ND	ND	ND
TF-13	5/19/95	ND	BLQ	ND	1.1	ND	ND
TF-13	7/16/96	ND	BLQ	ND	1.0	ND	ND
TF-14	5/19/95	BLQ	7.5	ND	1.6	ND	ND
TF-14	7/16/96	ND	ND	ND	ND	ND	ND
TF-15	5/19/95	ND	ND	ND	BLQ	ND	ND
TF-15	7/18/96	BLQ	ND	ND	ND	ND	ND
TF-16	5/19/95	ND	ND	ND	ND	ND	ND
TF-16	7/17/96	ND	BLQ	ND	ND	ND	ND

^{a/} PCE = Tetrachloroethene.

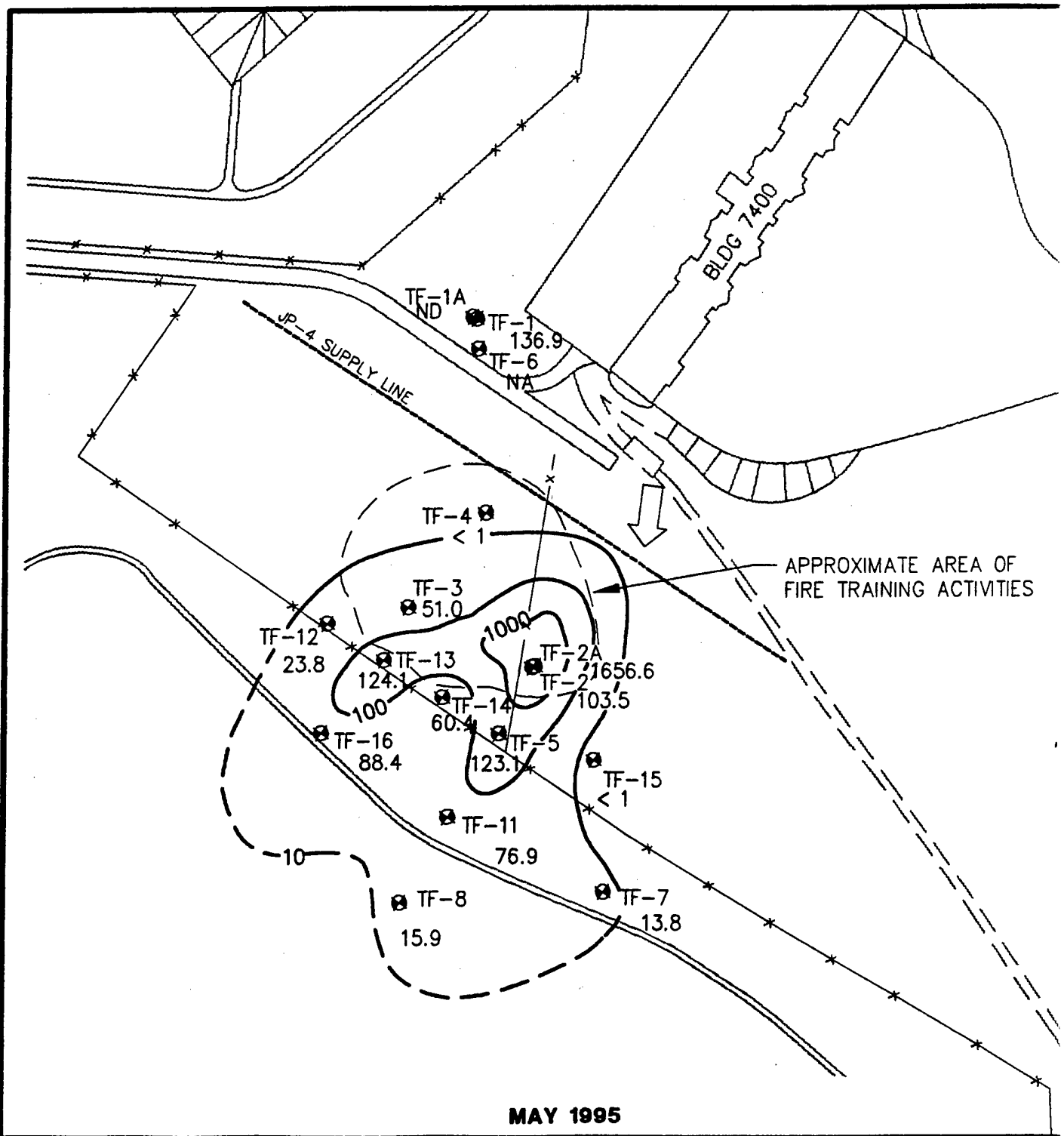
^{b/} TCE = Trichloroethene.

^{c/} DCE = Dichloroethene.

^{d/} µg/L = micrograms per liter.

^{e/} ND = Not detected.

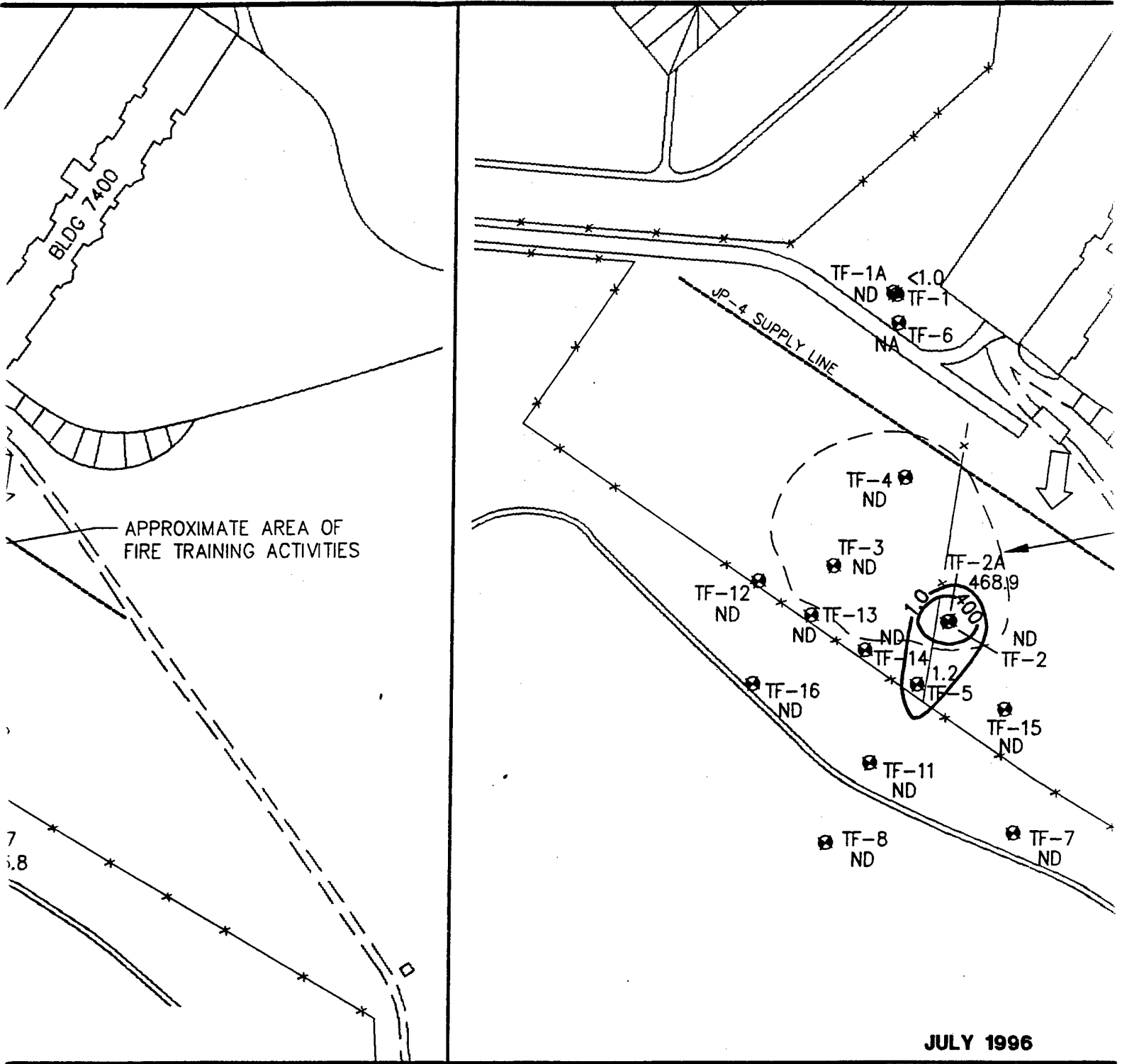
^{f/} BLQ = Below limit of quantitation.



MAY 1995

LEGEND

- TF-8 15.9 MONITORING WELL LOCATION WITH TOTAL BTEX CONCENTRATION (µg/L)
- 100 LINE OF EQUAL BTEX CONCENTRATION (µg/L) (DASHED WHERE INFERRED)
- GROUNDWATER FLOW DIRECTION
- FENCE
- NA NOT ANALYZED
- BLQ BELOW LIMIT OF QUANTIFICATION
- NOTE: SHALLOW GROUNDWATER WERE USED FOR CONTROLS

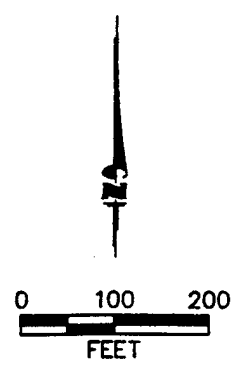


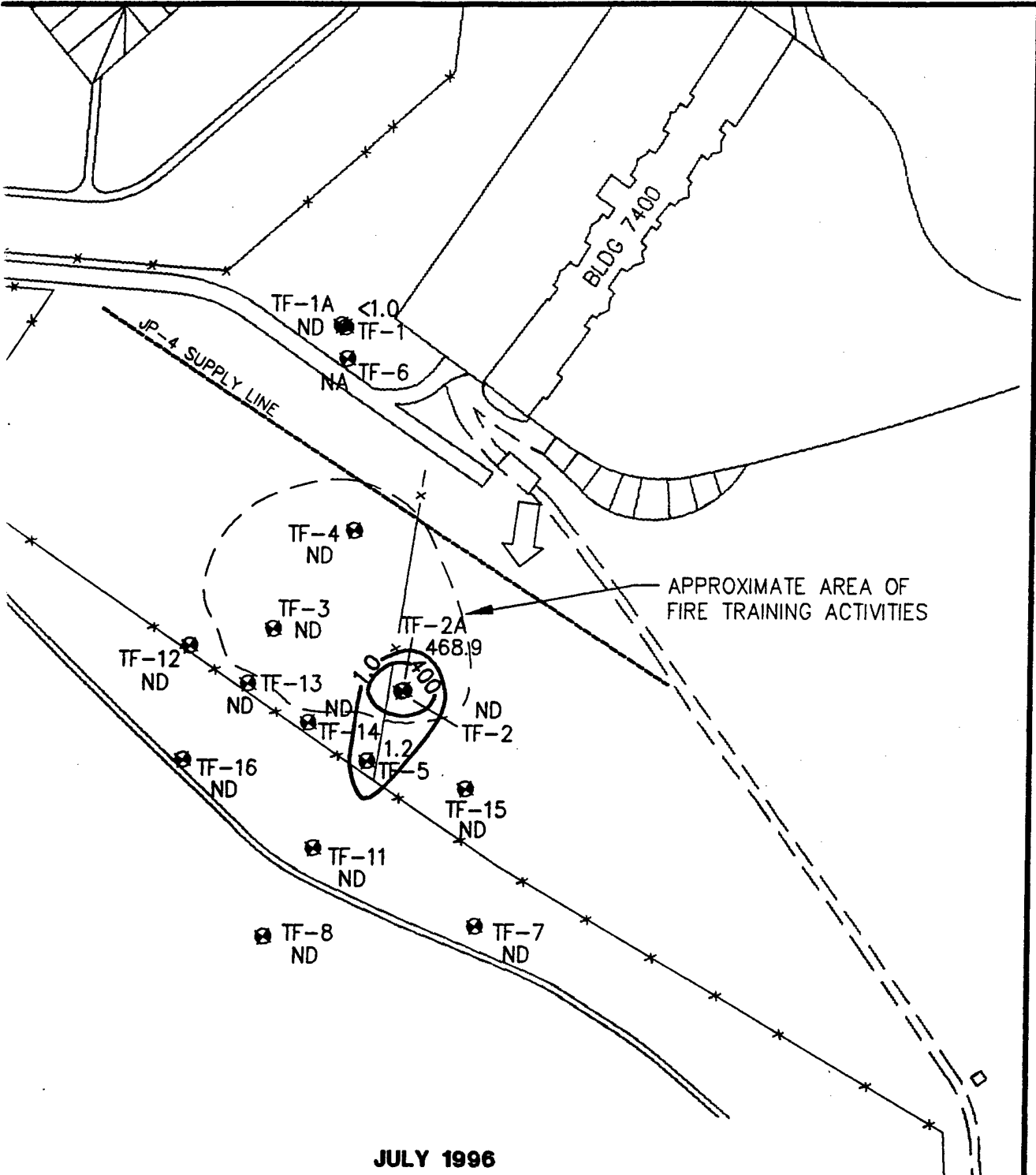
JULY 1996

NA NOT ANALYZED

BLQ BELOW LIMIT OF QUANTATION

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING





JULY 1996

FIGURE 4.2
TOTAL BTEX ISOPLETH
MAPS FOR GROUNDWATER

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

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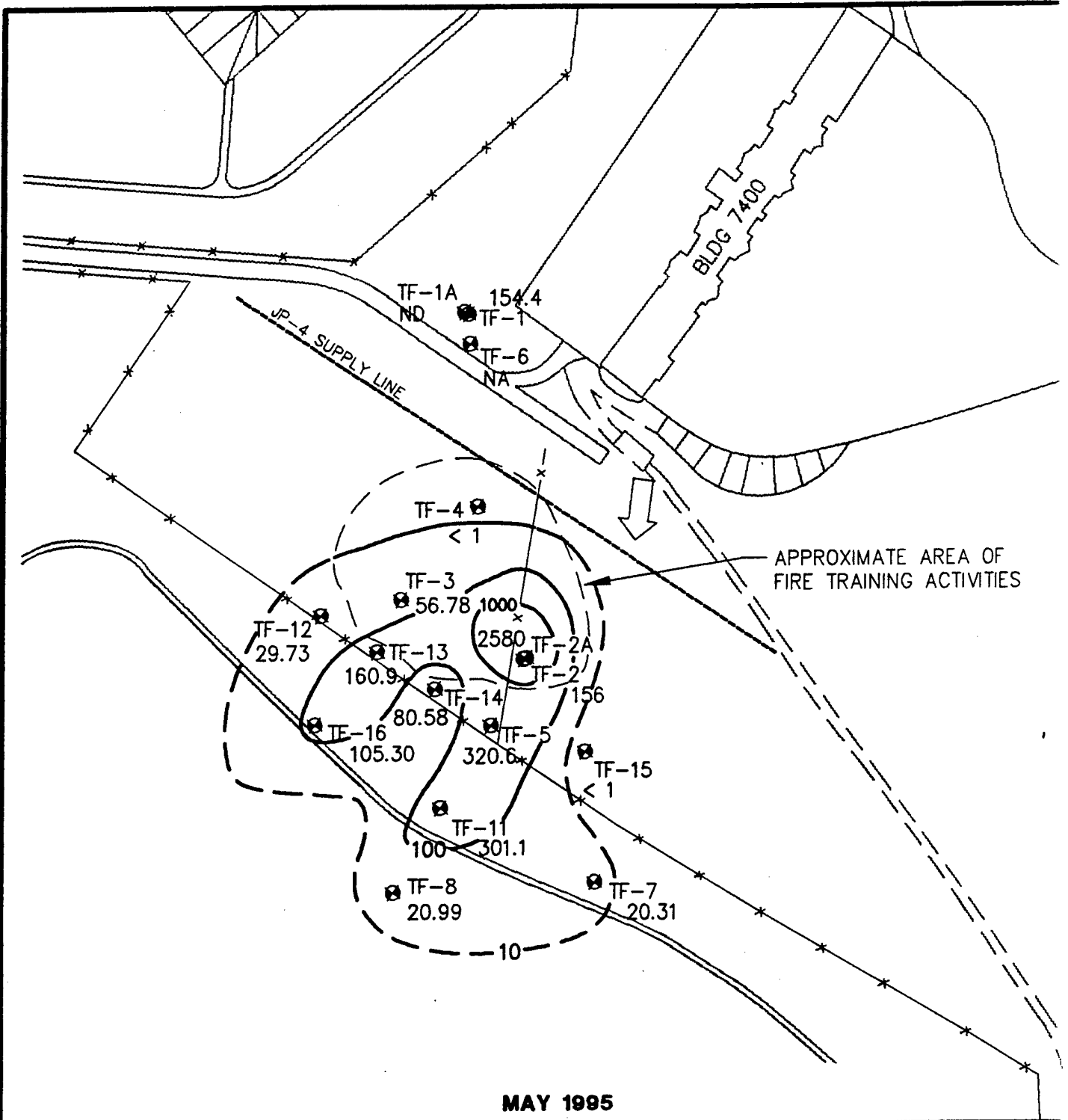
significant change in the site is the installation and operation of the bioventing system, the conclusion can be drawn that the addition of oxygen to contaminated soils is not only increasing aerobic biodegradation processes in the soil, but also substantially reducing the amount of contaminant mass migrating from the soils into the groundwater.

In May 1995, vertical extent samples were collected from the two wells screened approximately 35 feet below the top of the water table (TF-1 and TF-2). While total BTEX concentrations in excess of 100 µg/L were detected in both samples, the contamination was believed to originate from an alternate source for the following reasons:

- Well TF-1 is located upgradient from the former fire training area, and dissolved fuel constituents have not been detected in the shallow well, TF-1A, clustered with TF-1. Given the groundwater gradient at the site and the lack of a shallow source at this upgradient location, contamination would have to migrate over 4 feet vertically upgradient from the identified source area to TF-1.
- The fuel signatures for the samples from TF-1 and TF-2 are nearly identical. In other words, groundwater samples from TF-1 and TF-2 contain similar isomers of TMB and TEMB and similar concentration ratios of all measured dissolved fuel constituents. The signatures at other wells are less similar.
- Chlorinated solvents were not detected in groundwater samples from either deep well; however, they were detected at TF-2A, the water table well clustered with TF-2. If BTEX, light non-aqueous phase liquids (NAPL), are migrating vertically downward through the groundwater at the source area, then chlorinated solvents, dense NAPL, would be expected also to migrate vertically downward. Typically chlorinated solvents also have lower sorption coefficients and are therefore more mobile than BTEX compounds.

These trends pointed to one of two possibilities: 1) consistent external sample contamination during sampling, handling, or analysis or 2) an upgradient source. Therefore, resampling of these two deep locations was recommended to determine if these anomalous concentrations would persist through time. The July 1996 sampling results from monitoring wells TF-1 and TF-2 confirm that dissolved fuel constituents are not present in deep groundwater, (i.e., dissolved BTEX data from May 1995 from these two wells is not valid) and also dispel any theories that an unknown upgradient source exists for deep groundwater contamination.

The distribution of total fuel carbons in site groundwater for both May 1995 and July 1996 are presented on Figure 4.3. Where nested wells are present, isopleths are drawn using the concentration detected at the well screened across the water table. The distribution of fuel carbons is similar to the distribution of BTEX compounds presented on Figure 4.2. Dissolved fuel carbons were detected at the same locations where dissolved BTEX compounds were detected. At no location were fuel carbons detected and BTEX compounds not detected. In May 1995, total fuel carbon concentrations ranged from less than 1 to 2,580 µg/L. For the same reasons previously given for BTEX contamination, the fuel carbon concentrations from the May 1995 sampling

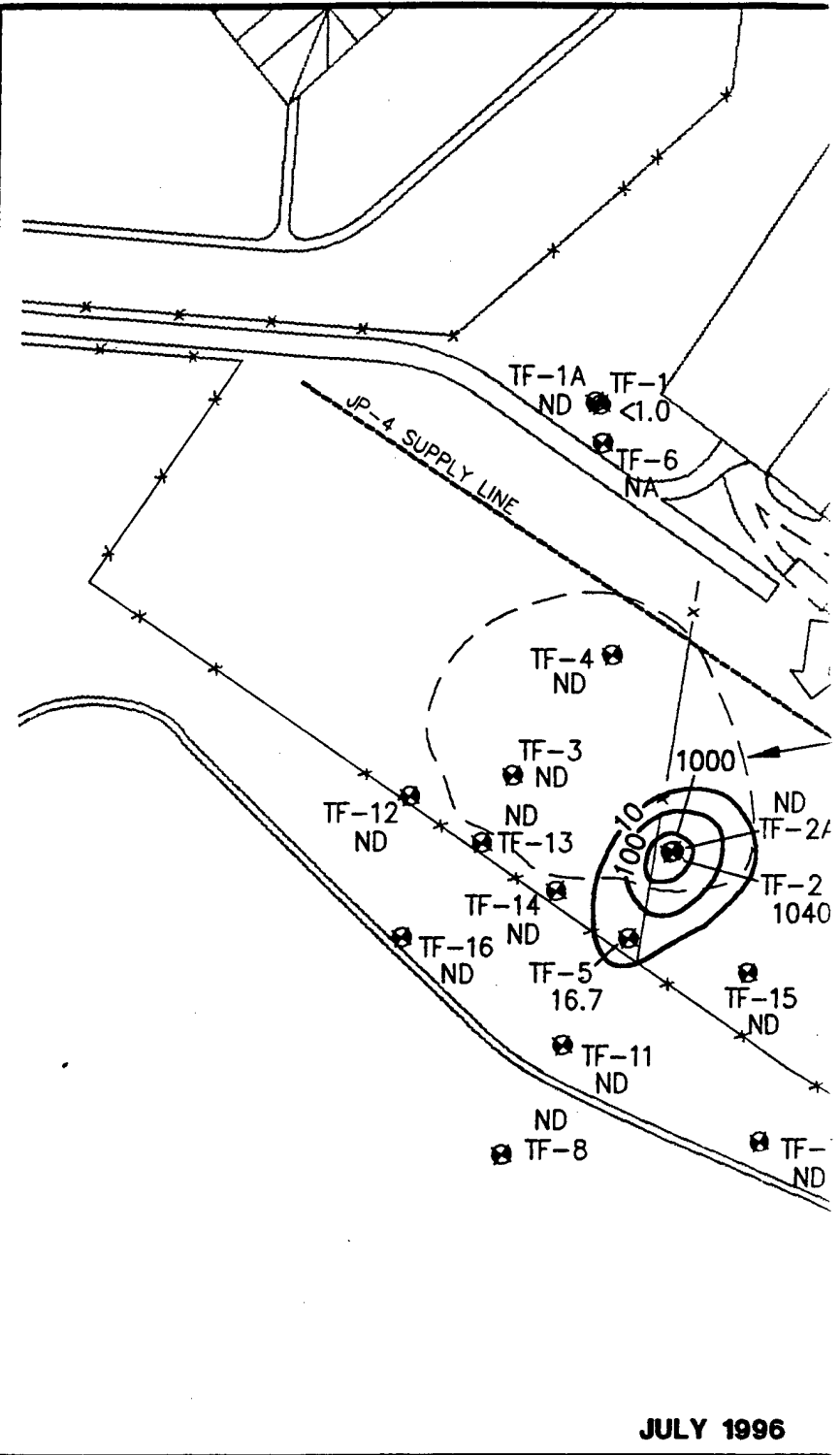
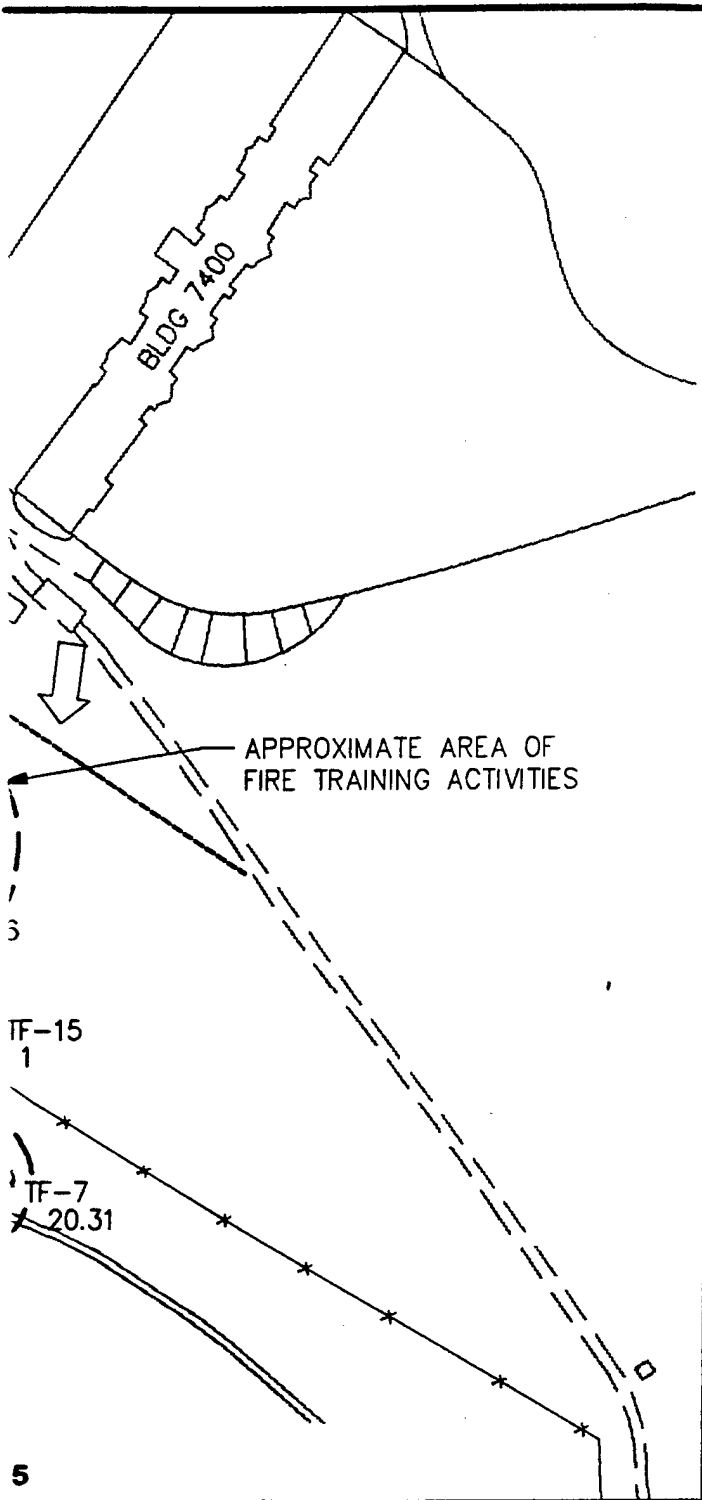


MAY 1995

LEGEND

- TF-8 20.99 MONITORING WELL LOCATION WITH TOTAL FUEL CARBON CONCENTRATION (µg/L)
- 1.0 LINE OF EQUAL CHLORINATED SOLVENT CONCENTRATION (µg/L) (DASHED WHERE INFERRED)
- GROUNDWATER FLOW DIRECTION
- FENCE

- NA NOT ANALYZED
- BLQ BELOW LIMIT OF QUANTITATION
- NOTE: SHALLOW GROUNDWATER MONITORING WELLS WERE USED FOR CONTOURING



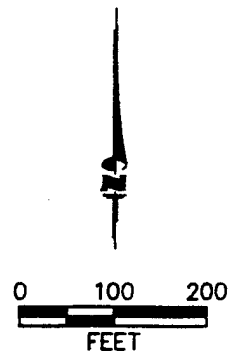
JULY 1996

OTAL
)
NT

NA NOT ANALYZED

BLQ BELOW LIMIT OF QUANTATION

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING



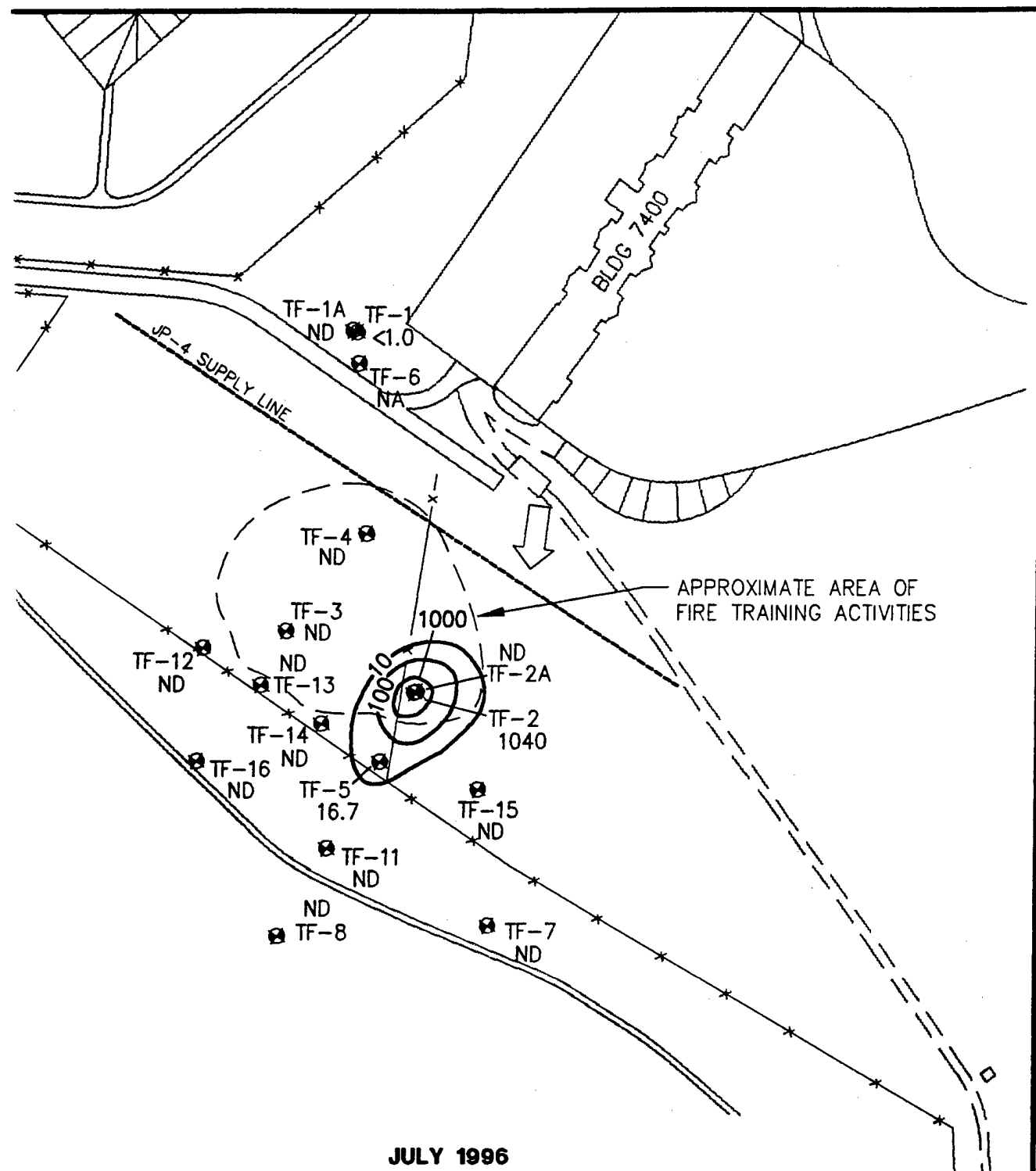


FIGURE 4.3

**TOTAL FUEL CARBON
ISOPLETH MAPS FOR
GROUNDWATER**

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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Denver, Colorado

event at TF-1 and TF-2 are considered invalid. In July 1996, the two detected concentrations of fuel carbons were 1,040 $\mu\text{g/L}$ (TF-2A), and 16.4 $\mu\text{g/L}$ (TF-5). Decreases in total fuel carbon concentration from May 1995 to July 1996 are of the same magnitude found in dissolved BTEX concentrations. This suggests that fuel compounds, other than BTEX, have been degraded at similar rates to those observed for the BTEX compounds.

4.3.1.2 Dissolved Chlorinated Solvent Contamination

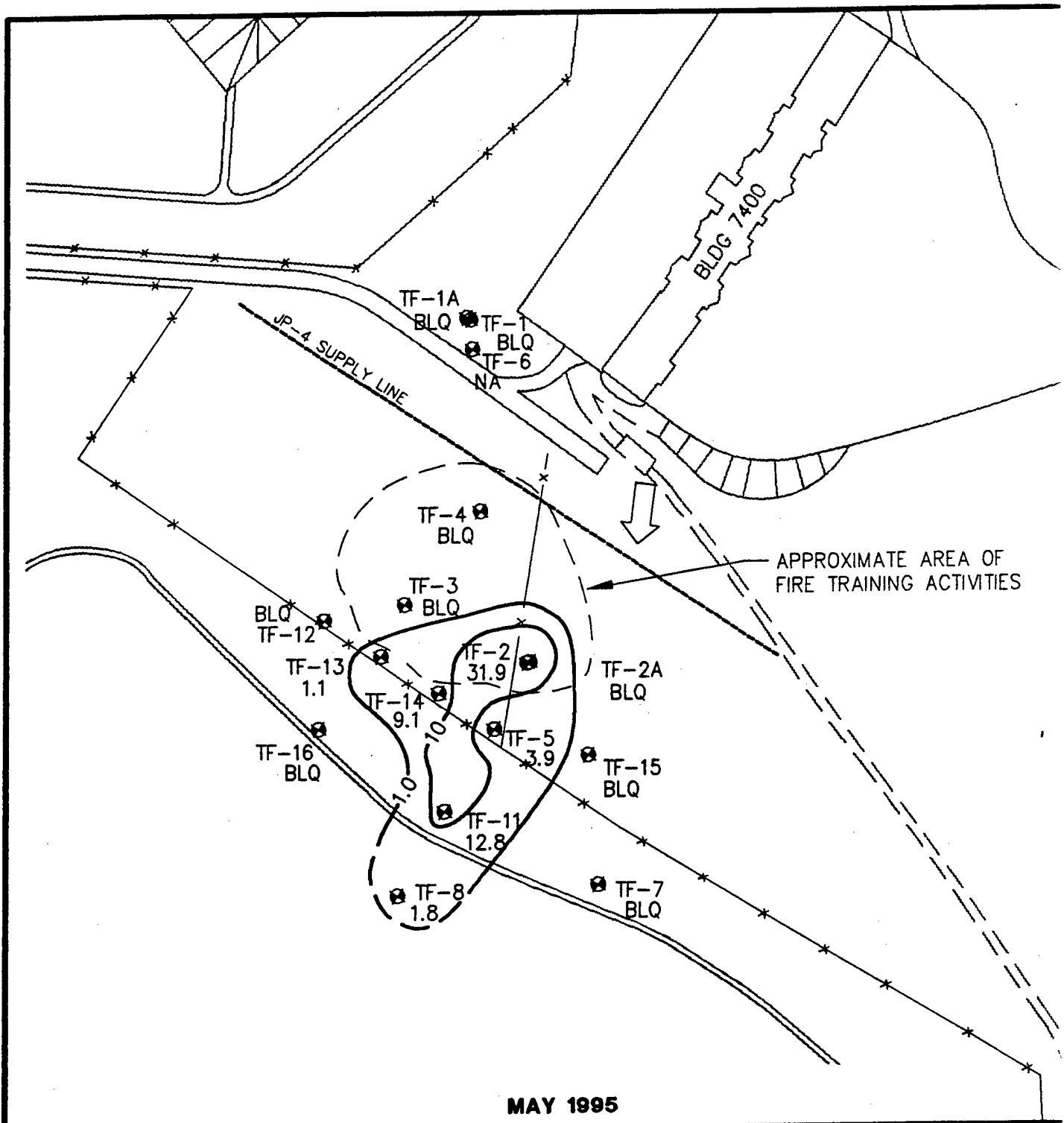
The areal extents of total dissolved chlorinated solvents detected in groundwater for May 1995 and July 1996 are presented on Figure 4.4. During both sampling rounds both cis-1,2-DCE and TCE were detected. The only other detection of a CAH during either sampling round was a single concentration of tetrachloroethene (1.5 $\mu\text{g/L}$) from TF-3 in 1996. The concentrations of individual chlorinated solvents, ethene, and ethane are presented in Table 4.4. Dissolved chlorinated solvents were not detected above the quantitation limit in either deep well (TF-1 and TF-2) during either sampling round.

In May 1995, the chlorinated solvent plume was approximately 500 feet long and 350 feet wide as defined by the 1- $\mu\text{g/L}$ isopleth. The plume source area corresponds to the BTEX source, however the plume is smaller than the BTEX plume. The estimated extent of the plume covered a total area of approximately 97,600 square feet, or approximately 2.2 acres. The maximum observed total chlorinated solvent concentration was 31.9 $\mu\text{g/L}$, in the sample collected from monitoring point TF-2A. Chlorinated solvent concentrations at the three wells immediately downgradient of TF-2A ranged from 1.8 to 12.8 $\mu\text{g/L}$. Elsewhere, total chlorinated solvents ranged from below quantitation levels to 9.1 $\mu\text{g/L}$. The CAH cis-1,2-DCE was detected at the highest concentrations and at the largest number of locations. Approximately 85 percent of detected dissolved CAH mass was cis-1,2-DCE; the remaining 15 percent was TCE.

Concentrations measured in July 1996 indicated that the chlorinated solvent plume had decreased in both size and concentration from the previous sampling round in May 1995. The July 1996 chlorinated plume was approximately 550 feet long by 75 feet wide, 41,300 square feet, or 0.9 acres with a maximum total chlorinated solvent concentration of 4.7 $\mu\text{g/L}$ measured at TF-3. At several other sampling locations, chlorinated solvent compounds were detected at low (<4 $\mu\text{g/L}$) or non-quantifiable (<1 $\mu\text{g/L}$) concentrations.

4.3.2 Inorganic Chemistry and Geochemical Indicators of BTEX Biodegradation

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of jet fuel and gasoline, including the BTEX compounds (e.g., Jamison *et al.*, 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.*, 1991 and 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Edwards *et al.*, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994).



MAY 1995

LEGEND

TF-8
1.8

MONITORING WELL LOCATION WITH TOTAL ANALYZED CHLORINATED SOLVENT CONCENTRATION ($\mu\text{g/L}$)

NA NOT ANALYZED

BLQ BELOW LIMIT OF QUA

1.0

LINE OF EQUAL CHLORINATED SOLVENT CONCENTRATION ($\mu\text{g/L}$) (DASHED WHERE INFERRED)

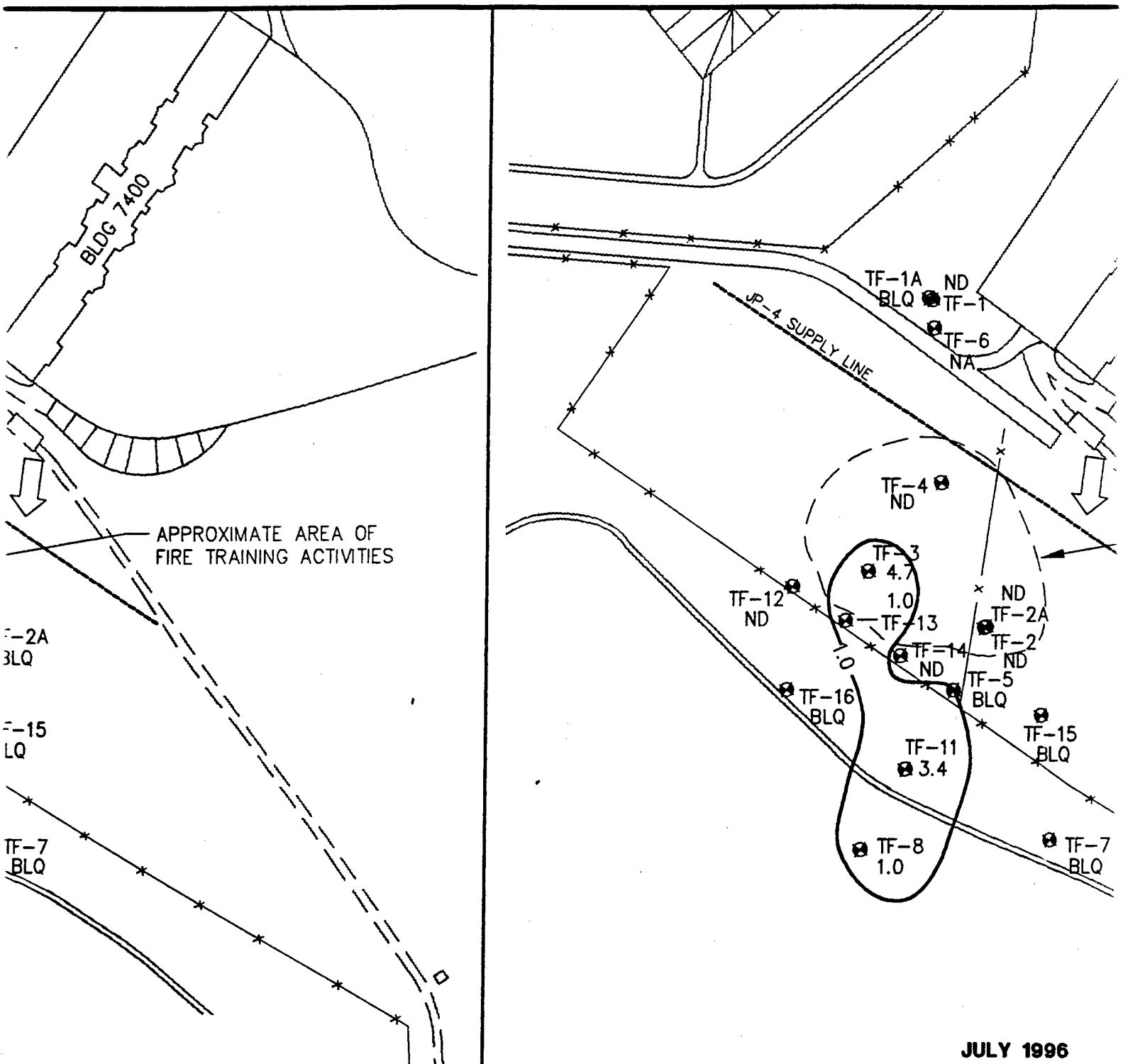
NOTE: SHALLOW GROUNDWA WERE USED FOR CON



GROUNDWATER FLOW DIRECTION



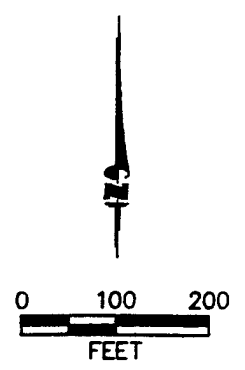
FENCE

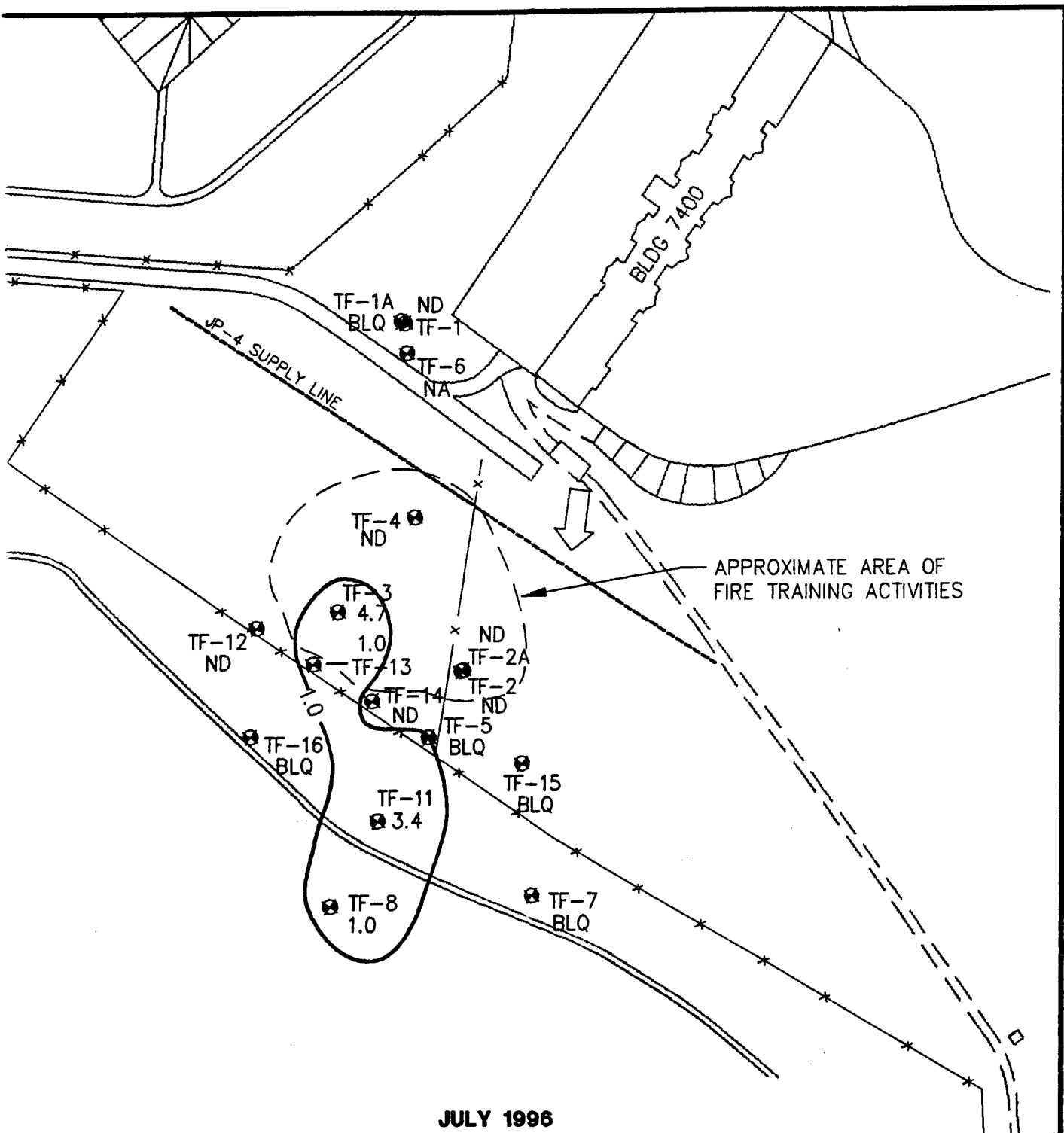


JULY 1996

ND
 TOTAL ANALYZED CONCENTRATION ($\mu\text{g/L}$)
 NA NOT ANALYZED
 BLQ BELOW LIMIT OF QUANTATION
 ND NOT DETECTED

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING





JULY 1996

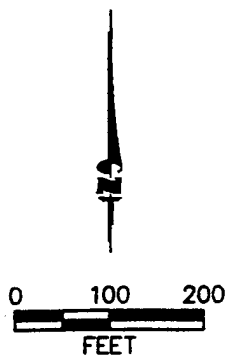
FIGURE 4.4
TOTAL ANALYZED CHLORINATED
SLOVENTS ISOPLETH MAPS
FOR GROUNDWATER

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

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Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms.

Microorganisms obtain energy for cell production and maintenance by facilitation of thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at FT-03 include natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include DO, nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer, which is quantified by the Gibbs free energy of the reaction (ΔG°) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of ΔG° represents the quantity of free energy consumed or yielded to the system during the reaction. Table 4.5 lists stoichiometry of the redox equations involving BTEX and the resulting ΔG° . Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e., $\Delta G^\circ < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors (as available) in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide. Because the biodegradation of fuel hydrocarbons should deplete the concentrations of these electron acceptors, construction of isopleth maps depicting their concentrations can provide evidence of whether biodegradation is occurring, and the degree to which it is occurring.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, ferric iron, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

Site groundwater data for electron acceptors at FT-03 indicate that intrinsic remediation of hydrocarbons in the shallow aquifer may be occurring by aerobic respiration, ferric iron reduction, denitrification, sulfate reduction, and methanogenesis. This is evidenced by significant changes in groundwater geochemistry

TABLE 4.5
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ <i>Benzene oxidation / aerobic respiration</i>	-765.34	-3202	3.07:1
$6NO_3 + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ <i>Benzene oxidation / denitrification</i>	-775.75	-3245	4.77:1
$3.75NO_3^- + C_6H_6 + 7.5H^+ + 0.75H_2O \Rightarrow 6CO_2 + 3.75NH_4^+$ <i>Benzene oxidation / nitrate reduction</i>	-524.1	-2193	2.98:1
$60H^+ + 30Fe(OH)_{3,s} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ <i>Benzene oxidation / iron reduction</i>	-560.10	-2343	21.5:1 ^{av}
$75H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S^0 + 3H_2O$ <i>Benzene oxidation / sulfate reduction</i>	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ <i>Benzene oxidation / methanogenesis</i>	-32.40	-135.6	0.77:1 ^{bv}

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9O_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4H_2O$ <i>Toluene oxidation / aerobic respiration</i>	-913.76	-3823	3.13:1
$7.2NO_3 + 7.2H^+ + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 7.6H_2O + 3.6N_{2,g}$ <i>Toluene oxidation / denitrification</i>	-926.31	-3875	4.85:1
$4.5NO_3^- + 9H^+ + 0.5H_2O + C_6H_5CH_3 \Rightarrow 7CO_2 + 4.5NH_4^+$ <i>Toluene oxidation / nitrate reduction</i>	-624.24	-2609	3.03:1
$72H^+ + 36Fe(OH)_{3,s} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ <i>Toluene oxidation / iron reduction</i>	-667.21	-2792	21.86:1 ^{av}
$9H^+ + 4.5SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4.5H_2S^0 + 4H_2O$ <i>Toluene oxidation / sulfate reduction</i>	-142.86	-597.7	4.7:1
$5H_2O + C_6H_5CH_3 \Rightarrow 2.5CO_{2,g} + 4.5CH_4$ <i>Toluene oxidation / methanogenesis</i>	-34.08	-142.6	0.78:1 ^{bv}

TABLE 4.5
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Coupled Ethylbenzene Oxidation reactions	ΔG_r° (kcal/mole Ethyl- benzene)	ΔG_r° (kJ/mole Ethyl- benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>Ethylbenzene oxidation / aerobic respiration</i>	-1066.13	-4461	3.17:1
$8.4 NO_3^- + 8.4 H^+ + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>Ethylbenzene oxidation / denitrification</i>	-1080.76	-4522	4.92:1
$5.25 NO_3^- + 10.5 H^+ + 0.25 H_2O + C_6H_5C_2H_5 \Rightarrow 8 CO_2 + 5.25 NH_4^+$ <i>Ethylbenzene oxidation / nitrate reduction</i>	-746.04	-3118	3.07:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_5C_2H_5 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>Ethylbenzene oxidation / iron reduction</i>	-778.48	-3257	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^0 + 5 H_2O$ <i>Ethylbenzene oxidation / sulfate reduction</i>	-166.75	-697.7	4.75:1
$5.5 H_2O + C_6H_5C_2H_5 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>Ethylbenzene oxidation / methanogenesis</i>	-39.83	-166.7	0.79:1 ^{b/}

Coupled m-Xylene Oxidation Reactions	ΔG_r° (kcal/mole m-xylene)	ΔG_r° (kJ/mole m-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>m-Xylene oxidation / aerobic respiration</i>	-1063.25	-4448	3.17:1
$8.4 NO_3^- + 8.4 H^+ + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>m-Xylene oxidation / denitrification</i>	-1077.81	-4509	4.92:1
$5.25 NO_3^- + 10.5 H^+ + 0.25 H_2O + C_6H_4(CH_3)_2 \Rightarrow 8 CO_2 + 5.25 NH_4^+$ <i>m-Xylene oxidation / nitrate reduction</i>	-743.52	-3108	3.07:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>m-Xylene oxidation / iron reduction</i>	-775.61	-3245	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^0 + 5 H_2O$ <i>m-Xylene oxidation / sulfate reduction</i>	-163.87	-685.6	4.75:1
$5.5 H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>m-Xylene oxidation / methanogenesis</i>	-36.95	-154.6	0.79:1 ^{b/}

^{a/} mass of ferrous iron produced during microbial respiration.

^{b/} mass of methane produced during microbial respiration.

in comparison to background conditions. Areas of the site that show the greatest variation in concentrations of geochemical parameters generally correspond well with areas of low redox potential and high BTEX concentrations. Table 4.6 summarizes groundwater geochemical data gathered during the May 1995 intrinsic remediation site investigation and the July 1996 groundwater sampling event at Westover ARB. Geochemical parameters for site FT-03 are discussed in the following sections.

In the following sections, the assumption that BTEX can be treated as a given ratio of the constituent compounds has been made for two important reasons. First, biodegradation rates of each of the compounds are very similar to each other. Second, while degradation pathways are relatively well known for fuel hydrocarbons, the preferential degradation of one BTEX compound over another is difficult to predict from site to site, spatially or temporally. In order to avoid making inaccurate conclusions on which BTEX compounds are degraded when or where in any given groundwater system the compounds are treated as a ratio. This ratio provides a basis for more reliable conclusions about the spatial and temporal biodegradation of BTEX as one contaminant.

4.3.2.1 Dissolved Oxygen

DO concentrations were measured at monitoring wells at the time of groundwater sampling during the May 1995 and July 1996 sampling events. Table 4.6 summarizes measured DO concentrations. Figure 4.5 presents two isopleth maps showing the distribution of DO concentrations in groundwater in May 1995 and July 1996. These data are a strong indication that aerobic biodegradation of the BTEX compounds is occurring at the site. In May 1995, high background DO concentrations were measured at monitoring well TF-1A [10.43 milligrams per liter (mg/L)]; therefore, it is likely that DO is an important electron acceptor at FT-03. Within the area characterized by BTEX concentrations in excess of 100 µg/L in shallow wells, DO concentrations ranged from 3.72 mg/L to 0.18 mg/L (TF-13 and -2A respectively). DO levels measured outside or on the margin of the plume ranged from 4.86 mg/L to 11.19 mg/L. In July 1996, DO concentrations were still reasonably high; however, groundwater DO concentrations in site wells, in general, increased by 0.9 to 5.8 mg/L. The more significant increases in DO concentrations were all observed on the west side of the contaminant plume centerline, where the dissolved BTEX concentrations were completely attenuated between May 1995 and July 1996. The increase in DO is attributed to recovery of the aquifer, to normal background conditions, following depletion of the dissolved BTEX in the aquifer. The disappearance of dissolved BTEX on the west side of the site is attributed to the elimination of the source through bioventing. Although the bioventing effort has focused on the west side of the site, influence from the system is observed on the east side of the site, through dissolved contaminant concentration decreases and changing geochemistry.

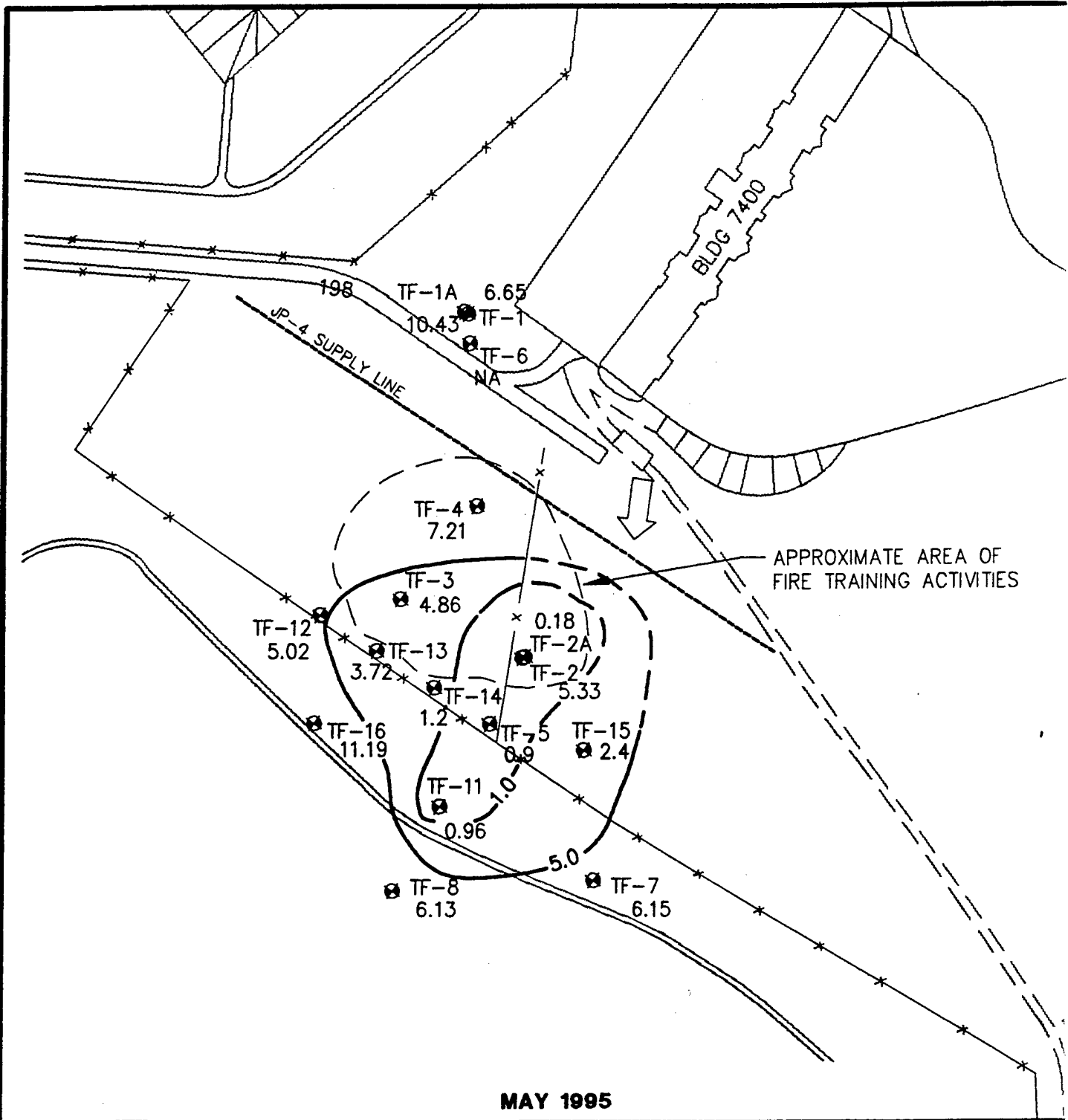
The stoichiometry of BTEX mineralization to carbon dioxide and water caused by aerobic microbial biodegradation is presented in Table 4.5. The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to the mineralization of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With an assumed background DO concentration of 10.43 mg/L in May 1995, the shallow groundwater at this site has the capacity to assimilate approximately 3.2 mg/L

TABLE 4.6

GROUNDWATER GEOCHEMICAL
ANALYTICAL DATAChristmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

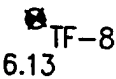
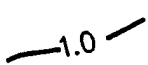


Sample ID	Date Sampled	Temperature (°C) ^{a/}	Field pH	Lab pH	Lab Conductivity (µs/cm) ^{b/}	Field Conductivity (µs/cm) ^{b/}	Lab		Total		Chloride (mg/L)	Sulfate (mg/L)	NO ₂ ⁻ + NO ₃ ⁻ (mg/L)	Iron (mg/L)	Methane (mg/L)	Total Organic Carbon (mg/L)
							Redox Potential (mV) ^{c/}	Redox Potential (mV)	Alkalinity (mg/L)	Dissolved Oxygen (mg/L)						
TF-1	5/17/95	13.3	6.63	5.5	127.5	NA	60.5	NA	15	4.58	21.7	0.99	2.5	<0.003	16.6	
TF-1	7/16/96	14.4	6.10	6.6	870	145	NA	205	62	8.03	29	0.52	<0.05	<0.001	4.91	
TF-1 A	5/17/95	13.3	6.34	5.5	78.7	NA	42.1	NA	20	3.47	7.18	1.25	<0.1	<0.003	6.4	
TF-1 A	7/16/96	13.1	7.49	6.3	20	105	NA	300	80	3.87	9.83	1.62	<0.05	<0.001	0.41	
TF-2	5/18/95	13.3	6.44	5.4	143.6	NA	210.8	NA	20	4.02	19.8	1.28	<0.1	ND	16.6	
TF-2	7/18/96	13.2	NA	6.3	NA	151	NA	250	66	2.29	16.4	1.32	<0.05	<0.001	8.93	
TF-2 A	5/18/95	13.0	6.52	6.6	552	NA	-39.8	NA	275	3.47	6.32	0.07	600	0.18	26	
TF-2 A	7/18/96	15.7	NA	6.0	NA	625	NA	-159	NA	3.47	208	<0.05	23.5	0.006	16.8	
TF-3	5/18/95	13.5	6.40	5.9	296	NA	85	NA	55	4.29	21.9	2.64	<0.1	<0.003	7.2	
TF-3	7/16/96	12.6	7.92	6.6	340	200	40	88.6	34	3.16	33.3	3.02	<0.05	<0.001	4.62	
TF-4	5/18/95	13.3	6.09	5.5	235	NA	70	196.3	90	4.13	35.8	3.88	<0.1	<0.003	8.7	
TF-4	7/16/96	14.0	7.36	6.6	1010	551	50	131.6	84	5.88	210	6.67	<0.05	<0.001	2.61	
TF-5	5/18/95	12.7	6.25	6.0	281	NA	140	26.7	150	1.45	6.1	0.35	25	0.003	6.1	
TF-5	7/16/96	12.4	7.46	6.0	360	185	20	36.2	76	2.98	58	1.86	1.5	<0.001	2.55	
TF-7	5/19/95	12.2	6.11	5.7	339	NA	120	138.6	40	1.69	41.9	2.59	<0.1	<0.003	4.2	
TF-7	7/17/96	12.4	NA	6.1	NA	255	126	NA	158	<0.5	61.1	2.42	<0.05	<0.001	1.78	
TF-8	5/19/95	11.7	6.56	6.1	510	NA	160	105.3	45	2.6	51.6	1.79	<0.1	<0.003	6.2	
TF-8	7/17/96	11.4	NA	6.5	NA	305	134	NA	84	<0.5	73.6	1.9	<0.05	<0.001	3.37	
TF-11	5/19/95	11.9	6.59	7.2	697	NA	320	-33	175	4.41	37.7	0.07	1	0.004	15.5	
TF-11	7/17/96	11.8	NA	6.4	NA	503	54	NA	176	3.94	224	1.32	3.1	<0.001	5.8	
TF-12	5/18/95	12.1	6.01	5.5	228	NA	50	175.3	65	1.95	14.2	2.64	<0.1	<0.003	6.8	
TF-12	7/16/96	12.0	7.93	6.3	200	109	30	119	70	2.96	18.5	1.98	<0.05	<0.001	1.78	
TF-13	5/18/95	12.4	6.20	5.3	394	NA	90	170.2	100	2.79	39.3	3.18	<0.1	<0.003	6.5	
TF-13	7/16/96	12.1	7.94	6.4	390	201	43	122	140	3.11	44.7	2.52	<0.05	<0.001	2.16	
TF-14	5/18/95	13.6	6.37	6.2	586	NA	240	35.8	100	5.42	52.8	2.89	<0.1	<0.003	9.7	
TF-14	7/16/96	13.0	7.36	6.7	1940	910	57	113.2	48	6.14	436	7.31	<0.05	<0.001	5.33	
TF-15	5/18/95	12.7	6.00	5.6	297	NA	55	62.9	100	1.97	35.7	2.29	<0.1	<0.003	5.5	
TF-15	7/18/96	12.7	NA	6.0	NA	208	45	NA	240	1.58	38.7	0.95	<0.05	<0.001	4.79	
TF-16	5/19/95	11.0	6.14	5.8	123.1	NA	11.19	-33	25	1.66	16.4	2.01	<0.1	<0.003	5.7	
TF-16	7/17/96	10.8	NA	6.2	NA	53	64	NA	148	1.6	4.15	0.61	<0.05	<0.001	1.00	

^{a/} °C = degrees Celsius.^{b/} µs/cm = microsiemens per centimeter.^{c/} mV = millivolts.



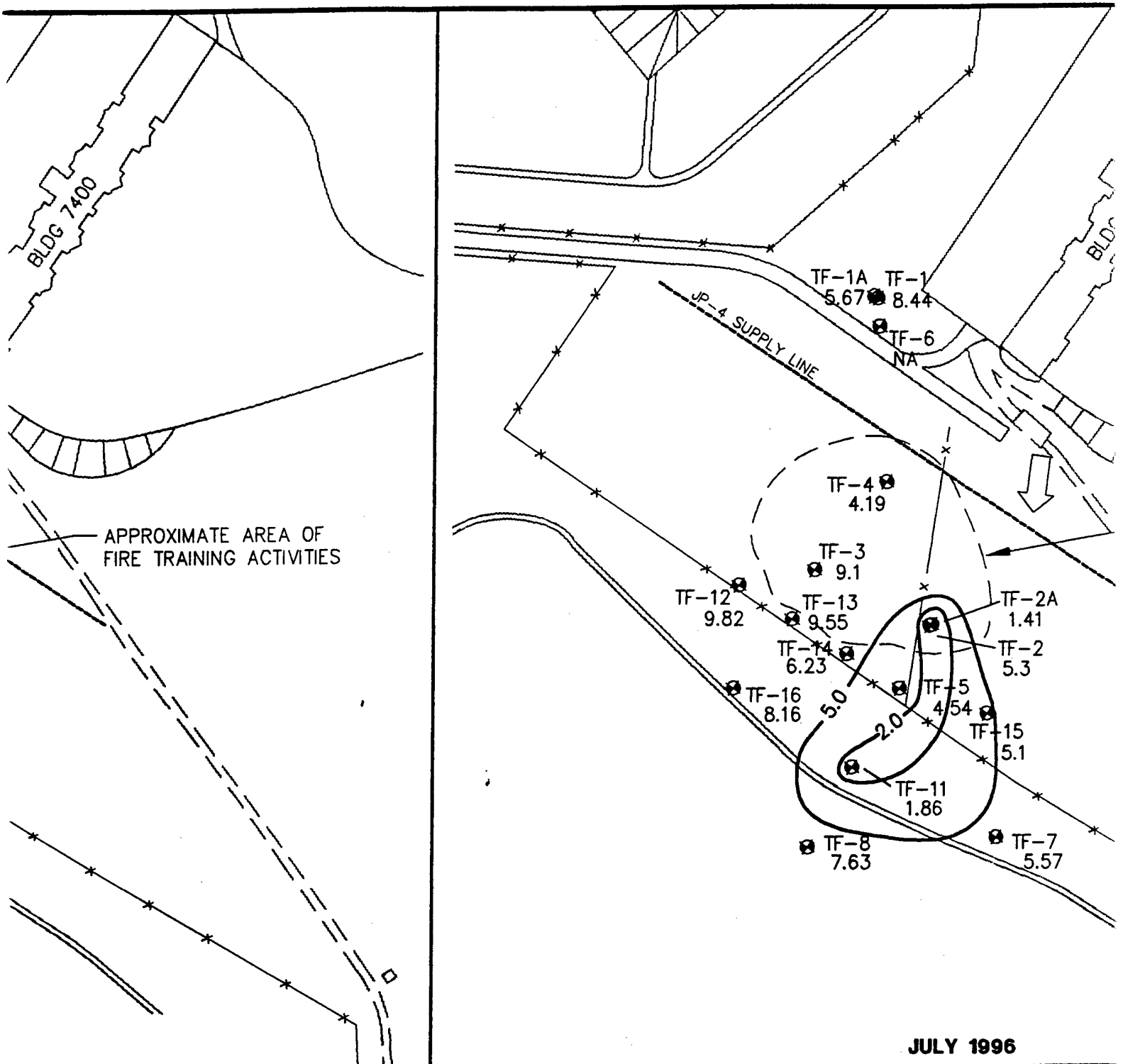
MAY 1995

LEGEND

- 
 MONITORING WELL LOCATION WITH DISSOLVED OXYGEN CONCENTRATION (mg/L)
- 
 LINE OF EQUAL DISSOLVED OXYGEN CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
- 
 GROUNDWATER FLOW DIRECTION
- 
 FENCE

NA NOT ANALYZED

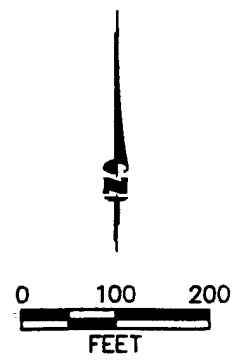
NOTE: SHALLOW GROUNDWATER (WERE USED FOR CONTOUR

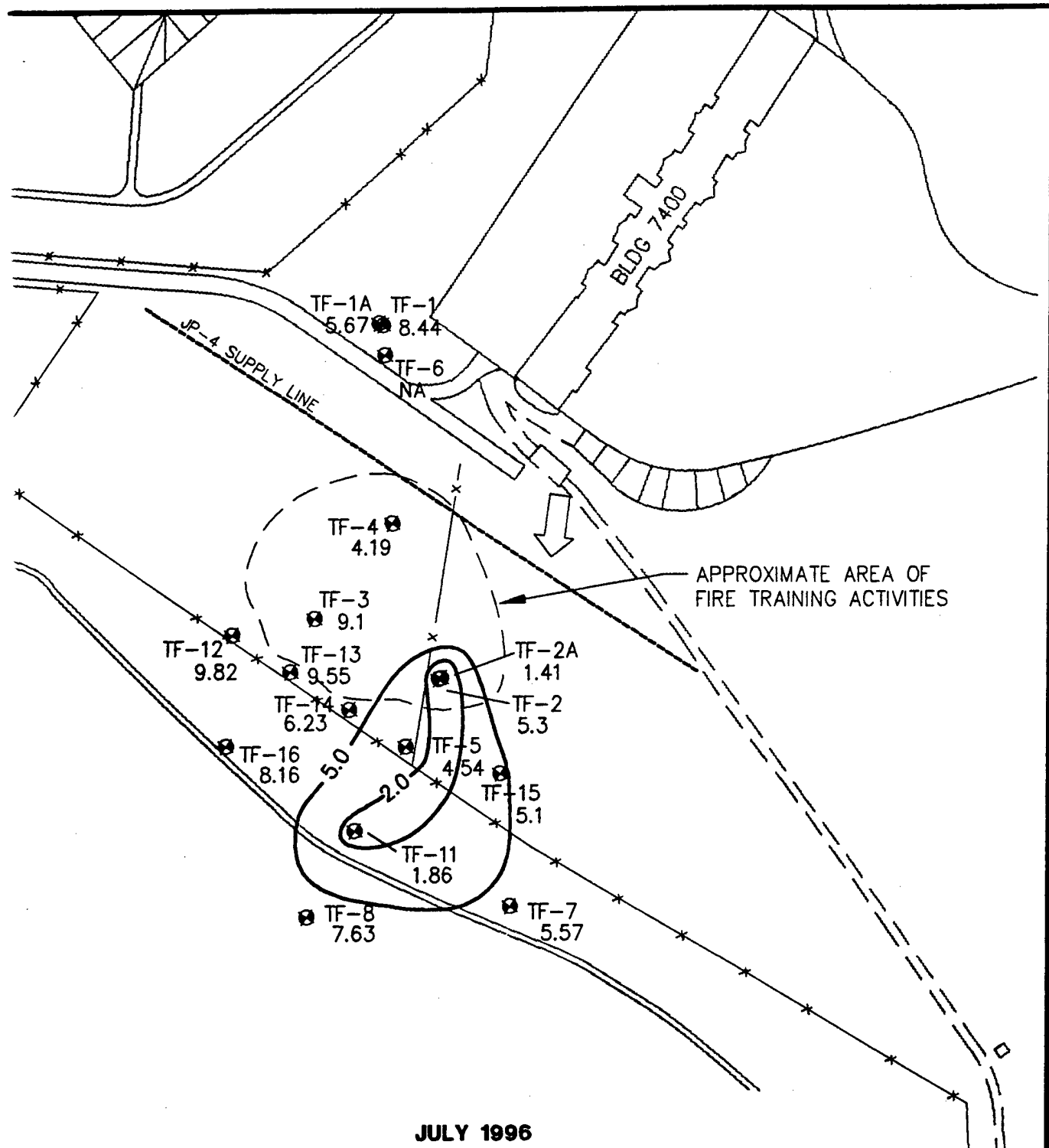


JULY 1996

NA NOT ANALYZED

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING



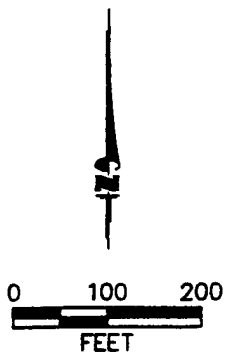


JULY 1996

FIGURE 4.5

**DISSOLVED OXYGEN
ISOPLETH MAPS FOR
GROUNDWATER**

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

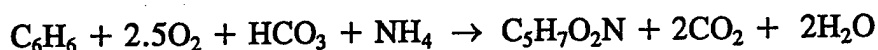


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Denver, Colorado

(3,200 µg/L) of total BTEX through aerobic biodegradation. In July 1996, a background DO concentration of 8.44 mg/L, suggests the site has the capacity to assimilate approximately 2.7 mg/L (2,700 µg/L) These are conservative estimates of the expressed assimilative capacity of DO because microbial cell mass production is not taken into account by the stoichiometry presented in Table 4.5.

When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:



From this it can be seen that 5 fewer moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

$$\text{Benzene} \quad 6(12) + 6(1) = 78 \text{ gm}$$

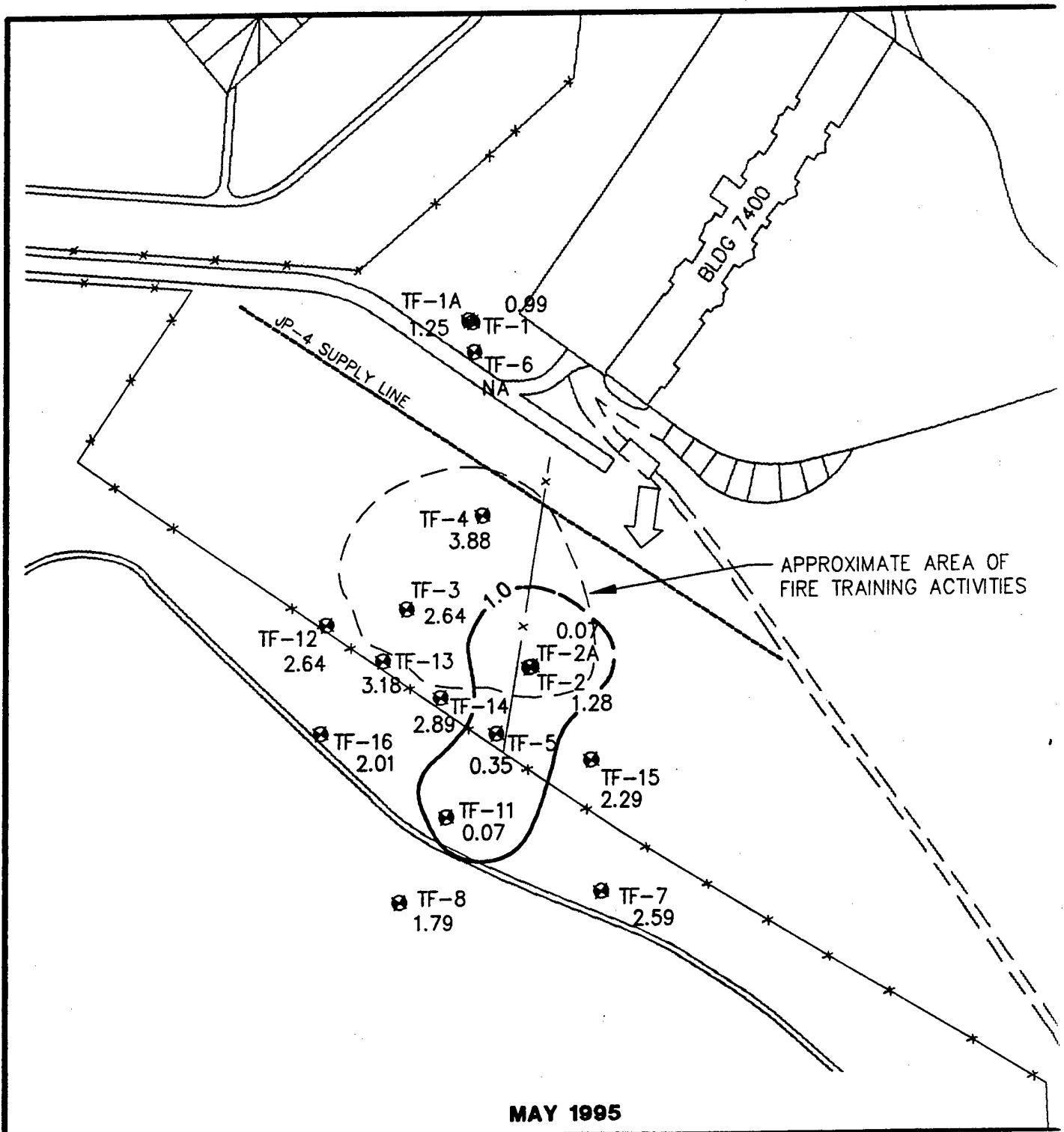
$$\text{Oxygen} \quad 2.5(32) = 80 \text{ gm}$$

$$\text{Mass Ratio of Oxygen to Benzene} = 80/78 = 1.03:1$$


On the basis of these stoichiometric relationships, 1.03 mg of oxygen is required to mineralize 1 mg of benzene. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. On the basis of these calculations, approximately 0.95 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed. With a maximum background DO concentration of approximately 10 mg/L, the shallow groundwater at this site had the capacity to assimilate 9.5 mg/L (9,500 µg/L) of total BTEX if microbial cell mass production is taken into account. Assuming a background DO concentration of approximately 8.4 mg/L, and taking into account mass cell production, the shallow groundwater in July 1996 has the capacity to assimilate 8.0 mg/L (8,000 µg/L) of total BTEX.

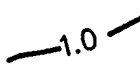
4.3.2.2 Nitrate/Nitrite

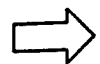
Concentrations of nitrate and nitrite [as nitrogen (N)] were measured in groundwater samples collected in May 1995 and July 1996. Table 4.6 summarizes measured nitrate/nitrite (as N) concentrations. Figure 4.6 presents two isopleth maps illustrating the areas of low nitrate/nitrite concentrations for both sampling events. Nitrate/nitrite was detected in site groundwater at concentrations ranging from 0.07 mg/L within the plume, to 3.88 mg/L at the plume boundaries in May 1995 and from less than 0.05 mg/L to 7.31 mg/L in 1996. The data suggest that, in general, reduced nitrate/nitrite concentrations correspond to areas of groundwater BTEX contamination, and that nitrate is an important electron acceptor at this site. Small anomalies to this trend occur in the July 1996 data at two downgradient locations. This may be a shadowing effect caused by use of the electron acceptor at an upgradient location. In time and as dissolved BTEX concentrations are entirely degraded, nitrate concentrations are likely to recover at these locations by replenishment from upgradient groundwater.




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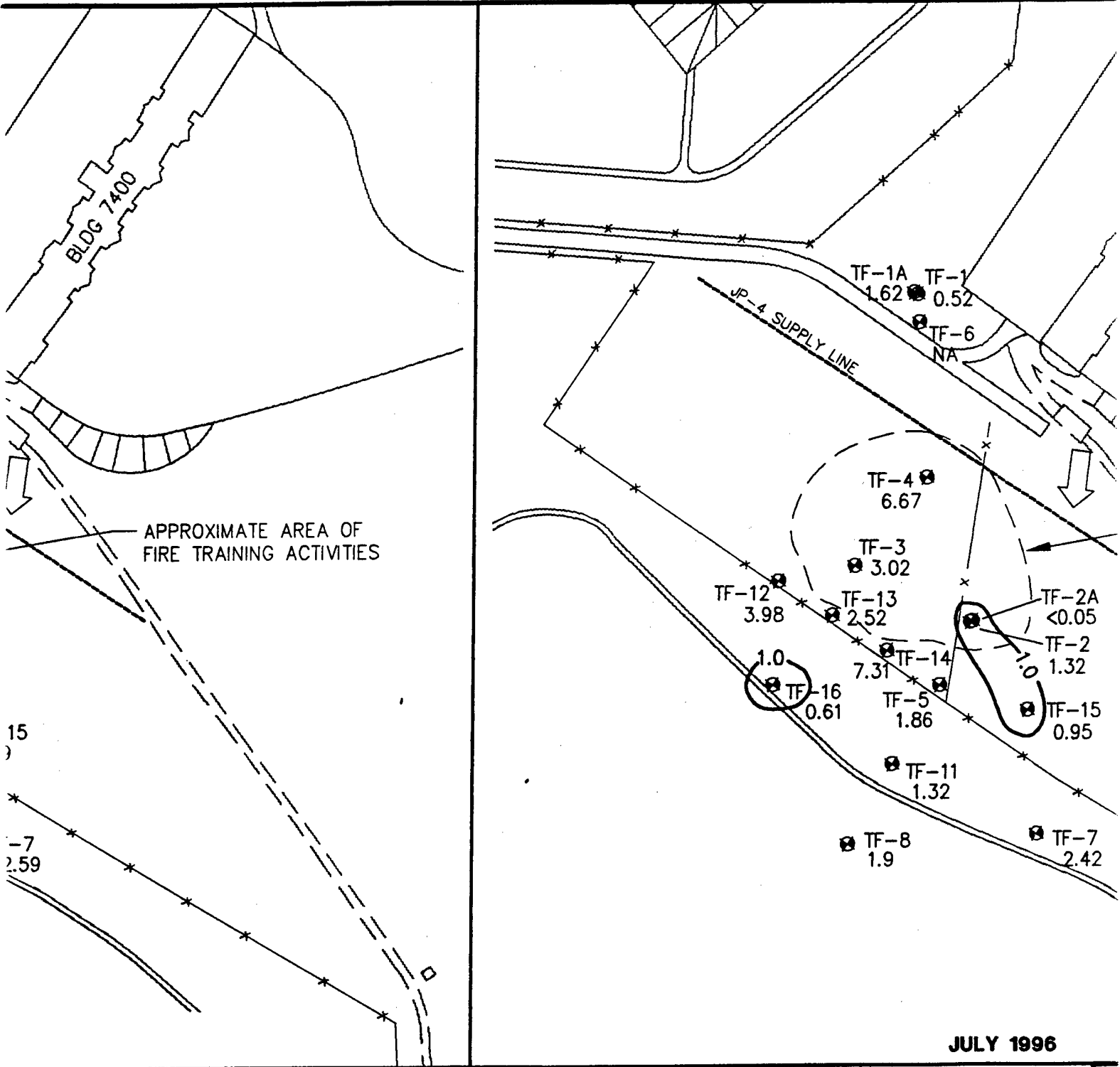
-  TF-8
1.79

MONITORING WELL LOCATION WITH GROUNDWATER NITRATE + NITRITE CONCENTRATIONS (mg/L)
-  1.0

LINE OF EQUAL NITRATE + NITRITE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
- 

GROUNDWATER FLOW DIRECTION
- 

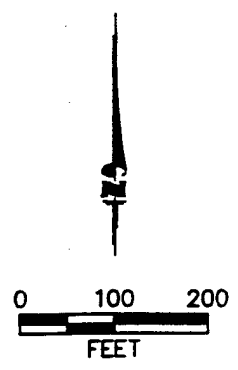
FENCE
- NA NOT ANALYZED
- NOTE: SHALLOW GROUNDWATER WERE USED FOR CONTO

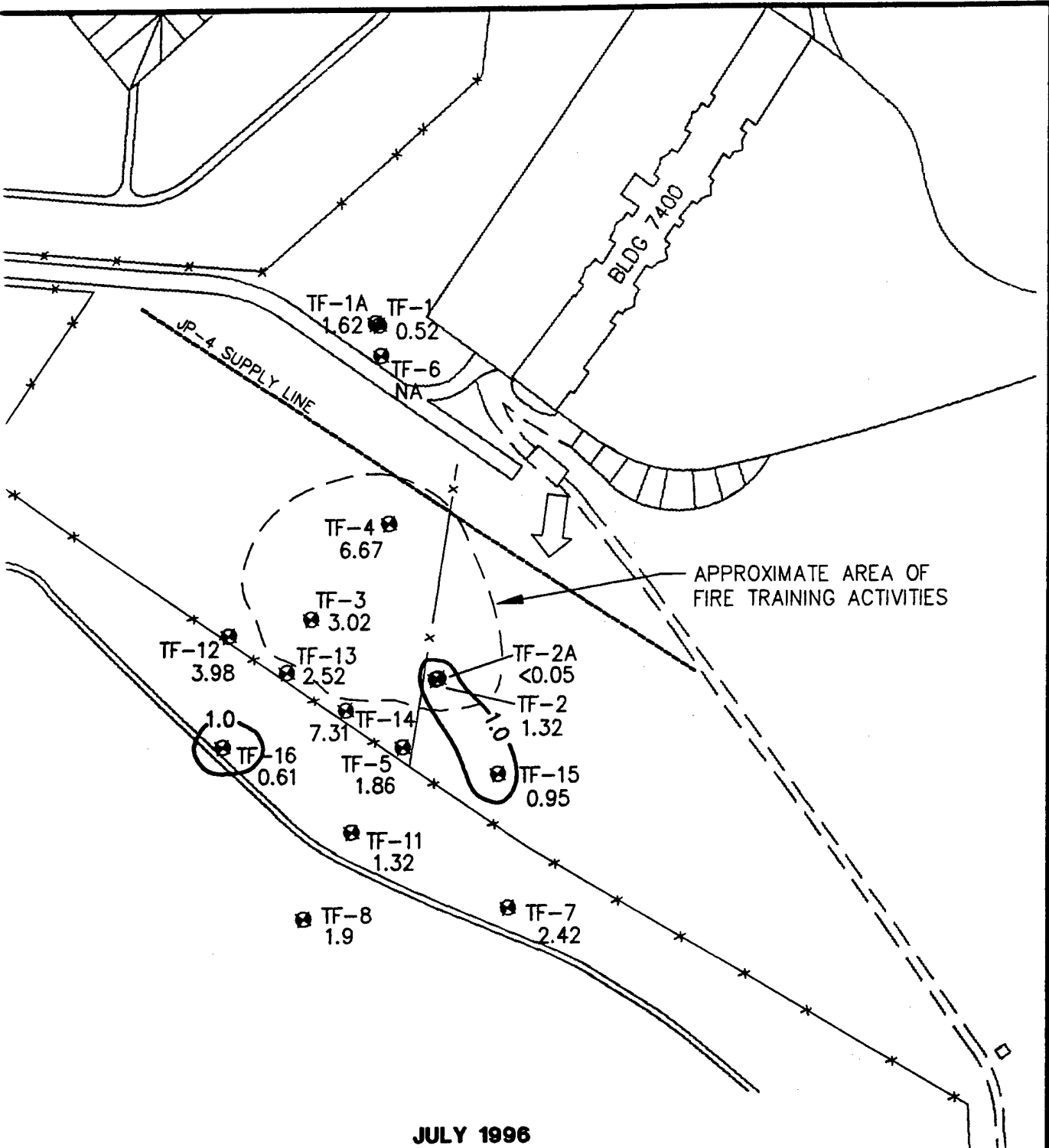


JULY 1996

NDWATER (mg/L) NA NOT ANALYZED

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING





JULY 1996



FIGURE 4.6

**NITRATE + NITRITE
ISOPLETH MAPS FOR
GROUNDWATER**

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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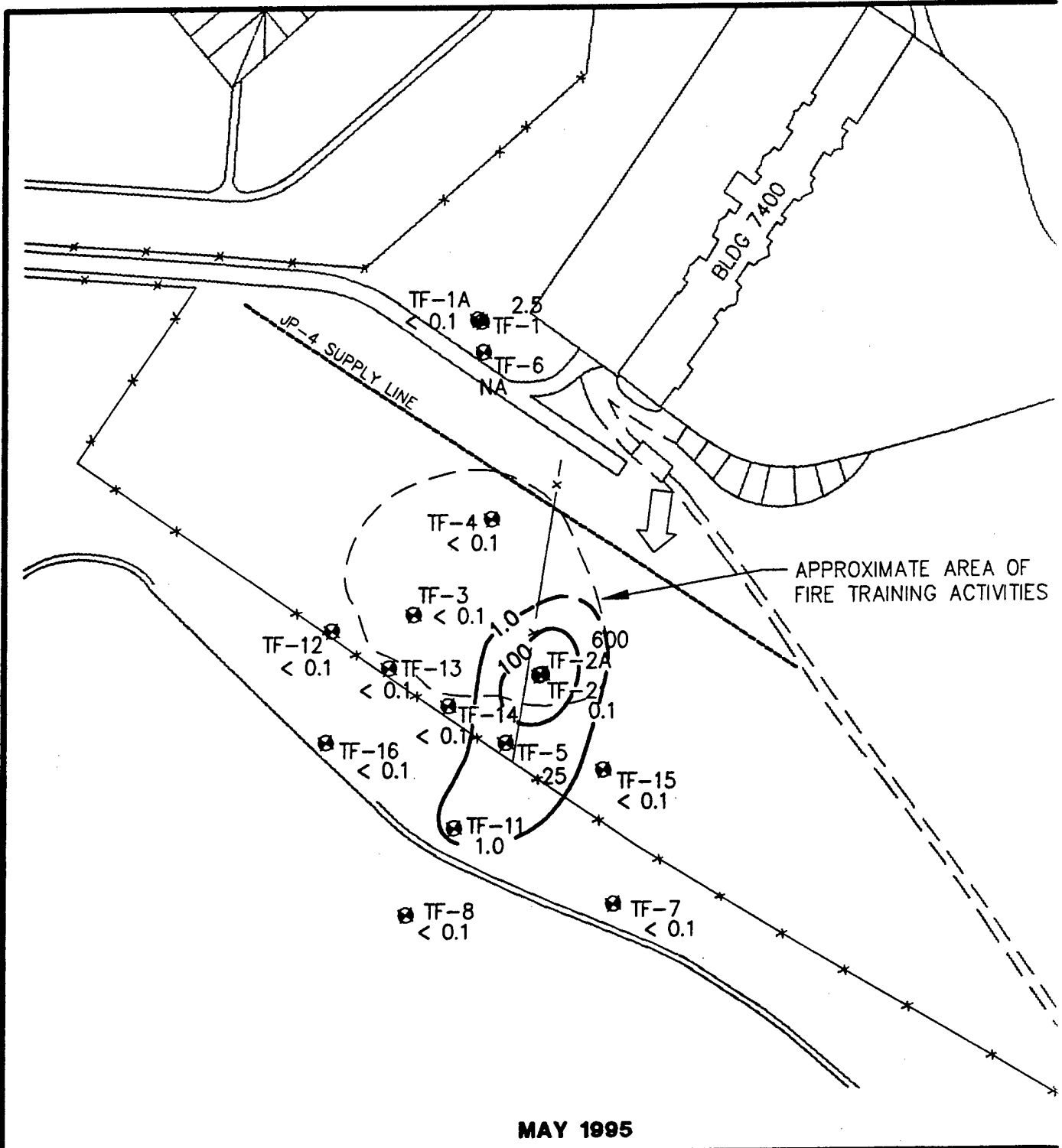
Denver, Colorado

In the absence of microbial cell production, the stoichiometry of BTEX mineralization to carbon dioxide, water, and nitrogen caused by denitrification is presented in Table 4.5. The average mass ratio of nitrate to total BTEX is approximately 4.9 to 1. This translates into the mineralization of approximately 0.20 mg of BTEX for every 1.0 mg of nitrate consumed. Due to the variation of nitrate/nitrite levels between the BTEX plume boundaries and the background well, a background nitrate/nitrite concentration of 2.0 mg/L was assumed for both sampling events. Since the nitrate concentrations are reported as mg/L as N, the values must be multiplied by 4.42 to be converted to mg/L as NO_3^- , hence 2.0 mg/L as N is equivalent to 8.84 mg/L as NO_3^- . Therefore, the shallow groundwater at this site has the capacity to assimilate 1.77 mg/L (1,770 $\mu\text{g/L}$) of total BTEX during denitrification. This is a conservative estimate of the expressed assimilative capacity of nitrate, for May 1995 and July 1996, because microbial cell mass production has not been taken into account by the stoichiometry presented in Table 4.5.

4.3.2.3 Ferrous Iron

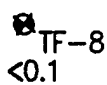
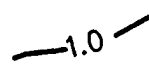


Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected in May 1995 and July 1996. Table 4.6 summarizes ferrous iron concentrations. Measured ferrous iron concentrations ranged from <0.1 mg/L to 600 mg/L and <0.05 mg/L to 23.5 mg/L in May 1995 and July 1996, respectively. Figure 4.7 presents two isopleth maps showing the distribution of ferrous iron in groundwater. Comparison of Figures 4.2, 4.5, and 4.7 indicates that ferrous iron is being produced in the area of the BTEX plume via the reduction of ferric iron hydroxide (Fe^{3+}) during anaerobic biodegradation of BTEX compounds. Background ferrous iron concentrations are <0.1 mg/L, as measured at wells with little or no BTEX contamination. Groundwater from monitoring well TF-2A, which had the highest BTEX concentration in both sampling events, also had the highest concentration of ferrous iron at 600 mg/L in May 1995 and 23.5 mg/L in July 1996. These relationships are a strong indication that anaerobic biodegradation of BTEX compounds is occurring through iron reduction. However, according to July 1996 data, iron reduction does not appear to be an important electron acceptor in any area other than groundwater near TF-2A. Furthermore, the importance of iron as an electron acceptor at TF-2A has declined as falling dissolved BTEX concentrations has resulted in a lower demand for all electron acceptors.

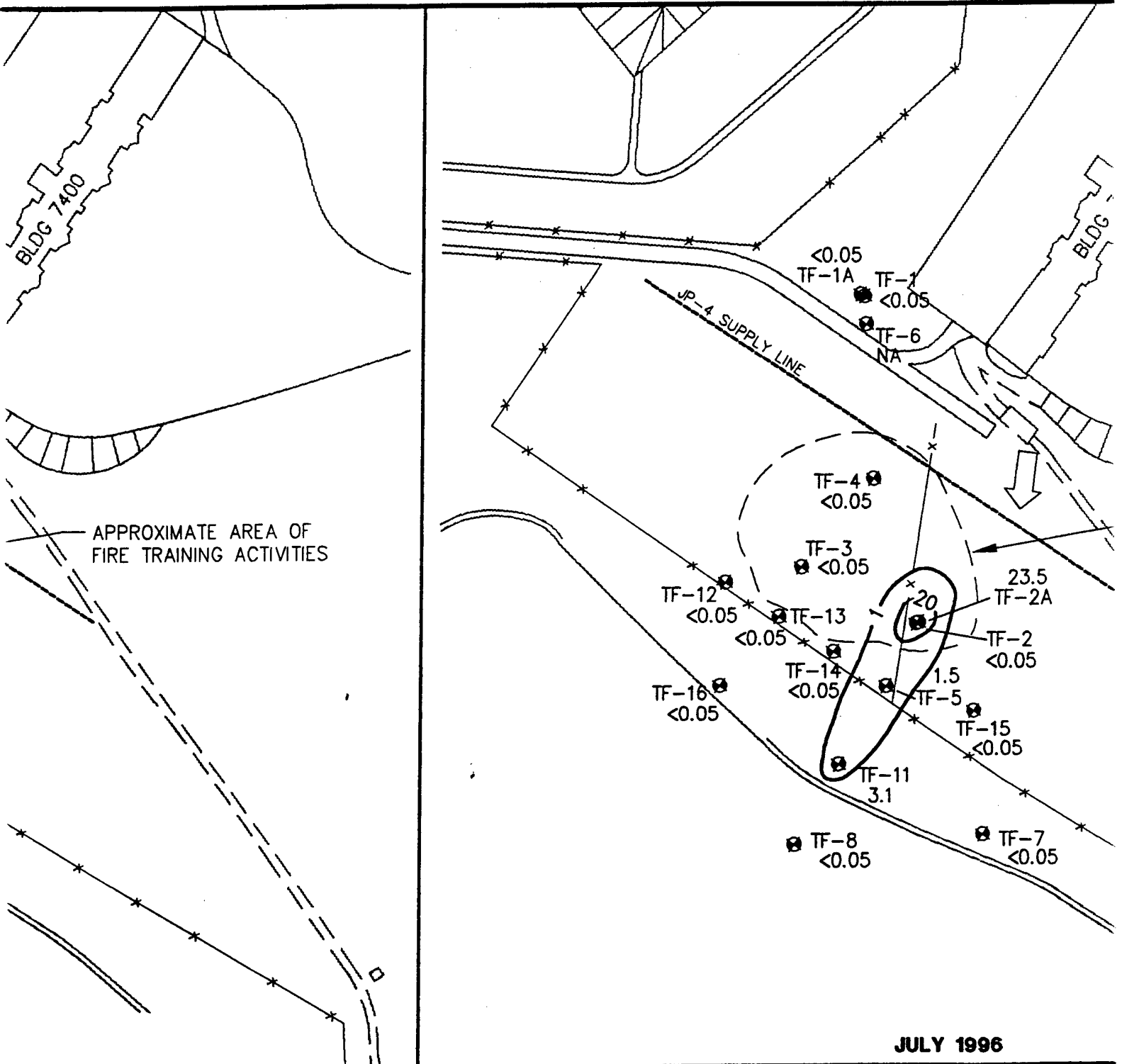
The stoichiometry of BTEX oxidation to carbon dioxide, ferrous iron, and water by iron reduction through anaerobic microbial biodegradation is presented in Table 4.5. On average 37.5 moles of ferric iron hydroxide are required to metabolize one mole of total BTEX. Conversely, an average of 37.5 moles of ferrous iron are produced for each mole of total BTEX consumed. On a mass basis, this translates to approximately 21.8 mg ferrous iron produced for each 1 mg of total BTEX metabolized. Given a background ferrous iron concentration of <0.1 mg/L and a maximum ferrous iron concentration of 600 mg/L, the shallow groundwater in May 1995 had the capacity to assimilate approximately 27.5 mg/L (27,500 $\mu\text{g/L}$) of total BTEX through iron reduction. In July 1996, using an assumed background ferrous iron concentration of <0.05 mg/L and a maximum ferrous iron concentration of 23.5, the shallow groundwater capacity to assimilate total BTEX has dropped to 1.08 mg/L or 1,080 $\mu\text{g/L}$. These are conservative estimates of the expressed assimilative capacity of iron because microbial cell mass production was not taken into account by the stoichiometry



MAY 1995

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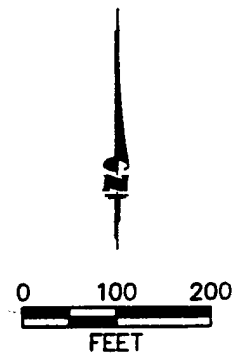
- 
TF-8
 < 0.1
- 
1.0
 LINE OF EQUAL FERROUS IRON CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
- 
 GROUNDWATER FLOW DIRECTION
- 
 FENCE
- NA NOT ANALYZED
- NOTE: SHALLOW GROUNDWAT WERE USED FOR CON



JULY 1996

ER NA NOT ANALYZED

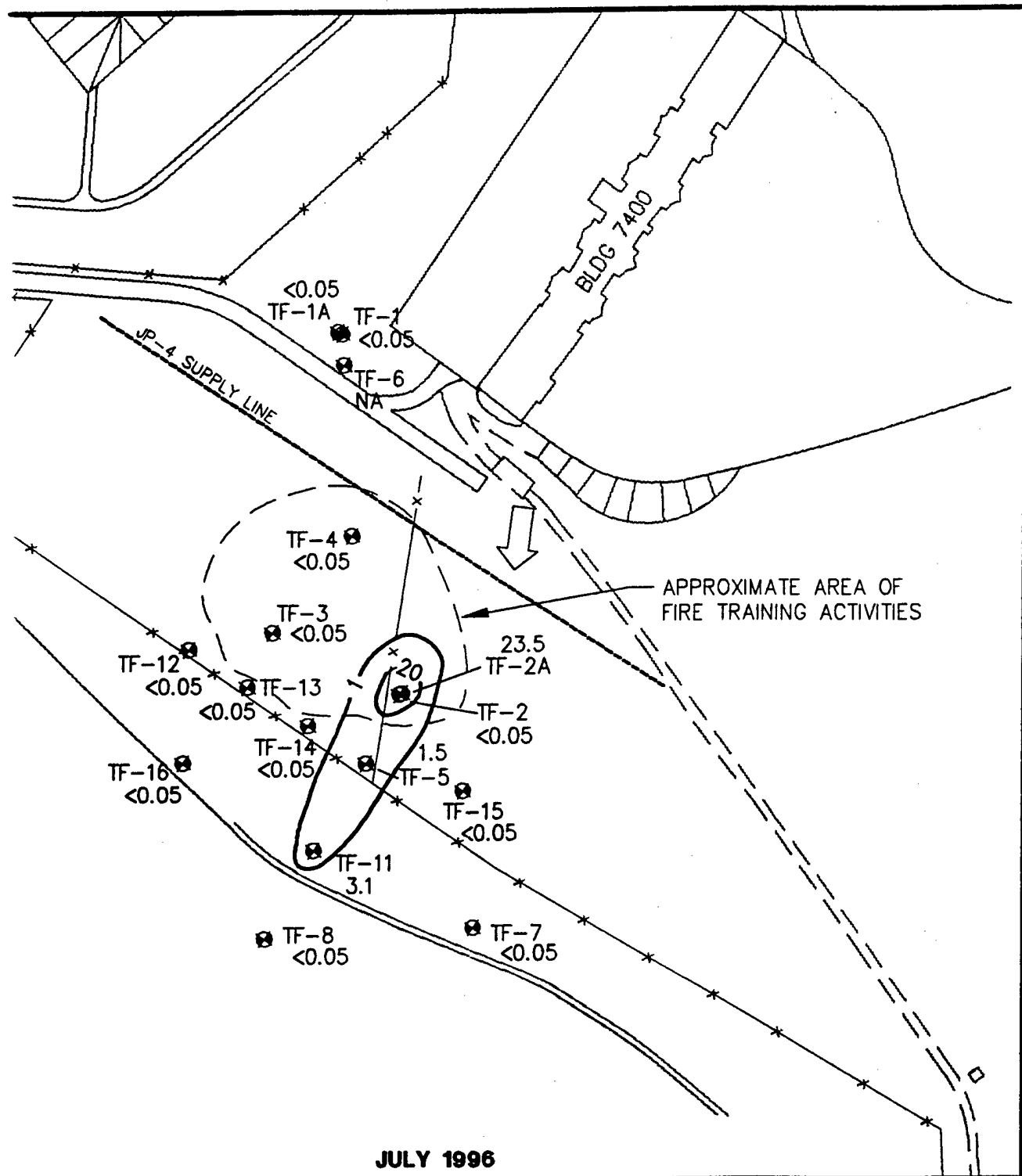
NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING



Fl

Chr

W



JULY 1996

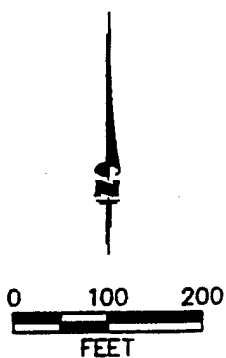


FIGURE 4.7

**FERROUS IRON ISOPLETH
MAPS FOR
GROUNDWATER**

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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Denver, Colorado

shown on Table 4.5. In addition, this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, iron assimilative capacity could be much higher. The significant decrease in ferrous iron concentrations is indicative of the effects that bioventing has on the groundwater geochemistry through elimination of the source of dissolved BTEX, i.e., contaminated soils.

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

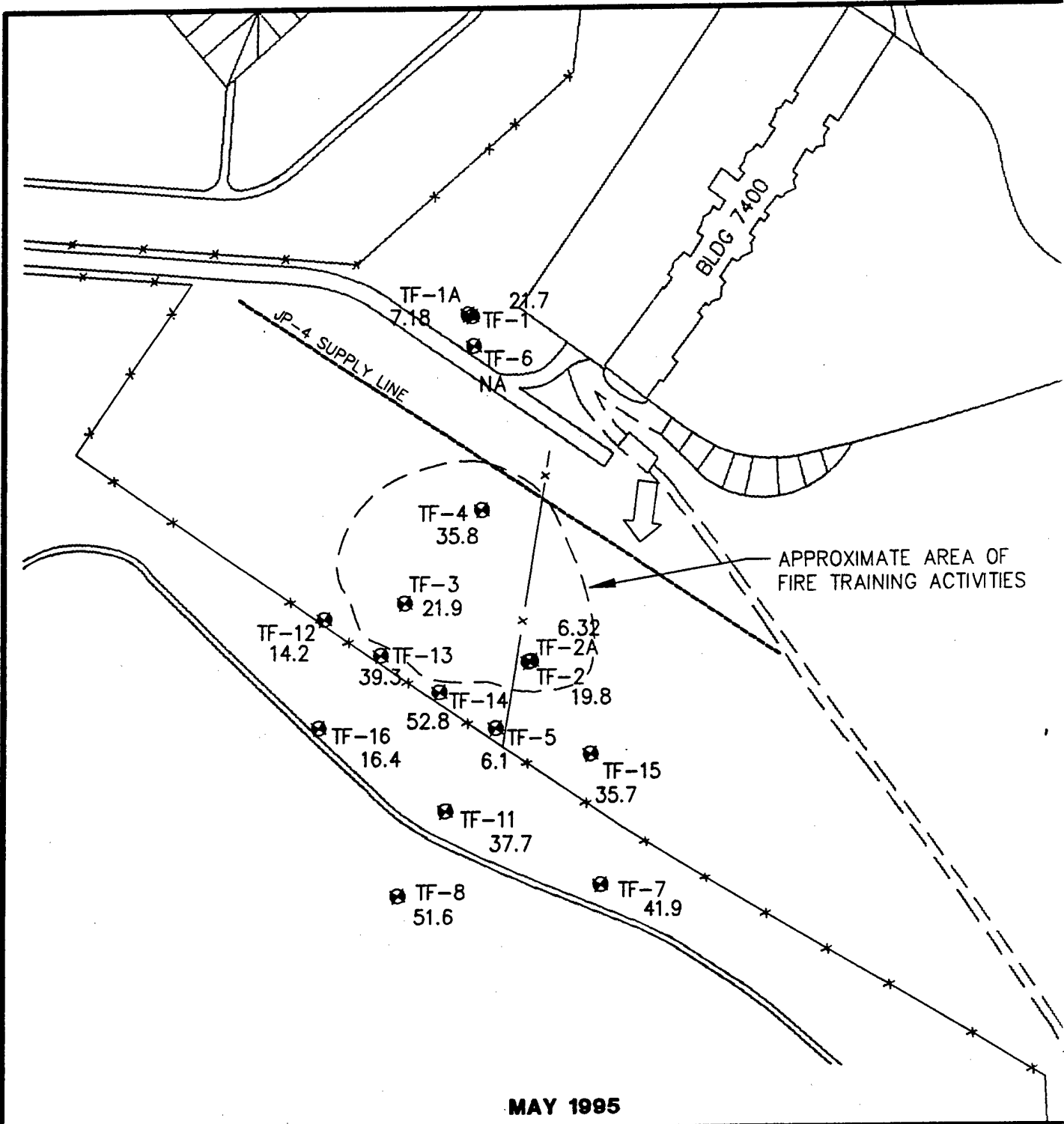
4.3.2.4 Sulfate

Sulfate concentrations were measured in groundwater samples collected in May 1995 and July 1996. Sulfate concentrations at the site ranged from 6.1 mg/L to 52.8 mg/L in May 1995 and from 4.15 mg/L to 436 mg/L in July 1996. Table 4.6 summarizes measured sulfate concentrations. Figure 4.8 presents two maps illustrating the distribution of sulfate in groundwater. Although sulfate reduction is likely occurring at the core of the BTEX plume, the variability of sulfate concentrations throughout the site makes it difficult to evaluate the magnitude of the reduction in sulfate concentrations.




The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water by sulfate reduction through anaerobic microbial biodegradation is presented in Table 4.5. The average mass ratio of sulfate to total BTEX is approximately 4.7 to 1. This translates to the mineralization of approximately 0.21 mg of total BTEX for every 1.0 mg of sulfate consumed. Because of the variability in site sulfate concentrations and to be conservative, an assimilative capacity based on sulfate reduction was not calculated.

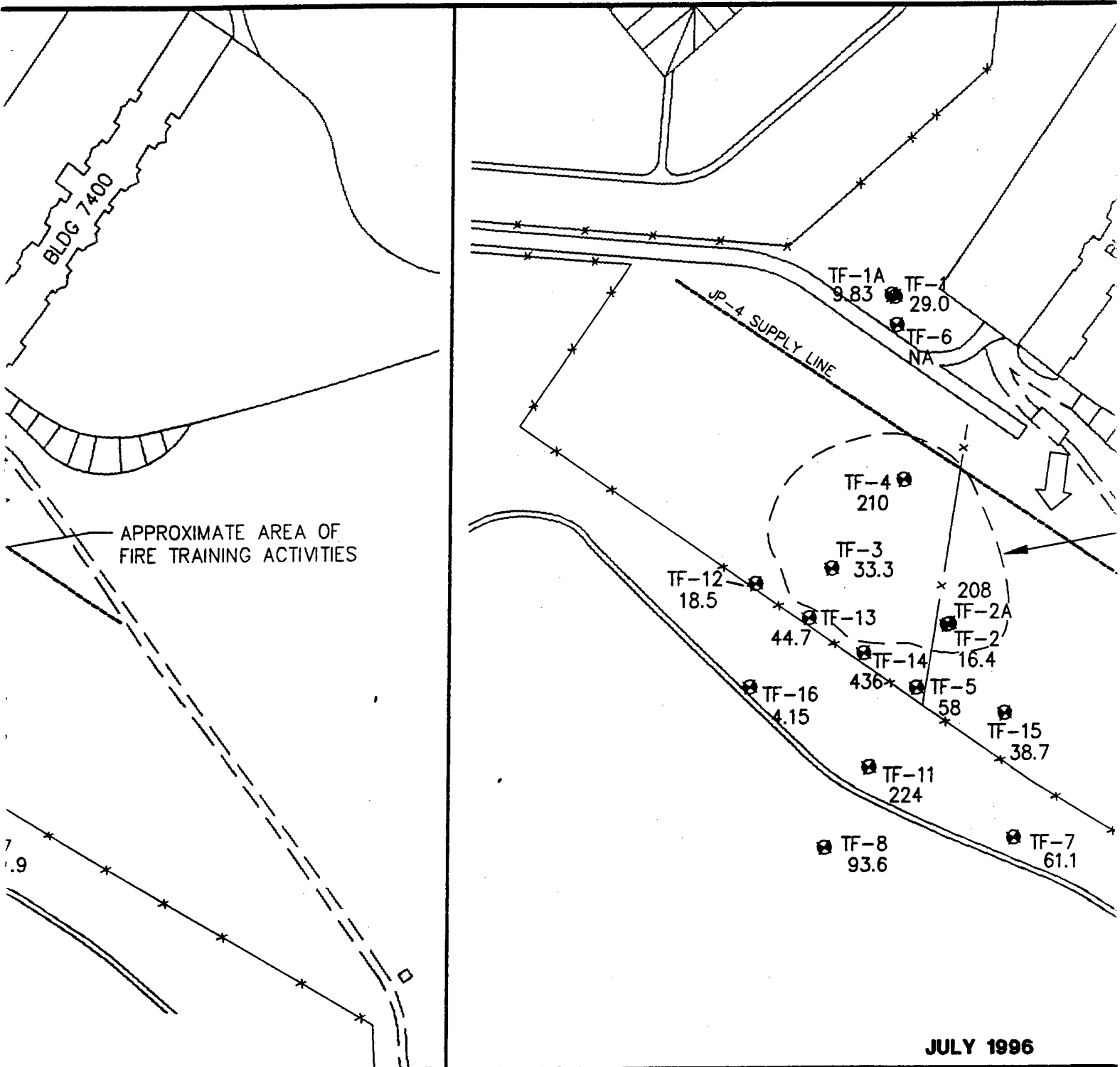
4.3.2.5 Methane

Methane concentrations were measured in groundwater samples collected in May 1995 and July 1996. Table 4.6 summarizes methane concentrations. For May 1995, the majority of methane concentrations are <0.003 mg/L (the analytical quantitation limit). The highest methane concentration (0.18 mg/L) was detected in the center of the plume at monitoring well TF-2A. The only other detected concentrations of methane, 0.003 mg/L and 0.004 mg/L were measured at TF-5 and TF-11 respectively, both located immediately downgradient from well TF-2A. In July 1996, measurable concentrations of methane were observed only in TF-2A (0.006 mg/L); at all other sampling location methane concentrations were below the analytical quantitation limit of 0.001 mg/L.



LEGEND

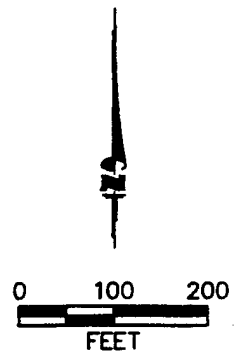
-  TF-8
51.6
MONITORING WELL LOCATION WITH GROUNDWATER SULFATE CONCENTRATION (mg/L)
-  GROUNDWATER FLOW DIRECTION
-  FENCE
- NA NOT ANALYZED
- NOTE: SHALLOW GROUNDWATER WERE USED FOR CONTOU

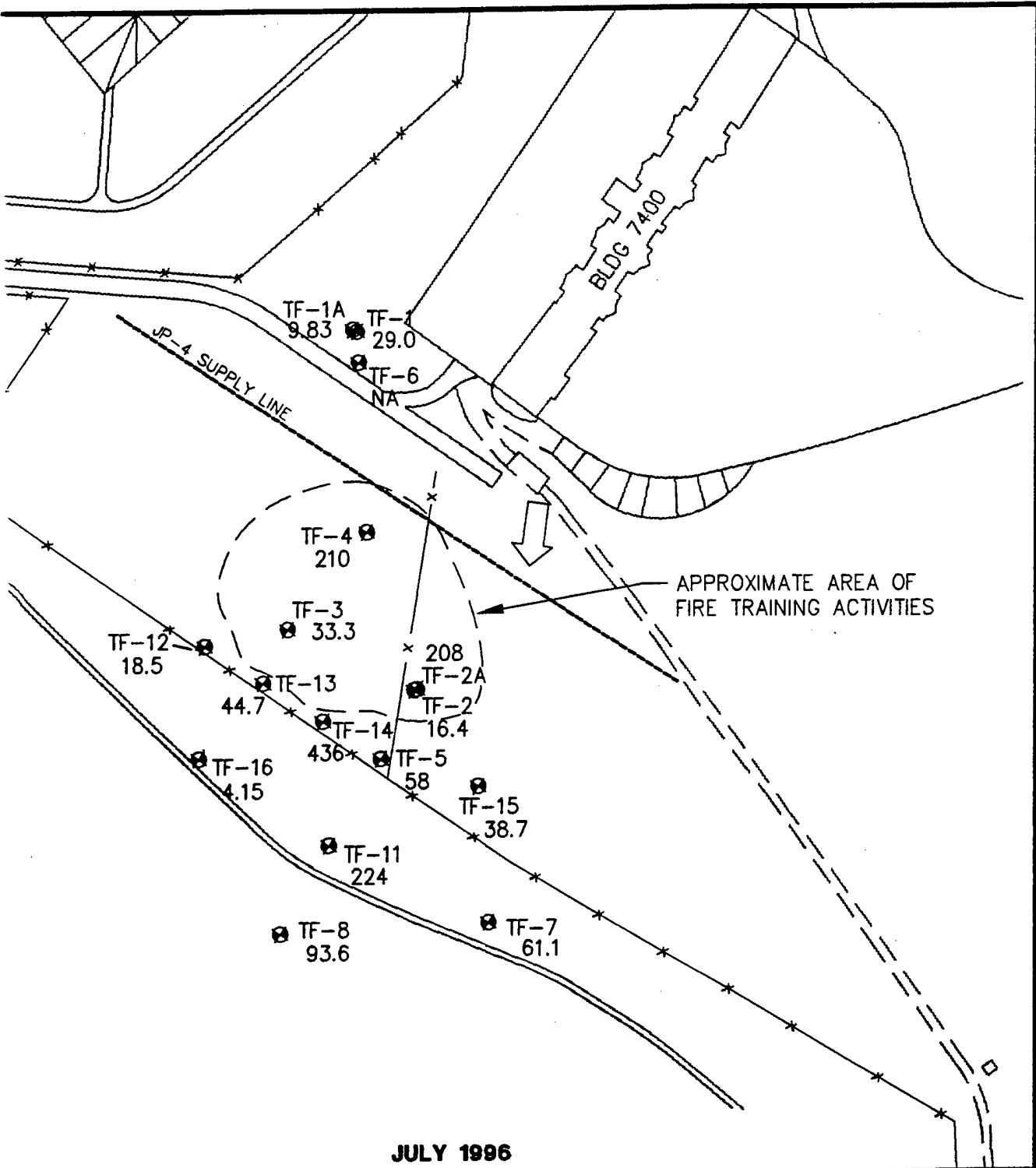


JULY 1996

WATER NA NOT ANALYZED

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING





JULY 1996

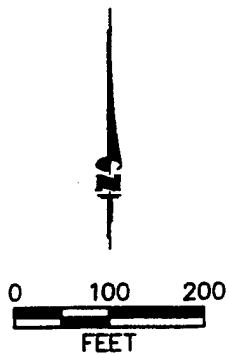


FIGURE 4.8

SULFATE DISTRIBUTION IN GROUNDWATER

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

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The stoichiometry of BTEX oxidation to carbon dioxide and methane by methanogenesis is presented in Table 4.5. On average, approximately 1 mg of total BTEX is mineralized for every 0.78 mg of methane produced. Given a maximum detected methane concentration of 0.18 mg/L in May 1995, the shallow groundwater has the capacity to assimilate approximately 0.23 mg/L (230 µg/L) of total BTEX through methanogenesis. In July 1996, a maximum detected methane concentration of 0.006 mg/L correspond to an assimilative capacity of less than 10 µg/L of total BTEX for the shallow groundwater. Although this estimate is conservative for several reasons, it is clear that methanogenesis is not an important process at this site. Nevertheless, it is important to note that the site supports microbial populations that are capable of creating methane reducing conditions in the presence of fuel hydrocarbon contamination.

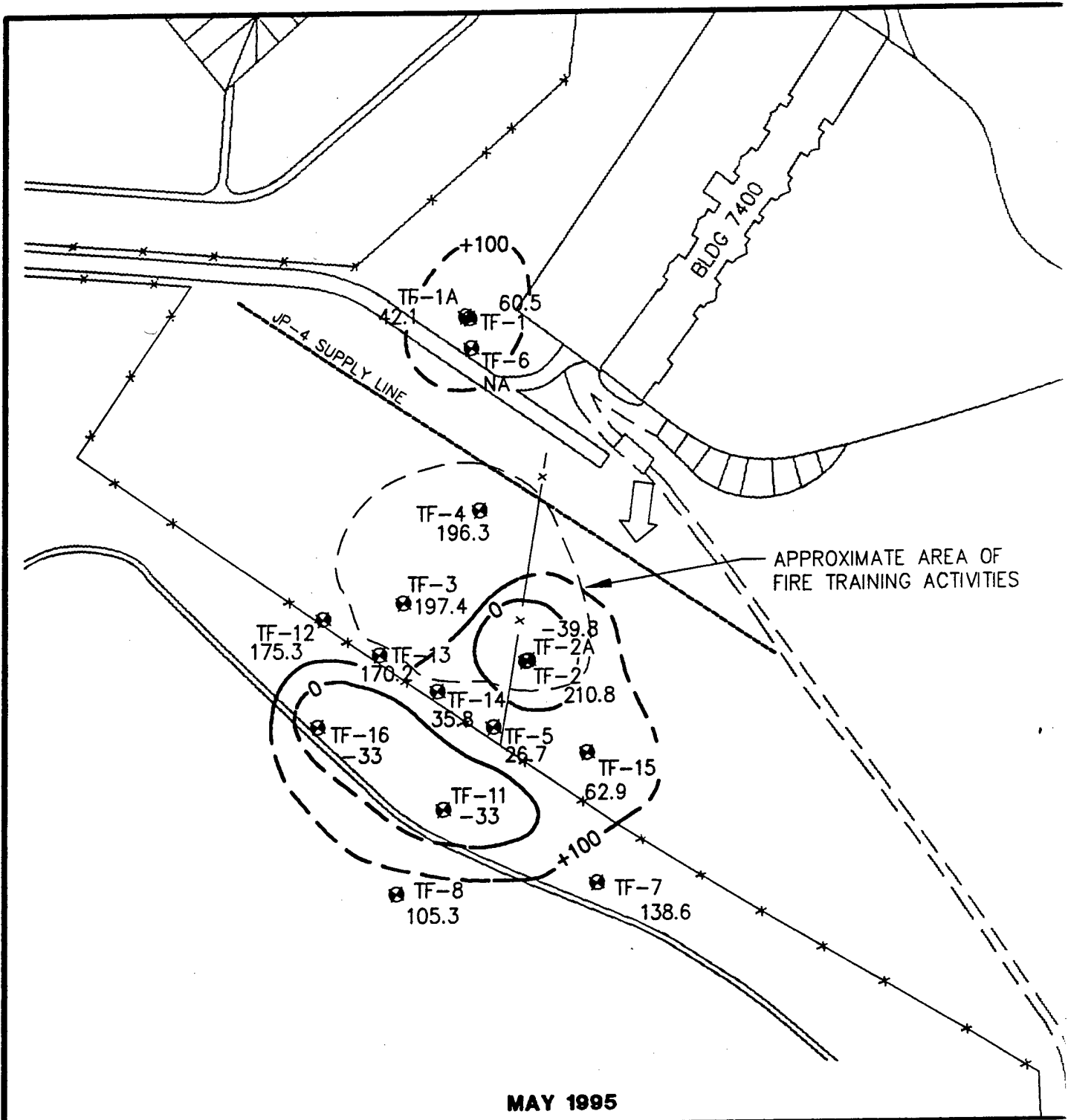
4.3.2.6 Reduction/Oxidation Potential

Redox potentials were measured at groundwater monitoring wells in May 1995 and July 1996. These measurements are summarized in Table 4.6. Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during BTEX oxidation. The shallow groundwater redox potential for May 1995 ranged from -39.8 millivolts (mV) at well TF-2A to 197.4 mV at well TF-3. In July 1996 redox potentials ranged from -159 mV at TF-2A to 300 mV at TF-1A. Figure 4.9 presents two isopleth maps comparing redox potentials for May 1995 and July 1996. As expected, areas at the site with low redox potentials coincide with areas of high BTEX contamination, low DO, nitrate, and sulfate concentrations, and elevated ferrous iron levels (compare Figure 4.9 with Figures 4.2, 4.5, 4.6, 4.7, and 4.8).

The redox potentials measured at the site are higher than the theoretical optimum redox potentials for various electron acceptor reactions (Norris *et al.*, 1994). This discrepancy is a common problem associated with measuring oxidizing potential using field instruments. It is likely that the platinum electrode probes are not sensitive to some of the redox couples (e.g., sulfate/sulfide). Many authors have noted that field measured redox data alone cannot be used to reliably predict the electron acceptors that may be operating at a site (Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994). Integrating redox measurements with analytical data on reduced and oxidized chemical species allows a more thorough and reasonable interpretation of which electron acceptors are being used to biodegrade site contaminants.


4.3.2.7 Volatile Fatty Acids

In May 1995, a groundwater sample was collected at TF-2A and analyzed for volatile fatty acids. This test is a gas chromatography/mass spectrometry (GC/MS) method wherein the samples are compared to a standard mixture containing a total of 58 phenols, aliphatic acids, and aromatic acids. Compounds in the standard mixture are generally associated with microbial processes that break down petroleum hydrocarbons. USEPA researchers reported that the sample from TF-2A contained 17 of the compounds in the standard mixture at concentrations above the detection limit of 5 µg/L. However, because of a procedural error, the quantitation of 12 phenols and



MAY 1995

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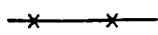
 TF-8
 105.3 MONITORING WELL LOCATION WITH TOTAL REDOX POTENTIAL VALUE (mV)

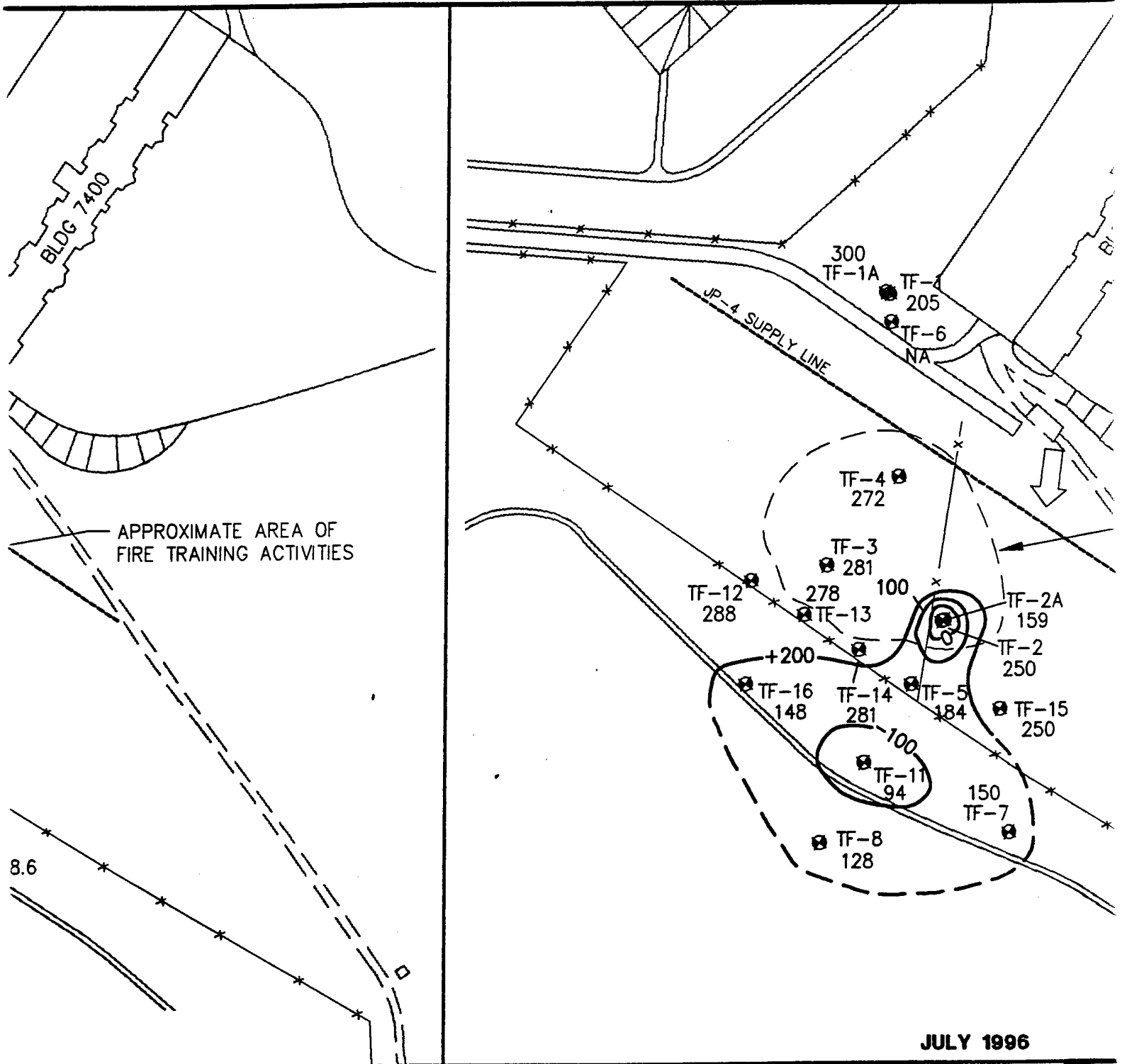
NA NOT ANALYZED

 -1.0
 LINE OF EQUAL REDOX POTENTIAL (mV) (DASHED WHERE INFERRED)

NOTE: SHALLOW GROUNDWATER WERE USED FOR CONTOUR

 GROUNDWATER FLOW DIRECTION

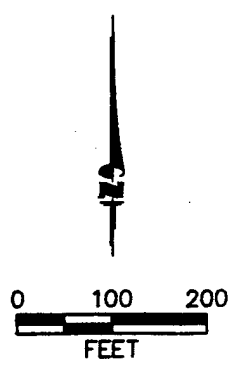
 FENCE

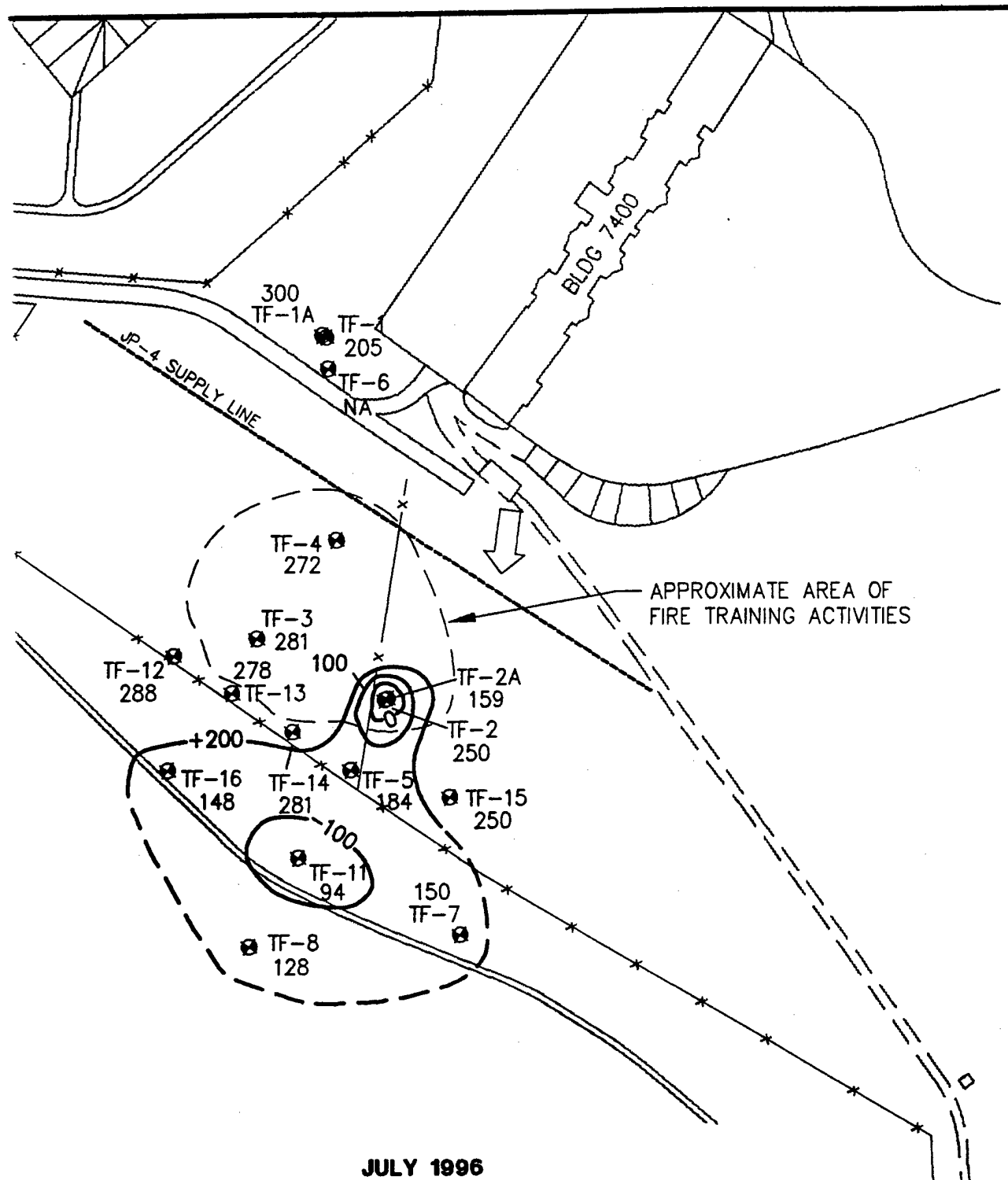


JULY 1996

EDOX NA NOT ANALYZED

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING





JULY 1996

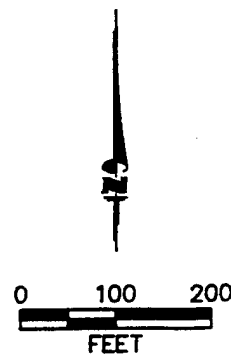


FIGURE 4.9

**REDOX POTENTIAL
ISOPLETH MAPS
FOR GROUNDWATER**

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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creosols was not possible, resulting in a possible maximum of 46 rather than 58 compounds that could be detected.

4.3.2.8 Alkalinity

Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity (as calcium carbonate) was measured in groundwater samples from 20 to 320 mg/L, in May 1995, and from 20 to 134 mg/L in July 1996. These measurements are summarized in Table 4.6 and presented as two isopleth maps on Figure 4.10. Comparison with the BTEX plume (Figure 4.2) reveals a correlation between the elevated alkalinity isopleths and the groundwater BTEX plume. The increase in alkalinity in the areas of groundwater BTEX contamination is in response to increased carbon dioxide levels which are a product of BTEX biodegradation (Morell and Hering, 1993). Frequently, an increase in alkalinity resulting from biological activity is difficult to observe because the magnitude of the change is low compared to background levels. Because the background alkalinity is low at FT-03, the correlation is easily observed for both May 1995 and July 1996 data. In July 1996, the elevated alkalinity downgradient from the dissolved fuel hydrocarbon contamination is a shadow effect, resulting from groundwater migration and the rapid contraction in the size of the dissolved BTEX plume.

4.3.2.9 Carbon Dioxide in Groundwater

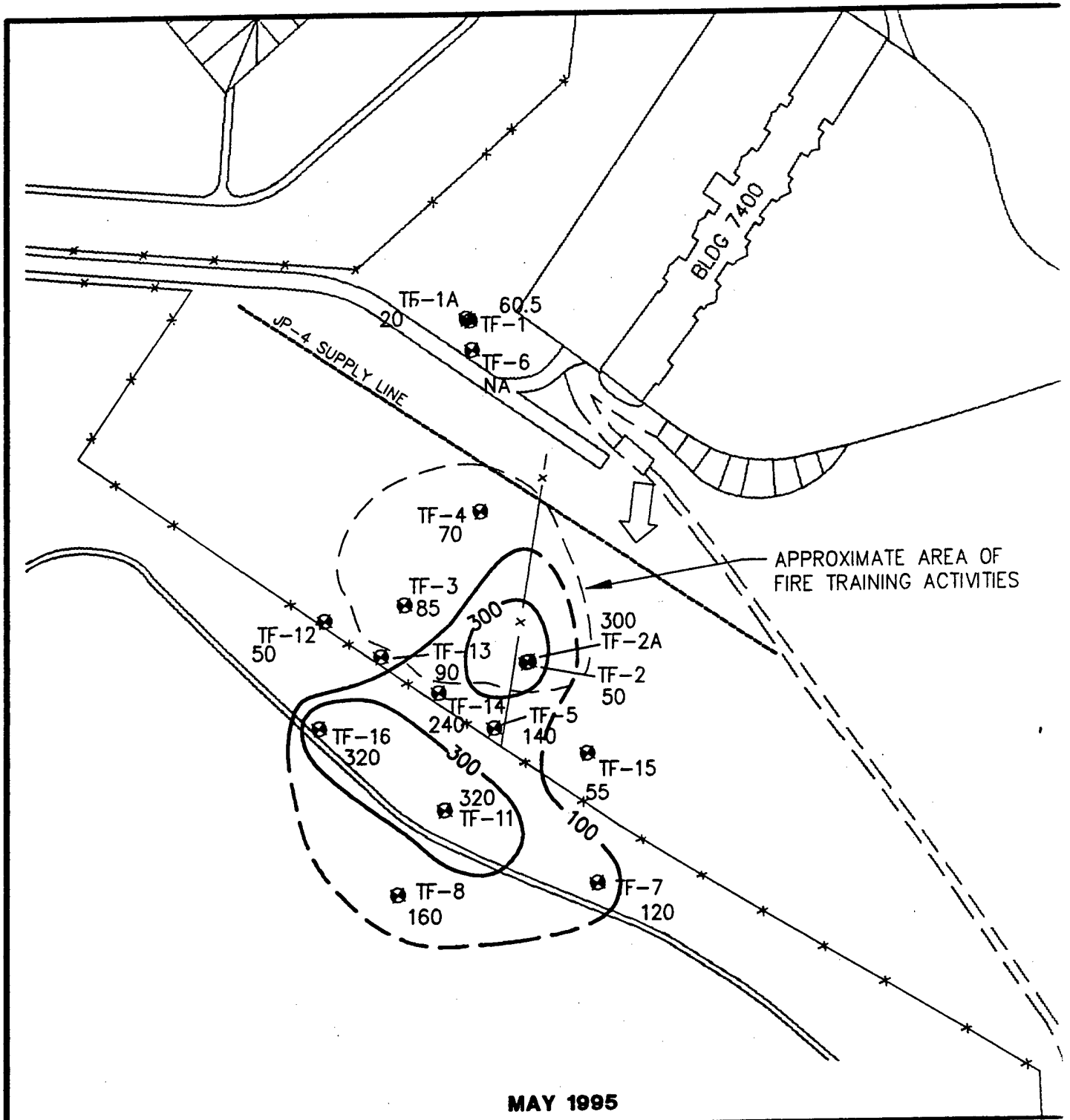
Groundwater carbon dioxide (CO₂) measurements were collected from site monitoring wells in May 1995 and July 1996. Table 4.6 summarizes the groundwater carbon dioxide measurements and Figure 4.11 illustrates the carbon dioxide concentrations present at FT-03 for May 1995 and July 1996. Carbon dioxide is produced in the plume area as a byproduct of aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis (Table 4.5). Comparison of the area of elevated carbon dioxide on Figure 4.11 with Figures 4.5, 4.6, 4.7, and 4.8 supports the inferred biodegradation of BTEX. July 1996 data shows more elevated carbon dioxide concentrations downgradient from observed dissolved BTEX contamination. Like alkalinity, these elevated concentrations are a probable shadow effect.

4.3.2.10 pH

The pH of a solution is the negative logarithm of the hydrogen ion concentration [H⁺]. pH was measured for groundwater samples collected from groundwater monitoring wells in May 1995 and July 1996. Measurements performed by both Parsons ES and the USEPA are summarized in Table 4.6. Parsons ES measured groundwater field pH at the site across a range of 6.00 to 6.63 and 6.10 to 7.94 in May 1995 and July 1996 respectively. These ranges of pH are within the optimal range for BTEX-degrading microbes.


4.3.2.11 Temperature

Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with high temperatures generally resulting in higher growth rates. Groundwater temperature measurements made in May 1995 and July

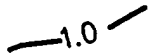


MAY 1995

LEGEND


 TF-8
 105.3 MONITORING WELL LOCATION WITH ALKALIINITY
 VALUE (mg/L)

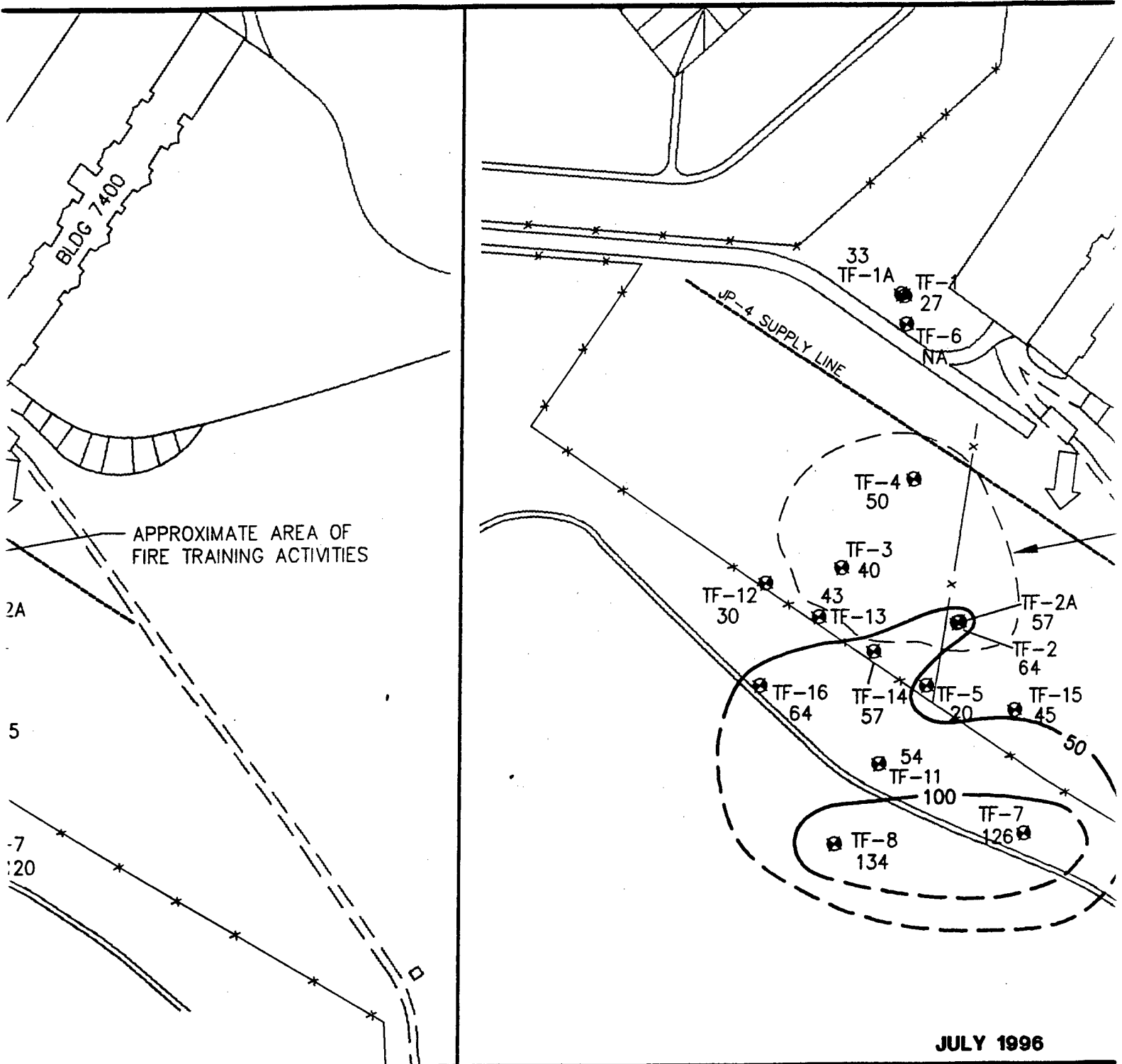
NA NOT ANALYZED

 1.0
 LINE OF EQUAL ALKALIINITY VALUES
 (mg/L) (DASHED WHERE INFERRED)

NOTE: SHALLOW GROUNDWATER
 WERE USED FOR CONTOU

 GROUNDWATER FLOW DIRECTION

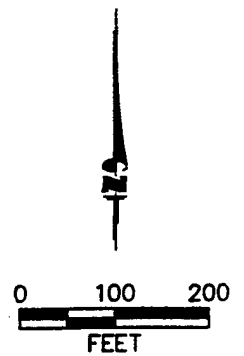
 FENCE

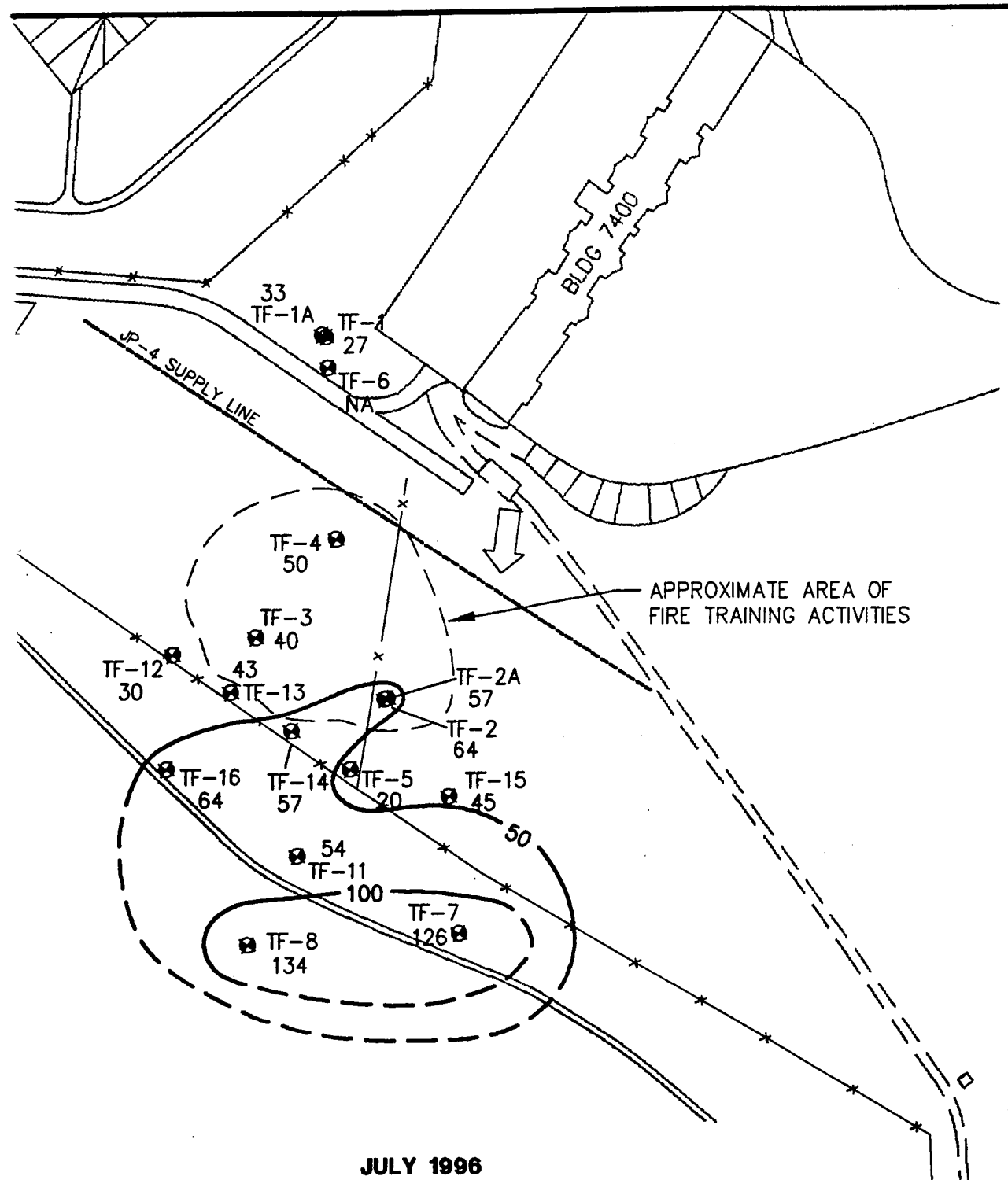


JULY 1996

NITY NA NOT ANALYZED

NOTE: SHALLOW GROUNDWATER MEASUREMENTS WERE USED FOR CONTOURING

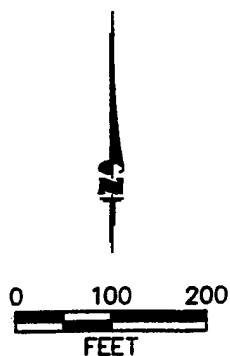




JULY 1996

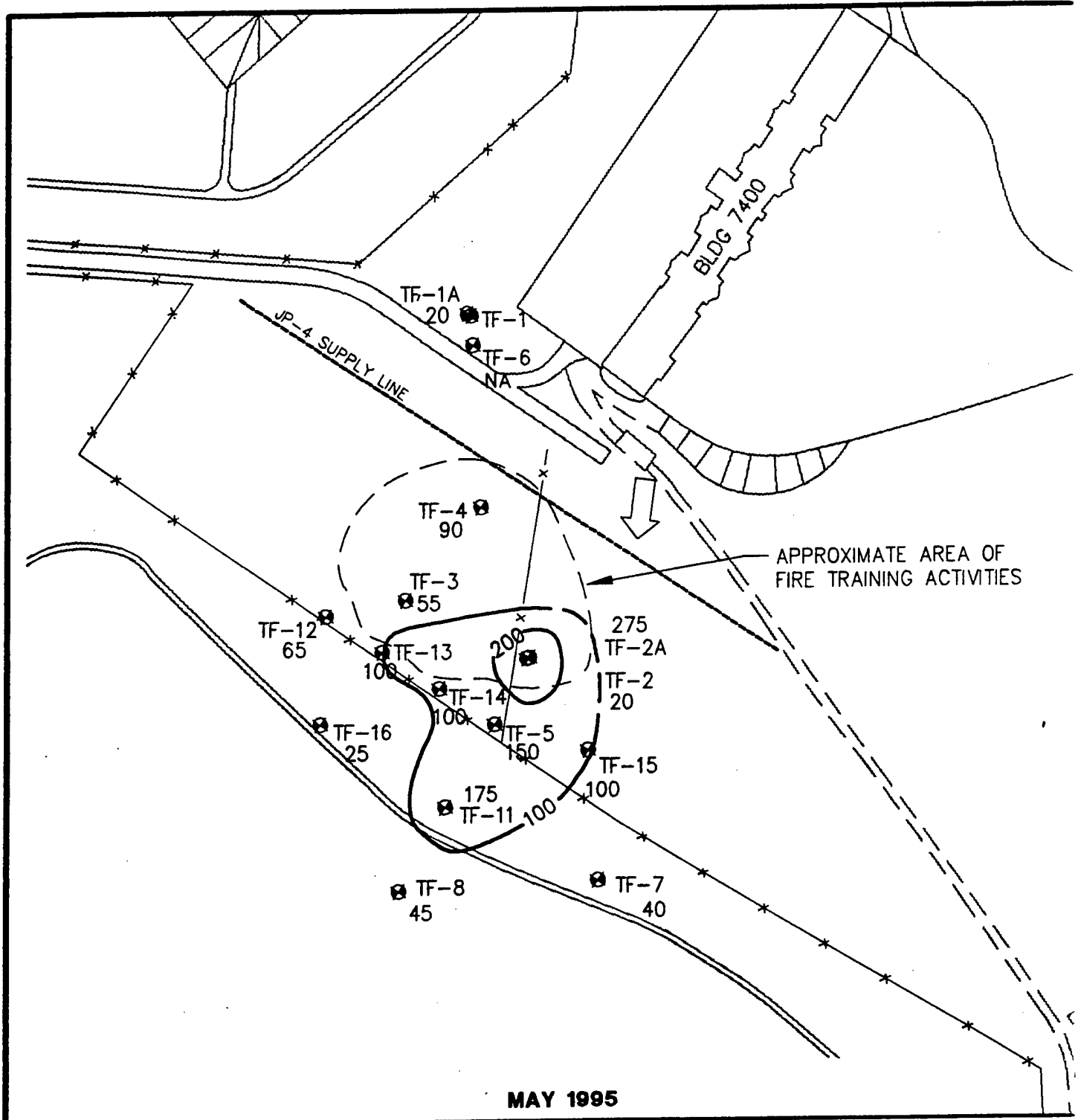
FIGURE 4.10
GROUNDWATER
ALKALINITY

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts



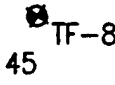
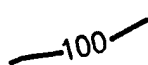


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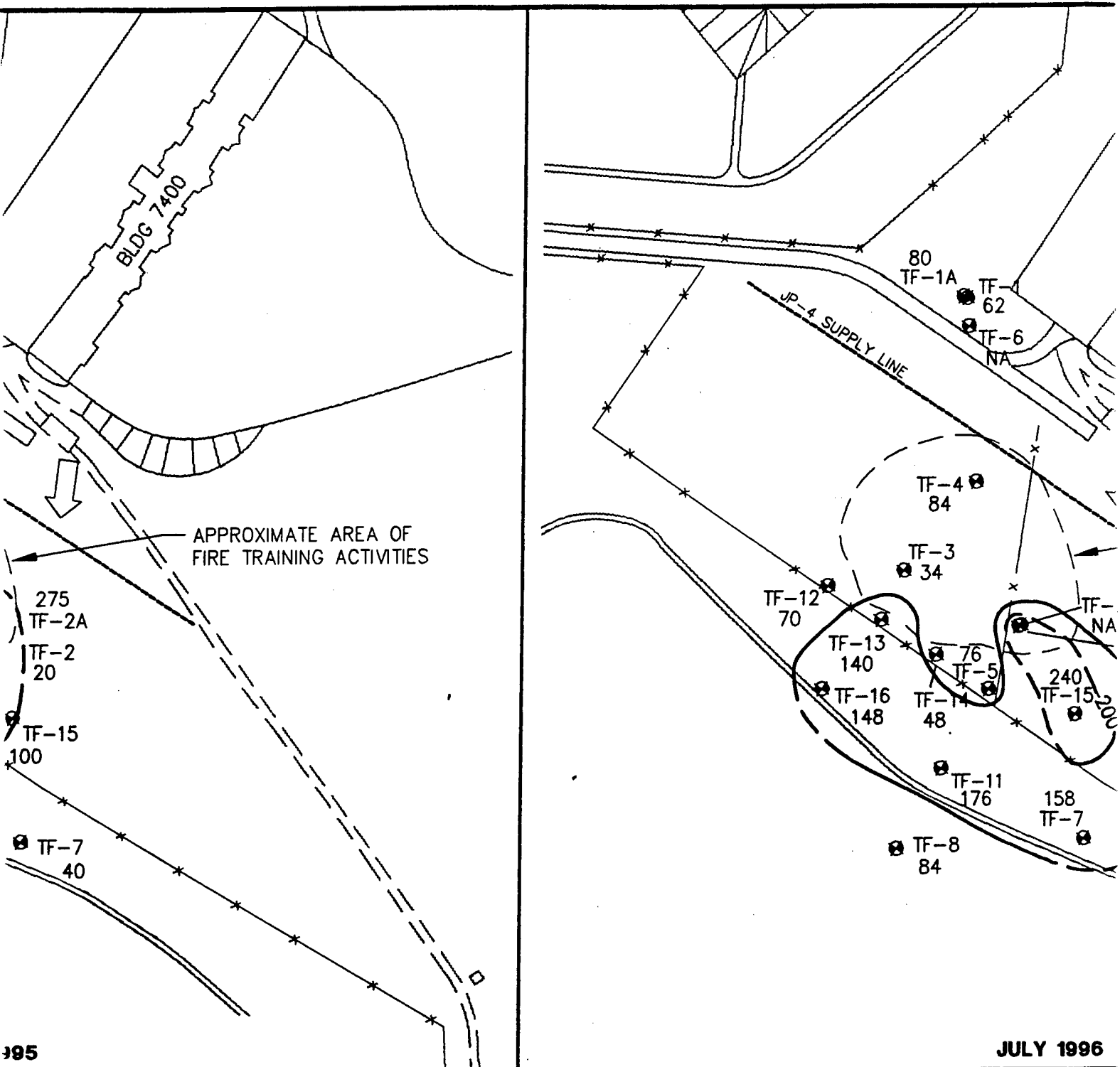
Denver, Colorado



MAY 1995

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- 
 TF-8
45
- 
 100
- 
 GROUNDWATER FLOW DIRECTION
- 
 FENCE
- NA NOT ANALYZED
- NOTE: SHALLOW GROUNDWATER CON WERE USED FOR CONTOURING



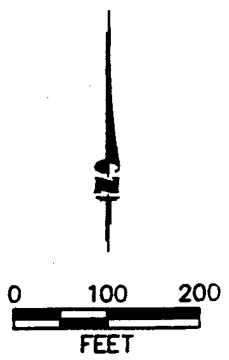
195

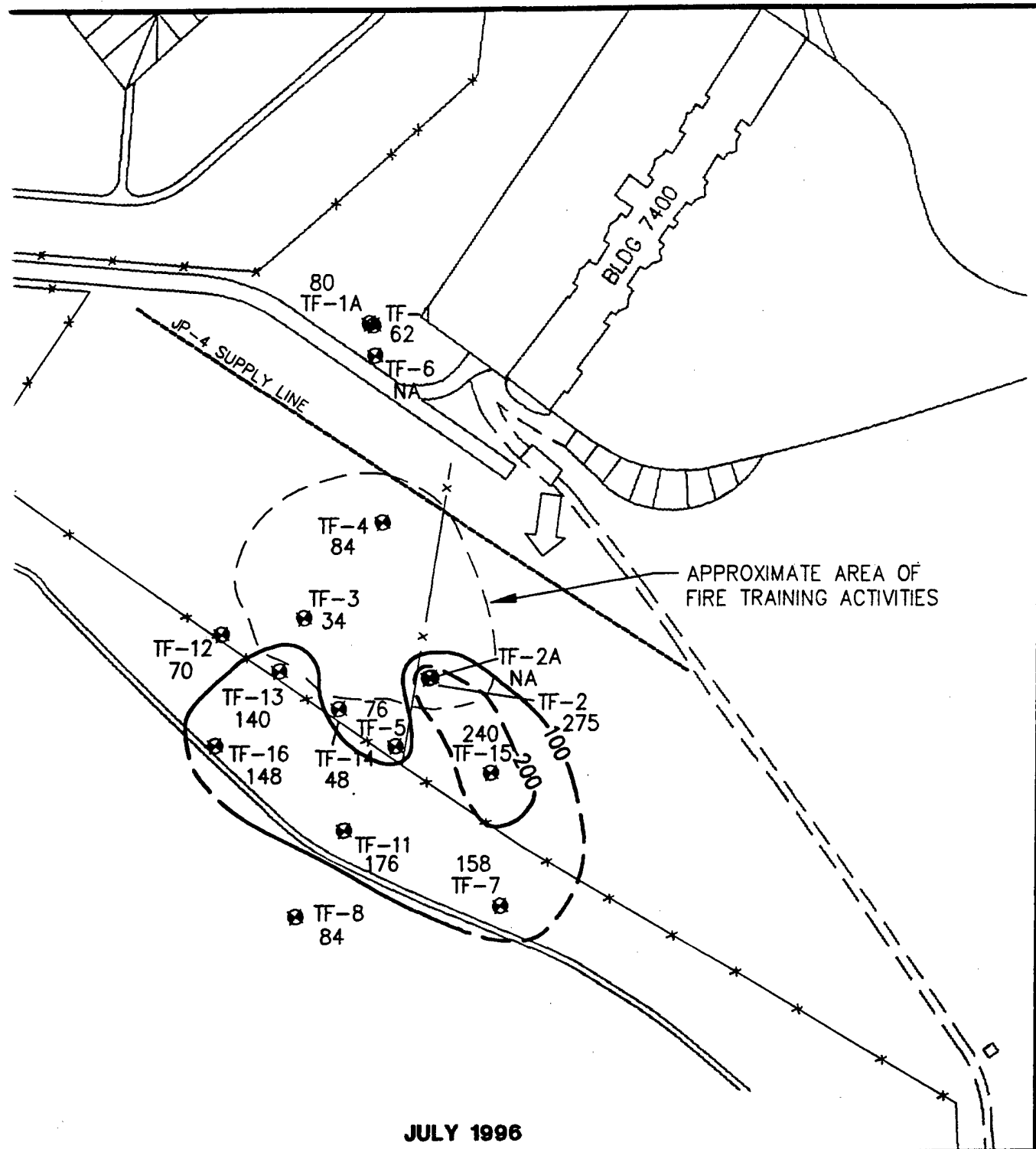
JULY 1996

LEGEND

GROUNDWATER (mg/L) NA NOT ANALYZED

NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING





JULY 1996

FIGURE 4.11

GROUNDWATER CARBON DIOXIDE CONCENTRATIONS

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts



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1996 are summarized in Table 4.6. Temperatures in the shallow aquifer varied from 11.0 degrees Celsius (°C) to 13.6 °C in May 1995, and from 10.8 to 15.7 in July 1996. These are relatively moderate temperatures for shallow groundwater, suggesting that bacterial growth rates should not be inhibited.

4.3.3 Degradation of Chlorinated Solvents

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and Mccarty, 1991a, 1991b; Destefano *et al.*, 1991; Henry, 1991; Mccarty *et al.*, 1992; Hartmans and de Bont, 1992; Mccarty and Semprini, 1994; Vogel, 1994). Biodegradation of chlorinated aliphatic hydrocarbons (CAHs) is similar in principle to biodegradation of BTEX as described in Section 4.3.2; however, CAH degradation typically results from a more complex series of processes. Whereas BTEX is biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs may undergo several types of biodegradation involving several steps. CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most likely. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

4.3.3.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. In general, reductive dehalogenation occurs by sequential dehalogenation from TCE to DCE to vinyl chloride to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, vinyl chloride is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and Mccarty, 1985; Bouwer, 1994). Murray and

Richardson (1993) have postulated that this rate decrease may explain the accumulation of vinyl chloride in TCE plumes that are undergoing reductive dehalogenation.

In addition to being affected by the degree of chlorination of the CAH, reductive dehalogenation can also be controlled by the redox conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or iron (III) reduction (Vogel *et al.*, 1987), while the transformation of DCE to vinyl chloride, or the transformation from vinyl chloride to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; Destefano *et al.*, 1991; DeBruin *et al.*, 1992).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons such as BTEX.

The presence of *cis*-1,2-DCE and the absence of *trans*-1,2-DCE in site groundwater suggests that TCE is being reductively dehalogenated. Limited sulfate reduction and methanogenesis in the core of contaminant plume also supports the possibility that reductive dehalogenation is occurring. Redox conditions in the core of the plume also are favorable for the reductive dehalogenation of TCE. Because vinyl is not observed at the site, it is likely that reductive dehalogenation of *cis*-1,2-DCE is not occurring.

4.3.3.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. Davis and Carpenter (1990) describe the aerobic oxidation of vinyl chloride in groundwater. McCarty and Semprini (1994) describe investigations in which vinyl chloride was shown to serve as a primary substrate. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of oxidation of vinyl chloride under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of vinyl chloride may be characterized by a loss of vinyl chloride mass, a decreasing molar ratio of vinyl chloride to other CAH compounds, and the presence of chloromethane. Klier *et al.* (1996) provide evidence to suggest that DCE can be aerobically biodegraded in both contaminated soils and groundwater. Klier *et al.* write that naturally occurring microorganisms in soil and groundwater are capable of biodegrading DCE contamination, by using DCE as a primary substrate, i.e. and electron donor. Aerobic oxidation of DCE may be characterized by loss of DCE contaminant mass, a decreasing

molar ratio of DCE to other CAH compounds, and the presence of elevated CO₂ concentrations.

The disappearance of cis-1,2-DCE from the site groundwater between May 1995 and July 1996 without a corresponding accumulation of vinyl chloride suggests that cis-1,2-DCE is being metabolized as an electron donor as the groundwater returns to its natural aerobic conditions.

4.3.3.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases. There is no evidence to either support or disallow that dissolved TCE and cis-1,2-DCE concentrations are being reduced through cometabolic processes.

4.3.3.4 Chloride

Chloride concentrations also were measured in groundwater samples collected in May 1995 and July 1996. Chloride is a byproduct of the biodegradation of chlorinated solvents. Concentrations at the site range from 1.45 mg/L to 5.42 mg/L in May 1995, and from <0.5 mg/L to 6.14 mg/L in July 1996. Table 4.6 summarizes measured chloride concentrations. Because site chlorinated solvent concentrations are low, the increase in chloride concentrations that can be anticipated as a result of chlorinated solvent degradation also is low. The variability in chloride concentrations in background locations at FT-03 masks any increase in chloride that may have occurred as a result of chlorinated solvent degradation. Instead, the significant reduction in chlorinated solvent concentrations throughout the site since May 1995 serve as a better indicator that biodegradation of CAHs is occurring.

4.3.4 Expressed Assimilative Capacity For BTEX Degradation

The May 1995 data presented in the preceding sections suggest that mineralization of BTEX compounds was occurring through the microbially mediated processes of aerobic respiration, denitrification, iron reduction, and methanogenesis. On the basis of the stoichiometry presented in Table 4.5, the expressed BTEX assimilative capacity of groundwater at FT-03 is at least 32,700 µg/L (Table 4.7).

July 1996 data indicates that bioventing operations contributed to a decrease in BTEX dissolving into groundwater and a subsequent return of groundwater geochemistry to conditions closer to background. Electron acceptor concentrations, biodegradation byproduct concentrations, alkalinity, and contaminant concentrations all moved rapidly in the direction of background conditions between May 1995 and July 1996. Downgradient trends of decreased nitrate and sulfate, and increased ferrous iron and methane appear to be shadows of past anaerobic degradation activity at FT-03. Therefore, the calculated assimilative capacity of 5,560 µg/L (Table 4.7) for July 1996 data is in some ways also a shadow of what has occurred in site groundwater.

TABLE 4.7
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
Christmas Tree Fire Training Area, FT-03
Intrinsic Remediation TS
Westover Air Reserve Base, Massachusetts

Electron Acceptor or Process	May 1995 Expressed BTEX Assimilative Capacity (mg/L)	July 1996 Expressed BTEX Assimilative Capacity (mg/L)
Dissolved Oxygen	3,200	2,700
Nitrate	1,770	1,770
Iron Reduction	27,500	1,080
Methanogenesis	230	10
Expressed Assimilative Capacity	32,700	5,560

A closed system with two liters of water can be used to help visualize the physical meaning of assimilative capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has an assimilative capacity of exactly "x" µg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these two liters of water are kept separate, the biodegradation of fuel hydrocarbons will not occur. If these two liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons are depleted, the electron acceptors are depleted, or the environment becomes acutely toxic to the fuel-degrading microorganisms. Assuming a nonlethal environment, if less than "x" µg of fuel hydrocarbons are in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than "x" µg of fuel hydrocarbons were in the second liter of water, only "x" µg of fuel hydrocarbons would ultimately degrade.

The groundwater beneath a site is an open system, which continually receives additional electron receptors from through the flow of the aquifer and the percolation of

precipitation. This means that the assimilative capacity is not fixed as it would be in a closed system, and therefore cannot be compared directly to contaminant concentration in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. Although the expressed assimilative capacity at this site is greater than the highest measured total BTEX concentrations measured in May 1995 and July 1996, the fate of BTEX in groundwater and the potential impact to receptors is dependent on the relationship between the kinetics of biodegradation and the solute transport velocity (Chappelle, 1994). This significant expressed assimilative capacity is a strong indicator that biodegradation is occurring; however, it is not an indication that biodegradation will proceed to completion before potential downgradient receptors are impacted.

At FT-03, the expressed assimilative capacity for groundwater and the rapid decrease in groundwater contaminant concentrations between May 1995 and July 1996 suggest that biodegradation will proceed to completion.

4.3.5 Discussion

Throughout this section, two lines of evidence for intrinsic remediation of petroleum hydrocarbons at FT-03 were presented. Contaminant data presented in Section 4.3.1 indicate that contaminant mass has essentially been completely removed from shallow groundwater. In Section 4.3.2, comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for FT-03 provides strong qualitative geochemical evidence of biodegradation of BTEX compounds through aerobic respiration, denitrification, iron reduction, and methanogenesis. Other observations and patterns in the data provide further evidence that biodegradation is reducing hydrocarbon concentrations at the site. In Section 4.3.3, similar lines of evidence suggest qualitatively that chlorinated solvent degradation also is occurring at the site.

SECTION 5

GROUNDWATER MODELING

5.1 GENERAL OVERVIEW

To help estimate degradation rates for dissolved BTEX at FT-03 and to help predict the future migration of these compounds, Parsons ES modeled the fate and transport of the dissolved BTEX plume. The modeling effort has three primary objectives: (1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; (2) to assess the potential for exposure of downgradient receptors to contaminant concentrations that exceed regulatory standards intended to be protective of human health and the environment; and (3) to provide technical support for the intrinsic remediation option at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Because of the conservative nature of model input, the reduction in contaminant mass caused by natural attenuation is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

Partial differential equations that describe groundwater flow and/or solute transport can be solved analytically or numerically. The type of model selected to simulate site conditions depends on the complexity of the problem, the amount of available data, the importance of the decisions that will be based upon the model, and project scope. Analytical methods (models) provide exact, closed-form solutions, and numerical methods (models) provide approximate solutions. Analytical models are the simplest to set up and solve, allowing the user to evaluate many scenarios in a relatively short time. Numerical methods are more efficient for those systems that are too complex for analytical methods. Analytical models are restricted in the nature of the problems for which they can be used, and for some transport problems they may become so complex and unwieldy that the use of numerical methods may be more efficient. Theoretically there are no limits on the characteristics of the hydrogeological system and the properties of the solute(s) that can be simulated using a numerical model code. There are, however, practical limits on the ways in which the system and any reactions within it can be represented. The basic parameters for both types of models typically include groundwater seepage velocity, hydraulic conductivity, saturated thickness of the aquifer, porosity, source area configuration, source area contaminant concentrations, leakage rates, dispersion coefficients, retardation values, and decay rates.

If limited data are available, or the hydrogeologic conditions are simple, an analytical model can be selected to simulate contaminant fate and transport. Analytical solutions provide exact, closed-form solutions to the governing advection-dispersion

equation by making significant simplifying assumptions. The more closely the actual system approximates these assumptions, the more accurate the analytical model will be in predicting solute fate and transport. Because of the nature of the simplifying assumptions, analytical models may overestimate or underestimate the spread of contamination. By making assumptions that will ensure the model will overpredict contaminant concentrations and travel distances (or at least not underpredict them), the model predictions will be conservative. The more conservative a model is, the more confidence there should be that potential receptors will not be impacted by site contamination. Analytical solutions are generally limited to steady, uniform flow or radial flow, and should not be used for groundwater flow or solute transport problems in strongly anisotropic or heterogeneous media.

Numerical solutions provide approximate solutions to the advection-dispersion equation. Numerical models are less burdened by simplifying assumptions and are capable of addressing more complicated problems. Unlike analytical models, numerical models allow subsurface heterogeneities and varying aquifer parameters to be simulated, as well as transient simulations (i.e., one or more properties or conditions change over time), if the requisite data are available. Many of the assumptions required for the analytical solutions are not necessary when numerical techniques are used to solve the governing solute transport equation. However, a greater amount of site-specific data is needed to implement a numerical model, and the solutions are inexact numerical approximations. The added complexity of performing a numerical model typically is not warranted unless the spatial distribution of input parameters is known.

Analytical models were selected to evaluate contaminant fate and transport at FT-03. Analytical models are appropriate at this site because hydrogeologic conditions are uniform, limited geochemical and contaminant concentration information is available spatially, and remediation of the site source area is in progress.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Before developing a groundwater model, it is important to develop a reasonable interpretation of aquifer conditions. On the basis of the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a shallow unconfined aquifer composed of well-sorted, interbedded sand and sandy gravel, with some clean coarse gravel seams present (Figure 3.3). Water level data suggest a relatively uniform local groundwater flow system without a significant vertical component.

Geochemical data presented in Section 4 suggest that biodegradation of site contaminants is occurring. In particular, BTEX compounds are being degraded by aerobic respiration and the anaerobic processes of denitrification, ferric iron reduction, sulfate reduction, and methanogenesis. Past analytical data which show temporal decreases in dissolved BTEX concentrations were used for model calibration and to support source reduction assumptions. Chlorinated solvents were not modeled because the distribution of contaminants made estimation of a reliable decay coefficient difficult to obtain. Furthermore, the maximum downgradient concentration is below state and federal groundwater guidelines, and source area concentrations proportionally are significantly lower than the observed BTEX concentrations. Therefore dissolved BTEX groundwater contamination at the site was modeled.

The contaminated soils at the site are undergoing remediation through bioventing. As a result, they are unlikely to serve as a significant continuing source of dissolved BTEX contamination at the site.

5.3 INITIAL MODEL SETUP

Where possible, the initial setup for the models was based on site data. Where site-specific data were not available (e.g., for effective porosity), reasonable assumptions were made on the basis of widely accepted literature values. The analytical model solution is based on calculations for retarded flow with biodegradation and a decaying source (van Genuchten and Alves, 1982). The following sections describe the basic model setup. The analytical model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Groundwater Gradient

The May 1995 water table elevation map presented on Figure 3.4 was used to determine the hydraulic gradient. Groundwater flow in the vicinity of the site is to the south with an average gradient of approximately 0.01 ft/ft. Data review indicates the groundwater elevation seasonally fluctuates approximately 1.5 feet. Although the historic groundwater elevation data suggested a slightly steeper groundwater gradient than the May 1995 groundwater elevation data, historic data were compiled from fewer monitoring wells. Therefore, it was assumed that the May 1995 water levels and gradient are representative of steady-state conditions.

5.3.2 BTEX Concentrations

The total dissolved BTEX concentrations obtained from laboratory analytical results were used for model development. Table 4.3 presents May 1995 dissolved BTEX concentration data. Figure 4.2 shows the areal distribution of dissolved groundwater BTEX in May 1995. The shape and distribution of the total BTEX plume are the result of advective-dispersive transport and biodegradation of dissolved BTEX contamination originating from source area at FT-03. The BTEX concentrations from the May 1995, 1993, and 1989 investigations were used in the models to project future downgradient concentrations.

5.3.3 Degradation Rates

Available data strongly suggest that aerobic and anaerobic degradation is occurring at the site. In May 1995, combined anaerobic processes account for over 90 percent of the assimilative capacity of site groundwater (Table 4.7). As with a large number of biological processes, biodegradation can generally be described using a first-order rate constant and the equation:

$$\frac{C}{C_0} = e^{-kt}$$

where: C = Contaminant Concentration at Time t
C₀ = Initial Contaminant Concentration
k = Coefficient of Anaerobic Decay (anaerobic rate constant)
t = time

Two methods of calculating rate constants are currently available to quantify rates of biodegradation at the field scale and area applicable for use with available site data. The first method involves the use of a biologically recalcitrant compound found in the dissolved BTEX plume that can be used as a conservative tracer. The second method, proposed by Buscheck and Alcantar (1995), involves interpretation of a steady-state contaminant plume configuration and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (1979).

5.3.3.1 Trimethylbenzene Tracer Method

To calculate rate constants, the apparent degradation rate must be normalized for the effects of dilution caused by advective-dispersive processes and sorption. This can be accomplished by normalizing the concentration of each contaminant to the concentration of a component of jet fuel (a tracer) that has similar sorptive properties but that is fairly recalcitrant. Observed BTEX concentration data can be normalized to 1,3,5-TMB, 1,2,4-TMB, and/or 1,2,3-TMB or another tracer with similar physiochemical properties. The TMB compounds can serve as good tracers because they can be biologically recalcitrant under anaerobic conditions, and they have sorptive properties similar to the BTEX compounds (Cozzarelli *et al.*, 1990 and 1994). Thus, the TMB is assumed to respond similarly to the processes of advection, dispersion, and sorption without experiencing a reduction in concentration due to biodegradation. Under aerobic conditions, TMB compounds are less recalcitrant, leading to reduction in TMB concentrations by processes other than dispersion, dilution, and sorption. This in turn results in the calculation of an overly low, albeit conservative, rate constant.

The normalized (corrected) concentration of a compound is the concentration of the compound that would be expected at one point (B) located downgradient from another point (A) after correcting for the effects of dispersion, dilution, and sorption between points A and B. One relationship that can be used to calculate the corrected contaminant concentration is:

$$C_{B,corr} = C_B(TMB_A/TMB_B)$$

where:

- $C_{B,corr}$ = Corrected concentration of compound at Point B
- C_B = Measured concentration of compound at Point B
- TMB_A = Measured TMB concentration at Point A
- TMB_B = Measured TMB concentration at Point B.

A log-linear plot of the corrected contaminant concentrations along a flow path versus the travel time from the origin can be used to determine whether the data set can be described using a first-order exponential equation (i.e., r^2 is greater than approximately 0.9). When this occurs, the exponential slope can be used as the rate constant. Once again, if aerobic conditions exist along the selected flow path, the rate constant calculation will be conservative because TMBs are not recalcitrant under aerobic conditions.

An average rate constant for BTEX decay at FT-03 was determined from May 1995 BTEX and TMB data. The selected flow path from TF-2A to TF-11 is anaerobic.

Table 5.1 presents the data for a first-order rate constant calculation for BTEX using 1,2,4-TMB as a conservative tracer. The TMB-corrected total BTEX concentration represents the theoretical BTEX concentration at a point if biodegradation were the only process affecting BTEX concentrations. The graph that accompanies the table illustrates that a rate constant of 0.0013 day⁻¹ is predicted. TMB should serve as a conservative tracer because retardation coefficients for 1,2,4-TMB are from 1.4 to 7 times higher than those of benzene, toluene, ethylbenzene, or xylene. Therefore, the rate constant is expected to be higher than calculated from this technique. Furthermore, downgradient from well TF-11, the biodegradation rate constant would be expected to increase because the aquifer becomes aerobic. Typically, aerobic degradation rates exceed anaerobic degradation rates (Borden and Bedient, 1986).

5.3.3.2 Method of Buscheck and Alcantar

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order decay rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation. For a steady-state plume, the first-order decay rate is given by (Buscheck and Alcantar, 1995):

$$\lambda = \frac{v_c}{4\alpha_x} \left(\left[1 + 2\alpha_x \left(\frac{k}{v_x} \right) \right]^2 - 1 \right)$$

where: λ = first-order decay rate
 v_c = retarded contaminant velocity in the x-direction
 α_x = dispersivity
 k/v_x = slope of line determined from a log-linear plot of contaminant concentration versus distance downgradient along flow path

The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Table 5.2 presents the data for a first-order rate constant calculation for BTEX using May 1995 data at FT-03 and the method proposed by Buscheck and Alcantar (1995). An exponential fit to the data estimates a log-linear slope of 0.0369. This value translates to a decay constant of 0.0034 day⁻¹.

5.3.3.3 Selection of a Decay Rate Constant

A review of recent literature indicates that higher rate constants generally have been observed in anaerobic plumes at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic groundwater conditions the rate constants were both approximately 0.01 day⁻¹. Wilson *et al.* (1994) report first-order anaerobic biodegradation rates of 0.05 to 1.3 week⁻¹ (0.007 to 0.185 day⁻¹); Buscheck *et al.* (1993) report first-order attenuation rates in a range of 0.001 to 0.01 day⁻¹; and Stauffer *et al.* (1994) report rate constants of 0.01 and 0.018 day⁻¹ for benzene and *p*-xylene, respectively. A first-order rate constant of 0.0034 day⁻¹ was used in two of the analytical models for this site. The third analytical model used a rate constant of

**TABLE 5.1
FIRST-ORDER RATE CONSTANT CALCULATION
USING 1,2,4-TMB AS A CONSERVATIVE TRACER**

**Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts**

Point	Distance Downgradient (ft)	Travel Time Between Upgradient and Downgradient Points (days)	Measured Total BTEX Concentration (µg/L)	Measured 1,2,4-Trimethylbenzene Concentration (µg/L)	Trimethylbenzene-Corrected Total BTEX Concentration (µg/L)
TF-2A	0	0	1657	280	1657
TF-5	105	584	123	47	737
TF-11	240	1334	77	13	278

$v_c = 0.18$ ft/day (average for all BTEX compounds)

**PLOT OF TMB-CORRECTED TOTAL BTEX CONCENTRATION
VERSUS TRAVEL TIME**

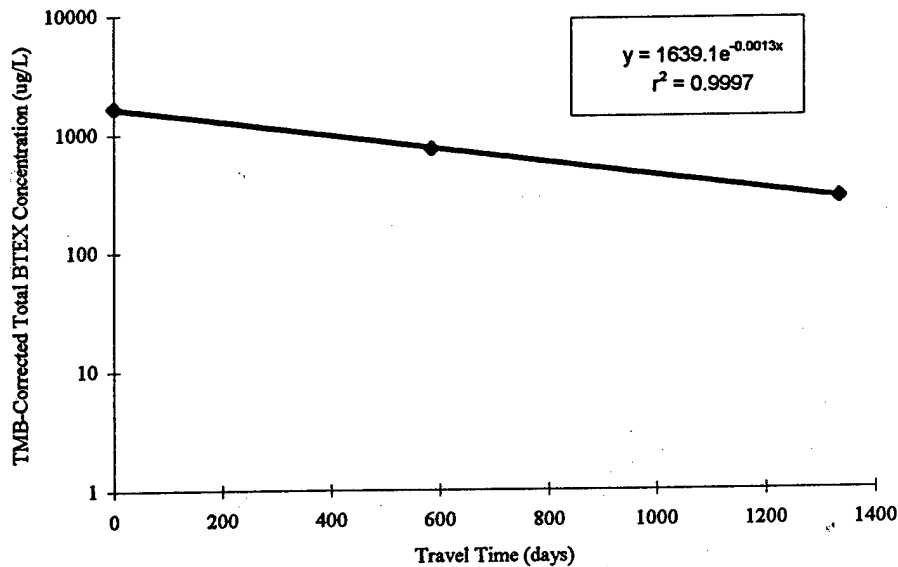
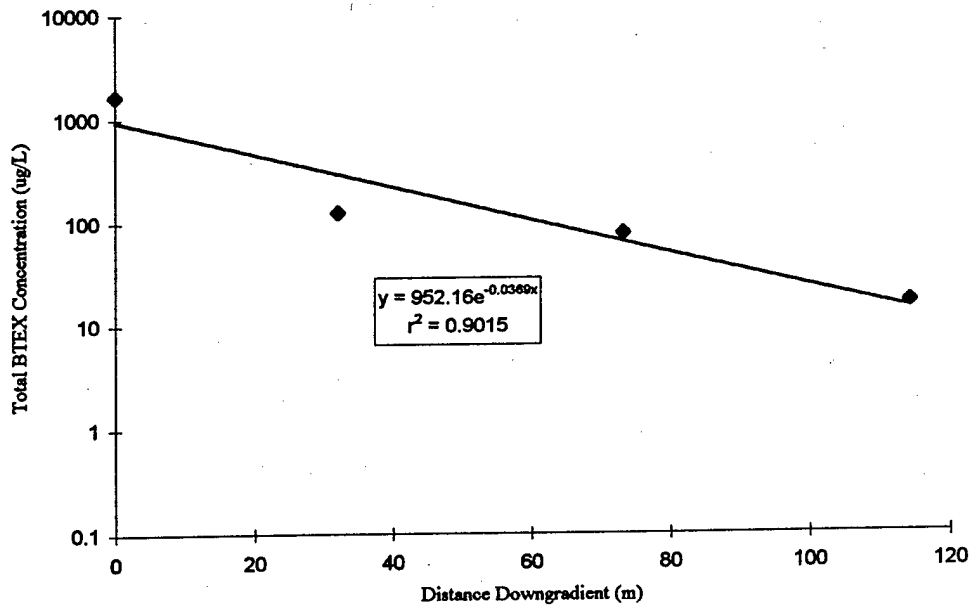


TABLE 5.2
FIRST-ORDER RATE CONSTANT CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Point	Distance	Total BTEX (µg/L)
	Downgradient(m)	May-95
TF-2A	0	1656.6
TF-5	32	123.1
TF-11	73	76.9
TF-8	114	15.9

PLOT OF TOTAL BTEX CONCENTRATION
VERSUS DISTANCE



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

where $v_c = 0.06$

$\alpha_x = 15$

$k/v_c = 0.0369$

therefore $\lambda = 0.0034$

0.0013 day⁻¹. Rate constants estimated from both methods were used in the models because they are relatively similar and are in the low range of the literature values.

5.4 ANALYTICAL MODEL RESULTS

One-dimensional analytical models were used to evaluate contaminant fate and transport at FT-03. Analytical models provide exact, closed-form solutions to the advection/dispersion equation, provided that several simplifying assumptions can be made. The models used with FT-03 data provided first-order solute decay solutions for a semi-infinite system with a point source of diminishing concentration (van Genuchten and Alves, 1982). The models assume a homogeneous, isotropic aquifer; a uniform, constant-velocity flow field in the x-direction only; a constant longitudinal hydrodynamic dispersion; a first-order rate of decay for biodegradation; and a linear sorption rate. It was not appropriate to use a constant-source model due to the low levels of soil contamination and the presence of an operational bioventing system designed to remediate the hydrocarbon contaminated soils.

5.4.1 Model Calibration

Calibration of the contaminant fate and transport model is an important component in the development of a defensible groundwater model. It demonstrates that the model is capable of predicting actual observed hydraulic and contaminant conditions given conditions observed in the past. The analytical flow models presented herein were calibrated using historical analytical data for initial contaminant concentrations and altering source and solute decay rates until modeled data matched current observed BTEX concentrations. Data from UNC Geotech (1991) and O'Brien and Gere (1994) were used for initial conditions in 5.5-year and 2-year models, respectively. A third model was calibrated over a 30-year period spanning the time from the cessation of fire training exercises to the present. Initial BTEX concentrations indicative of free product were assumed in the calibrated 30-year model. Values for the hydraulic parameters were not varied among the three models. For each model the hydraulic gradient was 0.01 ft/ft, the hydraulic conductivity was 1.05 m/day, and the effective porosity was 0.2.

All of the models were successfully calibrated to reproduce BTEX concentrations observed at the source area (well TF-2A) and leading plume edge (well TF-8) in May 1995. At the two mid-plume wells (TF-5 and TF-11), where modeled concentrations could not be successfully matched with the observed concentrations, the modeled concentrations were higher than actual observed concentrations. Consequently, the total dissolved contaminant mass predicted from the models is higher than the mass estimated from the observed contaminant concentrations. Thus, the models are considered conservative. Model input and output are included in Appendix C.

TOC was not measured above 1 mg/kg in the five soil samples collected from the saturated zone. The absence of organic carbon in saturated soils significantly influences the model calibration. With so little TOC in the saturated soil, the contaminant migration was modeled with no retardation resulting from sorption. This means that the modeled contaminant velocities were identical to the advective groundwater velocity. This is a very conservative estimate because it is unlikely that

saturated soils are barren of all TOC. It is expected that some sorption, and therefore some contaminant retardation with respect to groundwater velocity, is occurring.

Each of the three calibrated models was used to estimate the downgradient travel distance, expected remediation timetable, and future BTEX concentrations at both the source and downgradient locations.

5.4.2 Model-Decay 1%

Model-Decay 1% was calibrated over a 5.5-year interval using BTEX analytical results from 1989 and 1995. The model assumes an initial background BTEX concentration, attributable to existing contamination, of 16 µg/L and a measured source area concentration of 2,820 µg/L in 1989. The calibrated model successfully predicts observed 1995 BTEX concentrations at three of the four monitoring wells along the flow path using a solute decay rate of 0.0034 day⁻¹ and a source decay rate of 1 percent per year. Where calibration was not achieved, the modeled concentration was higher than the measured concentration, and therefore is a conservative estimate of site conditions.

The calibrated model was used as the foundation for two future scenarios incorporating annual source decay rates of 5 and 50 percent. Implementation of a bioventing soil remediation system has been accompanied by source decay rates averaging over 90 percent per year in vadose zone soils at a group of 16 other Air Force sites (AFCEE, 1994). Similarly high source decay rates, however, would be expected in capillary fringe soils only in the presence of a falling or fluctuating water table. Therefore to model the future of the site, models were run with annual source decay rates of 5 percent (negligible bioventing of capillary fringe) and 50 percent (significant bioventing of capillary fringe). An increase in the source decay rate to 5 percent per year is still conservative, but it presents a more reasonable scenario of site conditions after implementation of soil remediation if the water table is stable or rising. An annual source reduction rate of 50 percent was used to model the effect of bioventing given a water table that is falling or varies periodically by a couple of feet. Because groundwater levels have been documented to fluctuate by 1.5 feet at the site, the average annual rate of 50 percent may be more realistic given the probability of remediation of the capillary fringe zone through bioventing within the next few years.

The 5 percent model of future annual source decay suggests a minor plume expansion through the year 2005 followed by differing rates of plume recession. The model incorporates a 5-percent annual decay rate beginning in 1995 and suggests that the 5-µg/L concentration will withdraw into Base boundaries after 80 years. Under the scenario of a 50-percent annual source decay rate, the model predicts that the 5-µg/L total BTEX contour would retreat to the Base boundary in approximately 8 years.

Assuming a 5-percent annual source decay rate results in a predicted total BTEX concentration of 750 µg/L in the source area after 50 years, as well as correspondingly lower total BTEX concentrations at the Base boundary and monitoring well TF-8. In comparison, the model incorporating a 50-percent annual source decay rate suggests that a total BTEX concentration of only 6 µg/L would remain in the source area after 10 years. Model outputs, including graphs of concentration versus time and distance, are provided in Appendix C.

5.4.3 Model-Decay 8%

This model was developed by assuming the presence of free product in 1965 and varying the model input parameters to achieve the May 1995 BTEX values. The initial 1965 source was assumed to have a total BTEX concentration of 30,000 $\mu\text{g/L}$. To calibrate the model, an 8-percent annual source decay rate and 0.0034-day⁻¹ solute decay rate were used. Before implementation of bioventing, an 8-percent annual source decay rate may be an accurate representation of site conditions because a rate of this magnitude could account for natural degradation of the source as well as dissolution of the source into groundwater. With the startup of bioventing in 1995, the decay rate could be expected to increase to as high as 90 percent under ideal conditions; therefore, it is believed this model underestimates the actual rate of source decay currently occurring. The 30-year calibration run was able to achieve two of the observed 1995 concentrations, and was slightly higher (within a factor of 4) than the other two observed 1995 BTEX concentrations. This model also is conservative because the modeled concentrations are slightly higher than the observed concentrations.

Continuation of the 8-percent model past 1995 indicates the 5- $\mu\text{g/L}$ isopleth for total BTEX will begin to recede from a maximum downgradient distance of approximately 500 feet downgradient of the source in 2 years. The model suggests that the 5- $\mu\text{g/L}$ isocontour will recede to 435 feet downgradient in 10 years, and to within the Base boundary after 55 years. This version of the model suggests the total BTEX concentration will be approximately 30 $\mu\text{g/L}$ in the source area after 50 years. If the annual source decay rate was increased to 50 percent to accommodate bioventing, BTEX source area concentrations would be reduced to less than 5 $\mu\text{g/L}$ after approximately 11 years. To run the model under a bioventing scenario, the modeled 1995 concentrations were input into the model, and the source decay rate was increased to 50 percent per year.

At TF-8, the furthest downgradient monitoring well, the BTEX concentration is not predicted to exceed 20 $\mu\text{g/L}$. The bioventing model suggests Base boundary concentrations have already peaked and will continue to decrease from the 1995 modeled BTEX concentration of approximately 500 $\mu\text{g/L}$. Again, these are conservative estimates because the model was calibrated slightly above the observed 1995 BTEX concentrations at three locations. The version of the model that attempts to incorporate bioventing through the use of a 50-percent annual source decay predicts sharp drops in downgradient BTEX concentrations as a result of the rapid reduction in source concentrations. Model outputs, including graphs of concentration versus time and distance are provided in Appendix C.

5.4.4 Model-Decay 10%

Model-Decay 10% was designed using observed 1993 BTEX concentrations and calibrating the input parameters to achieve 1995 concentrations. The model uses an assumed initial background BTEX concentration of 16 $\mu\text{g/L}$ and the 1993 observed BTEX source area concentration of 2,690 $\mu\text{g/L}$. Using a lower solute decay rate of 0.0013 day⁻¹ and a 10-percent annual source decay rate, the model was able to calibrate 3 of the 4 observed 1995 concentrations along the groundwater flow path. At the point where the modeled concentration could not be calibrated to observed concentration, the

modeled concentration was higher than the measured concentration. This results in a conservative model because the total mass of BTEX in the aquifer accounted for in the model is higher than estimated from observed total BTEX concentrations. In addition, the solute decay rate of 0.0013 day^{-1} is considered conservative because it is derived from the assumption that oxygen is not present in the aquifer (Section 5.3.3.1). While this assumption may be legitimate for the source area of the plume, DO is present at the leading edge of the plume, and oxygen influx is possible via rainwater recharge throughout the plume. Typically anaerobic biodegradation rates are lower than aerobic biodegradation rates, and therefore the solute decay coefficient would be expected to increase downgradient as the aquifer becomes more aerobic. Another conservative estimate of the model is that it does not simulate the effect of the newly installed bioventing system on the source decay rate; however, this may be partially offset by the 10-percent annual source decay rate that may be somewhat high in the absence of active remediation (i.e., bioventing).

As a result of the low solute decay rate, this model presents a "worst-case" scenario for downgradient BTEX migration. Continued modeling suggests that the $5\text{-}\mu\text{g/L}$ isocontour will advance to approximately 950 feet downgradient from the source area. The plume is predicted to continue advancing for 10 additional years (until 2005), and then begin to recede. In 55 years, the model suggests that the $5\text{-}\mu\text{g/L}$ total BTEX isocontour will have withdrawn to the Base boundary. If the solute decay rate is increased by a factor of 2, the $5\text{-}\mu\text{g/L}$ extent of the plume would withdraw to the Base boundary after approximately 45 years. Increasing the solute decay rate by a factor of two could help account for aerobic biodegradation that likely is occurring along the plume fringe.

The model predicts that source area concentrations will decrease from $1,700 \mu\text{g/L}$ in 1995, to $700 \mu\text{g/L}$ in 2005, to $12 \mu\text{g/L}$ in 2045. The maximum total BTEX concentration at monitoring well TF-8 is predicted to occur in year 2000 at just over $150 \mu\text{g/L}$. Again, the reason this model predicts higher downgradient BTEX concentrations is due to the use of an anaerobic decay rate for the entire length of the plume. Without changing the solute decay constant, the model suggests that the maximum total BTEX concentration at the Base boundary will reach almost $800 \mu\text{g/L}$ at the turn of the century. If the solute decay constant is increased by a factor of two, to account for some aerobic decay, the maximum predicted BTEX concentration at the Base boundary does not exceed $430 \mu\text{g/L}$, similar to Model-Decay 8%.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. The sensitivity analysis for this model was conducted on individual runs of Model-Decay 1% by varying hydraulic conductivity (± 5 times), the organic carbon content (± 10 times), effective porosity ($\pm 50\%$), and dispersivity (± 2 times). The effects of variation on the solute decay rate and the annual rate of source decay are examined as a part of the model discussion (Section 5.4). To perform the sensitivity analyses, Model-Decay 1% was run with the same input as the calibrated model excluding the tested parameter. The models were run for a 10-year period so the effects could be seen when plume expansion was at a maximum. Model output data from the sensitivity analysis are presented in Appendix C.

The results of the sensitivity analysis suggest that the calibrated model is most sensitive to hydraulic conductivity, effective porosity, and longitudinal dispersivity. Increasing hydraulic conductivity and dispersivity increases the distance of plume migration, while decreasing these variables decreases the distance of plume migration. Conversely, increasing the effective porosity decreases the distance of plume migration. The increase in the organic carbon content had only a minor effect on the modeled BTEX plume. However, a factor of 10 increase in site TOC levels is not significant because of the very low TOC concentrations present. The hydraulic conductivity, dispersivity, and effective porosity values used in the models are valid because they are similar to documented accepted values. The sensitivity results suggest the values used in the model are appropriate because they quantify the uncertainty in the calibrated models caused by uncertainty in the estimates of aquifer parameters.

5.6 CONCLUSIONS AND DISCUSSION

The three calibrated models were used to predict the fate and transport of the dissolved BTEX plume with and without source remediation through bioventing. Model-Decay 1% was calibrated using observed BTEX concentrations in 1989 and then used to simulate the effects of bioventing by increasing the annual source decay to rates of 5 and 50 percent per year. Model-Decay 8% and Model-Decay 10% assumed that the conditions that produced the calibrated model would remain constant for the full duration of the simulation. Model-Decay 8%, assumed that free product BTEX levels were present in 1965 and degraded to 1995 observed levels. This model also was run with a 50 percent annual source decay rate to simulate bioventing; however, results were virtually identical to the results of Model-Decay 1% under the same scenario. Model-Decay 10% was calibrated based on 1993 and 1995 concentrations and conservatively uses a solute decay rate that assumes the absence of any aerobic biodegradation. Consequently, this model provides a "worst-case" scenario for plume migration distances.

The results of analytical model scenarios for FT-03 at Westover ARB suggest that the dissolved BTEX plume front is not likely to migrate more than 1,000 feet downgradient from the source area, and at the current distance of approximately 500 feet downgradient from the source area, the plume may already have reached its maximum downgradient extent. An estimated maximum travel distance of 1,000 feet would place the leading edge of the plume within the state park, and would cover only half of the distance to the Chicopee Reservoir. Therefore, the models suggest that it is extremely unlikely that the plume will impact either the Chicopee Reservoir or any groundwater pumping wells beyond the state park.

The three models predict that the 5- $\mu\text{g}/\text{L}$ total BTEX isocontour will recede to the Base boundary within 55 to 80 years without the assistance of engineered remediation systems. With the implementation of source reduction via bioventing, the models predict that the 5- $\mu\text{g}/\text{L}$ total BTEX isocontour may return to the Base boundary within 8 years.

The removal of BTEX compounds predicted by the simulations is largely a function of aerobic and anaerobic biodegradation. In all cases, model simulations are conservative for several reasons, including those listed below:

- The stoichiometry used to determine the ratio between DO and total BTEX assumed that no microbial cell mass was produced during the reaction. As discussed in Section 4.3.2.1, this approach may be too conservative by a factor of three.
- As a result of low TOC concentrations in the aquifer matrix, the coefficient of retardation was calculated to be 1, with the result that contaminants were modeled to migrate at the advective groundwater velocity. Consequently, this provides a worst-case scenario for estimated distances of contaminant migration from the source area.
- The solute decay constants (0.0013 and 0.0034 day⁻¹) covering both aerobic and anaerobic processes are conservative when compared to literature values of 0.001 to 0.185 day⁻¹ (see Section 5.3.5.3) for anaerobic decay alone. The use of a low solute decay constant increases the length time required for natural attenuation processes to completely attenuate the BTEX contamination. Consequently, the dissolved BTEX contamination is capable of migrating greater distances downgradient before destruction.
- The models assume a uniform contaminant concentration over the entire aquifer thickness; however, observed concentrations were collected from near the water table where the highest BTEX concentrations in an aquifer frequently are found. Therefore, the modeled contaminant mass may be considerably higher than the actual dissolved contaminant mass at the site. Consequently, the time required for natural attenuation processes to degrade the contamination is increased.
- All three models have been calibrated such that whenever the calibrated concentrations do not match observed calibrations at a given location, the calibrated concentration is higher. This results in a greater modeled mass than estimated from observations. Consequently, the time required for natural attenuation processes to degrade the contamination is increased.

The ranges for degradation and stabilization of the BTEX plumes observed in the three model simulations (and variations) are feasible, given the observed BTEX concentrations, the conservative assumptions made in constructing the simulation, and the strong geochemical evidence of aerobic and anaerobic biodegradation. All of the models were calibrated to known endpoints in a continuum of known past contaminant levels.

With a full-scale bioventing system in operation at the site, source reduction is occurring. Consequently, the variations of Model-Decay 1% incorporating 5- and 50-percent rates of annual source reduction after May 1995 are most appropriate for comparison to concentrations observed during the July 1996 sampling event. The 50-percent annual source reduction scenario is the more optimistic of the two bioventing scenarios, predicting that the dissolved BTEX plume, as defined by the 5- $\mu\text{g/L}$ isopleth, will retreat to the Base boundary within 8 years. The July 1996 results suggest that the plume actually returned to the Base boundary in less than 14 months following the start-up of the bioventing system. The observed concentration of approximately 470 $\mu\text{g/L}$ of total dissolved BTEX in the source area was predicted to occur at approximately 21 months by the 50-percent annual source reduction scenario

of Model-Decay 1%. Additional long-term monitoring should be performed to confirm the continuation of the trends observed between May 1995 and July 1996.

The magnitude of plume contraction observed over 14 months suggests that both the amount of contaminant mass entering the system and the biodegradation rate may be higher than incorporated into the 50-percent annual source reduction scenario of Model-Decay 1%. To simulate the reduction in plume extent and concentration using Model-Decay 1% would require the use of an annual source reduction of approximately 25 percent and a biodegradation rate that is approximately 5 times as large as the rate estimated by the steady-state method of Buscheck and Alcantar (1995). The 25 percent source reduction rate falls in the 5 to 50 percent range evaluated for bioventing impact on groundwater; however, the biodegradation rate is higher than estimated from observed data in 1995. A biodegradation rate this high may be appropriate because the steady-state plume method predicts overly conservative rates if the plume is actually shrinking. Furthermore, the rate lies within the range of literature values discussed in Section 5.3.3.3. The shrinking plume method (Buscheck and Alcantar, 1995) predicts a total attenuation rate between 1995 and 1996 at the plume's leading edge of more than twice the calibrated degradation rate. This total plume attenuation at a point will be lower than the solute degradation rate because source influx is a component only of the total plume attenuation rate.

SECTION 6

EVALUATION OF THE REMEDIATION ALTERNATIVE

The intent of this treatability study is to determine if intrinsic remediation of groundwater is an appropriate remedial technology to consider when developing final remedial strategies for the Christmas Tree Fire Training Area at Westover ARB. The intrinsic remediation alternative consists of three components:

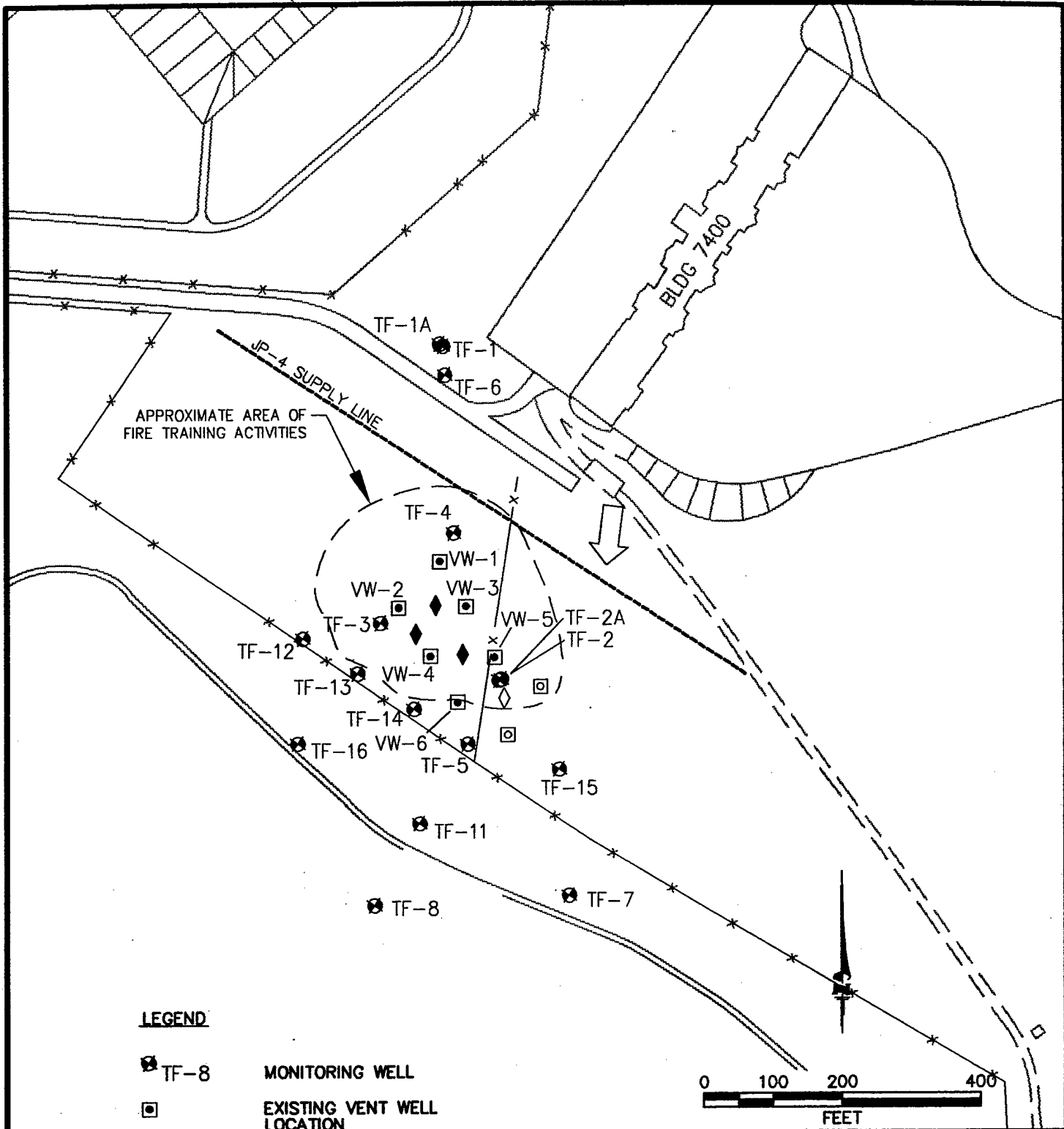
- Processes of natural attenuation to remediate the groundwater contamination and attain remedial goals;
- Institutional controls to prevent exposure to contaminated groundwater; and
- LTM to assess site conditions over time, confirm the effectiveness of natural attenuation processes at reducing contaminant mass, monitor compliance with regulatory requirements, and evaluate the need for additional remediation.

Remedial alternatives are assessed on the basis of long-term effectiveness, implementability, and cost. By definition, natural attenuation is the least expensive remedial option. The only costs associated with the intrinsic remediation alternative arise from LTM and institutional controls. Both are inexpensive and necessary components of most remedial alternatives. The occurrence of natural attenuation processes to remediate groundwater at FT-03 is demonstrated in Section 4. In Section 5, conservative models suggest that these processes, in conjunction with ongoing bioventing of source area soils, are sufficient to limit contaminant migration and protect downgradient receptors. The remainder of this section is devoted to evaluation of the future effectiveness of the intrinsic remediation alternative through attainment of remedial goals as measured in a long-term groundwater monitoring program.

6.1 REMEDIAL SYSTEM FOR SOILS

To promote aerobic degradation of fuel hydrocarbon contamination in shallow soils, a full-scale bioventing system was installed at the Christmas Tree Fire Training Area in May 1995. Location of site vent wells and soil gas monitoring points are presented on Figure 6.1. Figure 6.1 also includes the proposed new locations for vent wells VW-1 and VW-2 which will expand the bioventing area of influence on the east side of the dissolved BTEX plume.

Bioventing operations at the Christmas Tree Fire Training Area, have not only increased aerobic biodegradation processes in the soil, but also have substantially



LEGEND

- TF-8 MONITORING WELL
- EXISTING VENT WELL LOCATION
- EXISTING MONITORING POINT LOCATION
- PROPOSED RELOCATION OF VENT WELLS VW-1 & VW-2
- PROPOSED NEW MONITORING POINT LOCATION
- *-*- FENCE
- GROUNDWATER FLOW DIRECTION



FIGURE 6.1

BIOVENTING LAYOUT

Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

reduced the amount of contaminant mass available to desorb from contaminated soils into groundwater. In addition, outside the source area and where little to no smear zone is present, the addition of oxygen to the soil may be promoting oxygen diffusion into the groundwater, effectively changing the natural attenuation processes from anaerobic to aerobic. Aerobic biodegradation of hydrocarbons is faster than all anaerobic natural attenuation processes. The increase in degradation rate resulting from a change from anaerobic to aerobic degradation mechanisms can easily explain the sudden, rapid decrease in dissolved BTEX contamination over one year. Since May 1995, bioventing operations have helped to decrease the size of the dissolved BTEX plume from 5.7 acres to 2/3 of an acre and have contributed to a 97-percent reduction in total dissolved BTEX mass throughout the plume (Figure 4.2).

The effect of bioventing on the dissolved concentrations of chlorinated solvents in groundwater is unclear. The two most likely reactions are both indirect and opposite in effect; therefore, the net effect is difficult to predict. The destruction of fuel hydrocarbons in source soils will result in a decrease in the mass of fuel hydrocarbons dissolving into the groundwater. Ultimately, this may lead to an insufficient supply of electron donors in the groundwater to continue to support the highly reducing conditions required for reductive dechlorination. On the positive side, bioventing also may result in the reduction of chlorinated solvent concentrations in source soils. In this case the chlorinated solvents may be destroyed through cometabolic processes, but more likely the chlorinated solvents would be stripped from source area soils by the movement of soil gas induced by the bioventing system. The elimination of chlorinated solvents from source area soils would result in a decrease in the mass of chlorinated solvents dissolving into the groundwater.

Operation of the bioventing system is unlikely to have a significant impact on dissolved oxygen concentrations within the area where reductive dechlorination is currently occurring. Outside the source area and where little to no smear zone is present, bioventing may promote oxygen diffusion into the groundwater; however, these areas are beyond the zone where reductive dechlorination appears to occur. Dissolved oxygen downgradient from the zone of reductive dechlorination can be positive because of the resulting aerobic degradation of the less chlorinated solvents (i.e., dichloroethenes and vinyl chloride). In the source area or where a significant smear zone is present, any oxygen diffusing into the groundwater would be utilized by fuel hydrocarbon degradation within inches of the groundwater surface.

6.2 REMEDIAL GOALS FOR GROUNDWATER

The intrinsic remediation strategy assumes that compliance with promulgated, single-point remediation goals is not necessary if site-related contamination does not pose a threat to human health or the environment (i.e., the exposure pathway is incomplete). Therefore, a POC for remedial goals is chosen at a location between the contaminant source and potential receptor exposure points. Results of the conservative analytical models suggest that BTEX concentrations in excess of 5 µg/L are not likely to migrate more than 475 to 950 feet downgradient from the source area. Therefore, an area approximately 1,000 feet downgradient from monitoring well TF-2A, has been identified as the POC for groundwater remedial activities because this appears to be beyond the maximum extent of future contaminant migration. This is a suitable location for monitoring and for demonstrating compliance with protective groundwater

quality standards, such as promulgated groundwater maximum contaminant levels (MCLs). There are no known potable water wells located within at least 1 mile downgradient from site FT-03. The POC location is approximately 1,000 feet upgradient from Chicopee Reservoir. Given an estimated advective groundwater velocity of 66 ft/yr and a retardation coefficient of 1, the travel time from the POC to Chicopee Reservoir is approximately 15 years.

Available data suggest that exposure pathways involving shallow groundwater do not exist under current conditions; however, a pathway could be completed in the future if shallow groundwater within approximately 1,000 feet downgradient of monitoring well TF-2A is used as a potable or industrial water supply. Because promulgated, single-point remediation goals are not in effect in the area of intrinsic remediation, institutional controls must be placed on groundwater use within the remediation zone to prevent completion of potential future pathways. The institutional controls must remain in effect until it can be demonstrated that the potential for pathway completion no longer exists. By this mechanism, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted use.

The primary remedial objective for shallow groundwater within and downgradient from FT-03 is limiting plume expansion to prevent exposure of downgradient receptors to concentrations of BTEX or chlorinated solvents in groundwater at levels that exceed regulatory standards. The remedial objective for shallow groundwater at the POC is attainment of State of Massachusetts groundwater standards and federal MCLs listed in Table 6.1 for each of the BTEX and detected chlorinated solvent compounds. Although it is unlikely that groundwater would be ingested by humans, this level of long-term protection is appropriate. Because the depths to the water table are greater than 40 feet bgs, there are no completed pathways to ecological receptors (e.g., plants with root systems extending to the water table).

**TABLE 6.1
POINT-OF-COMPLIANCE REMEDIATION GOALS**

**Christmas Tree Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts**

Compound	Massachusetts Groundwater Standard ($\mu\text{g/L}$)	Federal MCL ($\mu\text{g/L}$)
Benzene	5	5
Toluene	1,000	1,000
Ethylbenzene	700	700
Total Xylenes	10,000	10,000
TCE	5	5
PCE	200	200
cis-1,2-DCE	70	70
trans-1,2-DCE	100	100
Vinyl Chloride	2	2

6.3 LONG-TERM GROUNDWATER MONITORING

As part of the intrinsic remediation alternative for FT-03, a long-term groundwater monitoring plan will be developed on the basis of 1995 groundwater sampling results and the analytical models. This LTM plan identifies the location of two separate groundwater monitoring networks and develops a groundwater sampling and analysis strategy to demonstrate the effectiveness of intrinsic remediation. The strategy described in this section is designed to monitor plume migration over time and to verify that intrinsic remediation is occurring at rates sufficient to protect potential receptors. Prior to implementation of the plan, any interim groundwater results should be evaluated to refine the placement of any additional groundwater monitoring wells, if needed. In the event that data collected under the LTM program indicate that natural processes are insufficient to protect human health and the environment, contingency controls to augment the beneficial effects of intrinsic remediation would be necessary.

Two separate sets of wells will be utilized at the site as part of the intrinsic remediation with LTM remedial alternative. The first set will consist of five LTM wells located in, upgradient, and downgradient from the observed contaminant plume to verify model predictions that natural attenuation is occurring at rates sufficient to minimize plume expansion and reduce BTEX concentrations. This network of wells will consist of five monitoring wells screened within the shallow aquifer to provide short-term confirmation of the effectiveness of intrinsic remediation. An optional sentry well is also proposed in the LTM monitoring network. The second set of wells will consist of three shallow POC wells located along a line perpendicular to the general direction of groundwater flow, approximately 1,000 feet south-southwest of monitoring well TF-2A. The purpose of the POC wells is to verify that no BTEX and chlorinated solvent concentrations exceeding state groundwater criteria migrate beyond the area under institutional control. Available data indicate that groundwater VOC concentrations are below current state and federal groundwater BTEX standards except in the vicinity of monitoring well TF-2A. Therefore, future contaminant concentrations are expected to remain below state and federal standards, as the models predict decreases in future contaminant concentrations. Furthermore, source reduction by the operational bioventing system should help reduce future contaminant concentrations in groundwater. The LTM and POC wells will be sampled and analyzed of the parameters listed in Tables 6.2 and 6.3, respectively.

6.3.1 Long-Term Monitoring Wells

At five locations, groundwater wells within, upgradient, and downgradient from the current BTEX and chlorinated solvent plume will be used to monitor the effectiveness of intrinsic remediation in reducing total contaminant mass and minimizing contaminant migration at FT-03. Groundwater conditions upgradient from the plume will be monitored at well TF-1A. Wells TF-2A and TF-5 will be used to monitor conditions in the source area and within the anaerobic treatment zone. Well TF-8 is proposed for monitoring the aerobic treatment zone near the downgradient plume boundary. A new monitoring well is proposed to monitor immediately downgradient from the plume. This well will be screened across the water table in order to intercept the hydrogeologic unit that contains the contaminant plume. Figure 6.2 identifies the proposed locations of the wells to be used for LTM. This network will supplement the POC wells to

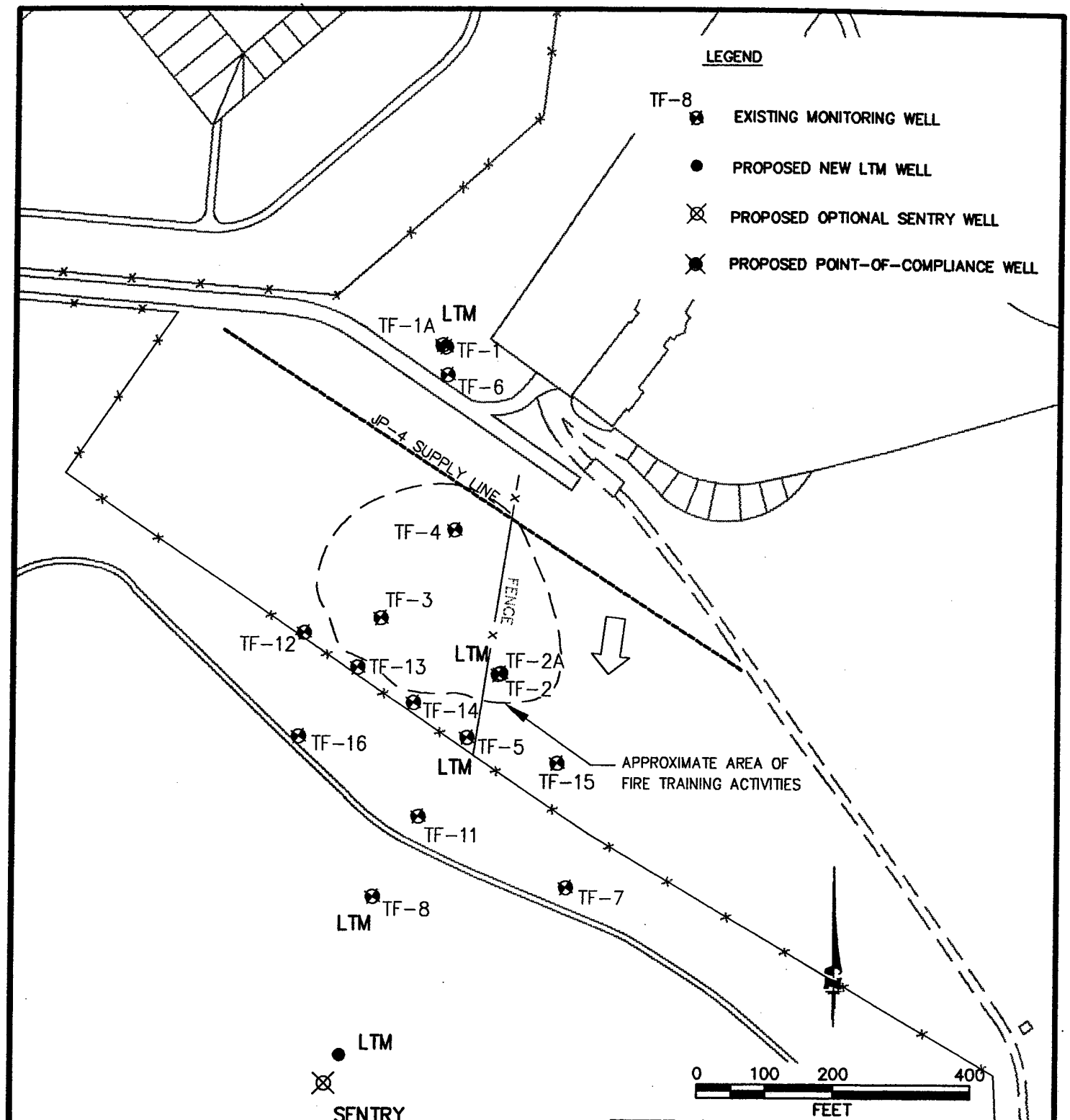


FIGURE 6.2

PROPOSED LOCATIONS OF LONG-TERM MONITORING AND POINT-OF-COMPLIANCE WELLS

Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

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**TABLE 6.2
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL**

Christmas Tree Fire Training Area

Intrinsic Remediation TS

Westover ARB, Massachusetts

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe ²⁺)	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Every Year for 10 years	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous Iron (Fe ²⁺)	Colorimetric HACH 25140-25	Alternate method; field only	Same as above.	Every Year for 10 Years	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Every Year for 10 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is an indicator of biodegradation conditions; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Every Year for 10 Years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^{a/}	Aerobic and anaerobic processes are pH-sensitive	Every Year for 10 Years	Collect 100-250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Every Year for 10 Years	Collect 100-250 mL of water in a glass or plastic container	Field
Nitrate (NO ₃ ⁻¹)	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Every Year for 10 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base

TABLE 6.2 (Concluded)
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
 Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO ₄ ²⁻)	IC method E300 or method SW9056 or HACH SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. HACH method is Photometric	Substrate for anaerobic microbial respiration	Every Year for 10 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for HACH method)
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Every Year for 10 Years	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Methane, Ethane, and Ethene	RKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis).	Every Year for 10 Years	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020.	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Every Year for 10 Years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base
Volatile Organics	GS/MS method 8240	Handbook method	Measured for regulator compliance	Every Year for 10 years	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	

a/ Protocol methods are presented by Wiedemeier *et al.* (1995).

TABLE 6.3
POINT-OF-COMPLIANCE GROUNDWATER MONITORING ANALYTICAL PROTOCOL
 Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Well development	Every Year for 10 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is an indicator of biodegradation conditions; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Every Year for 10 Years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^{a/}	Aerobic and anaerobic processes are pH-sensitive	Every Year for 10 Years	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Every Year for 10 Years	Collect 100–250 mL of water in a glass or plastic container	Field
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Every Year for 10 Years	Collect 100–250 mL of water in a glass container, filling container from bottom, analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX are the primary target analytes for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Every Year for 10 Years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH \leq	Fixed-base

TABLE 6.3 (Concluded)
POINT-OF-COMPLIANCE MONITORING ANALYTICAL PROTOCOL
 Christmas Tree Fire Training Area
 Intrinsic Remediation TS
 Westover ARB, Massachusetts

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Volatile Organics	GC method SW8010 or GC/MS method SW 8240	Handbook method	Measured for regulatory compliance	Every Year for 10 years	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	

^a Protocol methods are presented by Wiedemeier *et al.* (1995).

provide evidence of continuing intrinsic remediation and to allow additional response time if site conditions deteriorate.

6.3.2 Point-of-Compliance Wells

Three POC monitoring wells are proposed for installation approximately 1,000 feet south-southwest from monitoring well TF-2A on state park property. Figure 6.2 shows the proposed locations of the POC wells. The purpose of the POC wells is to verify that no contaminated groundwater exceeding regulatory criteria migrates beyond these locations. Although available evidence strongly suggests that the contaminant plume will not migrate beyond this area at concentrations exceeding chemical-specific federal MCLs or state groundwater standards, these POC wells are the technical mechanisms used to demonstrate protection of human health and the environment and compliance with regulatory criteria. These wells will be installed and monitored for the parameters listed in Table 6.3 to assure that intrinsic remediation is providing the anticipated level of risk reduction and remediation at the site.

As with the LTM wells, the POC wells will be screened in the same hydrogeologic unit as the contaminant plume. Data presented in this report concerning the nature and extent of contamination at the site suggest that a 10-foot screen with approximately 8 feet of screen below the groundwater surface will be sufficient to intercept the contaminant plume at this site.

6.3.3 Sentry Well

An optional sentry well is proposed for installation adjacent to the furthest downgradient LTM well, located approximately 600 feet south of well TF-2A. Figure 6.1 shows the proposed location of the sentry well. The purpose of the sentry well is to verify that contaminated groundwater is not migrating vertically as it travels downgradient from the source. This well would be monitored for the parameters listed in Table 6.3.

Unlike the LTM and POC wells, the sentry well will not be screened in the same portion of the hydrogeologic unit as the contaminant plume. Data presented in this report suggest BTEX contamination not related to FT-03 is present in the deeper zones of the shallow aquifer. Therefore, the optional sentry well would have a 10-foot screen placed approximately 30 to 40 feet below the water table.

6.4 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at FT-03 to meet site-specific remediation goals, the long-term groundwater monitoring plan includes a comprehensive sampling and analysis plan. Groundwater samples will be collected annually from LTM wells to verify that naturally occurring processes are effectively reducing the mass and mobility of BTEX and chlorinated solvent contamination. The sampling and analysis plan also is aimed at confirming that intrinsic remediation can achieve site-specific remediation concentration goals for BTEX and chlorinated solvent compounds that are protective of human health and the environment. In the May 1995 sampling event, concentrations equaled or exceeded regulatory criteria at only four locations: benzene above 5 µg/L was measured at TF-1, TF-2, and TF-2A; and TCE

was measured at 7.5 µg/L from TF-14. In the July 1996 sampling event, contaminant levels suggested regulatory standards had been achieved.

6.4.1 Sampling Frequency

Each of the LTM and POC wells should initially be sampled annually for 10 years. If the data collected during this time period support the anticipated effectiveness of the intrinsic remediation alternative at this site, the sampling frequency could be reduced, or sampling could be eliminated. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, the sampling frequency should be adjusted accordingly. Likewise, if the data indicate that the dissolved plume has been remediated to below 5 µg/L of total BTEX or CAH throughout its entire areal extent, LTM could be discontinued.

6.4.2 Analytical Protocol

All LTM, and POC wells in the LTM program will be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the effectiveness of intrinsic remediation at the site. At the beginning of each annual sampling event, water levels will be measured at all site monitoring wells. Groundwater samples will be analyzed for the parameters listed in Tables 6.2 and 6.3. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating this LTM program.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of intrinsic remediation for remediation of fuel-hydrocarbon-contaminated groundwater in the vicinity of site FT-03 at Westover ARB, Massachusetts. Site-specific geologic, hydrologic, and laboratory analytical data were used to evaluate the occurrence and rates of natural attenuation of BTEX compounds dissolved in groundwater. To perform the intrinsic remediation demonstration, Parsons ES researchers collected and analyzed groundwater samples from the site and utilized data collected during previous site characterization events.

Two lines of evidence were used to document the occurrence of intrinsic remediation at FT-03: The documented loss of contaminant mass at the field scale and geochemical evidence. A review of groundwater sampling data obtained from 1989 through 1996 indicates that the dissolved BTEX concentrations have significantly decreased. Furthermore, rates of biodegradation were estimated from flow path analyses using conservative tracers and the methods of Buscheck and Alcantar (1995). Comparison of BTEX, chlorinated solvent, electron acceptor, and biodegradation byproduct isopleth maps for both May 1995 and July 1996 sampling events at FT-03 (Section 4) provides strong qualitative geochemical evidence of biodegradation of both BTEX and chlorinated solvent compounds. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via aerobic respiration and the anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. In addition, the ratio of TCE to the daughter product cis-1,2-DCE suggests that chlorinated solvents in the groundwater are being degraded through reductive dechlorination. Furthermore, the significant decrease in both dissolved fuel hydrocarbon and chlorinated solvent concentrations suggest that bioventing operations at FT-03 have had only a positive effect on groundwater remediation. Since May 1995, bioventing operations, in conjunction with natural attenuation processes, have helped to decrease the size of the dissolved BTEX plume from 5.7 acres to 2/3 of an acre and to reduce the concentration of BTEX compounds in the groundwater throughout the site an average of 97 percent.

Site-specific geologic, hydrologic, and laboratory analytical data (collected in May 1995) were used in three conservative analytical models to simulate the effects of dispersion and biodegradation on the fate and transport of the dissolved BTEX plume. Historical and current site-specific data were used for model calibration and implementation. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for soils similar to those found at the site. Conservative aquifer parameters were used to construct the analytical models

for this study, and therefore, the model results presented herein represent worst-case scenarios given the other modeling assumptions regarding source removal.

Two of the analytical models suggested a continued expansion of the BTEX plume over the next 10 years. However, throughout all three of the model simulations, source area concentrations continued to decrease. At year 50, all of the models suggested significant decreases in the source concentration and plume extent. The models assumed different source and solute decay rates to model the long-term effects of bioventing and changes in the groundwater geochemistry. Implementation of bioventing soil remediation systems have been accompanied by source decay rates averaging over 90 percent per year in vadose zone soils at other Air Force sites. The analytical models suggested a significant decrease in dissolved BTEX concentrations and a rapid retreat of the BTEX plume when source decay rates were modeled at 50 percent per year. July 1996 sampling results support the analytical model prediction of significant reduction in dissolved BTEX concentrations with the implementation of bioventing at FT-03 (Section 4).

The results of this study suggest that natural attenuation of BTEX and chlorinated solvent compounds is occurring at FT-03. In May 1995, with the exception of monitoring well TF-2A, dissolved groundwater BTEX concentrations were below the state and federal regulatory guidelines. TCE was detected at a concentration above the federal groundwater standard at monitoring well TF-14. However, the remaining chlorinated solvents at the site are currently below regulatory guidelines, or have not been detected. In July 1996, all detected BTEX and chlorinated solvent concentrations were below both the state and federal regulatory guidelines. The estimated rates of biodegradation, when coupled with sorption, dispersion, and dilution, should be sufficient to maintain dissolved BTEX and chlorinated solvent concentrations at levels below current regulatory guidelines. Given the observed retreat of the dissolved BTEX and chlorinated solvent plumes, intrinsic remediation and LTM is a viable remedial option for BTEX-impacted groundwater at the site.

To continue to verify the results of the analytical modeling effort, and to ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, a LTM plan was developed on the basis of the 1995 groundwater results and analytical models. The plan includes sampling and analyzing groundwater from five LTM wells for the parameters listed in Table 6.2. In addition, the plan recommends that three POC groundwater monitoring wells be installed downgradient from the predicted maximum travel distance of the BTEX plume and sampled for the parameters listed in Table 6.3. An optional sentry well could be installed in a cluster with the farthest downgradient LTM well and sampled as a POC well. Figure 6.2 shows suggested locations for the POC, LTM, and sentry monitoring wells. Annual monitoring was recommended for a duration of 10 years. At that time, sampling could cease, decrease in frequency, or continue annually as dictated by the analytical results. On the basis of 1996 groundwater sampling results, it may be possible to reduce the number of wells included in the LTM plan as well as the duration of annual monitoring. If dissolved BTEX or chlorinated solvent concentrations in groundwater collected from the sentry or POC wells exceed regulatory criteria, additional evaluation or corrective action may be necessary at this site.

SECTION 8

REFERENCES

- Air Force Center for Environmental Excellence (AFCEE), 1994, Bioventing Performance and Cost Summary. Brooks Air Force Base, p. 8.
- Altenschmidt, U. and Fuchs, G., 1991, Anaerobic degradation of toluene in denitrifying *Pseudomonas* sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: Arch. Microbiol., vol. 156, p. 152-158.
- Alvarez, P.J.J., and Vogel, T.M., 1991, Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: Applied Environmental Microbiology, vol. 57, p. 2981-2985.
- Alvarez-Cohen, L.M. and McCarty, P.L., 1991a, Effects of toxicity, aeration, and reductant supply on trichloroethylene transformation by a mixed methanotrophic culture: Appl. Environ. Microbiol., vol. 57, no. 1, p. 228-235.
- Alvarez-Cohen, L.M., and McCarty, P.L., 1991b, Product toxicity and cometabolic competitive inhibition modeling of chloroform and trichloroethylene transformation by methanotrophic resting cells: Appl. Environ. Microbiol., vol. 57, no. 4, p. 1031-1037.
- Arciero, D., Vannelli, T., Logan, M., and Hooper, A.B., 1989, Degradation of trichloroethylene by the ammonia-oxidizing bacterium *Nitrosomonas europaea*: Biochem. Biophys. Res. Commun., vol. 159, p. 640-643.
- Arthur D. Little, Inc. 1987. The Installation Restoration Program Toxicology Guide, Volume 3. Prepared for Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, June.
- Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons - an environmental perspective: Microbiological Reviews, vol. 45, no. 1, p. 180-209.
- Atlas, R.M., 1984, Petroleum Microbiology: Macmillan Publishing Company, New York.
- Atlas, R.M., 1988, Microbiology - Fundamentals and Applications: Macmillan Publishing Company, New York.

- Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M., 1988, The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species and geochemical facies, In: G.E. Mallard, and S.E. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.
- Baedecker, M.J., and Cozzarelli, I.M., 1991, Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.
- Ball, H.A., Reinhard, M., and McCarty, P.L., 1991, Biotransformation of monoaromatic hydrocarbons under anoxic conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 458-463.
- Barker, J.F., Patrick, G.C., and Major, D., 1987, Natural attenuation of aromatic hydrocarbons in a shallow sand aquifer: Ground Water Monitoring Review, Winter, 1987, p. 64-71.
- Bartha, R., 1986, Biotechnology of petroleum pollutant biodegradation: Microbial Ecology, vol. 12, p. 155-172.
- Bauman, B., 1991, Biodegradation research of the American Petroleum Institute. Presented at: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. San Diego, CA. March 19-21, 1991.
- Bear, J., 1979, Hydraulics of Groundwater. McGraw-Hill, Inc., New York, New York, 569p.
- Beller, H.R. Reinhard, M., and Grbic-Galic, D., 1992, Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: Appl. Environ. Microbiol., vol. 58, p. 3192-3195.
- Borden, R.C., 1991, Simulation of enhanced in situ bioreclamation of petroleum hydrocarbons. In: In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 529-534.
- Borden, R.C., and Bedient, P.B., 1986, Transport of dissolved hydrocarbons influenced by oxygen limited biodegradation - theoretical development: Water Resources Research, vol. 22, no. 13, p. 1973-1982.
- Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants, In: Mitchell, R., ed.: Environmental Microbiology. Wiley-Liss, New York, New York.
- Bouwer, E.J., 1994, Bioremediation of chlorinated solvents using alternate electron acceptors: In: Handbook of Bioremediation. Lewis Publishers. Boca Raton, FL. 1994.

- Bouwer, E.J., Rittman, B.E., and McCarty, P.L., 1981, Anaerobic degradation of halogenated 1- and 2-carbon organic compounds: *Environ. Sci. Technol.*, vol. 15, no. 5, p. 596-599.
- Bouwer, E.J. and Wright, J.P., 1988, Transformations of trace halogenated aliphatics in anoxic biofilm columns: *J. Contam. Hydrol.*, vol. 2, p. 155-169.
- Bouwer, H., 1989, The Bouwer and Rice slug test - an update: *Ground Water*, 27(3), p. 304-309.
- Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: *Water Resources Research*, 12(3), p. 423-428.
- Bradley, P.M., and Chapelle, F.H., 1996, Anaerobic mineralization of vinyl chloride in Fe(III)-reducing aquifer sediments: *Environmental Science and Technology*, v. 40, p. 2084-2086.
- Brown, R.A., Dey, J.C. and McFarland, W.E., 1991, Integrated site remediation combining groundwater treatment, soil vapor extraction, and bioremediation, In: *In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation*. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 444-449.
- Buscheck, T. E., O'Reilly, K. T., and Nelson, S. N., 1993, Evaluation of INtrinsic Bioremediation at Field Sites: *Proceedings, Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration*, pp. 367-381. National Ground Water Association/API, Houston, TX.
- Buscheck, T. E., and Alcantar, C. M., 1995, Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation. In: *Proceedings of the 1995 Battelle International Symposium on In Situ and On-Site Bioreclamation*, April 1995.
- CH2M Hill, 1982, U.S. Air Force Installation Restoration Program Records Search for Westover Air Force Base, April 1982.
- Chapelle, F.H., 1993, *Ground-water Microbiology and Geochemistry*. John Wiley and Sons, Inc., New York, NY.
- Chapelle, F.H., 1994, Assessing the Efficiency of Intrinsic Bioremediation, *in Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water*, August 30 - September 1, 1994: US Environmental Protection Agency, p. 171.
- Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L., 1989, Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: *Ground Water*, vol. 27, no. 6, p. 823-834.
- Cline, P.V., and Delfino, J.J., 1989, Transformation kinetics of 1,1,1-trichloroethane to the stable product 1,1-dichloroethene, In: *Biohazards of Drinking Water Treatment*. Lewis Publishers, Inc. Chelsea, MI. p. 47-56.

- Cozzarelli, I.M., Eganhouse, R.P., and Baedecker, M.J., 1990, Transformation of monoaromatic hydrocarbons to organic acids in anoxic ground water environment: *Environmental and Geological Water Science*, vol. 16.
- Cozzarelli, I.M., Baedecker, M.J., Eganhouse, R.P., 1994, The geochemical evolution of low-molecular-weight organic acids derived from the degradation of petroleum contaminants in groundwater: *Geochimica et Cosmochimica Acta*, vol. 58, no. 2, p. 863-877.
- Davis, J.W., and Carpenter, C.L., 1990, Aerobic biodegradation of vinyl chloride in groundwater samples: *Applied and Environmental Microbiology*, v. 56, p. 3878.
- Davis, J.W., Klier, N.J., and Carpenter, 1994, Natural biological attenuation of benzene in ground water beneath a manufacturing facility: *Ground Water*, vol. 32, no. 2, p. 215-226.
- DeBruin, W.P., Kotterman, M.J.J., Posthumus, M.A., Schraa, G., and Zehnder, A.J.B., 1992, Complete biological reductive transformation of tetrachloroethene to ethane: *Applied and Environmental Microbiology*, v. 58, no. 6, p. 1966-2000.
- DeStefano, T.D., Gossett, J.M., and Zinder, S.H., 1991, Reductive dechlorination of high concentrations of tetrachloroethene to ethene by an anaerobic enrichment culture in the absence of methanogenesis: *Appl. Environ. Microbiol.*, vol. 57, no. 8, p. 2287-2292.
- Edwards, E., Wills, L.E., Grbic-Galic, D., and Reinhard, M., 1991, Anaerobic degradation of toluene and xylene--evidence for sulfate as the terminal electron acceptor, In: *In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation*. Eds. R.E. Hinchee and R.F. Olfenbittel. Butterworth-Heinemann. Boston, MA. p. 463-471.
- Edwards, E.A., and Grbic-Galic, D., 1992, Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: *Appl. Environ. Microbiol.*, vol. 58, p. 2663-2666.
- Edwards, E.A., Wells, L.E., Reinhard, M., and Grbic-Galic, D., 1992, Anaerobic degradation of toluene and xylene by aquifer microorganisms under sulfate-reducing conditions: *Appl. Environ. Microbiol.*, vol. 58, p. 794-800.
- Engineering-Science, Inc. (ES), 1986, Installation Restoration Program, Phase II - Technical Operations Plan, September 1986.
- ES, 1988, Installation Restoration Program, Phase II - Confirmation/Quantification Stage 2. Final Report, October 1988.
- ES, 1993, *Health and Safety Plan for the Bioplume Modeling Initiative*. Prepared for the Air Force Center for Environmental Excellence, Environmental Restoration Division, USAF Contract F41624-92-D-8036.
- Evans, P.J., Mang, D.T., and Young, L.Y., 1991a, Degradation of toluene and m-xylene and transformation of o-xylene by denitrifying enrichment cultures: *Appl. Environ. Microbiol.*, vol. 57, p.450-454.

- Evans, P.J., Mang, D.T., Kim, K.S., and Young, L.Y., 1991b, Anaerobic degradation of toluene by a denitrifying bacterium: *Appl. Environ. Microbiol.*, vol. 57, p. 1139-1145.
- Folsom, B.R., Chapman, P.J., and Pritchard, P.H., 1990, Phenol and trichloroethylene degradation by *Pseudomonas cepacia* G4: Kinetics and interactions between substrates: *Appl. Environ. Microbiol.*, vol. 56, no. 5, p. 1279-1285.
- Freedman, D.L., and Gossett, J.M., 1989, Biological reductive dechlorination of tetrachloroethylene and trichloroethylene to ethylene under methanogenic conditions: *Appl. Environ. Microbiol.*, vol. 55, no. 4, p. 1009-1014.
- Gibson, D.T., and Subramanian, V., 1984, Microbial degradation of aromatic hydrocarbons, In: Gibson, D.T., ed: *Microbial Degradation of Organic Compounds*, Marcel Dekker, Inc., p. 181-252.
- Godsey, E.M., 1994, Microbiological and geochemical degradation processes, In: *Symposium on Intrinsic Bioremediation in Ground Water*. Denver, CO. August 30 - September 1, 1994, p.35-40.
- Grbic-Galic, D., 1989, Microbial degradation of homocyclic and heterocyclic aromatic hydrocarbons under conditions: *Dev. Ind. Microbiol.*, vol. 30, p. 237-253.
- Grbic-Galic, D., 1990, Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments, In: Bollag, J.M., and Stotzky, G., eds.: *Soil Biochemistry*: Marcel Dekker, Inc., New York, NY. p. 117-189.
- Haag, F., Reinhard, M., and McCarty, P.L., 1991, Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: *Environ. Toxicol. Chem.*, vol. 10, p. 1379-1389.
- Harker, A.R., and Kim, Y., 1990, Trichloroethylene degradation by two independent aromatic-degrading pathways in *Alcaligenes eutrophus* JMP134: *Appl. Environ. Microbiol.*, vol. 56, no. 4, p. 1179-1181.
- Hartmans, S., and de Bont, J.A.M., 1992, Aerobic vinyl chloride metabolism in *Mycobacterium aurum* Li: *Appl. Environ. Microbiol.*, vol. 58, no. 4, p. 1220-1226.
- Henry, S.M., 1991, Transformation of Trichloroethylene by Methanotrophs from a Groundwater Aquifer. Ph.D. Thesis. Stanford University. Palo Alto, California.
- Henson, J.M., Yates, M.V., and Cochran, J.W., 1989, Metabolism of chlorinated methanes, ethanes, and ethylenes by a mixed bacterial culture growing on methane: *J. Ind. Microbiol.*, vol. 4, p. 29-35.
- Hutchins, S.R., and Wilson, J.T., 1991, Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: *In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation*. Eds. R.E. Hinchey and R.F. Olfenbittel. Butterworth-Heinemann. Boston, MA. p. 157-172.

- Hutchins, S.R., Sewell, G.W., Sewell, D.A., Kovacs, D.A., and Smith, G.A., 1991a, Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate, or nitrous oxide as the terminal electron acceptor: *Environ. Sci. Technol.*, vol. 25, no. 1, p. 68-76.
- Hutchins, S.R., Downs, W.C., Smith, G.B., Smith, J.T., Wilson, D.J., Hendrix, D.J., Fine, D.D., Kovacs, D.A., Douglass, R.H., and Blaha, F.A., 1991b, Nitrate for Bioremediation of an Aquifer Contaminated with Jet Fuel. U.S. Environmental Protection Agency. Robert S. Kerr Environmental Research Laboratory. Ada, Oklahoma. epa/600/2-91/009. April, 1991.
- Jamison, V.W., Raymond, R.L., and Hudson, J.O. Jr., 1975, Biodegradation of high-octane gasoline in ground water: *Developments in Industrial Microbiology*, vol. 16.
- Klier, N.J., West, R.J., and Donberg, P.A., 1996, Aerobic biodegradation of dichloroethylenes in surface and subsurface soils: Accepted for publication in *Chemosphere*.
- Leahy, J.G., and Colewell, R.R., 1990, Microbial degradation of hydrocarbons in the environment: *Microbiological Reviews*, vol. 53, no. 3, p. 305-315.
- Lee, M.D., 1988, Bioremediation of Aquifers Contaminated with Organic Compounds: *CRC Critical Reviews in Environmental Control*. vol. 18. p. 29-89.
- Little, C.D., Palumbo, A.V., Herbes, S.E., Lidstrom, M.E., Tyndall, R.L., and Gilmer, P.J., 1988, Trichloroethylene biodegradation by a methane-oxidizing bacterium: *Appl. Environ. Microbiol.*, vol. 54, no. 4, p. 951-956.
- Lovley, D.R., and Phillips, E.J.P., 1988, Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron or manganese: *Applied and Environmental Microbiology*, v. 54, no. 6, p. 1472 - 1480.
- Lovley, D.R., Phillips, E.J.P., and Lonergan, D.J., 1991, Enzymatic versus nonenzymatic mechanisms for Fe(III) reduction in aquatic sediments: *Environmental Science and Technology*, v. 26, no. 6, p. 1062 - 1067.
- Lovely, D.R., Chappelle, F.H., and Woodward, J.C., 1994, Use of Dissolved H₂ Concentrations to Determine Distribution of Microbially Catalyzed Redox Reactions in Anoxic Groundwater: *Environmental Science and Technology*, v 28, no. 7, p. 1205-1210.
- Malone, D.R., Kao, C.M., and Borden, R.C., 1993, Dissolution and bioremediation of nonaqueous phase hydrocarbons - models development and laboratory evaluation: *Water Resources Research*, vol. 29, no. 7, p. 2003-2213.
- Mayer, K.P., Grbic-Galic, D., Semprini, L., and McCarty, P.L., 1988, Degradation of trichloroethylene by methanotrophic bacteria in a laboratory column of saturated aquifer material: *Wat. Sci. Tech. (Great Britain)*, vol. 20, no. 11/12, p. 175-178.

- McCarty, P.L., 1994, An Overview of Anaerobic Transformation of Chlorinated Solvents: In Symposium on Intrinsic Bioremediation in Ground Water. Denver, CO. August 30 - September 1, 1994, p. 135-142.
- McCarty, P.L., Roberts, P.V., Reinhard, M., and Hopkins, G., 1992, Movement and transformations of halogenated aliphatic compounds in natural systems, In: Fate of Pesticides and Chemicals in the Environment. Ed., J.L. Schnoor. John Wiley & Sons, Inc. New York, New York. p. 191-209.
- McCarty, P.L., and Semprini, L., 1994, Ground-Water Treatment for Chlorinated Solvents, In: Handbook of Bioremediation. Lewis Publishers, Boca Raton, FL. 1994.
- Miller, R.E., and Guengerich, F.P., 1982, Oxidation of trichloroethylene by liver microsomal cytochrome P-450: Evidence for chlorine migration in a transition state not involving trichloroethylene oxide: Biochemistry, vol. 21, p. 1090-1097.
- Morell, F.M.M. and Hering, J.G., 1993, Principals and Applications of Aquatic Chemistry: John Wiley & Sons, Inc., New York.
- Murray, W.D. and Richardson, M., 1993, Progress toward the biological treatment of C₁ and C₂ halogenated hydrocarbons: Critical Reviews in Environmental Science and Technology, v. 23, no. 3, p. 195-217.
- Nelson, M.J.K., Montgomery, S.O., O'Neill, E.J., and Pritchard, P.H., 1986, Aerobic metabolism of trichloroethylene by a bacterial isolate: Appl. Environ. Microbiol., vol. 52, no. 2, p. 949-954.
- Norris, R.D., Hinchee, R.E., Brown, R., McCarty, P.L. Semprini, L., Wilson, J.T., Kampbell, D.H., Reinhard, M., Bouwer, E.J., Borden, R.C., Vogel, T.M., Thomas, J.M., and Ward, C.H., 1994 Handbook of Bioremediation: Lewis Publishers, Inc., 257 p.
- O'Brien and Gere Engineers, Inc. 1993, Installation Restoration Program, Health and Safety Plan; Site FT-03 "Christmas Tree" Fire Training Area, Site FT-08 Current Fire Training Area, SS-19 Aqua Systems Site, SS-16 Hangar Apron Area, April 1993.
- O'Brien and Gere Engineers, Inc. 1994, Installation Restoration Program, Supplemental Remedial Investigation/Feasibility Study; Site FT-03 "Christmas Tree" Fire Training Area, Site FT-08 Current Fire Training Area, September 1994.
- O'Brien and Gere Engineers, Inc. 1995, Summary Report, Groundwater Monitoring Site FT-03 "Christmas Tree" Fire Training Area, February 1995.
- Parsons Engineering Science, Inc., 1995, Work Plan for a Treatability Study in Support of Intrinsic Remediation at The Current Fire Training Area (FT-08) and The Christmas Tree Fire Training Area (FT-03), Westover Air Reserve Base, April.
- Reinhard, M., Goodman, N.L., and Barker, J.F., 1984, Occurrence and distribution of organic chemicals in two landfill leachate plumes: Environ. Sci. Technol., vol. 18, no. 12, p. 953-961.

- Stauffer, T.B., Antworth, T.B., Boggs, J.M., and MacIntyre, W.G., 1994, A Natural Gradient Tracer Experiment in a Heterogeneous Aquifer with Measured In Situ Biodegradation Rates: A Case for Natural Attenuation, *in* Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water, August 30 - September 1, 1994: US Environmental Protection Agency, p. 73 - 84.
- Stumm, W. and Morgan, J.J., 1981, Aquatic Chemistry. John Wiley & Sons, New York, NY.
- Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M., 1992, Natural degradation rates of BTEX compounds and naphthalene in a sulfate-reducing ground water environment, In: In-Situ Bioremediation Symposium "92". Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.
- Thomas, G.M., "Sedimentation in a Proglacial Lake: Glacial Lake Hitchcock", 1987, Rutgers University.
- Tsien, H.-C., Brusseau, G.A., Hanson, R.S., and Wackett, L.P., 1989, Biodegradation of trichloroethylene by *Methylosinus trichosporium* OB3b: Appl. Environ. Microbiol., vol. 55, no. 12, p. 3155-3161.
- UNC Geotech, 1991, Final Remedial Investigations Report, prepared for 439th Military Airlift Wing.
- UNC Geotech, Remedial Investigations/Feasibility Studies Work Plan, prepared for 439th Military Airlift Wing.
- US Geological Survey (USGS), 1979, 7.5 Minute Quadrangle Map of the Springfield North Quadrangle, Massachusetts
- van Genuchten, M. Th. and Alves, W. J., 1982, Analytical Solutions of the One-Dimensional Convective-Dispersive Solute Transport Equation: US Department of Agriculture, Technical Bulletin Number 1661, 151p.
- Vogel, T.M. and McCarty, P.L., 1985, Biotransformation of Tetrachloroethylene to Trichloroethylene, Dichloroethylene, Vinyl Chloride, and Carbon Dioxide Under Methanogenic Conditions. Appl. Environ. Microbiol. 49:1080-1083.
- Vogel, T.M., Criddle, C.S. and McCarty, P.L., 1987, Transformations of halogenated aliphatic compounds: Environmental Science and Technology, v. 21, no. 8, p. 722-736.
- Vogel, T.M., 1994, Natural Bioremediation of Chlorinated Solvents, In: Handbook of Bioremediation. Lewis Publishers, Boca Raton, FL. 1994.
- Vroblesky, D.A., and Chapelle, F.H., 1994, Temporal and spatial changes of terminal electron-accepting processes in a petroleum hydrocarbon-contaminated aquifer and the significance for contaminant biodegradation: Water Resources Research, v. 30, no. 5, p. 1561-1570.
- Walton, W.C., 1988, Practical Aspects of Ground Water Modeling. National Water Well Association, Worthington, Ohio, 587 p.

- Weston 1984, Installation Restoration Program Final Report Phase II - Problem Confirmation Study, Westover Air Force Base, May 1984.
- Westover Air Force Base. 1993. The Westover 2000 Plan, p. 10, 17-18.
- Wexler, E.J. 1992, Analytical solutions for one-, two-, and three-dimensional solute transport in ground-water systems with uniform flow: United States Geological Survey, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B7, 190 p.
- Wiedemeier, Todd H., Downey, Douglas C., Wilson, John T., Kampbell, Donald H., Miller, Ross N., and Hansen, Jerry E., 1995, *Technical Protocol for Implementing the Intrinsic Remediation with Long-term Monitoring for Fuel Contamination Dissolved in Groundwater*. Prepared by the Air Force Center for Environmental Excellence.
- Wilson, J.T., and Wilson, B.H., 1985, Biotransformation of trichloroethylene in soil: *Appl. Environ. Microbiol.*, vol. 49, no. 1, p. 242-243.
- Wilson, B.H., Smith, G.B., and Rees, J.F., 1986, Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: *Environmental Science and Technology*, 20(10):997-1002.
- Wilson, B.H., Bledsoe, B., and Kampbell, D., 1987, Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, *Chemical Quality of Water and the Hydrologic Cycle*. Lewis Publishers, Chelsea, Michigan, p.125-137.
- Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M., 1990, Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: *Geomicrobiology Journal*, 8:225-240.
- Wilson, B.H., Wilson, J.T., Kampbell, D.H., and Bledsoe, B.E., 1994, Traverse City: Geochemistry and Intrinsic Bioremediation of BTEX Compounds, In: *Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water*. August 30 - September 1, 1994. US Environmental Protection Agency, p. 94 - 102.
- Young, L.Y., 1984, Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: *Microbial Degradation of Aromatic Compounds*. Marcel-Dekker, New York.

APPENDIX A

APPENDIX A-1
MONITORING WELL INSTALLATION LOGS

Client: WAFB Location: "Christmas Tree Area"	Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.
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Project No.: 629M0414 Proj Mgr: T. Keefe Geologist: T. Keefe	Drilling Co.: Seaboard Environmental Driller: Frank Harrington, Rob Ingram Drill Rig: Mobile B-53	Weather: Rain 50's
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Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S1	0-2	1,3	7	1.5	Brown LOAM, and light tan coarse SAND.	2.5		steel casing to 3 ft above grade cement to 2 ft
			4,4						
5	S2	5-7	4,12	27	1.5	Light tan coarse SAND, and some medium GRAVEL.	0.5		native fill to 31 ft
			15,14						
10	S3	10-12	3,5	10	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		2 in solid PVC riser
			5,6						
15	S4	15-17	5,8	17	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
			9,5						
20	S5	20-22	6,5	11	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
			4,4						
25	S6	25-27	5,6	13	1.5	Light tan and reddish coarse SAND, and some medium GRAVEL.	0		
			7,9						
30									

Sample Types: S = Split Spoon T = Shelby Tube R = Rock Core O = Other:	Cement Sand	Native Fill Bentonite
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Environmental
PRODUCTS & SERVICES, INC.

Subsurface

Hole No.: TF-12

Date Started: 5/15/95

Sheet 2 OF 2

Date Finished: 5/15/95

Client: WAFB
Location: "Christmas Tree Area"

Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.

Project No.: 629M0414
Proj Mgr: T. Keefe
Geologist: T. Keefe

Drilling Co.: Seaboard Environmental
Driller: Frank Harrington, Rob Ingram
Drill Rig: Mobile B-53

Weather: Rain 50's

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S7	30-32	3,7	17	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		native fill 2 ft of bentonite sand pack to 33 ft water table at 39 ft 2 in 0.010 slot PVC well screen point set at 45 ft
				10,7					
35	S8	35-37	6,11	24	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
				13,17					
40	S9	40-42	6,10	20	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
				10,13					
45	S10	45-47	1	1	0.0	Light tan coarse SAND, and some medium GRAVEL.	0		
50									
55									
60									

Sample Types: S = Split Spoon T = Shelby Tube
R = Rock Core O = Other:

Cement
 Sand
 Native Fill
 Bentonite

Environmental PRODUCTS & SERVICES, INC.	Subsurface	Hole No.: TF-13 Sheet 1 OF 2	Date Started: 5/15/95 Date Finished: 5/15/95
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Client: WAFB Location: "Christmas Tree Area"	Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.
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Project No.: 629M0414 Proj Mgr: T. Keefe Geologist: T. Keefe	Drilling Co.: Seaboard Environmental Driller: Dave Pitcher, Robert Carlisle Drill Rig: Mobile B-53	Weather: Rain 50's
--	--	--------------------

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
0-5	S1	0-2	3.5	10	1.5	Brown LOAM, and light tan coarse SAND.	0		steel casing to 3 ft above grade cement to 2 ft
			5.5						
5-10	S2	5-7	8.2	27	1.5	Light tan coarse SAND, and some medium GRAVEL..	0		native fill to 31 ft
			25.25						
10-15	S3	10-12	8.8	16	1.5	Light tan coarse SAND, and some medium GRAVEL..	0		2 in solid PVC riser
			8.9						
15-20	S4	15-17	3.5	10	1.5	Light tan coarse SAND, and some medium GRAVEL..	0		
			5.6						
20-25	S5	20-22	6.8	20	2.0	Light tan and gray coarse SAND, and some medium GRAVEL..	0		
			12.12						
25-30	S6	25-27	8.10	22	1.5	Light tan and gray coarse SAND, and some medium GRAVEL..	0		
			12.11						

Sample Types: S = Split Spoon T = Shelby Tube R = Rock Core O = Other:	 Cement  Sand	 Native Fill  Bentonite
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Environmental PRODUCTS & SERVICES, INC. **Subsurface** Hole No.: **TF-13** Date Started: **5/15/95**
 Sheet **2 OF 2** Date Finished: **5/15/95**

Client: **WAFB** Method of Investigation: **Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.**
 Location: **"Christmas Tree Area"**

Project No.: **629M0414** Drilling Co.: **Seaboard Environmental** Weather: **Rain 50's**
 Proj Mgr: **T. Keefe** Driller: **Dave Pitcher, Robert Carlisle**
 Geologist: **T. Keefe** Drill Rig: **Mobile B-53**

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S7	30-32	10,11	25	2.0	Light tan and gray coarse SAND, and some medium GRAVEL.	0		native fill 2 ft of bentonite sand pack to 33 ft water table at 40 ft 2 in 0.010 slot PVC well screen point set at 45 ft
			14,20						
35	S8	35-37	12,16	34	1.5	Light tan and gray coarse SAND, and some medium GRAVEL.	0		
			18,21						
40	S9	40-42	10,12	31	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
			19,18						
45	S10	45-47	8,9	23	2.0	Light tan coarse SAND, and some medium GRAVEL.	0		
			14,15						
50									
55									
60									

Sample Types: S = Split Spoon T = Shelby Tube
 R = Rock Core O = Other.

Environmental
PRODUCTS & SERVICES, INC.

Subsurface

Hole No.: *TF-14*
Sheet 1 OF 2

Date Started: 5/15/95
Date Finished: 5/15/95

Client: WAFB
Location: "Christmas Tree Area"

Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.

Project No.: 629M0414
Proj Mgr: T. Keefe
Geologist: T. Keefe

Drilling Co.: Seaboard Environmental
Driller: Dave Pitcher, Robert Carlisle
Drill Rig: Mobile B-53

Weather: Rain 50's

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S1	0-2	2,3	7	1.0	Brown LOAM, and light tan coarse SAND.	0	steel casing to 3 ft above grade	cement to 2 ft
			4,4						
5	S2	5-7	17,18	42	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		native fill to 31 ft
			24,25						
10	S3	10-12	7,11	23	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		2 in solid PVC riser
			12,12						
15	S4	15-17	5,8	18	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
			10,11						
20	S5	20-22	6,9	20	1.5	Light tan coarse SAND, and some medium GRAVEL.	0		
			11,14						
25	S6	25-27	10,20	42	2.0	Light tan coarse SAND, and some medium GRAVEL.	0		
			22,23						
30									

Sample Types: S = Split Spoon T = Shelby Tube
R = Rock Core O = Other:



Environmental
PRODUCTS & SERVICES, INC.

Subsurface

Hole No.: **TF-14**
Sheet **2 OF 2**

Date Started: **5/15/95**
Date Finished: **5/15/95**

Client: **WAFB**
Location: **"Christmas Tree Area"**

Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.

Project No.: **629M0414**
Proj Mgr: **T. Keefe**
Geologist: **T. Keefe**

Drilling Co.: **Seaboard Environmental**
Driller: **Dave Pitcher, Robert Carlisle**
Drill Rig: **Mobile B-53**

Weather: **Rain 50's**

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S7	30-32	9,12	28	1.5	Light tan coarse SAND, and some medium GRAVEL..	0		native fill 2 ft of bentonite
			16,17						
35	S8	35-37	17,25	54	1.5	Light tan and gray coarse SAND, and some medium GRAVEL..	0		sand pack to 33 ft
			29,16						
40	S9	40-42	6,14	35	1.5	Light tan coarse SAND, and some SILT..	0		water table at 40 ft
			21,36						
45	S10	45-47	10,12	20	2.0	Gray coarse SAND.	0		2 in 0.010 slot PVC well screen point set at 45 ft
			8,9						
50									
55									
60									

Sample Types: S = Split Spoon T = Shelby Tube
R = Rock Core O = Other:

	Cement		Native Fill
	Sand		Bentonite

Environmental
PRODUCTS & SERVICES, INC.

Subsurface

Hole No.: **TF-15**
Sheet 1 OF 2

Date Started: 5/15/95
Date Finished: 5/15/95

Client: WAFB
Location: "Christmas Tree Area"

Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.

Project No.: 629M0414
Proj Mgr: T. Keefe
Geologist: T. Keefe

Drilling Co.: Seaboard Environmental
Driller: Frank Harrington, Rob Ingram
Drill Rig: Mobile B-53

Weather: Rain 50's

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
0-5	S1	0-2	1,5	7	0.5	Brown LOAM, and light tan coarse SAND.	0	steel casing to 3 ft above grade cement to 2 ft	
			2,1						
5-10	S2	5-7	1,11	24	1	Brown LOAM and light tan coarse SAND, and some medium GRAVEL..	0	native fill to 36 ft	
			13,13						
10-15	S3	10-12	3,4	9	0.5	Light tan coarse SAND, and some medium GRAVEL..	0	2 in solid PVC riser	
			5,7						
15-20	S4	15-17	6,9	20	1.0	Coarse tan SAND.	1		
			11,13						
20-25	S5	20-22	4,7	14	0.3	Coarse tan SAND.	0		
			7,7						
25-30	S6	25-27	6,7	14	1.5	Light tan and reddish coarse SAND,	0		
			7,8						

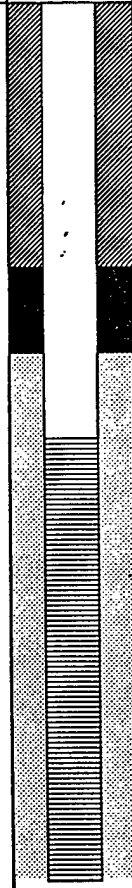
Sample Types: S = Split Spoon T = Shelby Tube
R = Rock Core O = Other:

 Cement
 Sand
 Native Fill
 Bentonite

Environmental PRODUCTS & SERVICES, INC.	Subsurface	Hole No.: TF-15 Sheet 2 OF 2	Date Started: 5/15/95 Date Finished: 5/15/95
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Client: WAFB Location: "Christmas Tree Area"	Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.
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Project No.: 629M0414 Proj Mgr: T. Keefe Geologist: T. Keefe	Drilling Co.: Seaboard Environmental Driller: Frank Harrington, Rob Ingram Drill Rig: Mobile B-53	Weather: Rain 50's
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Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
35	S7	30-32	8,9	18	1.5	Coarse gray SAND.	0		native fill
			9,9						
40	S8	35-37	5,9	19	1.5	Coarse gray SAND.	0		2 ft of bentonite
			10,11						
45	S9	40-42	10,13	28	1.5	Light tan and reddish coarse SAND.	0		sand pack to 38 ft
			15,22						
50	S10	45-47	7,6	11	1.0	Coarse tan SAND.	0		water table at 44 ft
			5,5						
55		50-52			0.0	No sample was retained by the split spoon.			2 in 0.010 slot PVC well screen
60									point set at 50 ft

Sample Types: S = Split Spoon T = Shelby Tube R = Rock Core O = Other:	 Cement  Sand	 Native Fill  Bentonite
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Client: WAFB
 Location: Chicopee State

Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.

Project No.: 629M0414
 Proj Mgr: T. Keefe
 Geologist: T. Keefe

Drilling Co.: Seaboard Environmental
 Driller: Frank Harrington, Rob Ingram
 Drill Rig: Mobile B-53

Weather: Overcast 60's

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S1	0-2	1,2	4	1.5	Fine tan SAND, some coarse SAND and some brown LOAM.	22 no odor		steel casing to 3 ft above grade cement to 2 ft
			2,3						
5	S2	5-7	5,12	29	1	Fine tan SAND, and some coarse SAND	300 no odor		native fill to 35 ft
			17,16						
10	S3	10-12	6,8	18	1.0	Fine tan SAND, and some coarse SAND.	600 no odor		2 in solid PVC riser
			10,10						
15	S4	15-17	5,4	10	1.5	Fine tan SAND, and trace reddish fine SAND.	30 no odor		
			6,7						
20	S5	20-22	6,9	17	1.5	Fine tan SAND.	200 no odor		
			8,10						
25	S6	25-27	6,10	22	1.5	Fine tan SAND.	100 no odor		
			12,12						
30									

Sample Types: S = Split Spoon T = Shelby Tube
 R = Rock Core O = Other

Cement	Native Fill
Sand	Bentonite

Environmental PRODUCTS & SERVICES, INC. **Subsurface** Hole No.: **TF-16** Date Started: 5/18/95
 Sheet 2 OF 2 Date Finished: 5/18/95

Client: WAFB Method of Investigation: Advance a 4.25 ID HSA collecting split spoon samples at the surface and every 5 feet. Interface sample retained for laboratory analysis. 2" monitoring well installed.
 Location: Chicopee State Park

Project No.: 629M0414 Drilling Co.: Seaboard Environmental Weather: Overcast 60's
 Proj Mgr: T. Keefe Driller: Frank Harrington, Rob Ingram
 Geologist: T. Keefe Drill Rig: Mobile B-53

Depth (ft.)	Sample					Sample Description	H-NU Reading (ppm)	Well Details	Groundwater and Other Observations
	No.	Depth (ft.)	Blows /6"	"N"	Recovery (ft.)				
	S7	30-32	10,16	34	2.0	Fine tan SAND.	90 no odor	native fill	
			18,23						
35	S8	35-37	17,15	33	1.5	Fine gray SAND, some reddish fine SAND.	10 no odor	2 ft of bentonite sand pack to 37 ft	
			18,23						
40	S9	40-42	10,13	27	1.5	Fine tan SAND.	5 no odor	water table at 43 ft	
			14,13						
45	S10	45-47	6,5	15	2.0	Fine tan SAND, some fine reddish SAND.	4 no odor	2 in 0.010 slot PVC well screen	
			10,9						
50		50-52	6,11	20	2.0	Fine tan SAND, and coarse SAND.	30 no odor	point set at 50 ft	
			9,12						
55									
60									

Sample Types: S = Split Spoon T = Shelby Tube Cement Native Fill
 R = Rock Core O = Other Sand Bentonite

APPENDIX A-2
GROUNDWATER SAMPLING FORMS

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/17/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-14 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/17/95 17:00 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Cloudy 60
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED: UNLOCKED
WELL NUMBER (IS - ~~IS NOT~~) APPARENT
STEEL CASING CONDITION IS: Good, however pad is severely cracked and pulling away from casing
INNER PVC CASING CONDITION IS: OK
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [] EQUIPMENT CLEANED BEFORE USE WITH Alconox, Water
Items Cleaned (List): Grundfos Redi-Flow II Pump

2 [] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 41.19 (5/11/95) Bottom (T.D) 91.28 (5/11/95) FT. BELOW DATUM
Measured with: water level meter

3 [] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Slightly cloudy
Odor: None
Other Comments:

4 [] WELL EVACUATION:
Method: Grundfos Redi-Flow II Pump
Volume Removed: 40
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change) ^{slightly} 41.31
Water odors: None
Other comments:

15:25 20 Gal pH 6.70 Temp 13.3 D.O. 6.60
15:37 30 Gal pH 6.65 Temp 13.3 D.O. 6.84
15:45 35 Gal pH 6.63 Temp 13.3 D.O. 6.78
15:50 40 Gal pH 6.60 Temp 13.3 D.O. 6.60

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: HDPE (Disposable)
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

- | | |
|------------------------------------|---|
| Temp: <u>13.3 °C</u> | Measured with: <u>Orion 250A YSI 35</u> |
| pH: <u>6.63</u> | Measured with: <u>Orion 250A</u> |
| Conductivity: _____ | Measured with: _____ |
| Dissolved Oxygen: <u>6.65 mg/L</u> | Measured with: <u>YSI 55</u> |
| Redox Potential: _____ | Measured with: _____ |
| Salinity: _____ | Measured with: _____ |
| Nitrate: _____ | Measured with: _____ |
| Sulfate: _____ | Measured with: _____ |
| Ferrous Iron: _____ | Measured with: _____ |
| Other: _____ | Measured with: _____ |

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

- Filtration: Method _____ Containers: _____
- Method _____ Containers: _____
- Method _____ Containers: _____

- Preservatives added:
- Method _____ Containers: _____
- Method _____ Containers: _____
- Method _____ Containers: _____
- Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB. FT-08
SAMPLING DATE(S) T 5/17/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF- 1A (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/17, 1995 1715 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Lt Rain, 60
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (15) IS NOT APPARENT
STEEL CASING CONDITION IS: Good; however ped is severely cracked and has pulled away from casing
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (15) IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): Grouties - Tube Inside - Water Outside - Iso & DI

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH _____
Items Cleaned (List): _____

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 40.77 T.D. 51.54 (5/11/95) FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Grouties Redi-Flo II Pump
Volume Removed: _____
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: _____
Other comments: _____

1634 15gal pH 6.34 Temp 13.3 condim D.O. 10.80
1640 20gal pH 6.35 Temp 13.3 D.O. 10.45
25gal pH 6.34 Temp 13.3 D.O. 11.30

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>13.3</u> °C	Measured with: <u>YSI 55</u>
pH: <u>6.34</u>	Measured with: <u>O2m 250 A</u>
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>10.43</u>	Measured with: <u>YSI 55</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	Measured with: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-3
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18/95, 1995, 12:40 a.m./p.m.
SAMPLE COLLECTED BY: DMV of Parsons ES, Denver
WEATHER: Cloudy 60
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (IS) IS NOT APPARENT
STEEL CASING CONDITION IS: Good; however, pad is in poor condition
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS) IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Inside Grounds - Water Flush
Items Cleaned (List): outside " - Isopropyl + D.I.

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 42.65/54.42 WLTD (5/11/95) FT. BELOW DATUM
Measured with: Water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: None
Other Comments: -

4 WELL EVACUATION:
Method: Ground For Redi-Flo II
Volume Removed: 17 Gal
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change) Not Measured because did not arise
Water odors: to introduce well prior to
Other comments: Sampling with bailer

704 5-Gal pH 6.42 Temp 13.7 D.O. 7.45
709 10-Gal pH 6.40 Temp 13.7 D.O. 6.78
717 15-Gal pH 6.42 Temp 13.6 D.O. 7.28

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 13.5 ° C Measured with: YSI
pH: 6.40 Measured with: OMDm
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 7.21 mg/l Measured with: YSI
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-4 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18, 1995 0850 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Cloudy - Low 60's
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS IS NOT) APPARENT
STEEL CASING CONDITION IS: Good; however, pad is severely cracked + tilted
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS IS NOT) APPARENT (Labeled)
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Grundfos - Inside - Water Flush
Items Cleaned (List): outside - Isopanol, Det

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 41.86 / 54.26 W.L./T.D 5/11/95 FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: None
Other Comments:

4 WELL EVACUATION:
Method: Grundfos Redi-Flo II Pump
Volume Removed: 17 gal
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change) Not Measured see TF-3
Water odors: None
Other comments:

5 Gal - 0802 pH 6.08 Temp 13.4 D.O. 5.09
10 Gal - 0809 pH 6.08 Temp 13.3 D.O. 4.80
15 Gal - 0814 pH 6.09 Temp 13.3 D.O. 4.91

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: HDPE
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

- | | |
|------------------------------------|-----------------------------|
| Temp: <u>13.3</u> ° <u>C</u> | Measured with: <u>YSI</u> |
| pH: <u>6.09</u> | Measured with: <u>ORION</u> |
| Conductivity: _____ | Measured with: _____ |
| Dissolved Oxygen: <u>4.86</u> mg/l | Measured with: <u>YSI</u> |
| Redox Potential: _____ | Measured with: _____ |
| Salinity: _____ | Measured with: _____ |
| Nitrate: _____ | Measured with: _____ |
| Sulfate: _____ | Measured with: _____ |
| Ferrous Iron: _____ | Measured with: _____ |
| Other: _____ | Measured with: _____ |

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

- Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

- Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-12
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18, 1995 1045 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Cloudy 65
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT corrected
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT -corrected
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): None

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Grundfos - Inside Water Flex
Items Cleaned (List): outside Isopropyl, Del

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 42.08 / 47.46 FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Cloudy - Brown
Odor: None
Other Comments: well has supposedly been developed; however, this is uncertain

4 WELL EVACUATION:
Method: Grundfos Redi-Flo II Pump
Volume Removed: 21
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change) NM
Water odors:
Other comments: Small spots of sheen

0922	5-Gal	pH 6.05	Temp 12.6	D.O. 5.33
0927	10-Gal	pH 6.03	Temp 12.2	D.O. 5.11
	15-Gal	pH 6.02	Temp 12.1	D.O. 5.19
0938	20-Gal	pH 6.01	Temp 12.1	D.O. 5.04

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: Sample was cloudy brown

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 12.1 ° C Measured with: OM YSI
pH: 6.01 Measured with: OM YSI
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 5.02 mg/l Measured with: YSI
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-13 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18, 1995 11:55 a.m./p.m.
SAMPLE COLLECTED BY: DMMV of Parsons ES, Denver
WEATHER: Cloudy Upper 60s
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - (S NOT) APPARENT Corrected)
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - (S NOT) APPARENT Corrected)
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 [] EQUIPMENT CLEANED BEFORE USE WITH Inside Ground Pgs - Water Flush
Items Cleaned (List): outside " - Isopropanol + DeI

2 [] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 41.91 / 47.21 FT. BELOW DATUM
Measured with: water level probe

3 [] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Cloudy Brown
Odor: None
Other Comments: _____

4 [] WELL EVACUATION:
Method: Ground Pgs
Volume Removed: 22 gal
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change) NM
Water odors: None
Other comments: _____

1029 10 gal pH 6.16 , Temp 12.1 , D.O. 3.58
1035 15 gal pH 6.32 , Temp 12.3 , D.O. 3.88
20 gal pH 6.22 , Temp 12.4 , D.O. 3.72

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: HDPE
- Pump, type: _____
- Other, describe: Sample was cloudy brown

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

- | | |
|------------------------------------|-----------------------------|
| Temp: <u>12.4</u> ° <u>C</u> | Measured with: <u>YSI</u> |
| pH: <u>6.20</u> | Measured with: <u>Orion</u> |
| Conductivity: _____ | Measured with: _____ |
| Dissolved Oxygen: <u>3.72</u> mg/l | Measured with: <u>YSI</u> |
| Redox Potential: _____ | Measured with: _____ |
| Salinity: _____ | Measured with: _____ |
| Nitrate: _____ | Measured with: _____ |
| Sulfate: _____ | Measured with: _____ |
| Ferrous Iron: _____ | Measured with: _____ |
| Other: _____ | Measured with: _____ |

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

- Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

- Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB. FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-5
(number)

REASON FOR SAMPLING: Regular Sampling; [] Special Sampling;
DATE AND TIME OF SAMPLING: 5/18/95, 1995, 1330 a.m./p.m.
SAMPLE COLLECTED BY: DMMV of Parsons ES, Denver
WEATHER: _____
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED: [] UNLOCKED
WELL NUMBER (IS - ~~IS NOT~~ APPARENT)
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[] MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 [] EQUIPMENT CLEANED BEFORE USE WITH Grundfos - Inside-water Flush
Items Cleaned (List): Outside - Isopropanol, DEI

2 [] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 41.99/51.78 W.L./T.D. FT. BELOW DATUM
Measured with: water level probe

3 [] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Cloudy, Red-brown
Odor: None
Other Comments: _____

4 [] WELL EVACUATION:
Method: Grundfos
Volume Removed: 35
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

1140	pH	6.35	Temp	12.7	D.O.	1.01	25 gal
	pH	6.24	Temp	12.7	D.O.	1.00	27.5 gal
	pH	6.25	Temp	12.7	D.O.	0.90	30 gal

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 12.7 ° 0 Measured with: _____
pH: 6.25 Measured with: _____
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 0.90 mg/l Measured with: _____
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-14
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18, 1995 1340 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Cloudy, 70
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (IS - NOT) APPARENT Corrected
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - NOT) APPARENT Corrected
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Inside Pump - Water Flush
Items Cleaned (List): Outside Pump - Isopropanol, Det.

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 41.97 / 46.33 FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Brown, Muddy
Odor: None
Other Comments: Not developed well. See TF-12

4 WELL EVACUATION:
Method: Grundfos Redi-Flo II
Volume Removed: 35
Observations: Water (slightly - very) cloudy clear
Water level (rose - fell - no change)
Water odors: None
Other comments:

5/18	15gal	pH 6.36	Temp 13.2	D.O. 1.75
1237				
1244	20gal	pH 6.37	Temp 13.5	D.O. 1.50
1249	25gal	pH 6.35	Temp 13.5	D.O. 1.37

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: Sample was cloudy brown

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>13.6</u> °C	Measured with: <u>YSI</u>
pH: <u>6.37</u>	Measured with: <u>Orion</u>
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>1.20</u> mg/L	Measured with: <u>YSI</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	Measured with: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[] Preservatives added:
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-15 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling:
DATE AND TIME OF SAMPLING: 5/18, 1995 11:30 a.m./p.m.
SAMPLE COLLECTED BY: DMMV of Parsons ES, Denver
WEATHER: Cloudy 70
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - ~~IS NOT~~) APPARENT corrected
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - ~~IS NOT~~) APPARENT Corrected
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Inside Pump - Water Flush
Items Cleaned (List): Outside Pump - Isopropanol, D.I

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 45.07/52.98 FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Cloudy Brown
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Grundfos Redi-Flu II
Volume Removed: 30⁺ gal
Observations: Water (slightly) - very) cloudy
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

1444 15 gal DO. 2.48 Temp 12.8 pH 6.11
1447 20 gal DO. 2.38 Temp 12.7 pH 6.03
1450 25 gal DO. 2.38 Temp 12.7 PH 6.02

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: sample was cloudy brown

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 12.7 °C Measured with: YSI
pH: 6.00 Measured with: OMN
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 2.40 mg/l Measured with: YSI
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

SAMPLING LOCATION Westover ARB. FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-2
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18, 1995 a.m./p.m.
SAMPLE COLLECTED BY: DMV of Parsons ES. Denver
WEATHER: Cloudy 70
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:

LOCKED: UNLOCKED
WELL NUMBER (IS) IS NOT APPARENT
STEEL CASING CONDITION IS: Good; however, pad is poor
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS) IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Inside Pump - Water Flush
Items Cleaned (List): Outside Pump - Isopropyl, DE I

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 43.32/86.89 W.L./T.D. (5/11/95) FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: None
Other Comments:

4 WELL EVACUATION:
Method: Grundfos Redi-Flo II Pump
Volume Removed: 45 Gal
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: None
Other comments: White gyt was caked on top of pump. Head.

did not appear to be PVC.

1524 20 Gal pH 6.49 Temp 12.8 D.O. 6.20
1527 25 Gal pH 6.48 Temp 12.8 D.O. 5.90
1530 30 Gal pH 6.44 Temp 12.7 D.O. 5.8 Am 6.04
1533 35 Gal pH 6.44 Temp 12.7 D.O. 5.86

1537 40 Gal pH 6.44 Temp 13.2 D.O. 5.35

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: HDPE
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>13.3 ° C</u>	Measured with: <u>YSI</u>
pH: <u>6.44</u>	Measured with: <u>ORION</u>
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>5.33</u>	Measured with: <u>YSI</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	Measured with: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

- Filtration:

Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____
- Preservatives added:

Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB. FT-08
SAMPLING DATE(S) 5/18/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-2A
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/18, 1995 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Cloudy, Upper 60s
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED: UNLOCKED
WELL NUMBER (IS IS NOT) APPARENT
STEEL CASING CONDITION IS: Good, Pad is no longer evident
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Inside Pump - Water Flush
Items Cleaned (List): Outside Pump - Isopropyl, DeI

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH TF-2A DM 42.05 / 53.84 WL/T.D FT. BELOW DATUM
Measured with: water level probe (5/11/95)

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: Slight Petroleum - Moderate
Other Comments:

4 WELL EVACUATION:
Method: Grundfos Redi-Fluo II
Volume Removed: 20 gal
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: Moderate weathered petroleum
Other comments:

16 ⁰⁴	5 Gal	pH 6.52	Temp 13.4	D.O. 0.35
16 ¹⁰	10 Gal	pH 6.53	Temp 13.1	D.O. 0.24
16 ¹⁶	15 Gal	pH 6.53	Temp 13.0	D.O. 0.33

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: HDPE
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

- | | |
|---|-----------------------------|
| Temp: <u>13.0</u> ° <u>C</u> | Measured with: <u>YSI</u> |
| pH: <u>6.52</u> | Measured with: <u>orion</u> |
| Conductivity: _____ | Measured with: _____ |
| Dissolved Oxygen: <u>0.18</u> <u>mg/l</u> | Measured with: <u>YSI</u> |
| Redox Potential: _____ | Measured with: _____ |
| Salinity: _____ | Measured with: _____ |
| Nitrate: _____ | Measured with: _____ |
| Sulfate: _____ | Measured with: _____ |
| Ferrous Iron: _____ | Measured with: _____ |
| Other: _____ | Measured with: _____ |

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

- Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

- Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/19/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-16
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/19, 1995 0930 a.m./p.m.
SAMPLE COLLECTED BY: DMMV of Parsons ES, Denver
WEATHER: Cloudy, lt rain, Low 60's
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - ~~IS NOT~~) APPARENT Corrected
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - ~~IS NOT~~) APPARENT Corrected
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Inside Pump - Water Flush
Items Cleaned (List): Outside Pump - Double Isopropanol & DeT

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 44.13/53.09 W.L./T.D. FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Slightly Cloudy, Brown
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Gravities Redi-Flow II
Volume Removed: 20
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

0857 5-Gal pH 6.35 Temp 11.0 D.O. 11.55
0902 10-Gal pH 6.17 Temp 11.0 D.O. 11.70
0907 15-Gal pH 6.14 Temp 11.0 D.O. 11.12

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>11.0</u> ° <u>C</u>	Measured with: <u>YSI</u>
pH: <u>6.14</u>	Measured with: <u>Orion</u>
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>11.9</u> mg/l	Measured with: <u>YSI</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/19/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-7
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/19, 1995 11:55 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: _____
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT Corrected
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Disconnected
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Inside of pump - water flush
Items Cleaned (List): outside of pump - Isopropanol + DI: Z

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 43.75 / 50.28 w.l. / T.D (5/11/95) FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: slightly cloudy
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Groundwater Redi-Flo II
Volume Removed: 18
Observations: Water (slightly - very) cloudy clear
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

11:37 5 Gal 6.12 pH Temp 12.2 D.O. 6.27
11:40 10 gal pH 6.12 Temp 12.2 D.O. 6.28
11:43 15 gal pH 6.11 Temp 12.2 D.O. 6.09

SAMPLING LOCATION Westover ARB. FT-08
SAMPLING DATE(S) 5/19/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-8
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/19/95, 19 11 15 a.m./p.m.
SAMPLE COLLECTED BY: DMMV of Parsons ES, Denver
WEATHER: _____
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:

LOCKED: _____ UNLOCKED
WELL NUMBER (IS IS NOT) APPARENT No Cap
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Inside of pump - water flush
Items Cleaned (List): Outside of pump - Isopropanol & DEI

2 PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 44.77/48.67 W.L./T.D (5/11/95) FT. BELOW DATUM
Measured with: water level probe

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: slightly cloudy
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Grundfos Redi-Flt II Pump
Volume Removed: 16 gal
Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

10 ⁵⁴	5gal	pH 6.52	Temp 11.8	D.O.	6.42
12 ⁵⁸	10gal	pH 6.56	Temp 11.7	D.O.	6.16
11 ⁰²	15gal	pH 6.56	Temp 11.7	D.O.	6.13

SAMPLING LOCATION Westover ARB, FT-08
SAMPLING DATE(S) 5/19/95

GROUND WATER SAMPLING RECORD - MONITORING WELL TF-11 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 5/19/95, 1995 1030 a.m./p.m.
SAMPLE COLLECTED BY: DM/MV of Parsons ES, Denver
WEATHER: Cloudy, Low 60's
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT corrected
STEEL CASING CONDITION IS: Good, but no concrete pad
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 [] EQUIPMENT CLEANED BEFORE USE WITH Inside of pump - Water Flush
Items Cleaned (List): outside of pump - Isopropanol + De I

2 [] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: NA

WATER DEPTH 43.17/52.22 WL FT.D (5/11/95) FT. BELOW DATUM
Measured with: water level probe

3 [] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Brown, Cloudy
Odor: Yes, Swamplike or Very old and decayed fuel
Other Comments: _____

4 [] WELL EVACUATION:
Method: Grundfos Redi-Flow II
Volume Removed: 22 gal
Observations: Water (slightly - very) cloudy mod. cloudy, H₂S, grey brown
Water level (rose - fell - no change)
Water odors: anaerobic?
Other comments: _____

1000	5gal	pH	6.50	Temp	11.8	D.O.	0.57
1000	10gal	pH	6.57	Temp	11.7	D.O.	0.45
	15gal	pH	6.58	Temp	11.6	D.O.	0.63
1010	20gal		6.59		11.7		0.82

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 11.9 ° C Measured with: YSI
pH: 6.59 Measured with: orion
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 0.96 mg/l Measured with: YSI
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION TF-1
SAMPLING DATE(S) 7/16/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-1 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/16/96, 1996 12:15 a.m./pm.
SAMPLE COLLECTED BY: _____ of _____
WEATHER: Clear - 80°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of CASING

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED — no top cap
WELL NUMBER (IS - NOT) APPARENT
STEEL CASING CONDITION IS: RUSTED
INNER PVC CASING CONDITION IS: FAIR
WATER DEPTH MEASUREMENT DATUM (IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH PUMP - Alconax, TAP WATER,
Items Cleaned (List): DI
AN TAPS - DIA

2 LNAPL DEPTH NP FT. BELOW DATUM
Measured with: NA
WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: cloudy Brown
Odor: none
Other Comments: _____

4 WELL EVACUATION:
Method: 2-STAGE PUMP
Volume Removed: 13 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

- [] Bailer made of: _____
- [] Pump, type: _____
- [] Other, describe: _____

Sample obtained is [] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

- | | |
|------------------------------------|----------------------|
| Temp: <u>14.4 °C</u> | Measured with: _____ |
| pH: <u>6.10</u> | Measured with: _____ |
| Conductivity: <u>870 µS/cm</u> | Measured with: _____ |
| Dissolved Oxygen: <u>8.44 mg/L</u> | Measured with: _____ |
| Redox Potential: _____ | Measured with: _____ |
| Salinity: _____ | Measured with: _____ |
| Nitrate: _____ | Measured with: _____ |
| Sulfate: _____ | Measured with: _____ |
| Ferrous Iron: _____ | Measured with: _____ |
| Other: _____ | _____ |

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

- [] Filtration: Method _____ Containers: _____
- Method _____ Containers: _____
- Method _____ Containers: _____

- [] Preservatives added:
- Method _____ Containers: _____
- Method _____ Containers: _____
- Method _____ Containers: _____
- Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- [] Container Sides Labeled
- [] Container Lids Taped
- [] Containers Placed in Ice Chest

10 [] OTHER COMMENTS: 12 GALL 20 GALL

RD	<u>5.66</u>	<u>5.80</u>
PH	<u>7.28</u>	<u>7.26</u>
Cond =	<u>50</u>	<u>20</u>

TF-1A

SAMPLING LOCATION 7/16/96
SAMPLING DATE(S) Christmas Tree FFA

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-1A (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/16, 1996 13:00 a.m./p.m.
SAMPLE COLLECTED BY: mv of _____
WEATHER: P. Cloudy - 85°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (S) IS NOT APPARENT
STEEL CASING CONDITION IS: Rusted
INNER PVC CASING CONDITION IS: FAIR
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Pump - Alcomax - 15 min
Items Cleaned (List): TAP - 15 min
DI - 1 min

2 LNAPL DEPTH
NP FT. BELOW DATUM
Measured with: _____
WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: none
Other Comments: _____

4 WELL EVACUATION:
Method: 2-STAGE Pump
Volume Removed: 30 Gallons
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 13.1 °C Measured with: _____
pH: 7.49 Measured with: _____
? Conductivity: 20 Measured with: _____
Dissolved Oxygen: 5.76 Measured with: _____
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS: -conductivity probe hard to stabilize

SAMPLING LOCATION Xmas Tree FTA
SAMPLING DATE(S) 7/18/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-2 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/18/96, 19 10⁰⁰ 09⁴⁵ a.m./p.m.
SAMPLE COLLECTED BY: Dave Montoye of Parsons ES
WEATHER: Sunny, Upper 70's, Calm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Notch in PVC

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (IS/ IS NOT) APPARENT _____
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS/ IS NOT) APPARENT _____
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Alconox + Water
Items Cleaned (List): Pump + Tubing

2 LNAPL DEPTH NA FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Envirotech Pump
Volume Removed: 35
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

SAMPLING LOCATION Ymas Tree FTA
SAMPLING DATE(S) 7/18/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-2A

REASON FOR SAMPLING: Regular Sampling; Special Sampling; _____ (number)

DATE AND TIME OF SAMPLING: 7/18/96, 19 10:30 a.m./p.m.

SAMPLE COLLECTED BY: Dave Mustons of Parsons ES

WEATHER: Sunny, Calm, Mid 80's

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Notch in FVG

MONITORING WELL CONDITION:

LOCKED; UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT _____

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: Good

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____

DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Alconox & Water

Items Cleaned (List): Pump & Tubing
Tubing discarded after this well

2 LNAPL DEPTH

NA FT. BELOW DATUM

Measured with: _____

WATER DEPTH _____

Measured with: _____ FT. BELOW DATUM

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: Gray w/ Black Fleck

Odor: Septic / Sulfurous

Other Comments: _____

4 WELL EVACUATION:

Method: Envirotech Pump

Volume Removed: 20

Observations: Water (slightly - very) cloudy

Water level (rose - fell - no change)

Water odors: Sulfurous

Other comments: Lt Gray Tint

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: _____
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 15.7 ° C Measured with: Omn 840
pH: _____ Measured with: _____
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 1.4 Measured with: Omn 840
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION CTFA
SAMPLING DATE(S) 7/16/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-3 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/16, 1996, 1500 a.m./p.m.
SAMPLE COLLECTED BY: MV of _____
WEATHER: P. Cloudy - 85°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT - TF-4?
STEEL CASING CONDITION IS: RUSTED
INNER PVC CASING CONDITION IS: FAIR
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Pump - 15 min - Alcon & TAP WATER
Items Cleaned (List): metals - DI

2 LNAPL DEPTH NP FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: slightly cloudy
Odor: none
Other Comments: _____

4 WELL EVACUATION:
Method: 2-STAGE
Volume Removed: 25 GALLONS
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>12.6 °C</u>	Measured with: _____
pH: <u>7.92</u>	Measured with: _____
Conductivity: <u>340 µS/cm</u>	Measured with: _____
Dissolved Oxygen: <u>9.16 mg/L</u>	Measured with: _____
Redox Potential: <u>+88.6 mV</u>	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

Preservatives added:
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 [] OTHER COMMENTS:	6 GALLONS	12 GALLONS	18 GALLONS
DO (mg/L) =	9.14	9.09	9.11
pH	7.99	7.98	7.9
cond (µS/cm)	320	340	340
redox (mV)	125.3	+ 91.8	87.8
T = (°C)	13.5	12.8	12.7

SAMPLING LOCATION CTFA

SAMPLING DATE(S) 7/16/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-4

(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;

DATE AND TIME OF SAMPLING: 7/16, 1996 14:00 a.m./p.m.

SAMPLE COLLECTED BY: M.V. of _____

WEATHER: P-Cloudy - 80°

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of casing

MONITORING WELL CONDITION:

LOCKED: UNLOCKED

WELL NUMBER (IS NOT) APPARENT

STEEL CASING CONDITION IS: RUSTED

INNER PVC CASING CONDITION IS: FAIR

WATER DEPTH MEASUREMENT DATUM (IS NOT) APPARENT

DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Pump - Abrax - 15 min

Items Cleaned (List): TAP - 15 min

DF - 1 min

meters - DI

2 LNAPL DEPTH

NP

FT. BELOW DATUM

Measured with: _____

WATER DEPTH _____

FT. BELOW DATUM

Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: Clear

Odor: none

Other Comments: _____

4 WELL EVACUATION:

Method: 2-STAGE Pump

Volume Removed: 20 GALLONS

Observations: Water (slightly - very) cloudy

Water level (rose - ~~fell~~ - no change)

Water odors: none

Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 14.0 ° F Measured with: _____
pH: 7.36 Measured with: _____
Conductivity: +31.61010 Measured with: _____
Dissolved Oxygen: 9.19 Measured with: _____
Redox Potential: +131.6 Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: 6- GALLONS - 12 GALL
PH 6.93 ~~7.3~~
DO = 9.69 7.61
COND = 330 330
REDOX = 190.2 195.2

SAMPLING LOCATION CFRFTA

SAMPLING DATE(S) 7/16/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-25

(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;

DATE AND TIME OF SAMPLING: 7/16, 1996 17:00 a.m./p.m.

SAMPLE COLLECTED BY: MV of _____

WEATHER: P. Cloudy 85°

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

LOCKED: UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT _____

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____

DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Pump - 15 min POTABLE & Alconox
Items Cleaned (List): _____

2 LNAPL DEPTH

NP FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: Rust Brown

Odor: none

Other Comments: _____

4 WELL EVACUATION:

Method: 2-Stage Pump

Volume Removed: _____

Observations: Water (slightly - very) cloudy

Water level (rose - fell - no change)

Water odors: _____

Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: _____
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>12.4° C</u>	Measured with: _____
pH: <u>7.46</u>	Measured with: _____
Conductivity: <u>360 µs/cm</u>	Measured with: _____
Dissolved Oxygen: <u>4.94 mg/l</u>	Measured with: _____
Redox Potential: <u>+36.2 mV</u>	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

Preservatives added:

Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

	<u>6 Gallons</u>	<u>12 gallons</u>	<u>18 gallons</u>
pH	<u>7.16</u>	<u>7.13</u>	<u>7.42</u>
DO	<u>5.13</u>	<u>4.92</u>	<u>4.90</u>
redox	<u>15.3</u>	<u>32.5</u>	<u>33.3</u>
Cond.	<u>360</u>	<u>360</u>	<u>370</u>
T=	<u>12.8</u>	<u>12.4</u>	<u>12.4</u>

SAMPLING LOCATION Kings Tree FTA
SAMPLING DATE(S) 7/17/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-7

REASON FOR SAMPLING: Regular Sampling; Special Sampling; _____ (number)
DATE AND TIME OF SAMPLING: 7/17/96, 1996, 1600 a.m./p.m.
SAMPLE COLLECTED BY: Dave Minton of Parsons ES
WEATHER: Partly cloudy, Mid 80s, Cal
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Watch in PVC

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (S) IS NOT APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (S) IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): Needs Lock

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Alconox + Distilled water
Items Cleaned (List): Envirotech Pump & Tubing

2 LNAPL DEPTH NA FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Envirotech Pump
Volume Removed: 25 gal
Observations: Water (slightly) very cloudy
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: _____
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>12.4 °C</u>	Measured with: <u>YSI 55</u>
pH: <u>Cracked Probe</u>	Measured with: _____
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>5.57</u>	Measured with: <u>YSI 55</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

<input type="checkbox"/> Filtration:	Method _____	Containers: _____
	Method _____	Containers: _____
	Method _____	Containers: _____

Preservatives added:

Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION XTree FTA
SAMPLING DATE(S) 7/17/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-8

(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/17/96, 1996, 1515 a.m./p.m.
SAMPLE COLLECTED BY: Dave Mouton of Parsons ES
WEATHER: Mostly Cloudy, mid 80's, calm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Notch in PVC

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (S) IS NOT APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (S) IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): Needs work

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Alconox + Distilled Water
Items Cleaned (List): Pump (Envirotech) + Tube

2 LNAPL DEPTH NA FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: Clear
Odor: None
Other Comments: _____

4 WELL EVACUATION:

Method: Envirotech Pump

Volume Removed: 15

Observations: Water (slightly - very) cloudy Clear
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: _____
- Pump, type: _____
- Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>11.4 °C</u>	Measured with: <u>YSI 55</u>
pH: _____	Measured with: _____
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>4.63</u>	Measured with: <u>YSI 55</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

SAMPLING LOCATION Impas Tree FTA
SAMPLING DATE(S) 7/17/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-11

(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;

DATE AND TIME OF SAMPLING: 7/17/96, 1996 1640 a.m./p.m.

SAMPLE COLLECTED BY: Dave Montoye of Parsons ES

WEATHER: Partly Cloudy Mid 50's Calm

DATUM FOR WATER DEPTH MEASUREMENT (Describe): North on PVC

MONITORING WELL CONDITION:

LOCKED; UNLOCKED

WELL NUMBER (IS) (IS NOT) APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: Good

WATER DEPTH MEASUREMENT DATUM (IS) (IS NOT) APPARENT

DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

MONITORING WELL REQUIRED REPAIR (describe): Needs Lock

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Acronox & Distilled Water
Items Cleaned (List): Pump (Envirotech) & Tube

2 LNAPL DEPTH

NA

FT. BELOW DATUM

Measured with:

WATER DEPTH

FT. BELOW DATUM

Measured with:

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: Cloudy, Grey Brown

Odor: Sw/Errors

Other Comments:

4 WELL EVACUATION:

Method: Envirotech Pump

Volume Removed:

Observations: Water (slightly - very) cloudy

Water level (rose - fell - no change)

Water odors:

Other comments:

5 [] SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
[] Pump, type: _____
[] Other, describe: _____

Sample obtained is [] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 11.8 ° C Measured with: YSI 55
pH: _____ Measured with: _____
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 1.86 Measured with: YSI 55
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[] Preservatives added:

 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

[] Container Sides Labeled
[] Container Lids Taped
[] Containers Placed in Ice Chest :

10 [] OTHER COMMENTS: _____

SAMPLING LOCATION CTFTA
SAMPLING DATE(S) 7/16/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-12
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/16, 1996, 15:45 a.m./p.m.
SAMPLE COLLECTED BY: MV of _____
WEATHER: P. Cloudy 90°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT _____
STEEL CASING CONDITION IS: _____
INNER PVC CASING CONDITION IS: _____
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Pump - Alconof & POTABLE for 15 min
Items Cleaned (List): meters DE

2 LNAPL DEPTH ND FT. BELOW DATUM
Measured with: _____
WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: cloudy
Odor: none
Other Comments: _____

4 WELL EVACUATION:
Method: 2-STAGE
Volume Removed: 22 GALLONS
Observations: Water (slightly - very) cloudy
Water level (rose - fell) - no change
Water odors: none
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: HDPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>12.0</u> ° <u>C</u>	Measured with: _____
pH: <u>7.93</u>	Measured with: _____
Conductivity: <u>200</u> <u>µS/cm</u>	Measured with: _____
Dissolved Oxygen: <u>9.82</u> <u>mg/L</u>	Measured with: _____
Redox Potential: <u>+119.0</u> <u>mV</u>	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

Preservatives added:
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: 6 GALLONS 12 GALLONS 18gall

DO	<u>9.8</u>	<u>9.9</u>	<u>9.78</u>
pH	<u>7.73 7.81</u>	<u>7.91</u>	<u>7.92</u>
Cond	<u>200</u>	<u>210</u>	<u>200</u>
redox	<u>+157.4</u>	<u>116.2</u>	<u>116.8</u>
T=	<u>12.5</u>	<u>12.1</u>	<u>11.9</u>

SAMPLING LOCATION CTFTA-13
SAMPLING DATE(S) 7/16/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-13
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/16, 1996, 16:30 a.m./p.m.
SAMPLE COLLECTED BY: MU of _____
WEATHER: P. Cloudy 90°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT _____
STEEL CASING CONDITION IS: _____
INNER PVC CASING CONDITION IS: _____
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH PUMP - 15 min Alconox & POTABLE
Items Cleaned (List): _____

2 LNAPL DEPTH
Measured with: _____ FT. BELOW DATUM
WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Cloudy Brown
Odor: non
Other Comments: _____

4 WELL EVACUATION:
Method: 2-STAGE Pump
Volume Removed: 22 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - ~~fell~~ - no change)
Water odors: none
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

- [] Bailer made of: _____
- [] Pump, type: _____
- [] Other, describe: _____

Sample obtained is [] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>12.1</u> ° <u>0</u>	Measured with: _____
pH: <u>7.94</u>	Measured with: _____
Conductivity: <u>370</u> <u>µs/cm</u>	Measured with: _____
Dissolved Oxygen: <u>7.55</u> <u>mg/l</u>	Measured with: _____
Redox Potential: <u>+122.0</u> <u>mV</u>	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration: Method _____ Containers: _____

 Method _____ Containers: _____

 Method _____ Containers: _____

[] Preservatives added:

 Method _____ Containers: _____

 Method _____ Containers: _____

 Method _____ Containers: _____

 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- [] Container Sides Labeled
- [] Container Lids Taped
- [] Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

	6 Gallon	12 Gallon	18 Gallons
D.O	9.4	9.4	9.5
Cond	360	400	390
redox	+136.5	+127.7	123.2
pH	7.70	7.85	7.94
T	12.8	12.4	12.3

SAMPLING LOCATION CTFTA
SAMPLING DATE(S) 7/6/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-14 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/16, 1996 16:30 a.m./p.m.
SAMPLE COLLECTED BY: mv of _____
WEATHER: P. Cloudy 70°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT _____
STEEL CASING CONDITION IS: _____
INNER PVC CASING CONDITION IS: _____
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Pump- POTABLE & Alconox For 15 min
Items Cleaned (List): _____

2 LNAPL DEPTH NP FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Slightly cloudy
Odor: none
Other Comments: _____

4 WELL EVACUATION:
Method: 2-STAGE
Volume Removed: 22 GALLONS
Observations: Water (slightly - very) cloudy
Water level (rose - ~~fell~~ - no change)
Water odors: none
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: H DPE
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>13.0 ° C</u>	Measured with: _____
pH: <u>7.36</u>	Measured with: _____
Conductivity: <u>1940 µs/cm</u>	Measured with: _____
Dissolved Oxygen: <u>6.23 mg/L</u>	Measured with: _____
Redox Potential: <u>+113.2 mv</u>	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration:	Method _____	Containers: _____
	Method _____	Containers: _____
	Method <u>-</u>	Containers: _____

[] Preservatives added:	Method _____	Containers: _____
	Method _____	Containers: _____
	Method _____	Containers: _____
	Method _____	Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS:	6 Gall	12 Gall	18 Gall
D.O.	<u>6.62</u>	<u>6.45</u>	<u>6.30</u>
Cond.	<u>1950</u>	<u>1960</u>	<u>1930</u>
redox	<u>115.8</u>	<u>112.4</u>	<u>113.2</u>
pH	<u>6.48</u>	<u>7.20</u>	<u>7.31</u>
T	<u>13.4</u>	<u>13.2</u>	<u>13.0</u>

SAMPLING LOCATION Xmas Tree FTA
SAMPLING DATE(S) 7/18/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-15 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/18/96, 1996 0900 a.m./p.m.
SAMPLE COLLECTED BY: Dave Masterson of Perkins ES
WEATHER: Sunny, mid 70's, calm
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Notch in PVC

MONITORING WELL CONDITION:
 LOCKED; UNLOCKED
WELL NUMBER IS NOT APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
 MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off
1 EQUIPMENT CLEANED BEFORE USE WITH Alconox + H₂O₂
Items Cleaned (List): Pump + Tube

2 LNAPL DEPTH
NA FT. BELOW DATUM
Measured with: _____
WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Brown cloudy
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Envirotech Pump
Volume Removed: 25 gal
Observations: Water (slightly) - very cloudy
Water level (rose - fell - no change)
Water odors: None
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

- Bailer made of: _____
- Pump, type: _____
- Other, describe: _____

Sample obtained is [] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: <u>12.7</u> ° <u>C</u>	Measured with: <u>Orion DO 840</u>
pH: _____	Measured with: _____
Conductivity: _____	Measured with: _____
Dissolved Oxygen: <u>5.1</u>	Measured with: <u>Orion DO 840</u>
Redox Potential: _____	Measured with: _____
Salinity: _____	Measured with: _____
Nitrate: _____	Measured with: _____
Sulfate: _____	Measured with: _____
Ferrous Iron: _____	Measured with: _____
Other: _____	_____

7 [] SAMPLE CONTAINERS (material, number, size):

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration:	Method _____	Containers: _____
	Method _____	Containers: _____
	Method _____	Containers: _____

[] Preservatives added:

Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____
Method _____	Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS:

SAMPLING LOCATION Christmas Tree F71
SAMPLING DATE(S) 7/17/96

GROUNDWATER SAMPLING RECORD - MONITORING WELL/POINT TF-16 (number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;
DATE AND TIME OF SAMPLING: 7/17/96, 19 1415 a.m./p.m.
SAMPLE COLLECTED BY: Dave Minkoff of Parsons ES
WEATHER: Sunny, mid 80's light breeze out of West
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Notch in casing

MONITORING WELL CONDITION:

LOCKED; UNLOCKED
WELL NUMBER (IS) IS NOT APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM (IS) IS NOT APPARENT
 DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR No
 MONITORING WELL REQUIRED REPAIR (describe): Needs Lock

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH Alconox & water
Items Cleaned (List): Pump (Envirotech)

2 LNAPL DEPTH NA FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Slightly Cloudy
Odor: None
Other Comments: _____

4 WELL EVACUATION:
Method: Pump - Envirotech
Volume Removed: 24
Observations: Water (slightly) - very cloudy
Water level (rose - fell - no change)
Water odors: _____
Other comments: _____

5 [] SAMPLE EXTRACTION METHOD:

Bailer made of: Bailer
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Temp: 10.0 ° C Measured with: YSZ 55
pH: Probe Cracked + Instable Measured with: _____
Conductivity: _____ Measured with: _____
Dissolved Oxygen: 7.688.16 Measured with: YSZ 55
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

- Container Sides Labeled
- Container Lids Taped
- Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

FT-03, WELL TF-8 (Falling Head Test-1)

DATA SET:

tf8f1.dat
05/23/95

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

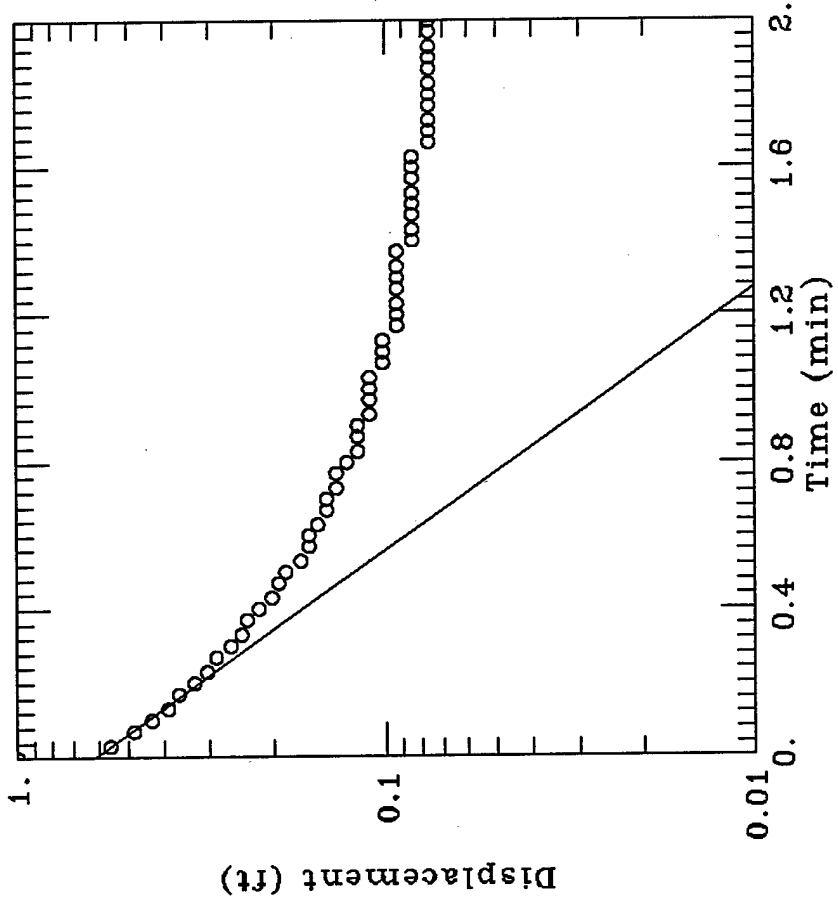
Bouwer-Rice

ESTIMATED PARAMETERS:

$K = 0.002186 \text{ ft/min}$
 $y_0 = 0.6129 \text{ ft}$

TEST DATA:

$H_0 = 1. \text{ ft}$
 $rc = 0.083 \text{ ft}$
 $rw = 0.33 \text{ ft}$
 $L = 10. \text{ ft}$
 $b = 3.9 \text{ ft}$
 $H = 3.9 \text{ ft}$



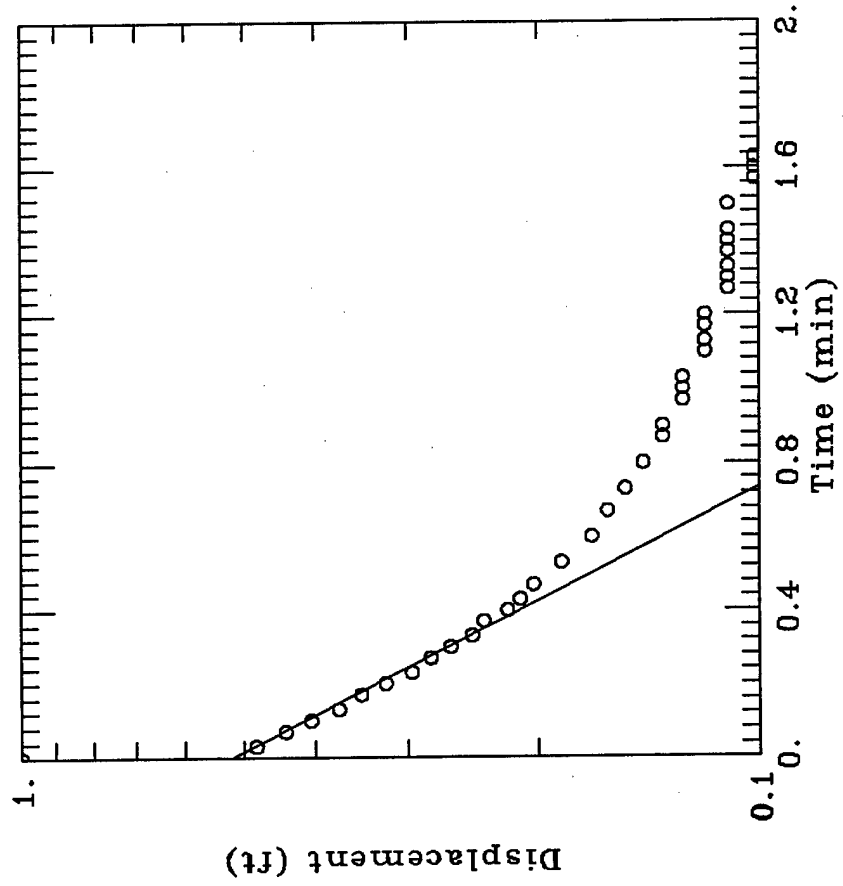
TF-03, WELL TF-8 (Falling Head Test-2)

DATA SET:
tf8f2.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.001515 ft/min
y0 = 0.5191 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 3.9 ft
H = 3.9 ft



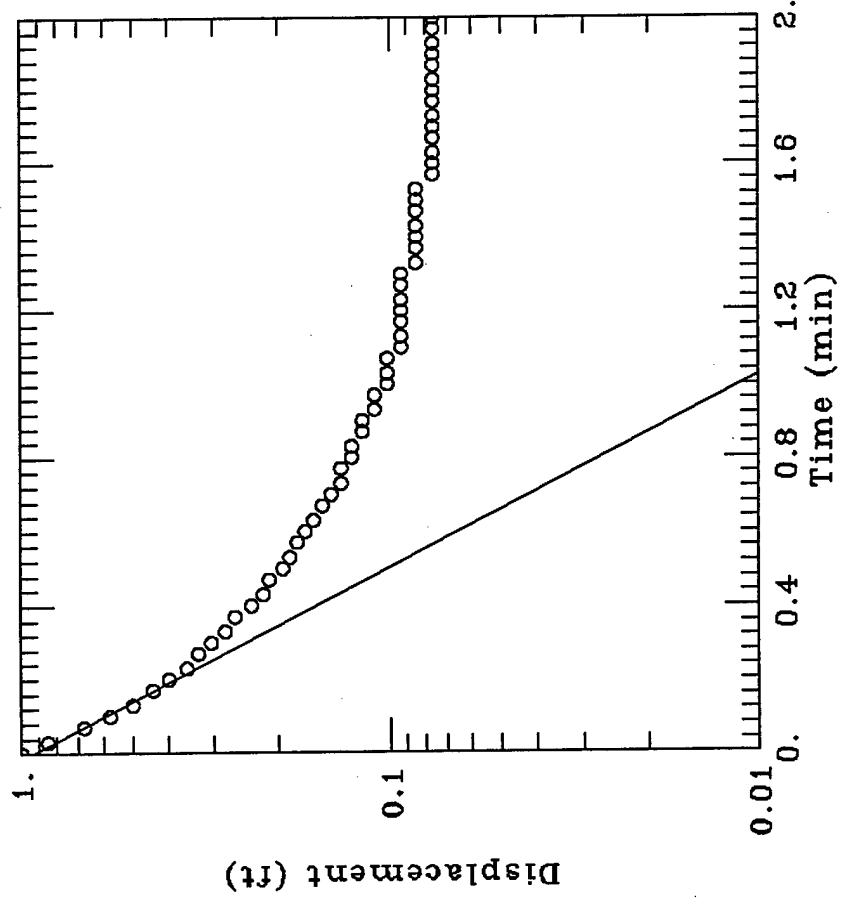
FT-03, WELL TF-8 (Rising Head Test-1)

DATA SET:
tf8r1.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002988 ft/min
Y0 = 0.9237 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 3.9 ft
H = 3.9 ft



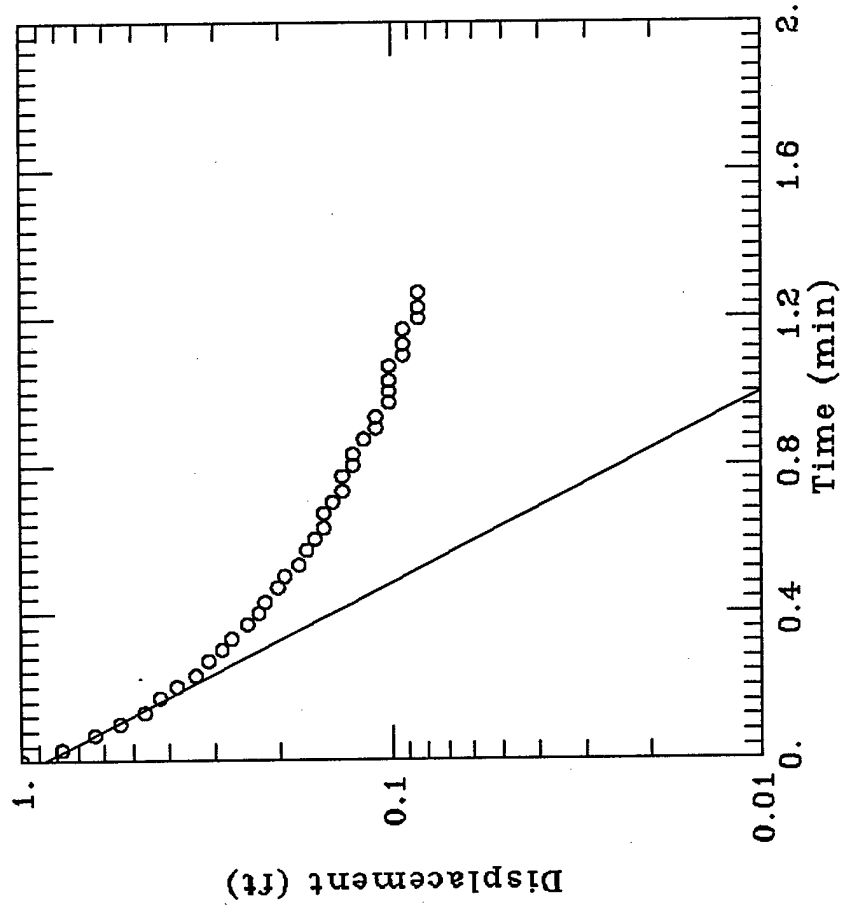
FT-03, WELL TF-8 (Rising Head Test-2)

DATA SET:
tfr2.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.00302 ft/min
y0 = 0.8618 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 3.9 ft
H = 3.9 ft



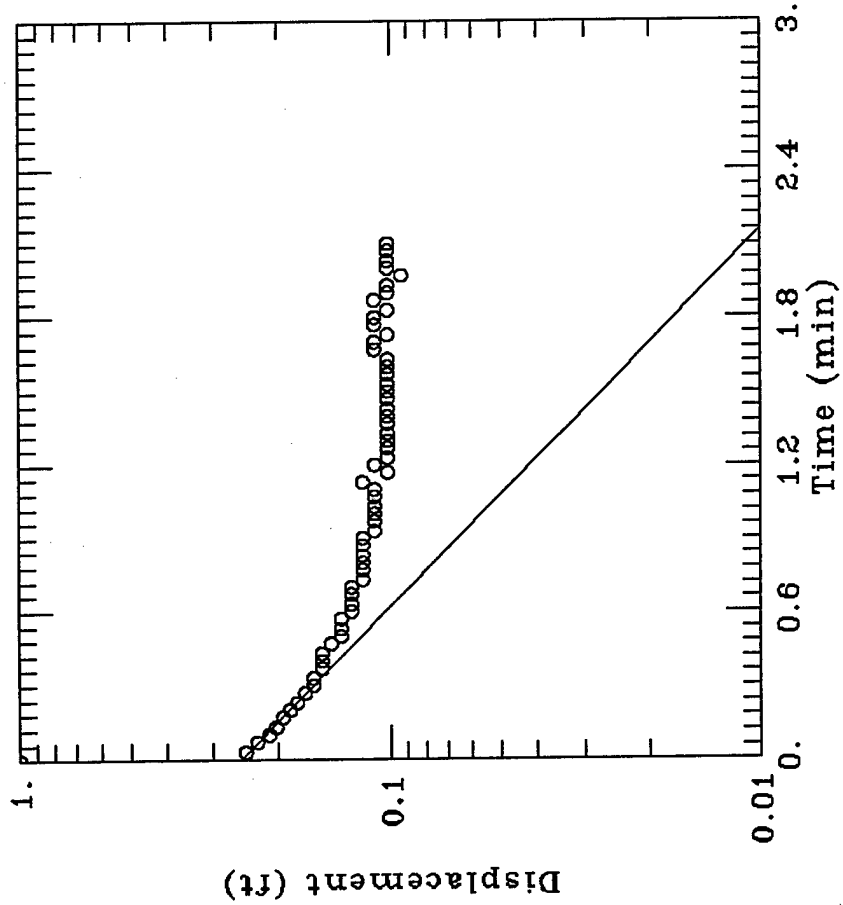
FT-03, WELL TF-16 (Falling Head Test-1)

DATA SET:
tf16f1.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.001296 ft/min
y0 = 0.2531 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 8.96 ft
H = 8.96 ft



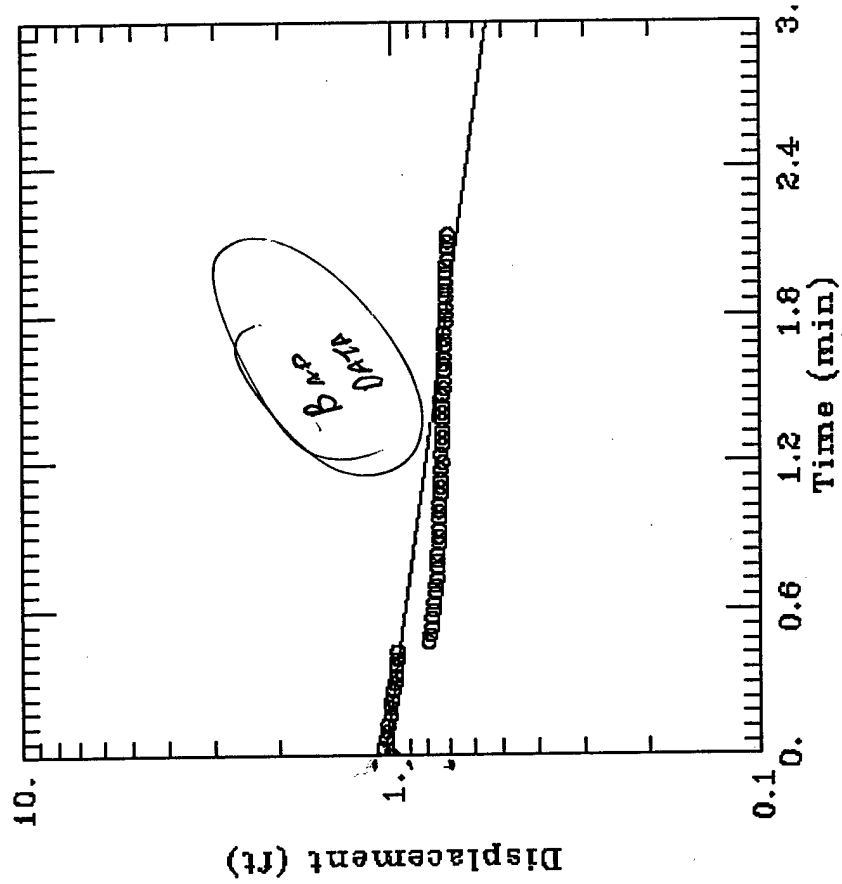
FT-03, WELL TF-16 (Falling Head Test-2)

DATA SET:
tf16f2.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bolwer-Rice

ESTIMATED PARAMETERS:
K = 0.0001848 ft/min
y0 = 1.047 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 8.96 ft
H = 8.95 ft



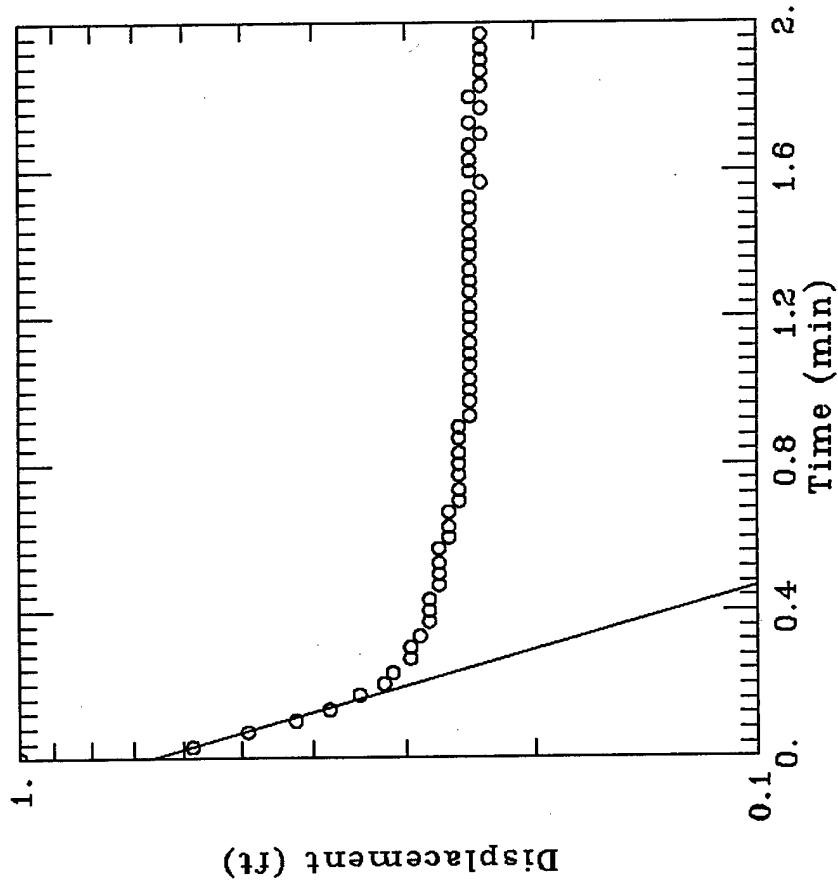
FT-03, WELL TF-16 (Rising Head Test-1)

DATA SET:
tf16r1.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.003515 ft/min
y0 = 0.6613 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 8.96 ft
H = 8.96 ft



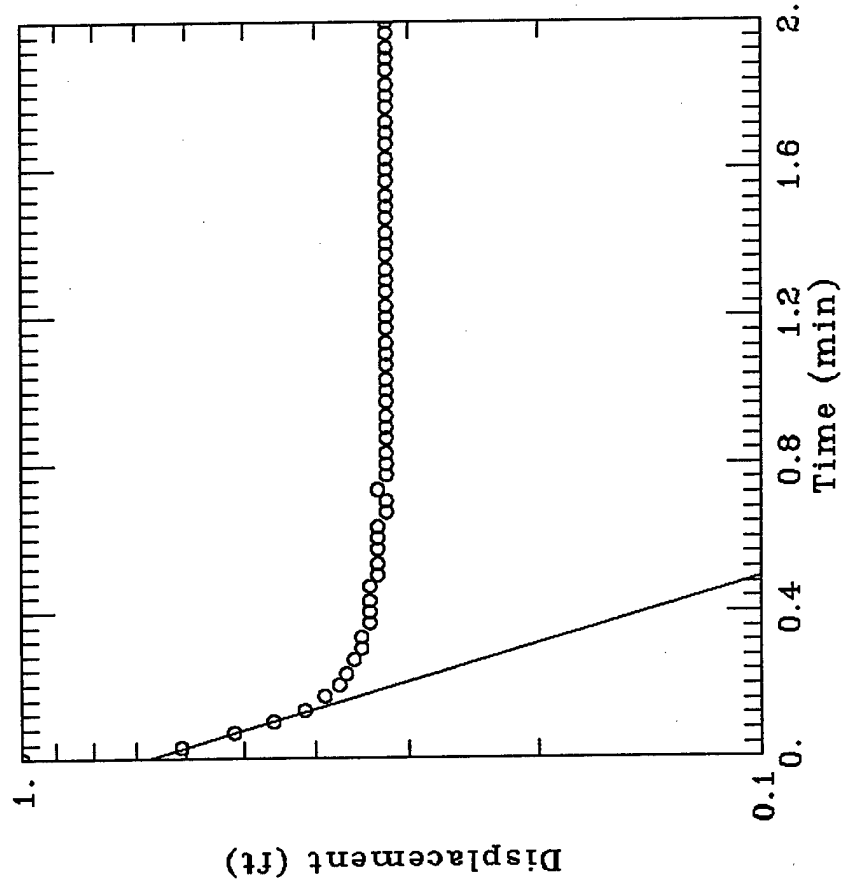
FT-03, WELL TF-16 (Rising Head Test-2)

DATA SET:
tf16r2.dat
05/24/95

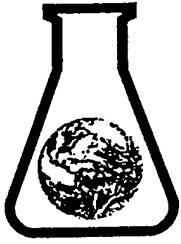
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bower-Rice

ESTIMATED PARAMETERS:
K = 0.003358 ft/min
y0 = 0.6737 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 10. ft
b = 8.96 ft
H = 8.96 ft



APPENDIX B
SOIL AND GROUNDWATER ANALYTICAL RESULTS



Environmental LABORATORY SERVICES

7280 Caswell Street, Hancock Air Park
(315) 458-8033 FAX (315) 458-0249

North Syracuse, NY 13212
(800) 842-4667

E.P.S. - SPRINGFIELD
53 TURNBULL ST.

PROJECT #: 950948
RECEIVED: 05/19/95

SPRINGFIELD MA 01104
ATTN: ENVIRONMENTAL COORDINATOR

P.O. # 82285
CLIENT JOB NUMBER: 629M0414

TEST PERFORMED	RESULTS	UNITS	DATE PERFORMED	METHOD NUMBER	PERFORMED BY
SAMPLE #: 99946	CLIENT SAMPLE ID: 861-NA-1		DATE SAMPLED: 05/15/95		
SOLIDS, TOTAL	78	PERCENT	05/19/95	EPA 160.3	MM
CARBON, TOTAL ORGANIC	<1	MG/KG	05/24/95	SW9060 MOD.	10900 (NY)
SAMPLE #: 99947	CLIENT SAMPLE ID: 861-NA-2		DATE SAMPLED: 05/15/95		
SOLIDS, TOTAL	82	PERCENT	05/19/95	EPA 160.3	MM
CARBON, TOTAL ORGANIC	<1	MG/KG	05/24/95	SW9060 MOD.	10900 (NY)
SAMPLE #: 99948	CLIENT SAMPLE ID: 861-NA-3		DATE SAMPLED: 05/15/95		
SOLIDS, TOTAL	82	PERCENT	05/19/95	EPA 160.3	MM
CARBON, TOTAL ORGANIC	<1	MG/KG	05/24/95	SW9060 MOD.	10900 (NY)
SAMPLE #: 99949	CLIENT SAMPLE ID: 861-NA-4		DATE SAMPLED: 05/15/95		
SOLIDS, TOTAL	95	PERCENT	05/19/95	EPA 160.3	MM
CARBON, TOTAL ORGANIC	<1	MG/KG	05/24/95	SW9060 MOD.	10900 (NY)
SAMPLE #: 99950	CLIENT SAMPLE ID: 861-NA-5		DATE SAMPLED: 05/18/95		
SOLIDS, TOTAL	79	PERCENT	05/19/95	EPA 160.3	MM
CARBON, TOTAL ORGANIC	<1	MG/KG	05/24/95	SW9060 MOD.	10900 (NY)

Your Full-Service Analytical Laboratory

Holding Certifications in Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New York, Pennsylvania, and Rhode Island

**MANAGEMENT
TECHNOLOGY**

Ref: 95-JH37/vg

July 11, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift ^{SV}

Dear Don:

Find attached results for methane on samples received on May 22, 1995 and analyzed on June 9, June 13, June 20, June 22, and June 26, 1995 under Service Request #SF-1-133. Samples were prepared and calculations were done as per RSKSOP-175. Analyses were performed as per RSKSOP-147.

If you have any questions, feel free to contact me.

Sincerely,

Jeff Hickerson
Jeff Hickerson

xc: R.L. Cosby
J.L. Seeley *JS*
G.B. Smith

ANALYSIS PERFORMED 6-9-95
SAMPLE METHANE

LAB BLANK	BLQ
WETF-1	BLQ
WETF-1A	BLQ
WETF-2	ND
WETF-2A	0.180
* FIELD DUP	0.154
WETF-3	BLQ
WETF-4	BLQ
WETF-5	0.003
WETF-7	BLQ
* FIELD DUP	ND
WETF-8	BLQ
* LAB DUP	BLQ
10 PPM CH4	10.39
100 PPM CH4	99.96
1000 PPM CH4	1052.50
1% CH4	1.00 %

ANALYSIS PERFORMED 6-13-95
SAMPLE METHANE

LAB BLANK	BLQ
WETF-11	0.004
WETF-12	BLQ
WETF-13	BLQ
WETF-14	BLQ
* FIELD DUP	0.0003
WETF-15	BLQ
WETF-16	BLQ
WECF-1	BLQ
WECF-1A	BLQ
WECF-2	BLQ
* LAB DUP	BLQ
10 PPM CH4	9.17
100 PPM CH4	100.07
1000 PPM CH4	1058.81

MANTECH
TECHNOLOGY

Ref: 95/JAD33

June 19, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

As requested in Service Request # SF-1-133, headspace GC/MS analysis of 46 Westover AFB water samples for tetrachloroethene (PCE), trichloroethene (TCE), dichloroethenes (DCE's) and vinyl chloride was completed. The samples were received on May 22, 1995 and analyzed on June 5-8, 1995. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the six compounds. The standard curves were prepared from 1.0 to 5000 ppb. The lower calibration limits were 1.0 ppb.

A quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in table 1 & 2.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel
John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley *JL*

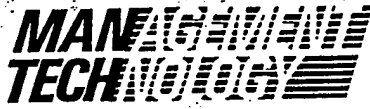
ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

Table 1. Quantitation Report for S.R. # SF-1-133 from Westover AFB.

Concentration = ppb

Compound	WECF-1A	WECF-1	WECF-2A	WECF-2	WECF-3	WECF-3 Lab Dup	WECF-3 1/10 Dil	WECF-4	WECF-5	WECF-6A
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	6.4	6.0	6.0	^^	ND	ND	2.6
T-1,2-DICHLOROETHENE	ND	ND	ND	2.1	1.8	1.8	^^	ND	ND	1.3
C-1,2-DICHLOROETHENE	ND	ND	ND	732	676	676	692	ND	7.6	2.5
TRICHLOROETHENE	ND	ND	ND	*****	*****	*****	12800	---	1.5	56.2
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WECF-6 WECF-8 WECF-8 WECF-1A WECF-1 WECF-2 WECF-2 WECF-3 WECF-3 WECF-4 WECF-5 WECF-6A										
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	---	---	ND	ND	31.9	31.9	ND	ND	ND	3.9
TRICHLOROETHENE	1.6	ND	ND	ND	ND	ND	---	---	---	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	---	ND	---
WECF-7 WECF-8 WECF-8 WECF-11 WECF-11 WECF-12 WECF-13 WECF-14 WECF-14 WECF-15 WECF-16										
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	---	12.8	13.0	1.1	1.1	1.6	1.5	---	ND
TRICHLOROETHENE	---	1.8	ND	ND	---	---	7.5	7.7	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	---	---	ND	ND
WEMP-1D WEMP-1S WEMP-2S WEMP-3S WEMP-4S WEMP-4S WEMP-5D WEMP-5S WEMP-6S WEMP-7S										
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	---	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	---	---	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	4.4	1.5	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-8M WEMP-8S WEMP-9S WEMP-10S WEMP-11S WEMP-12S WEMP-12S WEMP-14D WEMP-14M WEMP-14M Lab Dup										
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	2.2	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	2.7	---	---
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	3.0	---	---
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	158	86.7	86.3
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	4.1	541	25.8	25.9
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	1.4	ND	ND



Ref: 95-DF33

June 23, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

As requested in Service Request SF-1-133, GC/MS analysis for phenols and aliphatic/aromatic acids was done on two water samples labelled WEMP-4S and WETF-2A from Westover AFB. Liquid-liquid extraction was done by Amy Zhao on May 31, 1995. The extract was analyzed by GC/MS on June 7, 1995. A SOP describing the extraction, derivatization and GC/MS analysis is in preparation.

Liquid-Liquid Extraction of Phenols and Aliphatic/Aromatic Acids.

For the extraction of the phenols and aliphatic/aromatic acids from the water sample, 100 ml of the water sample is placed in a dried, silanized 125 ml separatory funnel. Spike solutions if applicable were added to the sample at this time. The pH of the water is adjusted to 2.0 using 1:1 H₂SO₄. For a water blank without Na₃PO₄ added, a pH of 2 is reached with ten drops. For 100 ml of water sample preserved with Na₃PO₄, twenty drops of acid is required. Next 25 g of NaCl is added to the separatory funnel after which the liquid is swirled to dissolve the salt.

The water sample is extracted four times with 5 ml aliquots of acid free methylene chloride. To remove acids from methylene chloride and other solvents, 10 g of Celite Micro-Cel T-49 is added to one liter of GC/MS grade solvent. This mixture is stirred for one hour, allowed to settle and is filtered through a Millipore organic filter pad using Millipore vacuum apparatus. The methylene chloride extracts are collected in silanized 40 ml VOA vials. The total extract volume is recorded.

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R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

Phenol/Acid Derivatization to Form PFB Ethers and Esters.

A 200 μl aliquot of the methylene chloride extract is delivered to a 2 ml screw cap vial containing 2.5 mg of dried potassium carbonate. Next 790 μl of acid free acetonitrile, 10 μl of 100 ppm benzoic acid- d_5 , and 10 μl of pentafluorobenzyl bromide is added to the vial. Benzoic acid- d_5 is the internal standard for the analysis. The vials are momentarily placed in a sonic bath to free the solid salt from the bottom of the vial. The screw caps of the vials are tightened and the vials are heated in a oven at 60°C for 2 hours. When the vials are removed from the oven, 500 μl of 0.1M HCl is added. The vials are shaken for 30 seconds and 200 μl of the top organic layer is delivered to the liner of a 2 ml crimp cap autosampler vial.

Negative Ion Chemical Ionization GC/MS Analysis of PFB-Derivatives.

For negative ion chemical ionization GC/MS, a chemical ionization ion volume is placed in the ion source block of the Finnigan 4615 GC/MS. Methane gas is regulated using a needle valve until the ionizer pressure reaches 0.40 torr. With the ionizer at this pressure, the high vacuum pressure indicates 1.0×10^{-5} torr. The mass spectrometer is tuned using the calibration gas, FC-43, to obtain good peak shape for ions 414 and 633 m/z and a relative intensity of 100:14:4 for ions 633, 414 and 127 m/z. The ion source is heated at 150°C. The injector and transfer lines are held at 275°C.

The Hewlett Packard 7673 autoinjector delivered 0.5 μl of the sample or standard to the GC injection port. A splitless injection for 1 minute was used for the analysis. The analytical column was a 60 meter, 0.25 mm J&W DB5-MS capillary column with 0.25 μm film thickness. The column was temperature programmed from 50°C to 100°C at 30°C/min and then to 300°C at 6°C/min. The helium linear velocity measured with air was 36 cm/s when the oven temperature was 100°C and the helium head pressure on the column was 29 psi. The Finnigan 4615 GC/MS was scanned from 42 to 550 m/z in 0.5 sec.

Standard curves are prepared using a mixture containing thirteen phenols, twenty-five aliphatic acids and nineteen aromatic acids. Calibration curves for acetic acid was not prepared due to artefact levels of this acid in solvents. Derivatization of the standard solutions and samples was done in the same manner. Standards are prepared at 5, 10, 25, 50, 100, 500 and 1000 ppb. Quality assurance was maintained during the sample analysis by running check standards, derivatization blanks, extraction blanks, extraction recovery check standards and spiked field samples.

Quantitative Results of Phenols and Aliphatic/Aromatic Acids.

Table I provides the concentrations aliphatic/aromatic acids found in the water sample taken at the Westover AFB site and quality assurance samples run at the same time as the samples. The lowest reported value of acid in this table is at or about 5 ppb. Please note that quantitation of phenols was not possible due to a derivatization procedure error which will be corrected in future samples.

Spike recoveries for each of the acids and phenols were determined in 50 ppb spikes of 100 ml of water blank. Recovery of the 50 ppb concentration was poor for low molecular weight aliphatic acids due to the poor extraction efficiencies of these acids from water. Higher molecular weight aliphatic and aromatic acids exhibit good recoveries.

Please note that a problem has occurred in the determination of benzoic acid at levels below 50 ppb. The benzoic acid levels found in the extraction blank are higher than that found in the sample. We will determine the source of the benzoic acid artifact before the next acid/phenol sample queue is started.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine
Dennis D. Fine

xc: J.L. Seeley *JL*
G.B. Smith
R.L. Cosby

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids for Samples from Westover AFB (Service Request SF-1-133).

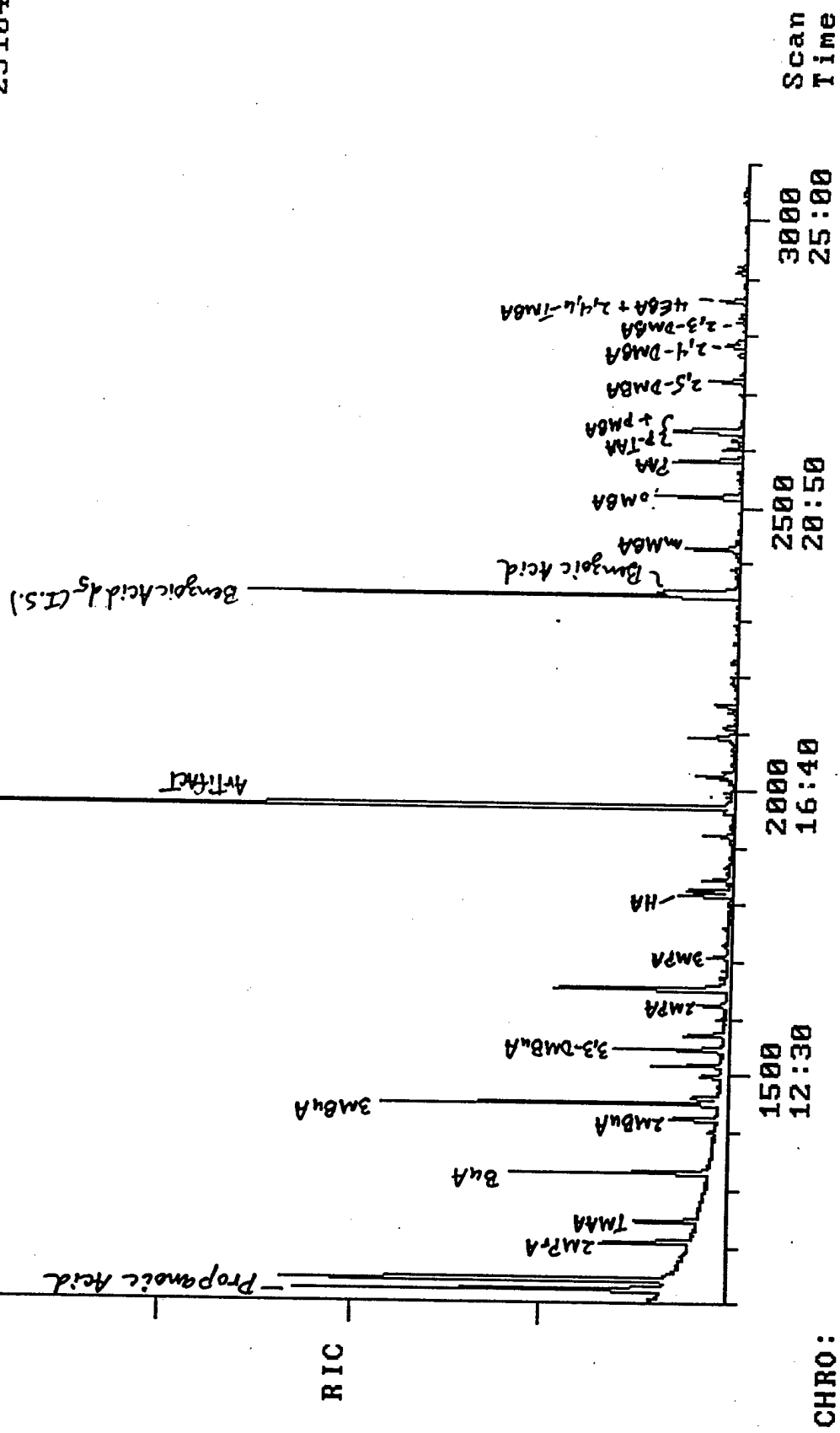
		Concentration ppb							
		WEMP-4S	WETF-2A	Extraction Blank	50 ppb Extr. Recovery	10 ppb Chk. Std.	50 ppb Chk. Std.	100 ppb Chk. Std.	500 ppb Chk. Std.
1	PROPANOIC ACID - PFB	214	19	***	9	12	53	94	732
2	2-METHYLPROPANOIC ACID - PFB	57	***	***	23	10	52	91	653
3	TRIMETHYL ACETIC ACID - PFB	35	***	***	59	10	51	90	679
4	BUTYRIC ACID - PFB	144	***	***	22	9	51	90	588
5	2-METHYLBUTYRIC ACID - PFB	28	***	***	51	10	52	93	559
6	3-METHYLBUTYRIC ACID - PFB	362	5	***	49	10	51	95	448
7	3,3-DIMETHYLBUTYRIC ACID - PFB	110	11	***	66	9	51	93	537
8	PENTANOIC ACID - PFB	52	***	6	55	8	50	91	435
9	2,3-DIMETHYLBUTYRIC ACID - PFB	10	41	***	65	8	51	95	442
10	2-ETHYLBUTYRIC ACID - PFB	N.F.	***	***	65	10	50	94	441
11	2-METHYLPENTANOIC ACID - PFB	54	***	***	66	10	50	94	435
12	3-METHYLPENTANOIC ACID - PFB	43	8	***	66	9	52	97	466
13	4-METHYLPENTANOIC ACID - PFB	N.F.	***	***	65	8	51	94	457
14	HEXANOIC ACID - PFB	13	***	18	72	6	49	89	449
15	2-METHYLHEXANOIC ACID - PFB	10	N.F.	N.F.	68	8	50	94	450
16	PHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
17	CYCLOPENTANECARBOXYLIC ACID - PFB	24	***	***	51	7	52	90	436
18	5-METHYLHEXANOIC ACID - PFB	13	***	***	68	8	51	86	463
19	o-CRESOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
20	2-ETHYLHEXANOIC ACID - PFB	77	***	26	94	12	39	80	340
21	HEPTANOIC ACID - PFB	***	N.F.	8	73	6	51	91	443
22	m-CRESOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
23	p-CRESOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	***	49	7	51	97	461
25	o-ETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
26	CYCLOPENTANEACETIC ACID - PFB	13	***	***	63	8	50	90	442
27	2,6-DIMETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
28	2,5-DIMETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
29	CYCLOHEXANECARBOXYLIC ACID - PFB	16	***	***	64	7	52	92	431
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	***	61	8	51	97	480
31	2,4-DIMETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
33	OCTANOIC ACID - PFB	***	24	15	77	7	50	92	435
34	2,3-DIMETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
35	p-ETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.
36	BENZOIC ACID - PFB	205	20	10	85	51	45	128	477
37	3,4-DIMETHYLPHENOL - PFB	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	N.Q.	36
38	m-METHYLBENZOIC ACID - PFB	316	***	N.F.	57	***	51	101	487
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	64	6	51	87	429
40	CYCLOHEXANEACETIC ACID - PFB	8	***	N.F.	65	6	51	90	441
41	2-PHENYLPROPANOIC ACID - PFB	8	N.F.	N.F.	64	6	50	103	541
42	o-METHYLBENZOIC ACID - PFB	327	12	N.F.	64	6	51	111	525
43	PHENYLACETIC ACID - PFB	266	***	***	64	5	50	108	529
44	m-TOLYLACETIC ACID - PFB	159	27	N.F.	71	***	55	99	479
45	o-TOLYLACETIC ACID - PFB	16	20	N.F.	74	27	51	96	530
46	2,6-DIMETHYLBENZOIC ACID - PFB	32	***	N.F.	67	11	56	134	626
47	p-TOLYLACETIC ACID - PFB	603	23	N.F.	83	***	59	103	578
48	p-METHYLBENZOIC ACID - PFB	237	***	N.F.	61	8	53	107	530
49	3-PHENYLPROPANOIC ACID - PFB	35	N.F.	N.F.	65	***	50	101	557
50	2,5-DIMETHYLBENZOIC ACID - PFB	221	15	N.F.	63	6	52	110	549
51	DECANOIC ACID - PFB	N.F.	8	***	66	***	51	93	470
52	2,4-DIMETHYLBENZOIC ACID - PFB	87	19	N.F.	68	7	50	107	514
53	3,5-DIMETHYLBENZOIC ACID - PFB	29	7	N.F.	63	6	49	104	519
54	2,3-DIMETHYLBENZOIC ACID - PFB	59	***	N.F.	65	6	51	115	555
55	4-ETHYLBENZOIC ACID - PFB	68	N.F.	N.F.	68	5	51	104	547
56	2,4,6-TRIMETHYLBENZOIC ACID - PFB	98	11	N.F.	64	8	52	117	545
57	3,4-DIMETHYLBENZOIC ACID - PFB	64	10	N.F.	60	***	52	104	526
58	2,4,5-TRIMETHYLBENZOIC ACID - PFB	29	***	N.F.	64	5	50	105	545

*** indicates concentration of extract was below lowest calibration standard (5 ppb).

N.F. indicates not found.

N.Q. indicates no quantitation due to derivative procedure error.

RIC 06/07/95 0:12:00 Data: 746WEMP4S #1967 Scans 1100 to 3100
 Cali: 746WEMP4S #3
 Sample: 0.5UL PFB DERIV. WESTOVER AFB SAMPLE WEMP-4S
 Conds.: 50C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS DB5MS60.25.25
 Range: G 1.4000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 50.0 23104.



CHRO:



Ref: 95-LB38
May 26, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
919 Kerr Research Drive
Ada, OK 74820

THRU: Steve Vandegrift *SV*

Dear Don:

Please find attached the analytical results for Service Request SF-1-133, Westover AFB, requesting the analysis of up to 50 groundwater samples to be analyzed for BTEXXX, TriMBs, TetraMBs, and Total Fuel Carbon. A total of 46 samples were received, some in duplicate, in capped, 40 mL VOA vials on May 22, 1995. The samples were analyzed on May 23-25, 1995. All samples were acquired and processed using the Millennium data system. A 1-500 ppb external calibration curve was used to determine the concentration for the tetramethylbenzene compounds; a 1-1000 external calibration curve was used to determine the concentration for the remaining compounds.

RSKSOP-133 "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Auto-sampling was performed using a Dynatech autosampler in-line with a Tekmar LSC 2000 sample concentrator.

Sincerely,

Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J. L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SampleName	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	1,2,4,5-Tetra	1,2,3,5-Tetra	1,2,3,4-Tetra	Fuel Carbon
100 PPB	103.02	103.50	106.67	101.83	102.44	104.42	N/A
QC, OBSERVED, PPB	47.41	47.89	46.55	45.80	50.16	50.98	N/A
QC, TRUE VALUE, PPB	50.00	50.00	50.00	50.00	50.00	50.00	N/A
WETF-1	3.05	10.83	3.80	BLQ	1.18	ND	154.4
WETF-1A	ND	ND	ND	ND	ND	ND	ND
*WETF-2	3.67	14.04	4.89	1.30	1.69	1.17	156
WETF-2A	87.43	280.06	92.38	10.08	15.67	17.36	2580
WETF-3	1.69	5.21	1.83	ND	ND	ND	56.78
WETF-4	ND	ND	ND	ND	ND	ND	BLQ
WETF-5	2.71	46.80	3.94	3.21	3.87	6.29	320.6
WETF-5 Duplicate	1.94	35.31	3.16	2.67	3.03	5.48	275.1
WETF-7	1.15	3.03	1.29	ND	ND	ND	20.31
WETF-8	1.12	2.79	1.11	ND	ND	ND	20.99
WETF-11	1.45	12.95	3.05	4.35	3.53	8.39	301.1
10 PPB	9.31	9.28	9.43	9.35	9.20	9.51	N/A
WETF-12	1.22	3.38	1.21	ND	ND	ND	29.73
WETF-13	4.46	17.32	5.39	0.96	1.55	ND	160.9
WETF-14	2.52	9.26	2.95	ND	1.00	ND	80.58
WETF-15	ND	ND	ND	ND	ND	ND	BLQ
WETF-16	2.75	10.14	3.23	ND	0.89	ND	105.3
WECF-1	ND	ND	ND	ND	ND	ND	ND
WECF-1A	ND	ND	ND	ND	ND	ND	ND
WECF-2	ND	ND	ND	ND	ND	ND	ND
WECF-2A	202.38	503.89	328.44	37.57	57.27	62.70	4720
WECF-3	185.98	549.35	309.57	24.54	40.09	52.62	11000
500 PPB	513.16	506.78	512.68	490.29	491.89	497.95	N/A
*WECF-4	ND	1.99	1.34	ND	ND	ND	21.85
WECF-5	ND	1.82	1.43	ND	ND	ND	9.71
WECF-6	ND	ND	ND	ND	ND	ND	ND
WECF-6A	ND	ND	ND	ND	ND	ND	42.88
WECF-6A Duplicate	ND	ND	ND	ND	ND	ND	46.11
WECF-8	ND	ND	ND	ND	ND	ND	ND
WEMP-1D	ND	ND	ND	ND	ND	ND	ND
WEMP-1S	ND	ND	ND	ND	ND	ND	ND
WEMP-2S	ND	ND	ND	ND	ND	ND	BLQ
WEMP-3S	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	47.41	47.97	46.40	45.32	49.87	50.24	N/A
QC, TRUE VALUE, PPB	50.00	50.00	50.00	50.00	50.00	50.00	N/A
WEMP-4S	263.39	816.95	502.99	106.28	141.10	182.62	30400
WEMP-5D	2.29	3.08	1.64	ND	ND	ND	55.97
WEMP-5S	1.13	1.80	1.13	ND	ND	ND	22.96
WEMP-6S	ND	ND	ND	ND	ND	ND	ND
WEMP-6 Duplicate	ND	ND	ND	ND	ND	ND	BLQ
WEMP-7S	ND	ND	ND	ND	ND	ND	ND
WEMP-8M	ND	ND	ND	ND	ND	ND	ND
WEMP-8S	ND	ND	ND	ND	ND	ND	ND
WEMP-9S	ND	ND	ND	ND	ND	ND	ND
WEMP-10S	ND	ND	ND	ND	ND	ND	BLQ
10 PPB	9.99	10.16	10.52	10.47	10.54	10.71	N/A
WEMP-11S	15.38	13.61	18.62	4.08	4.62	4.24	335.3
WEMP-11S Duplicate	13.24	13.57	18.75	5.13	5.71	5.18	337.6
WEMP-12S	218.23	650.25	353.72	22.61	37.71	47.00	32600
WEMP-14D	24.66	62.50	40.48	2.08	3.66	5.47	2021
WEMP-14M	19.28	43.26	27.36	2.75	4.02	5.18	668.1
WEMP-15D	1.85	3.54	3.57	ND	ND	ND	52.06
WEMP-15M	ND	ND	ND	ND	ND	ND	ND
WEMP-15S	ND	ND	ND	ND	ND	ND	BLQ
WEMP-16D	ND	ND	ND	ND	ND	ND	BLQ
100 PPB	100.10	100.14	99.92	99.00	99.32	98.55	N/A

* Sample was analyzed after a very contaminated sample, therefore the concentrations reported may not represent the true values.

ND = None Detected; N/A = Not Analyzed; BLQ = Below Limit of Quantitation, 1 ppb

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE
100 PPB	102.58	101.76	102.01	101.32	102.15	103.44
QC, OBSERVED, PPB	48.12	49.82	52.23	47.13	46.51	50.31
QC, TRUE VALUE, PPB	50.00	50.00	50.00	50.00	50.00	50.00
WETF-1	14.51	57.17	13.86	9.84	23.74	17.74
WETF-1A	ND	ND	ND	ND	ND	ND
*WETF-2	7.84	39.38	11.52	9.22	21.00	14.58
WETF-2A	5.01	184.60	378.61	255.13	559.53	273.67
WETF-3	1.89	20.17	6.10	4.48	10.97	7.35
WETF-4	ND	BLQ	ND	ND	BLQ	ND
WETF-5	2.29	19.39	45.65	31.01	15.59	9.18
WETF-5 Duplicate	1.52	12.83	36.57	23.81	10.75	6.23
WETF-7	BLQ	4.54	1.87	1.53	3.45	2.45
WETF-8	BLQ	5.81	2.12	1.60	3.73	2.64
WETF-11	1.99	11.58	39.75	10.14	8.37	5.07
10 PPB	9.93	10.52	10.06	9.82	10.23	9.70
WETF-12	BLQ	8.84	2.89	2.37	5.77	3.90
WETF-13	3.71	42.29	16.54	12.28	29.36	19.92
WETF-14	1.69	20.34	8.18	6.20	14.56	9.44
WETF-15	ND	BLQ	ND	ND	ND	ND
WETF-16	3.46	32.79	11.27	8.10	19.51	13.23
WECF-1	ND	ND	ND	ND	ND	ND
WECF-1A	ND	ND	ND	ND	ND	ND
WECF-2	ND	ND	ND	ND	ND	ND
WECF-2A	170.39	35.03	370.47	471.31	1032.92	940.26
WECF-3	271.40	2642.91	637.12	584.69	1252.41	877.40
500 PPB	509.38	510.67	507.87	502.29	513.55	508.78
*WECF-4	BLQ	3.40	BLQ	1.06	2.71	1.62
WECF-5	1.75	ND	BLQ	1.96	ND	ND
WECF-6	ND	ND	ND	ND	ND	ND
WECF-6A	25.30	ND	ND	ND	ND	ND
WECF-6A Duplicate	24.69	BLQ	ND	BLQ	BLQ	BLQ
WECF-8	ND	ND	ND	ND	ND	ND
WEMP-1D	ND	ND	ND	ND	ND	ND
WEMP-1S	ND	ND	ND	ND	ND	ND
WEMP-2S	ND	BLQ	ND	ND	ND	ND
WEMP-3S	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	48.49	50.47	52.13	46.89	46.99	50.42
QC, TRUE VALUE, PPB	50.00	50.00	50.00	50.00	50.00	50.00
WEMP-4S	8488.59	15760.45	1568.85	1184.67	3397.00	2157.05
WEMP-5D	6.95	BLQ	2.45	7.21	18.41	14.63
WEMP-5S	2.40	BLQ	0.59	3.57	6.93	6.97
WEMP-6S	ND	ND	ND	ND	ND	ND
WEMP-6S Duplicate	ND	BLQ	ND	ND	BLQ	ND
WEMP-7S	ND	ND	ND	ND	ND	ND
WEMP-8M	ND	ND	ND	ND	ND	ND
WEMP-8S	ND	ND	ND	ND	ND	ND
WEMP-9S	ND	ND	ND	ND	ND	ND
WEMP-10S	ND	BLQ	ND	ND	ND	ND
10 PPB	10.63	10.47	10.62	10.43	10.37	10.45
WEMP-11S	2.82	BLQ	19.62	12.36	10.97	11.45
WEMP-11S Duplicate	3.63	0.97	19.31	12.52	11.04	11.50
WEMP-12S	2260.51	15263.80	1455.23	1146.72	3017.60	1868.31
WEMP-14D	266.53	780.16	126.11	116.53	236.12	126.19
WEMP-14M	153.26	1.62	70.41	90.26	6.65	1.64
WEMP-15D	2.03	ND	4.85	7.84	18.68	13.40
WEMP-15M	ND	ND	ND	ND	ND	ND
WEMP-15S	0.92	BLQ	ND	ND	ND	ND
WEMP-16D	ND	ND	ND	ND	BLQ	BLQ
100 PPB	98.40	100.86	101.63	100.70	99.51	100.71

* Sample was analyzed after a very contaminated sample, therefore the concentrations reported may not represent the the true values.

ND = None Detected; N/A = Not Analyzed; BLQ = Below Limit of Quantitation, 1 ppb

**MANTECH
TECHNOLOGY**

Ref: 95-MW62/vg
95-CH14/vg

June 27, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

Attached are the results of 46 field samples from Westover submitted to ManTech as part of S.R. #SF-1-133. The samples were received on May 22, 1995 and analyzed immediately. The methods used for analysis were EPA Method 350.1, 353.1, and Water's capillary electrophoresis Method N-601. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results please feel free to contact us.

Sincerely,



Mark White



Cherri Heard

xc: R.L. Cosby
J.L. Seeley
G.B. Smith

<u>Sample</u>	<u>mg/l</u> <u>Cl⁻</u>	<u>mg/l</u> <u>SO₄⁻²</u>	<u>mg/l</u> <u>NO₂⁻+NO₃⁻(N)</u>	<u>mg/l</u> <u>NH₃(N)</u>
WETF-1	4.58	21.7	.99	.17
WETF-1A	3.47	7.18	1.25	<.05
WETF-1A Dup	3.50	7.16	----	----
WETF-2	4.02	19.8	1.28	<.05
WETF-2A	3.63	6.32	.07	4.12
WETF-3	4.29	21.9	3.88	<.05
WETF-4	4.13	35.8	2.64	<.05
WETF-5	1.45	6.10	.35	1.58
WETF-5 Dup	----	----	.35	1.57
WETF-7	1.69	41.9	2.59	<.05
WETF-8	2.60	51.6	1.79	<.05
WETF-11	4.41	37.7	.07	3.11
WETF-12	1.95	14.2	2.64	.14
WETF-13	2.79	39.4	3.18	.17
WETF-13 Dup	2.98	39.3	3.17	.18
WETF-14	5.42	52.8	2.89	.12
WETF-15	1.97	35.7	2.29	.09
WETF-16	1.66	16.4	2.01	<.05
WECF-1	9.17	21.7	<.05	.11
WECF-1A	.52	7.16	<.05	<.05
WECF-1A Dup	.51	7.38	----	----
WECF-2	1.1	13.2	<.05	.13
WECF-2 Dup	----	----	<.05	.14
WECF-2A	.67	<.5	.22	6.55
WECF-3	1.93	1.43	<.05	3.17
WECF-4	<.5	6.14	<.05	<.05
WECF-5	1.07	24.6	.34	.20
WECF-5 Dup	1.07	25.2	----	----
WECF-6	2.72	9.44	.07	.32
WECF-6A	9.42	11.3	<.05	.16
WECF-8	.79	3.55	.53	<.05
WEMP-1D	3.03	<.5	5.77	.07
WEMP-1D Dup	----	----	5.73	.07
WEMP-1S	1.19	6.52	3.87	<.05
WEMP-2S	1.39	13.9	5.60	<.05
WEMP-3S	1.17	8.07	2.46	<.05
WEMP-4S	8.06	2.41	<.05	4.72
WEMP-5D	8.38	2.28	<.05	.38
WEMP-5D Dup	8.47	2.27	----	----
WEMP-5S	4.21	1.46	.06	.21
WEMP-6S	1.45	10.9	1.19	<.05
WEMP-6S Dup	----	----	1.18	<.05
WEMP-7S	1.11	6.37	.33	<.05
WEMP-8S	1.30	8.56	1.84	.06
WEMP-8M	1.23	3.46	1.71	.18
WEMP-9S	.94	7.91	3.99	<.05
WEMP-10S	1.30	8.57	.12	<.05
WEMP-11S	1.77	6.60	<.05	15.5
WEMP-11S Dup	----	----	<.05	13.8
WEMP-12S	1.10	<.5	<.05	5.87
WEMP-14D	150	.86	.09	6.11

**MANAGEMENT
TECHNOLOGY**

Ref: 95-TL23/vg

June 28, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Attached are TC, TOC, and TIC results for a set of 46 liquid samples received by MERSC May 22, 1995 under Service Request #SF-1-133. Determinations were begun June 5, 1995 and completed June 27, 1995 using RSKSOP-102.

A known AQC sample was analyzed with your samples for quality control. If you have any questions concerning these results please feel free to contact me.

Sincerely,

Teresa Leon

Teresa Leon

xc: R.L. Cosby
J.L. Seeley *JS*
G.B. Smith

TC, TOC, AND TIC RESULTS FOR DON KAMBELL (SF-1-133)

SAMPLE	MG/L		MG/L		SAMPLE	MG/L		MG/L	
	TC	TIC	TC	TIC		TC	TIC	TC	TIC
WETF-1	23.1	16.6	6.5	6.5	WEMP-15M	14.4	1.6	1.6	12.8
WETF-1A	20.7	6.4	14.3	14.3	WEMP-15S	20.3	7.1	7.1	13.2
WETF-2	40.9	16.6	24.3	24.3	WEMP-16D	13.9	3.7	3.7	10.2
WETF-2A	96.0	26.0	70.0	70.0	WEMP-8M	5.0	2.0	2.0	3.0
WETF-3	42.8	7.2	35.6	35.6					
WETF-4	37.8	8.7	29.1	29.1	WPO33-II				35.1
WETF-5	39.9	6.1	33.8	33.8					35.1
WETF-7	47.5	4.2	43.3	43.3					35.1
WETF-8	70.3	6.2	64.1	64.1					35.7
WETF-11	114.7	15.5	99.2	99.2					34.9
WETF-11 DUP	114.3	15.4	98.9	98.9					35.0
WETF-12	39.6	6.8	32.8	32.8					35.2
WETF-13	54.3	6.5	47.8	47.8					35.0
WETF-14	90.6	9.7	80.9	80.9					35.3
WETF-15	45.6	5.5	40.1	40.1					35.2
WETF-16	20.4	5.7	14.7	14.7					35.4
WECF-1	5.6	1.0	4.6	4.6					35.0
WECF-1A	2.3	1.2	1.1	1.1					35.4
WECF-2	4.7	0.8	3.9	3.9					35.4
WECF-2A	114.3	52.5	61.8	61.8					35.9
WECF-3	41.8	25.8	16.0	16.0					
WECF-3 DUP	41.2	25.0	16.2	16.2					
WECF-4	7.0	5.6	1.4	1.4					
WECF-5	11.0	3.9	7.1	7.1					
WECF-6	8.8	1.1	7.7	7.7					
WECF-6A	16.4	4.1	12.3	12.3					
WECF-8	10.2	1.7	8.5	8.5					
WEMP-1D	7.1	1.0	6.1	6.1					
WEMP-1S	3.3	1.8	1.5	1.5					
WEMP-2S	12.0	3.8	8.2	8.2					
WEMP-3S	6.2	2.7	3.5	3.5					
WEMP-4S	77.1	60.2	16.9	16.9					
WEMP-5D	22.5	4.3	18.2	18.2					
WEMP-5D DUP	21.8	4.4	17.4	17.4					
WEMP5S	16.0	3.0	13.0	13.0					
WEMP-6S	11.2	4.5	6.7	6.7					
WEMP-7S	3.1	2.4	0.7	0.7					
WEMP-8S	10.7	1.3	9.4	9.4					
WEMP-9S	8.2	3.1	5.1	5.1					
WEMP-10S	5.7	3.4	2.3	2.3					
WEMP-11S	65.8	24.0	41.8	41.8					
WEMP-12S	85.7	67.8	17.9	17.9					
WEMP-14D	115.0	94.4	20.6	20.6					
WEMP-14M	108.1	53.3	54.8	54.8					
WEMP-14M DUP	107.0	53.3	53.7	53.7					
WEMP-15D	18.2	2.0	16.2	16.2					

TRUE VALUES: WPO33-II = 35.0 MG/L

**MANTECH
TECHNOLOGIES**

Ref: 95-MB7/vg

May 31, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SAV*

Dear Don:

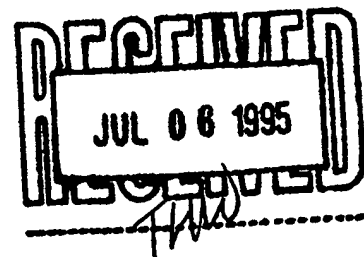
As per Service Request #SFTA-1-56, analysis was completed on 46 water samples from Westover AFB, MA. I performed analysis on-site for pH, specific conductance ($\mu\text{S}/\text{cm}$), phenolphthalein alkalinity (ppm as CaCO_3), total alkalinity (ppm as CaCO_3), and redox potential (mV). The analysis began May 17, 1995 and was completed May 19, 1995. Please find attached the data compiled from my lab book. Other data from the site was tabulated for your convenience.

If you have any questions, please contact me at your convenience.

Sincerely,

Mark Blankenship
Mark Blankenship

xc: R.L. Cosby
J.L. Seeley *JS*
G.B. Smith



ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

sample	pH	spec. cond. (uS/cm)	pheno alk (ppm)	total alk. (ppm)	redox (mV)	phenols (ppm)	soluble Fe (ppm)	HS (ppm)	CO ₂ (ppm)	Mn (ppm)
WECF-1	6.8	240	15	40	168.1	< 0.1	5.5	< 0.1	1.25	< 0.1
WECF-1A	5	28.3	< 0.1	5	195.2	< 0.1	< 0.1	< 0.1	7.5	< 0.1
WECF-2	5	77.7	< 0.1	35	13.2	< 0.1	4.5	< 0.1	14	< 0.1
WECF-2A	6.4	501	< 0.1	240	-3.2	*****	3	< 0.1	75	< 0.1
WECF-3	5.5	118.8	< 0.1	35	46.1	*****	10	2	100	< 0.1
WECF-4	5.5	35.3	< 0.1	15	-5	*****	< 0.1	< 0.1	15	< 0.1
WECF-5	5.2	87.9	< 0.1	10	184.7	< 0.1	5.5	< 0.1	30	< 0.1
WECF-6	5	87	< 0.1	35	19.4	< 0.1	8	< 0.1	18.75	0.2
WECF-6A	5	98.4	< 0.1	20	126.1	< 0.1	6.5	< 0.1	33	< 0.1
WECF-8	5	43.8	< 0.1	15	150.5	< 0.1	1.5	< 0.1	40	< 0.1
WEMP-1D	5.2	96.3	< 0.1	10	170	< 0.1	1	< 0.1	25	0.8
WEMP-1S	5.1	80.4	< 0.1	5	187.1	*****	1	< 0.1	15	< 0.1
WEMP-2S	5.3	145.9	< 0.1	20	160.8	*****	0.4	< 0.1	25	< 0.1
WEMP-3S	5.4	67.5	< 0.1	10	177.8	< 0.1	< 0.1	< 0.1	20	< 0.1
WEMP-4S	6.4	423	< 0.1	180	-18	*****	100	< 0.1	200	< 0.1
WEMP-5D	5	89.4	< 0.1	30	115.7	< 0.1	9	< 0.1	60	< 0.1
WEMP-5S	5	30.4	< 0.1	20	113.4	< 0.1	5.5	< 0.1	25	< 0.1
WEMP-6S	4.9	56.5	< 0.1	< 0.1	165	< 0.1	0.2	< 0.1	40	< 0.1
WEMP-7S	6.1	26.9	< 0.1	5	249.5	< 0.1	0.2	< 0.1	20	< 0.1
WEMP-8M	5.8	90.4	< 0.1	25	129.7	< 0.1	3.5	< 0.1	50	< 0.1
WEMP-8S	4.9	86.5	< 0.1	10	170	< 0.1	1.5	< 0.1	25	< 0.1
WEMP-9S	4.6	76.3	< 0.1	5	200.5	< 0.1	0.2	< 0.1	40	< 0.1
WEMP-10S	5.5	55.1	< 0.1	15	89	*****	2.5	< 0.1	15	< 0.1
WEMP-11S	6	392	< 0.1	200	-32.8	*****	9	< 0.1	55	< 0.1
WEMP-12S	5.7	138.1	< 0.1	45	68.4	*****	20	< 0.1	100	< 0.1
WEMP-14D	6	842	< 0.1	260	-105.1	10	280	< 0.1	250	< 0.1
WEMP-14	6	832	< 0.1	260	-45.5	10	280	< 0.1	275	< 0.1
WEMP-15D	5.4	132.9	< 0.1	10	77.2	< 0.1	9	< 0.1	60	< 0.1
WEMP-15	5	73.9	< 0.1	25	35	< 0.1	7.5	< 0.1	40	< 0.1
WEMP-15S	5.4	155.5	< 0.1	50	39.2	< 0.1	9	< 0.1	50	< 0.1
WEMP-16D	5	68.2	< 0.1	25	59.9	< 0.1	8	< 0.1	30	< 0.1
WETF-1	5.5	127.5	< 0.1	35	60.5	< 0.1	2.5	0.7	15	< 0.1
WETF-1A	5.5	78.7	< 0.1	20	42.1	< 0.1	< 0.1	0.7	20	< 0.1
WETF-2	5.4	143.6	< 0.1	50	210.8	*****	< 0.1	0.5	20	< 0.1
WETF-2A	6.6	552	< 0.1	300	-39.8	*****	600	< 0.1	275	< 0.1
WETF-3	5.9	296	< 0.1	85	197.4	< 0.1	< 0.1	0.7	55	< 0.1
WETF-4	5.5	235	< 0.1	70	196.3	< 0.1	< 0.1	0.5	90	< 0.1
WETF-5	6	281	< 0.1	140	26.7	*****	25	< 0.1	150	0.4
WETF-7	5.7	339	< 0.1	120	138.6	*****	< 0.1	< 0.1	40	< 0.1
WETF-8	6.1	510	< 0.1	160	105.3	*****	< 0.1	< 0.1	45	< 0.1
WETF-11	7.2	697	< 0.1	320	-33	*****	1	0.5	175	0.5
WETF-12**	5.5	228	< 0.1	50	175.3	*****	< 0.1	1	65	< 0.1
WETF-13**	5.3	394	< 0.1	90	170.2	*****	< 0.1	0.7	100	< 0.1
WETF-14	6.2	586	< 0.1	240	35.8	*****	< 0.1	0.5	100	< 0.1
WETF-15	5.6	297	< 0.1	55	62.9	*****	< 0.1	< 0.1	100	< 0.1
WETF-16	5.8	123.1	< 0.1	320	-33	*****	< 0.1	0.3	25	0.3

***** = ran out of ampoules and could not perform analysis

WETF-12** = very muddy sample

WETF-13** = very muddy sample

MANTECH TECHNOLOGY

Ref: 96-LP86/vg
96-MW81/vg
96-TH48/vg

July 24, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift^{SV}

Dear Don:

Attached are the results of 36 Westover AFB samples submitted to MERSC as part of Service Request #SF-2-223. The samples were received July 18 and 22, 1996 and analyzed immediately. The methods used for analysis were EPA Methods 353.1 for NO₂ and NO₃, and 350.1 for NH₃ and Waters capillary electrophoresis Method N-601 for Cl and SO₄. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Lynda Pennington
Lynda Pennington

Mark White

Mark White

Tim Hensley
Tim Hensley

xc: R.L. Cosby
G.B. Smith
J.L. Seeley^{SV}
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Samples Received July 18, 1996

Sample	mg/L <u>Cl⁻</u>	mg/L <u>SO₄⁻²</u>	mg/L <u>NO₂⁻+NO₃⁻(N)</u>	mg/L <u>NH₃</u>
WETF-1A	3.87	9.83	1.62	0.17
WEFT-1	8.03	29.0	0.52	<.05
WETF-4	5.88	210	6.67	<.05
WETF-3	3.16	33.3	3.02	<.05
WETF-12	2.96	18.5	1.98	<.05
WETF-13	3.11	44.7	2.52	<.05
WETF-13 Dup	3.46	44.9	----	----
WETF-14	6.14	436	7.31	<.05
WETF-5	2.98	58.0	1.86	0.20
WEMP-1S	1.40	5.55	1.86	<.05
WEMP-1D	2.46	<.5	5.57	<.05
WEMP-1D Dup	----	----	5.59	<.05
WECF-8	.91	4.70	0.45	0.14
WEMP-8M	1.57	10.7	2.61	<.05
WEMP-16D	1.82	3.96	<.05	0.26
WEMP-5M	6.10	2.45	<.05	0.28
WEMP-14M	84.6	11.1	<.05	5.21
WEMP-14M Dup	84.1	10.6	----	----
WEMP-14D	131	<.5	0.09	4.18
WEMP-14D Dup	----	----	0.11	4.17
Blank	<.5	<.5	<.05	<.05
AQC	56.0	52.4	0.37	1.41
AQC	56.3	52.5	0.39	1.40
Spike Rec.	101%	98%	101%	102%

Samples Received July 22, 1996

WECF-2	<.5	10.6	<.05	.28
WECF-2A	<.5	<.5	.10	4.49
WECF-3	<.5	<.5	<.05	2.81
WECF-5	<.5	16.6	.41	<.05
WECF-6	5.93	4.21	<.05	.53
WECF-6A	<.5	13.3	1.45	<.05
WECF-6A Dup	<.5	13.5	----	----
WEFT-2	2.29	16.4	1.32	<.05
WEFT-2A	3.47	208	<.05	1.54
WEFT-7	<.5	61.1	2.42	<.05
WEFT-8	<.5	73.6	1.90	<.05

Sample	mg/L <u>Cl⁻</u>	mg/L <u>SO₄⁻²</u>	mg/L <u>NO₂⁻+NO₃⁻(N)</u>	mg/L <u>NH₃</u>
WEFT-8 Dup	-----	-----	1.92	<.05
WEFT-11	3.94	224	1.32	1.63
WEFT-15	1.58	38.7	.95	<.05
WEFT-16	1.60	4.15	.61	<.05
WEMP-4S	1.57	<.5	<.05	4.81
WEMP-10S	1.31	7.88	.75	<.05
WEMP-11S	.76	76.7	.64	3.93
WEMP-12S	1.48	<.5	<.05	5.17
WEMP-12S Dup	1.51	<.5	<.05	5.13
WEMP-15D	9.75	3.83	<.05	.32
WEMP-15M	3.33	<.5	<.05	.18
WEMP-15S	1.59	3.16	2.73	<.05
Blank	<.5	<.5	<.05	<.05
AQC	55.5	52.0	.39	1.50
True Value	55.9	52.0	.39	1.40
Spike Rec.	102%	101%	101%	102%

MANTECH TECHNOLOGY

Ref: 96-DF46

Aug. 2, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

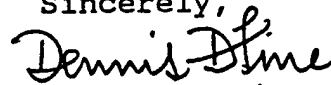
Dear Don:

As requested in Service Request SF-2-223, GC/MS analysis for phenols and aliphatic/aromatic acids was done on three water samples taken at Westover AFB. These samples were labeled: WEMP-14M, WEMP-14D and WEFT-2A. Derivatization of the samples was done by Amy Zhao on July 22, 1996. The extract was analyzed by GC/MS on July 28, 1996. RSKERL SOP 177 was used for the extraction, derivatization and GC/MS analysis of the samples.

Table I provides the concentrations of the phenols and aliphatic/aromatic acids found in the water samples from Westover AFB. Derivative and extraction blanks, an extraction recovery and a 100 ppb check standard are also included in the table.

Chromatograms of the three samples are provided to show additional information not evident from the quantitation report. Each chromatogram shows evidence of C₈ aliphatic acids. These acids were most abundant in sample WEMP-14D. C₇, C₉, and C₁₀ aliphatic acids were also found in this sample.

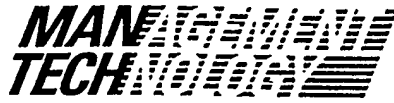
If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

xc: J. Wilson
J. Seeley
G. Smith
R. Cosby
D. Fine

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501



Ref: 96-NV138/vg

August 7, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: J.L. Seeley *JL*

Dear Don:

Attached is the metal analysis report (4535.LST) for six samples (Westover AFB) submitted to MERSC as part of Service Request #65 under EPA Contract #68-C3-0322. The samples were received on July 24, 1996 and analyzed July 29 and 31, 1996. The samples did not receive any further treatment and they were analyzed using the ICAP system. Lead was determined using GF-AAS and results are in report PB60731-Lis;1. SOP for the ICP and sample calculations were according to the procedure and instructions provided by Mr. Don Clark.

If you have any questions, please feel free to contact me.

Sincerely,

Nohora Vela

Nohora Vela

xc: R.L. Cosby
R. Puls
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

PROJECT: AQ FILTERED FIELD DIRECT READING WESTOVER AFB
KAMPBELL
SR65

CONCENTRATION IN: MG/L

TAG NO.	14552	14553	14554	14555
STATION	WEFT-12	WEFT-14	WEFC-2A	WEFC 8
TIME	09:26	09:07	09:16	09:18
DATE	29-JUL-96	29-JUL-96	29-JUL-96	29-JUL-96
PR DIL	1.0000	1.0000	1.0000	1.0000
DIL	1.0000	1.0000	1.0000	1.0000

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	2.07	0.20	10.7	1.0	0.960	0.095	2.03	0.20	0.0947
K	2.4	1.9	13.6	1.9	<1.9	1.9	<1.9	1.9	1.9371
Ca	16.5	1.6	185.	18.	94.5	9.4	4.01	0.40	0.0244
Mg	1.33	0.13	16.6	1.6	1.37	0.13	0.576	0.090	0.0904
Fe	0.0170	0.0046	<0.0047	0.0047	4.28	0.42	1.61	0.16	0.0046
Mn	<0.0017	0.0017	<0.0018	0.0018	0.330	0.033	0.0356	0.0036	0.0017
Co	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	<0.0084	0.0084	0.0084
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0125
Al	<0.082	0.082	<0.082	0.082	<0.082	0.082	<0.082	0.082	0.0824
As	<0.025	0.025	<0.025	0.025	<0.025	0.025	<0.025	0.025	0.0258
Se	<0.028	0.028	<0.028	0.028	<0.028	0.028	<0.028	0.028	0.0286
Cd	<0.0019	0.0019	<0.0020	0.0020	<0.0019	0.0019	<0.0019	0.0019	0.0019
Be	<0.0007	0.0007	<0.0016	0.0016	<0.0010	0.0010	<0.0007	0.0007	0.0007
Cu	<0.027	0.027	<0.028	0.028	<0.028	0.028	<0.027	0.027	0.0279
Cr	<0.0005	0.0005	0.0014	0.0005	0.0007	0.0005	<0.0005	0.0005	0.0005
Ni	<0.0061	0.0061	<0.0061	0.0061	<0.0061	0.0061	<0.0061	0.0061	0.0061
Zn	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	0.0031
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0158
Tl	<0.011	0.011	<0.011	0.011	<0.011	0.011	<0.011	0.011	0.0116
Pb	<0.030	0.030	<0.030	0.030	<0.030	0.030	<0.030	0.030	0.0306
Sr	0.0941	0.0096	0.696	0.069	0.130	0.013	0.0317	0.0032	0.0007
V	<0.018	0.018	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0182
Ba	0.0297	0.0031	0.0943	0.0098	0.0324	0.0035	0.0238	0.0024	0.0020
B	0.056	0.011	0.365	0.036	0.036	0.011	<0.011	0.011	0.0114
Ti	<0.0089	0.0089	<0.0089	0.0089	<0.0089	0.0089	<0.0089	0.0089	0.0089

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS
EPA/RSKRL/ADA, OK

PROJECT: AQ FILTERED FIELD DIRECT READING WESTOVER, AFB
KAMPBELL
SR65

CONCENTRATION IN: MG/L

TAG NO. 14556
STATION WEMP-14D
TIME 09:21
DATE 29-JUL-96
PR DIL 1.0000
DIL 1.0000

14557
WEMP-12S
09:23
29-JUL-96
1.0000
1.0000

ZSTD5
15:38
29-JUL-96
1.0000
1.0000

IECCHK2
15:40
29-JUL-96
1.0000
1.0000

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	30.2	3.0	1.76	0.17	<0.094	0.094	<0.094	0.094	0.0947
K	<1.9	1.9	<1.9	1.9	<1.9	1.9	<1.9	1.9	1.9371
Ca	15.0	1.5	2.35	0.23	<0.024	0.024	310.	31.	0.0244
Mg	5.06	0.53	0.514	0.090	<0.25	0.25	258.	25.	0.0904
Fe	202.	20.	13.1	1.3	101.	10.	<0.011	0.011	0.0046
Mn	0.935	0.092	0.0870	0.0086	103.	10.	<0.0068	0.0068	0.0017
Co	0.0143	0.0084	<0.0084	0.0084	<0.0084	0.0084	<0.012	0.012	0.0084
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0125
Al	<0.082	0.082	0.970	0.099	101.	10.	<0.15	0.15	0.0824
As	<0.025	0.025	<0.025	0.025	<0.19	0.19	<0.035	0.035	0.0258
Se	<0.20	0.20	<0.030	0.030	<0.10	0.10	<0.028	0.028	0.0286
Cd	<0.0020	0.0020	<0.0019	0.0019	0.0022	0.0020	<0.0020	0.0020	0.0019
Be	<0.0007	0.0007	<0.0007	0.0007	0.0041	0.0007	<0.0067	0.0067	0.0007
Cu	<0.029	0.029	<0.028	0.028	<0.028	0.028	<0.029	0.029	0.0279
Cr	<0.0021	0.0021	0.0030	0.0005	<0.0009	0.0009	0.0050	0.0007	0.0005
Ni	<0.0061	0.0061	0.0646	0.0066	<0.0061	0.0061	<0.0061	0.0061	0.0061
Zn	<0.0033	0.0033	0.0061	0.0031	0.0067	0.0032	0.0386	0.0062	0.0031
Ag	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.033	0.033	0.0158
Tl	<0.011	0.011	<0.011	0.011	<0.047	0.047	<1.1	1.1	0.0116
Pb	<0.030	0.030	0.035	0.030	<0.059	0.059	<0.031	0.031	0.0306
Sr	0.0350	0.0057	0.0074	0.0007	<0.0007	0.0007	0.0015	0.0008	0.0007
V	<0.018	0.018	0.028	0.018	<0.018	0.018	18.9	1.8	0.0182
Ba	0.0796	0.0082	0.0283	0.0029	<0.0020	0.0020	0.0107	0.0025	0.0020
B	<0.015	0.015	0.017	0.011	<0.012	0.012	<0.012	0.012	0.0114
Tl	<0.0089	0.0089	<0.0089	0.0089	<0.0089	0.0089	42.5	4.2	0.0089

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENT ANALYSIS BY: ICAP (DATA.DAT)
THIS REPORT (USER\$DISK:[CLARK.ICAP]LIST;4535) WAS GENERATED FROM USER\$DISK:[CLARK.ICAP]OUTPUT.DAT;3082
PROJECT: AQ FILTERED FIELD DIRECT READING WESTOVER AFB 30-JUL-96 09:15:16
KAMPBELL
SR65

THIS REPORT WAS GENERATED WITH THE FOLLOWING INFORMATION:

ERROR LEVEL PERCENTAGE : 10%

STATISTICAL SENSITIVITIES WITH A 2.0 SIGMA INTERVAL WERE USED

CONCENTRATION IN: MG/L

THE CONSTANT FILES USED:

USER\$DISK:[CLARK.ICAP]TYPE1.AMAX;1
USER\$DISK:[CLARK.ICAP]TYPE1.XQCA;1
USER\$DISK:[CLARK.ICAP]TYPE1.XQCB;1
USER\$DISK:[CLARK.ICAP]TYPE1.XQCC;1
USER\$DISK:[CLARK.ICAP]TYPE1.STD1;1
USER\$DISK:[CLARK.ICAP]TYPE1.STD2;1
USER\$DISK:[CLARK.ICAP]TYPE1.STD3;1
USER\$DISK:[CLARK.ICAP]TYPE1.STD4;1
USER\$DISK:[CLARK.ICAP]TYPE1.STD5;1
USER\$DISK:[CLARK.ICAP]TYPE1.XSS1;1
USER\$DISK:[CLARK.ICAP]TYPE1.XSS2;1
USER\$DISK:[CLARK.ICAP]TYPE1.FIXX;1
USER\$DISK:[CLARK.ICAP]TYPE1.LCN;46

LCN TIME: 15:53:07 LCN DATE: 19-JUN-96 FILTER FACTOR: 0.000002

THE DATA FILES USED:

USER\$DISK:[CLARK.ICAP]DATA.DAT;281
USER\$DISK:[CLARK.ICAP]IC0001.DAT;3913
USER\$DISK:[CLARK.ICAP]TAG.DAT;4847
USER\$DISK:[CLARK.ICAP]TAG.DAT;4848
USER\$DISK:[CLARK.ICAP]OUTPUT.DAT;3082
USER\$DISK:[CLARK.ICAP]OUTPUT.LST;2998
USER\$DISK:[CLARK.ICAP]ARCH.DAT;16
USER\$DISK:[CLARK.ICAP]LIST.LST;4535
USER\$DISK:[CLARK.ICAP]TRAILER.LST;690

(INSTRUMENT RAW DATA)
(INSTRUMENT CALC. DATA)
(ORIGINAL TAG FILE)
(TAG FILE FOR CALC.)

ELEMENTAL CONSTITUENT ANALYSIS BY AA MEASUREMENTS
 THIS REPORT ([.REPORT]PB60731.LIS;1) WAS GENERATED FROM DATASET [.DATA]PB60731.DAT;2

PROJECT: AQ FILT. SAMPLES. WESTOVER AFB. SR#65. KAMPBELL

METHOD: LEAD BY GF-AAS

CONCENTRATION UNITS: MG/L

TAG NUMBER	SAD #	STATION IDENT	MACHINE READING	PRIMARY DILUTION	REGULAR DILUTION	FINAL CONCENTRATION
14552	14552	WEFT-12	0.002	1.000	1.000	0.002
14553	14553	WEFT-14	0.000	1.000	1.000	0.000
14554	14554	WECF-2A	0.006	1.000	1.000	0.006
14555	14555	WECF 8	0.000	1.000	1.000	0.000
14556	14556	WEMP-14D	0.000	1.000	1.000	0.000
14557	14557	WEMP-12S	0.028	1.000	1.000	0.028
BLANK	????	*****	0.000	1.000	1.000	0.000
BLANK	????	*****	0.000	1.000	1.000	0.000
BLANK	????	*****	0.000	1.000	1.000	0.000
STD2PPB	????	*****	0.002	1.000	1.000	0.002
STD5PPB	????	*****	0.006	1.000	1.000	0.006
STD10PPB	????	*****	0.011	1.000	1.000	0.011
STD20PPB	????	*****	0.022	1.000	1.000	0.022
STD50PPB	????	*****	0.050	1.000	1.000	0.050
STD100PPB	????	*****	0.097	1.000	1.000	0.097

MANTECH TECHNOLOGY

Ref: 96\LB59

August 12, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

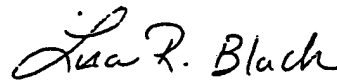
THRU: S.A. Vandegrift ✓

Dear Don:

Please find attached the analytical results for Service Request SF-2-223 requesting the analysis of Westover AFB groundwater samples to be analyzed by purge-and-trap/GC-FID:PID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-Xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained your 36 groundwater samples, most in duplicate, in capped, 40 mL VOA autosampler vials on July 22, 1996, and they were analyzed on July 24-25, 1996. All samples were acquired and processed using the Millennium data system. A 5 place (1-1000 ppb) external standard curve was used to quantitate the samples for the compounds of interest.

RSKSOP-133, "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,



Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J.T. Wilson
J.L. Seeley



ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample Name	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
10 PPB	9.3	10.1	10.4	10.1	9.8	10.0	10.2	10.1	10.3	N/A
WE-Trip Blank	BLQ	2.3	ND	BLQ	BLQ	ND	ND	ND	ND	5.8
WEMP-1D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-1S	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
WEMP-4S	6610	12860	1290	965	2650	1750	212	720	428	26000
WEMP-5M	7.7	2.3	2.1	5.4	3.6	2.8	1.5	2.8	1.2	34.9
WEMP-5M Duplicate	6.5	ND	1.8	5.3	3.6	2.7	1.5	2.3	1.2	27.2
WEMP-8M	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
WEMP-10S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	1.1	1.1	1.0	0.9	1.0	1.0	1.0	1.1	1.0	N/A
1 PPB	2220	13150	1090	880	2350	1520	180	521	314	20600
WEMP-12S	252	540	106	97.7	173	85.4	18.6	49.2	32.0	1540
WEMP-14D	85.3	1.2	35.2	48.6	1.3	1.0	8.9	21.4	14.1	333
WEMP-14M	2.0	ND	3.9	7.1	4.7	3.1	1.3	3.4	3.5	32.1
WEMP-15D	BLQ	ND	ND	BLQ	ND	ND	ND	ND	ND	BLQ
WEMP-15M	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-15S	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
WEMP-16D	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
WECF-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WECF-2 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WECF-2A	113	17.5	261	289	717	608	114	317	212	2920
WECF-3	69.5	1550	374	398	1010	645	98.1	270	173	5250
QC, OBSERVED, PPB	48.0	47.8	52.1	47.8	44.6	48.3	45.8	45.9	47.2	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
WECF-5	2.4	1.2	2.7	3.7	0.9	ND	ND	2.8	1.8	32.3
WECF-6	3.8	ND	ND	ND	ND	ND	ND	ND	ND	8.1
WECF-6A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WECF-6A Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WECF-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-1	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
WEFT-1A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-2A	BLQ	18.2	116	97.2	58.5	179	55.8	86.3	60.4	1040
WEFT-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
100 PPB	105	105	106	107	99.9	105	107	106	106	N/A
WEFT-5	BLQ	BLQ	1.2	107	ND	ND	BLQ	ND	0.9	16.4
WEFT-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-7 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEFT-16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	47.9	47.5	53.4	49.1	46.2	49.4	48.5	48.3	49.5	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

**MANTECH
TECHNOLOGY**

Ref: 96-SH83/vg

August 13, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Attached are TOC results for 38 Westover liquids submitted August 8, 1996 under Service Request #SF-2-223. Sample analysis was begun August 8 and completed August 12, 1996 using RSKSOP-102.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower
Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley *JL*
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL WESTOVER LIQUIDS SF-2-223

SAMPLE MG/L TOC

WECF-2	.282
WECF-2A	40.0
WECF-3	24.7
WECF-5	4.43
WECF-6	2.89
WECF-6A	2.87
WECF-8	9.20
WEFT-1	4.91
WEFT-1A	.409
WEFT-2	8.72
WEFT-2 DUP	8.93
WEFT-2A	16.8
WEFT-3	4.62
WEFT-4	2.61
WEFT-5	2.55
WEFT-7	1.78
WEFT-8	3.37
WEFT-11	5.80
WEFT-11S	11.7
WEFT-12	1.78
WEFT-13	2.16
WEFT-14	5.33
WEFT-15	4.79
WEFT-16	.997
WEMP-10	.373
WEMP-10 DUP	.409
WEMP-15D	3.31
WEMP-15M	1.15
WEMP-15S	1.52
WEMP-1S	1.08
WEMP-5M	2.72
WEMP-8M	1.31
WEMP-14D	77.4
WEMP-14M, REP 1	28.5
WEMP-14M, REP 2	29.3
WEMP-16D	3.18
WEMP-4S	42.6
WEMP-1S	3.80
WEMP-12S	61.8
WEMP-12S DUP	61.5
WPO35-II	39.6

WPO35-II STD t.v.=40.1

MANTECH

Ref: 96JAD44

August 14, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

As requested in Service Request # SF-2-223, headspace GC/MS analysis of 36 Westover water samples for chlorinated volatile organics was completed. The samples were received on July 22, 1996 and analyzed on August 9-10, 1996. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 12 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

A quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in table 1.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine *83*
J.L. Seeley
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Table 1. Quantitation Report for S.R. # SF-2-223 from Westover.

Concentration = ppb

Compound	Concentration = ppb																								
	WE- Trip Blink	WEMP-1D	WEMP-1S	WEMP-4S	WEMP-5M	WEMP-6M	WEMP-10S	WEMP-10S Field Dup	WEMP-12S	WEMP-14D	WEMP-14D Lab Dup	WEMP-14M	WEMP-15D	WEMP-15M	WEMP-16D	WEMP-16D Field Dup	WEMP-16D Field Dup	WEMP-2A	WEMP-2A Field Dup	WEMP-2B	WEMP-2B Field Dup				
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.7	
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.7	
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.1	
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	288	
CHLOROFORM	ND	ND	ND	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.5	
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
TRICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	289	
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	---	
CHLOROBENZENE	ND	ND	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
VINYL CHLORIDE	1.9	1.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	2.7	2.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	3.1	2.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1,1-DICHLOROETHANE	ND	ND	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	298	323	50.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	434
CHLOROFORM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
TRICHLOROETHENE	297	283	10.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1660
TETRACHLOROETHENE	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	3.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	ND	ND	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1,1-DICHLOROETHANE	ND	ND	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	435	35.0	3.0	3.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROFORM	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	1632	94.6	13.8	14.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate

Table 2. Quantitation Report for S.R. # SF-2-223 from Westover.

Concentration = ppb

Compound	WEFT-2A	WEFT-3	WEFT-4	WEFT-5	WEFT-7	WEFT-8	WEFT-8 Lab Dup	WEFT-11	WEFT-12	WEFT-13
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	1.8	ND	---	ND	1.0	1.0	3.4	ND	1.0
CHLOROFORM	ND	---	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	1.4	ND	---	---	---	---	ND	---	---
TETRACHLOROETHENE	ND	1.5	ND	---	ND	ND	ND	---	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Compound	WEFT-14	WEFT-16	WEFT-16	QC0809A	QC0809B	QC0809C	QC0809D	QC0809E	QC0809F	QC0809G
VINYL CHLORIDE	ND	ND	ND	20.3	207	20.7	209	22.7	216	20 ppb
1,1-DICHLOROETHENE	ND	ND	ND	21.7	217	22.0	224	22.4	229	22.1
T-1,2-DICHLOROETHENE	ND	ND	ND	22.5	221	23.1	223	22.7	223	22.0
1,1-DICHLOROETHANE	ND	ND	ND	22.2	200	23.5	199	24.1	195	21.8
C-1,2-DICHLOROETHENE	ND	ND	ND	22.3	229	22.3	219	23.2	209	23.5
CHLOROFORM	ND	ND	ND	21.6	213	22.3	212	23.0	204	21.6
1,1,1-TRICHLOROETHANE	ND	ND	ND	20.3	203	21.4	205	21.7	220	21.1
CARBON TETRACHLORIDE	ND	ND	ND	19.3	187	20.4	191	20.5	209	21.4
1,2-DICHLOROETHANE	ND	ND	ND	22.6	222	23.5	203	23.6	195	20.1
TRICHLOROETHENE	ND	ND	---	17.9	180	19.1	181	18.3	186	22.3
TETRACHLOROETHENE	ND	---	ND	19.5	188	20.0	188	19.6	196	18.4
CHLOROBENZENE	ND	ND	ND	20.1	207	21.2	204	21.0	202	18.4

Compound	QC0809H	QC0809I	QC0809J	BL0809A	BL0809B
VINYL CHLORIDE	207	22.0	208	ND	ND
1,1-DICHLOROETHENE	232	22.4	229	ND	ND
T-1,2-DICHLOROETHENE	222	21.8	218	ND	ND
1,1-DICHLOROETHANE	195	23.1	196	ND	ND
C-1,2-DICHLOROETHENE	211	22.1	216	ND	ND
CHLOROFORM	204	22.0	205	ND	ND
1,1,1-TRICHLOROETHANE	215	21.4	215	ND	ND
CARBON TETRACHLORIDE	208	20.7	210	ND	ND
1,2-DICHLOROETHANE	198	23.7	208	ND	ND
TRICHLOROETHENE	186	18.5	180	ND	ND
TETRACHLOROETHENE	195	18.9	184	ND	ND
CHLOROBENZENE	201	20.0	200	ND	ND

WESTOVER AIR FORCE BASE
FIELD DATA

Sample	Date	Redox mv	pH Units	Cond	Carbon Dioxide mg/l	Total Alkalinity mg/l CaCO ₃	Ferrous Iron mg/l	Hydrogen Sulfide mg/l
WE FT-1A	7-16-96	300	6.3	105	80	33	<.05	
WE FT-1	7-16-96	205	6.6	145	62	27	<.05	
WE FT- 4	7-16-96	272	6.6	551	84	50	<.05	
WE FT-3	7-16-96	281	6.6	200	34	40	<.05	
WE FT-12	7-16-96	288	6.3	109	70	30	<.05	
WE FT-13	7-16-96	278	6.4	201	140	43	<.05	
WE FT-14	7-16-96	281	6.7	910	48	57	<.05	
WE FT-5	7-16-96	184	6.0	185	76	20	1.5	
WE MP- 1S	7-17-96	249	4.9	43	40	8	<.05	
WE MP-1D	7-17-96	227	5.2	70	108	6	.3	
WE CF-8	7-17-96	212	5.3	43	96	13	1.5	
WE MP-8M	7-17-96	240	4.7	74	134	5	<.05	
WE MP-16D	7-17-96	175	5.6	64	51	32	5.6	
WE MP-5M	7-17-96	125	5.6	81	152	29	5.3	
WE MP-14M	7-17-96	-90	6.3	657	-----	184	40.5	<.1
WE MP-14D	7-17-96	-125	6.7	839	-----	238	45.3	<.1
We MP-15D	7-17-96	75	5.9	104	142	24	6.2	
WE MP-15S	7-17-96	170	5.6	59	82	28	<.05	
WE MP-15M	7-17-96	120	5.9	58	142	24	2.1	
WE FT-7	7-17-96	150	6.1	255	158	126	<.05	
WE FT-8	7-17-96	128	6.5	305	84	134	<.05	
WE FT 16	7-17-96	148	6.2	53	148	64	<.05	
WE FT-11	7-17-96	94	6.4	503	176	54	3.1	

WESTOVER AIR FORCE BASE
FIELD DATA

Sample	Date	Redox mv	pH Units	Cond	Carbon Dioxide	Total Alkalinity mg/l CaCO ₃	Ferrous Iron mg/l	Hydrogen Sulfide mg/l
WE MP-10S	7-18-96	280	5.0	33	142	6	<.05	
WE MP-115	7-18-96	137	6.1	318	180	72	3.0	
WE FT-1S	7-18-96	250	6.0	208	240	45	<.05	
WE MP-12S	7-18-96	90	5.4	96	154	31	7.0	
WE FT-2	7-18-96	250	6.3	151	66	64	<.05	
WE MP-45	7-18-96	-40	6.2	418	-----	205	37.3	
WE FT-2A	7-18-96	-159	6.0	625	-----	57	23.5	
WE CF-S	7-18-96	274	5.0	62	130	4	.4	
WECF-2	7-18-96	-66	6.5	77	144	16	4.7	<.1
WE CF-3	7-18-96	-185	5.9	111	252	45	5.4	<.3
WF CF6	7-18-96	-45	6.4	138	160	54	8.9	
WF CF-6A	7-18-96	135	5.4	68	138	6	<.05	
WF CF-2A	7-18-96	-125	6.3	440	263	212	3.8	



Ref: 96-JH76/vg

August 19, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Find attached results for methane and ethylene on samples received July 18 and 22, 1996 from Westover under Service Request #SF-2-223. Samples were prepared and calculations done as per RSKSOP-175. Analyses were performed as per RSKSOP-147.

If you have any questions concerning this data, please feel free to contact me.

Sincerely,

A handwritten signature in cursive script that reads "Jeff Hickerson".

Jeff Hickerson

xc: R.L. Cosby
G.B. Smith
J.L. Seeley *SV*
J.T. Wilson

S# SF-2-223
WESTOVER

ANALYSIS PRFORMED 8-7-96

SAMPLE METHANE ETHYLENE

LAB BLANK	BLQ	ND
WECF-8	0.007	ND
WEFT-1	BLQ	ND
WEFT-1A	BLQ	ND
* FIELD DUP	BLQ	ND
WEFT-3	BLQ	ND
WEFT-4	BLQ	ND
WEFT-5	BLQ	ND
* LAB DUP	BLQ	ND

ANALYSIS PRFORMED 8-8-96

SAMPLE METHANE ETHYLENE

LAB BLANK	BLQ	ND
WEFT-12	BLQ	ND
WEFT-13	BLQ	ND
WEFT-14	BLQ	ND
WEMP-1D	BLQ	ND
* LAB DUP	BLQ	ND
WEMP-1S	BLQ	ND
WEMP-5M	1.54	ND
WEMP-8M	BLQ	ND
WEMP-14D	14.63	BLQ
WEMP-14M	8.79	ND
* FIELD DUP	8.70	ND
WEMP-16D	0.007	ND
WEMP-4S	0.237	0.008
WEMP-10S	BLQ	ND
WEMP-12S	0.073	BLQ
WEMP-15D	0.129	ND
* LAB DUP	0.122	ND

ANALYSIS PRFORMED 8-9-96

SAMPLE METHANE ETHYLENE

LAB BLANK	BLQ	ND
BLANK LABEL	0.003	ND
WEMP-15M	0.021	ND
WEMP-15S	BLQ	ND
WECF-2	BLQ	ND
* FIELD DUP	BLQ	ND
WECF-2A	0.557	ND
WECF-3	0.028	ND
WECF-5	0.008	ND
WECF-6	0.874	ND
WECF-6A	BLQ	ND
* LAB DUP	BLQ	ND

S# SF-2-223
WESTOVER

ANALYSIS PRFORMED 8-12-96

SAMPLE METHANE ETHYLENE

LAB BLANK	BLQ	ND
WEFT-2	BLQ	ND
WEFT-2A	0.006	ND
WEFT-7	BLQ	ND
WEFT-8	BLQ	ND
" LAB DUP	BLQ	ND
WEFT-11	BLQ	ND
WEFT-11S	0.288	ND
WEFT-15	BLQ	ND
" FIELD DUP	BLQ	ND
WEFT-16	BLQ	ND
10 PPM CH4	9.59	NA
100 PPM CH4	99.97	NA
1000 PPM CH4	999.82	NA
1% CH4	1.03	NA
10% CH4	10.00	NA
20% CH4	20.28	NA
10 PPM C2H4	NA	10.16
100 PPM C2H4	NA	99.98

LIMIT OF QUANTITATION.

METHANE ETHYLENE

0.001 0.003

SAMPLE UNITS ARE mg/L.
STANDARDS UNITS CORRESPOND
TO THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.
ND DENOTES NONE DETECTED.
NA DENOTES NOT ANALYZED.

APPENDIX C
ANALYTICAL MODEL OUTPUT

APPENDIX C-1
ANALYTICAL MODEL-DECAY 1%

TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.82 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 15 \text{m}$
Concentration of Injected Contaminant	$C_s := 2.82 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

35 Meters from the Source Area (Base Boundary)

Initial Plume Distribution Calculation

year := 365-day i := 1..365 x := 35-m

Δt := 500-day

t_i := Δt · i

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

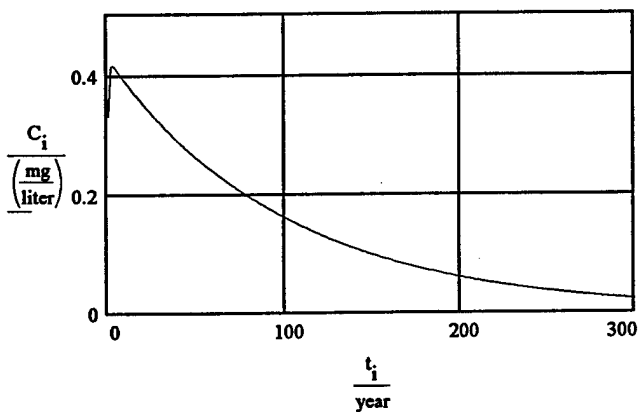
$$C_i = C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp \left[-\frac{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x - t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots$$

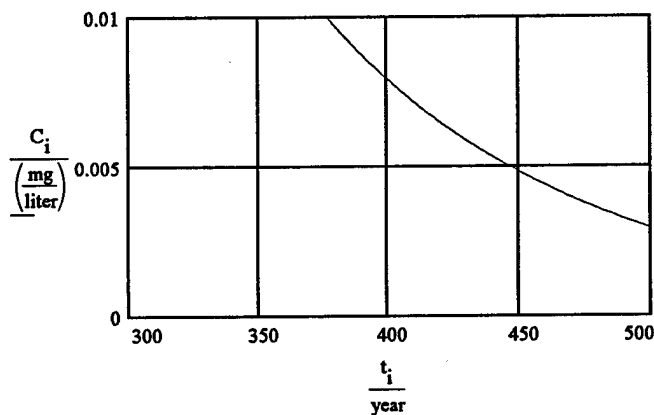
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp \left[-\frac{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right)$$

Dissolved BTEX Concentration (mg/L) versus Time (years)



Dissolved BTEX Concentration (mg/L) versus Time (years)



114 Meters from the Source Area (Monitoring Well TF-8)

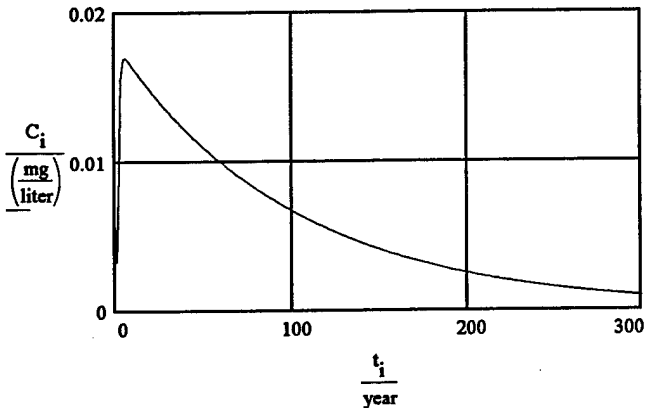
Initial Plume Distribution Calculation

year := 365.day i := 1..365 x := 114.m
 Δt := 500.day
 t_i := Δt.i

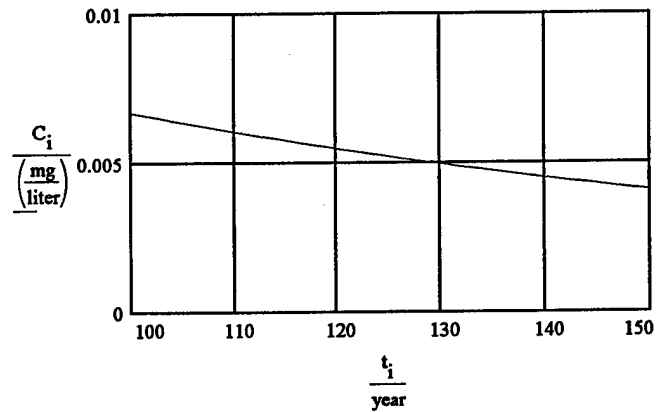
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned}
 C_i = & C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R-x-v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{v_x \cdot t_i}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R-x-v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R-x+v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\
 + & C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R-x-t_i \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\
 + & \left[\frac{v_x}{v_x - v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R-x+t_i \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\
 + & \left. \frac{v_x}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R-x+v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]
 \end{aligned}$$

Dissolved BTEX Concentration (mg/L) versus Time (years)



Dissolved BTEX Concentration (mg/L) versus Time (years)



150 Meters from the Source Area

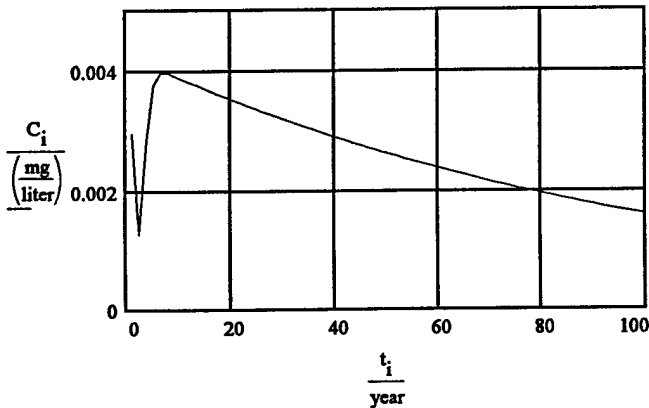
Initial Plume Distribution Calculation

$$\begin{aligned} \text{year} &:= 365 \cdot \text{day} & i &:= 1..365 & x &:= 150\text{-m} \\ \Delta t &:= 500 \cdot \text{day} \\ t_i &:= \Delta t \cdot i \end{aligned}$$

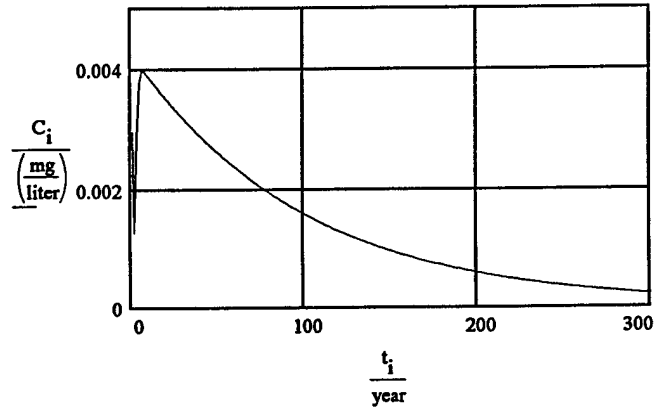
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned} C_i &:= C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\ &+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right. \\ &+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \\ &+ \left. \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \end{aligned}$$

Dissolved BTEX Concentration (mg/L) versus Time (years)



Dissolved BTEX Concentration (mg/L) versus Time (years)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.82 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15\text{-m}$
Concentration of Injected Contaminant	$C_s := 2.82 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

5.5 Years Ago (1989-1995)

Initial Plume Distribution Calculation

$$j := 0..400$$

$$t := 2000 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

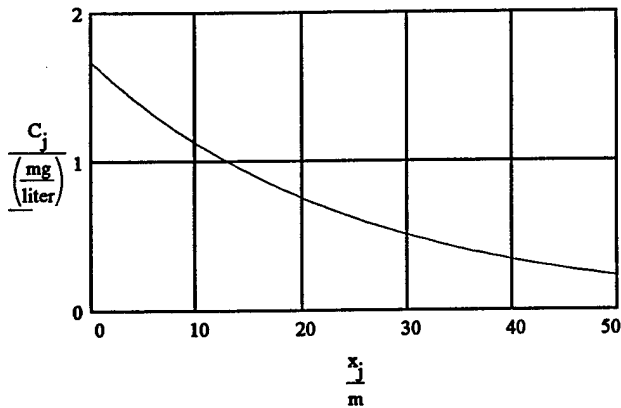
$$C_j := C_{o'} \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j + v_x \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_{s'} \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

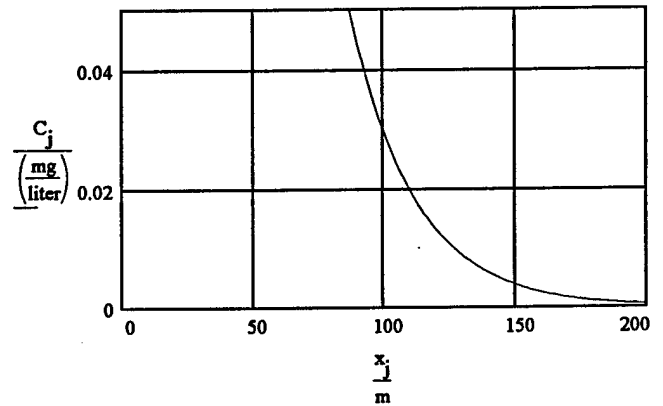
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

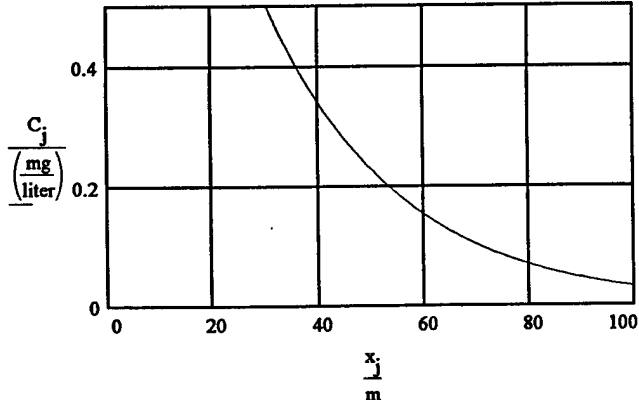
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



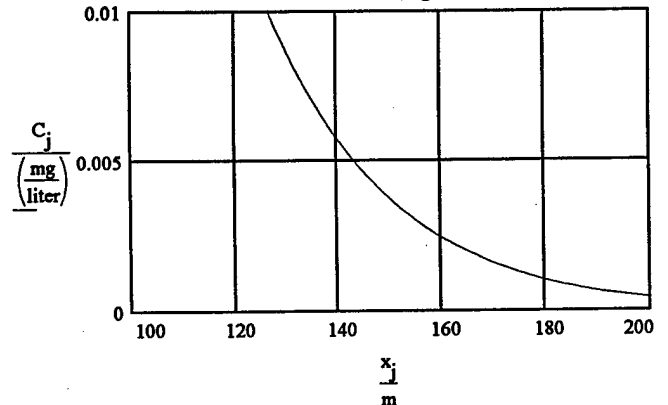
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



2 Years From Present (1989-1997)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 2730 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

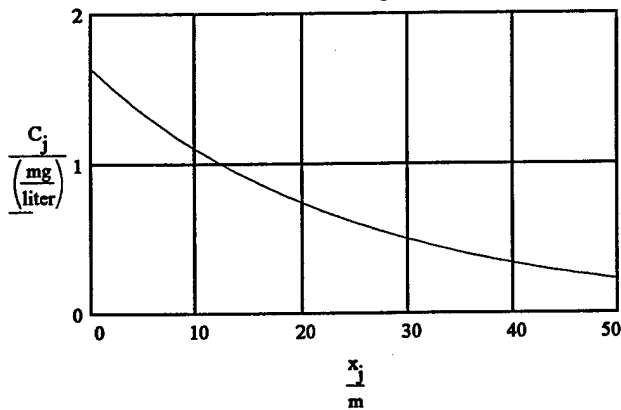
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

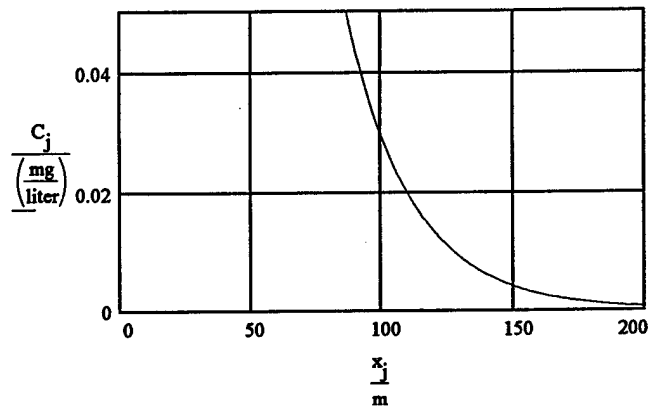
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

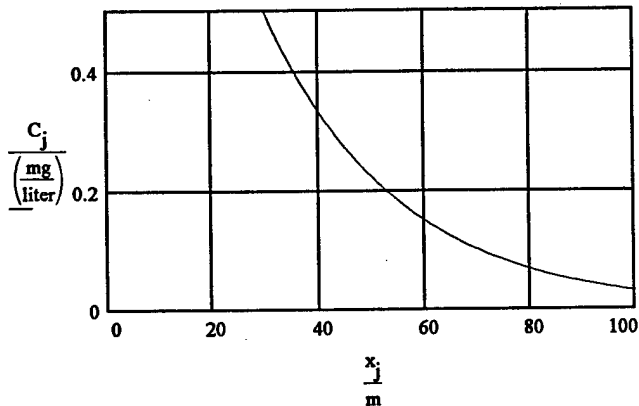
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



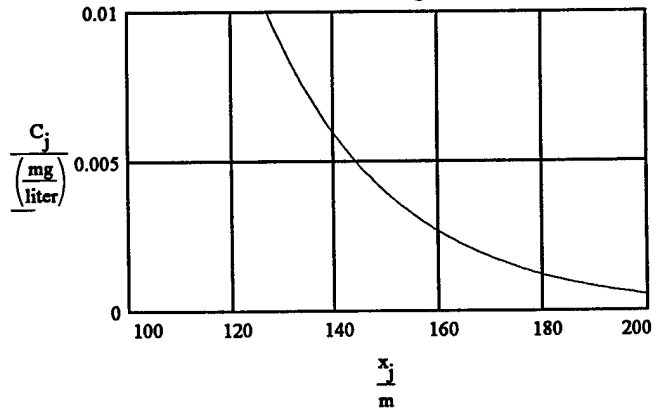
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.82 mg/l SOURCE DECAYING AT 5 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION) AFTER BIOVENTING STARTUP

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 15 \cdot \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.017 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.000137 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

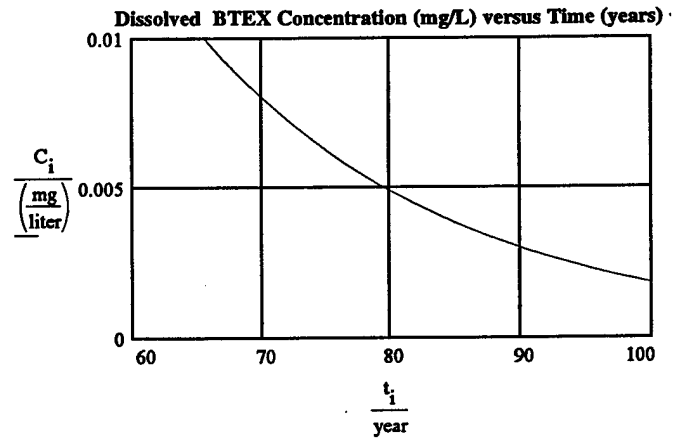
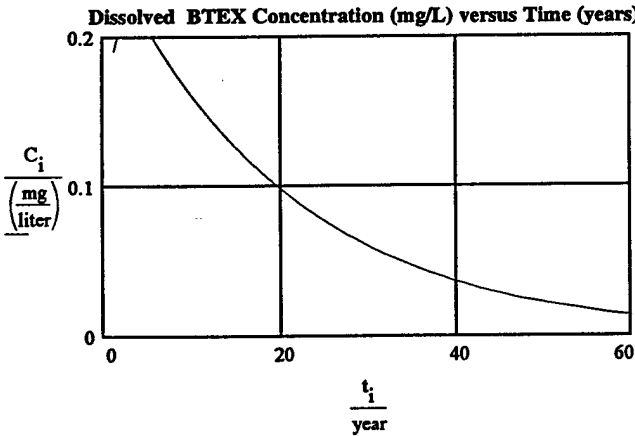
35 Meters from the Source Area (Base Boundary)

Initial Plume Distribution Calculation

year := 365.day i := 1..365 x := 35.m
 Δt := 500.day
 t_i := Δt.i

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned}
 C_i = & C_0 \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{(v_x \cdot t_i)^2}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\
 + & C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\
 + & \left[\frac{v_x}{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\
 + & \left. \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]
 \end{aligned}$$



114 Meters from the Source Area (Monitoring Well TF-8)

Initial Plume Distribution Calculation

$$\begin{aligned} \text{year} &:= 365 \cdot \text{day} & i &:= 1..365 & x &:= 114 \cdot \text{m} \\ \Delta t &:= 500 \cdot \text{day} \\ t_i &:= \Delta t \cdot i \end{aligned}$$

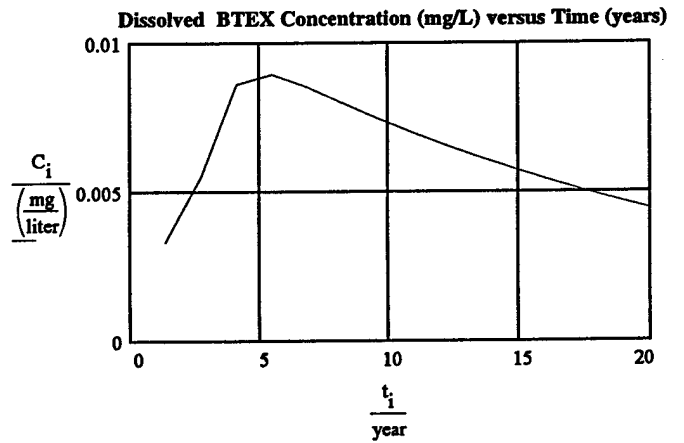
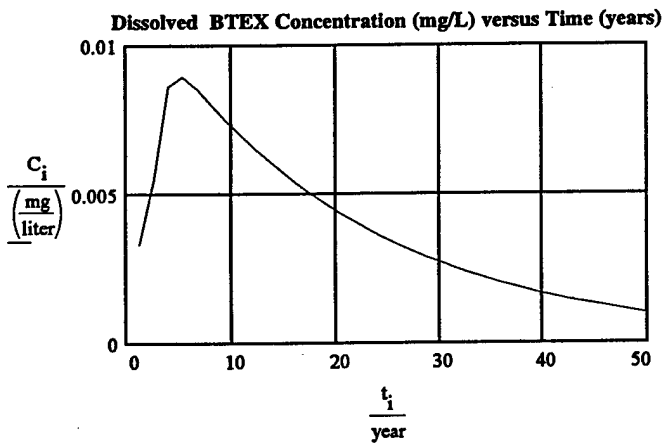
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp(-\lambda \cdot t_i) \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{v_x \cdot t_i}{x \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t_i) \left[\frac{v_x}{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x - t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x + t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



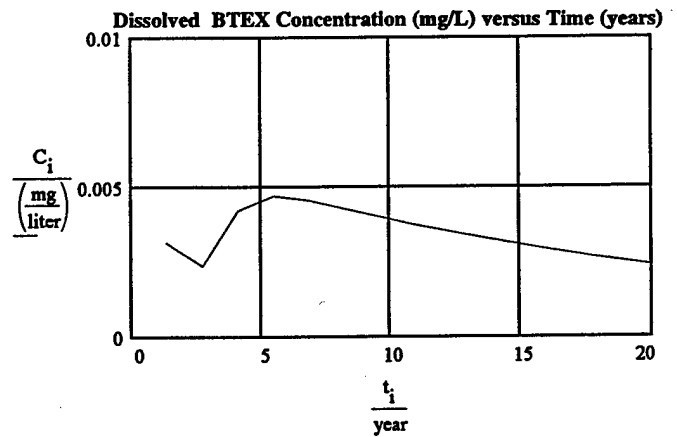
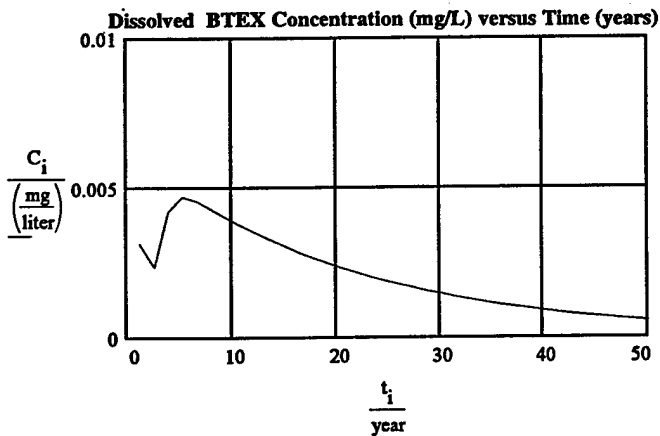
130 Meters from the Source Area

Initial Plume Distribution Calculation

year := 365-day i := 1..365 x := 130-m
 Δt := 500-day
 t_i := Δt·i

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned}
 C_i = & C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\
 & + C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\
 & + \left[\frac{v_x}{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\
 & \left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots
 \end{aligned}$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 5 %/year WITH A 0.0034 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION) AFTER BIOVENTING STARTUP

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.017 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$
Source Decay Rate	$\alpha := 0.000137 \frac{1}{\text{day}}$
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$
Organic carbon content	$f_{oc} := 0.000001$
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e} \quad R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

2 Years From Present (1995-1997) After Bioventing

Initial Plume Distribution Calculation

$$j := 0..400$$

$$t := 690 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

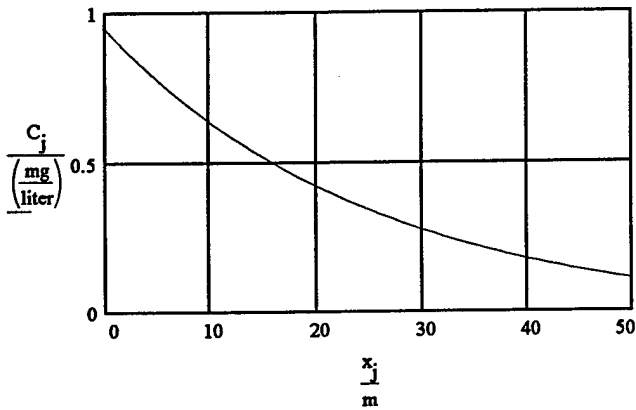
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[-\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

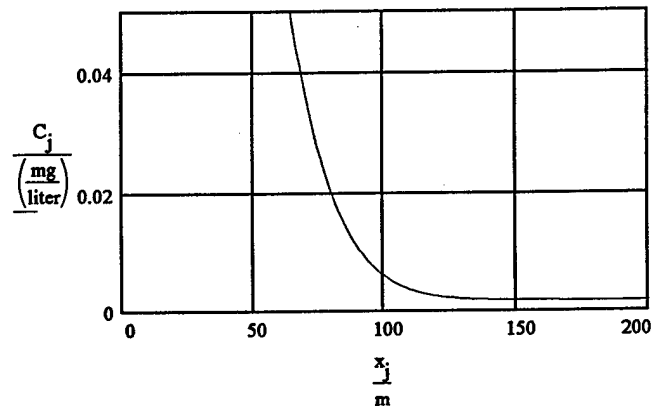
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[-\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

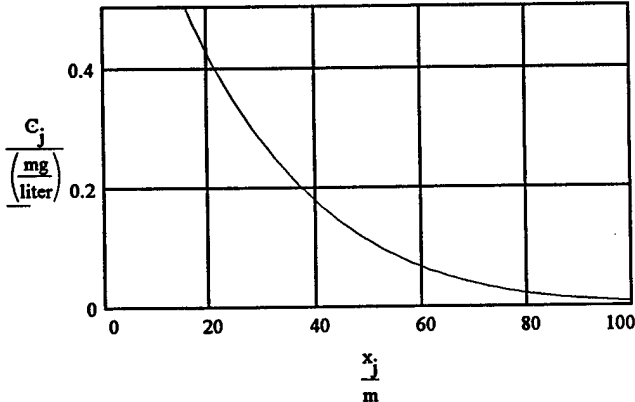
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



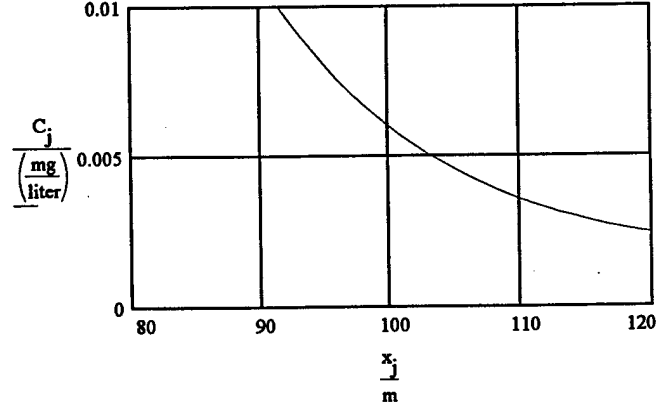
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



5 Years From Present (1995-2000) After Bioventing

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 1825 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

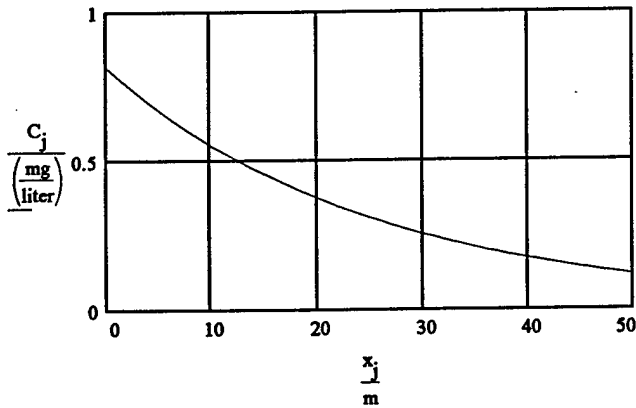
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \right) \dots \right.$$

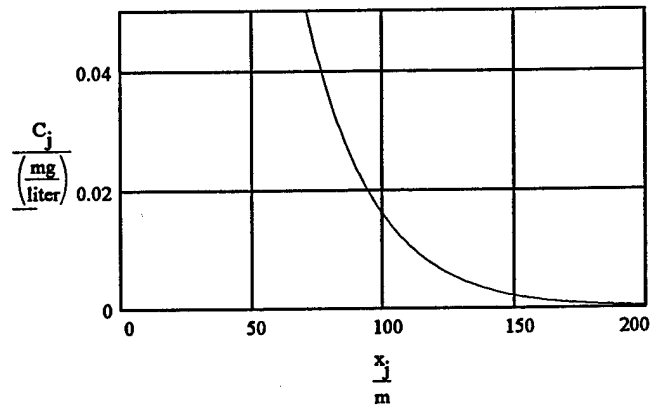
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \right) \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

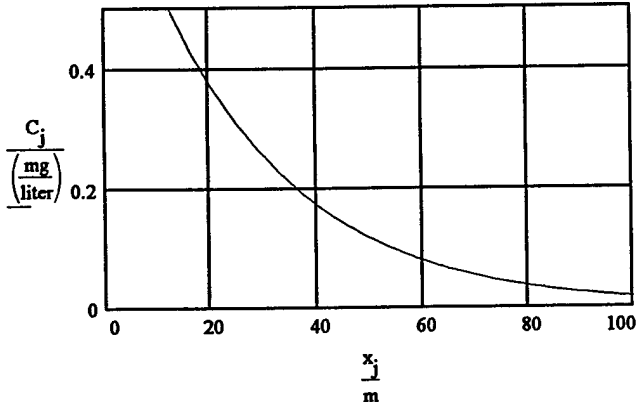
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



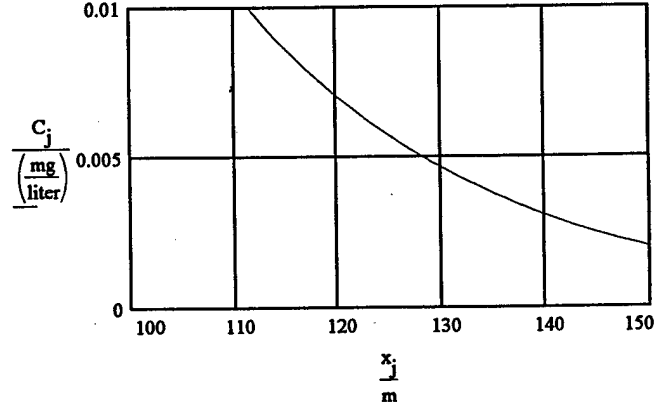
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



10 Years From Present (1995-2005) After Bioventing

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

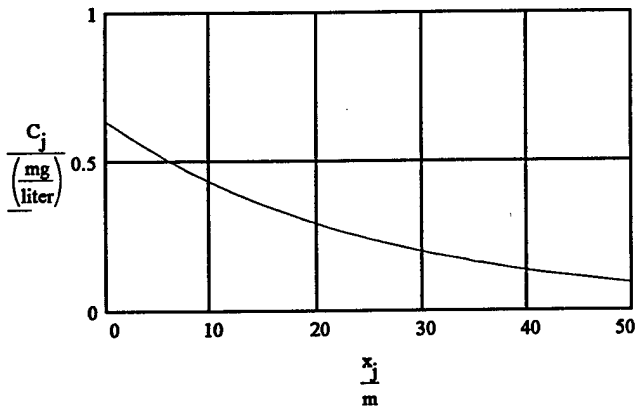
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

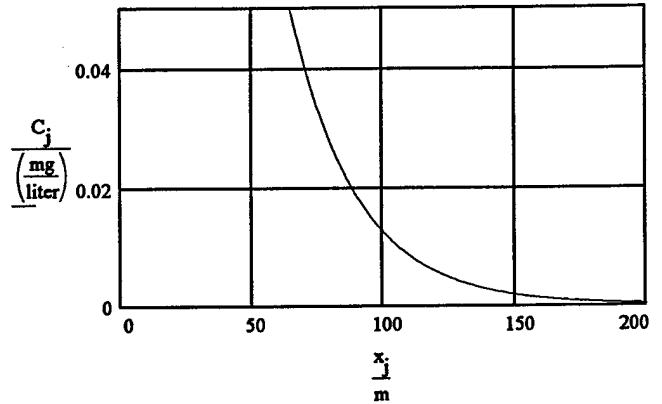
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

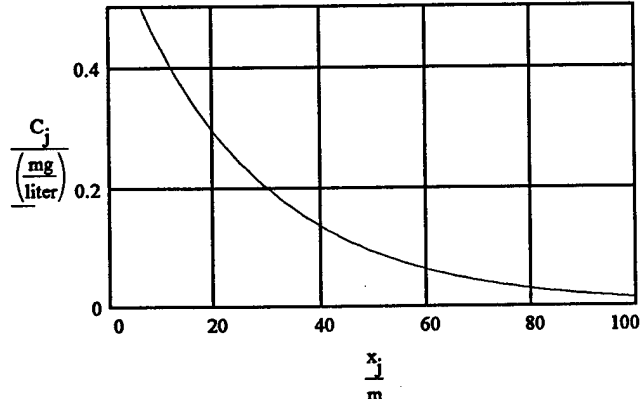
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



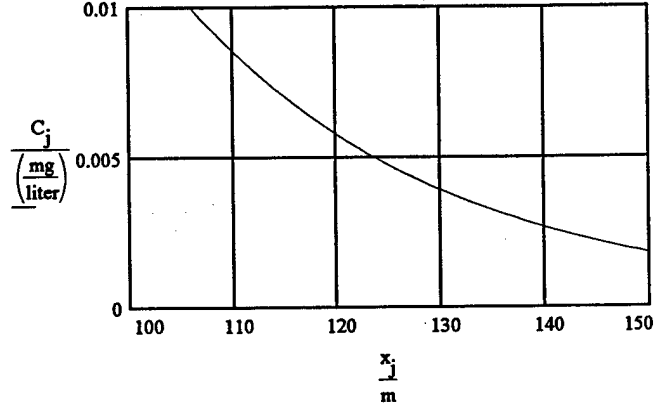
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



20 Years From Present (1995-2015) After Bioventing

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 7300 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

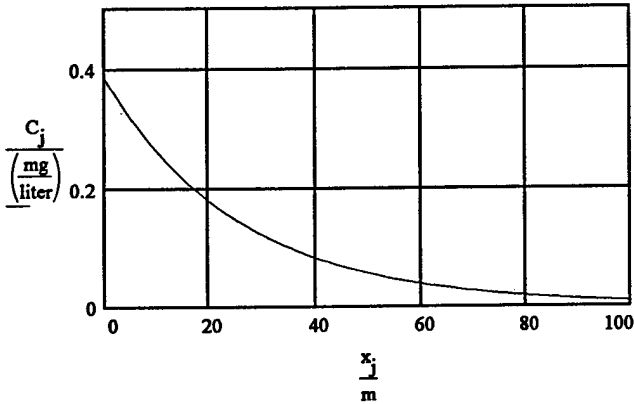
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \right] \dots$$

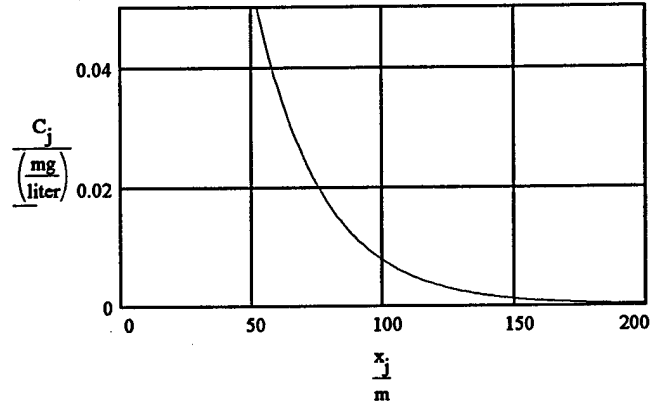
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

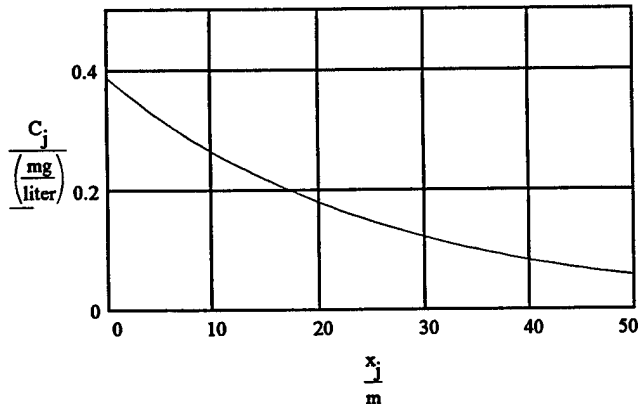
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



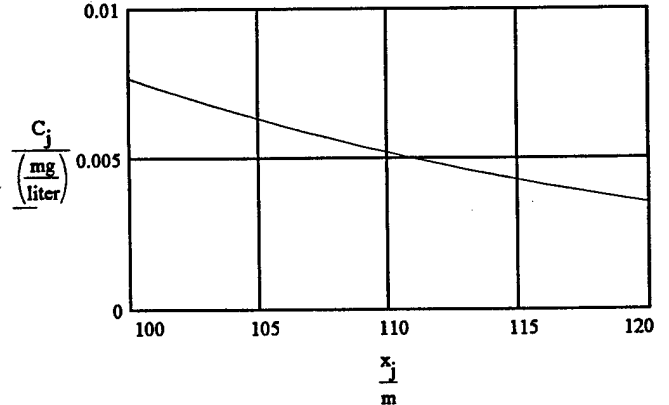
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



30 Years From Present (1995-2025) After Bioventing

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 10950 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

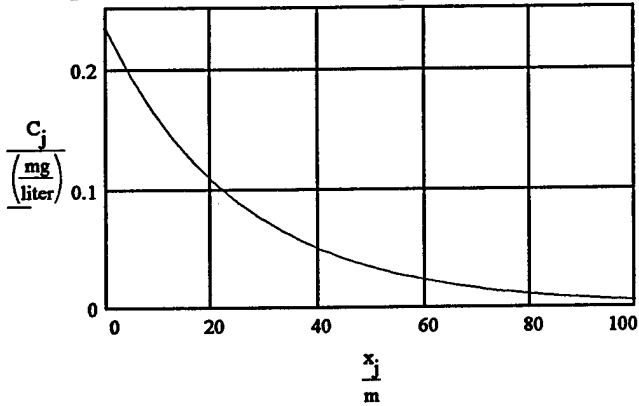
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

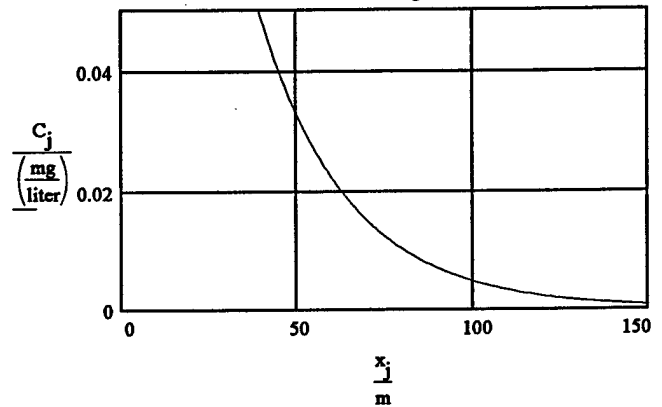
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

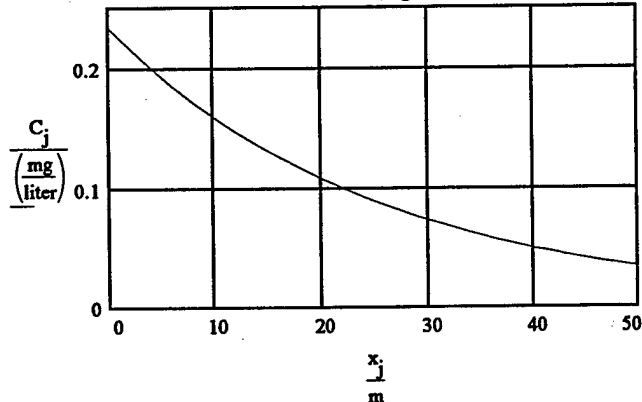
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



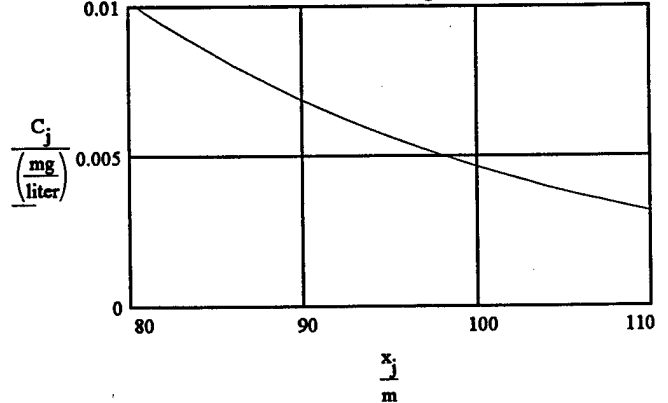
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



50 Years From Present (1995-2045) After Bioventing

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 18250 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

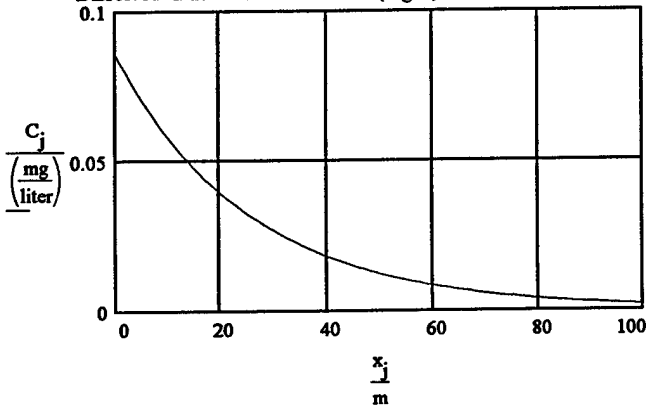
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

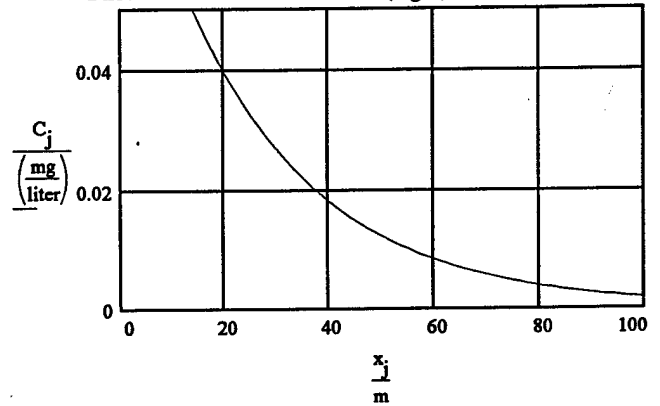
$$+ \left[\frac{v_x}{v_x - v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

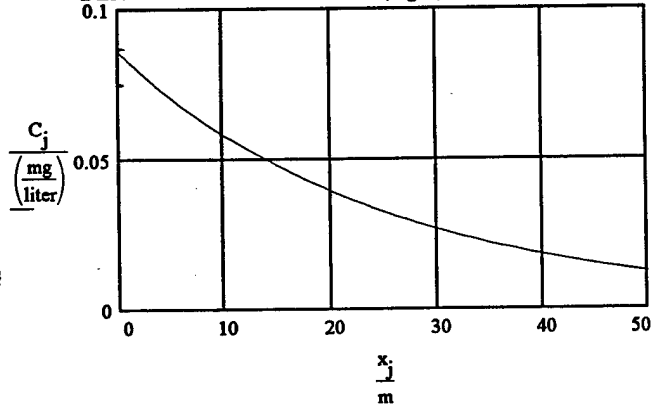
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



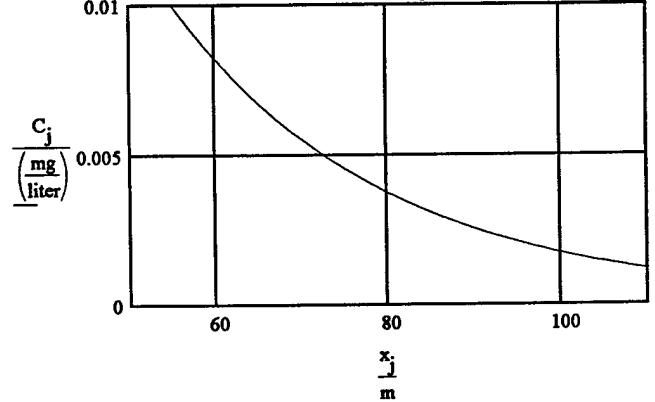
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.82 mg/l SOURCE DECAYING AT 50 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION) AFTER BIOVENTING STARTUP

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{m}{day}$
Hydraulic gradient	$I := 0.01 \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 15 \cdot m$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0.017 \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.00137 \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{ft^2}{day}$

35 Meters from the Source Area

Initial Plume Distribution Calculation

year := 365-day i := 1..365 x := 35-m

Δt := 100-day

t_i := Δt·i

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

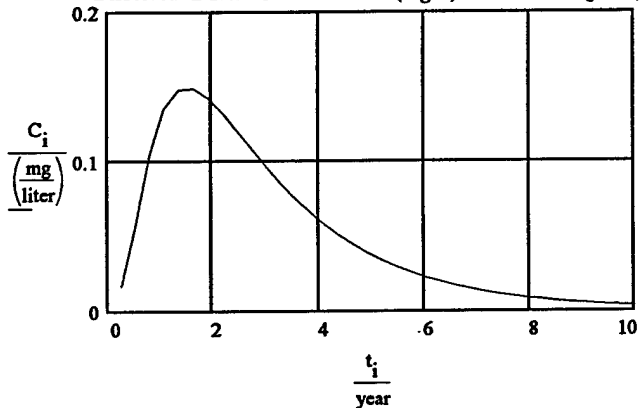
$$C_i := C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{(v_x^2 \cdot t_i)}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

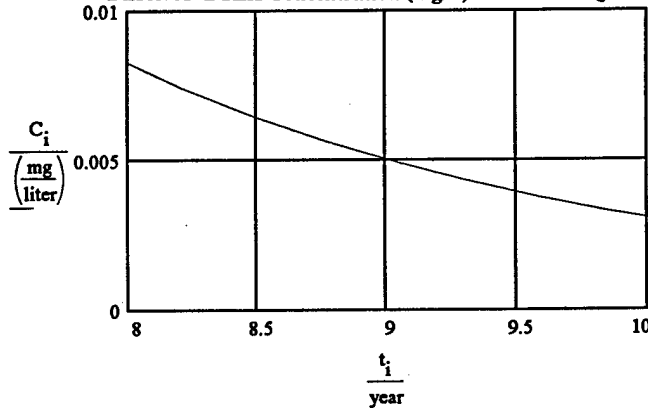
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right)$$

Dissolved BTEX Concentration (mg/L) versus Time (years)



Dissolved BTEX Concentration (mg/L) versus Time (years)



APPENDIX C-2
ANALYTICAL MODEL-DECAY 8%

TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (30 mg/l SOURCE DECAYING AT 8 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{m}{day}$
Hydraulic gradient	$I := 0.01 \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 15 \cdot m$
Concentration of Injected Contaminant	$C_s := 30 \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0.0 \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.000219 \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{ft^2}{day}$

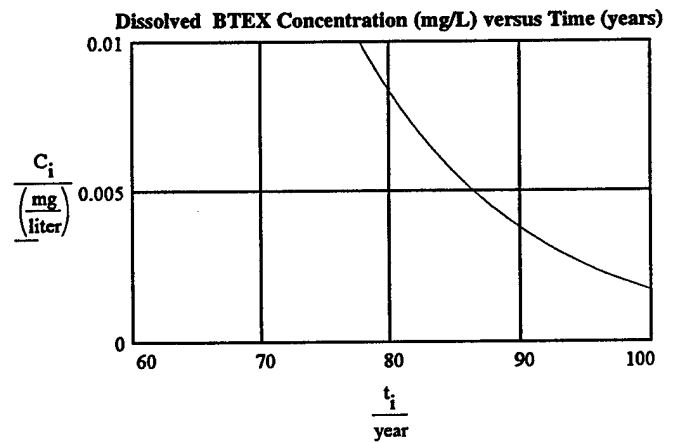
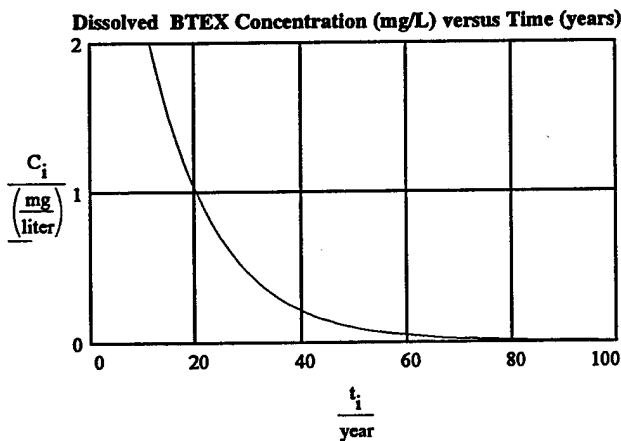
35 Meters from the Source Area (Base Boundary)

Initial Plume Distribution Calculation

$$\begin{aligned} \text{year} &:= 365 \cdot \text{day} & i &:= 1 \dots 365 & x &:= 35 \cdot \text{m} \\ \Delta t &:= 500 \cdot \text{day} \\ t_i &:= \Delta t \cdot i \end{aligned}$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned} C_i &:= C_0 \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\ &+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp \left[\frac{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x - t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots \\ &+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp \left[\frac{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots \\ &+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \end{aligned}$$



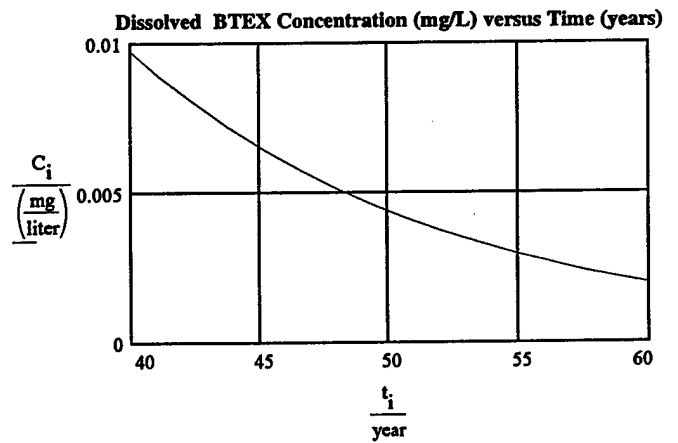
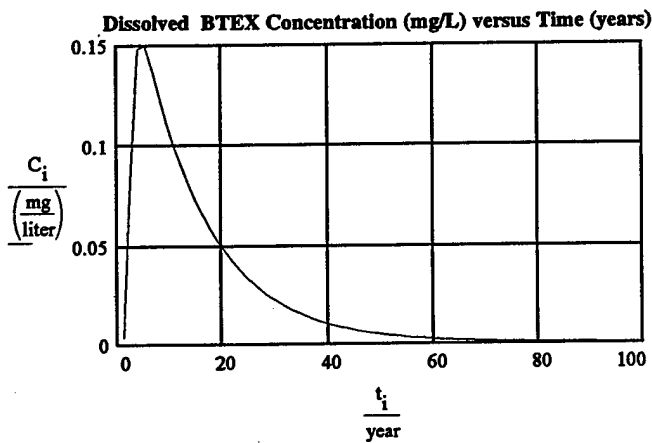
114 Meters from the Source Area (Monitoring Well TF-8)

Initial Plume Distribution Calculation

$year := 365 \cdot day$ $i := 1..365$ $x := 114 \cdot m$
 $\Delta t := 500 \cdot day$
 $t_i := \Delta t \cdot i$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned}
 C_i := & C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\
 & + C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp \left[\frac{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x - t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots \\
 & + \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp \left[\frac{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \dots \\
 & + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right)
 \end{aligned}$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (30 mg/l SOURCE DECAYING AT 50 %/year WITH A 0.0034 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION) AFTER BIOVENTING

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot \text{m}$
Concentration of Injected Contaminant	$C_s := 1.73 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.022 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.00137 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

11 Years From Present (1995-2006)

Initial Plume Distribution Calculation

$$j := 0..200$$

$$t := 4015 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

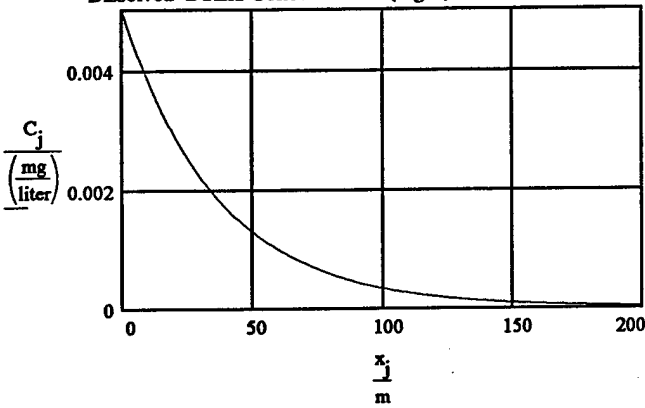
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[-\frac{v_x \cdot x_j}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right) \right] \dots$$

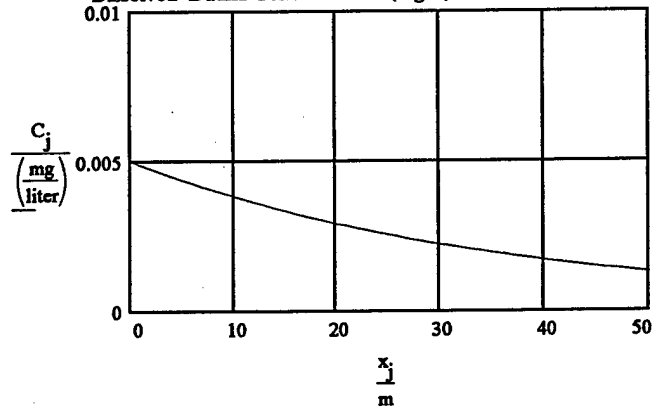
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[-\frac{v_x \cdot x_j}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

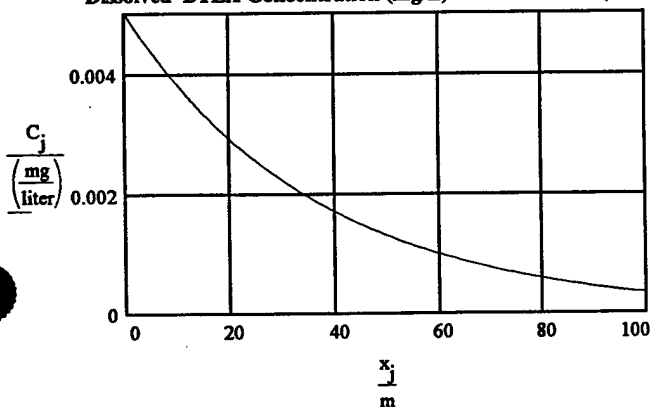
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



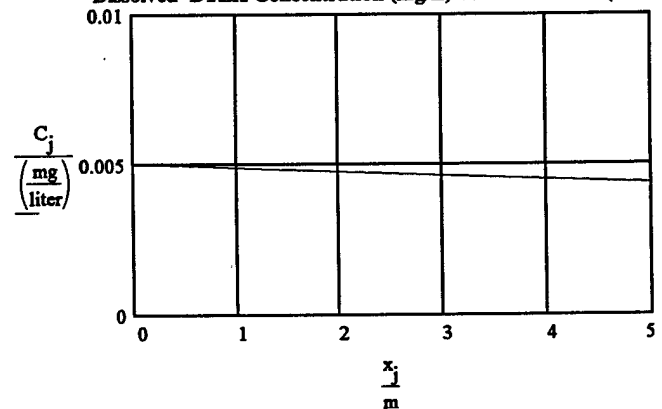
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (30 mg/l SOURCE DECAYING AT 8 %/year WITH A 0.0034 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{m}{day}$
Hydraulic gradient	$I := 0.01 \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot m$
Concentration of Injected Contaminant	$C_s := 30 \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0.0 \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.000219 \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{ft^2}{day}$

30 Years Ago (1965-1995)

Initial Plume Distribution Calculation

$$j := 0..200$$

$$t := 10950 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

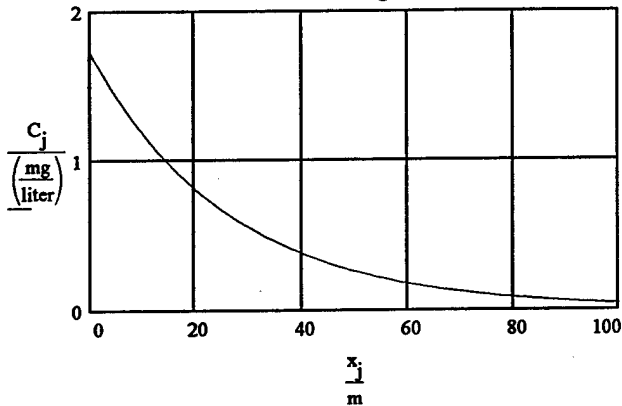
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \frac{(v_x \cdot t)^2}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \frac{1}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right) \dots \right]$$

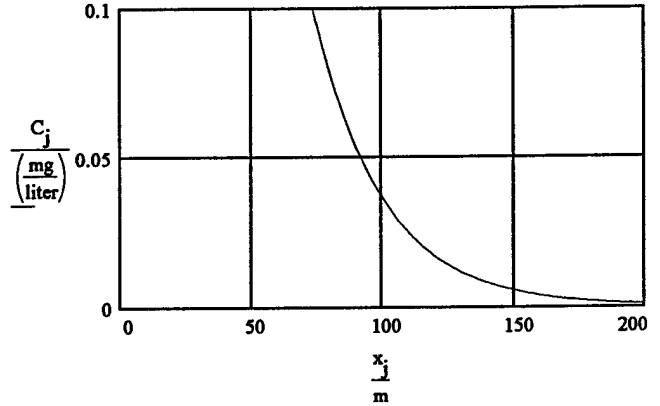
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \frac{1}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right) \dots \right]$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} \right] \cdot (\lambda - \alpha) \cdot t \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

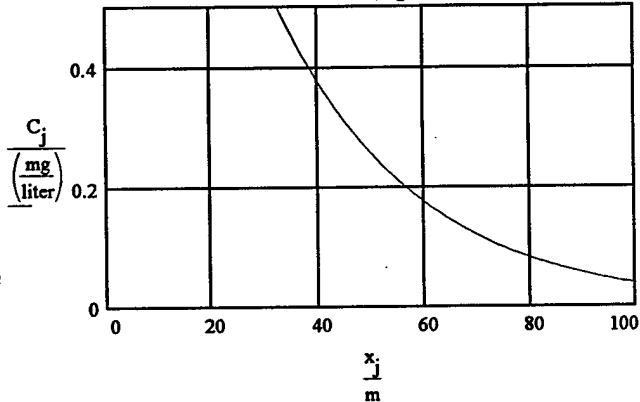
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



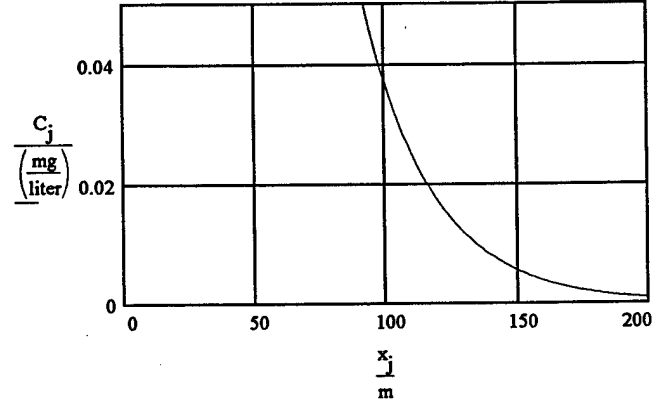
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



2 Years From Present (1965-1997)

Initial Plume Distribution Calculation

$$j := 0..200$$

$$t := 11680 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

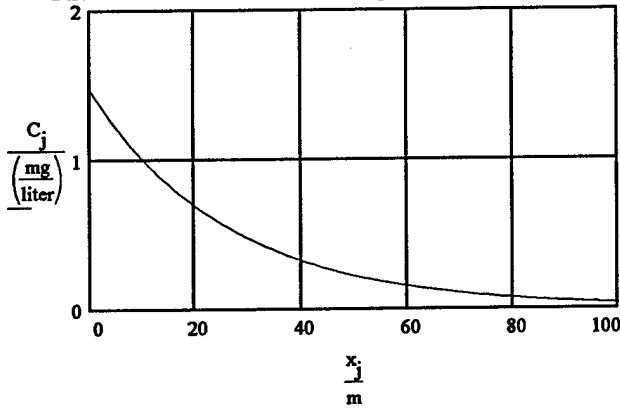
$$C_j := C_{0j} \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v \cdot x_j \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v \cdot x_j^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v \cdot x_j \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v \cdot x_j \cdot x_j}{D_x} + \frac{v \cdot x_j^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v \cdot x_j \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v \cdot x_j \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_{sj} \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v \cdot x_j} \cdot \exp \left[-\frac{v_x \cdot v \cdot x_j \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v \cdot x_j \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

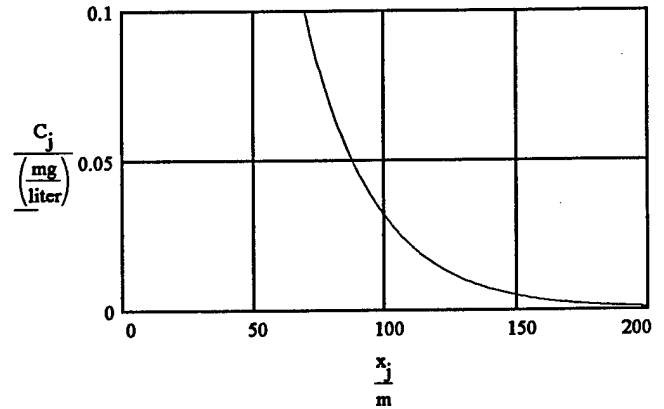
$$+ \left[\frac{v_x}{v_x - v \cdot x_j} \cdot \exp \left[-\frac{v_x \cdot v \cdot x_j \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v \cdot x_j \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v \cdot x_j \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v \cdot x_j \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

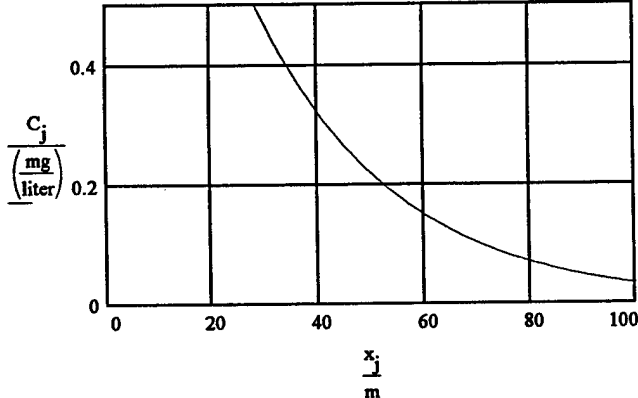
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



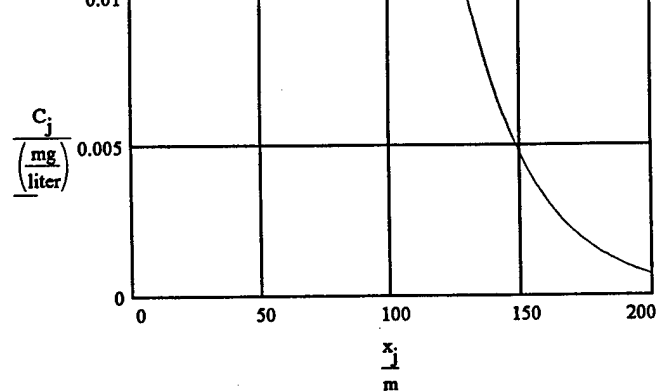
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



5 Years From Present (1965-2000)

Initial Plume Distribution Calculation

$$j := 0..200$$

$$t := 12675 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

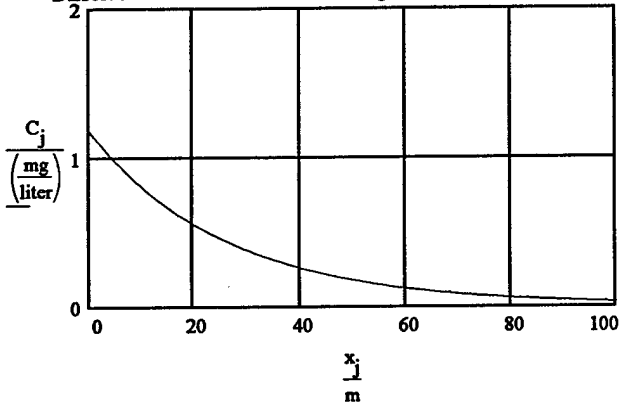
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

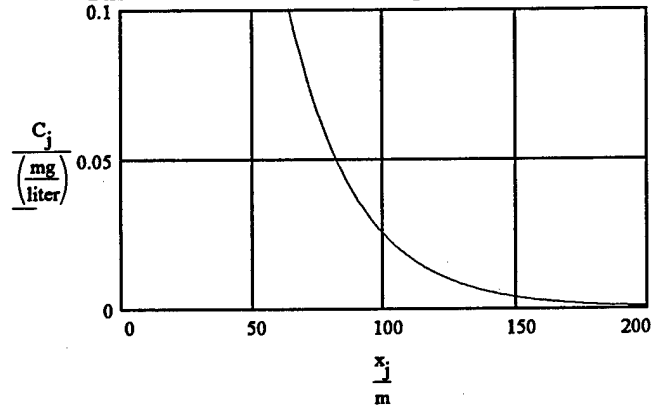
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

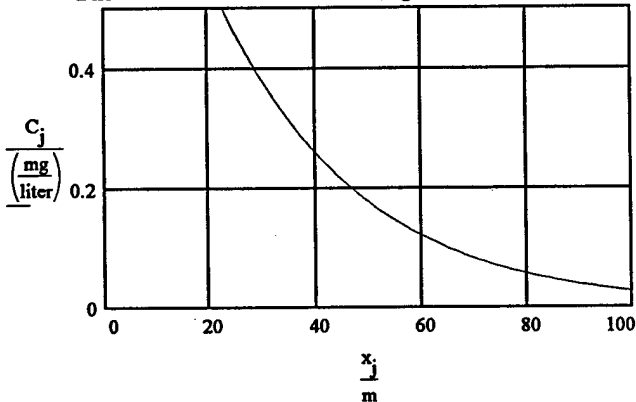
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



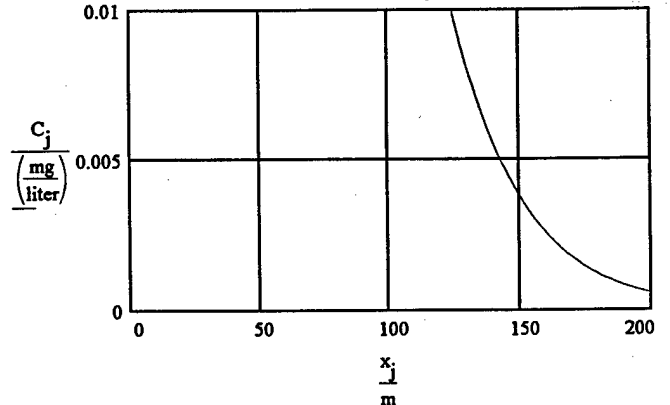
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



10 Years From Present (1965-2005)

Initial Plume Distribution Calculation

$$j := 0..200 \quad t := 14600 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

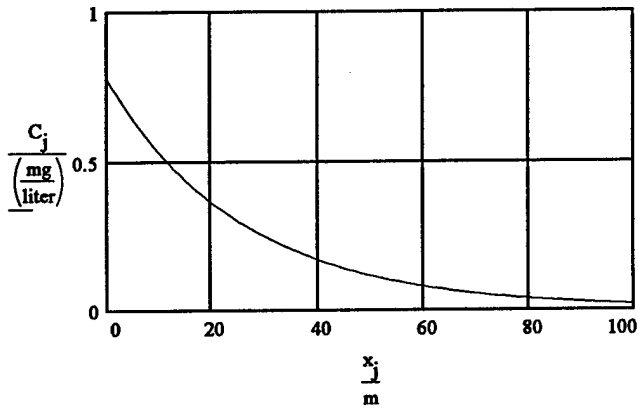
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

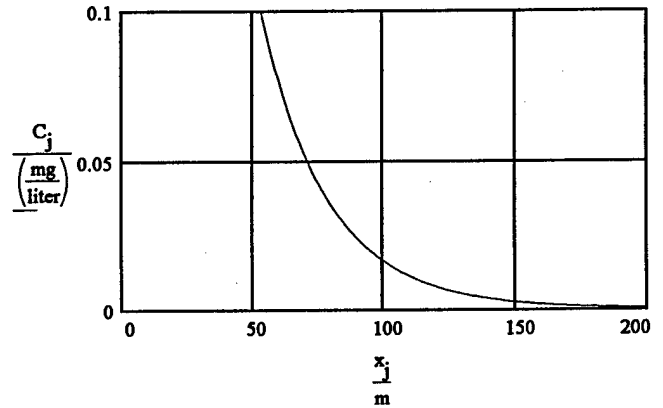
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

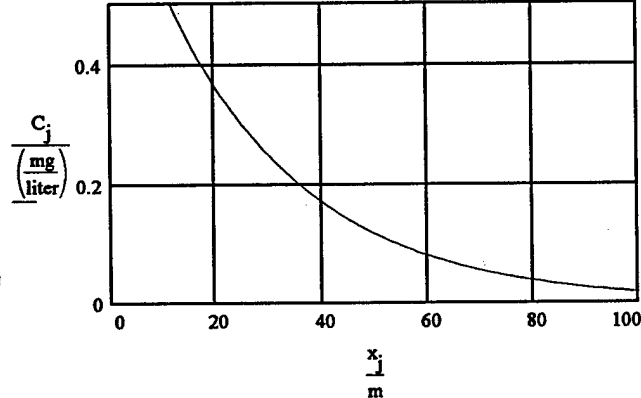
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



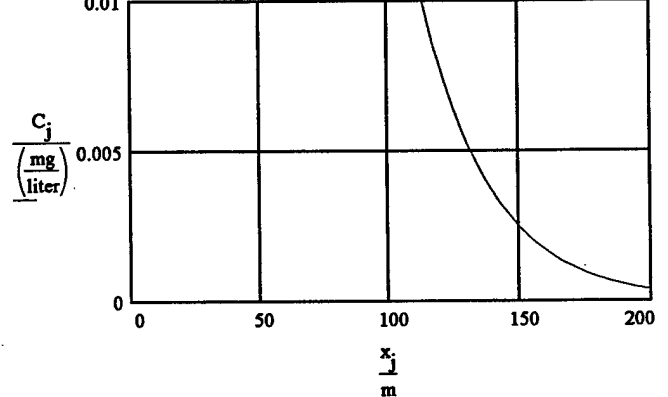
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



20 Years From Present (1965-2015)

Initial Plume Distribution Calculation

$$j := 0..200$$

$$t := 18250 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

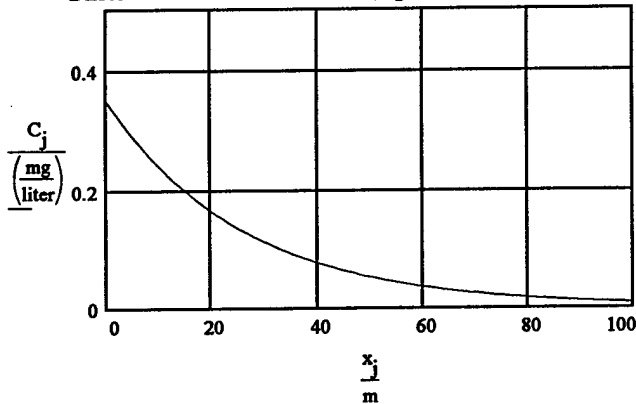
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \frac{(v_x^2 \cdot t)}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \frac{1}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots$$

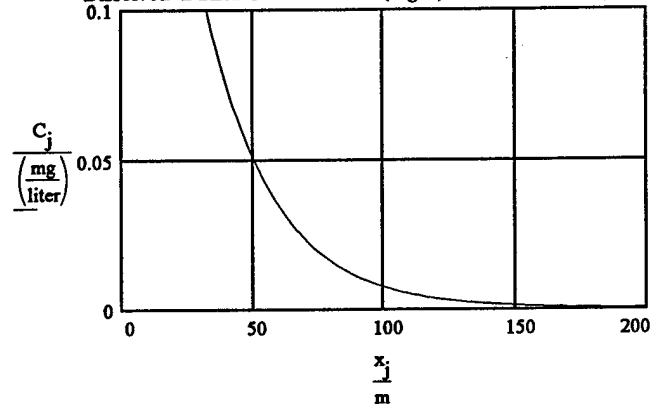
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \frac{1}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

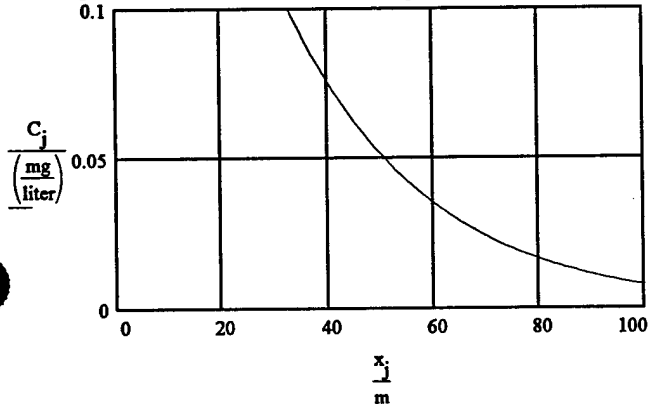
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



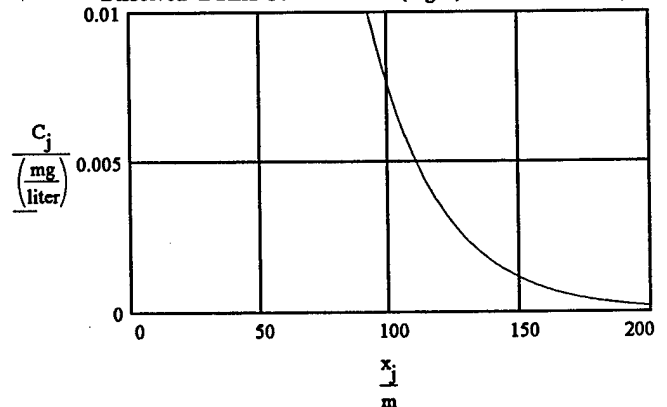
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



30 Years From Present (1965-2025)

Initial Plume Distribution Calculation

$$j := 0..200 \quad t := 21900 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

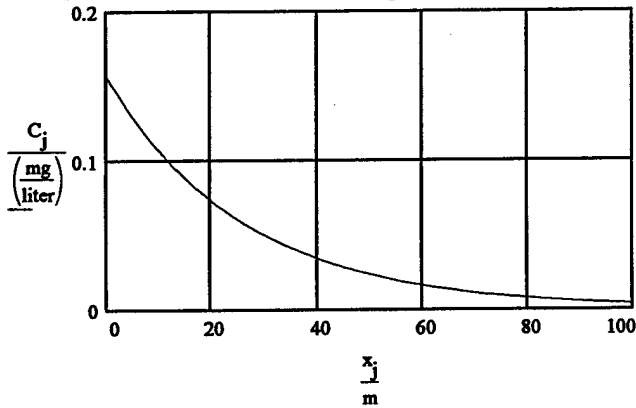
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \frac{(v_x^2 \cdot t)}{2 \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

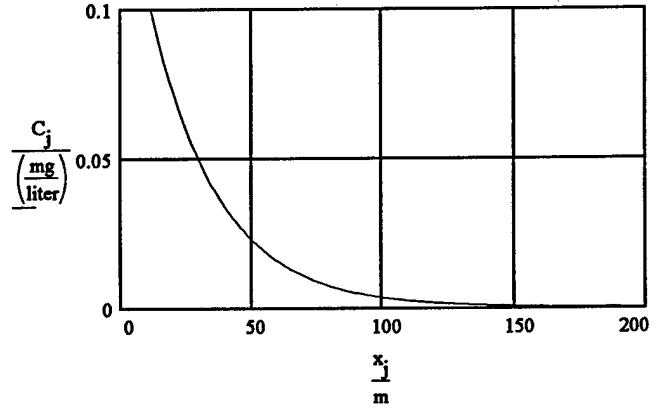
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

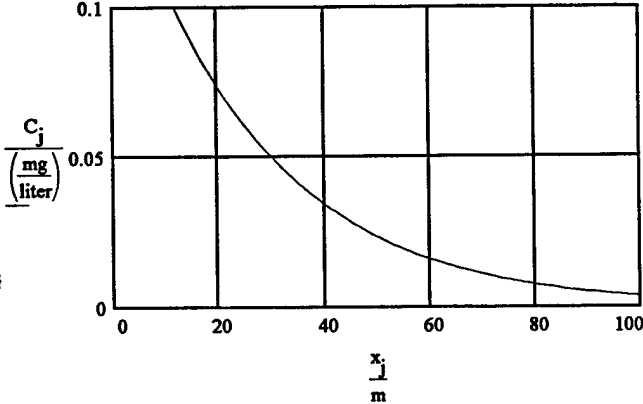
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



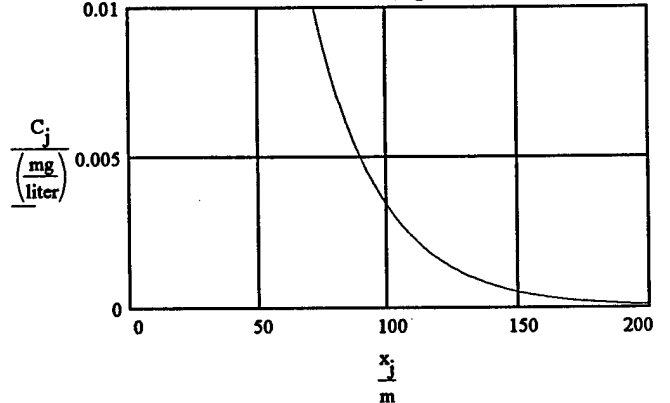
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



50 Years From Present (1965-2045)

Initial Plume Distribution Calculation

$$j := 0..200 \quad t := 29200 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

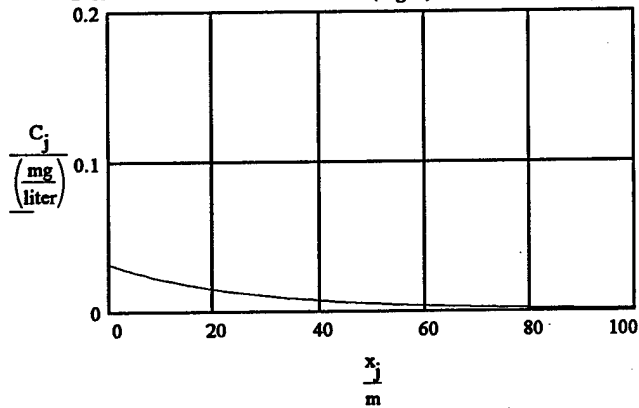
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

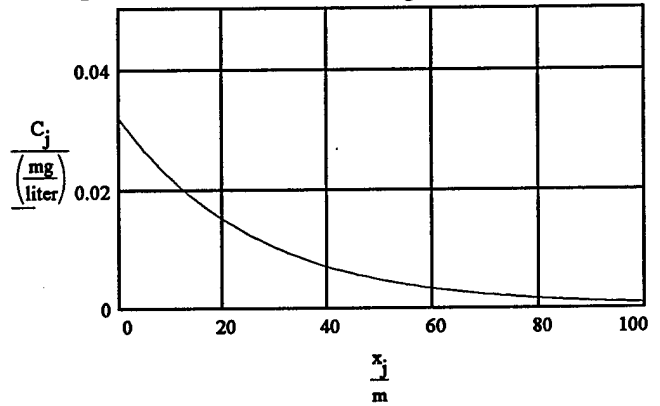
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

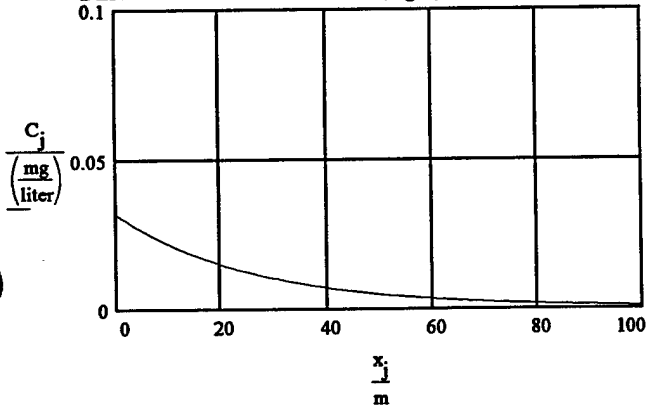
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



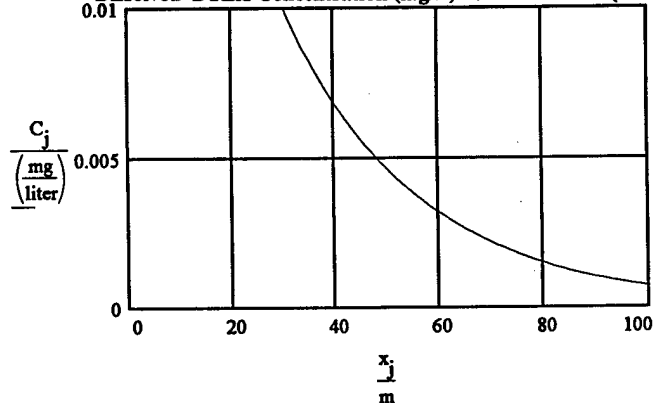
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



60 Years From Present (1965-2055)

Initial Plume Distribution Calculation

$$j := 0..200$$

$$t := 32850 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

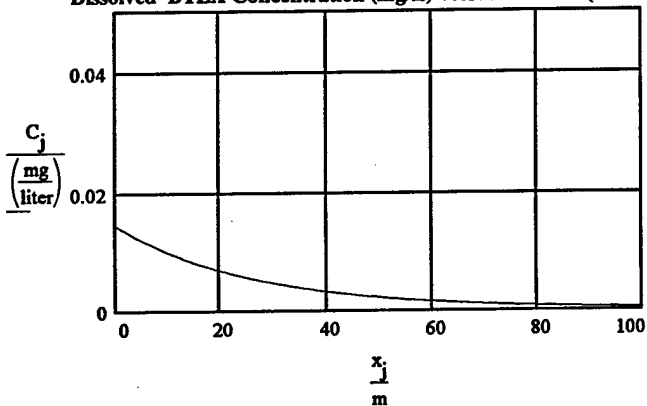
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j + v_x^2 \cdot t}{D_x + D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha) \right) \cdot x_j \right] \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

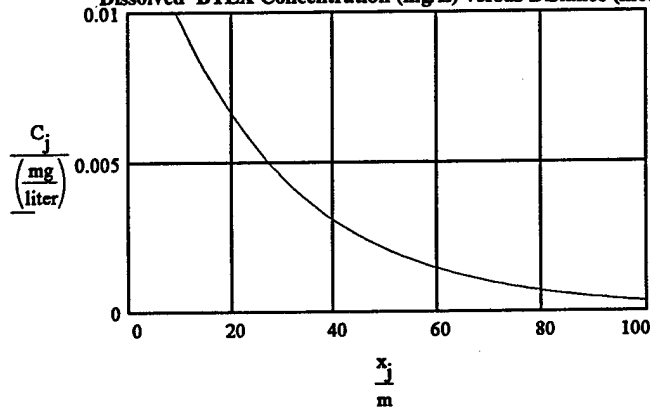
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha) \right) \cdot x_j \right] \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

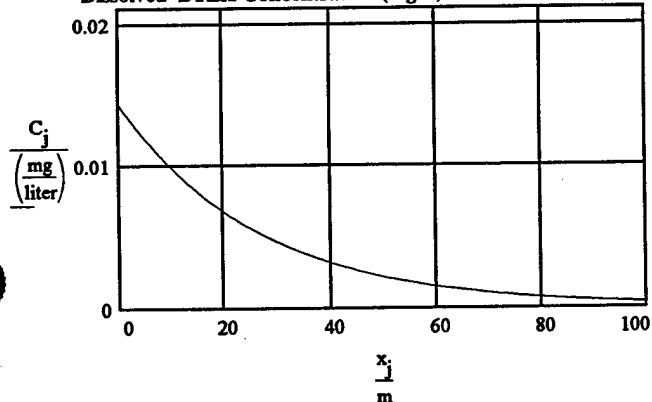
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



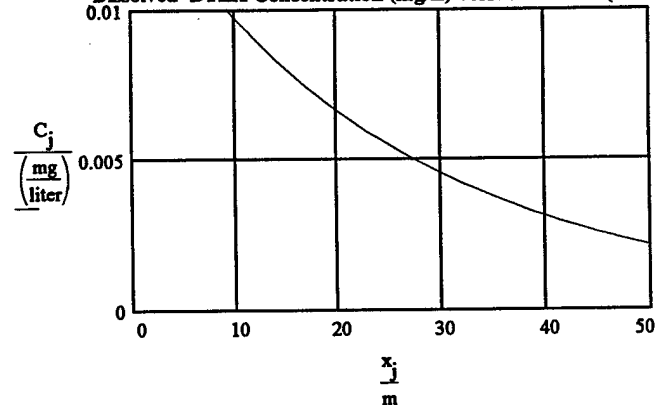
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



APPENDIX C-3
ANALYTICAL MODEL-DECAY 10%

TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.69 mg/l SOURCE DECAYING AT 10 %/year WITH A 0.0013 day⁻¹ ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 15 \text{ m}$
Concentration of Injected Contaminant	$C_s := 2.69 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0013 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

35 Meters from the Source Area (Base Boundary)

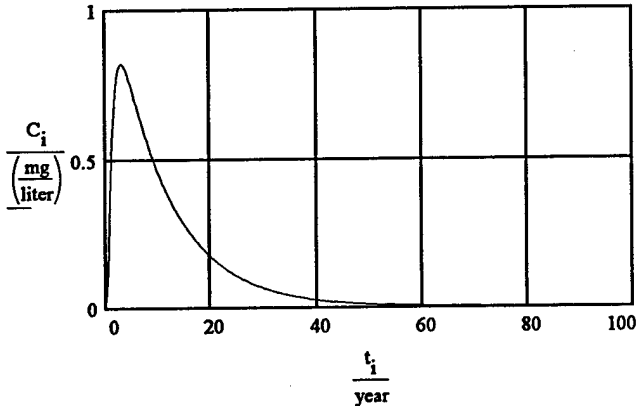
Initial Plume Distribution Calculation

$$\begin{aligned} \text{year} &:= 365 \cdot \text{day} & i &:= 1..365 & x &:= 35 \cdot \text{m} \\ \Delta t &:= 100 \cdot \text{day} \\ t_i &:= \Delta t \cdot i \end{aligned}$$

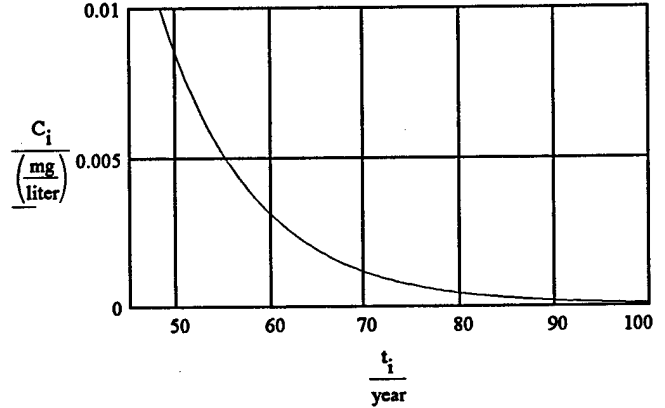
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$\begin{aligned} C_i &:= C_0 \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{(v_x \cdot t_i)^2}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots \\ &+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\ &+ \left. \frac{v_x}{v_x - v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right. \\ &+ \left. \frac{v_x}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \end{aligned}$$

Dissolved BTEX Concentration (mg/L) versus Time (years)



Dissolved BTEX Concentration (mg/L) versus Time (years)



114 Meters from the Source Area (Monitoring Well TF-8)

Initial Plume Distribution Calculation

$$\text{year} := 365 \cdot \text{day} \quad i := 1..365 \quad x := 114\text{-m}$$

$$\Delta t := 500 \cdot \text{day}$$

$$t_i := \Delta t \cdot i$$

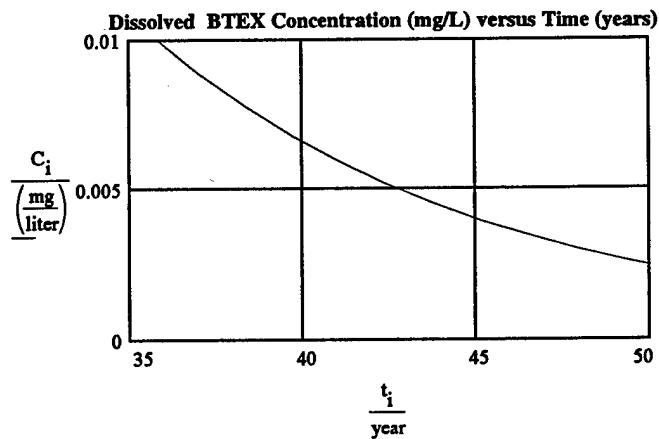
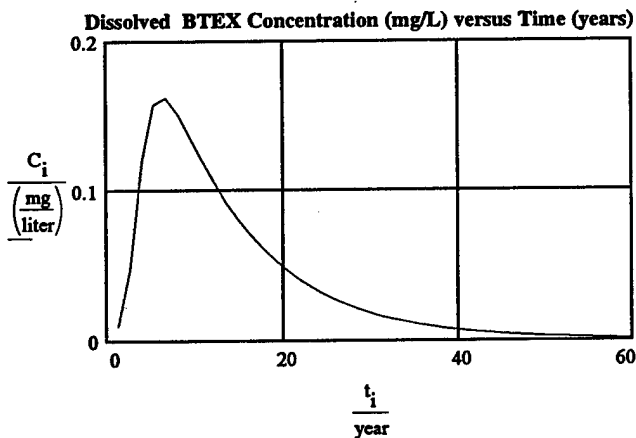
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{(v_x^2 \cdot t_i)}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.69 mg/l SOURCE DECAYING AT 10 %/year WITH A 0.0013 day⁻¹ ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION) AFTER BIOVENTING STARTUP

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 15\text{-m}$
Concentration of Injected Contaminant	$C_s := 2.69 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0026 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.052 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

35 Meters from the Source Area (Base Boundary)

Initial Plume Distribution Calculation

$$\text{year} := 365 \cdot \text{day} \quad i := 1..365$$

$$x := 35 \cdot \text{m}$$

$$\Delta t := 100 \cdot \text{day}$$

$$t_i := \Delta t \cdot i$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

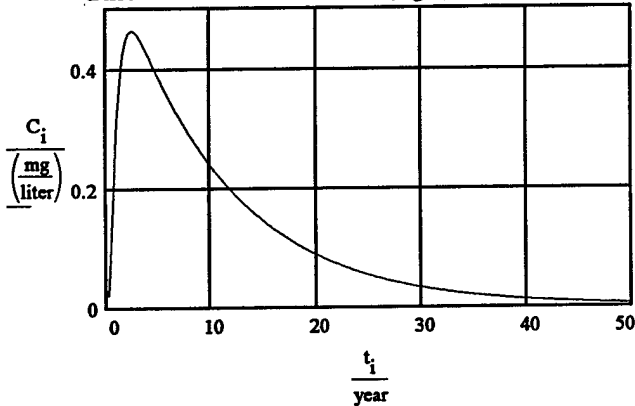
$$C_i := C_o \cdot \exp(-\lambda \cdot t_i) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x - v_x \cdot t_i)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t_i) \cdot \left[\frac{v_x}{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x - t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right.$$

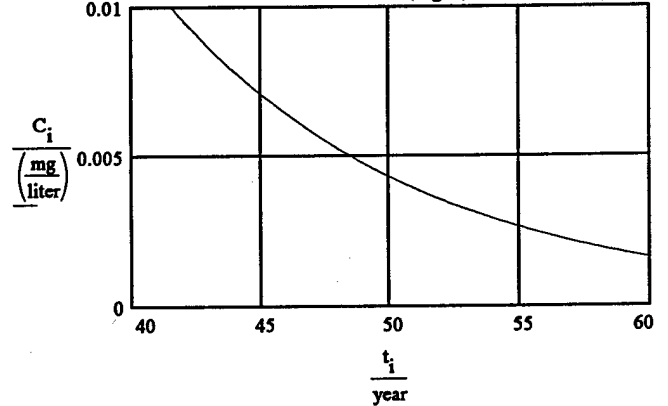
$$+ \left[\frac{v_x}{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}}{2 \cdot D_x} \cdot x \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x + t_i \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right] \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$

Dissolved BTEX Concentration (mg/L) versus Time (years)



Dissolved BTEX Concentration (mg/L) versus Time (years)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (2.69 mg/l SOURCE DECAYING AT 10 %/year WITH A 0.0013 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.05 \frac{\text{m}}{\text{day}}$
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Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.052 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.477 \frac{\text{ft}^2}{\text{day}}$

2 Years Ago (1993-1995)

Initial Plume Distribution Calculation

$$j := 0..300$$

$$t := 690 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

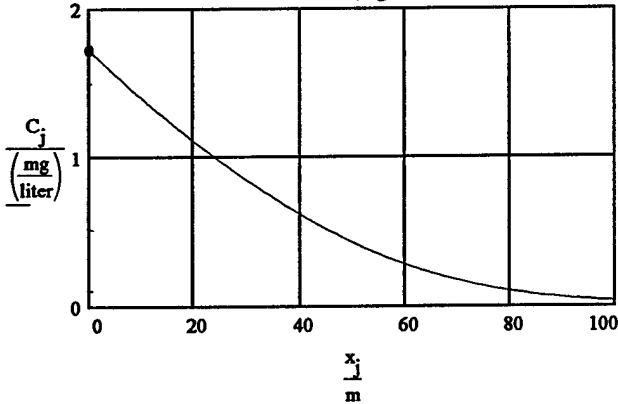
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \frac{(v_x \cdot x_j)^2}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x \cdot x_j^2}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \right] \dots$$

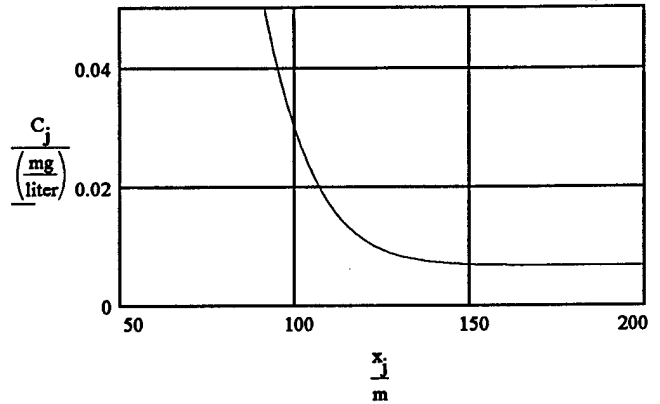
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x'}{\sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

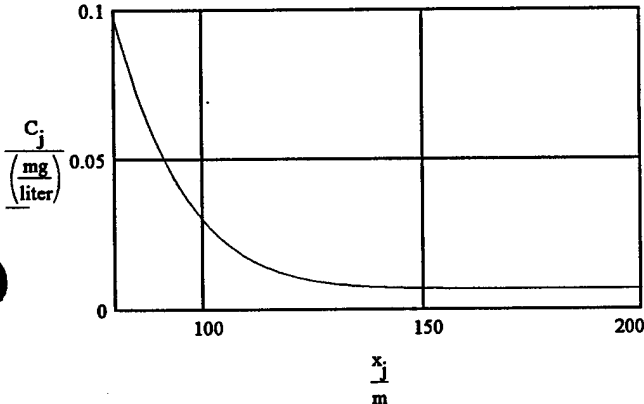
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



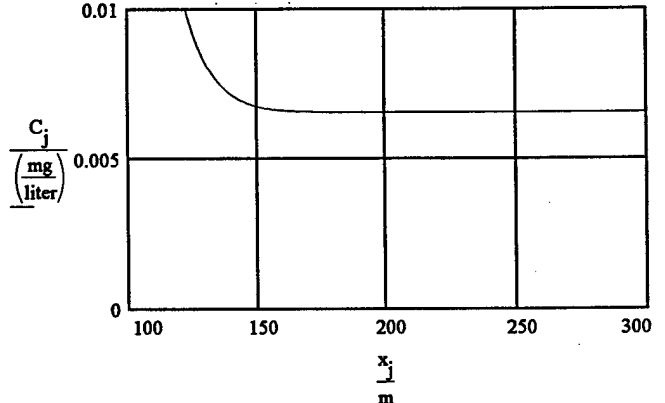
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



2 Years From Present (1993-1997)

Initial Plume Distribution Calculation

$$j := 0..300$$

$$t := 1420 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

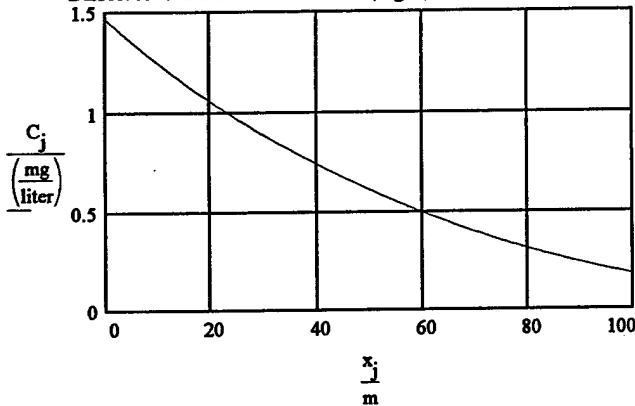
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \frac{(v_x \cdot t)^2}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

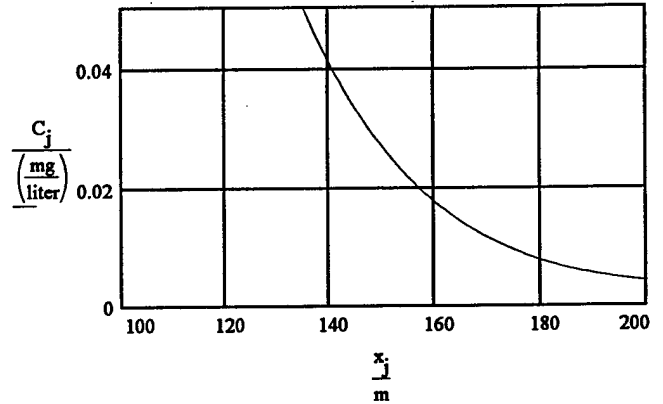
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x' \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

$$\left. + \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} \right] \cdot (\lambda - \alpha) \cdot t \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

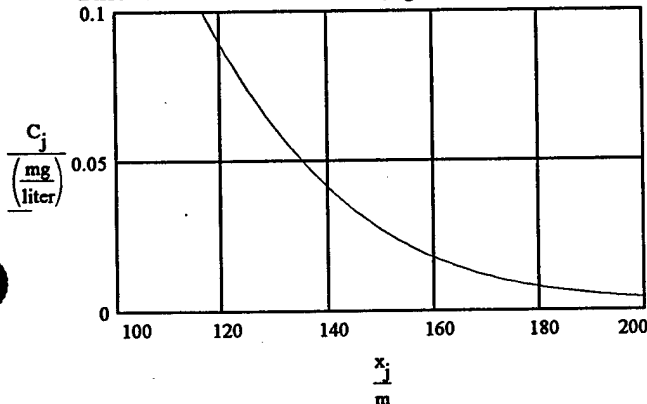
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



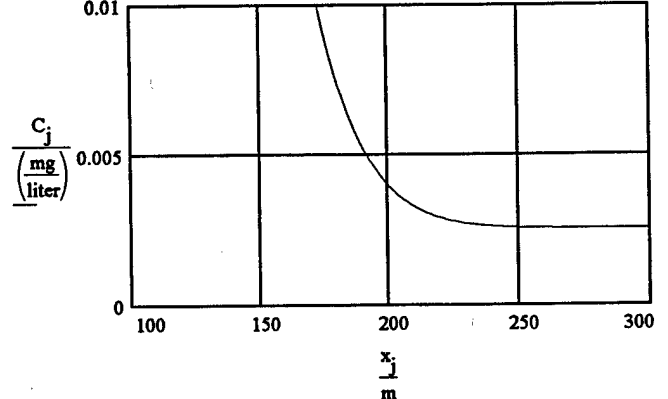
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



5 Years From Present (1993-2000)

Initial Plume Distribution Calculation

$$j := 0..300 \quad t := 2515 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

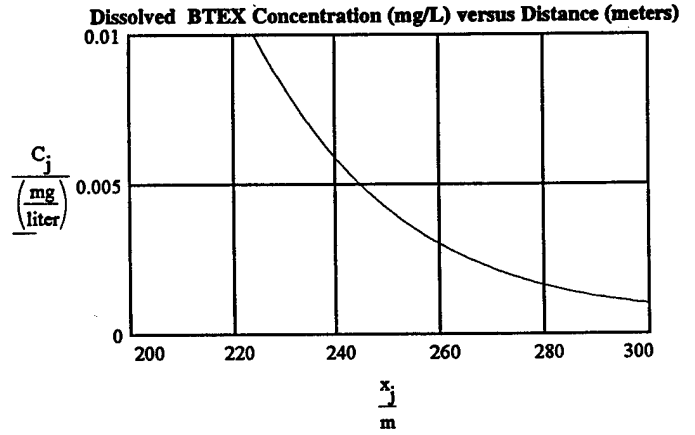
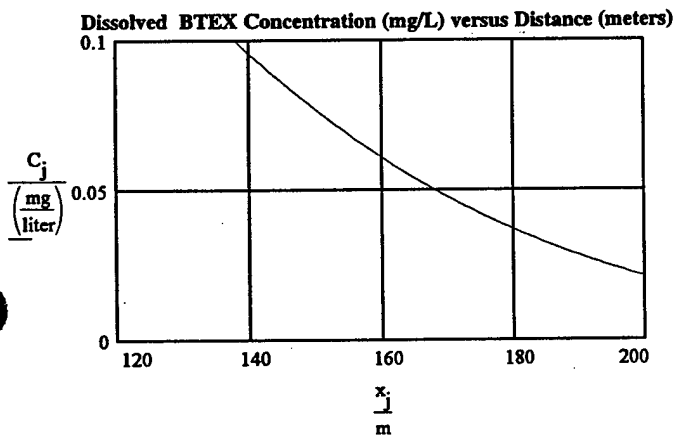
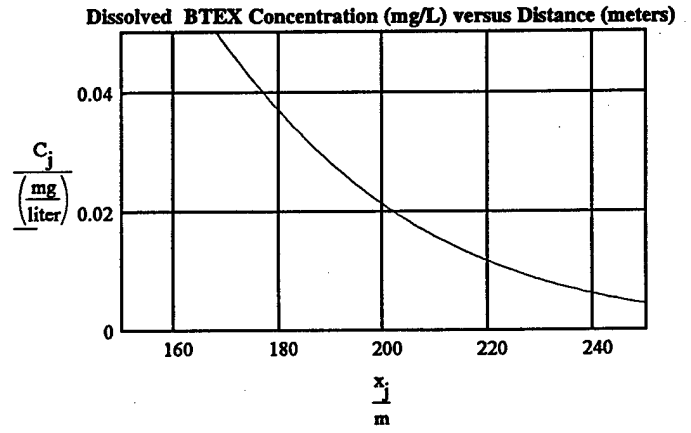
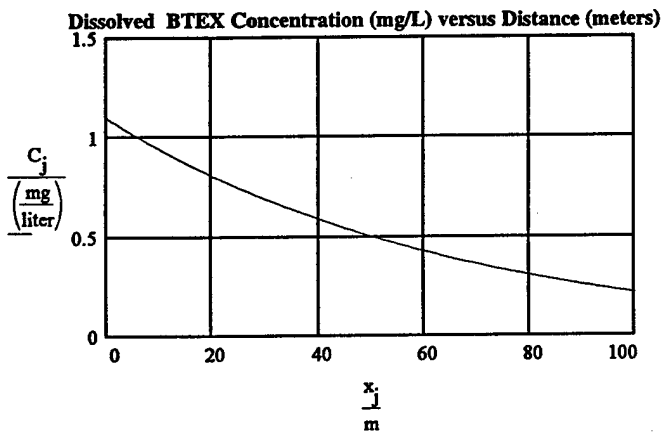
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot D_x} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$



10 Years From Present (1993-2005)

Initial Plume Distribution Calculation

$$j := 0..300 \quad t := 4340 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

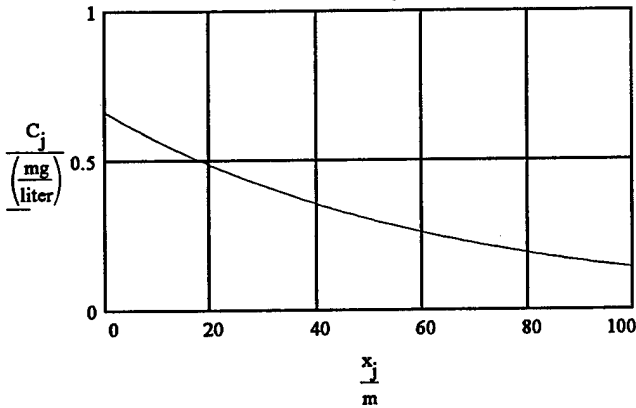
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right]$$

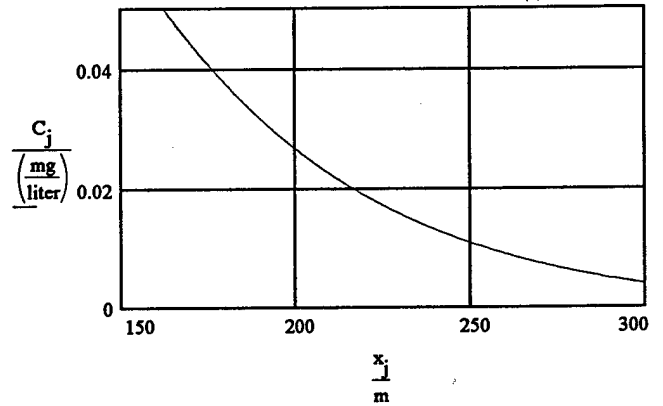
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right]$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

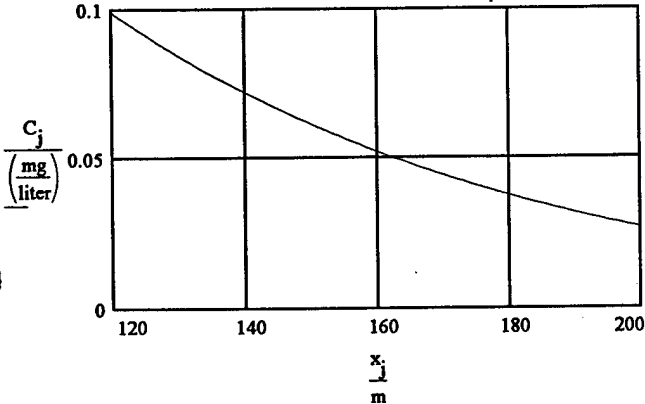
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



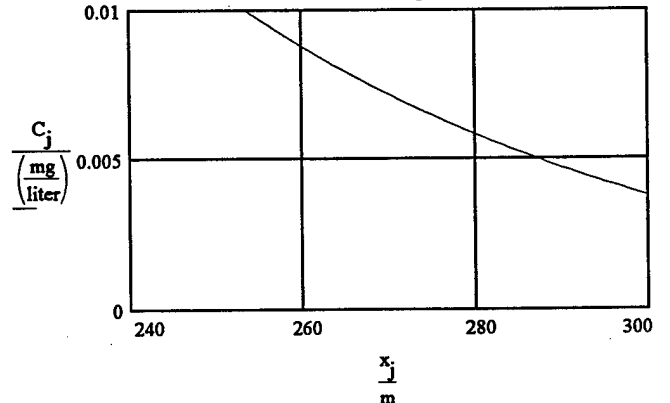
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



20 Years From Present (1993-2015)

Initial Plume Distribution Calculation

$$j := 0..300 \quad t := 7990 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

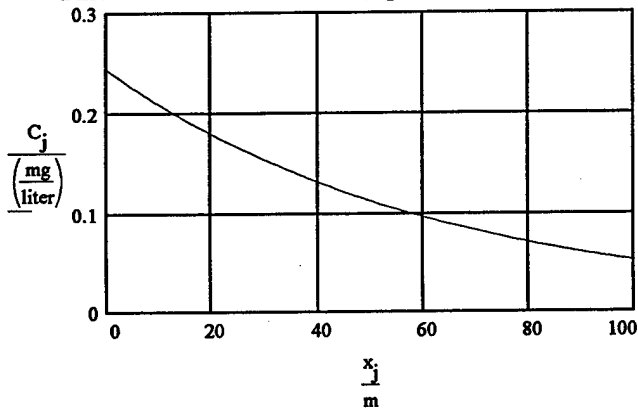
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots \right.$$

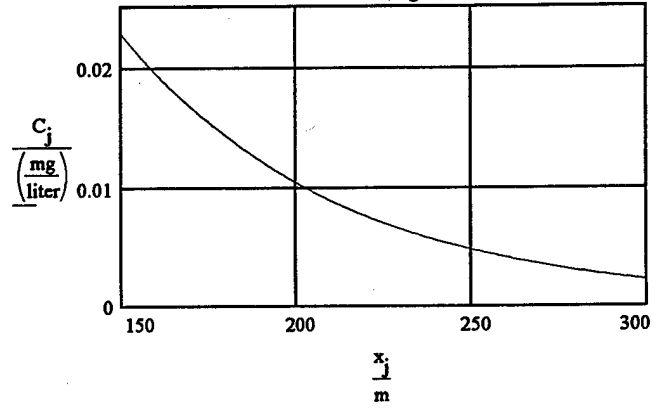
$$+ \left[\frac{v_x}{v_x - v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}} \right] \cdot \exp \left[\frac{v_x + v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

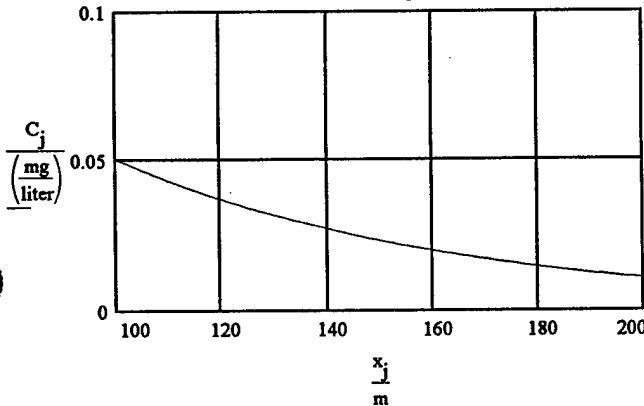
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



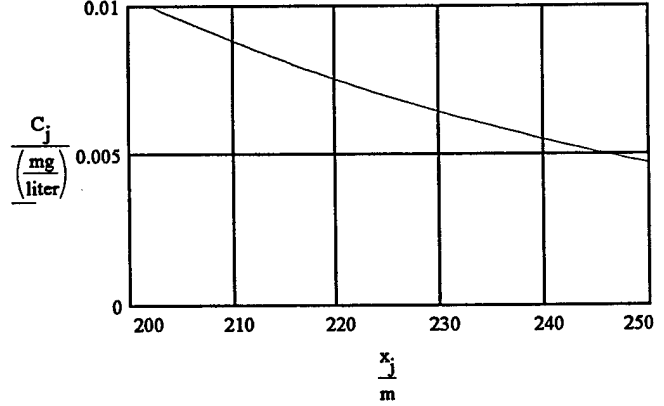
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



30 Years From Present (1993-2025)

Initial Plume Distribution Calculation

$$j := 0..300 \quad t := 11640 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

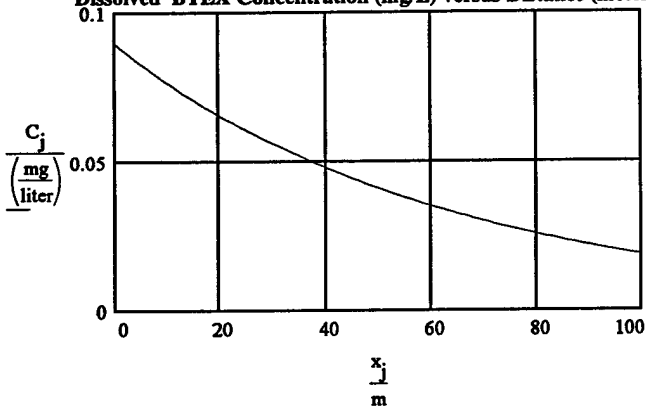
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

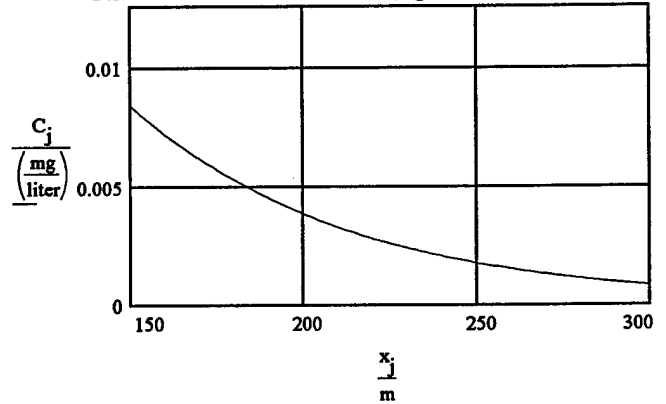
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

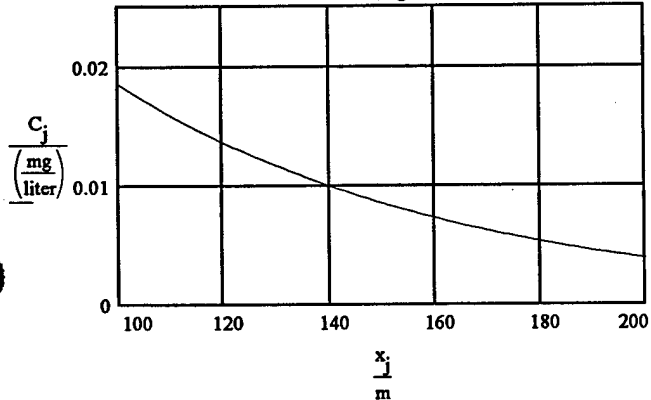
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



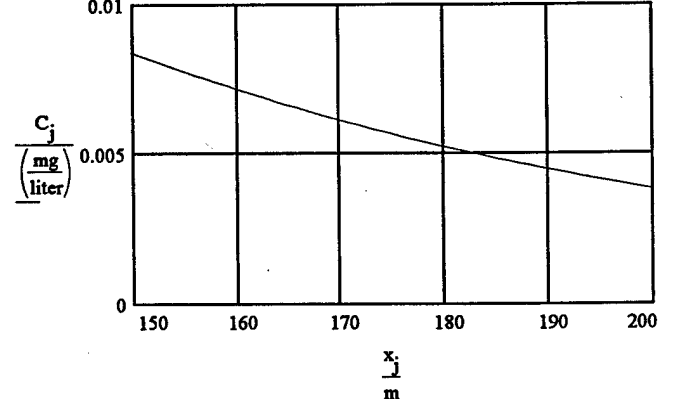
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



50 Years From Present (1993-2045)

Initial Plume Distribution Calculation

$$j := 0..300 \quad t := 18940 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

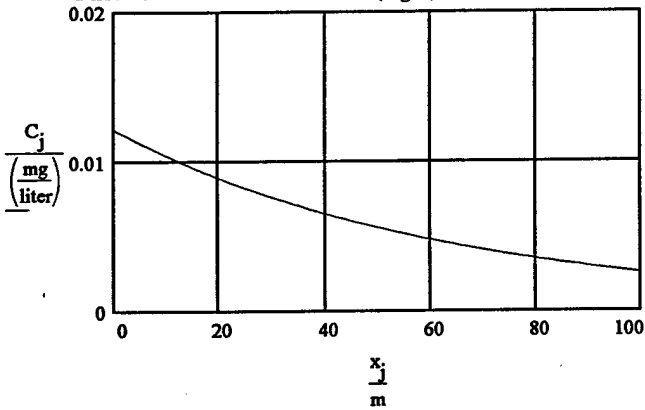
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

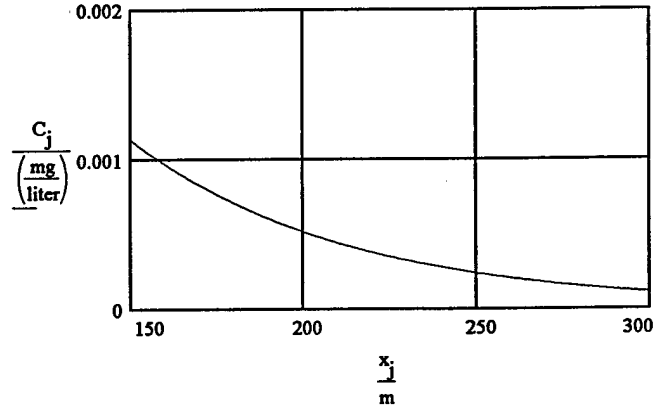
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x' \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

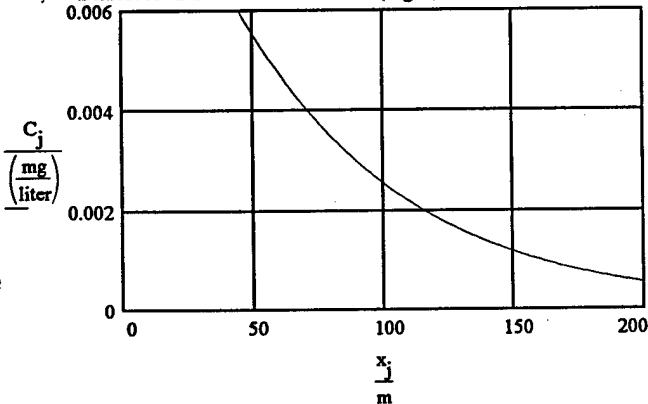
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



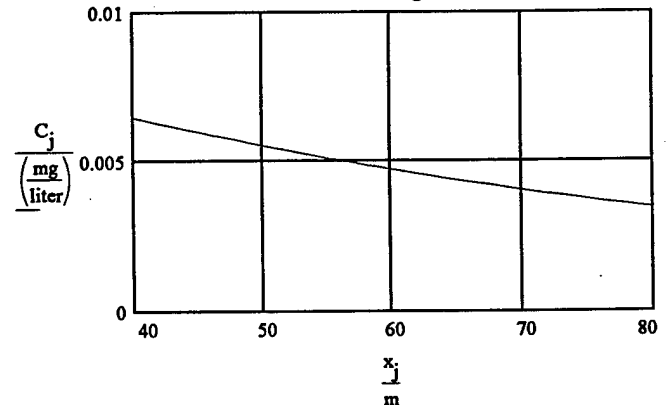
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



APPENDIX C-4
SENSITIVITY ANALYSIS

TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 5.0 \cdot \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \cdot \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \cdot \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \cdot \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \cdot \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \cdot \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.25 \cdot \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.25 \cdot \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 40.365 \cdot \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

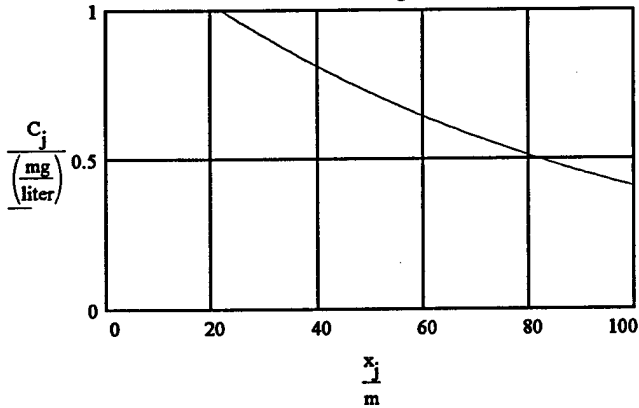
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha) \right) \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

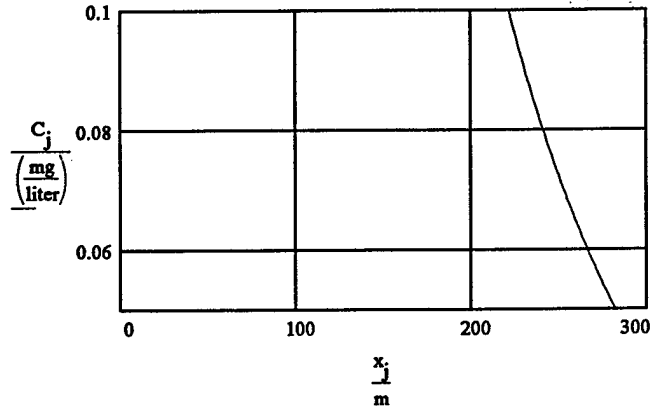
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha) \right) \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

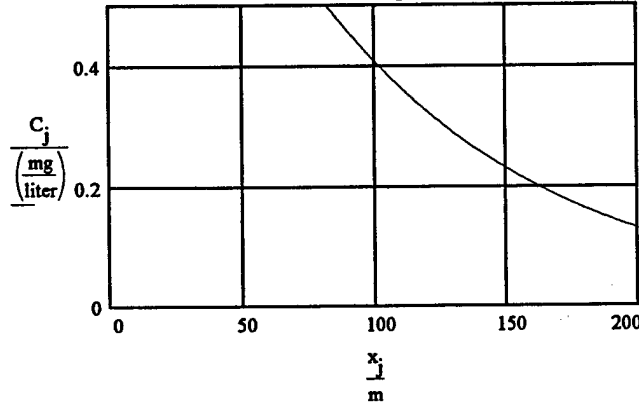
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



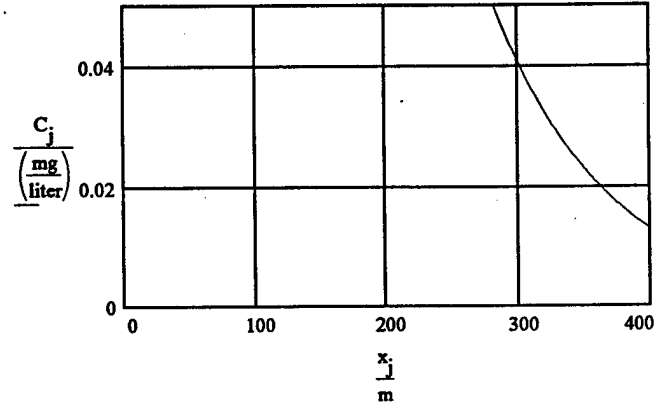
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 0.2 \frac{m}{day}$
Hydraulic gradient	$I := 0.01 \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot m$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.01 \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.01 \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 1.615 \frac{ft^2}{day}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

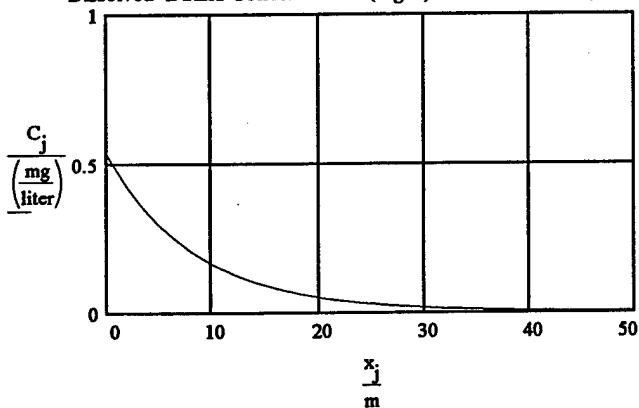
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

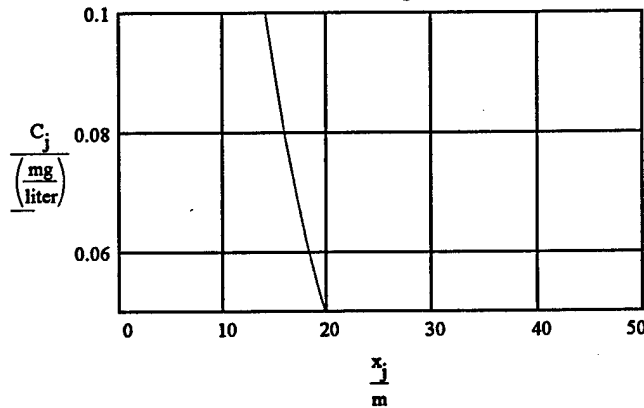
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

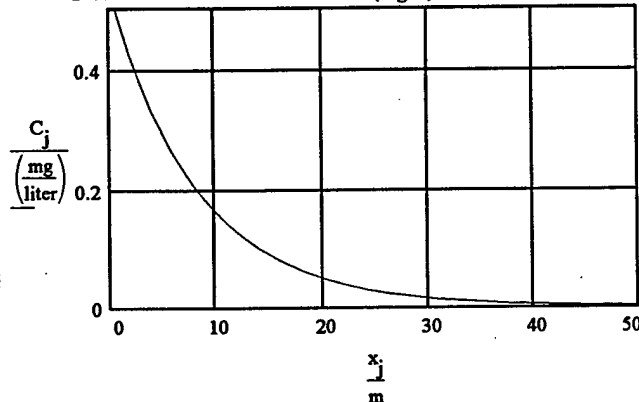
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



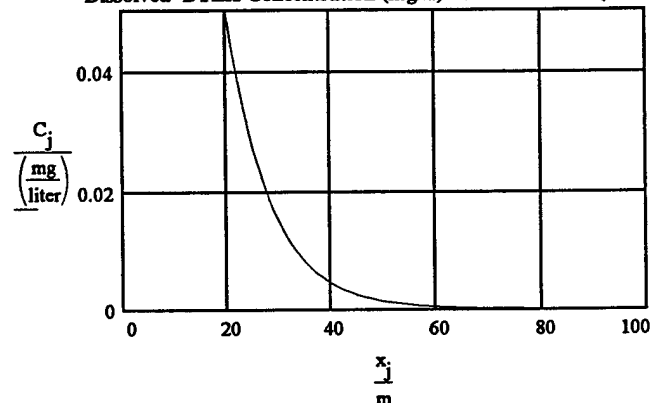
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000548 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.05 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.05 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.073 \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

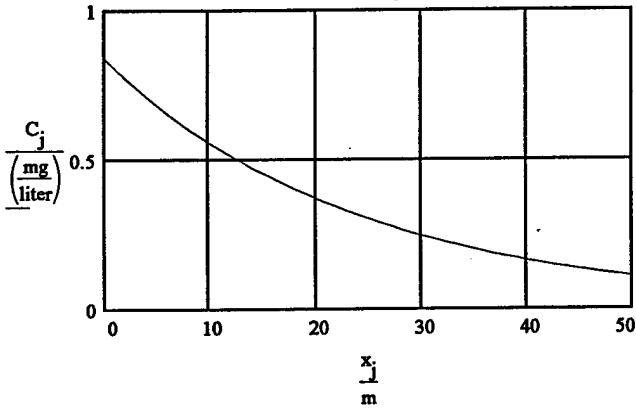
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \right) \right] \dots$$

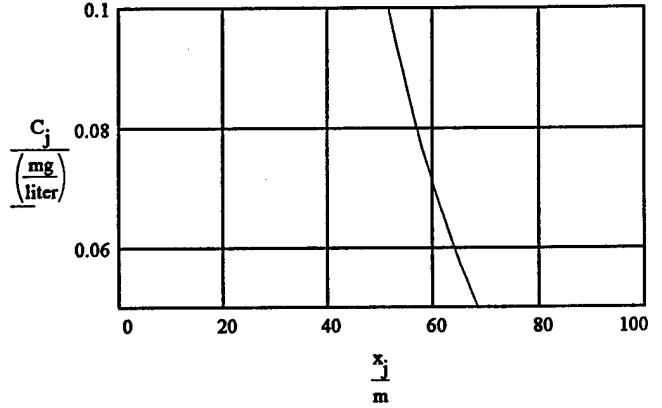
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

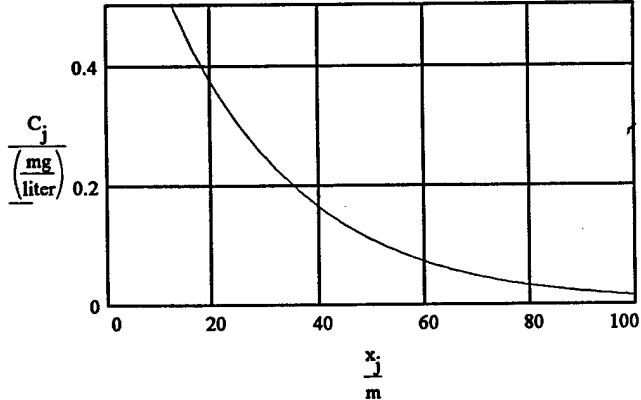
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



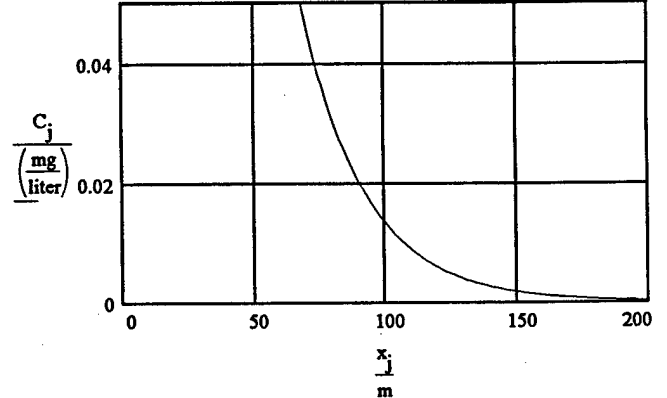
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000137 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.05 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.05 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.073 \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

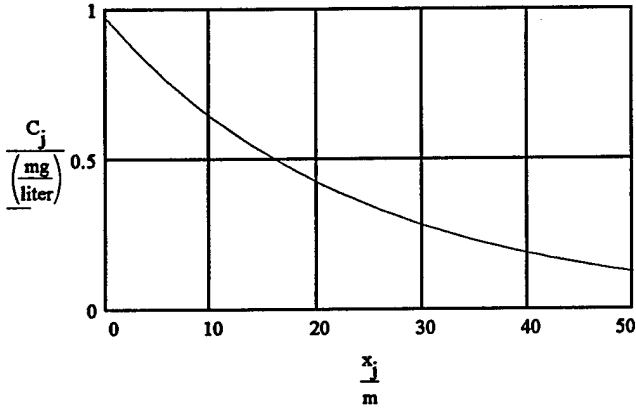
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

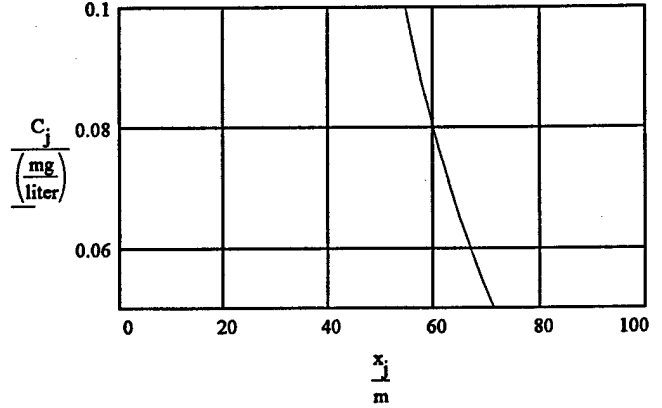
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

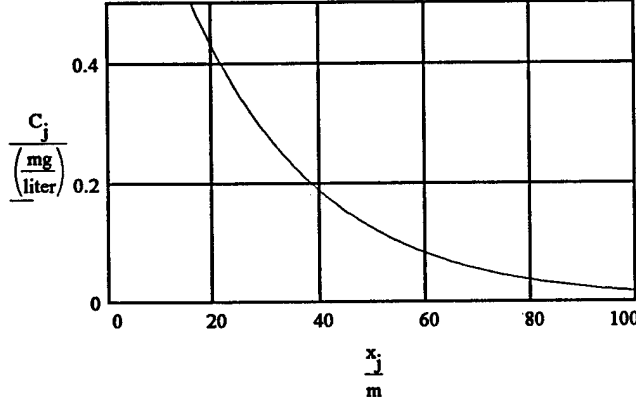
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



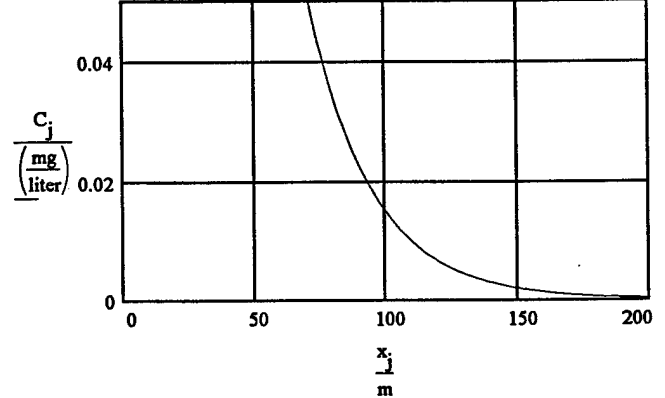
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \cdot \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \cdot \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15 \cdot \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \cdot \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \cdot \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \cdot \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \cdot \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.00001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.007$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.05 \cdot \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.05 \cdot \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 8.073 \cdot \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

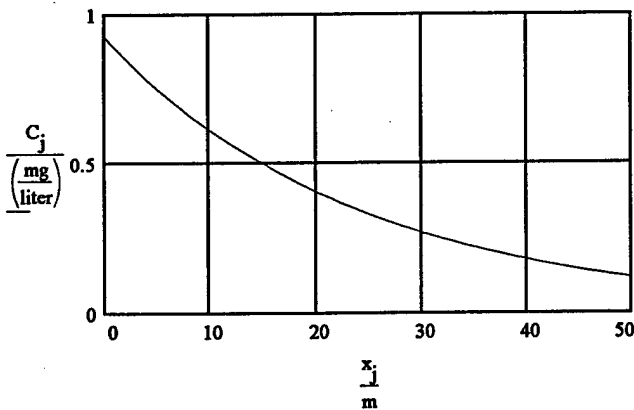
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \left[\frac{v_x}{v_x + v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

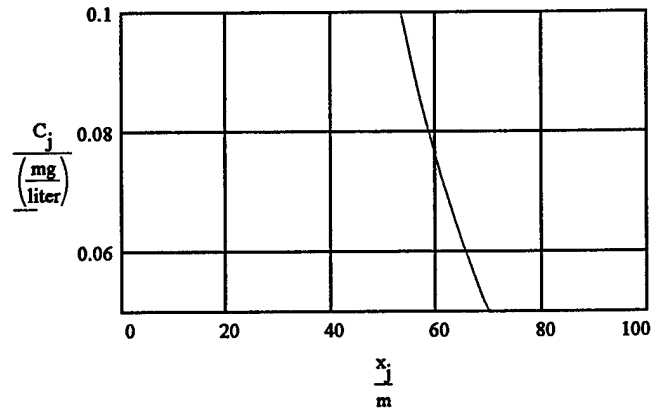
$$+ \left[\frac{v_x}{v_x - v_x'} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right)$$

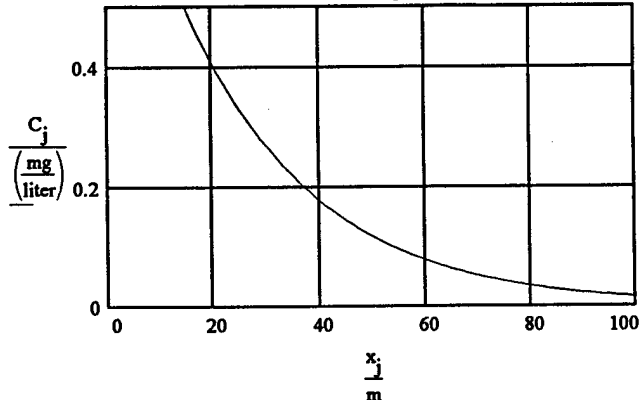
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



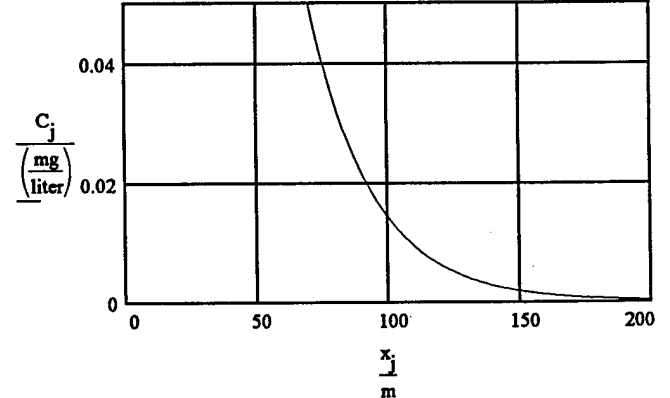
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.1$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15\text{-m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.1 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.1 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 16.146 \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

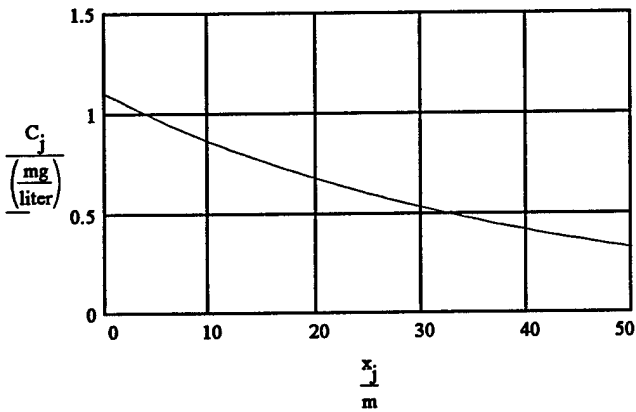
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

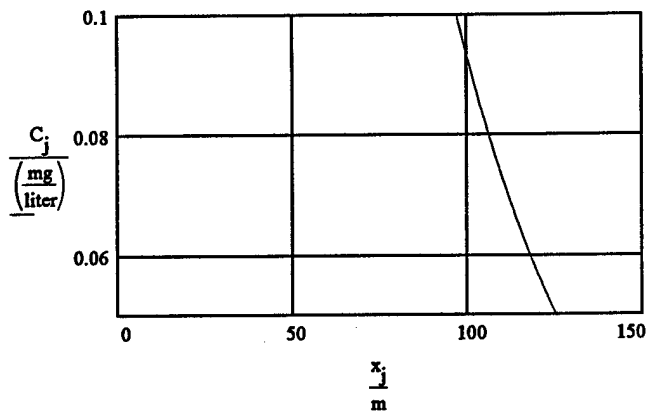
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right) \right] \dots \right.$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

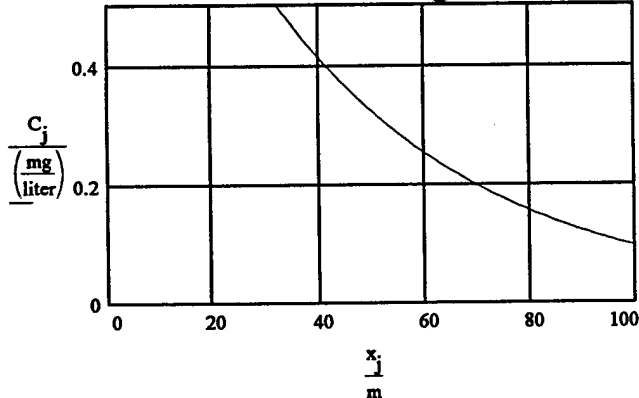
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



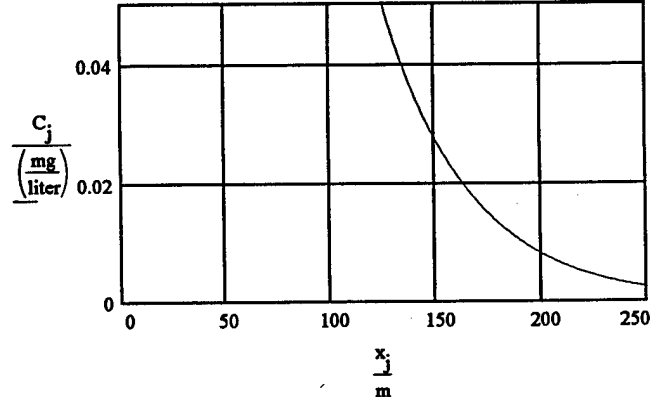
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.3$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 15\text{-m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.033 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.033 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 5.382 \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

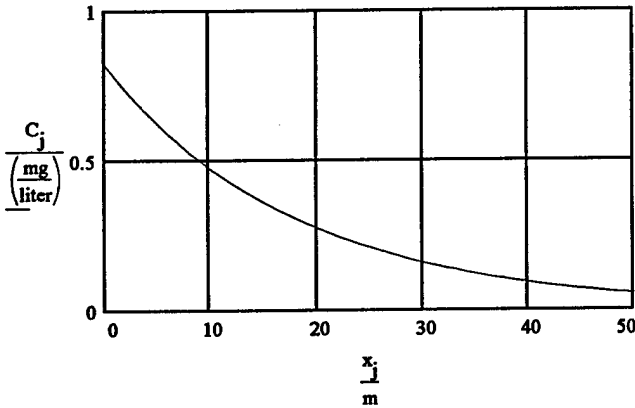
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \sqrt{\frac{4 \cdot D_x \cdot R}{v_x^2 \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2 \cdot (\lambda - \alpha)}} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2 \cdot (\lambda - \alpha)}} \right) \right] \dots \right.$$

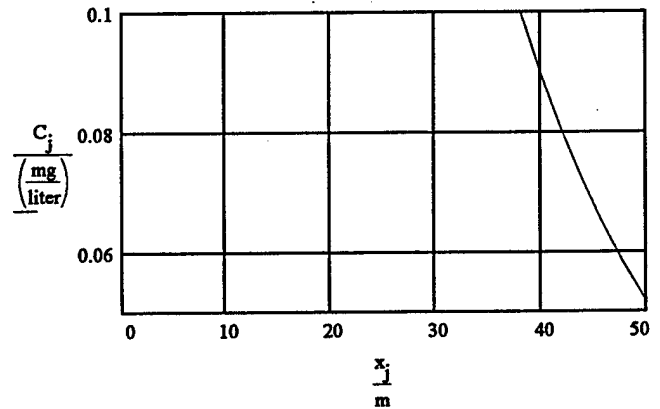
$$+ \left. \frac{v_x}{v_x - v_x'} \cdot \sqrt{\frac{4 \cdot D_x \cdot R}{v_x^2 \cdot (\lambda - \alpha)}} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2 \cdot (\lambda - \alpha)}} \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2 \cdot (\lambda - \alpha)}} \right) \right] \dots \right.$$

$$+ \left. \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

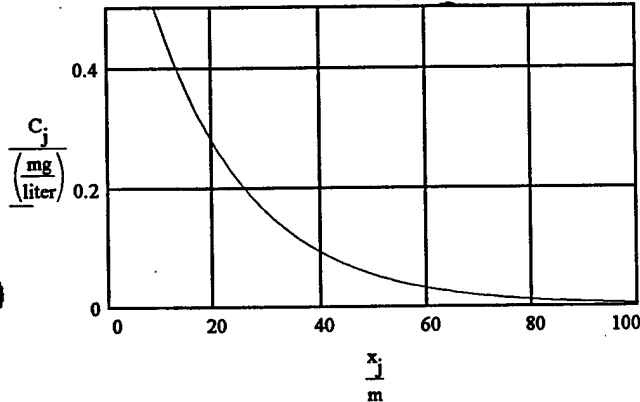
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



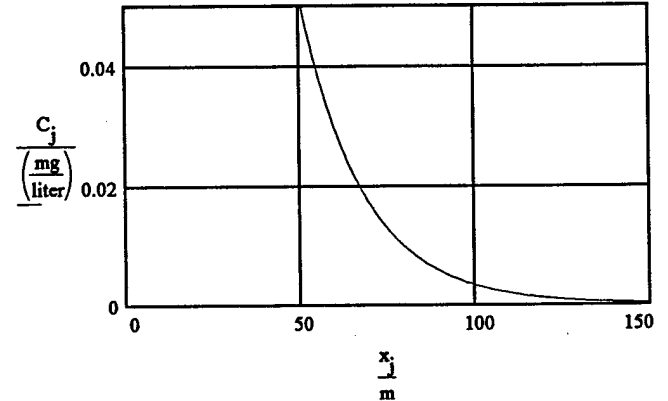
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 30\text{-m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.05 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.05 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 16.146 \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400 \quad t := 3650 \text{ day}$$

$$\Delta x := 1 \text{ m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

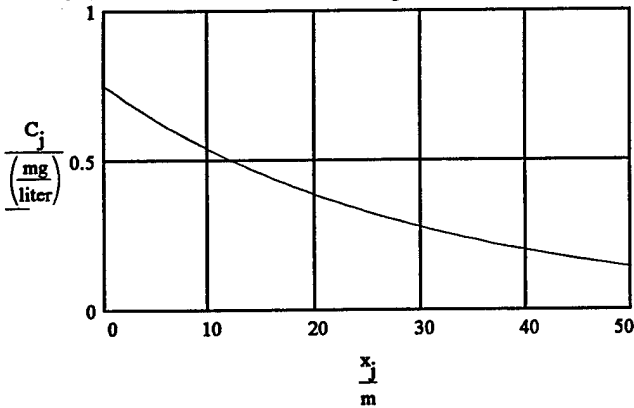
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[\frac{v_x - v_x'}{2 \cdot D_x} \cdot \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha) \right) \cdot x_j \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \right) \dots \right]$$

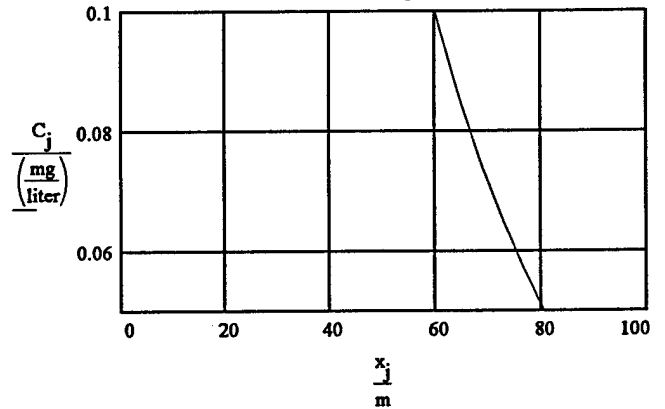
$$+ \left[\frac{v_x}{v_x - v_x'} \cdot \exp \left[\frac{v_x + v_x'}{2 \cdot D_x} \cdot \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha) \right) \cdot x_j \right] \cdot \left(1 - \operatorname{erf} \left[\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \right) \dots \right]$$

$$+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

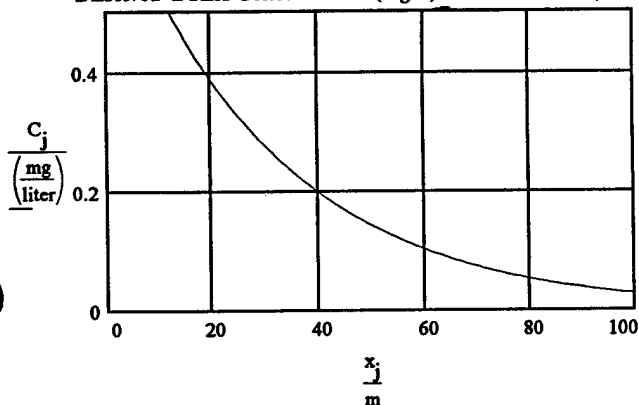
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



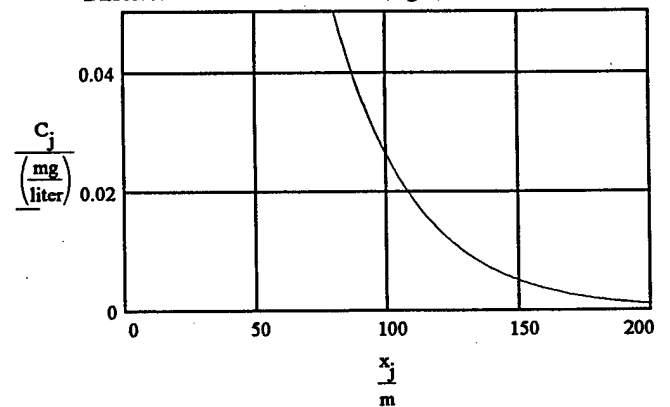
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.66 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0034 day⁻¹ ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivity	$K := 1.0 \frac{\text{m}}{\text{day}}$
Hydraulic gradient	$I := 0.01 \frac{\text{ft}}{\text{ft}}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 7.5 \text{m}$
Concentration of Injected Contaminant	$C_s := 1.66 \frac{\text{mg}}{\text{liter}}$
Initial Dissolved Contaminant Concentration	$C_o := 0.016 \frac{\text{mg}}{\text{liter}}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0034 \frac{1}{\text{day}}$	
Source Decay Rate	$\alpha := 0.0000274 \frac{1}{\text{day}}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \frac{\text{mL}}{\text{gm}}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \frac{\text{gm}}{\text{cm}^3}$	
Organic carbon content	$f_{oc} := 0.000001$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.001$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.05 \frac{\text{m}}{\text{day}}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.05 \frac{\text{m}}{\text{day}}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 4.036 \frac{\text{ft}^2}{\text{day}}$

10 Years From Present (1995-2005)

Initial Plume Distribution Calculation

$$j := 0..400$$

$$t := 3650 \cdot \text{day}$$

$$\Delta x := 1 \cdot \text{m}$$

$$x_j := \Delta x \cdot j$$

For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

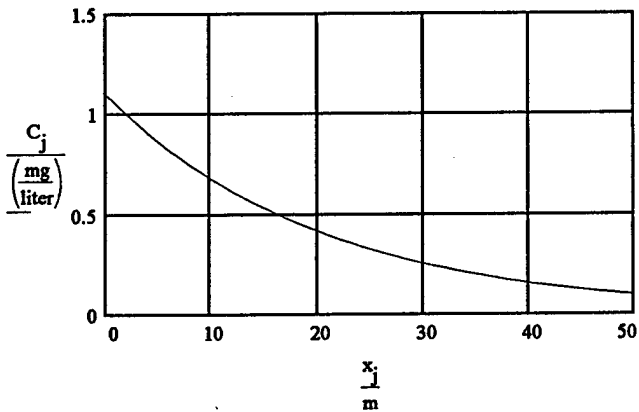
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp \left[-\frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp \left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\frac{v_x}{v_x + v_x'} \cdot \exp \left[-\frac{v_x \cdot v_x'}{2 \cdot D_x} \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha) \right) \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j - t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \right) \right] \dots \right.$$

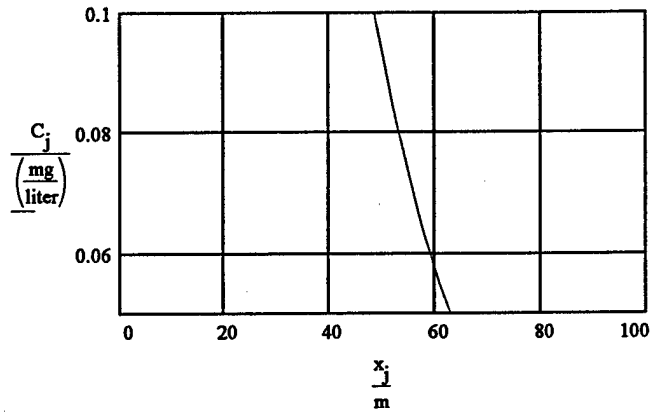
$$+ \left. \frac{v_x}{v_x - v_x'} \cdot \exp \left[-\frac{v_x \cdot v_x'}{2 \cdot D_x} \left(1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha) \right) \cdot x_j \right] \cdot \left[1 - \operatorname{erf} \left(\frac{R \cdot x_j + t \cdot v_x'}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} (\lambda - \alpha)} \right) \right] \dots \right.$$

$$+ \left. \frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \cdot \exp \left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf} \left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$

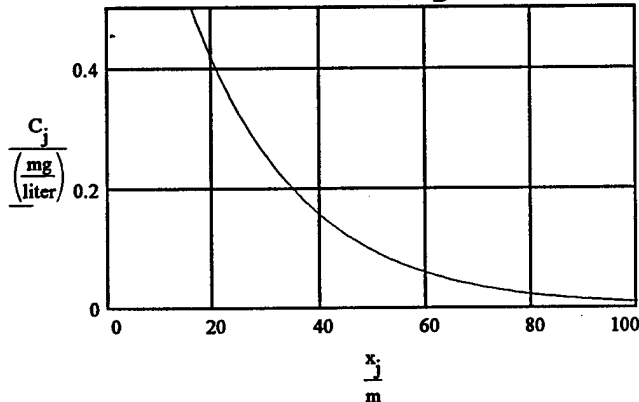
Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)



Dissolved BTEX Concentration (mg/L) versus Distance (meters)

