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FINAL

Treatability Study in Support of The Intrinsic Remediation Option at The Current Fire Training Area

Westover Air Reserve Base
Chicopee, Massachusetts

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

and

Westover Air Reserve Base
Chicopee, Massachusetts

February 1997

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
$\Delta G^{\circ}r$	gibbs free energy for the reaction
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
2-D	two dimensional
AFCEE	Air Force Center for Environmental Excellence
ARB	Air Reserve Base
ATM-m^{3}/mole	atmospheres. cubic meter per mole
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
CAH	chlorinated aliphatic hydrocarbon
$CaCO_3$	calcium carbonate
CO_2	carbon dioxide
day^{-1}	per day
DCE	dichloroethene
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
ES	Engineering-Science, Inc.
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron hydroxide
FT-08	Fire Training Area No. 08
ft/day	feet per day
ft/ft	feet per foot
ft/sec	feet per second
ft^{2}/day	square feet per day
ft^{3}/sec	cubic feet per second
ft/yr	feet per year
FTA	fire training area
g/cc	grams per cubic centimeter
GC/MS	gas chromatography/mass spectrometry
HDPE	high density polyethylene
ID	inside diameter
IRP	installation restoration program
K_{OC}	organic carbon partition coefficient
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum contaminant level
mg	milligrams
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm Hg	millimeters per mercury
MOC	method of characterization
msl	mean sea level
mV	millivolt
N	nitrogen
NAPL	non-aqueous phase liquid
NRMRL	National Risk Management Research Laboratory
OSWER	Office of Solid Waste and Emergency Response

Parsons ES	Parsons Engineering Science, Inc.
PCE	perchloroethene or tetrachlorotethene
PID	photoionization detector
POC	point of compliance
PVC	polyvinyl chloride
QC	quality control
R^2	correlation coefficient
redox	oxidation reduction
RAO	remedial action objective
RI	remediation investigation
RI/FS	remediation investigation/feasibility study
RMS	root mean squared
SAC	Strategic Air Command
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TCE	trichloroethene
TEMB	tetramethylbenzene
TMB	trimethylbezene
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TS	treatability study
USEPA	U.S. Environmental Protection Agency
USGS	United States Geologic Survey
VFA	valley fill alluvium
VOC	volatile organic compound
week^{-1}	per week

EXECUTIVE SUMMARY

This report presents the results of a treatability study performed by Parsons Engineering Science, Inc. (Parsons ES) at the Current Fire Training Area (FT-08), 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 and chlorinated solvents in the shallow groundwater. Residual light nonaqueous-phase liquid (LNAPL) present within the vadose zone and phreatic soils serves as a continuing source for the dissolved groundwater contamination. There is no evidence of mobile LNAPL at this site. This study focused on the fate and transport of dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) in the shallow groundwater system at the site. Dissolved chlorinated solvents also are present in the shallow groundwater; therefore, their probable fate and transport was investigated as well. Site history and the results of soil and groundwater investigations conducted previously are also summarized in this report.

Comparison of BTEX, chlorinated solvent, electron acceptor, and biodegradation byproduct isopleth maps from both the May 1995 and July 1996 sampling events for the FT-08 site provides strong qualitative 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. Patterns observed in the distribution of hydrocarbons, electron acceptors, and biodegradation byproducts further indicate that biodegradation is reducing dissolved BTEX concentrations in site groundwater. In addition, measured ratios of trichloroethene (TCE) to the daughter product cis-1,2-dichloroethene (1,2-DCE) suggest that chlorinated solvents in the groundwater are being degraded through reductive dehalogenation.

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. The Bioplume II numerical model was used to evaluate the fate and transport of dissolved BTEX in the shallow groundwater under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the Bioplume II model were obtained from previous site characterization data, supplemented with data collected by Parsons ES in May 1995. Model parameters that were not measured at the site were estimated using reasonable literature values. A conservative estimate for the transport velocity of dissolved chlorinated solvents was derived from the length of the chlorinated solvent plume and the length of time since chlorinated solvents were last used at the site.

The results of this demonstration suggest that intrinsic remediation of BTEX and chlorinated solvent compounds is occurring at FT-08; furthermore, the estimated rates of biodegradation, when coupled with sorption, dispersion, and dilution, should be sufficient to reduce and maintain dissolved BTEX and chlorinated solvent concentrations to levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected. Nevertheless, significant dissolved concentrations of both BTEX and chlorinated solvents are predicted to persist in shallow site groundwater for at least 60 years without engineered source reduction. The Air Force, therefore, recommends

implementation of horizontal bioventing, vertical groundwater circulation, intrinsic remediation, and LTM with institutional controls. Modeling suggests that by implementing bioventing to reduce BTEX concentrations in vadose zone soil, dissolved BTEX contamination throughout the plume would be reduced to concentrations below regulatory levels within 30 years. The vertical groundwater circulation component of the proposed remedial alternative is intended to enhance chlorinated solvent degradation as well as limit plume migration. Remediation of chlorinated solvents and BTEX dissolved in groundwater would be accomplished through natural attenuation processes. Institutional controls such as restrictions on shallow groundwater use would prevent completion of pathways while site remediation is in progress.

Groundwater data collected in July 1996 suggest that natural attenuation processes are proceeding more rapidly than model predictions. Even though biodegradation is progressing faster than numerical model predictions, groundwater contaminant concentrations are still expected to exceed federal groundwater criteria for at least 50 years unless more active remediation options are implemented at FT-08.

To continue to verify the Bioplume II model predictions, and to ensure that the selected technologies are meeting objectives, the Air Force recommends using 12 LTM wells and 6 point-of-compliance wells to monitor the long-term migration and degradation of the dissolved BTEX and chlorinated solvent 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 (or equivalent). If data collected under the LTM program indicate that the selected remedial system is not sufficient to reduce BTEX and chlorinated solvent concentrations at downgradient points of compliance to levels considered protective of human health and the environment, additional corrective actions may be required to remediate groundwater at the 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 Current Fire Training Area (FT-08) at Westover Air Reserve Base (ARB), Chicopee, Massachusetts. As used throughout this report, the term "intrinsic remediation" refers to a management strategy that relies on natural attenuation mechanisms to control exposure to the risks associated with subsurface contamination. "Natural attenuation" refers to the actual processes (e.g., biodegradation, dispersion, and sorption) 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 xylene (BTEX) and chlorinated solvents include biodegradation, 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 dissolved fuel-related compounds in groundwater to levels that meet federal- and state-specified groundwater protection standards. The potential for these mechanisms to effectively reduce the concentration of chlorinated solvents at the site, which is ancillary to the scope of this program, also was qualitatively considered.

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 groundwater modeling to evaluate the scientific defensibility of intrinsic remediation with long-term monitoring (LTM) as a remedial option for contaminated groundwater at FT-08.

There were two primary objectives of this project:

- Determine whether natural attenuation processes for fuel carbons and chlorinated solvents are occurring in groundwater at the site, and if so,
- Investigate the feasibility of using these processes to minimize the expansion of the fuel contaminant plume and 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, soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of soil and 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 the Bioplume II numerical model to simulate the fate and transport of fuel *hydrocarbons in* groundwater under the influence of biodegradation, advection, dispersion, and adsorption;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;
- Determining if natural processes are sufficient to minimize BTEX plume expansion so that groundwater quality standards can be met at a down gradient POC;
- Developing remedial action objectives (RAOs) and reviewing available remedial technologies;
- Using the results of modeling to recommend the most appropriate remedial option based on specific effectiveness, implementability, and cost criteria; and
- Providing an LTM plan that includes LTM and POC well locations and a sampling and analysis plan.

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 groundwater contaminated with fuel hydrocarbons and chlorinated solvents. During May 1995, site characterization activities performed in support of intrinsic remediation included use of the Geoprobe® direct push technology for soil sample collection and monitoring point installation; aquifer testing; and sampling and analysis of groundwater from newly installed groundwater monitoring points and previously installed monitoring wells. Much of the hydrogeological and geochemical 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.

Site-specific data collected in May 1995 were used to develop a fate and transport model for the site using the groundwater flow and solute transport model Bioplume II, to evaluate processes of natural attenuation, and to conduct a preliminary exposure pathway analysis. The Bioplume II model was used to simulate the movement of dissolved BTEX in the shallow saturated zone under the influence of biodegradation, advection, dispersion, and sorption. Site-specific data were also used to qualitatively evaluate the potential fate and transport of trichloroethene (TCE), cis-1,2-dichloroethene (cis-DCE), and vinyl chloride in the presence of fuel hydrocarbons. Potential biological degradation of these chlorinated solvents through anaerobic and aerobic processes was addressed qualitatively. Results of the model and of the qualitative investigation of chlorinated solvent biodegradation were used to assess the potential for completion of exposure pathways involving groundwater.

The 1995 investigation and model results also were used to determine if intrinsic remediation with LTM is an appropriate and defensible remedial option for contaminated groundwater at site FT-08. Furthermore, the results will be used to provide technical support for the intrinsic remediation with LTM remedial option during regulatory negotiations, as appropriate. Alternate remedial options also were considered in this report to identify the major advantages and disadvantages associated with different groundwater remedial strategies. The strategies included groundwater extraction/treatment, soil vapor extraction, and/or limited source removal coupled with natural contaminant attenuation, LTM, and institutional controls.

Another groundwater sampling event was performed in July 1996. Field and laboratory results from this sampling event were used to assess the accuracy of the model predictions and to confirm the effectiveness of natural attenuation processes occurring at FT-08.

This report contains nine sections, including this introduction, and five appendices. Section 2 summarizes 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 Bioplume II model and 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 Bioplume II modeling. Section 5 also includes a qualitative analysis of the fate and transport of chlorinated solvents. Section 6 presents a comparative analysis of remedial alternatives. Section 7 presents the LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document. Appendix A contains Geoprobe® borehole logs, monitoring point installation records, and slug test results. Appendix B presents soil and groundwater analytical results for both the May 1995 and

July 1996 sampling events. Appendix C contains calculations and model input parameters. Appendix D contains Bioplume II model input and output in ASCII format on a diskette. Appendix E contains calculations for remedial option design and costing.

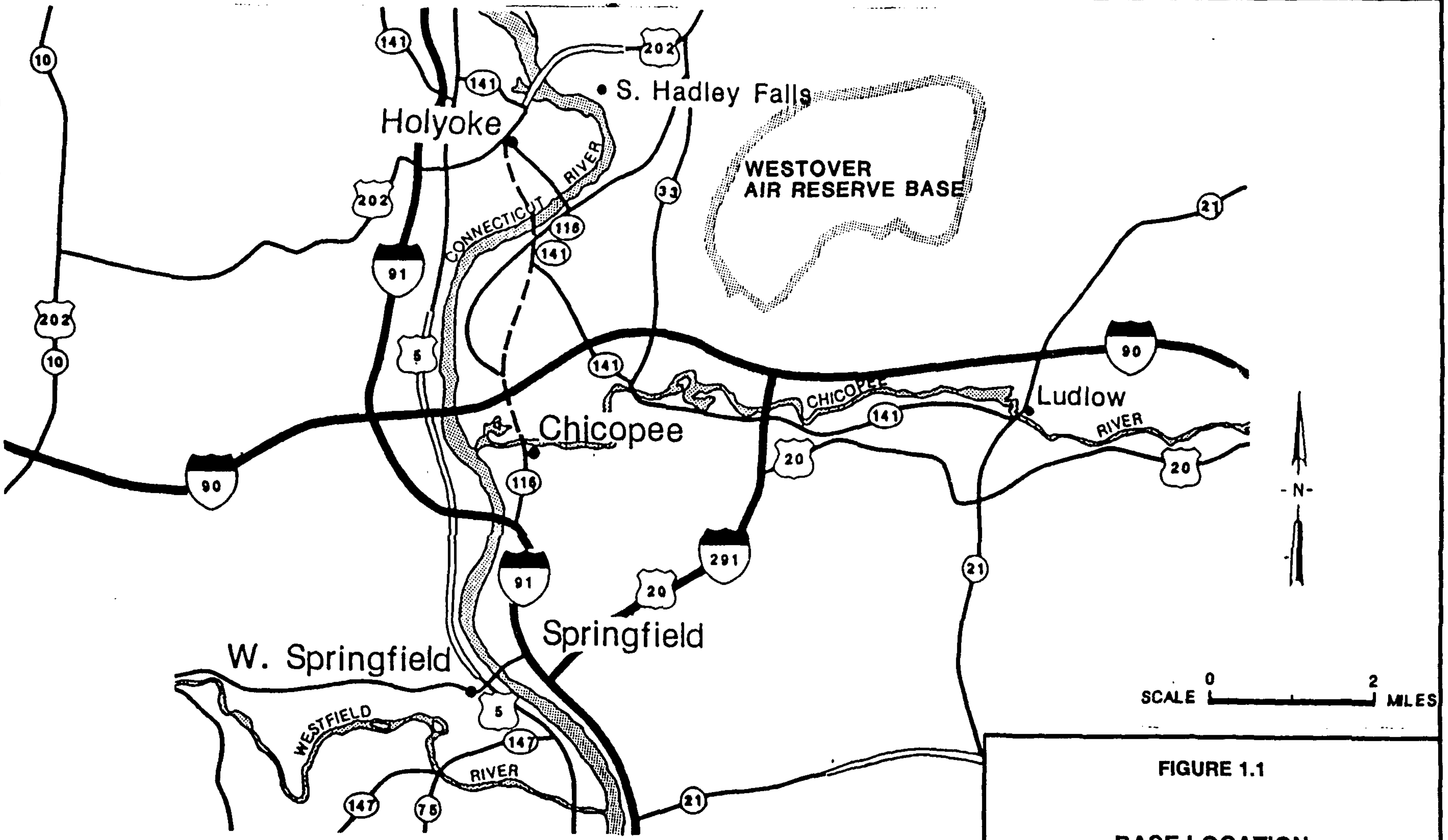
1.2 FACILITY BACKGROUND

The Base, located in south-central Massachusetts, covers nearly 2,400 acres within the Connecticut River Valley, in the northeastern portion of the city of Chicopee (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.

Site FT-08 is located in the northern portion of the Base (Figure 1.2). From 1964 to 1986, the site was used for fire training exercises in which fuels were spread over a metal replica of an aircraft fuselage and ignited. The volume of petroleum products and spent solvents used in the training area prior to 1974 is unknown. From 1974 to 1986, approximately 125 gallons of JP-4 jet fuel was used for each of the monthly exercises. A buried waste fuel tank was located northwest of the burn area, but was removed in 1986. During tank removal, a buried fuel line was abandoned in place between the former tank excavation and the edge of the burn area (Figure 1.3). The former burn area is not well defined, but it appears to lie within a sparsely vegetated area of sand, gravel, and cinder soil. The area is roughly elliptical, with a major axis approximately 300 feet long and a minor axis of approximately 250 feet. The area surrounding the site is primarily open space with an access road entering the site from the east. Storm sewer lines are located in the vicinity of the site (Figure 1.3).

A series of previous investigations have undertaken characterization of site FT-08 using numerous field techniques. In 1986, ES (1988) installed monitoring wells CF-1 through CF-4, CF-1A, and CF-2A, obtained water level measurements, and drilled and sampled four 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 four additional wells, collected soil samples for laboratory analysis from nineteen soil boreholes, and conducted a toluene soil gas survey. In 1993, 12 additional soil boreholes were sampled, and one well was constructed by O'Brien and Gere Engineers, Inc. (1993).



Sources: ES, 1988.

FIGURE 1.1

BASE LOCATION

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

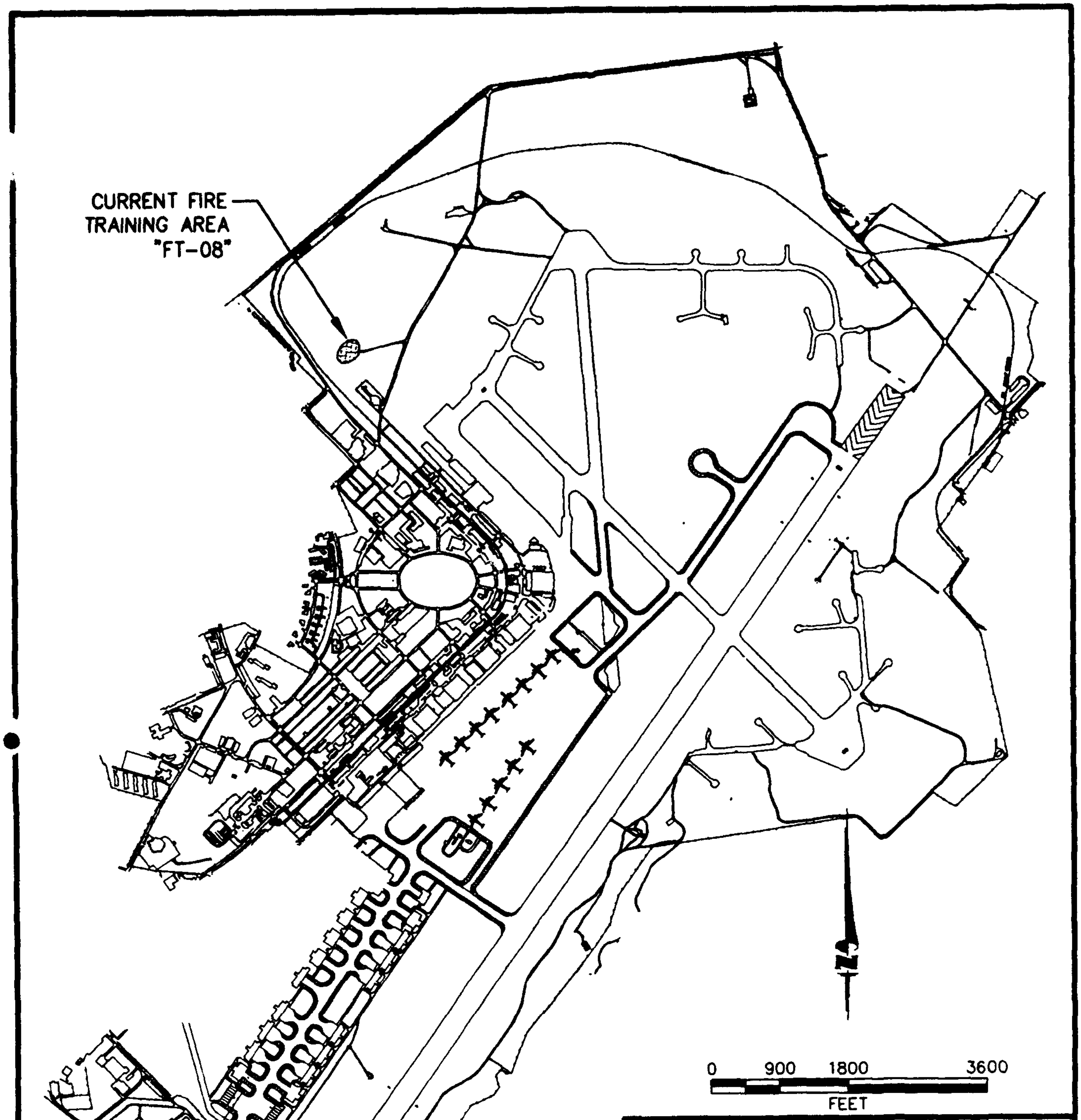


FIGURE 1.2

SITE LOCATION

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Source: Westover ARB, 1993

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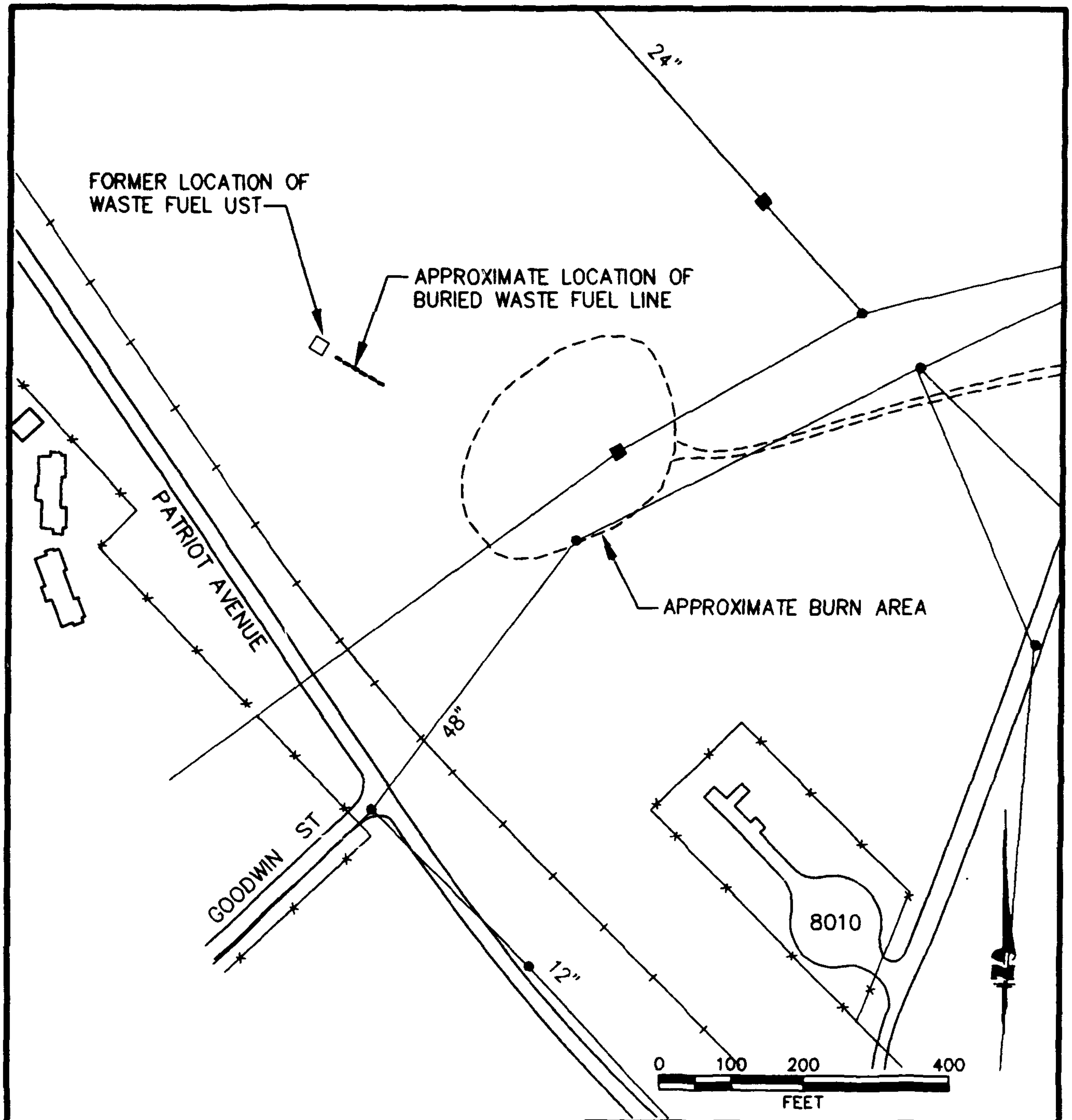

LEGEND

- RAILROAD TRACK
- FENCE
- 24" STORM SEWER WITH PIPE DIAMETER

FIGURE 1.3

SITE LAYOUT

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Results from past investigations have identified petroleum hydrocarbon and chlorinated solvent contamination in site environmental samples. Soil contamination was identified in the former burn area at depths up to 10 feet bgs. Dissolved groundwater contamination has been detected in the vicinity and downgradient of the burn area at site FT-08. Mobile light non-aqueous phase liquid (LNAPL) was not identified during past site investigations. Engineered solutions to remediate soil and groundwater have not been implemented at this site.

The results of these previous soil and groundwater investigations at the site have been documented in the Installation Restoration Program (IRP) Records Search (CH2M Hill, 1982); Final Report, Phase II - Problem Confirmation Study (Weston, 1984); IRP Phase II-Confirmation/Quantification Stage 2 Report (ES, 1988); Final Remedial Investigation (RI) Report (UNC Geotech, 1991); Bioventing Work Plan (O'Brien and Gere, 1993); and the Supplemental Remedial Investigation/Feasibility Study (RI/FS) Report (O'Brien and Gere, 1994). 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.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES personnel to collect site-specific data at FT-08, the Current Fire Training Area, Westover ARB, Massachusetts. To meet the requirements of the intrinsic remediation demonstration, additional data were required to evaluate near-surface geology, aquifer properties, and the extent of soil and groundwater contamination. Site characterization activities involved using the Geoprobe® direct push system for soil sampling and groundwater monitoring point placement. Groundwater sampling was accomplished during this investigation using both newly installed monitoring points and previously installed monitoring wells. Hydraulic conductivity (slug) tests were conducted at several of the site monitoring wells. 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. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1995).

2.1 DRILLING, SOIL SAMPLING, AND MONITORING POINT INSTALLATION

Geoprobe®-related field work occurred between May 10 and May 15, 1995, and consisted of drilling, soil sampling, and groundwater monitoring point installation for monitoring points MP-1S through MP-16D. These activities were performed according to the procedures described in the work plan (Parsons ES, 1995) and in the following sections.

The Geoprobe® system is a hydraulically powered percussion/probing machine used to advance sampling tools through unconsolidated soils. This system provides for the rapid collection of soil, soil gas, and groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 2.1 is a diagram of the Geoprobe® system.

2.1.1 Groundwater Monitoring Point Locations and Identification

Twenty-one new groundwater monitoring points were installed at fifteen locations to assist in the characterization of the contaminant distribution and the shallow groundwater flow system at FT-08. These points are identified as MP-1S, MP-1D, MP-2S, MP-3S, MP-4S, MP-5S, MP-5M, MP-6S, MP-7S, MP-8S, MP-8M, MP-9S,

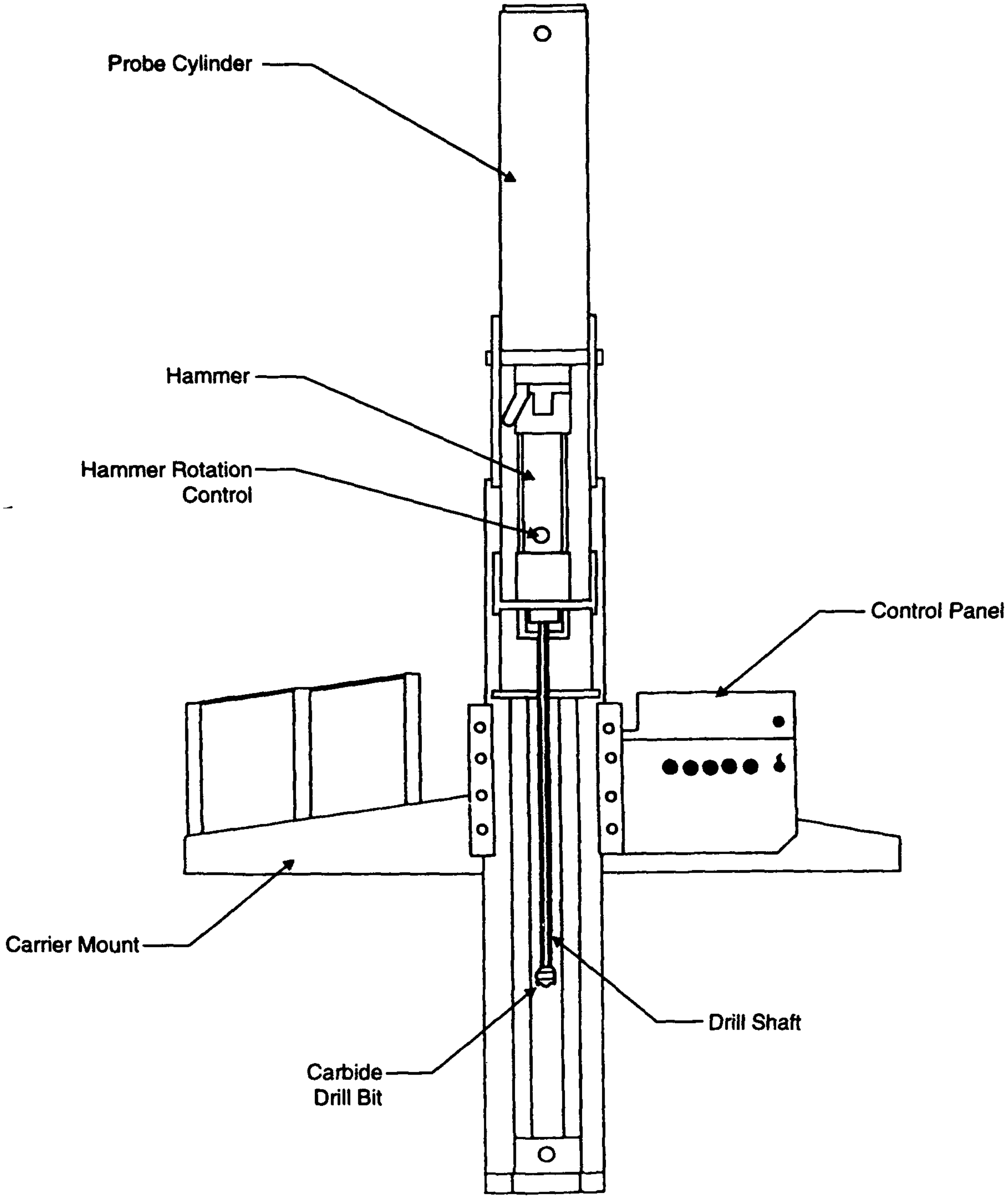

Figure 2.1

CROSS-SECTION OF GEOPROBE

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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MP-10S, MP-11S, MP-12S, MP-14M, MP-14D, MP-15S, MP-15M, MP-15D, and MP-16D. The new monitoring points were installed in the locations shown on Figure 2.2; Table 2.1 presents completion details. Nested points were installed adjacent to each other in pairs or triplets. Points screened across the water table were designated by the suffix "S"; points screened approximately 20 feet bgs were designated by the suffix "M"; and points screened approximately 40 feet bgs were designated by the suffix "D". The well locations were selected to provide the hydrogeologic data necessary for implementation of the Bioplume II model and to support the demonstration of intrinsic remediation.

2.1.2 Groundwater Monitoring Point Drilling and Soil Sampling Procedures

2.1.2.1 Pre-Drilling Activities

All subsurface utility lines or other man-made subsurface features were located, and proposed drilling locations were cleared and approved by the base prior to any drilling activities. The approximate location of an abandoned waste fuel line was identified by Parsons ES personnel. Water used in drilling, equipment cleaning, or grouting was obtained from an on-site potable water supply designated by the base.

2.1.2.2 Equipment Decontamination Procedures

Prior to arriving at the site and between each drilling location, all probe rods, tips, sleeves, pushrods, samplers, tools, and other down-hole equipment were decontaminated using an Alconox® detergent and potable water solution followed by a potable water wash. Fittings, tips, and samplers also underwent an additional rinse with isopropyl alcohol followed by a final rinse with deionized water.

During drilling operations, the Geoprobe®, probe rods, and all downhole drilling and/or sampling equipment were decontaminated. Precautions were taken to minimize impact to the area surrounding the decontamination pad that might result from the decontamination operations. All decontamination activities were conducted in a manner so that the excess water was controlled and not allowed to flow into any open borehole.

Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. All well completion materials were factory sealed and were not stored near or in areas that could be affected by these substances.

2.1.2.3 Drilling and Soil Sampling

Drilling was accomplished using the Geoprobe® direct push technology. The boreholes were driven and continuously sampled to the total depth of the borehole. Where two points were installed adjacent to each other (i.e., nested), only the deep point was logged and sampled. In many instances, highly saturated silts and sands below the water table prevented collection of samples. A final borehole diameter of 2 inches was used for the installation of shallow points with a 0.5-inch inside-diameter

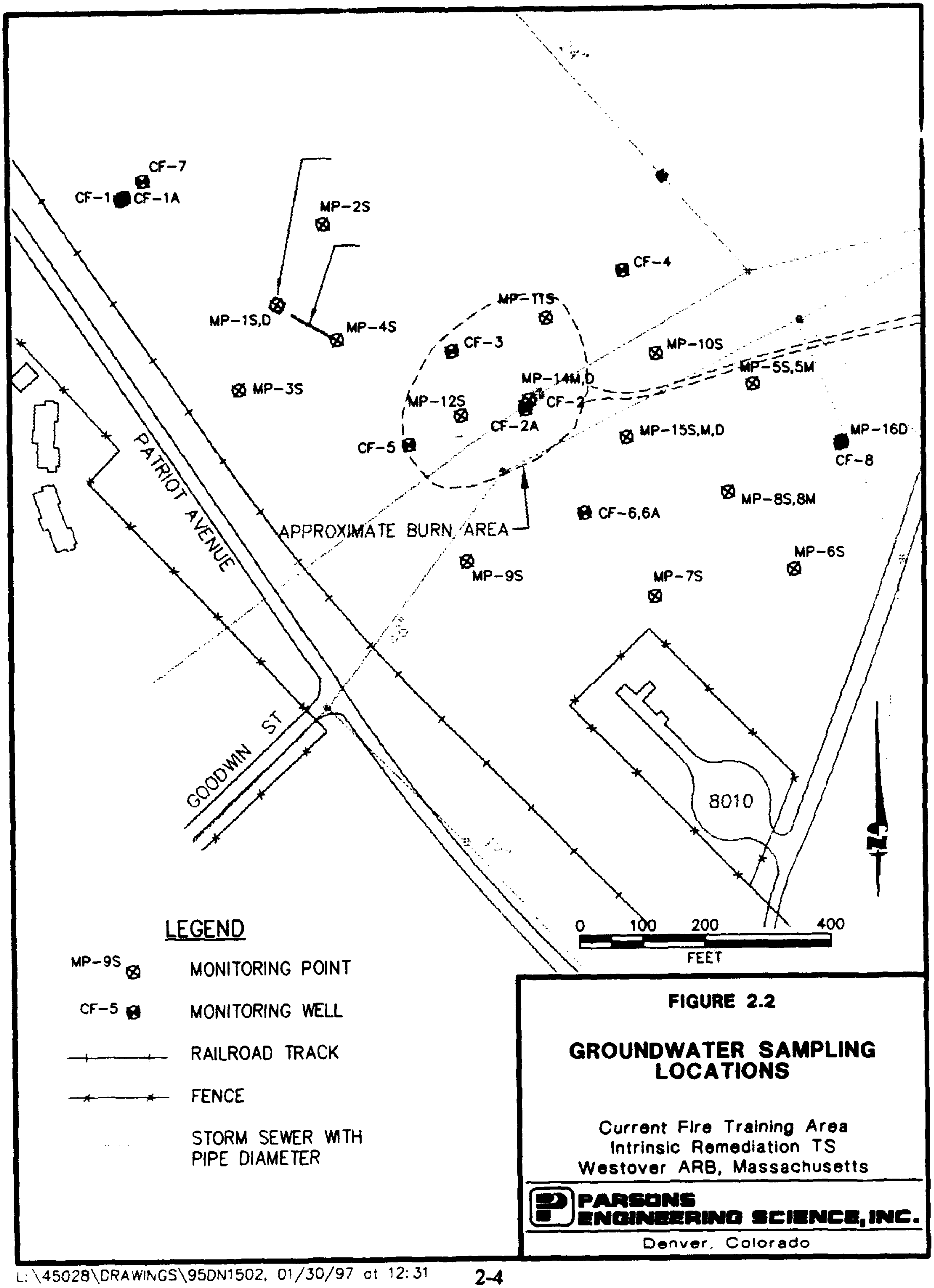

FIGURE 2.2

GROUNDWATER SAMPLING LOCATIONS

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

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TABLE 2.1
SUMMARY OF GROUNDWATER MONITORING WELL AND MONITORING POINT INSTALLATION DATA
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Identification	Northing	Easting	Completion Date	Borehole Depth (feet bgs)	Completion Depth (feet bgs)	Borehole Diameter (inches)	Casing Diameter (inches)	Slot Size (inches)	Screen Interval (feet bgs)	Land Surface Elevation (feet msl)[b/]	Elevation Top of PVC[a/] (feet msl)
Monitoring Points											
MP-1 S	17910.11	3728.85	5/10/95	8.0	8.0	2.0	0.5	0.010	3.0-8.0	243.96	243.79
MP-1 D	17910.11	3728.85	5/10/95	41.0	41.0	1.0	0.375	0.037	39.25-41.0	243.96	NM[c/]
MP-2 S	18055.20	3715.45	5/10/95	9.0	9.0	2.0	0.5	0.010	4.0-9.0	243.72	243.83
MP-3 S	17762.52	3757.14	5/10/95	9.5	9.5	2.0	0.5	0.010	4.5-9.5	243.42	243.32
MP-4 S	179 6.49	3839.00	5/10/95	9.0	9.0	2.0	0.5	0.010	4.0-9.0	243.92	243.88
MP-5 S	18234.31	4421.36	5/11/95	10.0	10.0	2.0	0.5	0.010	5.0-10.0	241.58	241.68
MP-5 M	18234.31	4421.36	5/13/95	19.0	19.0	1.0	0.375	0.037	18.5-19.0	241.58	NM
MP-6 S	18028.13	4644.43	5/11/95	10.0	10.0	2.0	0.5	0.010	5.0-10.0	243.09	243.07
MP-7 S	17866.78	4484.53	5/11/95	10.0	10.0	2.0	0.5	0.010	5.0-10.0	242.92	242.84
MP-8 S	18070.05	4488.15	5/11/95	10.0	10.0	2.0	0.5	0.010	5.0-10.0	242.10	241.94
MP-8 M	18070.05	4488.15	5/11/95	17.5	17.5	1.0	0.375	0.037	15.75-17.5	242.10	NM
MP-9 S	17742.46	4210.28	5/11/95	9.0	9.0	2.0	0.5	0.010	4.0-9.0	243.85	243.64
MP-10 S	18186.99	4263.86	5/11/95	10.0	10.0	2.0	0.5	0.010	5.0-10.0	243.44	243.27
MP-11 S	18133.78	4090.52	5/11/95	9.0	9.0	2.0	0.5	0.010	4.0-9.0	242.97	242.80
MP-12 S	17928.95	4069.52	5/12/95	9.0	9.0	2.0	0.5	0.010	4.0-9.0	243.34	242.94
MP-14 M	18009.81	4143.02	5/12/95	20.0	20.0	1.0	0.375	0.037	19.5-20.0	243.36	NM
MP-14 D	18009.81	4143.02	5/12/95	42.0	42.0	1.0	0.375	0.037	41.5-42.0	243.36	NM
MP-15 S	18049.20	4303.80	5/12/95	10.0	10.0	2.0	0.5	0.010	5.0-10.0	242.25	242.03
MP-15 M	18049.20	4303.80	5/12/95	20.0	20.0	1.0	0.375	0.037	19.5-20.0	242.25	NM
MP-15 D	18049.20	4303.80	5/12/95	38.5	38.5	1.0	0.375	0.037	38.0-38.5	242.25	NM
MP-16 D	18239.03	4589.09	5/13/95	36.5	36.5	1.0	0.375	0.037	36.0-36.5	243.22	NM

TABLE 2.1 (concluded)
SUMMARY OF GROUNDWATER MONITORING WELL AND MONITORING POINT INSTALLATION DATA
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Identification	Northing	Easting	Completion Date	Borehole Depth (feet bgs)	Completion Depth (feet bgs)	Borehole Diameter (inches)	Casing Diameter (inches)	Slot Size (inches)	Screen Interval (feet bgs)	Land Surface Elevation (feet msl)[b/]	Elevation Top of PVC[a/] (feet msl)
Monitoring Wells											
CF-1	17906.10	3428.31	11/13/86	92.0	87.0	8.0	2.0	0.020	72.0-87.0	245.31	247.86
CF-1 A	17911.99	3429.93	11/17/86	20.0	20.0	8.0	2.0	0.020	5.0-20.0	245.24	247.60
CF-2	18000.23	4143.50	11/20/86	92.0	89.0	8.0	2.0	0.020	74.0-89.9	243.21	246.23
CF-2 A	17994.49	4146.43	11/21/86	15.0	15.0	8.0	2.0	0.020	5.0-15.0	243.22	245.56
CF-3	18005.95	3998.48	11/18/86	22.0	19.5	8.0	2.0	0.020	4.5-19.5	243.23	244.99
CF-4	18265.12	4144.99	11/18/86	23.0	20.0	8.0	2.0	0.020	5.0-20.0	241.55	244.01
CF-5	17843.69	4028.16	NA[d/]	20.0	20.0	8.0	2.0	NA	5.0-20.0	243.34	246.00
CF-6	17912.38	4318.15	NA	92.0	90.0	8.0	2.0	NA	71.0-86.0	242.78	243.92
CF-6 A	17912.38	4318.15	NA	20.0	20.0	8.0	2.0	NA	3.0-18.0	242.78	244.59
CF-7	17949.81	3440.05	NA	95.0	95.0	8.0	4.0	NA	1.0-85.0	245.37	246.81
CF-8	18236.09	4588.87	6/16/93	22.0	20.0	8.0	2.0	0.010	5.0-20.0	243.28	245.59

[a/] PVC = polyvinyl chloride well casing.

[b/] feet msl = feet above mean sea level.

[c/] NM = Not measured.

[d/] NA = Not available.

Sources: ES, 1988; UNC Geotech, 1991; O'Brien and Gere, 1994 and 1995.

(ID) casing. For the intermediate and deep monitoring points, a final borehole diameter of 1 inch was utilized.

The Parsons ES field geologist observed drilling and monitoring point installation activities and maintained a detailed descriptive log of recovered subsurface materials. Final geologic borehole logs are presented in Appendix A. These logs contain:

- Sampled interval (top and bottom depth);
- Presence or absence of contamination based on odor, staining, and/or photoionization detector (PID) readings;
- Soil description, including color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and
- Lithologic contacts, with the depth of lithologic contacts and/or significant textural changes recorded to the nearest 0.1 foot.

The Geoprobe®-collected soil samples were obtained using 4 foot by 1.5 inch-ID and 2 foot by 1-1/16-inch-ID sampling devices. The large sampler was used for the initial 8 feet of soil. The smaller sampler was then used for the remainder of the borehole in an attempt to minimize the smearing of surface contamination into deeper portions of the borehole. A probe-drive sampler serves as both the driving point and the sample collection device and is attached to the leading end of the probe rods. To collect a soil sample, the sampler was pushed or driven to the desired sampling depth, the drive point was retracted to open the sampling barrel, and the sampler was subsequently pushed into the undisturbed soils. The soil cores were retained within a clear acetate liner inside the sampling barrel. The probe rods were then retracted, bringing the sampling device to the surface. The soil sample was then extruded from the liners for visual lithologic logging and PID headspace screening, or the liners were cut and capped, with the undisturbed samples submitted to the analytical laboratory for chemical testing.

Bags containing soil samples collected for the headspace screening procedure were quickly sealed and stored for 15 minutes or longer at the ambient temperature. Semiquantitative measurements were made by puncturing the bag seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total volatile organic compounds (VOCs) in the sample to an isobutylene calibration standard. The PID also was used to monitor for VOCs in the worker breathing zone.

For soil samples collected for laboratory analysis, the acetate liner was cut into six inch lengths, capped, and delivered to the USEPA/NRMRL field personnel for analysis of BTEX, TCE, tetrachloroethene (PCE), and total organic carbon (TOC). For each soil sample the Parsons ES field scientist recorded the following information:

- Sample interval (top and bottom depth);

- Sample identification;
- Sampling date; and,
- Sample collector's initials.

Fourteen soil samples were collected from areas in the vicinity of the waste fuel tank, buried fuel line, the burn area, and an upgradient location (Figure 2.3). Soil samples were collected immediately above and/or immediately below the water table. Samples were also selected where PID readings were elevated or visible contamination was present.

2.1.3 Monitoring Point Installation

Groundwater monitoring points were installed in twenty-one boreholes under this program. Detailed well point installation procedures are described in the following paragraphs.

2.1.3.1 Well Materials Decontamination

Well point completion materials were inspected by the field geologist and determined to be clean and acceptable prior to use. All well completion materials were factory sealed in plastic wrap. Pre-packaged casing, sand, bentonite, and concrete mix were used in well construction, and the bags were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field geologist were not used.

2.1.3.2 Monitoring Point Casing and Screen

Upon completion of Geoprobe® sampling to the proper borehole depth, a groundwater monitoring point was installed. Monitoring point construction details were noted on a monitoring point installation record. This information became part of the permanent field record for the site. Monitoring point installation records for FT-08 are presented in Appendix A.

Shallow monitoring points were constructed of Schedule 40 polyvinyl chloride (PVC) riser pipe and screen having an ID of 0.5 inch. All well casing and screen sections were flush-threaded; glued joints were not used. The riser pipe at each monitoring point was fitted with a PVC top cap, and a disposable stainless steel drive point was placed, using Teflon® tape, on the bottom of the screen. Monitoring point screens were five feet long and were factory-slotted with 0.010-inch openings. Each shallow well was screened so that seasonal fluctuations of the water table can be measured.

Deep monitoring points were constructed using Teflon® lined high-density polyethylene tubing (HDPE) threaded through the center of the drive rods and attached to a 1.75- or 0.5-foot-long, 0.375-inch-diameter stainless steel double-woven wire screen with 0.145 millimeter (0.037 inch) slot size. The well screen was threaded into a dedicated stainless steel drive point/implant anchor that remained in place after the

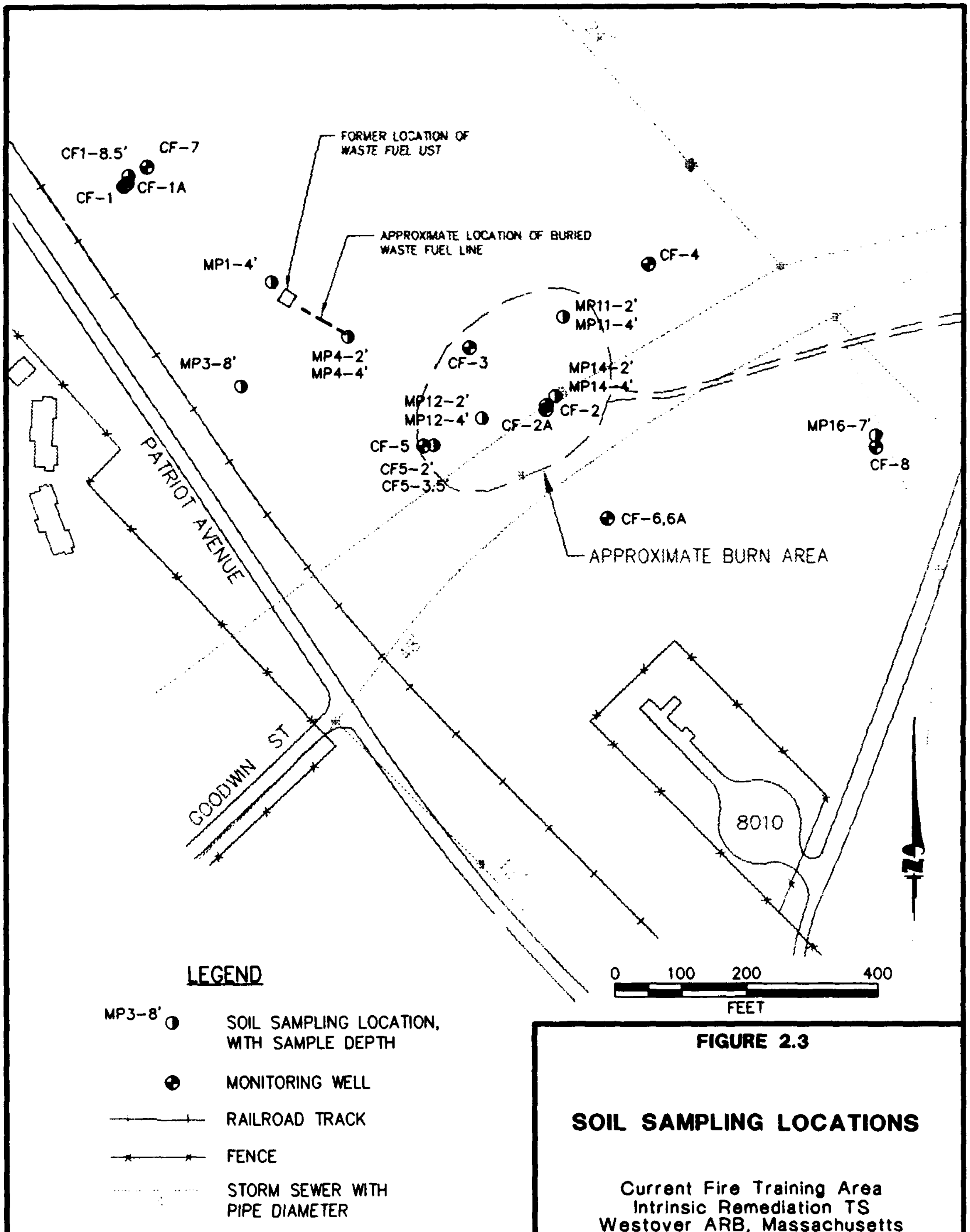

FIGURE 2.3

SOIL SAMPLING LOCATIONS

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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drive rods were removed. The tubing was fitted with a plastic top cap to prevent water and sediment from leaking down the tubing. Well screens for the intermediate monitoring points were placed approximately 20 feet bgs, at the base of the shallow sand and gravel layer. Deep monitoring points were placed at the top of a deeper sand and gravel layer, approximately 40 feet bgs.

The field geologist recorded the borehole depth, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials placed in the annulus between the casing and borehole wall.

2.1.3.3 Sand Filter Pack

A graded sand filter pack was placed around the screened interval from the bottom of the casing to approximately 2 feet above the top of the screen depending on borehole integrity. Locally purchased sand was used for the sand filter pack. However, placement of the filter pack around the monitoring point casing screens was occasionally compromised by the collapse of the sand borehole walls. Therefore, some of the monitoring wells are naturally sand-packed with the formation materials. Due to the sandy nature of the formation materials, well development and purging activities were accomplished without difficulty.

2.1.3.4 Annular Sealant

A filter pack seal of sodium bentonite chips or grout was placed above the sand pack in the monitoring points. The filter pack seal was 0.5 to 2 feet thick and, where chips were placed above the water table, was hydrated in place with potable water. On occasion, collapse of the formation sands into the borehole prevented the placement of a full 2 feet of bentonite. In all monitoring points at FT-08, the remainder of the annular seal up to the ground surface also consisted of hydrated bentonite chips or grout.

2.1.3.5 Flush-Mount Protective Cover

Each monitoring point was completed with an 8-inch diameter at-grade protective cover with a bolted cap. In all locations, the at-grade covers were cemented in place using concrete. All wells were completed with concrete pads that slope gently away from the protective casing to facilitate runoff during precipitation events. The space inside the protective covers (below the top of the PVC) was filled with native sandy soils to allow drainage of any precipitation that might collect within the cover. To clarify well numbers for future sampling events, intermediate-depth monitoring points at MP-14 and MP-15 were wrapped in red tape, and the deep points were wrapped with black tape.

2.1.4 Well Development

Before being sampled, newly installed monitoring points were developed. Typically, well development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. Use of the Geoprobe® system to place monitoring points eliminates cuttings and drilling fluids. As a result, development of monitoring points is primarily intended to minimize the amount of fine sediment that might accumulate in the casing.

Well development was accomplished using a peristaltic pump with dedicated silicon and HDPE tubing. The pump tubing was regularly lowered to the bottom of the shallow points so that fines were agitated and removed from the well in the development water. Development was continued until 10 casing volumes of water were removed from the well and the pH, temperature, conductivity, and DO of the groundwater had stabilized.

2.2 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater samples. In order 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.

Groundwater sampling occurred May 17 through May 19, 1995, and July 17 and 18, 1996. Groundwater sampling consisted of collecting groundwater samples from new monitoring points and previously installed monitoring wells. Monitoring well CF-7 was not sampled during either sampling event because the screen is open to the entire thickness of the aquifer, and therefore would not produce representative groundwater samples. Groundwater sampling forms were used to document the specific details of the sampling event for each location. Groundwater samples were analyzed for the parameters listed in Table 2.2. In addition to the groundwater sampling conducted in May 1995 and July 1996 under this program, ES (1988), UNC Geotech (1991), and O'Brien and Gere (1994) have conducted groundwater sampling at the site.

2.2.1 Groundwater Sampling Locations

Groundwater samples were collected from monitoring wells and newly installed monitoring points by Parsons ES personnel. Twenty-one new monitoring points were installed at the locations shown on Figure 2.2. After completion of installation and development activities, these monitoring points were all purged and sampled in May 1995 using a peristaltic pump with dedicated HDPE and silicon tubing. Ten existing monitoring wells, installed by ES (1988), UNC Geotech (1991) and O'Brien and Gere (1994), also were sampled under this program. Existing wells that were sampled included CF-1, CF-1A, CF-2, CF-2A, CF-3, CF-4, CF-5, CF-6, CF-6A, and CF-8. In July 1996, groundwater samples were collected at the same locations except samples were not collected from MP-2S, -3S, -5S, -6S, -7S, -8S, -11S, CF-1, CF-1A, and CF-4. Completion data for the newly installed monitoring points and previously installed monitoring wells are provided on Table 2.1.

2.2.2 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination

TABLE 2.2
SUMMARY OF GROUNDWATER ANALYTICAL METHODS
Current 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
Dissolved 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^-])	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/] RSKOP = Robert S. Kerr Laboratory (now known as NRMRL) standard operating procedure.

from improperly cleaned equipment; therefore, water level indicators and sampling equipment were thoroughly cleaned before and after field use and between uses at different sampling locations. In addition, a clean pair of new, disposable gloves was worn each time a different well/point was sampled.

2.2.2.1 Equipment Decontamination

All portions of sampling and test equipment that contacted the sample were thoroughly cleaned before use. This equipment included the water level probe and cable, equipment for measuring on-site groundwater chemical parameters, and other equipment that contacted the samples. The following cleaning protocol was used:

- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry prior to use.

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

2.2.2.2 Equipment Calibration

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

2.2.2.3 Preparation of Location

Prior to starting the sampling procedure, the area around the well was cleared of foreign materials, such as brush, rocks, and debris. These procedures prevented sampling equipment from inadvertently contacting debris around the monitoring well. Location preparation also included an inspection of the integrity of the well or monitoring point. At this time, irregularities with the protective cover, cap, lock, external surface seal, internal surface seal, well identification, well datum, and pad were noted.

2.2.2.4 Water Level and Total Depth Measurements

Prior to removing any water from the well the static water level was measured. In all groundwater wells and monitoring points, an electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. Free hydrocarbons (mobile LNAPL) were not detected in any of the wells. Commercially available water level probes are not sufficiently narrow to fit through the 1/4"-ID of the Teflon tubing used to construct the deeper monitoring points at the

Current Fire Training Area; therefore, water level measurements could not be taken at points constructed from Teflon tubing. 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). Based on these measurements, the volume of water to be purged from the wells was estimated.

Static groundwater levels were also measured on May 19, 1995, near the conclusion of the field activities. Measurements were obtained at all site wells and shallow monitoring points.

2.2.3 Well Purging and Sample Collection

Well purging consisted of removing at least three times the calculated casing volume with a peristaltic pump prior to sample collection. Once three casing volumes of water were removed from the well, purging continued until the pH, DO concentration, conductivity, and temperature stabilized

Within 24 hours of the purge event, a peristaltic pump with dedicated silicon and HDPE tubing was used to extract groundwater samples from the well. The dedicated HDPE tubing was lowered down to the approximate midpoint of the screened interval. Sampling from the deep points (constructed of tubing) was accomplished by attaching the silicon tubing directly to the well tubing. 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 (TMB), chlorinated solvents, and dissolved gas analyses were filled so that there was no headspace or air bubbles within the container. Table 2.2 lists the analyses performed on collected groundwater samples.

2.2.4 On-site Chemical Parameter Measurement

Measurement of DO, pH, specific conductance, and temperature was performed at the sampling location 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.

2.2.4.1 Dissolved Oxygen Measurements

DO measurements were taken using an Orion® model 840 DO meter in a flow-through cell at the outlet of the peristaltic pump. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed. The dissolved oxygen meter was calibrated to 100% air saturation in an enclosed calibration chamber. The DO meter was also tested in a solution of sodium sulfide to confirm that the meter was capable of reading very low concentrations of DO in solution.

2.2.4.2 pH and Temperature Measurements

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

2.2.4.3 Specific Conductance Measurements

Specific conductance measurements were taken using an EXTECH® Oyster meter in the same flow-through cell in which DO was measured. The conductance was recorded on the groundwater sampling record.

2.2.4.4 Redox Potential Measurements

Since redox measurements are very sensitive to exposed air, precautions were taken during sample collection and transport to minimize the impact. Samples were collected directly from the perstaltic pump discharge tube and directed down the side of the 250 mL plastic sample bottle to minimize aeration and turbulence. The sample bottle was completely filled, capped, and immediately transported to the EPA mobile laboratory. During transport, care was taken to minimize sample turbulence that could result in dispersal of the small amount of remaining headspace throughout the sample. Because of the sensitivity, redox measurements were taken immediately upon delivery to the mobile lab. Similar precautions were also required for the analysis of ferrous iron. Even if redox measurements were slightly affected by handling procedures, the trends in electron acceptor and donor concentrations in site groundwater samples are much better indicators of the types of redox reactions that are occurring in the groundwater at the Current Fire Training Area.

2.2.5 Sample Handling

2.2.5.1 Sample Preservation

The USEPA/NRMRL personnel provided appropriately preserved sample bottles. Samples were delivered to the 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 shipped by the USEPA field personnel to the NRMRL in Ada, Oklahoma for analysis.

2.2.5.2 Sample Containers and Labels

The sample containers were filled as described in Sections 2.2.3, 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;
- Sample type (groundwater);
- Sampling date;
- Sampling time;

- Requested analyses;
- Preservatives added; and
- Sample collector's initials.

2.2.5.3 Sample Shipment

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory. Samples were packaged to prevent leakage or vaporization from the containers, 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

In May 1995, slug tests were conducted at six monitoring well locations to estimate the hydraulic conductivity of the shallow saturated zone at FT-08. Slug tests are single-well 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 (ft^2/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 CF-1A, CF-4, CF-5, CF-6, CF-6A, and CF-8 (Figure 2.1). Detailed slug testing procedures are presented in the *Technical Protocol for Implementing 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 and Appendix A.

2.4 SURVEYING

After completion of the May 1995 field work, all new and existing monitoring point locations and elevations were surveyed by Huntley and Associates of Chicopee, Massachusetts. The horizontal locations were measured relative to existing monitoring wells. The vertical elevations of the ground surface adjacent to the well/point casing and the measurement datum (top of the PVC well/point casing) were measured relative to existing survey control points. Horizontal location was 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-08 as determined from data collected by Parsons ES in May 1995 and July 1996, 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.

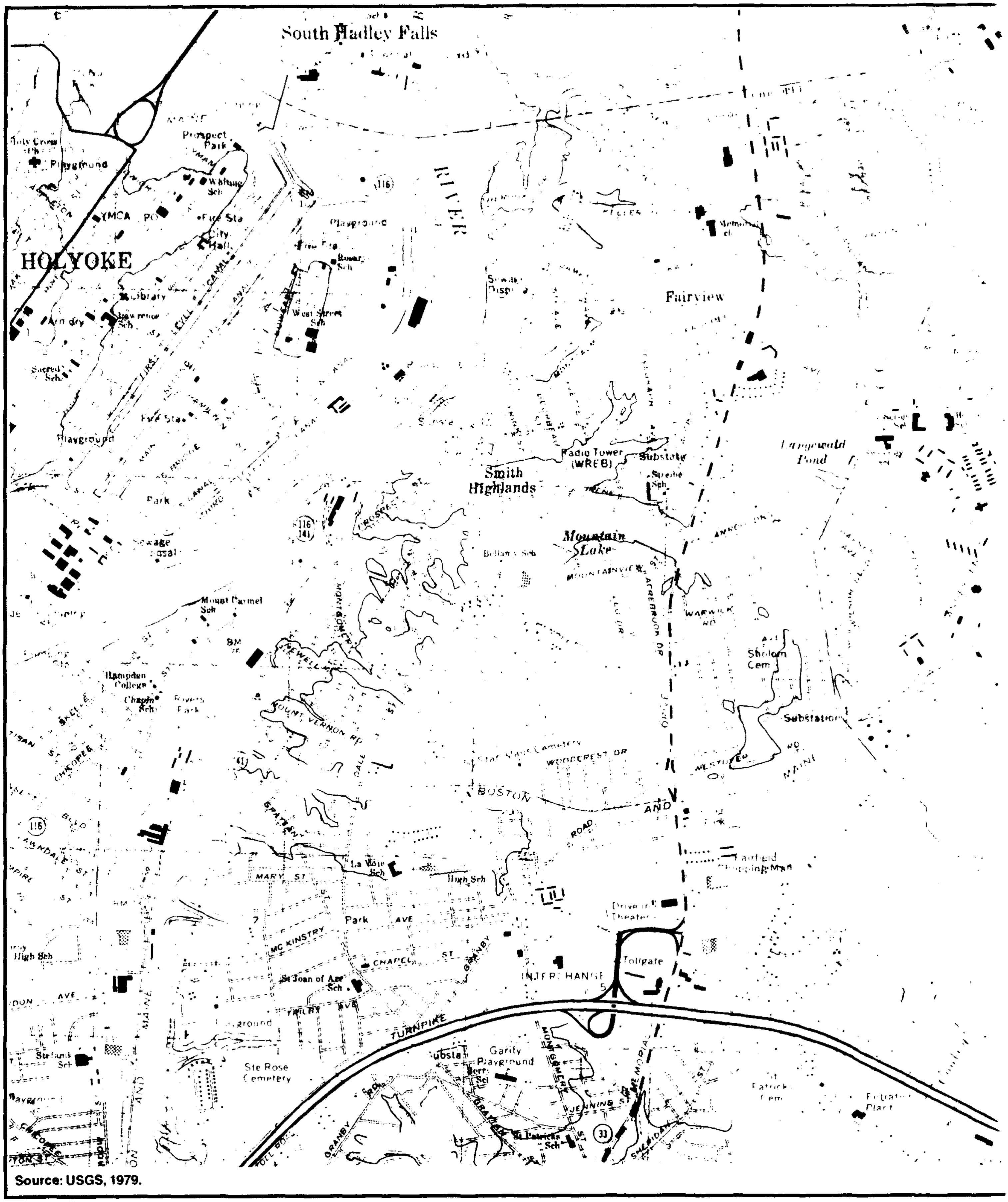
3.1 SURFACE FEATURES

3.1.1 Topography

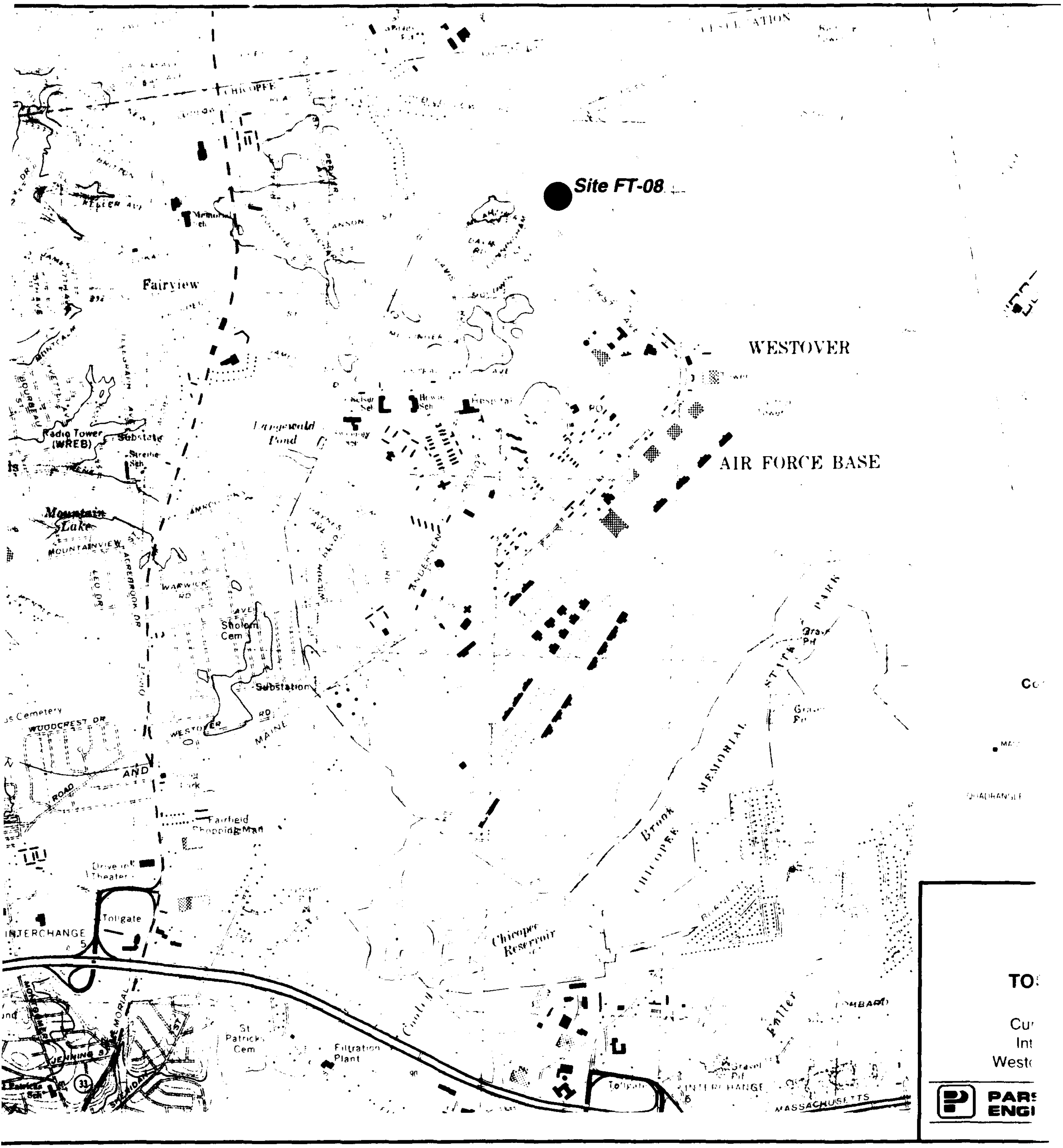
Westover ARB is located within the Connecticut River Valley Lowland Subdivision of the New England Upland Physiographic Province, which is part of the Northern Appalachian Mountain System. Topography at FT-08 consists of very gentle to flat slopes developed on fluvial sands, generally sloping to the south with an average elevation of approximately 240 feet above mean sea level (msl). 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 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.

3.1.2 Surface Water Hydrology

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. 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 separate any LNAPL from storm runoff prior to discharge into the Brook (O'Brien and Gere, 1993). Cooley Brook supplies water to Chicopee Reservoir and the Chicopee River. Stony Brook receives runoff, mainly through storm drains, from the northern portion of the Base. Surface water flow in the vicinity of FT-08 is generally northeast, to the Stony Brook watershed.



Source: USGS, 1979.



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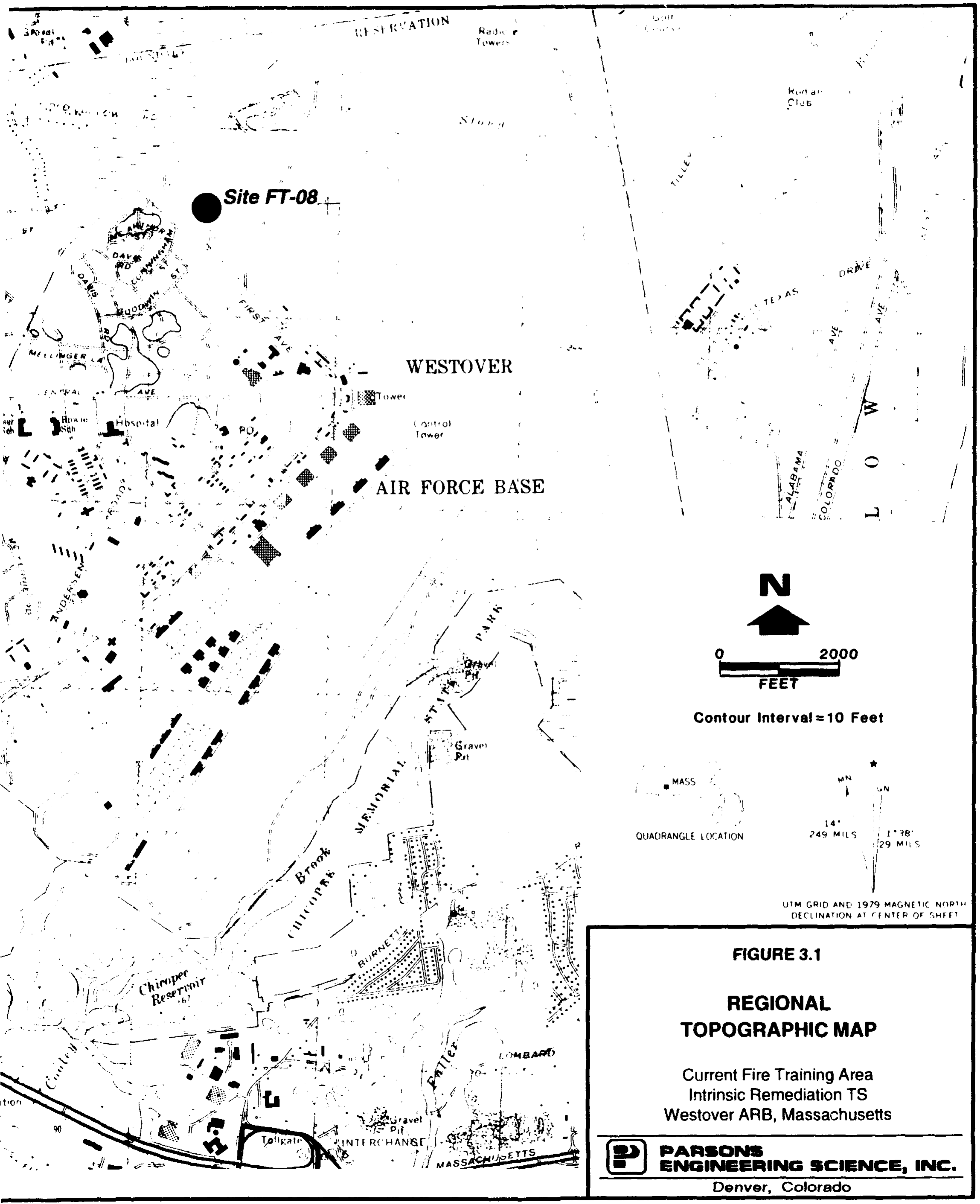

FIGURE 3.1

REGIONAL TOPOGRAPHIC MAP

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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Denver, Colorado

3.1.3 Manmade Features

FT-08 is located in a relatively undeveloped portion of the Base that is mostly vegetated. Manmade features at the site include a fire training pit, an abandoned underground waste-fuel line, a gravel road, and an abandoned railroad line (Figure 1.3). The abandoned fuel line was attached to an underground waste-fuel tank that was removed in 1986. At the boundaries of the site lie the active fire training facility (Building 8010) and Patriot Avenue. Other significant nearby manmade features include the runway located approximately 2,000 feet east of the site, and the industrial and residential portions of the base located approximately 1,000 feet west and southwest 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 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 and runoff 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. Base-wide 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 geology and deltaic outwash aquifer system at FT-08 has been the objective of several investigations. A site visit was conducted by CH$_2$M 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 10 monitoring wells, soil and soil gas sampling, and geophysical surveys. As part of the May 1995 investigation, 21 monitoring points were installed at 15 locations using a Geoprobe®.

3.3.1 Lithology and Stratigraphic Relationships

The shallowest sediments at FT-08 consist of 1 to 3 feet of a brown and black, silty, fine- to coarse-grained sand, with some decaying organic matter. This unit is underlain by 4 to 5 feet of tan to brown fine-grained sand with some silt. Below the fine sand is 10 to 15 feet of poorly sorted medium to coarse alluvial sands containing gravel up to 0.75 inch in diameter. The poorly-sorted sands are underlain by a well sorted fine-grained, silty sand that is approximately 20 feet thick. Below the silty fine sand is 10 to 30 feet of tan to brown, medium- to coarse-grained sand overlying 40 feet of varved silt and clay. Underlying the clay and silt deposit are the thin glacial till and Triassic bedrock units present throughout the region. The depth to the bedrock at FT-08 has not been determined.

To illustrate these stratigraphic relationships, hydrogeologic sections have been developed from subsurface data derived from logs of previously installed monitoring wells and from the May 1995 Geoprobe® investigation. Figure 3.2 shows the locations of these sections. Figure 3.3 presents hydrogeologic section A-A', which is approximately parallel to the direction of groundwater flow. Figure 3.4 presents hydrogeologic section B-B', which is approximately perpendicular to the direction of groundwater flow.

3.3.2 Groundwater Hydraulics

3.3.2.1 Flow Direction and Gradient

Groundwater is first encountered at the contact between the upper silty fine sand and the underlying medium to coarse sands. Depth to groundwater is approximately 5 to 7 feet bgs across the majority of the site. A summary of groundwater measurements from May 1995 and July 1996 is presented in Table 3.1. In May 1995, across the northern and western portions of the site, groundwater flow was to the southeast with an average gradient of 0.0018 foot per foot (ft/ft), excluding an anomalous groundwater elevation at MP-3S (Figure 3.5). July 1996 groundwater elevation data also suggests groundwater flow is to the southeast with an average gradient of 0.0034 ft/ft (Figure 3.5). Groundwater elevations for both May 1995 and July 1996, suggest the presence of an apparent convergent divide just south of the main burn pit.

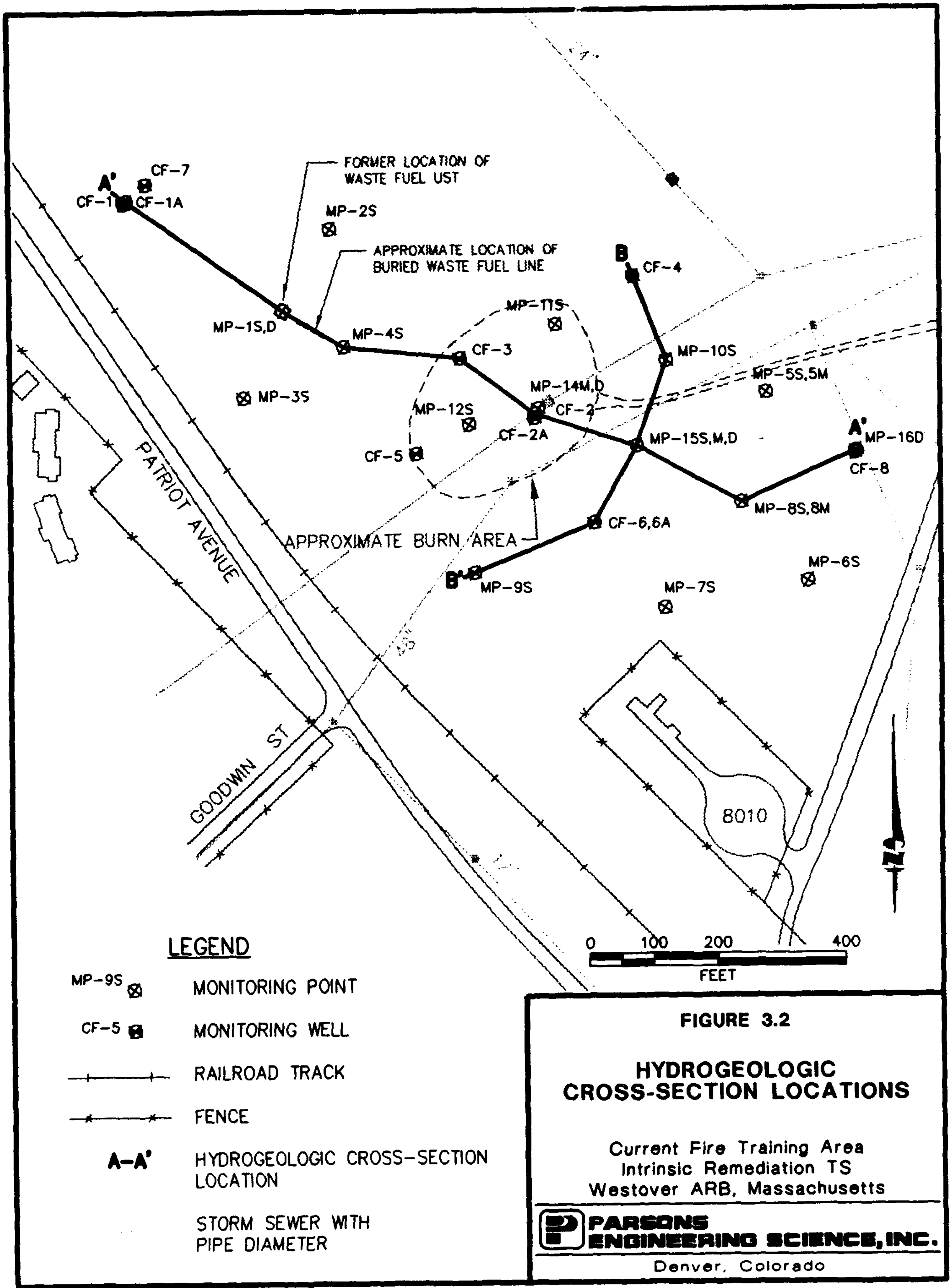
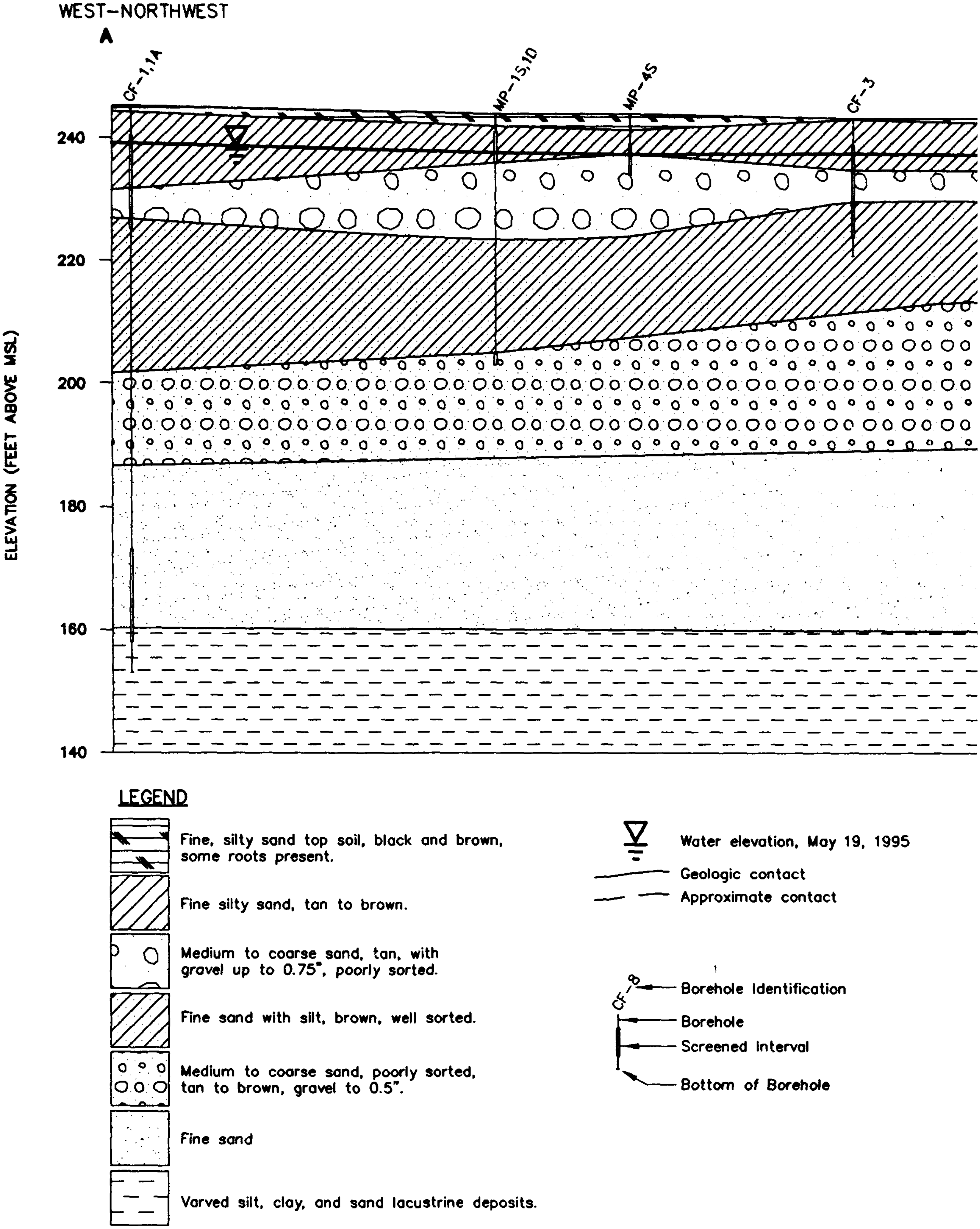


FIGURE 3.2

HYDROGEOLOGIC CROSS-SECTION LOCATIONS

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



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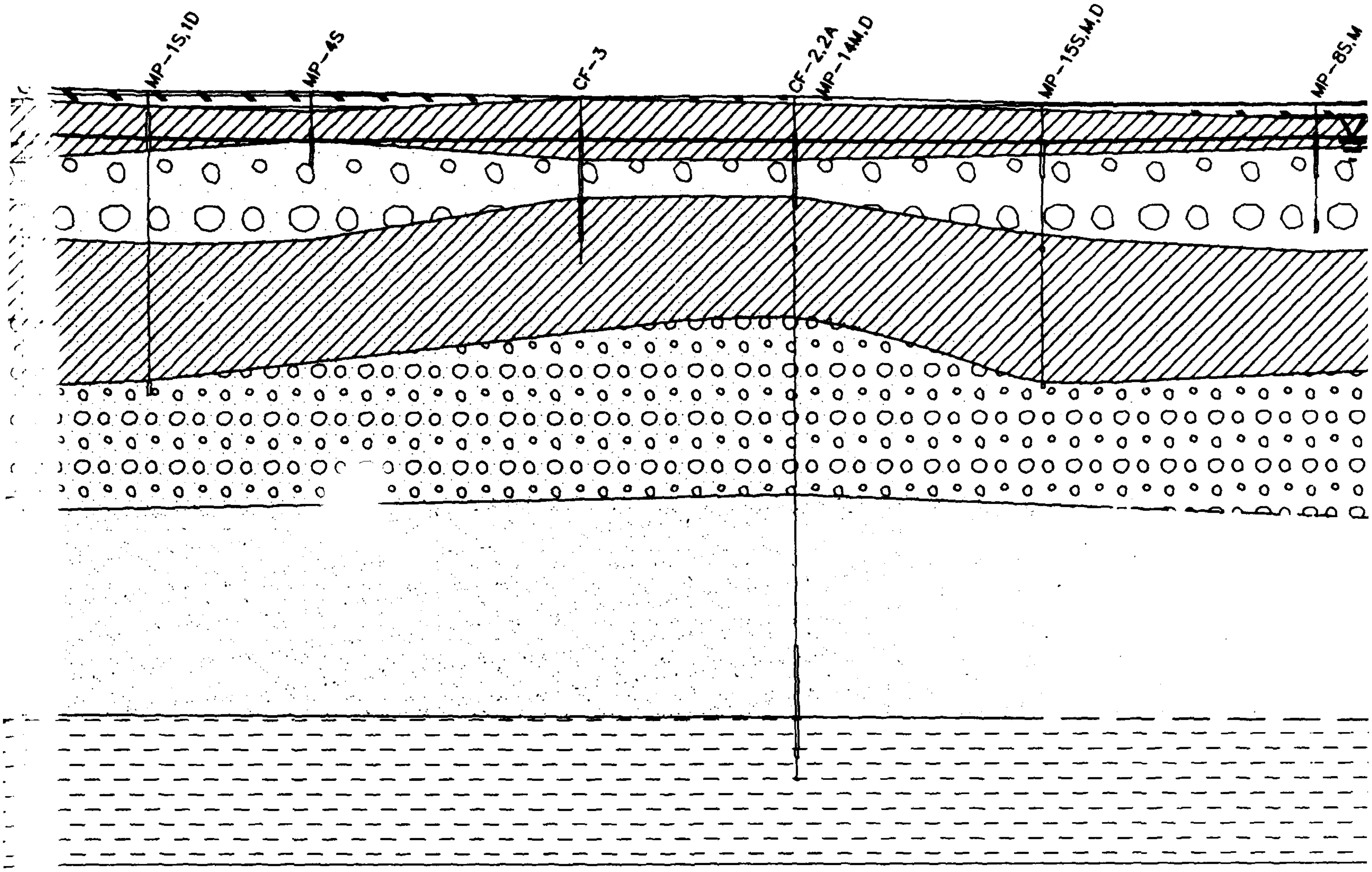


and brown,

▽ Water elevation, May 19, 1995

Geologic contact

Approximate contact

ith
ed.

CF-8 Borehole Identification

sorted.

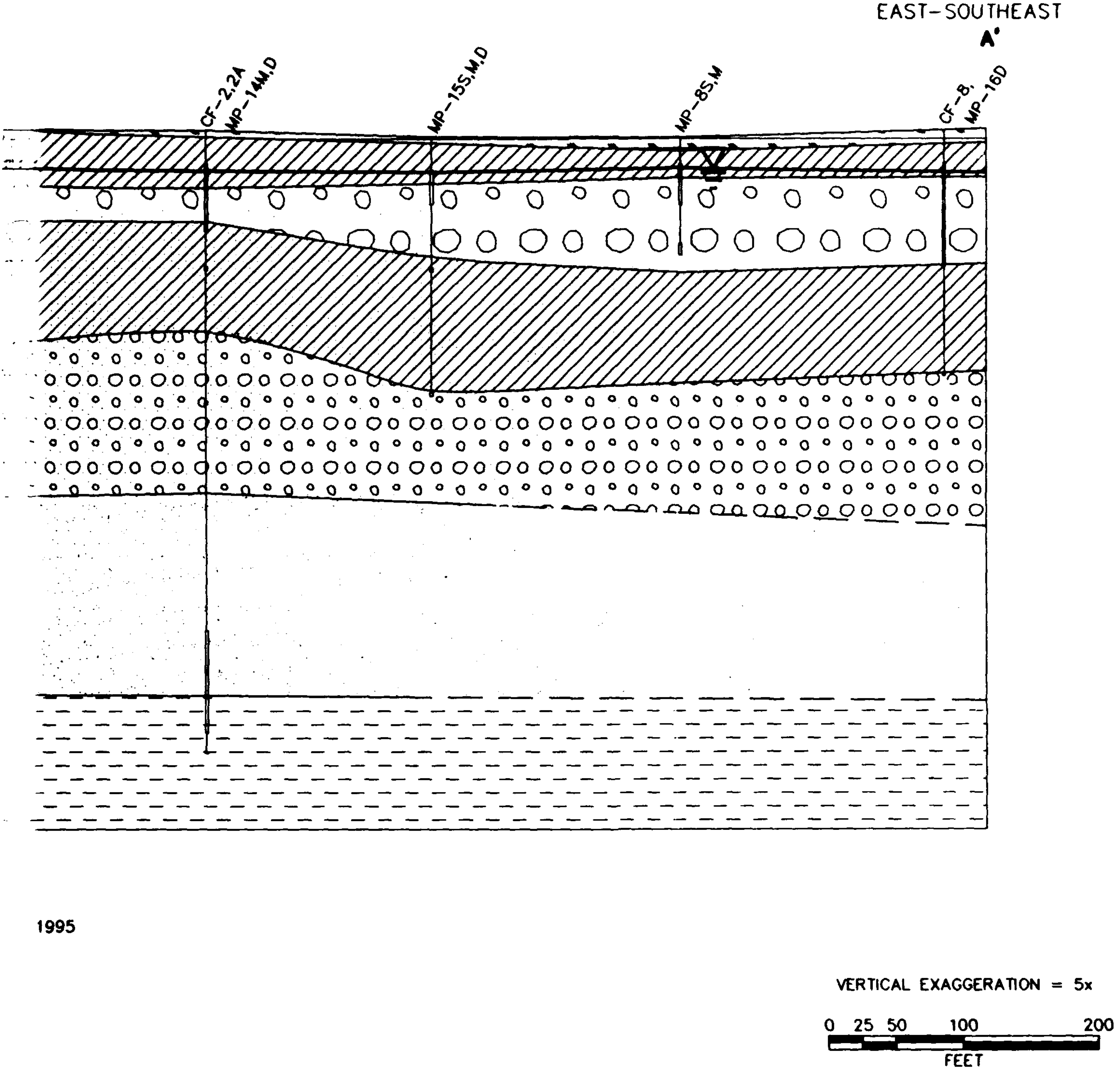
Borehole

Screened Interval

sorted,

Bottom of Borehole

ıstrine deposits.



1995

FIGURE 3.3

HYDROGEOLOGIC CROSS-SECTION A - A'

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

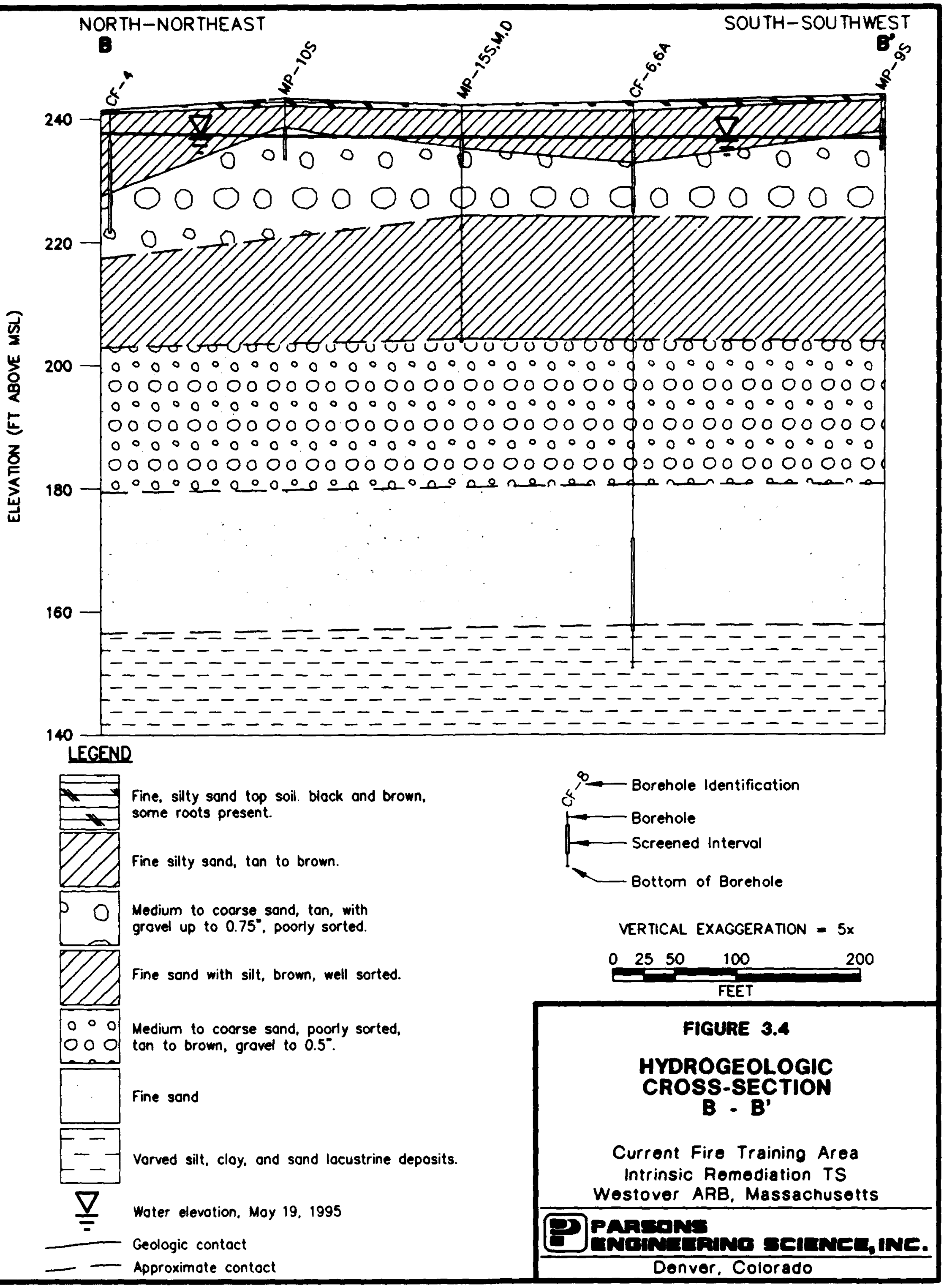


FIGURE 3.4

HYDROGEOLOGIC CROSS-SECTION B - B'

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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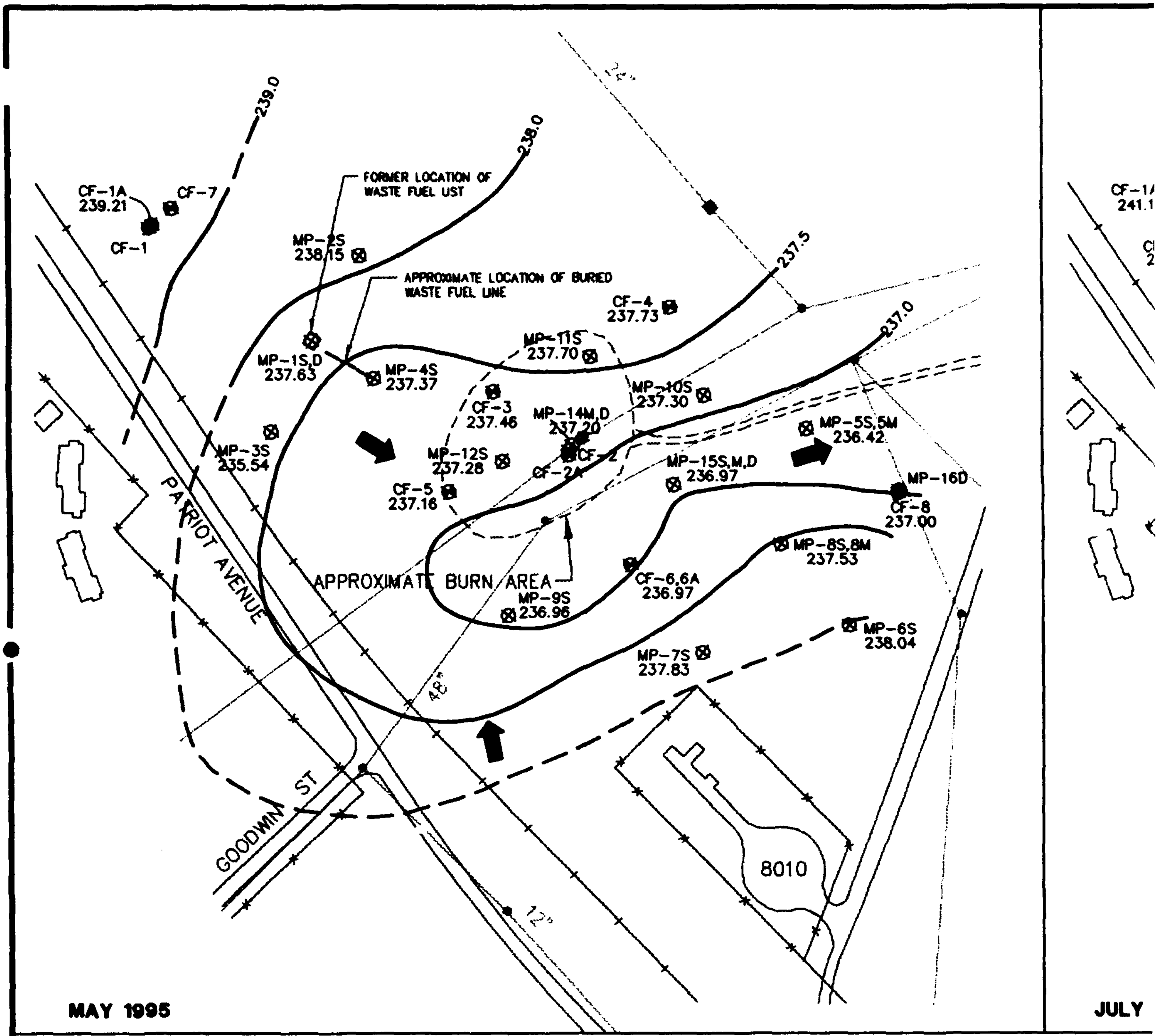
TABLE 3.1
SUMMARY OF GROUNDWATER ELEVATIONS
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Identification	Measurement Date	Screen Interval (ft bgs)	Depth to Water (ft TOC)	Groundwater Elevation (ft msl)
MP-1 S	5/19/95	3.0-8.0	6.16	237.63
	7/16/96	3.0-8.0	5.23	238.56
MP-2 S	5/19/95	4.0-9.0	5.68	238.15
MP-3 S	5/19/95	4.5-9.5	7.78	235.54
MP-4 S	5/19/95	4.0-9.0	6.51	237.37
MP-5 S	5/19/95	5.0-10.0	5.26	236.42
	7/16/96	5.0-10.0	3.25	238.43
MP-6 S	5/19/95	5.0-10.0	5.03	238.04
MP-7 S	5/19/95	5.0-10.0	5.01	237.83
	7/16/96	5.0-10.0	2.68	240.16
MP-8 S	5/19/95	5.0-10.0	4.41	237.53
	7/16/96	5.0-10.0	2.13	239.81
MP-9 S	5/19/95	4.0-9.0	6.68	236.96
	7/16/96	4.0-9.0	5.52	238.12
MP-10 S	5/19/95	5.0-10.0	5.97	237.30
	7/16/96	5.0-10.0	4.48	238.79
MP-11 S	5/19/95	4.0-9.0	5.10	237.70
	7/16/96	4.0-9.0	3.60	239.20
MP-12 S	5/19/95	4.0-9.0	5.66	237.28
	7/16/96	4.0-9.0	4.47	238.47
MP-15 S	5/19/95	5.0-10.0	5.04	236.99
	7/16/96	5.0-10.0	3.20	238.83
CF-1	5/11/95	72.0-87.0	10.18	237.68
	5/19/95	72.0-87.0	10.27	237.59
	7/16/96	72.0-87.0	9.12	238.74
CF-1 A	5/11/95	5.0-20.0	8.20	239.40
	5/19/95	5.0-20.0	8.39	239.21
	7/16/96	5.0-20.0	6.43	241.17
CF-2	5/11/95	74.0-89.9	8.93	237.30
	5/19/95	74.0-89.9	9.04	237.19
	7/16/96	74.0-89.9	7.89	238.34
CF-2 A	5/11/95	5.0-15.0	8.25	237.31
	5/19/95	5.0-15.0	8.36	237.20
	7/16/96	5.0-15.0	7.07	238.49
CF-3	5/11/95	4.5-19.5	7.45	237.54
	5/19/95	4.5-19.5	7.53	237.46
	7/16/96	4.5-19.5	6.06	238.93

TABLE 3.1 (Concluded)
SUMMARY OF GROUNDWATER ELEVATIONS
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Identification	Measurement Date	Screen Interval (ft bgs)	Depth to Water (ft TOC)	Groundwater Elevation (ft msl)
CF-4	5/11/95	5.0-20.0	6.24	237.77
	5/19/95	5.0-20.0	6.28	237.73
	7/16/96	5.0-20.0	4.71	239.30
CF-5	5/11/95	5.0-20.0	8.76	237.24
	5/19/95	5.0-20.0	8.84	237.16
	7/16/96	5.0-20.0	7.55	238.45
CF-6	5/11/95	71.0-86.0	6.60	237.32
	5/19/95	71.0-86.0	6.70	237.22
	7/16/96	71.0-86.0	5.57	238.35
CF-6 A	5/11/95	3.0-18.0	7.56	237.03
	5/19/95	3.0-18.0	7.62	236.97
	7/16/96	3.0-18.0	5.51	239.08
CF-7	5/11/95	1.0-85.0	8.53	238.28
	5/19/95	1.0-85.0	8.63	238.18
CF-8	5/11/95	5.0-20.0	8.46	237.13
	5/19/95	5.0-20.0	8.59	237.00
	7/16/96	5.0-20.0	7.32	238.27



LEGEND

⊠ MP-2S 236.96	MONITORING POINT WITH SHALLOW GROUNDWATER ELEVATION (FT MSL)
● CF-5 237.16	MONITORING WELL WITH SHALLOW GROUNDWATER ELEVATION (FT MSL)
—+—+—	RAILROAD TRACK
—x—x—	FENCE
······ 24"	STORM SEWER WITH PIPE DIAMETER
➡	GROUNDWATER FLOW DIRECTION
—237—	LINE OF EQUAL GROUNDWATER ELEVATION (FT MSL) (DASHED WHERE INFERRED)

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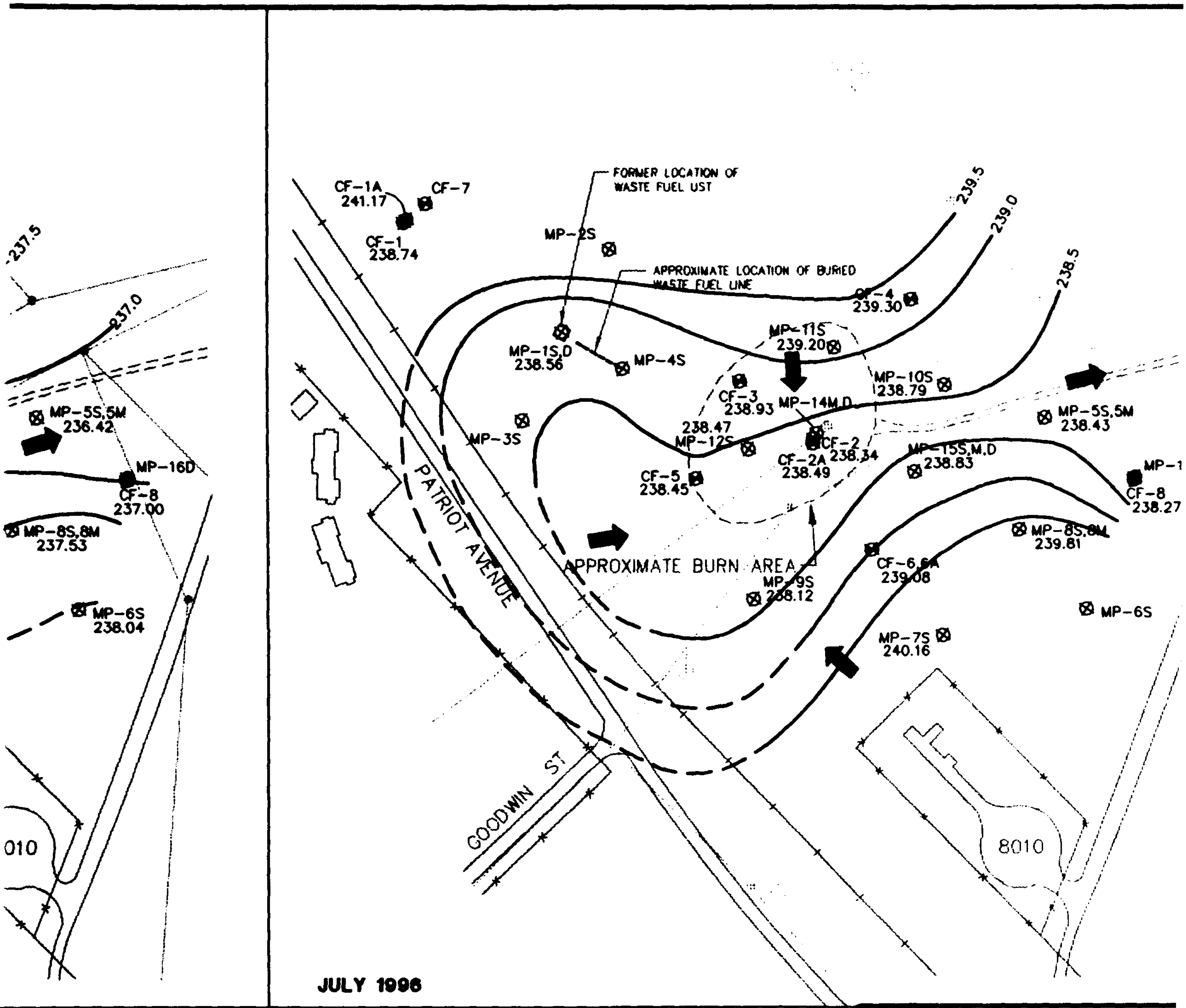


JULY 1996

)RM SEWER WITH
E DIAMETER

)UNDWATER FLOW DIRECTION

E OF EQUAL GROUNDWATER
VATION (FT MSL)
SHED WHERE INFERRED)

N

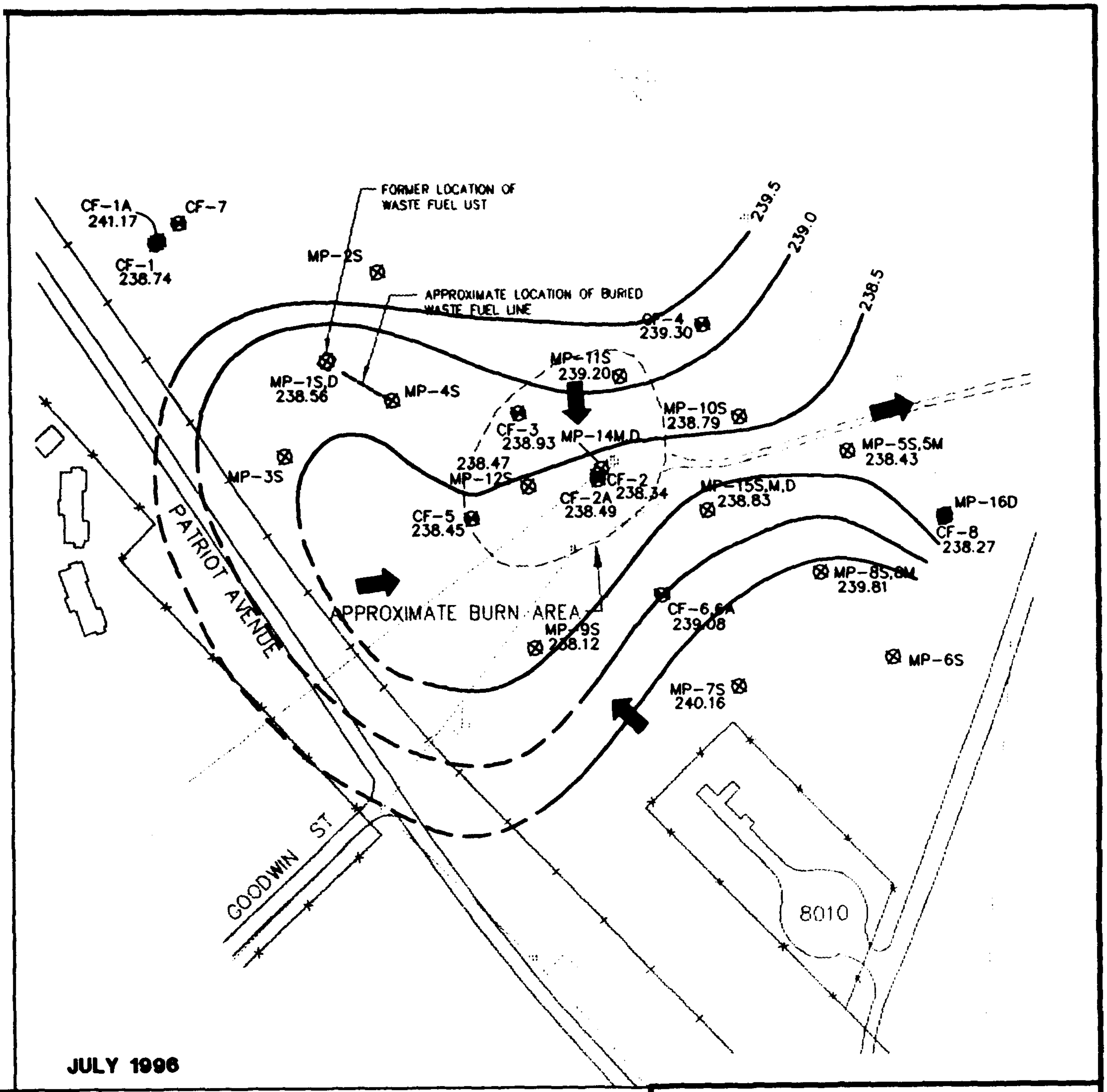
0 100 200 400
FEET

FIGURE 3.5

SHALLOW GROUNDWA
CONTOUR MAPS

Current Fire Training Ar
Intrinsic Remediation T
Westover ARB, Massachu

PARSONS ENGINEERING SCIEN
Denver, Colorado



JULY 1996

FIGURE 3.5

SHALLOW GROUNDWATER CONTOUR MAPS

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

The convergent groundwater divide appears to result from two interacting hydrogeologic conditions. The hydraulic conductivity data presented in Section 3.3.2.2 suggest that alluvial sand and gravel with a higher permeability than surrounding sediments are present in the vicinity of the convergent divide. Of the five hydraulic conductivities estimated for shallow groundwater at the site, the two highest are located within and at the head of the convergent divide. The convergent divide is also thought to result from the interaction between regional and local groundwater flow patterns. A southeastern regional flow direction has been estimated for the northern portion of the base (ES, 1988). This flow pattern is present over the northern and central portions of the site, in areas characterized by a general lack of topographic relief. The land surface rises to the west and south of the site. The groundwater contour map (Figure 3.5) suggests that groundwater from these topographically higher areas is flowing north and east into the topographically lower area of the site. The interaction of the southeastern and northeastern flows contribute to emphasize to preferential groundwater flow through the zone of elevated hydraulic conductivity that trends to the east through the site.

Evidence suggests that vertical flow gradients within the shallow aquifer can vary across the site seasonally. Three monitoring well clusters had shallow wells screened across the water table and deep wells screened at least 70 feet below the water table. Vertical gradients were computed at 0.024 ft/ft down between CF-1 and CF-1A and 0.0043 ft/ft up between CF-6 and CF-6A from data collected in May 1995. The estimated vertical gradient was negligible between CF-2 and CF-2A. Vertical gradients calculated using July 1996 groundwater elevation data showed a slight downward gradient at all the three locations. Calculated vertical gradients for CF-1/-1A, CF-2/-2A and CF-6/-6A are 0.0362 ft/ft down, 0.00217 ft/ft down, and 0.0105 ft/ft down, respectively. Because these gradients are relatively small and vary seasonally, vertical contaminant migration across the entire 70-foot thickness of the surficial aquifer is believed to be negligible. However, vertical groundwater movement between sub units of the surficial aquifer is possible, and expected. Dissolved contaminant concentrations (discussed in Section 4) suggest significant horizontal groundwater movement through both the 5 to 15 foot bgs and the 30-50 foot bgs intervals. Given the migration of BTEX compounds to the 30 to 50 foot depth, a significant downward vertical gradient is believed to exist in the upper half of the surficial aquifer in the vicinity of the source area.

3.3.2.2 Hydraulic Conductivity

Parsons ES estimated the hydraulic conductivity at wells CF-1A, CF-4, CF-5, CF-6, CF-6A, and CF-8 using falling/rising head slug tests run in May 1995 and the method of Bouwer and Rice (1976) as described in Section 2. The results of these slug tests are summarized in Table 3.2. Hydraulic conductivities ranging from 4.3 to 15.3 ft/day were estimated for five wells screened across the water table at FT-08 with the highest conductivities in the vicinity of the convergent groundwater divide. The average hydraulic conductivity of the sands in the shallow saturated zone as determined from these tests is 7.2 ft/day. An average of the historic and current hydraulic conductivity measurements in the shallow surficial aquifer was approximately 9.1 ft/day. Past investigations had measured hydraulic conductivities near the water table ranging from 2.6 to 16 ft/day. These values were also highest in the vicinity of the convergent groundwater divide. Parsons ES estimated the hydraulic conductivity of the deeper surficial aquifer to be 3.5 ft/day at CF-6, while UNC Geotech (1991) estimates for the deeper portion were 14 ft/day at CF-1 and 24 ft/day at CF-2.

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

WELL	HYDRAULIC CONDUCTIVITY (ft/day)	HYDRAULIC CONDUCTIVITY (ft/min)
CF-1A	4.8	0.0034
CF-4	4.3	0.0030
CF-5	9.9	0.0069
CF-6 (Deep)	3.5	0.0024
CF-6A	15.3	0.011
CF-8	5.1	0.0035
AVERAGE	7.2	0.0050

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil making up the shallow saturated zone were used. Walton (1988) gives ranges of effective porosity for medium to coarse sand of 0.15 to 0.35. An average effective porosity of 0.25 was assumed for this project.

3.3.2.4 Advective Groundwater Velocity

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

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

Where: $\bar{v}$ = Average advective groundwater velocity (seepage velocity) [L/T]

K = Hydraulic conductivity [L/T] (7.2 ft/day)

dH/dL = Gradient [L/L] (0.0018 ft/ft)

n_e = Effective porosity (0.25).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at the site in May 1995, was 0.057 ft/day, or approximately 20.8 feet per year.

3.3.2.5 Preferential Flow Paths

A preferential flow path has been identified along the axis of the convergent divide. As discussed in Section 3.3.2.1, the natural hydrogeologic setting, including a zone of elevated hydraulic conductivity and interacting groundwater flow patterns may account for the presence of the preferential pathway. In addition, two 48-inch concrete storm sewers bisect the site in the vicinity of the convergent groundwater divide and preferential flow pathway (Figure 3.5). The presence of the sewer lines has not been conclusively associated with the preferential flow pathway; however, they may have a contributing role.

3.3.3 Groundwater Use

Groundwater in the Westover ARB region is used for public water supply and industrial use. The ES report (1988) determined groundwater supply wells penetrate into the Triassic bedrock aquifer. Only one non-potable well, located approximately 3,000 feet east of the site, is currently operational on the base. All remaining wells at or near the Base have been abandoned in favor of municipal water provided by the City of Chicopee from surface water supplies.

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 1964 through 1986 has been identified as the primary source of soil and groundwater contamination at FT-08. As no liners or other containment devices were used within the burn pit, presumably many of the unburned fuels and solvents percolated through the soil and into the groundwater following each training exercise. The volume of contaminants released at the site prior to 1974 is unknown. From 1974 to 1986, approximately 125 gallons of JP-4 fuel were used during each monthly exercise. A waste-fuel storage tank was located northwest of the burn area and was removed in 1986. However, a buried pipe, originally attached to the waste tank, was also abandoned in place in 1986 and may continue to release small quantities of fuel into the surrounding soils and groundwater.

4.2 SOIL CHEMISTRY

Residual LNAPL is defined as the LNAPL that is trapped in the aquifer by the processes of cohesion and capillarity, and therefore, will not flow within the aquifer or from the aquifer matrix into a well under the influence of gravity. Mobile LNAPL is defined as LNAPL that is free to flow in the aquifer and will flow from the aquifer matrix into a well under the influence of gravity. At this site, the residual LNAPL consists of fuel hydrocarbons derived from JP-4. The following sections describe the residual LNAPL contamination found at the site. A surficial LNAPL film was visually observed in a groundwater sample from MP-4S. However, mobile LNAPL has not been observed at FT-08.

4.2.1 Soil BTEX and Fuel Hydrocarbon Contamination

In May 1995, fourteen soil samples were collected from nine locations at FT-08 and analyzed for BTEX by the USEPA NRMRL. BTEX compounds were detected in soil boreholes MP-4, MP-11, and MP-12. MP-11 and MP-12 are located within the main burn pit and MP-4 is located at the southern end of the waste fuel pipe. Soil samples were collected at 2 and 4 foot bgs from all three of these boreholes. The highest BTEX concentration at the site was 656.6 milligrams per kilogram (mg/kg) in the 4-foot sample from borehole MP-4. Within the burn pit, the maximum BTEX concentrations were detected at 2 and 4 feet bgs in borehole MP-12 at concentrations of 176.1 mg/kg and 24.86 mg/kg, respectively. With the exception of borehole MP-4, soil samples collected outside of the known burn area did not contain quantifiable levels of BTEX. Figure 4.1 shows the locations of soil BTEX contamination. Table 4.1 presents soil BTEX data.

Historically, BTEX compounds also were detected in the main burn pit at concentrations similar to those seen in this investigation. During site investigations performed in 1986 (ES, 1988), 1989 (UNC Geotech, 1991), and 1993 (O'Brien and Gere, 1994), soil samples were collected and analyzed from 35 soil boreholes across the site. The data indicated soil contamination extending to 15 feet bgs in the burn area, with the highest concentrations occurring within the upper 5 feet of soil. The maximum detected BTEX concentration was 440 mg/kg. All of the BTEX contamination was confined to the main burn pit and only about 20 percent of the historical soil samples had BTEX concentrations over 100 mg/kg.

The 14 site soil samples also were analyzed for total fuel hydrocarbons. Elevated concentrations of petroleum hydrocarbons were detected in the same three samples in which total BTEX concentrations measured in excess of 5 mg/kg (MP-4-4', MP-12-2', and MP-12-4'). These soil samples had TPH concentrations of 5,890 to 12,800 mg/kg. The remaining 11 soil samples had TPH concentrations ranging from 38 to 59 mg/kg. Table 4.1 also contains these data. Additional soil samples were not collected during the July 1996 sampling event.

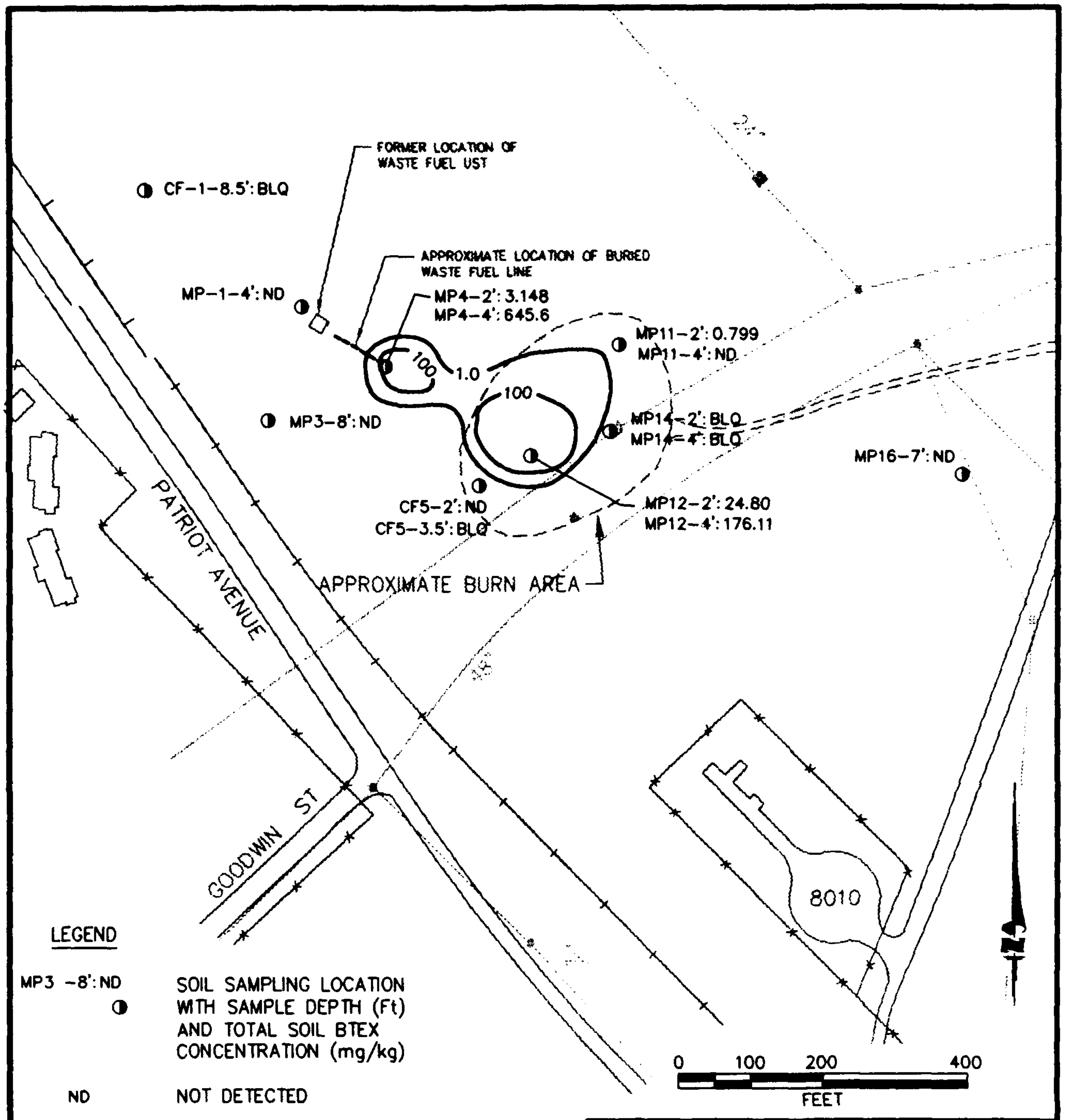
4.2.2 Soil Chlorinated Solvent Contamination

The 14 soil samples collected in May 1995 were also analyzed for chlorinated solvents; however, none of the analytes were present above detection limits. At FT-08, 32 previously collected soil samples were analyzed for trichloroethene (TCE) (ES, 1986 and O'Brien and Gere, 1994). TCE was not detected in soil samples during the ES (1988) investigation. However, O'Brien and Gere (1994) reported soil TCE concentrations ranging from 0.9 to 6.1 micrograms per kilogram (μg/kg). These results were below the laboratory reporting limits suggesting that there is no significant residual chlorinated solvent contamination in site soils. No additional chlorinated solvent soil contamination was detected at the site.

4.2.3 Total Organic Carbon

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.

Thirteen of the soil samples collected by Parsons ES in 1995 were analyzed by the USEPA NRMRL for TOC. The samples were taken at or near the groundwater interface and used to estimate contaminant retardation as a result of sorption. TOC results range from 0.04 to 20.3 percent. The 20.3 percent concentration was taken at the 2-foot interval in an organic soil layer and therefore may not be representative of actual TOC conditions within the aquifer. In fact, all four TOC concentrations above 1



LEGEND

MP3 -8': ND ◑ SOIL SAMPLING LOCATION WITH SAMPLE DEPTH (Ft) AND TOTAL SOIL BTEX CONCENTRATION (mg/kg)

ND NOT DETECTED

BLQ BELOW LEVEL OF QUANTITATION

1.0 LINE OF EQUAL SOIL BTEX CONCENTRATION (mg/kg)

RAILROAD TRACK

FENCE

STORM SEWER WITH PIPE DIAMETER

NOTE: WHERE MULTIPLE SAMPLES WERE COLLECTED AT THE SAME LOCATION, THE MAXIMUM CONCENTRATION WAS USED FOR CONSTRUCTION OF ISOPLETHS.

FIGURE 4.1

TOTAL BTEX ISOPLETH MAP FOR SOIL MAY 1995

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 4.1
SOIL ANALYTICAL DATA
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Identification	Benzene (mg/kg)[e]	Toluene (mg/kg)	Ethylbenezene (mg/kg)	p-Xylene (mg/kg)	m-Xylene (mg/kg)	o-Xylene (mg/kg)	Total BTEX[a] (mg/kg)	1,3,5-TMB[b] (mg/kg)	1,2,4-TMB (mg/kg)	1,2,3-TMB (mg/kg)	TPH[c] (mg/kg)	TOC[d] (%)
CF-1-8.5'	ND[f]	BLQ[g]	ND	ND	ND	ND	BLQ	ND	ND	ND	43	0.04
CF-5-2'	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	59	1.25
CF-5-3.5'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND	45	NA[h]
MP-1-4'	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	40	0.103
MP-3-8'	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	47	0.059
MP-4-2'	0.944	0.257	0.382	0.464	0.675	0.426	3.15	0.183	0.514	0.278	55	20.3
MP-4-4'	18.8	187	92.6	68.2	176	103	646	66.1	171	74.3	9950	0.321
MP-11-2'	0.199	BLQ	0.098	0.106	0.266	0.13	0.80	0.054	0.123	0.096	43	1.54
MP-11-4'	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	46	0.19
MP-12-2'	0.245	7.51	2.79	3.07	7.25	4.02	24.89	3.87	8.31	4.18	5890	1.1
MP-12-4'	2.11	56.6	20.8	19.8	50.2	26.6	176.1	23.2	49.9	24.1	12800	0.287
MP-14-2'	ND	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND	41	0.463
MP-14-4'	ND	BLQ	ND	ND	ND	ND	BLQ	ND	ND	ND	38	0.134
MP-16-7'	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	38	0.583

[a] BTEX = benzene, toluene, ethylbenzene, and xylenes.
[b] TMB = trimethylbenzene.
[c] TPH = total petroleum hydrocarbons.
[d] TOC = total organic carbon.
[e] mg/kg = milligrams per kilogram.
[f] ND = not detected.
[g] BLQ = below level of quantitation.
[h] NA = not analyzed.

percent were measured in samples collected at a depth of 2 feet. The average TOC concentration for the samples containing no detected BTEX and collected at a depth of at least 4 feet is 0.19 percent.

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. Geochemical evidence is used herein to support the occurrence of natural attenuation, as described in the following sections. The loss of contaminant mass is calculated and modeled in Section 5. 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

Groundwater samples collected at FT-08 were analyzed for fuel hydrocarbon and chlorinated solvent concentrations in 1986, 1991, and 1993. The highest detected total BTEX concentration during these investigations was 6,850 micrograms per liter (μg/L) at monitoring well CF-3 in 1991 (UNC Geotech, 1991). A groundwater sample collected from CF-2A in 1986 had the second-highest total BTEX concentration (5,400 μg/L). Historically, groundwater from monitoring well CF-3 also has contained the highest chlorinated solvent concentrations. In 1991, 11,000 μg/L of TCE was detected in CF-3. Monitoring well CF-2A has also contained significant TCE contamination in the past. With the exception of groundwater results from wells CF-3 and CF-2A, neither total BTEX or chlorinated solvent concentrations have exceeded 10 μg/L.

Analytical results for groundwater samples collected in May 1995 and July 1996 at previously installed monitoring wells confirmed these historical observations. Analytical results for samples from newly installed monitoring points were used to better define the extent of contamination. Tables 4.2 and 4.3 summarize groundwater contaminant data for the May 1995 and July 1996 samples. Analytical results from the current investigation 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 points or wells are present, isopleths are drawn using the maximum concentration detected at that location. For May 1995, as indicated by the 10-μg/L isopleth, the BTEX plume is approximately 750 feet long and 350 feet wide. The estimated area of the plume is about 244,800 square feet, or approximately 5.6 acres. The July 1996 observed dissolved BTEX plume is approximately the same length and 250 feet wide, estimated area is about 140,000 square feet (approximately 3.2 acres). The main body of both the May 1995 and July 1996 plumes is centered beneath the main burn pit with a secondary source located at the outfall of the abandoned and buried waste-fuel pipeline.

TABLE 4.2
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample ID	Date Sampled	Benzene (µg/L)[d/]	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylenes (µg/L)	m-Xylenes (µg/L)	o-Xylenes (µg/L)	Total BTEX[a/] (µg/L)	Fuel Carbon (µg/L)	1,3,5-TMB[b/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	1,2,4,5 TEMB[c/] (µg/L)	1,2,3,5 TEMB (µg/L)	1,2,3,4 TEMB (µg/L)
MP-1 S	5/18/95	ND[e/]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/17/96	ND	ND	ND	ND	BLQ[f/]	ND	BLQ	BLQ	ND	ND	ND	NA	NA	NA
MP-1 D	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
MP-2 S	5/18/95	ND	BLQ	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	ND	ND	ND
MP-3 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-4 S	5/18/95	8489	15760	1569	1185	3397	2157	32557	30400	263	817	503	106	141	183
	7/18/96	6610	12860	1290	965	2650	1750	26125	26000	212	720	428	NA	NA	NA
MP-5 S	5/17/95	2.40	BLQ	0.59	3.57	6.93	6.97	20.5	23.0	1.13	1.80	1.13	ND	ND	ND
MP-5 M	5/17/95	6.95	BLQ	2.45	7.21	18.4	14.6	49.7	56.0	2.29	3.08	1.64	ND	ND	ND
	7/17/96	7.70	2.30	2.10	5.40	3.6	2.8	23.9	34.9	1.50	2.80	1.20	NA	NA	NA
MP-6 S	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-7 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-8 S	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-8 M	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/17/96	ND	BLQ	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	NA	NA	NA
MP-9 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-10 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	ND	ND
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
MP-11 S	5/18/95	2.82	BLQ	19.6	12.4	11.0	11.5	57.2	335	15.4	13.6	18.6	4.08	4.62	4.24
MP-12 S	5/18/95	2261	15264	1455	1147	3018	1868	25012	32600	218	650	354	22.6	37.7	47.0
	7/18/96	2220	13150	1090	880	2350	1520	21210	20600	180	521	314	NA	NA	NA
MP-14 M	5/17/95	153	1.62	70.4	90.3	6.65	1.64	324	668	19	43	27	2.75	4.02	5.18
	7/17/96	85.3	1.20	35.2	48.6	1.30	1.00	172.6	333	8.9	21.4	14.1	NA	NA	NA
MP-14 D	5/17/95	267	780	126	117	236	126	1652	2021	24.7	62.5	40.5	2.08	3.66	5.47
	7/17/96	252	540	106	97.7	173	85.4	1254.1	1520	18.6	49.2	32.0	NA	NA	NA
MP-15 S	5/17/95	0.92	BLQ	ND	ND	ND	ND	0.92	BLQ	ND	ND	ND	ND	ND	ND
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
MP-15 M	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/18/96	BLQ	ND	ND	BLQ	ND	ND	BLQ	BLQ	ND	ND	ND	NA	NA	NA
MP-15 D	5/17/95	2.03	ND	4.85	7.84	18.7	13.4	46.8	52.1	1.85	3.54	3.57	ND	ND	ND
	7/18/96	2.00	ND	3.90	7.10	4.7	3.1	20.8	32.1	1.30	3.40	3.50	NA	NA	NA
MP-16 D	5/17/95	ND	ND	ND	ND	BLQ	BLQ	BLQ	BLQ	ND	ND	ND	ND	ND	ND
	7/17/96	ND	ND	ND	ND	BLQ	ND	BLQ	BLQ	ND	ND	ND	NA	NA	NA

TABLE 4.[illegible] (Concluded)
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample ID	Date Sampled	Benzene (µg/L)[d]	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylenes (µg/L)	m-Xylenes (µg/L)	o-Xylenes (µg/L)	Total BTEX[a] (µg/L)	Fuel Carbon (µg/L)	1,3,5-TMB[b] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	1,2,4,5 TEMB[c] (µg/L)	1,2,3,5 TEMB (µg/L)	1,2,3,4 TEMB (µg/L)
CF-1	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CF-1 A	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CF-2	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/18/96	ND	BLQ	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	NA	NA	NA
CF-2 A	5/18/95	170	35.0	370	471	1033	940	3020	4720	202	504	328	37.6	57.3	62.7
	7/18/96	113	17.5	261	289	717	608	2005.5	2920	114	317	212	NA	NA	NA
CF-3	5/18/95	271	2643	637	585	1252	877	6266	11000	186	549	310	24.5	40.1	52.6
	7/18/96	69.5	1550	374	398	1010	645	4046.5	5250	98.1	270	173	NA	NA	NA
CF-4	5/18/95	BLQ	3.40	BLQ	1.06	2.71	1.62	8.79	21.9	ND	1.99	1.34	ND	ND	ND
CF-5	5/18/95	1.75	ND	BLQ	1.96	ND	ND	3.71	9.71	ND	1.82	1.43	ND	ND	ND
	7/18/96	2.40	1.20	2.70	3.70	0.90	ND	10.90	32.30	ND	2.80	1.80	NA	NA	NA
CF-6	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/18/96	3.80	ND	ND	ND	ND	ND	3.80	8.10	ND	ND	ND	NA	NA	NA
CF-6 A	5/17/95	25.3	ND	ND	ND	ND	ND	25.3	42.9	ND	ND	ND	ND	ND	ND
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA
CF-8	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA

[a] BTEX = benzene, toluene, ethylbenzene, and xylenes.

[b] TMB = trimethylbenzene.

[c] TEMB = tetramethylbenzene.

[d] µg/L = micrograms per liter.

[e] ND = not detected.

[f] BLQ = below level of quantitation.

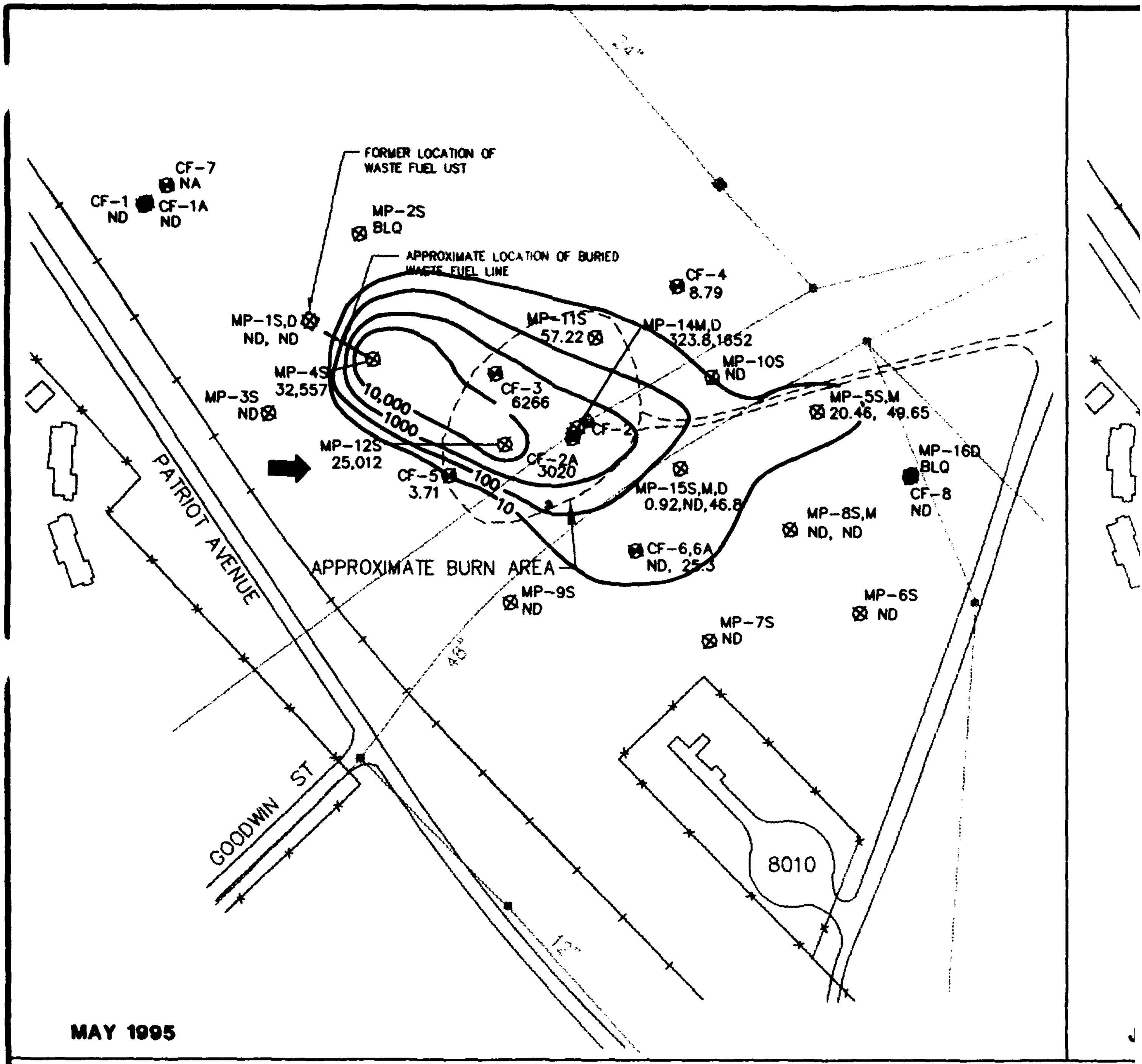
TABLE 4.3
CHLORINATED SOLVENTS AND ETHENE DETECTED IN GROUNDWATER
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Identification	Date Sampled	PCE[a] (µg/L)[f]	TCE[b] (µg/L)	1,1-DCE[c] (µg/L)	Trans-1,2-DCE[d] (µg/L)	Cis 1,2-DCE[e] (µg/L)	Vinyl Chloride (µg/L)	Total Solvents (µg/L)	Ethene (mg/L)
MP-1 S	5/18/95	ND[g]	ND	ND	ND	ND	ND	ND	NA
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-1 D	5/18/95	ND	ND	ND	ND	ND	ND	ND	NA
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-2 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND
MP-3 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	NA
MP-4 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	0.005
	7/18/96	ND	ND	ND	ND	ND	ND	ND	0.008
MP-5 S	5/17/95	ND	1.5	ND	ND	BLQ[h]	ND	1.5	NA
MP-5 M	5/17/95	BLQ	4.4	ND	BLQ	BLQ	ND	4.4	NA
	7/17/96	ND	3.2	ND	BLQ	BLQ	ND	3.2	ND
MP-6 S	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND
MP-7 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	NA
MP-8 S	5/17/95	ND	ND	ND	ND	ND	ND	ND	NA
MP-8 M	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-9 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	NA
MP-10 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-11 S	5/18/95	ND	ND	ND	ND	ND	ND	ND	NA
MP-12 S	5/18/95	ND	4.1	ND	ND	ND	ND	4.1	0.003
	7/18/96	ND	6.8	ND	ND	BLQ	ND	6.8	BLQ
MP-14 M	5/17/95	ND	25.8	BLQ	BLQ	86.7	ND	112.5	BLQ
	7/17/96	ND	10.1	BLQ	BLQ	50.6	ND	60.7	ND
MP-14 D	5/17/95	1.4	541	2.7	3	158	2.2	708.3	NA
	7/17/96	BLQ	289	2.7	3.1	288	1.7	584.5	BLQ
MP-15 S	5/17/95	ND	ND	ND	ND	ND	ND	ND	BLQ
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-15 M	5/17/95	ND	ND	ND	ND	ND	ND	ND	NA
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-15 D	5/17/95	ND	BLQ	ND	ND	ND	ND	ND	ND
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
MP-16 D	5/17/95	ND	ND	ND	ND	ND	ND	ND	NA
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 4.3 (Concluded)
CHLORINATED SOLVENTS AND ETHENE
DETECTED IN GROUNDWATER
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Identification	Date Sampled	PCE[a] (µg/L)[f]	TCE[b] (µg/L)	1,1-DCE[c] (µg/L)	Trans-1,2-DCE[d] (µg/L)	Cis-1,2-DCE[e] (µg/L)	Vinyl Chloride (µg/L)	Total Solvents (µg/L)	Ethene (mg/L)
CF-1	5/17/95	ND	ND	ND	ND	ND	ND	ND	NA
CF-1 A	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND
CF-2	5/17/95	ND	ND	ND	ND	ND	ND	ND	NA
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
CF-2 A	5/18/95	ND	ND	ND	ND	ND	ND	ND	ND
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
CF-3	5/18/95	ND	12800	6.4	2.1	732	ND	13541	NA
	7/18/96	ND	1660	3.7	ND	434	ND	2098	ND
CF-4	5/18/95	ND	BLQ	ND	ND	ND	ND	ND	ND
CF-5	5/18/95	ND	1.5	ND	ND	7.6	ND	9.1	ND
	7/18/96	ND	94.6	BLQ	ND	35	ND	129.6	ND
CF-6	5/17/95	ND	1.6	ND	ND	BLQ	ND	1.6	ND
	7/18/96	ND	13.8	BLQ	BLQ	3	ND	16.8	ND
CF-6 A	5/17/95	ND	56.2	2.6	1.3	2.5	ND	62.6	NA
	7/18/96	ND	ND	ND	ND	ND	ND	ND	ND
CF-8	5/17/95	ND	ND	ND	ND	ND	ND	ND	ND
	7/17/96	ND	ND	ND	ND	ND	ND	ND	ND

a/ PCE = Tetrachloroethene
b/ TCE = Trichloroethene
c/ 1,1-DCE = 1,1 Dichloroethene
d/ Trans-1,2-DCE = Trans-1,2,-Dichloroethene
e/ Cis-1,2-DCE = Cis-1,2-Dichloroethene
f/ µg/L = micrograms per liter
g/ ND = None Detected
h/ BLQ = Below Calibration Limit



LEGEND

MP-3S ⊠ ND	MONITORING POINT, WITH TOTAL BTEX CONCENTRATION (µg/L) (S=SHALLOW, M=INTERMEDIATE, D=DEEP)
CF-5 ● 3.71	MONITORING WELL, WITH TOTAL BTEX CONCENTRATION (µg/L)
100	LINE OF EQUAL TOTAL BTEX CONCENTRATION (µg/L)
➡	GROUNDWATER FLOW DIRECTION
NA	NOT ANALYZED
ND	NOT DETECTED
BLQ	BELOW LEVEL OF QUANTITATION
—+—	RAILROAD TRACK
—x—	FENCE
-------	STORM SEWER WITH PIPE DIAMETER

NOTE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS

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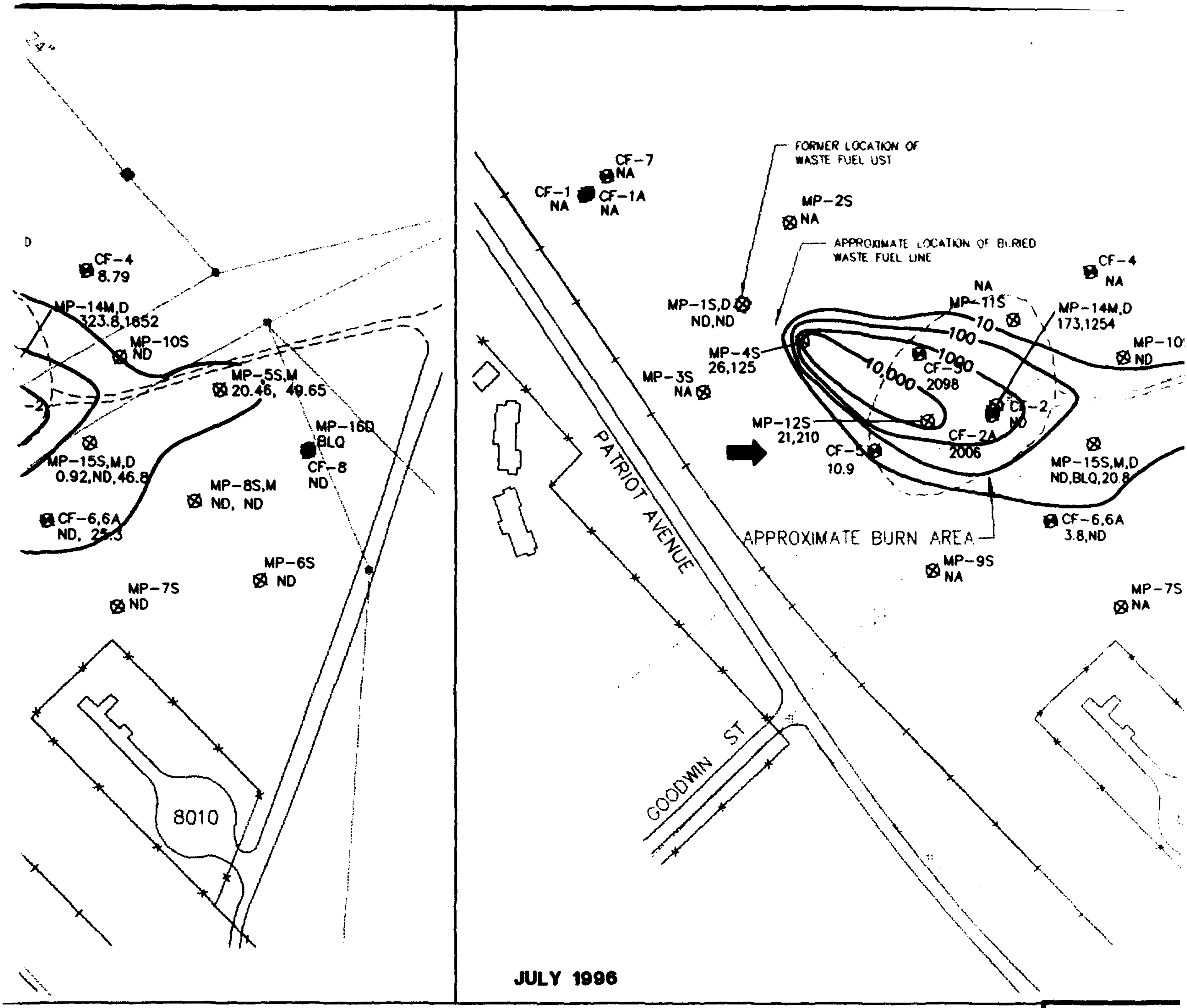
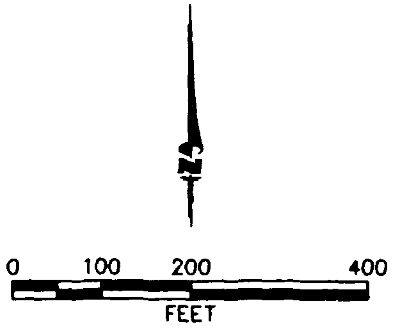


JULY 1996

NA	NOT ANALYZED
ND	NOT DETECTED
BLQ	BELOW LEVEL OF QUANTITATION
—+—+—	RAILROAD TRACK
—×—×—	FENCE
———	STORM SEWER WITH PIPE DIAMETER

OTE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS
SED FOR THE CONSTRUCTION OF ISOPLETHS



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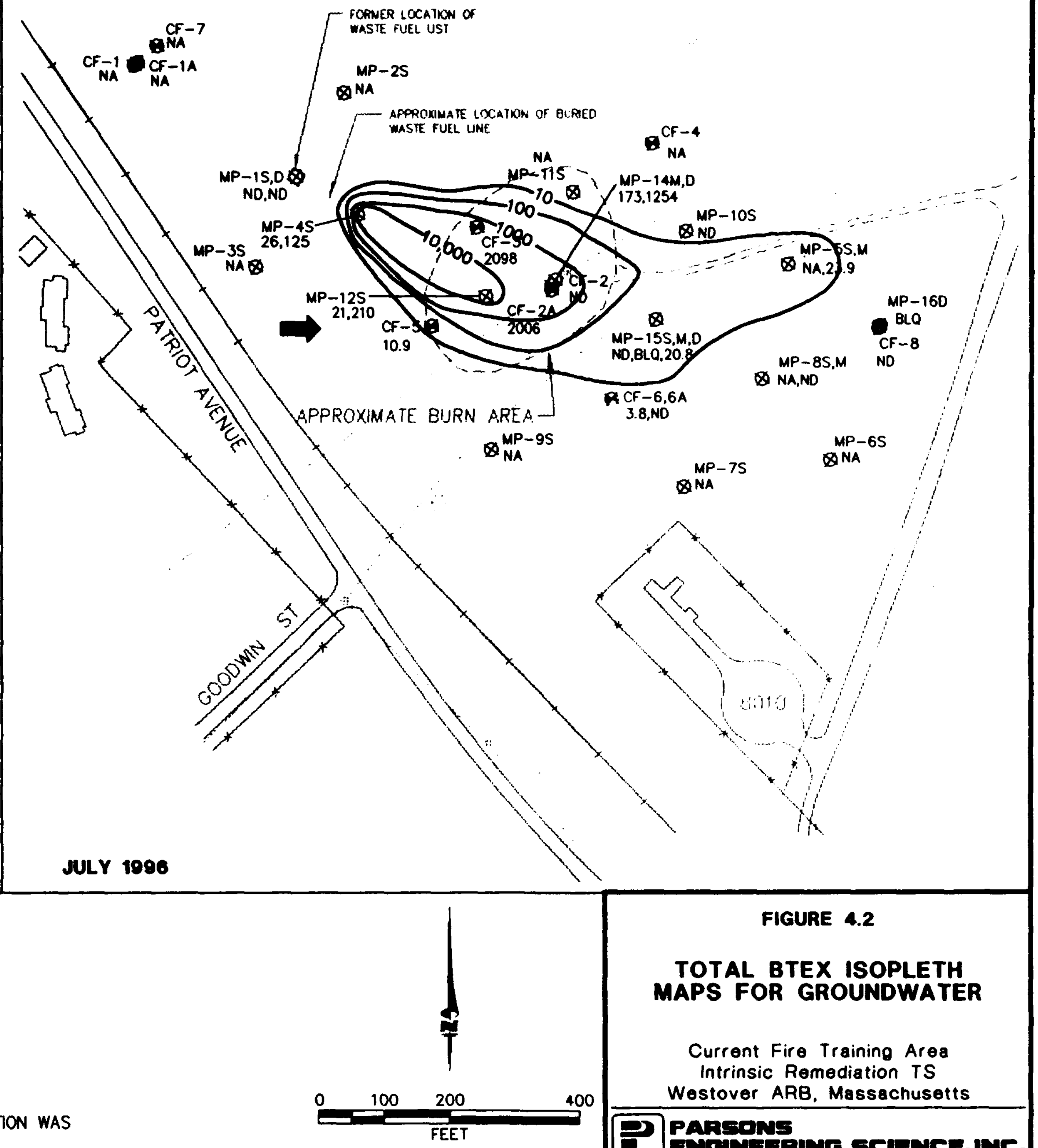

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FIGURE 4.2

TOTAL BTEX ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

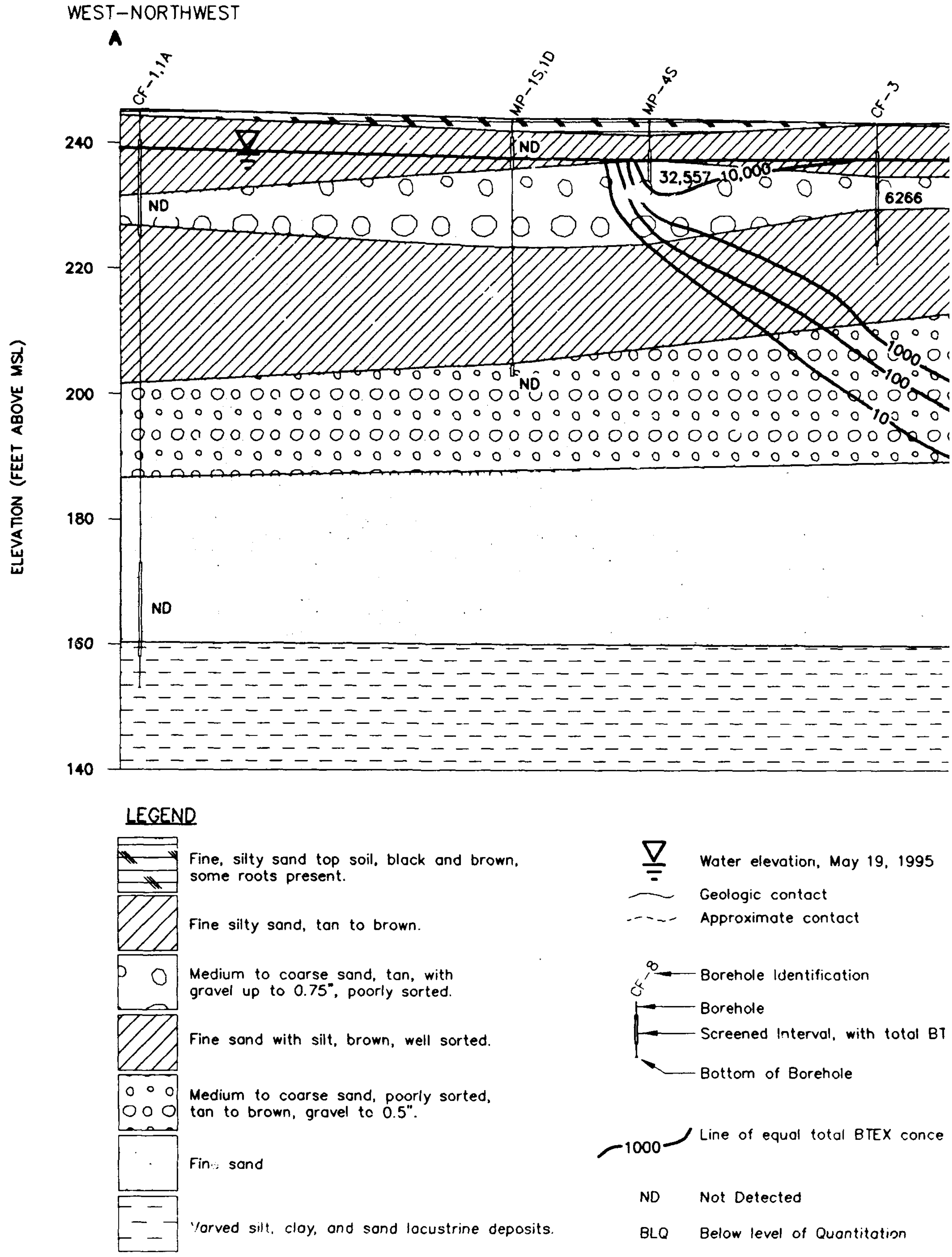
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

The vertical distributions of total dissolved BTEX in May 1995 and July 1996 along the main axis of the plume parallel to the direction of groundwater flow are presented on Figures 4.3a and 4.3b, respectively. The low horizontal groundwater gradient at the site reduces the horizontal groundwater velocity, and therefore, BTEX compounds migrate or disperse in groundwater both horizontally and vertically. On the basis of the analytical results from both sampling events, the maximum depth of the dissolved BTEX contamination is estimated to approximately coincide with the contract between the coarse sand/gravel and the fine sand. The vertical profiles illsutrate that the BTEX plume is split into two lobes separated by a silty sand unit with relatively low hydraulic conductivity. The fact that the total BTEX concentration is higher in the deeper zone of the aquifer downgradient from the source area suggests that most of the contamination found in the deep zone migrates vertically through the silty sand upgradient of the CF-2/MP-14 cluster. The contamination then resumes a more horizontal flow path in the coarse sands and gravels of the deeper zone. This trend is also evident, in both May 1995 and July 1996, at the downgradient well cluster at MP-15.

Total dissolved BTEX concentrations decreased throughout the plume extent between May 1995 and July 1996. In May 1995, the maximum observed total BTEX concentration was 32,557 μg/L, in the sample collected from monitoring point MP-4S. At this location, total BTEX concentrations dropped to 26,125 μg/L in July 1996. Likewise, in May 1995, the BTEX concentrations from the three shallow monitoring locations centered in the main burn pit and directly downgradient of MP-4S (i.e., MP-12S, CF-3, and CF-2A) had BTEX concentrations of 25,012 μg/L, 6,266 μg/L, and 3,020 μg/L, respectively. In July 1996, the total dissolved BTEX concentrations in these samples had decreased to 21,210 μg/L, 4,046 μg/L, and 2005 μg/L, respectively. Similar decreases also canbe observed deeper in the surficial aquifer. In May 1995, the maximum detected BTEX concentration in the deeper saturated zone was 1,652 μg/L at MP-14D. The total BTEX concentration in July 1996 at that point was 1,254 μg/L. The intermediate-depth sample at the same location (MP-14M) had a dissolved BTEX concentration of 323.8 μg/L in May 1995 and 172.6 μg/L in July 1996. Elsewhere, similar decreases in dissolved BTEX contamination were observed from May 1995 to July 1996.

4.3.1.2 Dissolved Chlorinated Solvent Contamination

The areal extents of total dissolved chlorinated solvents in groundwater for May 1995 and July 1996 are nearly identical and are presented on Figure 4.4. The concentrations of individual chlorinated solvents and ethene are presented in Table 4.3. Where nested wells are present, isopleths are drawn on the basis of the maximum detected concentration at each location. As defined by the 1-μg/L contour, the chlorinated solvent plume is approximately 600 feet long and 325 feet wide, with a total area of about 122,000 square feet (2.8 acres). The source of the plume is within the former burn area. The vertical distributions of contaminants along the axis of the plume parallel to the direction of groundwater flow are presented on Figures 4.5a and 4.5b. On the basis of the analytical results from both sampling events, the maximum depth of the dissolved chlorinated solvent plume lies between the screened intervals for MP-14D and CF-2 (42 to 74 feet bgs), and may approximately coincide with the contact between the coarse sand/gravel and the fine sand at 55 feet bgs.



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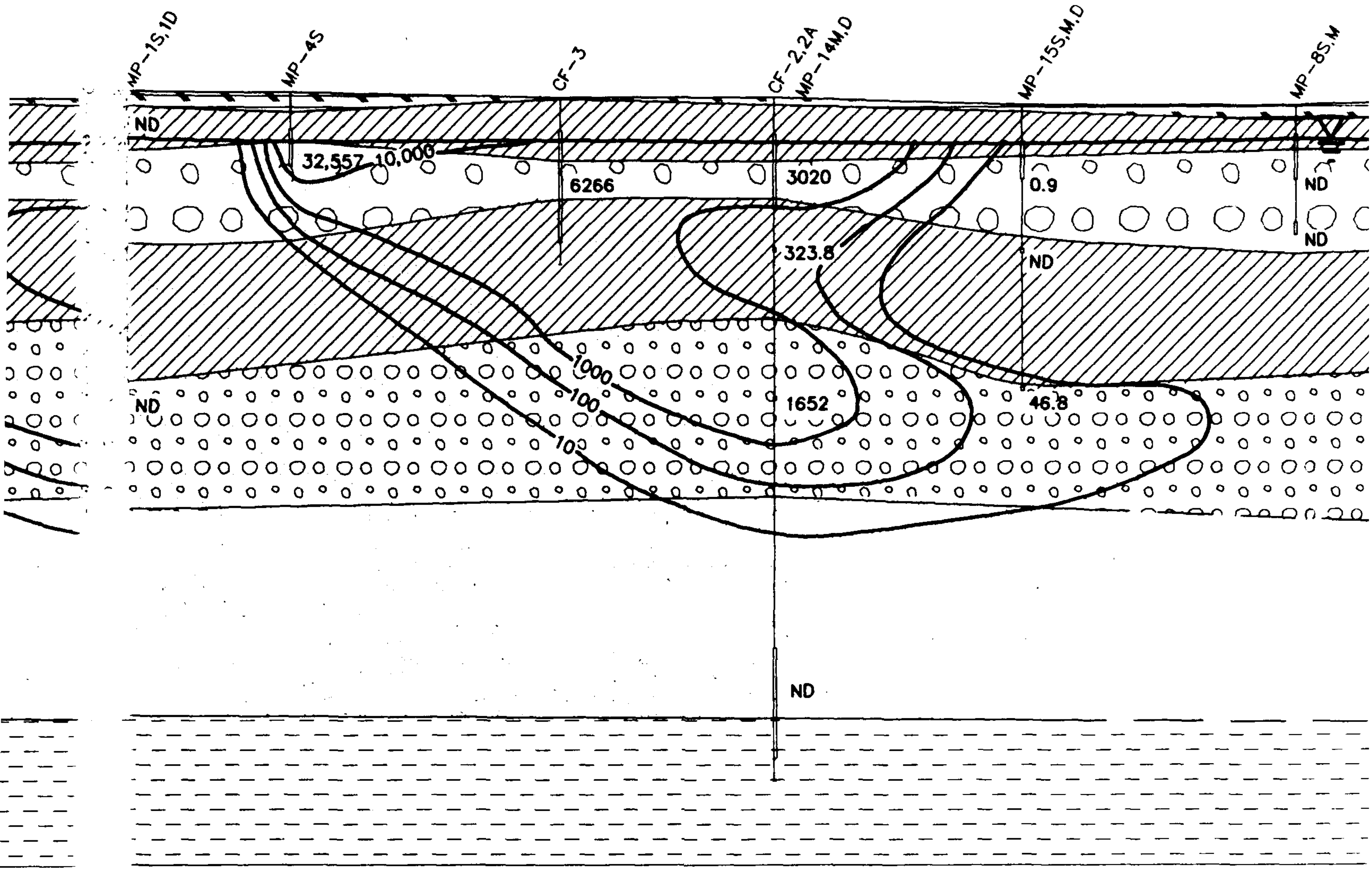

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▽ Water elevation, May 19, 1995

Geologic contact

Approximate contact

CF-8 Borehole Identification

Borehole

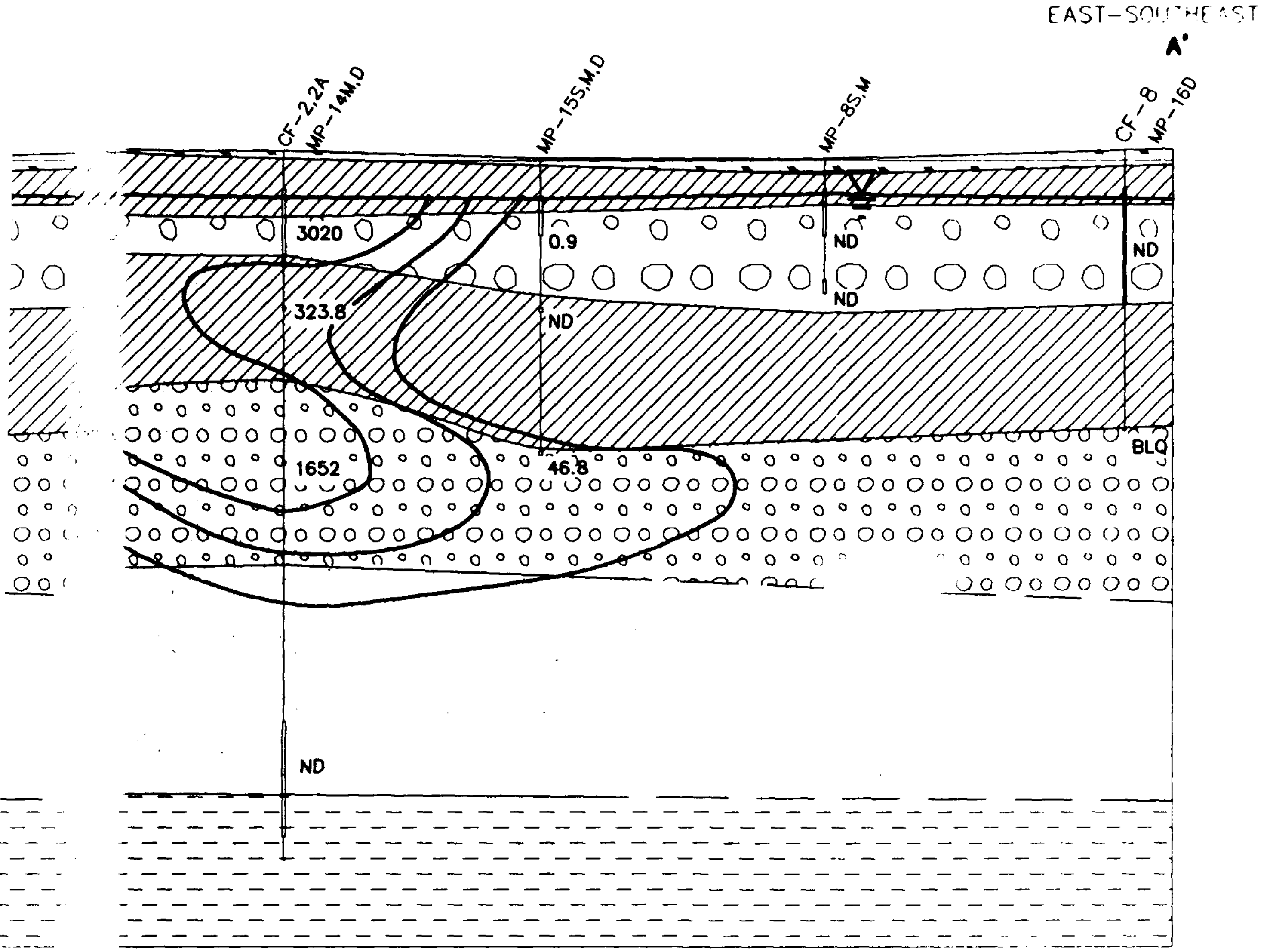
Screened Interval, with total BTEX concentration (µg/L)

Bottom of Borehole

1000 Line of equal total BTEX concentration (µg/L)

ND Not Detected

BLQ Below level of Quantitation



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BTEX concentration (µg/L)

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TO

centration (µg/L)

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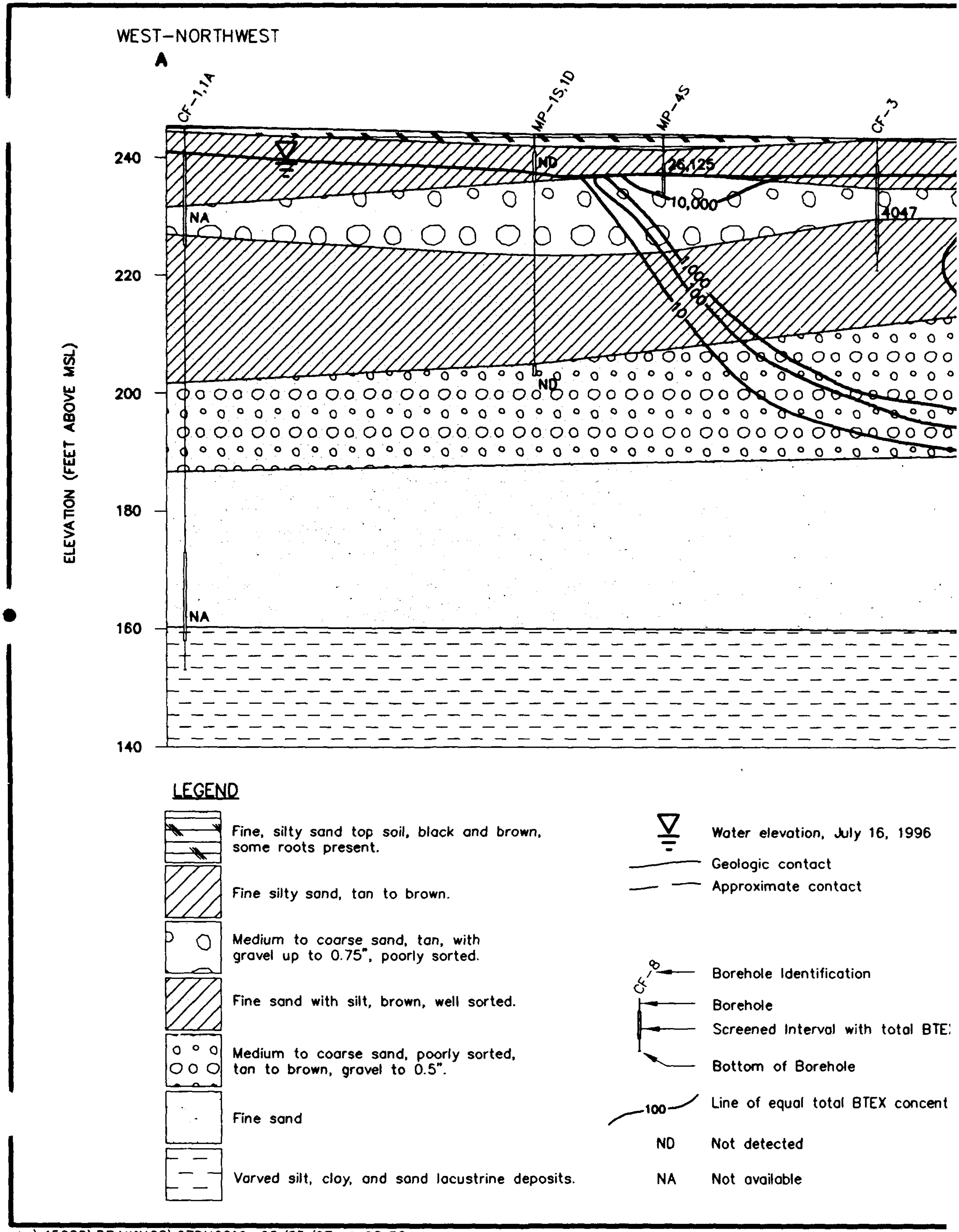
VERTICAL EXAGGERATION = 5x

FIGURE 4.3a

VERTICAL PROFILE OF TOTAL BTEX ISOPLETHS FOR GROUNDWATER MAY 1995

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



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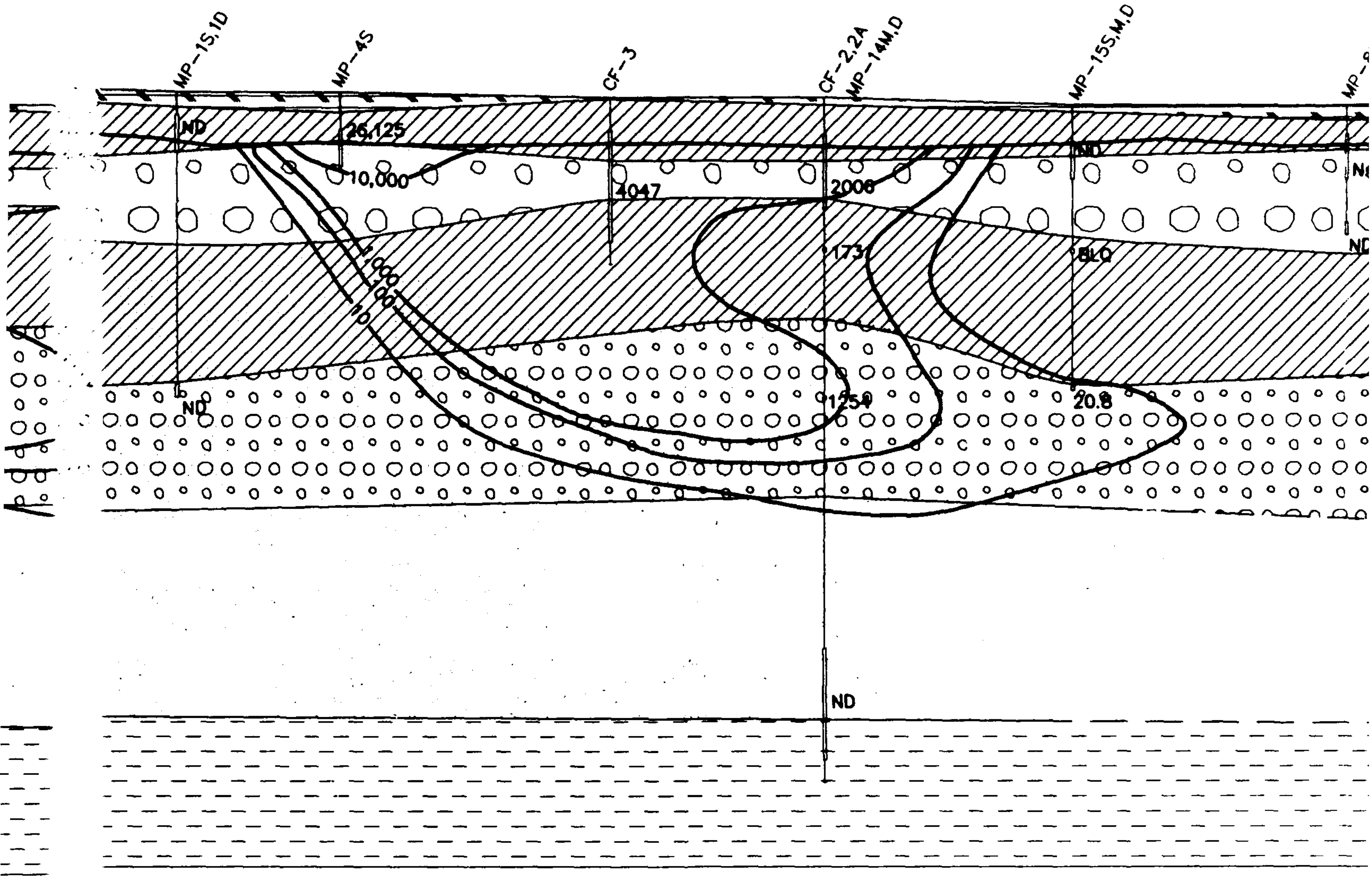

ıd brown,

▽ Water elevation, July 16, 1996

Geologic contact

Approximate contact

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trine deposits.

CF-8 Borehole Identification

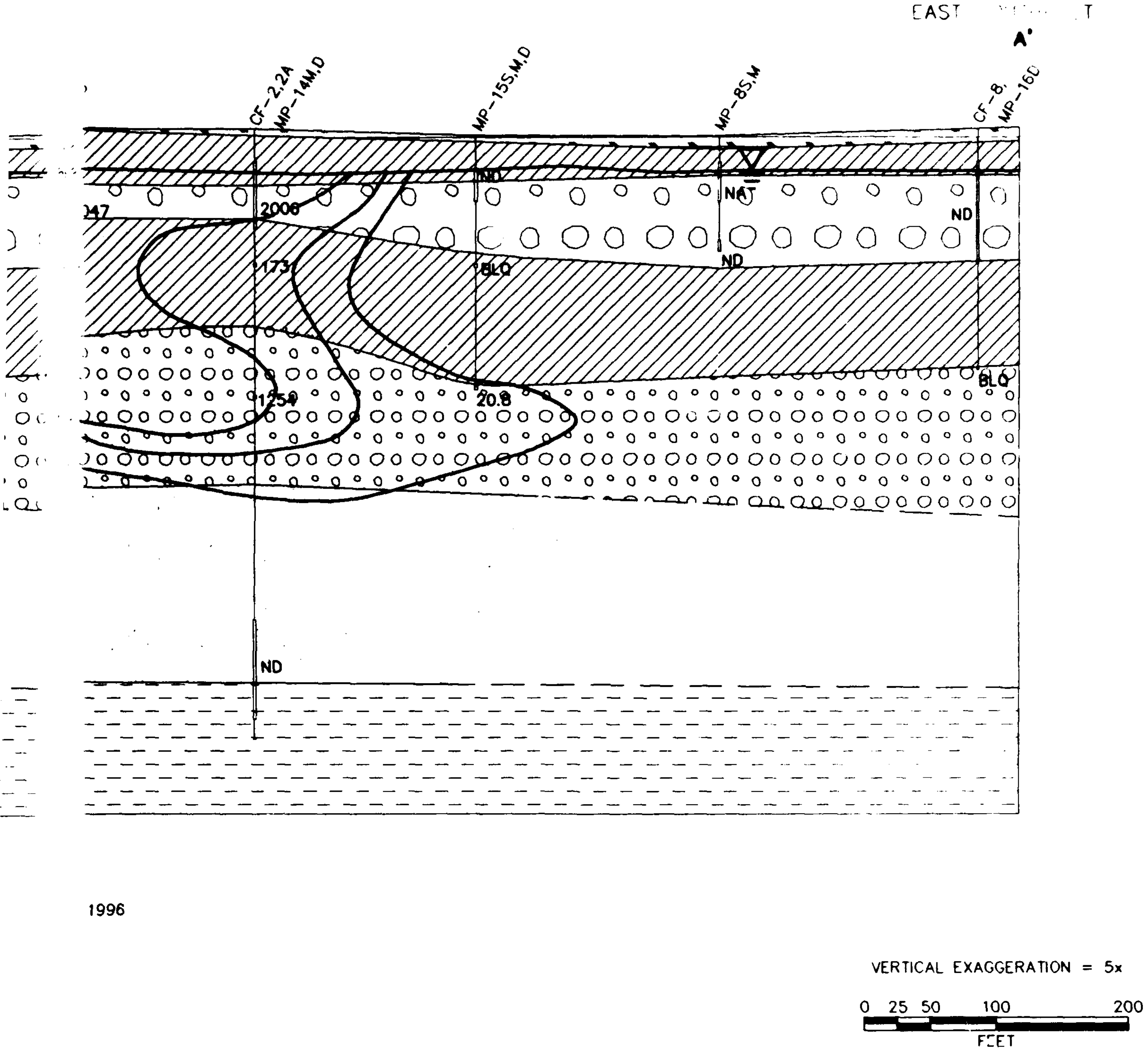
Borehole

Screened Interval with total BTEX concentration (µ g/L)

Bottom of Borehole

100 Line of equal total BTEX concentration (µ g/L)

ND	Not detected
NA	Not available



tal BTEX concentration (μg/L)

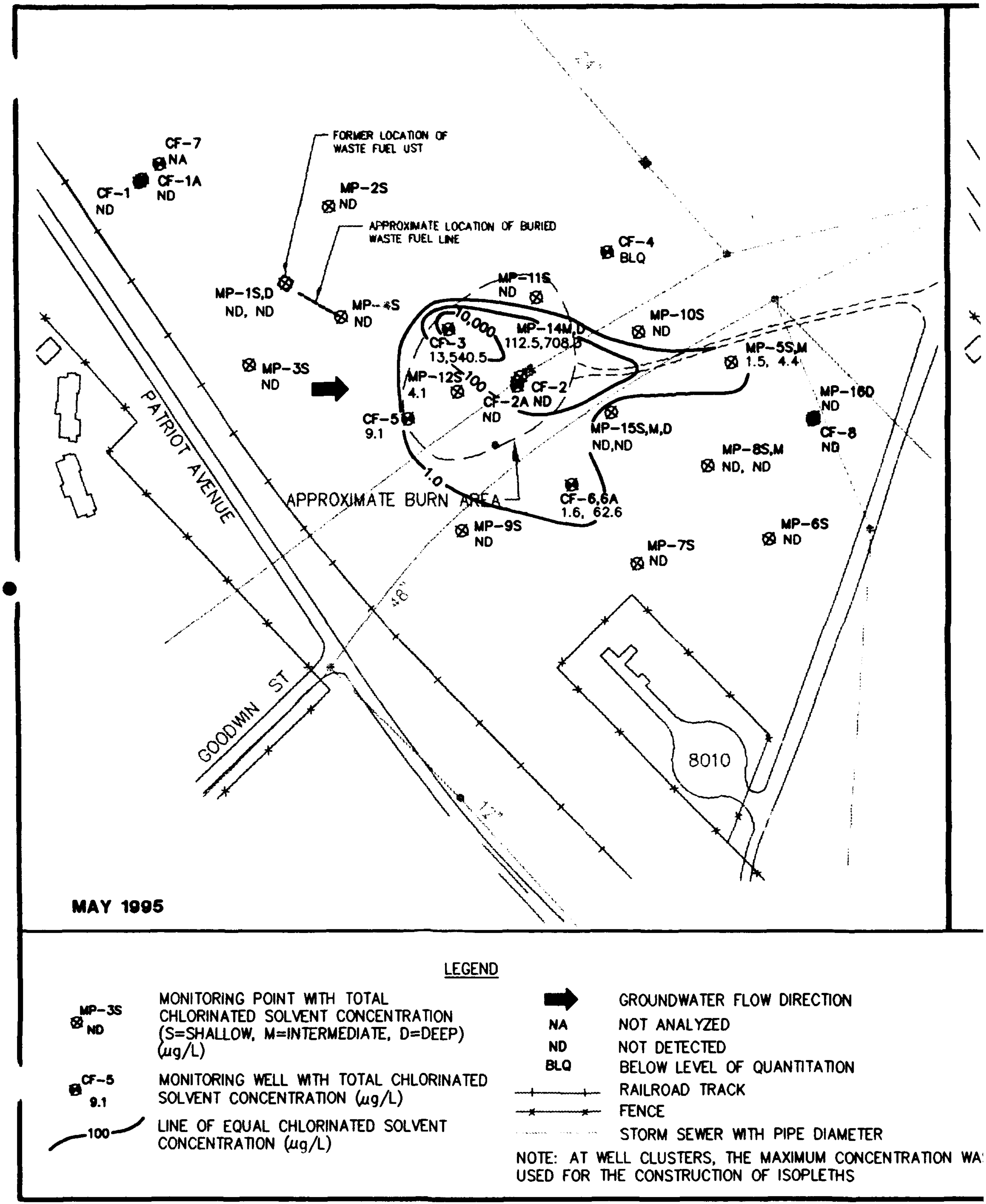
concentration (μg/L)

FIGURE 4.3b

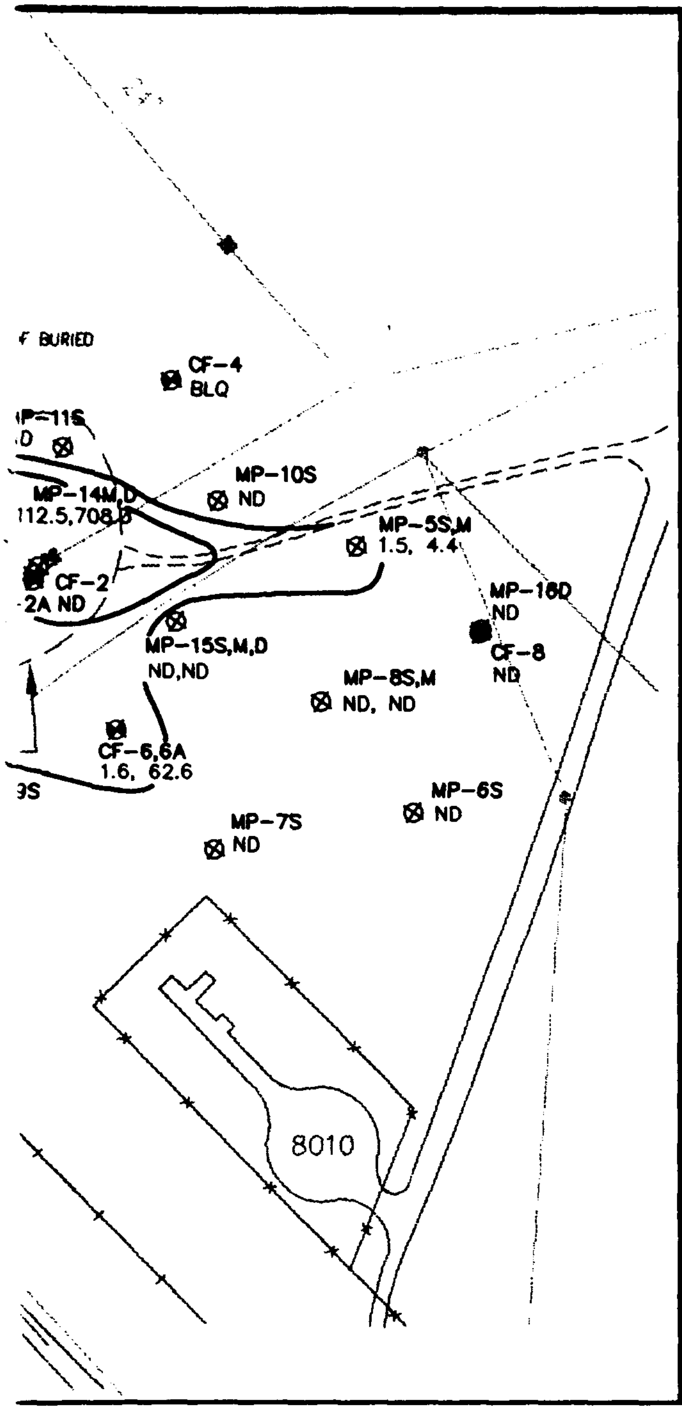
VERTICAL PROFILE OF TOTAL BTEX ISOPLETHS FOR GROUNDWATER JULY 1996

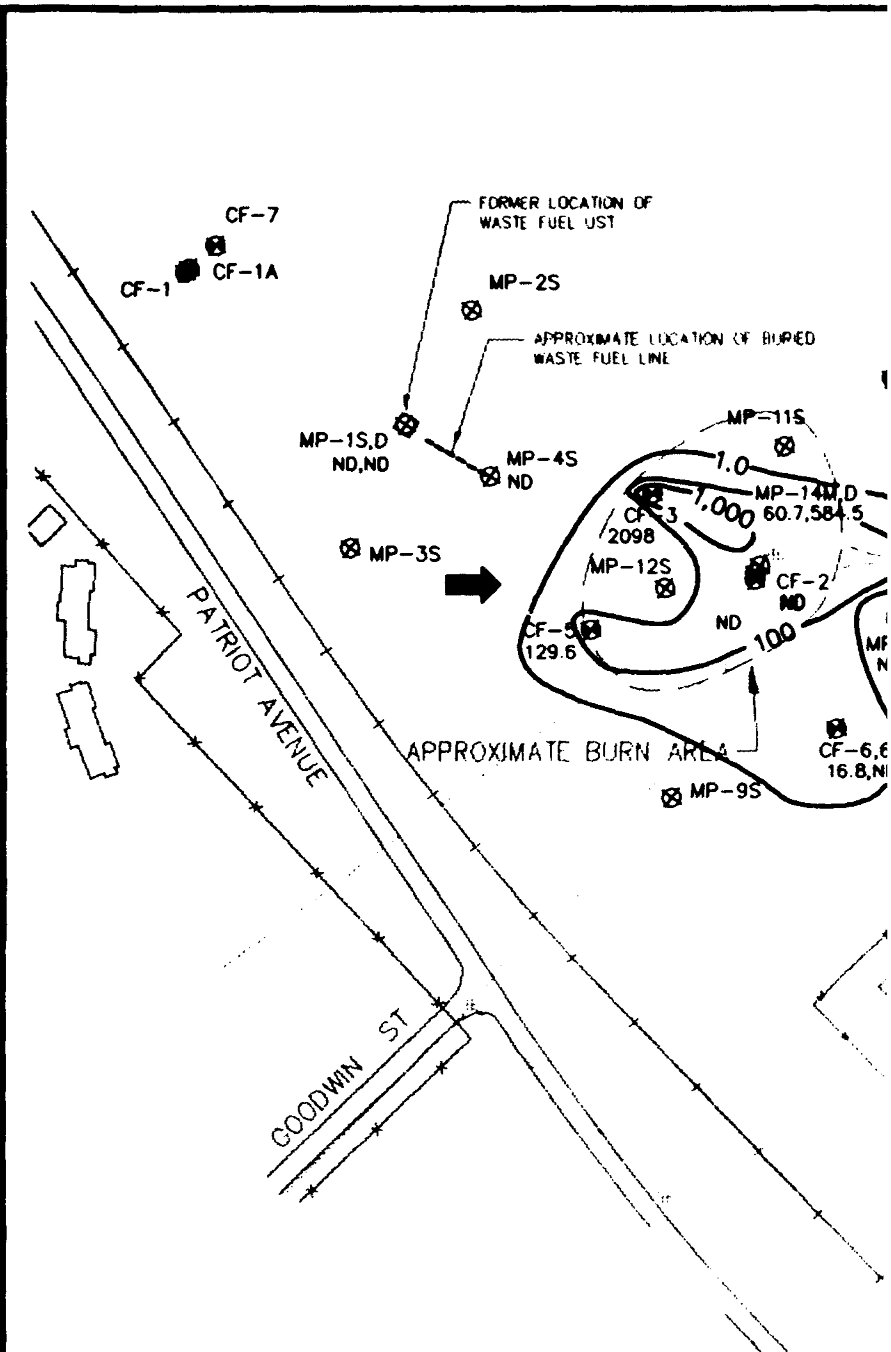
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



L:\45028\DRAWINGS\97DN0068, 02/25/97 at 13:29



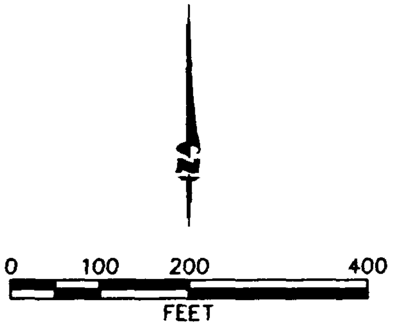


JULY 1996

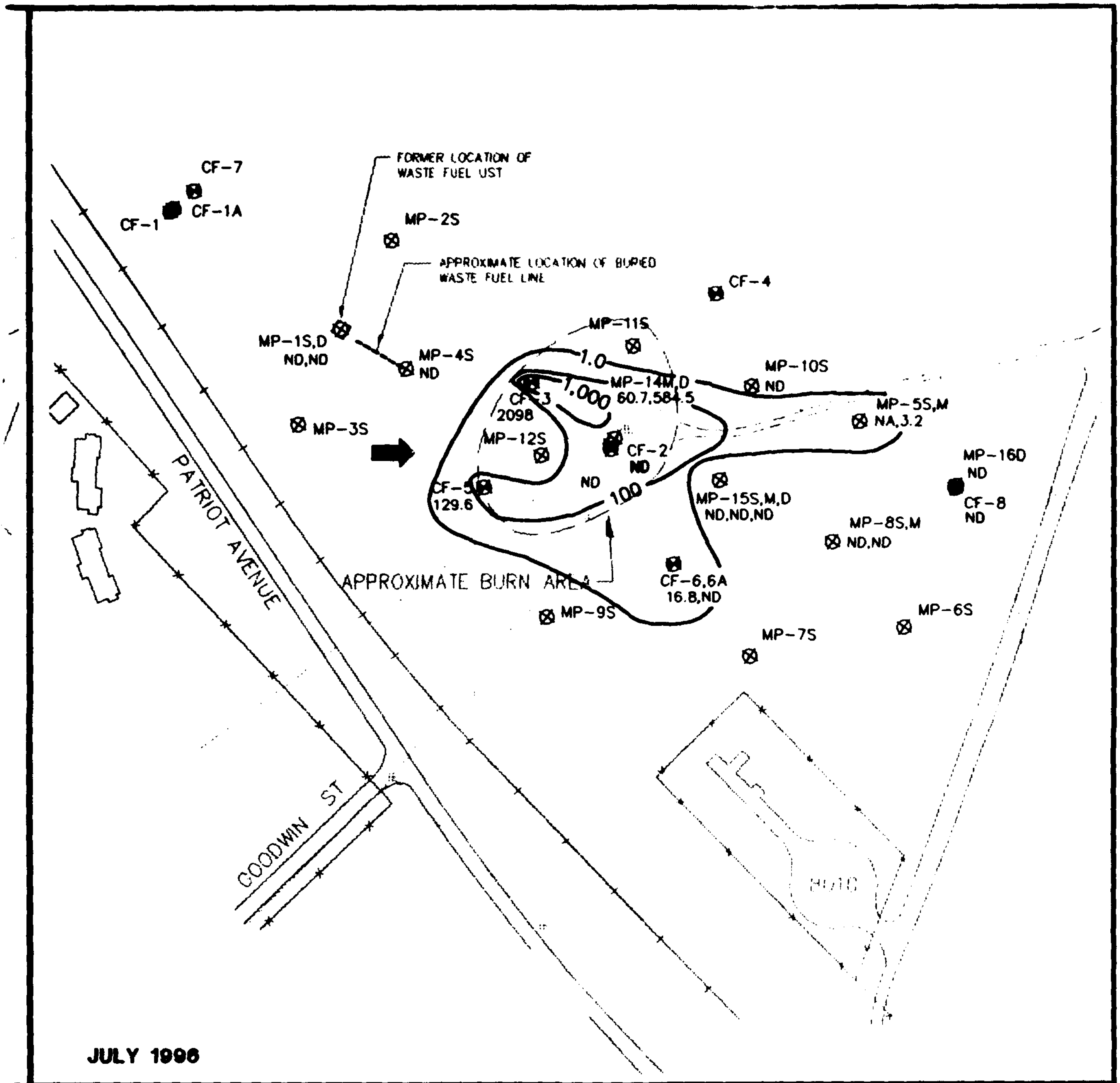
LY

➡	GROUNDWATER FLOW DIRECTION
NA	NOT ANALYZED
ND	NOT DETECTED
BLQ	BELOW LEVEL OF QUANTITATION
—+—+—	RAILROAD TRACK
—x—x—	FENCE
-------	STORM SEWER WITH PIPE DIAMETER

NOTE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS



TO



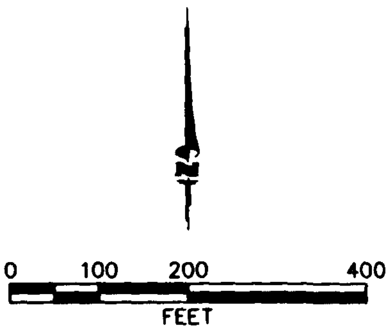
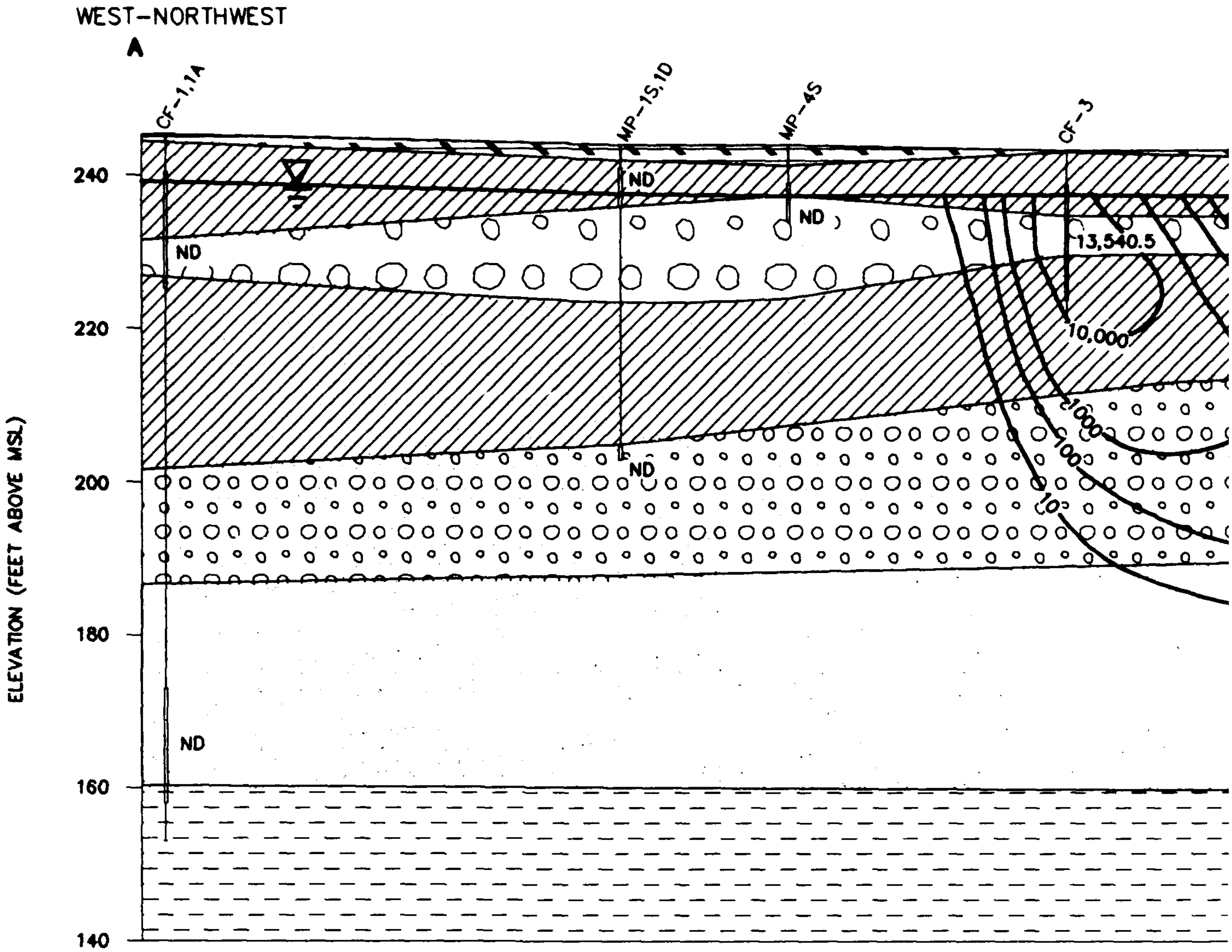


FIGURE 4.4

TOTAL CHLORINATED SOLVENTS IN GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



LEGEND

▧ Fine, silty sand top soil, black and brown, some roots present.

▨ Fine silty sand, tan to brown.

Medium to coarse sand, tan, with gravel up to 0.75", poorly sorted.

▨ Fine sand with silt, brown, well sorted.

Medium to coarse sand, poorly sorted, tan to brown, gravel to 0.5".

Fine sand

Varved silt, clay, and sand lacustrine deposits.

▽ Water elevation, May 19, 1995

Geologic contact

Approximate contact

CF-8 Borehole Identification

Borehole

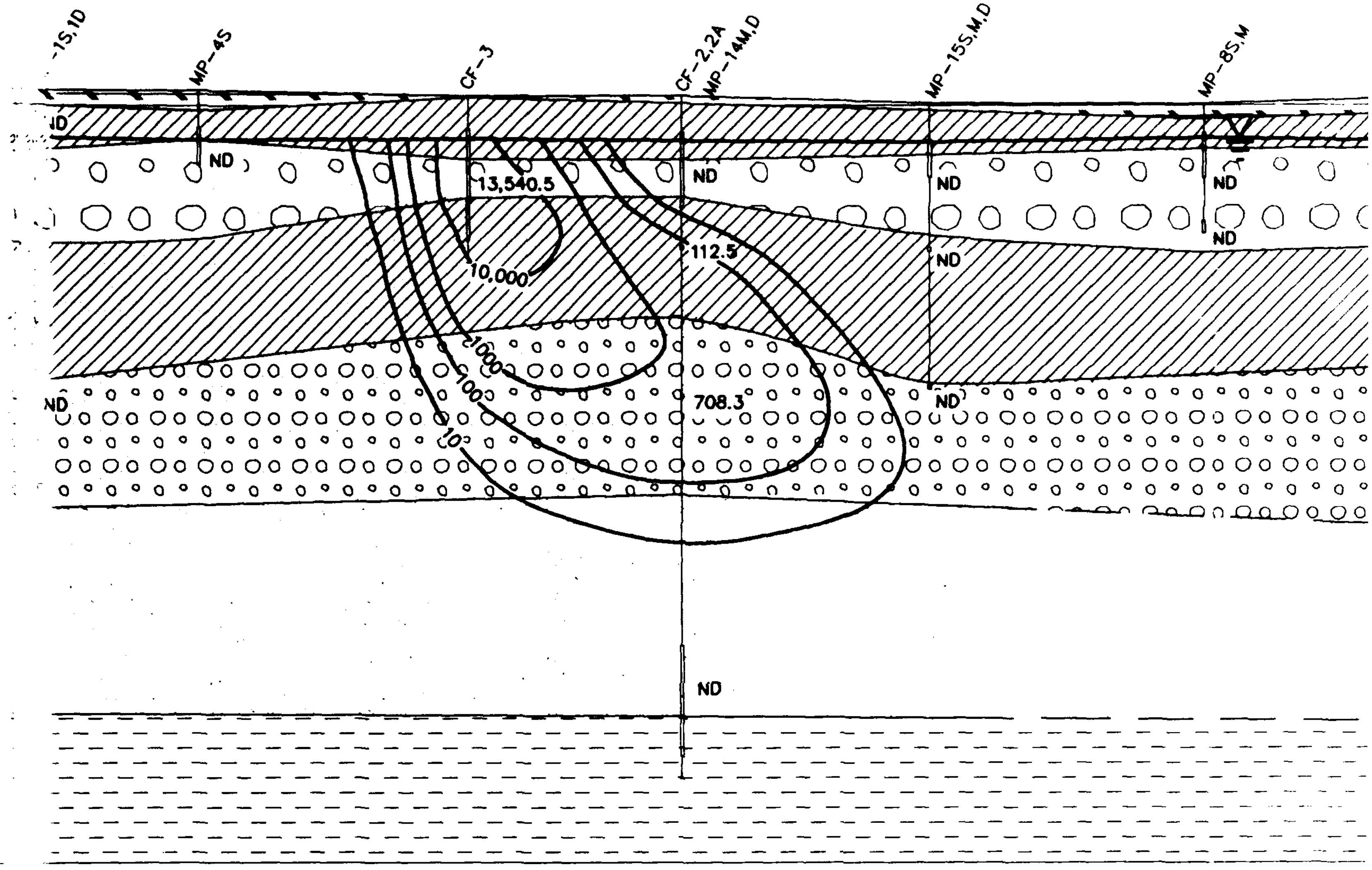
Screened Interval, with total chlorinate

Bottom of Borehole

1000 Line of equal total chlorinated solvent

ND Not Detected

L:\45028\DRAWINGS\95DN1498, 02/25/97 at 10:43



Water elevation, May 19, 1995

Geologic contact

Approximate contact

CF-8 Borehole Identification

Borehole

Screened Interval, with total chlorinated solvent concentration (µg/L)

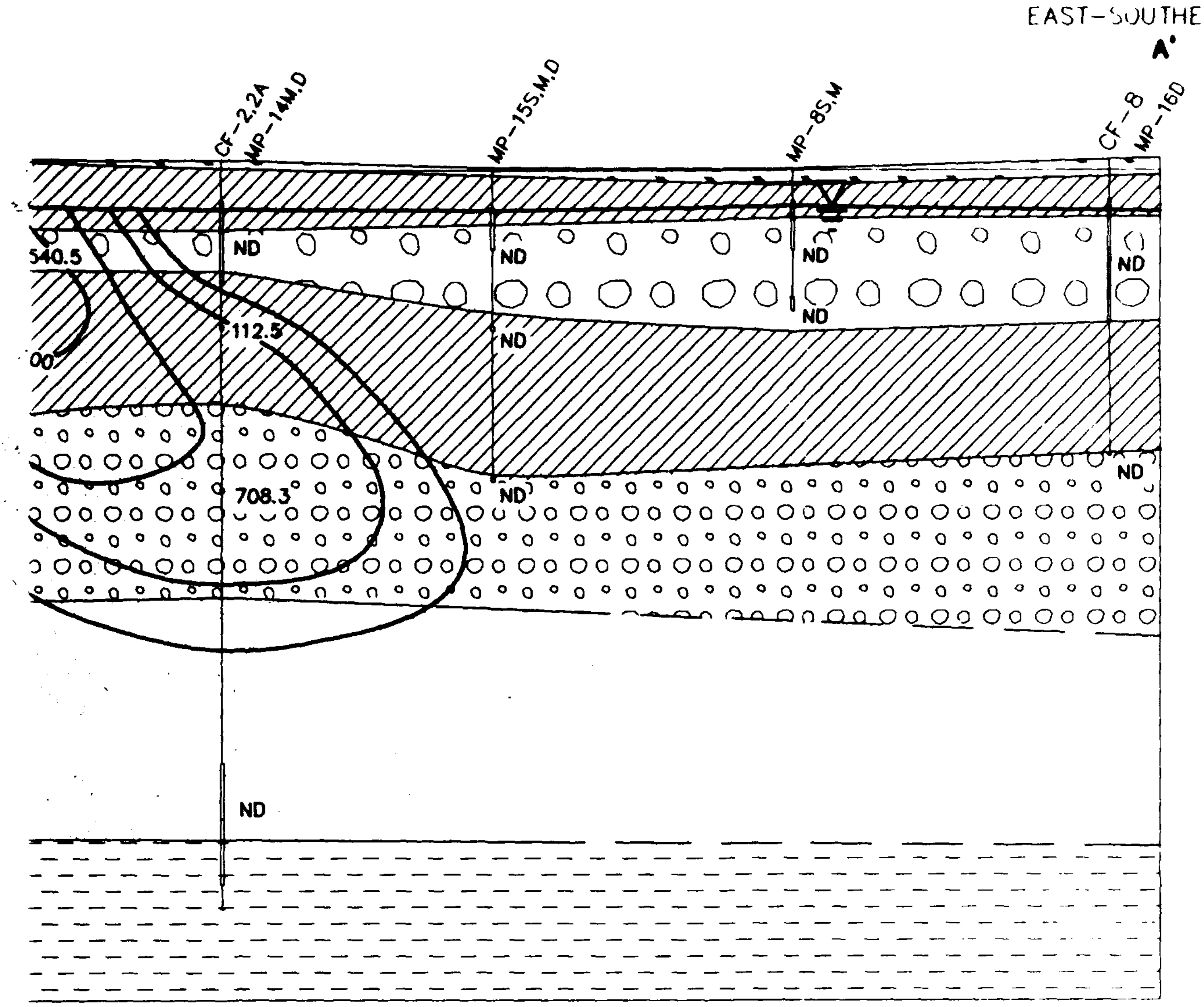
Bottom of Borehole

1000 Line of equal total chlorinated solvent concentration (µg/L)

ND Not Detected

sits.

TOT
ISOP



995

tal chlorinated solvent concentration (µg/L)

.ated solvent concentration (µg/L)

VERTICAL EXAGGERATION = 5x

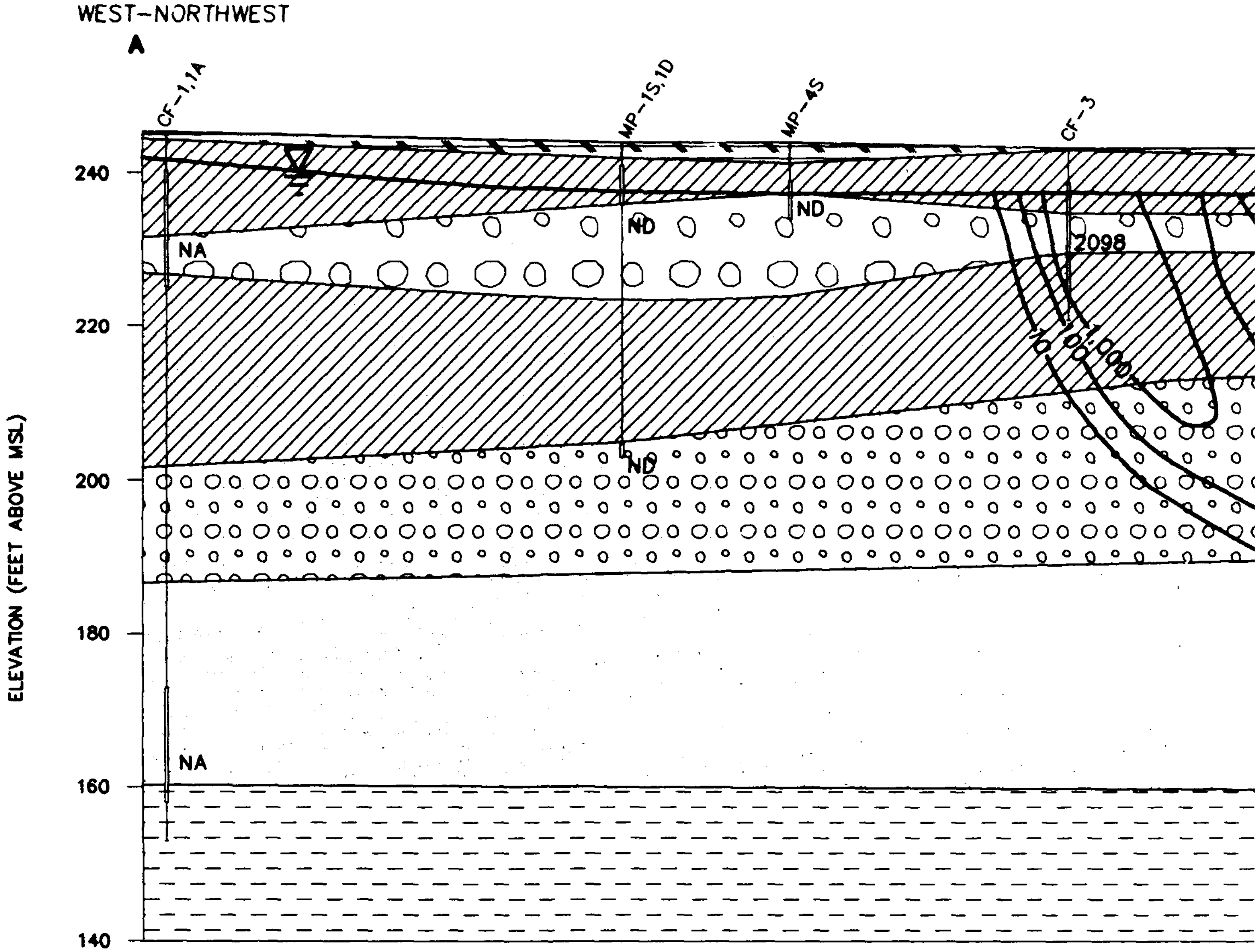
0 25 50 100 200
FEET

FIGURE 4.5a

VERTICAL PROFILE OF TOTAL CHLORINATED SOLVENT ISOPLETHS FOR GROUNDWATER MAY 1995

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

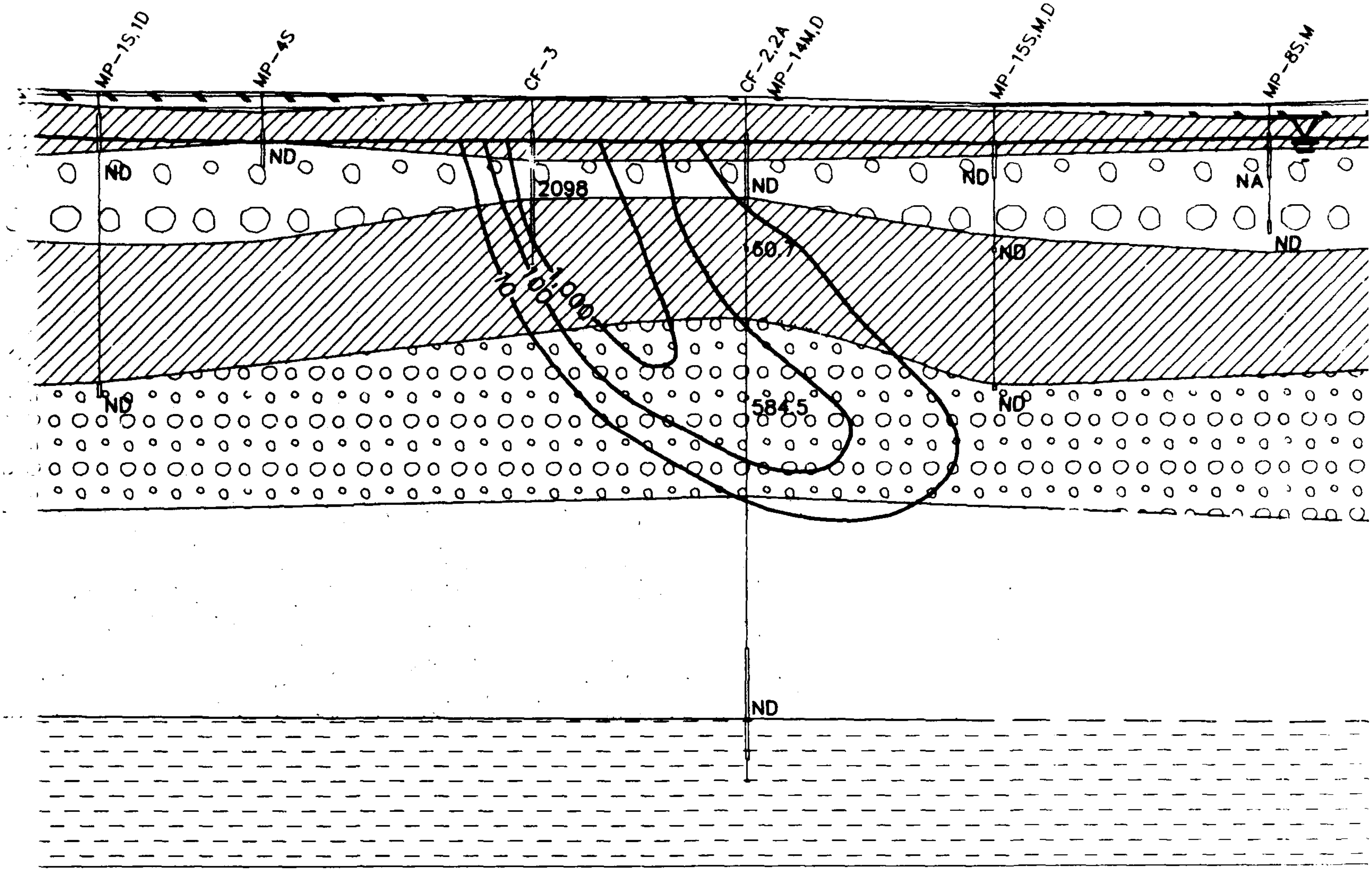


LEGEND

▤	Fine, silty sand top soil, black and brown, some roots present.
▨	Fine silty sand, tan to brown.
○	Medium to coarse sand, tan, with gravel up to 0.75", poorly sorted.
▨	Fine sand with silt, brown, well sorted.
○ ° ○	Medium to coarse sand, poorly sorted, tan to brown, gravel to 0.5".
·	Fine sand
– –	Varved silt, clay, and sand lacustrine deposits.

▽	Water elevation, July 16, 1996
———	Geologic contact
— —	Approximate contact
CF-8	Borehole identification
|	Borehole
▯	Screened interval, with total chlorinated solvent concentration (µg/L)
⊥	Bottom of borehole
—10—	Line of equal total chlorinated solvent concentration (µg/L)
ND	Not detected
NA	Not available

L:\45028\DRAWINGS\97DN0020, 02/25/97 at 11:11



ı brown,

-ted

-ted,

ine deposits.

▽ Water elevation, July 16, 1996

Geologic contact

Approximate contact

CF-8 Borehole identification

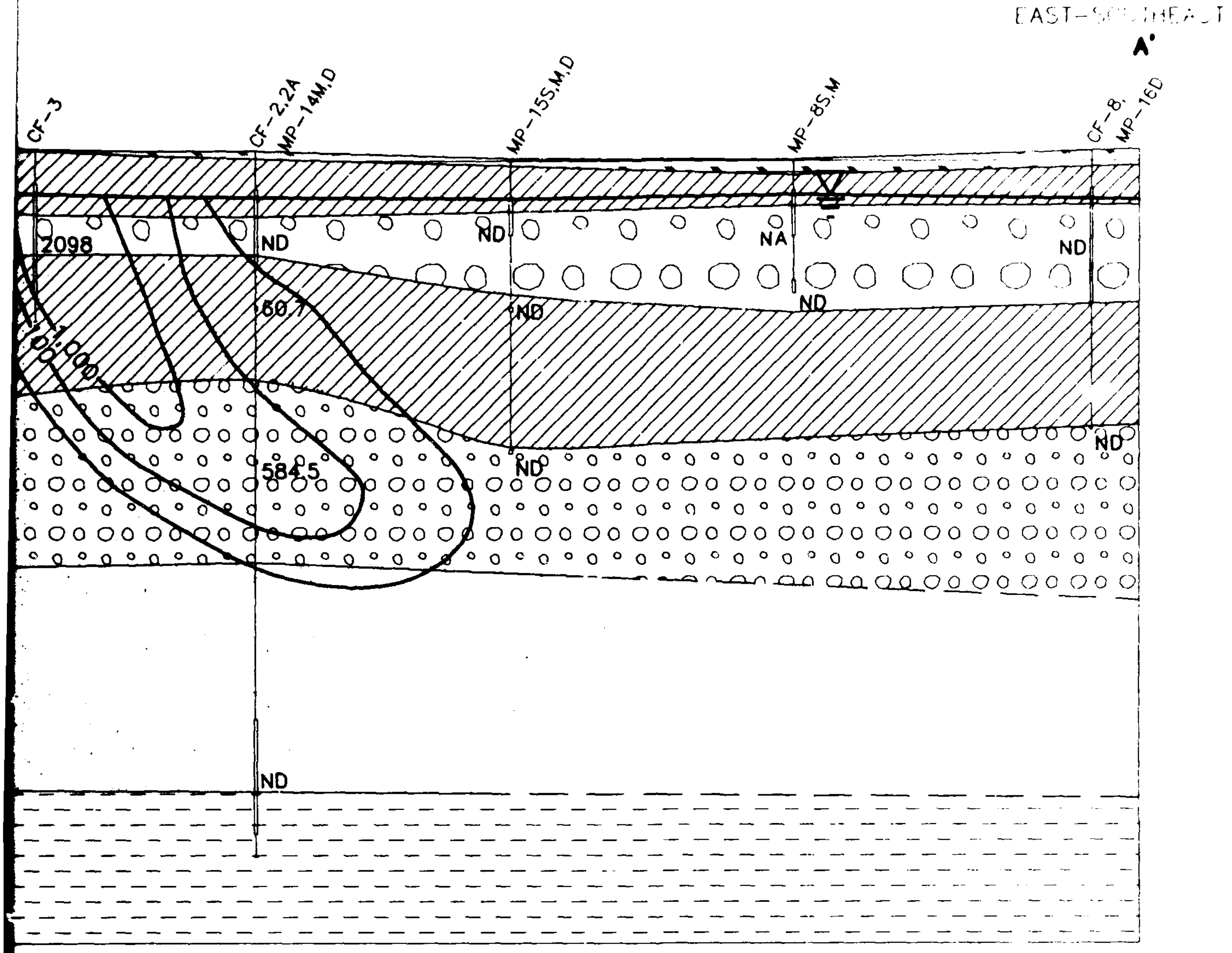
Borehole

Screened interval, with total chlorinated solvent concentration (μg/L)

Bottom of borehole

10 Line of equal total chlorinated solvent concentration (μg/L)

ND	Not detected
NA	Not available



16, 1996

VERTICAL EXAGGERATION = 5x

n

ith total chlorinated
n (µg/L)

hlorinated solvent

FIGURE 4.5b

VERTICAL PROFILE OF TOT
CHLORINATED SOLVENT
ISOPLETHS FOR GROUNDWAT
JULY 1996

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS
ENGINEERING SCIENCE, I
Denver, Colorado

Although the May 1995 and July 1996 chlorinated solvent plumes are almost identical in size and distribution, there is a general decrease in contaminant concentrations at all wells except for CF-5. In May 1995, the maximum observed total chlorinated solvent concentration of 13,541 μg/L was detected in shallow groundwater near the suspected source area (well CF-3). Total chlorinated solvent concentrations at CF-3 dropped to 2,098 μg/L in July 1996. Further downgradient, concentrations decreased from 708 μg/L to 585 μg/L at MP-14D and from 113 μg/L to 61 μg/L at MP-14M. The only increase was observed at well CF-5, located sidegradient from the main source area. At this location, dissolved chlorinated solvents increased from 9.1 μg/L in May 1995 to 130 μg/L in July 1996.

Unlike the dissolved BTEX plume where both lateral and vertical migration occur in the source area, the chlorinated solvent plume is dominated by vertical migration in the source area. This phenomenon is the likely result of slight density differences between fuel hydrocarbons (lighter than water) and chlorinated solvents (heavier than water). As illustrated on Figures 4.5a and 4.5b, the chlorinated solvent contamination appears to migrate vertically from the source near CF-3, through the silty sand, and into the underlying coarse sand. Once the contamination reaches the coarse sands, the vertical migration becomes less significant and horizontal migration appears to be more important. This interpretation is supported by the analytical results from the downgradient cluster CF-2A/MP-14M/MP-14D/CF-2. During both sampling events, the second-highest chlorinated solvent concentration (708.3 μg/L, May 1995 and 584.5 μg/L, July 1996) was observed in the sample from MP-14D, the second-deepest sampling location in this four point cluster. Above MP-14D, chlorinated solvent concentrations were lower in MP-14M and absent from the shallowest well, CF-2A. Furthermore, in groundwater samples from CF-2 (below MP-14D), no chlorinated solvents were detected in May 1995 or July 1996, suggesting that the solutes are not migrating down into the fine sand underlying the coarse sand/gravel unit. Chlorinated solvents were not detected above quantitation limits at any of the furthest downgradient shallow and deep groundwater monitoring locations.

In addition to a general decrease in concentration, the mix of solvents dissolved in groundwater shifted. In May 1995, TCE accounted for 93 percent of the total detected chlorinated solvents for the entire site; cis-DCE accounted for 6.8 percent; and PCE, 1,1-DCE, trans-DCE, and vinyl chloride accounted for the remaining 0.2 percent. In July 1996, the percentage of TCE for the entire site dropped to 71.6 and cis-DCE increased to 27.9 percent. The remaining 0.5 percent in July 1996 was trans-DCE, 1,1-DCE, and vinyl chloride. For both May 1995 and July 1996, the fraction of TCE is slightly higher in the source area (CF-3) and lower downgradient from the source area. For example, downgradient of the source area at MP-14D and MP-14M, TCE accounted for 76 and 23 percent of the total detected chlorinated solvent concentrations, respectively, in May 1995. Similarly, in July 1996, TCE accounted for 49 and 17 percent of the total chlorinated solvent concentrations in MP-14D and MP-14M, respectively. The temporal and spatial increase in the percentage of cis-DCE in the total chlorinated solvent concentrations suggests that TCE is being degraded to cis-DCE via reductive dehalogenation. Chlorinated solvent degradation pathways are discussed further in Section 4.3.4.

4.3.2 Inorganic Chemistry and Geochemical Indicators of 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; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). 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 facilitating of thermodynamically advantageous 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-08 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 dissolved oxygen (DO), nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer and is quantified by the Gibbs free energy of the reaction (ΔG°_r) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of ΔG°_r represents the quantity of free energy consumed or yielded to the system during the reaction. Table 4.4 lists stoichiometry of the redox equations involving BTEX and the resulting ΔG°_r. 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. $\Delta G^\circ_r < 0$). 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

TABLE 4.4
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
Current 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
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1
$6NO_3 + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1
$3.75\ NO_3^- + C_6H_6 + 7.5\ H^+ + 0.75\ H_2O \Rightarrow 6\ CO_2 + 3.75\ NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1
$60H^+ + \underline{30Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1[a/]
$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S^o + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1[b/]

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

TABLE 4.4 (Concluded)

COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
Current 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
$10.5O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5H_2O$ *Ethylbenzene oxidation /aerobic respiration*	-1066.13	-4461	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *Ethylbenzene oxidation / denitrification*	-1080.76	-4522	4.92:1
$5.25NO_3^- + 10.5H^+ + 0.25H_2O + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 5.25NH_4^+$ *Ethylbenzene oxidation / nitrate reduction*	-746.04	-3118	3.07:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *Ethylbenzene oxidation / iron reduction*	-778.48	-3257	22:1[a]
$10.5H^+ + 5.25SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ *Ethylbenzene oxidation / sulfate reduction*	-166.75	-697.7	4.75:1
$5.5H_2O + C_6H_5C_2H_5 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *Ethylbenzene oxidation / methanogenesis*	-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
$10.5O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5H_2O$ *m-Xylene oxidation /aerobic respiration*	-1063.25	-4448	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *m-Xylene oxidation / denitrification*	-1077.81	-4509	4.92:1
$5.25NO_3^- + 10.5H^+ + 0.25H_2O + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 5.25NH_4^+$ *m-Xylene oxidation / nitrate reduction*	-743.52	-3108	3.07:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *m-Xylene oxidation / iron reduction*	-775.61	-3245	22:1[a]
$10.5H^+ + 5.25SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ *m-Xylene oxidation / sulfate reduction*	-163.87	-685.6	4.75:1
$5.5H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *m-Xylene oxidation / methanogenesis*	-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.

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-08 indicate that intrinsic remediation of hydrocarbons in the shallow aquifer may be occurring by aerobic oxidation, ferric iron reduction, denitrification, sulfate reduction, and methanogenesis. This is evidenced by significant changes in groundwater geochemistry in comparison to background conditions. Areas of the site which show the greatest variation in concentrations of geochemical parameters generally correspond well with areas of low redox potential and high BTEX concentrations. Table 4.5 summarizes groundwater geochemical data gathered during the intrinsic remediation site investigation at Westover ARB. Geochemical parameters for site FT-08 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 in the May 1995 and July 1996. Table 4.5 summarizes measured DO concentrations. Figure 4.6 presents two isopleth maps showing the distribution of DO concentrations in shallow groundwater. These data provide strong evidence that aerobic biodegradation of the BTEX compounds is occurring at the site. Given high background DO concentrations in the shallow groundwater, 9.82 mg/L at monitoring well CF-1A in May 1995 and 8.93 mg/L in MP-1S in July 1996, and negligible DO concentrations within the area occupied by both the 1995 and 1996 BTEX plumes, it is likely that DO is an important electron acceptor at the Current Fire Training area. Within the area characterized by substantially elevated BTEX concentrations (greater than 100 μg/L), DO was less than 1 mg/L for both May 1995 and July 1996.

The stoichiometry of BTEX mineralization to carbon dioxide and water caused by aerobic microbial biodegradation is presented in Table 4.4. The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to the mineralization

TABLE 4.5
GROUNDWATER GEOCHEMICAL DATA
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Identification	Date Sampled	Dissolved Oxygen (mg/L)[b/]	Nitrite + Nitrate (as N) (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)	Redox[a/] (mV)[c/]	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	pH	Temperature (°C)[d/]	Conductivity (µs/cm)[e/]	Chloride (mg/L)	Total Organic Carbon (mg/L)
MP-1 S	5/18/95	9.13	3.87	1	6.52	BLQ[f/]	187.1	5	15	7.08	9.3	80	1.19	1.8
	7/17/96	8.93	1.86	<0.05	5.55	BLQ	249	8	40	6.43	13.6	200	1.40	NA
MP-1 D	5/18/95	4.61	5.77	1	< 0.5	BLQ	170	10	25	7.56	9.9	100	3.03	1
	7/17/96	4.80	5.57	0.3	<0.5	BLQ	227	6	108	6.84	12.6	120	2.46	NA
MP-2 S	5/18/95	5.13	5.6	0.4	13.9	BLQ	160.8	20	25	7.74	8.5	140	1.39	3.8
MP-3 S	5/18/95	9.03	2.46	< 0.1	8.07	BLQ	177.8	10	20	7.89	10.4	80	1.17	2.7
MP-4 S	5/18/95	0.52	< 0.05	100	2.41	0.073	-18	180	200	8.13	12.0	420	8.06	60.2
	7/18/96	1.23	<0.05	37.3	<0.5	0.237	-40	205	NA	6.84	17.0	1460	1.57	42.6
MP-5 S	5/17/95	0.28	0.06	5.5	1.46	0.187	113.4	20	25	7.27	8.6	80	4.21	3
MP-5 M	5/17/95	0.17	< 0.05	9	2.28	0.362	115.7	30	60	7.28	9.6	110	8.38	4.3
	7/17/96	0.25	<0.05	5.3	2.45	1.54	125	29	152	7.74	12.7	260	6.10	2.72
MP-6 S	5/17/95	7.91	1.19	0.2	10.9	BLQ	165	< 0.1	40	6.78	7.9	60	1.45	4.5
MP-7 S	5/18/95	9.67	0.33	0.2	6.37	BLQ	249.5	5	20	6.71	8.4	30	1.11	2.4
MP-8 S	5/17/95	1.19	1.84	1.5	8.56	BLQ	170	10	25	7.08	9.1	80	1.30	1.3
MP-8 M	5/17/96	0.82	1.71	3.5	3.46	BLQ	129.7	25	50	7.35	8.8	70	1.23	2
	7/17/96	3.95	2.61	<0.05	10.7	BLQ	240	5	134	6.80	12.1	30	1.57	1.31
MP-9 S	5/18/95	8.09	3.99	0.2	7.91	BLQ	200.5	5	40	7.06	8.7	80	0.94	3.1
MP-10 S	5/18/95	3.09	0.12	2.5	8.57	BLQ	89	15	15	NA[g/]	9.7	60	1.30	3.4
	7/18/96	8.76	0.75	<0.05	7.88	BLQ	280	6	142	7.26	13.7	70	1.31	NA
MP-11 S	5/18/95	0.54	< 0.05	9	6.6	0.139	-32.8	200	55	8.30	11.6	440	1.77	24
	7/18/96	0.28	0.64	3	76.7	0.288	137	72	180	7.40	16.8	440	0.76	11.7
MP-12 S	5/18/95	0.12	< 0.05	20	< 0.5	0.031	68.4	45	100	7.21	11.1	170	1.10	67.8
	7/18/96	0.17	<0.05	7	<0.5	0.073	90	31	154	7.15	15.7	1150	1.48	61.8
MP-14 M	5/17/95	0.21	0.09	280	7.62	3.421	-45.5	260	275	7.10	10.3	1060	146.00	53.3
	7/17/96	0.20	<0.05	40.5	11.1	8.79	-90	184	NA	7.36	13.4	1220	84.60	29.3
MP-14 D	5/17/95	0.28	0.09	280	0.86	4.286	-105.1	260	250	7.36	10.9	1110	150.00	94.4
	7/17/96	0.24	0.09	45.3	<0.5	14.63	-125	238	NA	7.49	13.9	1500	131.00	77.4
MP-15 S	5/17/95	0.67	0.7	9	20	0.002	39.2	50	50	8.23	10.5	220	3.21	7.1
	7/18/96	6.21	2.73	<0.05	3.16	BLQ	170	28	82	7.35	14.3	120	1.59	1.52

TABLE 4.5 (Concluded)
GROUNDWATER GEOCHEMICAL DATA
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Sample Identification	Date Sampled	Dissolved Oxygen (mg/L)$^{b/}$	Nitrite + Nitrate (as N) (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)	Redox$^{a/}$ (mV)$^{c/}$	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	pH	Temperature (°C)$^{d/}$	Conductivity (µs/cm)$^{e/}$	Chloride (mg/L)	Total Organic Carbon (mg/L)
MP-15 M	5/17/95	0.43	< 0.05	7.5	< 0.5	0.001	35	25	40	7.82	10.9	80	2.88	1.6
	7/18/96	0.15	<0.05	2.1	<0.5	0.021	120	24	142	7.54	12.0	110	3.33	1.15
MP-15 D	5/17/95	0.24	< 0.05	9	2.28	0.046	77.2	10	60	7.63	10.7	130	9.77	2
	7/18/96	0.43	<0.05	6.2	3.83	0.129	75	24	142	7.24	14.8	190	9.75	3.31
MP-16 D	5/17/95	0.13	< 0.05	8	3.06	BLQ	59.9	25	30	7.43	10.3	80	2.25	3.7
	7/17/96	0.24	<0.05	5.6	3.96	0.007	175	32	51	6.70	11.9	NA	1.82	3.18
CF-1	5/17/95	0.08	< 0.05	5.5	21.7	BLQ	168.1	40	1.25	10.03	10.4	180	9.17	1
CF-1 A	5/17/95	9.82	< 0.05	< 0.1	7.16	BLQ	195.2	5	7.5	7.18	9.1	50	0.52	1.2
CF-2	5/17/95	0.34	< 0.05	4.5	13.2	BLQ	13.2	35	14	7.67	12.1	90	1.10	0.8
	7/18/96	0.42	<0.05	4.7	10.6	BLQ	-66	16	144	NA	11.1	NA	<0.5	0.282
CF-2 A	5/18/95	0.40	0.22	3	< 0.5	0.305	-3.2	240	75	8.25	11.0	530	0.67	52.5
	7/18/96	1.80	0.1	3.8	<0.5	0.557	-125	212	263	NA	12.6	NA	<0.5	40.0
CF-3	5/18/95	0.12	< 0.05	10	1.43	0.008	46.1	35	100	8.03	9.7	180	1.93	25.8
	7/18/96	0.17	<0.05	5.4	<0.5	0.028	-185	45	252	6.57	14.4	1370	<0.5	24.7
CF-4	5/18/95	6.51	< 0.05	< 0.1	6.14	BLQ	-5	15	15	NA	8.8	40	< 0.5	5.6
CF-5	5/18/95	0.73	0.34	5.5	24.6	0.004	184.7	10	30	7.67	9.8	100	1.07	3.9
	7/18/96	2.68	0.41	0.4	16.6	0.008	274	4	130	5.20	12.8	1552	<0.5	4.43
CF-6	5/17/95	0.13	0.07	8	9.44	0.068	19.4	35	18.75	7.10	11.4	120	2.72	1.1
	7/18/96	1.40	<0.05	8.9	4.21	0.874	-45	54	160	NA	10.6	NA	5.93	2.89
CF-6 A	5/17/95	0.13	< 0.05	6.5	11.3	0.387	126.1	20	33	6.33	10.2	130	9.42	4.1
	7/18/96	7.60	1.45	<0.05	13.3	BLQ	135	6	138	NA	13.6	NA	<0.5	2.87
CF-8	5/17/95	0.51	0.53	1.5	3.55	0.0004	150.5	15	40	7.05	8.8	50	0.79	1.7
	7/17/96	0.86	0.45	1.5	4.7	0.007	212	13	96	7.40	12.1	NA	0.91	9.2

[a/] Redox = reduction/oxidation.

[b/] mg/L = milligrams per liter.

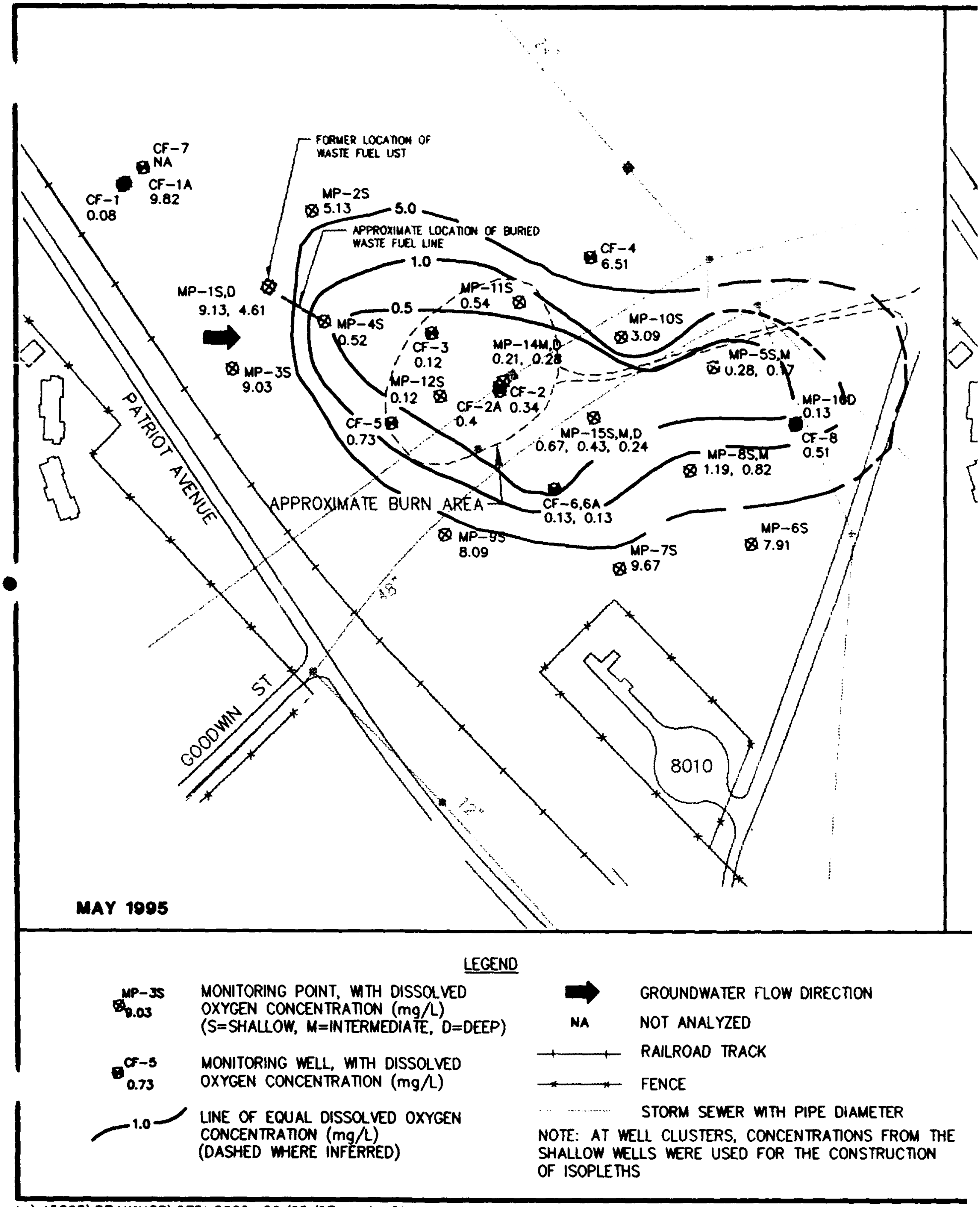
[c/] mV = millivolts.

[d/] °C = degrees Celcius.

[e/] µs/cm = microsiemens per centimeter.

[f/] BLQ = below level of quantitation.

[g/] NA = not analyzed.



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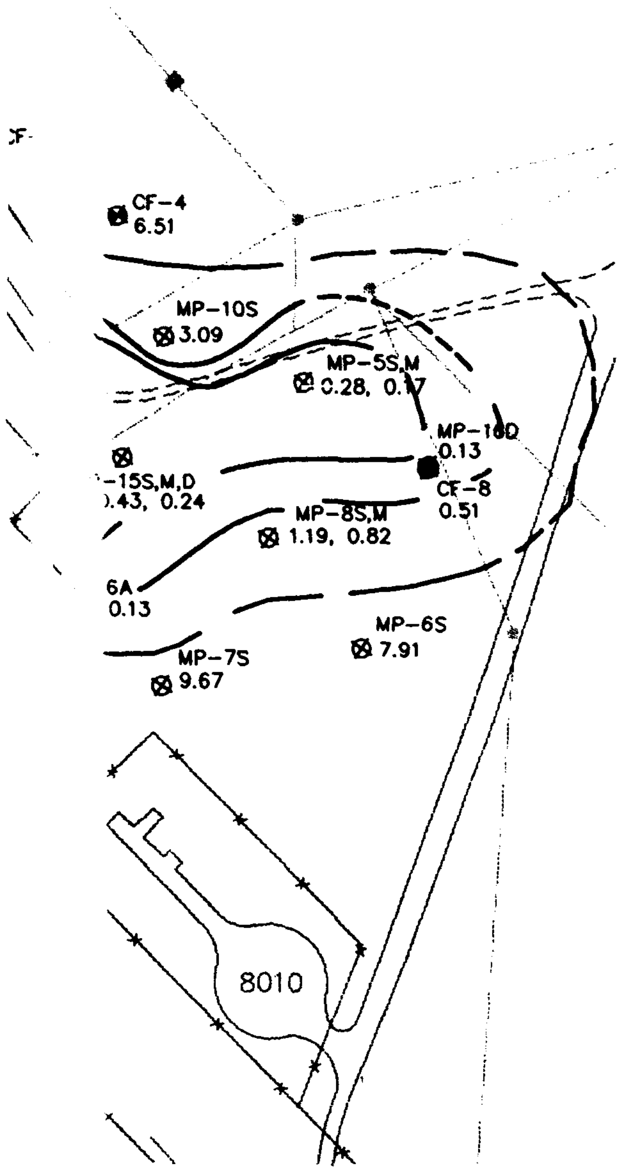

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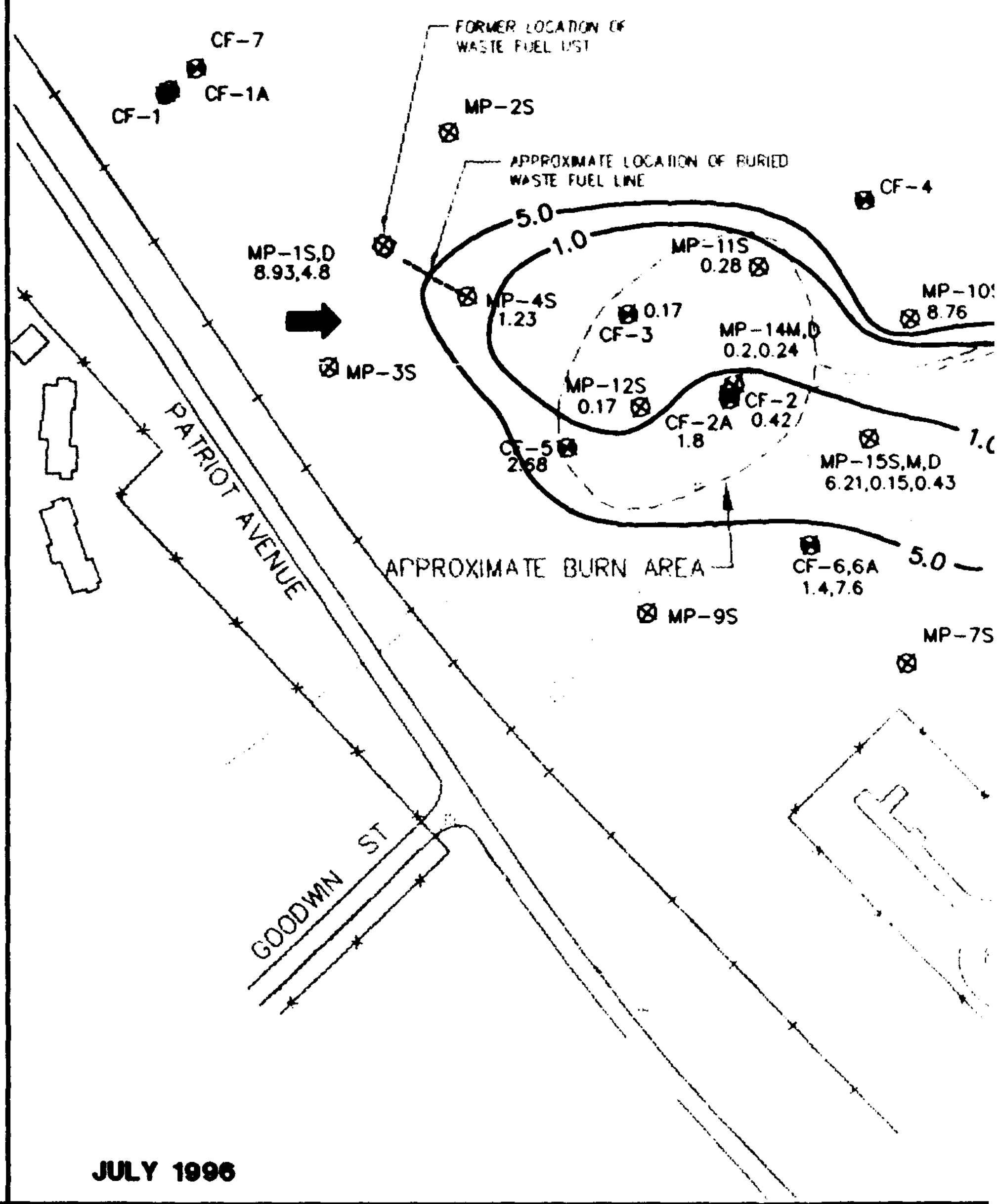

JULY 1996

➡ GROUNDWATER FLOW DIRECTION

A NOT ANALYZED

—+— RAILROAD TRACK

—*— FENCE

------ STORM SEWER WITH PIPE DIAMETER

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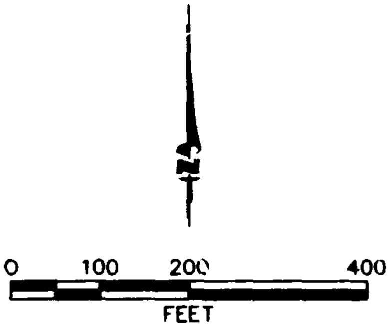

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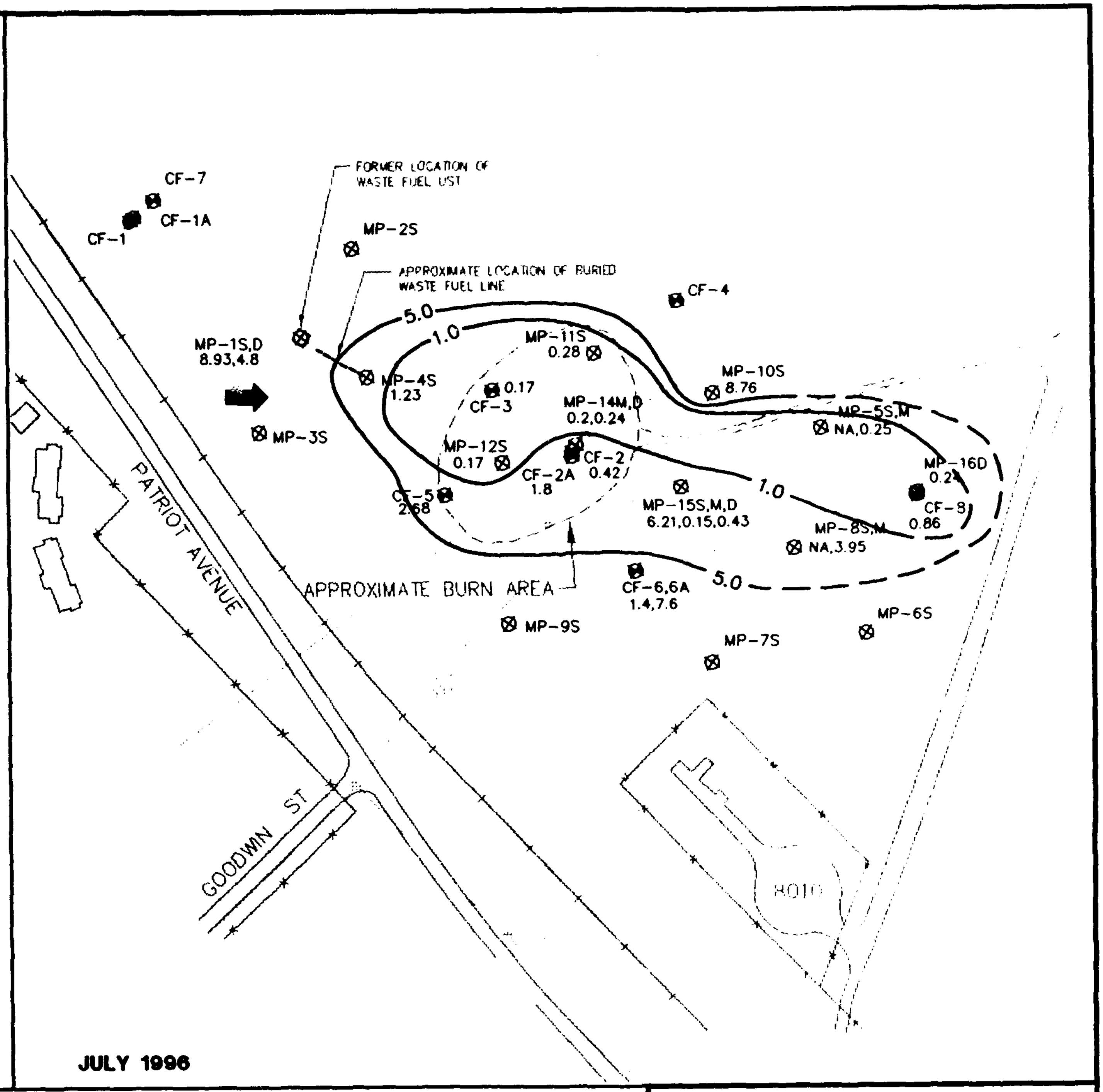


FIGURE 4.6

DISSOLVED OXYGEN ISOPLETH MAPS FOR SHALLOW GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With an assumed background DO concentration of 9.82 mg/L, the shallow groundwater for May 1995 had the capacity to assimilate 3.14 mg/L (3,140 μg/L) of total BTEX through aerobic biodegradation. In July 1996, an assumed background DO concentration of 8.93 mg/L, corresponds to an aerobic respiration assimilative capacity of 2.86 mg/L (2,860 μg/L) total BTEX. These are conservative estimates of the assimilative capacity of DO because microbial cell mass production was not taken into account by the stoichiometry present in Table 4.4.

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

$$C_6H_6 + 2.5O_2 + HCO_3 + NH_4 \rightarrow C_5H_7O_2N + 2CO_2 + 2H_2O$$

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:

Benzene $6(12) + 6(1) = 78$ gm

Oxygen $2.5(32) = 80$ gm

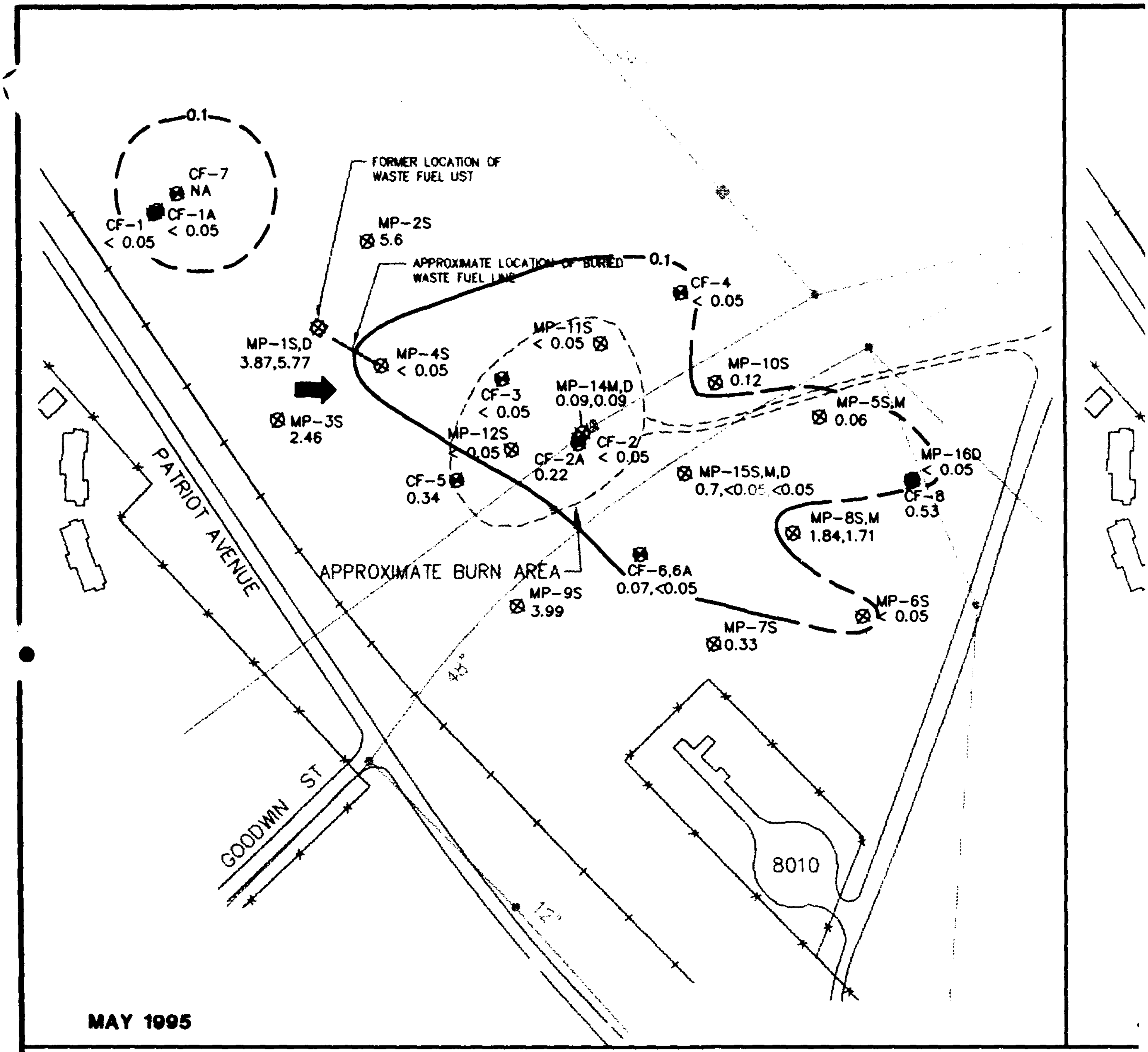
Mass Ratio of Oxygen to Benzene $= 80/78 = 1.03:1$

On the basis of these stoichiometric relationships, 1.03 mg of oxygen is required to mineralize 1 mg of benzene, if cell mass is being produced. 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.

Although this process results in more efficient utilization of electron acceptors, it is only applicable as the net cell mass of the microbial population continues to grow. Because groundwater contamination has been present at Site FT-08 for numerous years, it is possible that biomass mass production has reached steady-state. In that case, the cell mass reaction equations would no longer apply.

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 4.5 summarizes measured nitrate/nitrite (as N) concentrations. Figure 4.7 presents two isopleth map illustrating the areas of low nitrate/nitrite concentrations. The data from both May 1995 and July 1996 indicate reduced nitrate/nitrite concentrations within the groundwater BTEX plume and that nitrate is an important electron acceptor at this site. Nitrate/nitrite was detected in site groundwater at concentrations ranging from <0.05 mg/L to 5.77 mg/L and from <0.05 mg/L to 5.57 mg/L in May 1995 and July 1996, respectively.



LEGEND

⊗ MP-3S 2.46	MONITORING POINT, WITH NITRATE & NITRITE CONCENTRATIONS (mg/L) (S=SHALLOW, M=INTERMEDIATE, D=DEEP)	➡	GROUNDWATER FLOW DIRECTION
		NA	NOT ANALYZED
● CF-5 0.34	MONITORING WELL, WITH NITRATE & NITRITE CONCENTRATIONS (mg/L)	—+—+—	RAILROAD TRACK
		—×—×—	FENCE
—0.1—	LINE OF EQUAL NITRATE & NITRITE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)	········	STORM SEWER WITH PIPE DIAMETER

NOTE: AT WELL CLUSTERS, THE MINIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS

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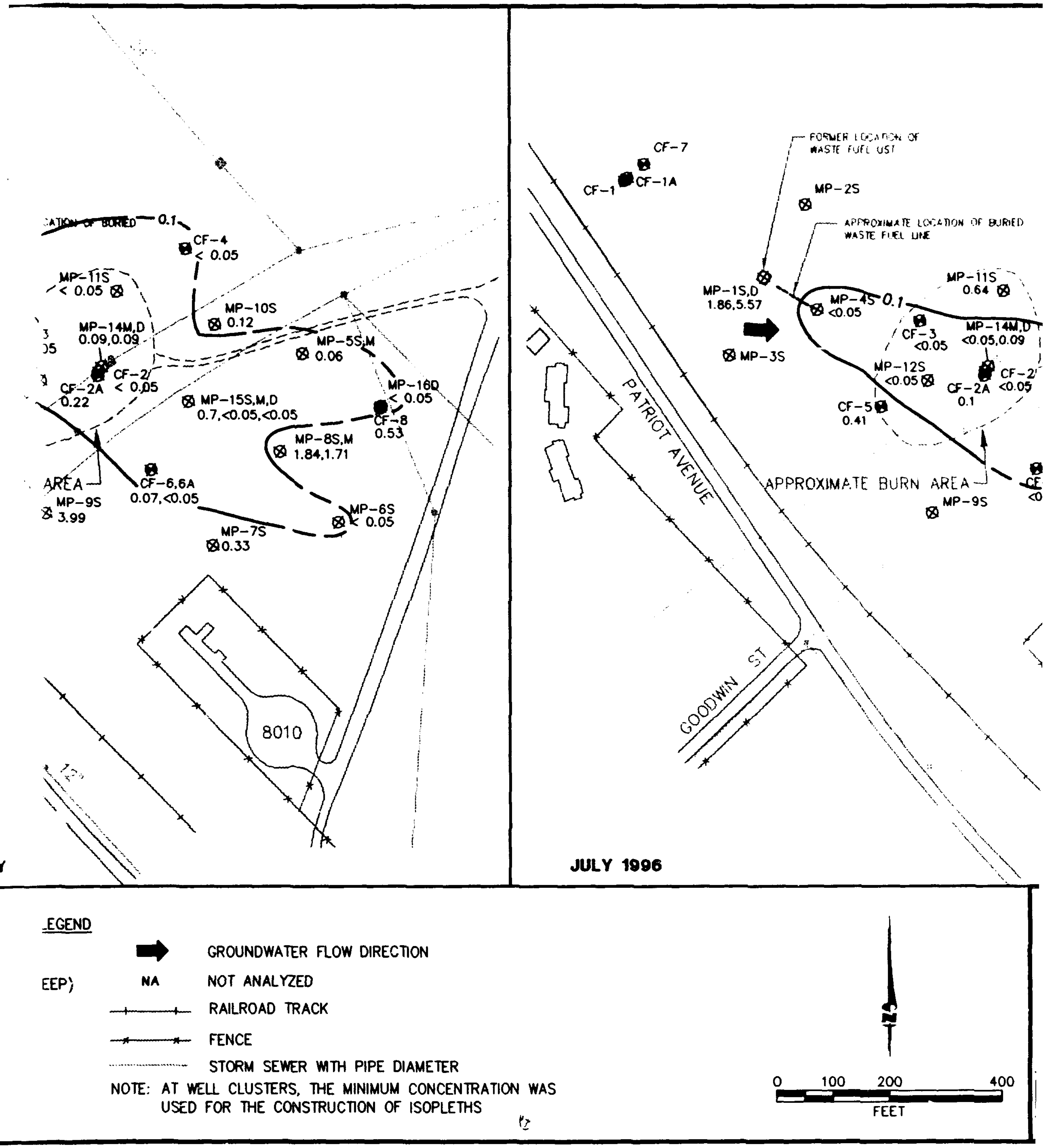


EGEND

GROUNDWATER FLOW DIRECTION

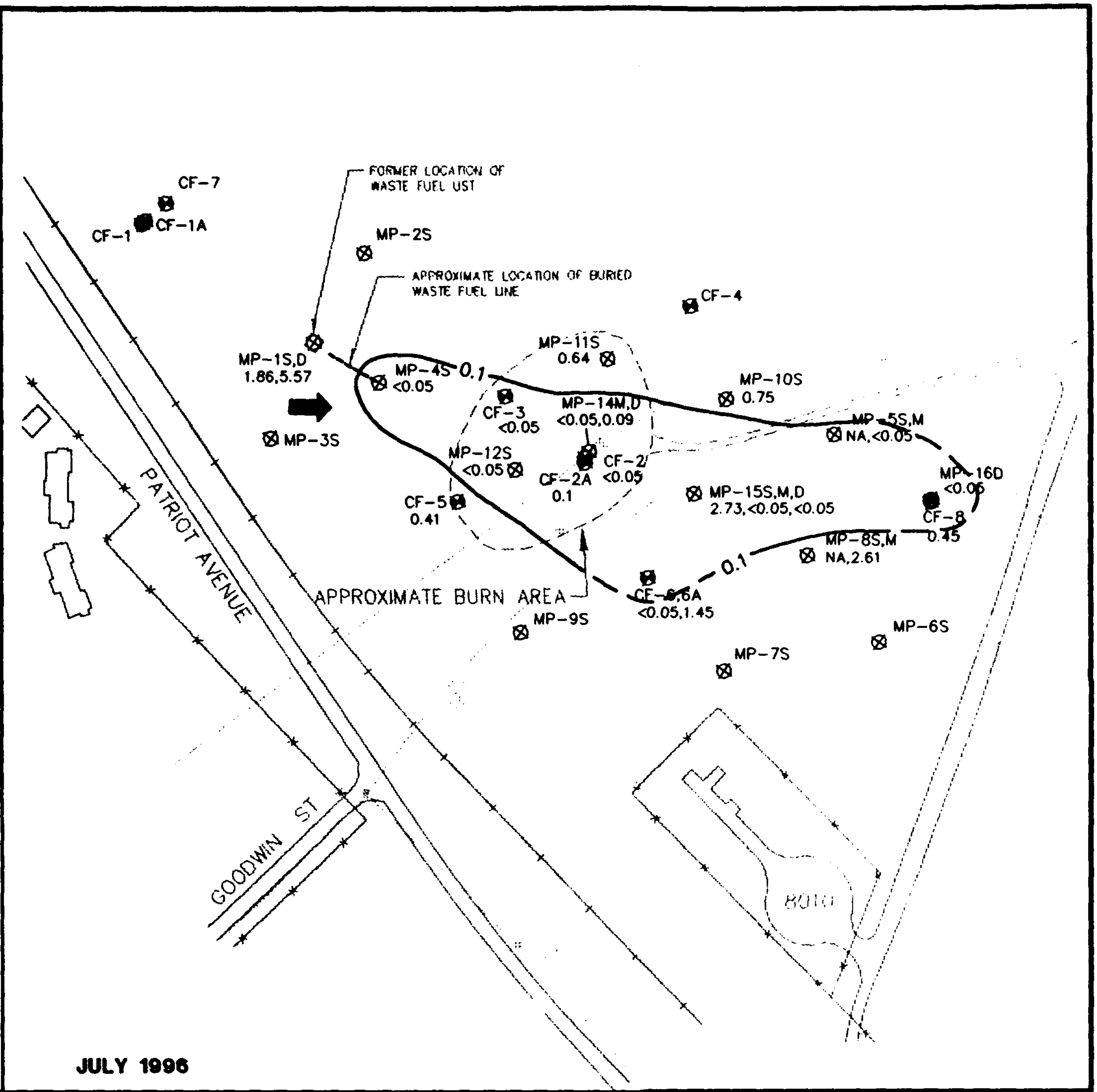
NA NOT ANALYZED

RAILROAD TRACK

FENCE

STORM SEWER WITH PIPE DIAMETER

NOTE: AT WELL CLUSTERS, THE MINIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS



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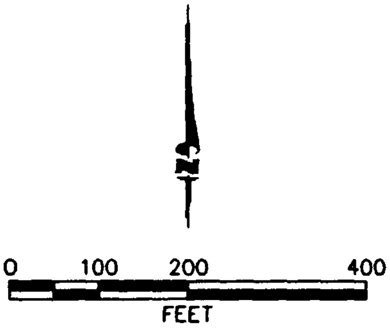


FIGURE 4.7

NITRATE & NITRITE ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

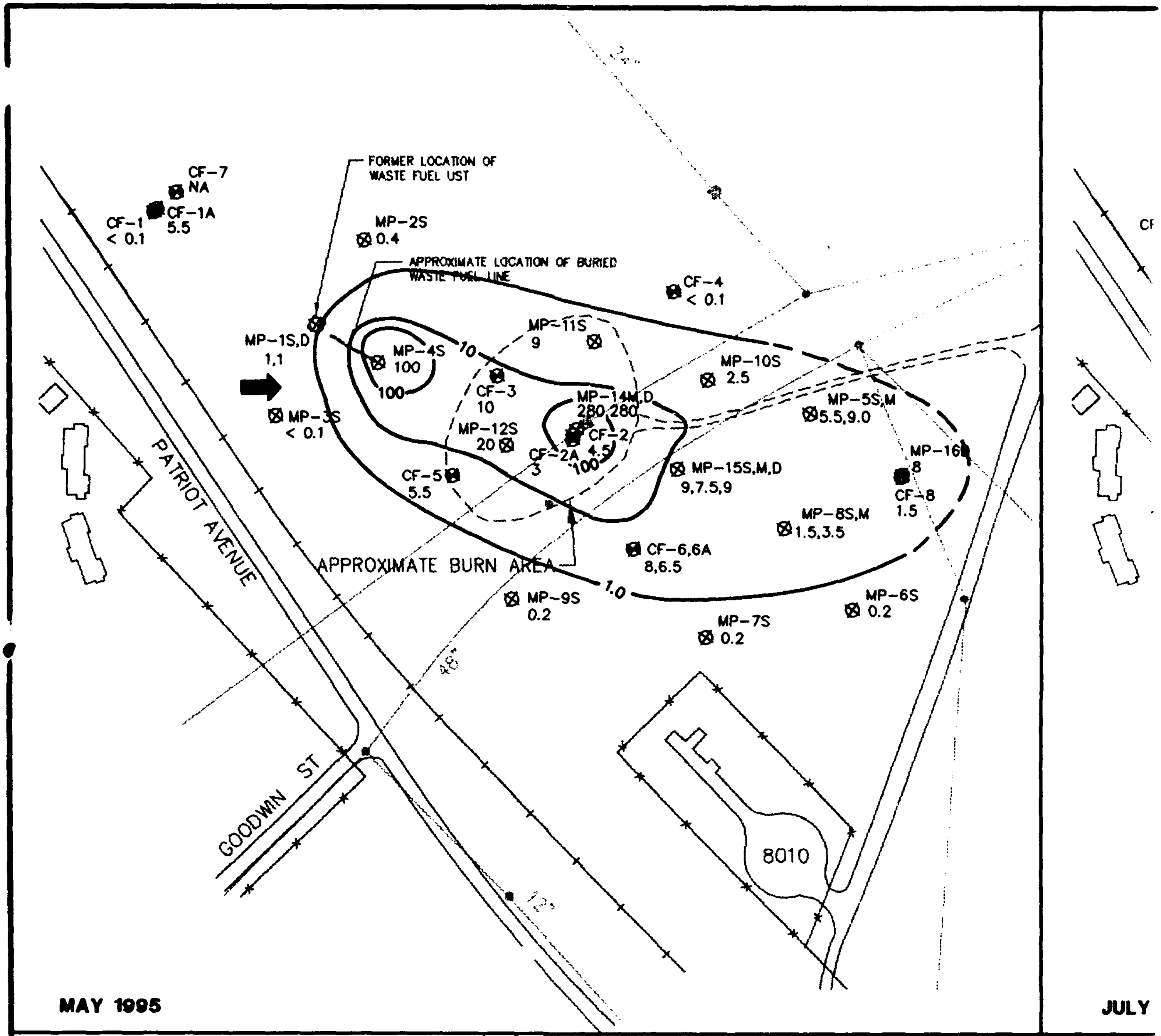
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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 4.4. 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 wells a background nitrate/nitrite concentration of 4.0 mg/L as N was assumed for both May 1995 and July 1996. 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^-. Therefore, the shallow groundwater at this site has the capacity to assimilate 3.53 mg/L (3,530 μg/L) of total BTEX during denitrification. Because biomass accumulation is not considered, the actual assimilative capacity attributable to denitrification could be somewhat higher.

4.3.2.3 Ferrous Iron

Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected in May 1995 and July 1996. Table 4.5 summarizes ferrous iron concentrations and Figure 4.8 presents two isopleth maps showing the distribution of ferrous iron in groundwater. Comparison of Figures 4.2, 4.6, and 4.8 indicates that ferrous iron is being produced in the anaerobic portion of the BTEX plume due to the reduction of ferric iron hydroxide (Fe^{3+}) during anaerobic biodegradation of BTEX compounds. Background ferrous iron concentrations are as low as <0.05 mg/L, as measured at wells with little or no BTEX concentration. Groundwater from monitoring points MP-14M and MP-14D, in the interior of the BTEX plume, had the highest ferrous iron concentrations, with 280 mg/L of Fe^{2+} measured in each sample in May 1995. In July 1996, the highest concentration of ferrous iron were once again detected in MP-14M and MP-14D (40.5 mg/L and 45.3 mg/L, respectively). These relationships are a strong indication that anaerobic biodegradation of BTEX compounds is occurring in the shallow groundwater through iron reduction. The vertical distribution of ferrous iron in groundwater is pictured for May 1995 and July 1996 on Figures 4.9a and 4.9b.

The stoichiometry of BTEX oxidation to carbon dioxide, ferrous iron, and water by microbial iron reduction is presented in Table 4.4. 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 280 mg/L, the shallow groundwater in May 1995 had the capacity to assimilate approximately 12.8 mg/L (12,800 μg/L) of total BTEX through iron reduction. In July 1996, a measured background ferrous iron concentration of <0.05 mg/L and a maximum ferrous iron concentration of 45.3 mg/L corresponds to a capacity to assimilate 2.08 mg/L (2,080 μg/L) of total BTEX through iron reduction. These are conservative estimates of the assimilative capacities of iron because the 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 the assimilative capacity of iron reduction since May 1995, suggests that groundwater conditions have adapted to either a reduction in the amount of bioavaible iron, or a change in the redox conditions at the site to a more reducing



LEGEND

MP-3S ⊗ <0.1	MONITORING POINT, WITH FERROUS IRON CONCENTRATION (mg/L) (S=SHALLOW, M=INTERMEDIATE, D=DEEP)	➡	GROUNDWATER FLOW DIRECTION
		NA	NOT ANALYZED
CF-5 ● 5.5	MONITORING WELL, WITH FERROUS IRON CONCENTRATION (mg/L)	—+—+—	RAILROAD TRACK
		—×—×—	FENCE
—1.0—	LINE OF EQUAL FERROUS IRON CONCENTRATION (mg/L) (DASHED WHERE INFERRED)	┈┈┈	STORM SEWER WITH PIPE DIAMETER

NOTE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS

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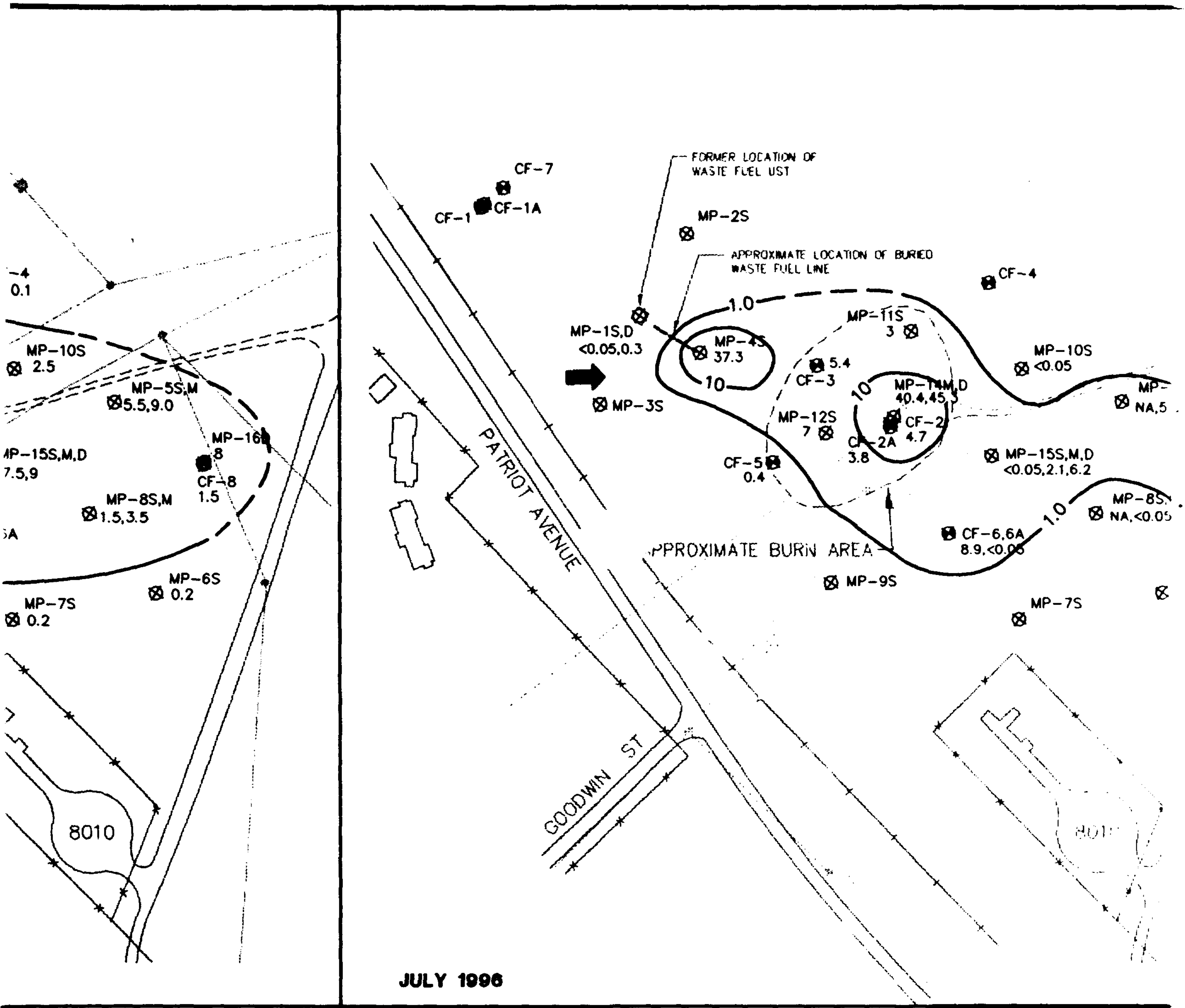

JULY 1996

ROUNDWATER FLOW DIRECTION

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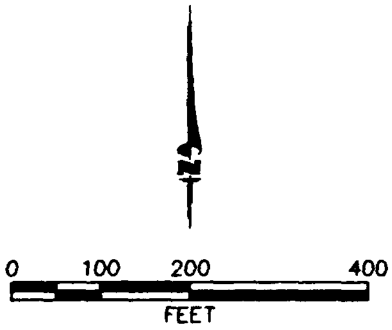

FIGURE

**FERROUS IRON
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Current Fire Tra
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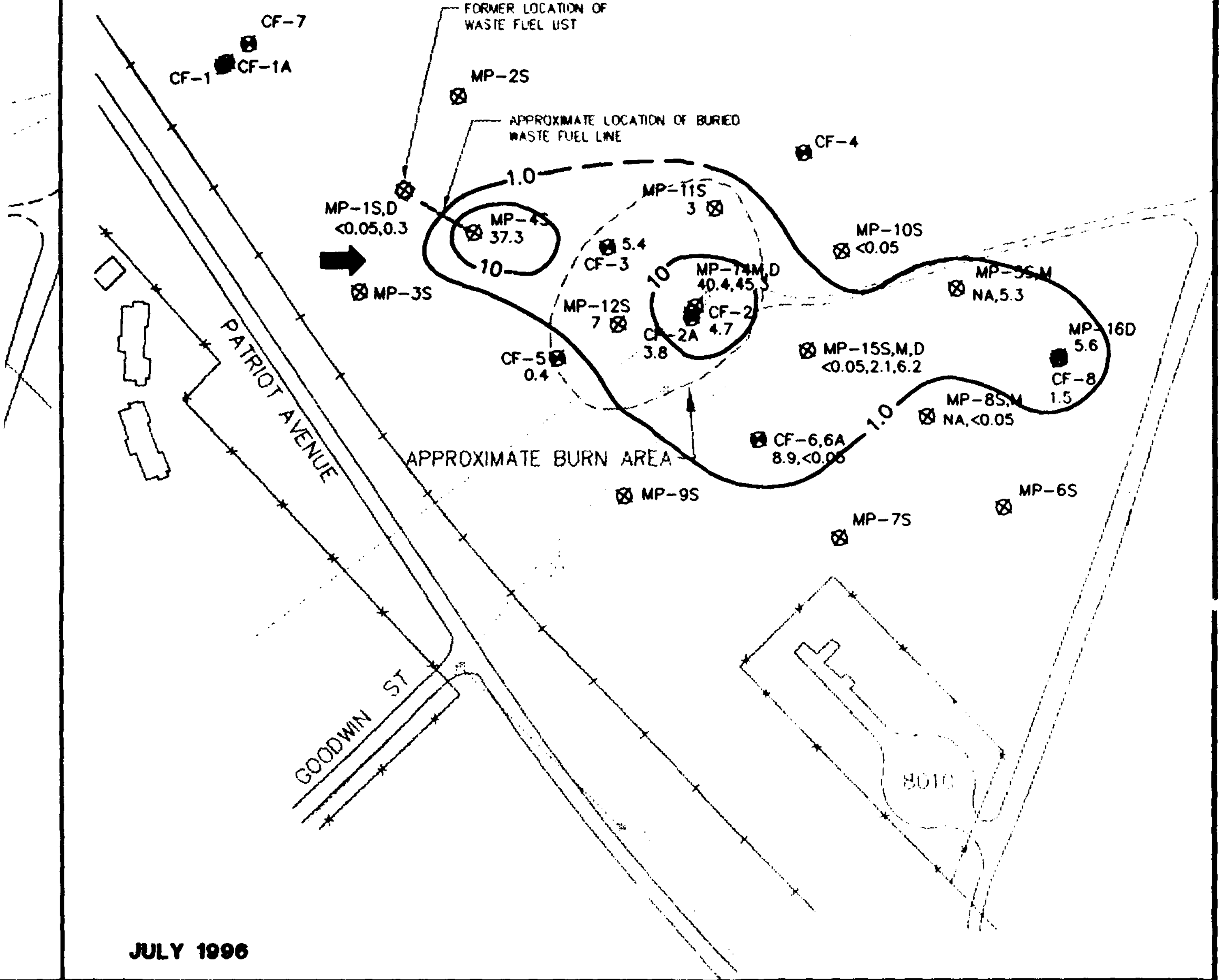
Westover ARB, M

PARSONS ENGINEERING

Denver, Co



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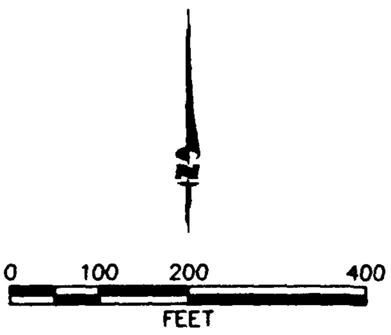
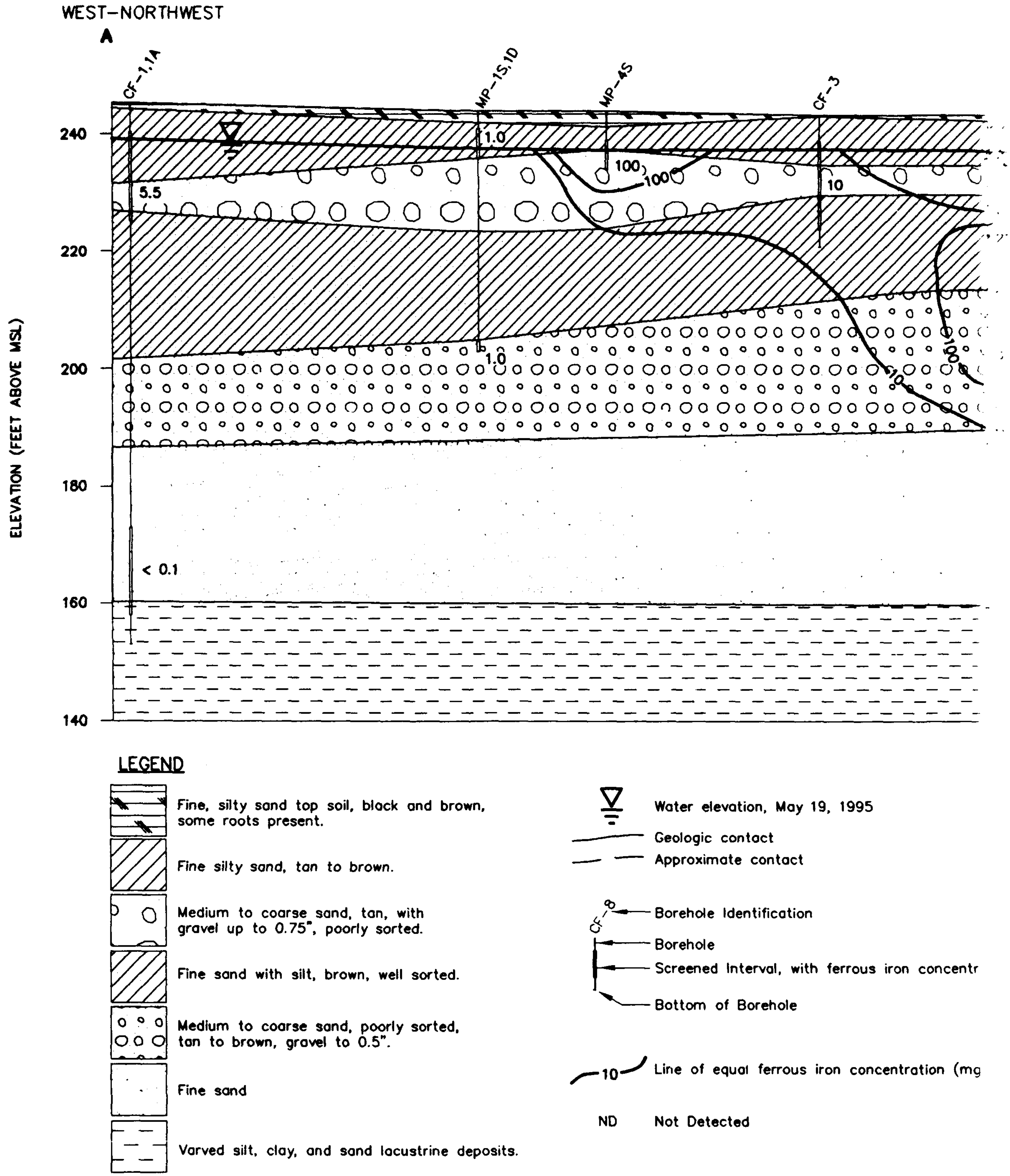


FIGURE 4.8

FERROUS IRON ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



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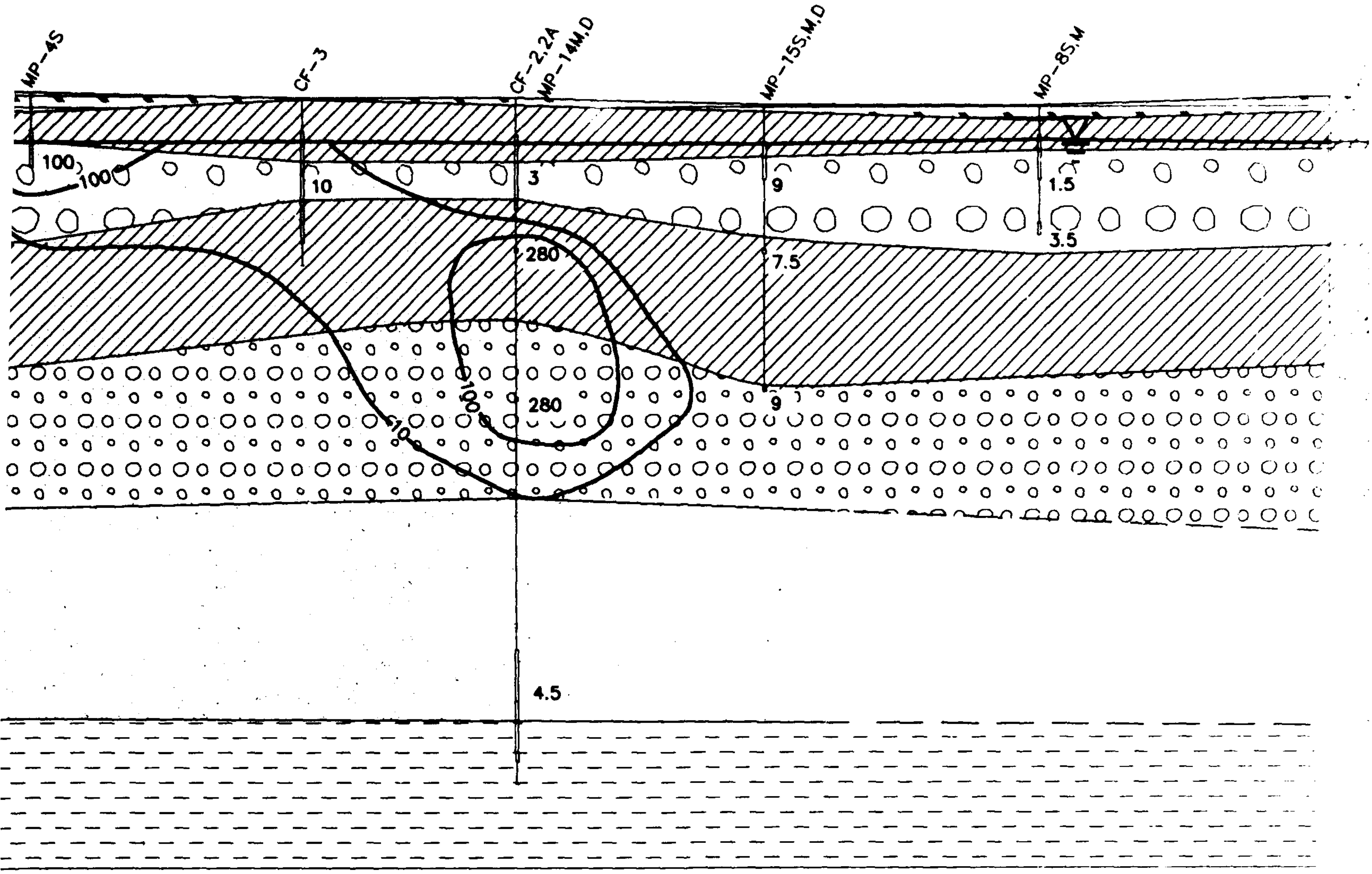

Water elevation, May 19, 1995

Geologic contact

Approximate contact

CF-8 Borehole Identification

Borehole

Screened Interval, with ferrous iron concentration (mg/L)

Bottom of Borehole

10 Line of equal ferrous iron concentration (mg/L)

ND Not Detected

VERTICAL E

0 25 50

FIG

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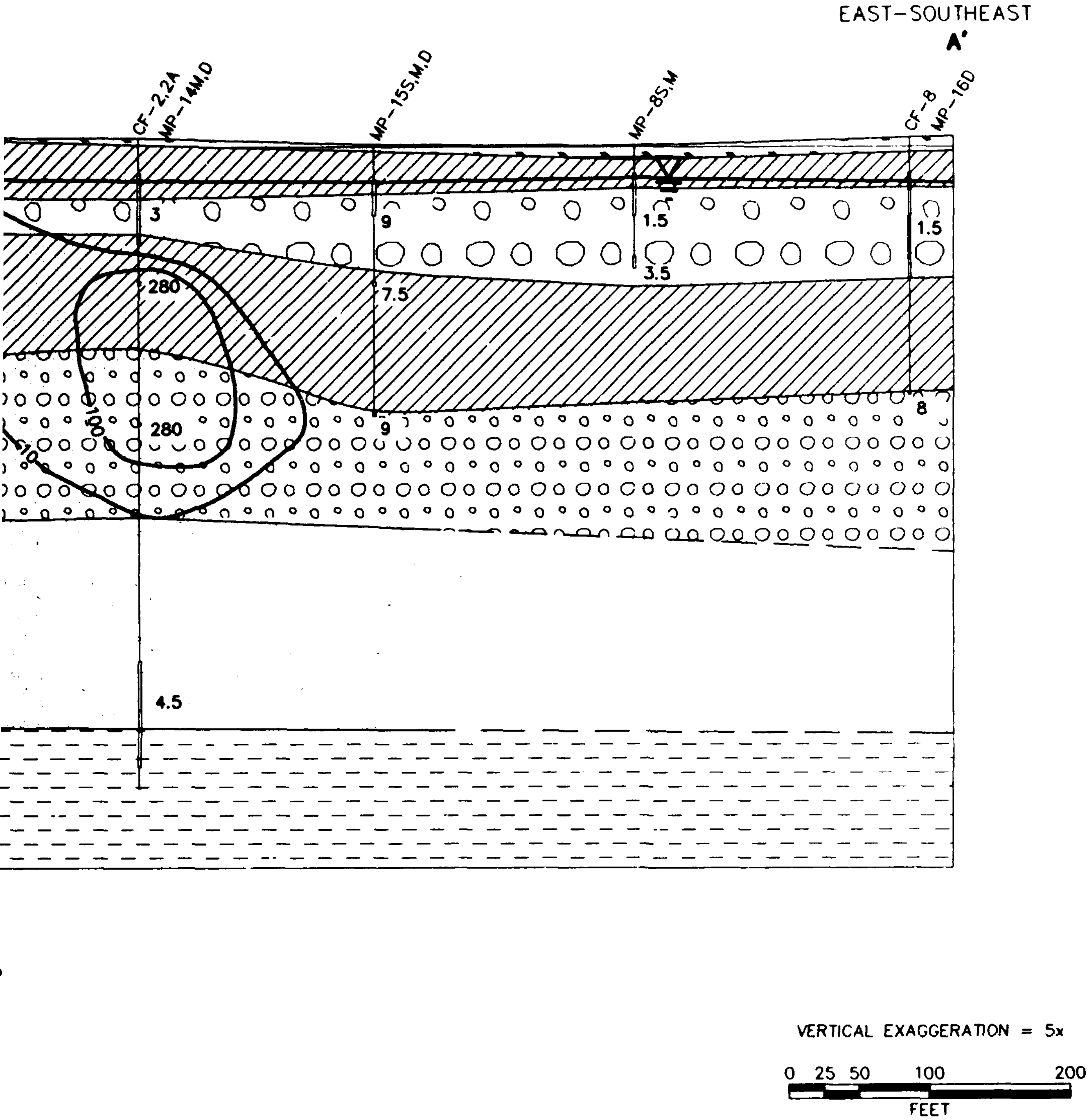


s iron concentration (mg/L)

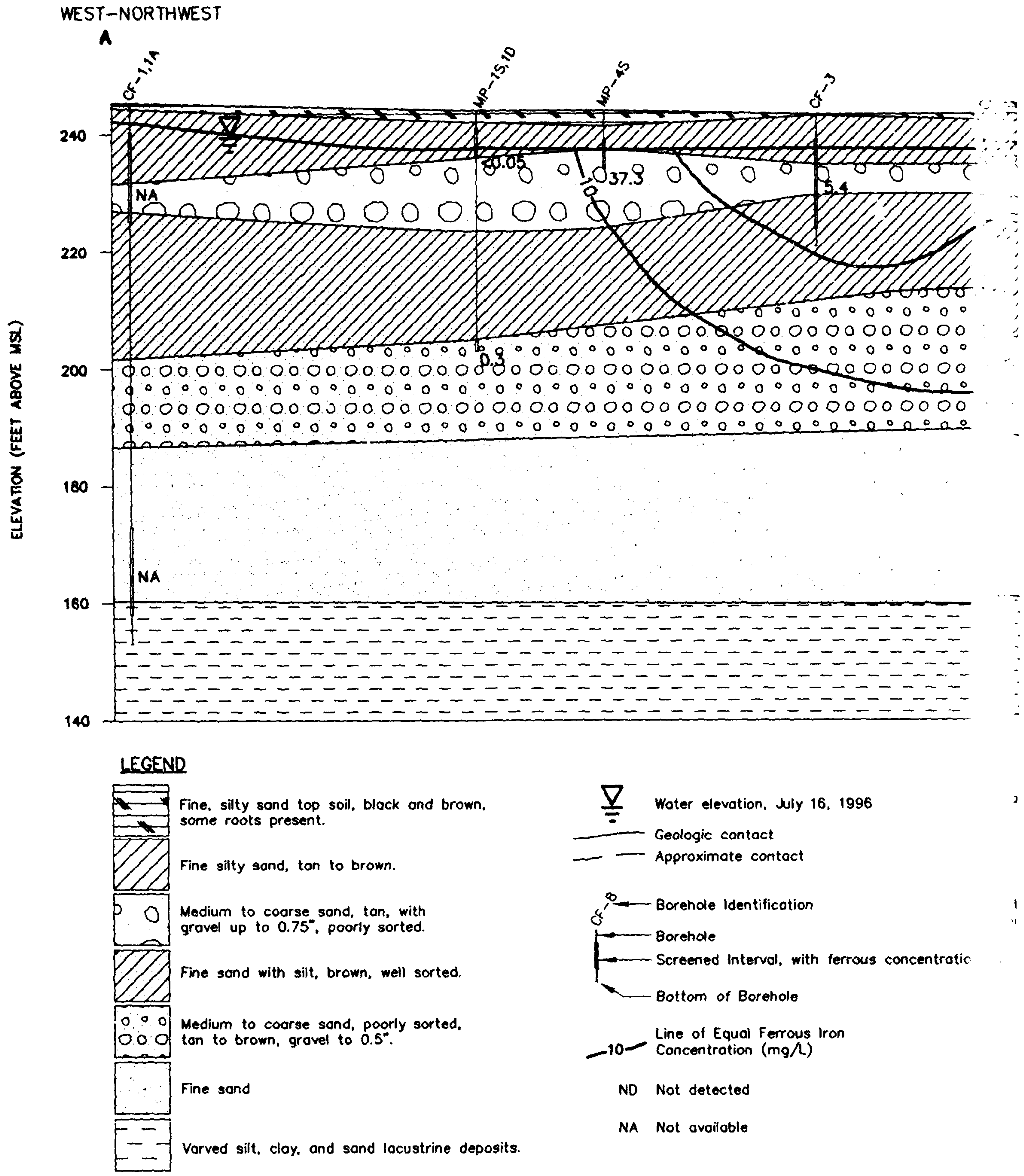
ncentration (mg/L)

FIGURE 4.9a

VERTICAL PROFILE OF FERROUS IRON ISOPLETHS FOR GROUNDWATER MAY 1995

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



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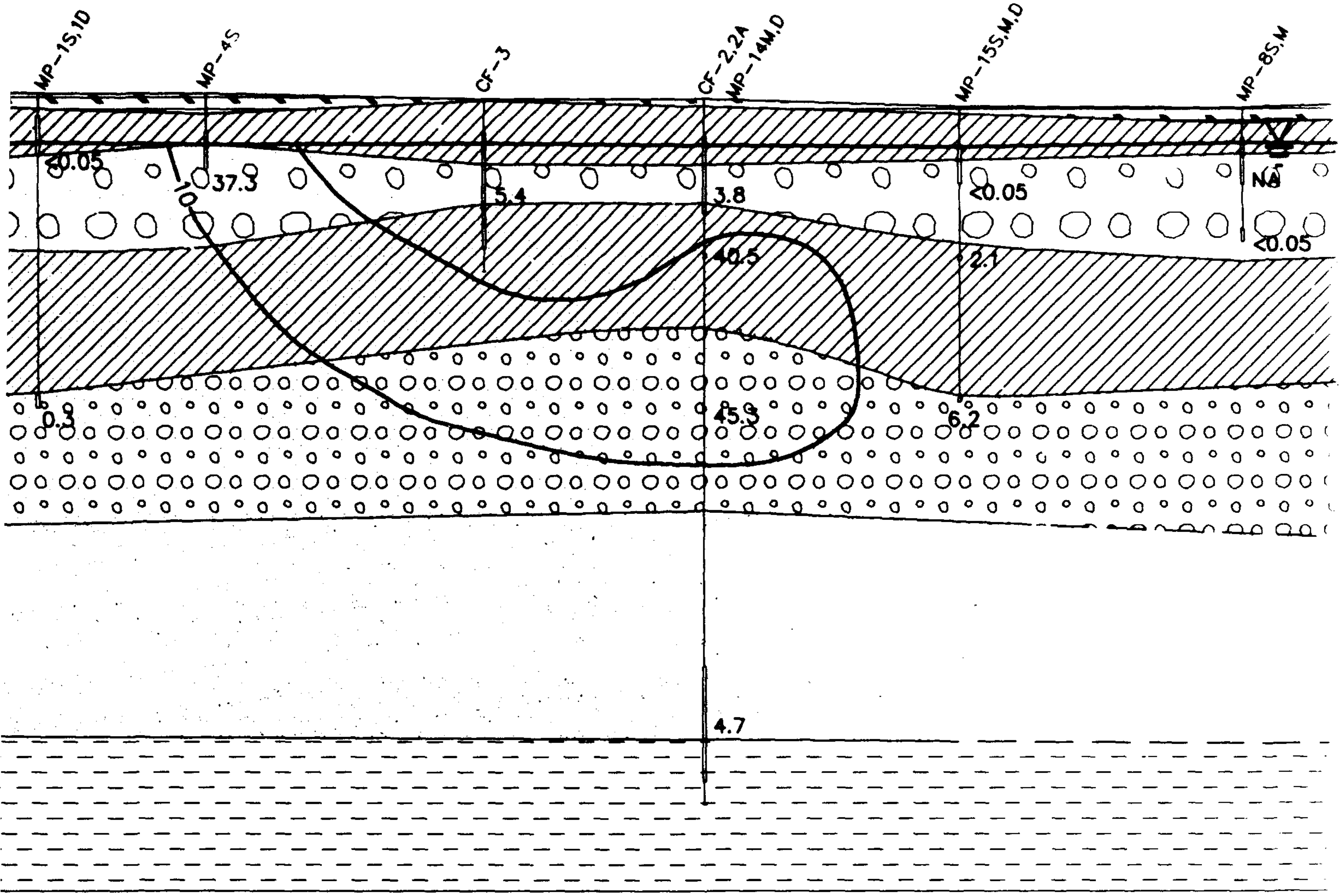

rown,

▽ Water elevation, July 16, 1996

—— Geologic contact

— — Approximate contact

CF-8 ← Borehole Identification

← Borehole

d.

← Screened Interval, with ferrous concentration (mg/L)

← Bottom of Borehole

d,

—10— Line of Equal Ferrous Iron Concentration (mg/L)

ND Not detected

NA Not available

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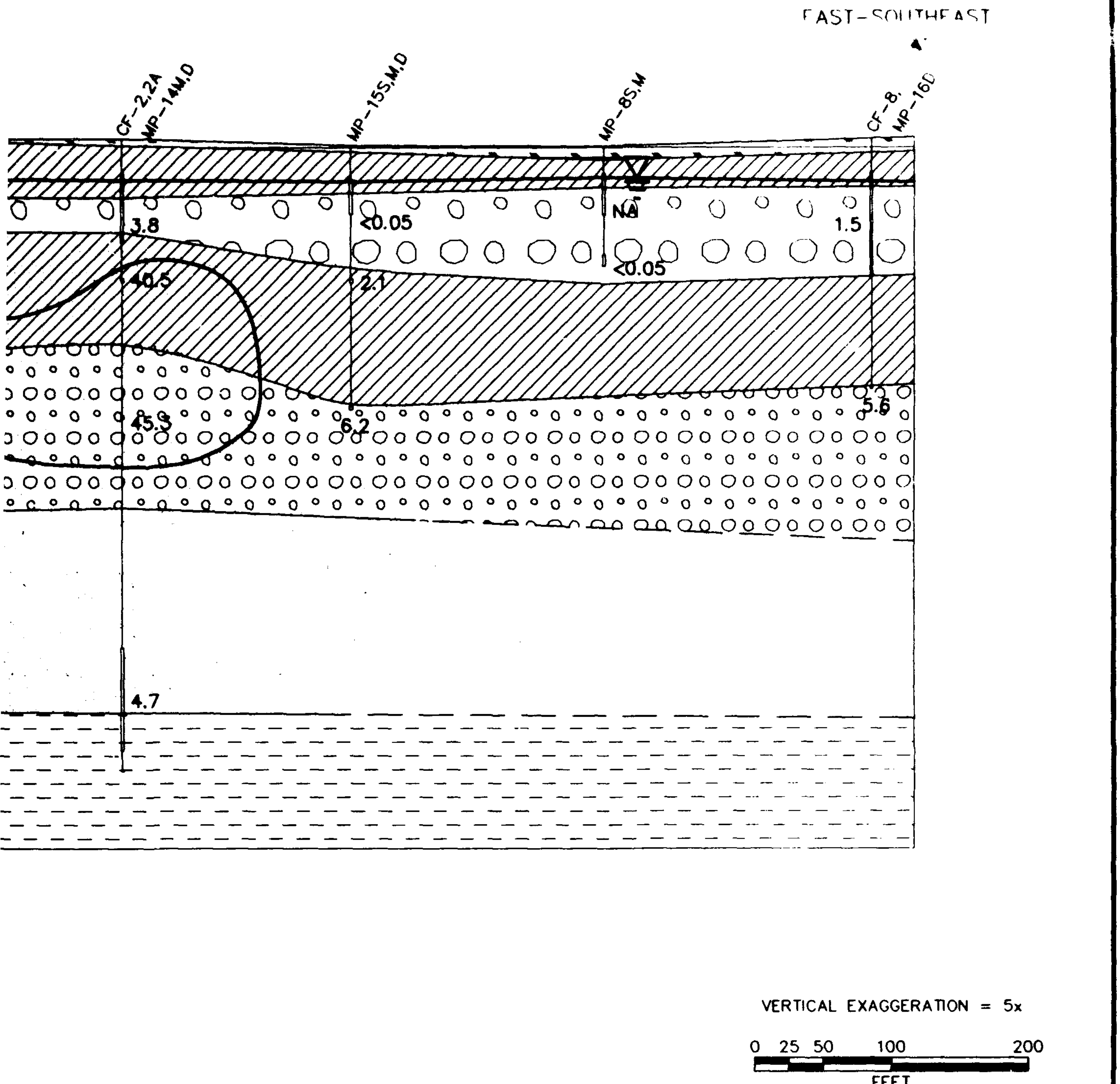


concentration (mg/L)

FIGURE 4.9b

VERTICAL PROFILE OF FERROUS IRON ISOPLETHS FOR GROUNDWATER JULY 1996

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

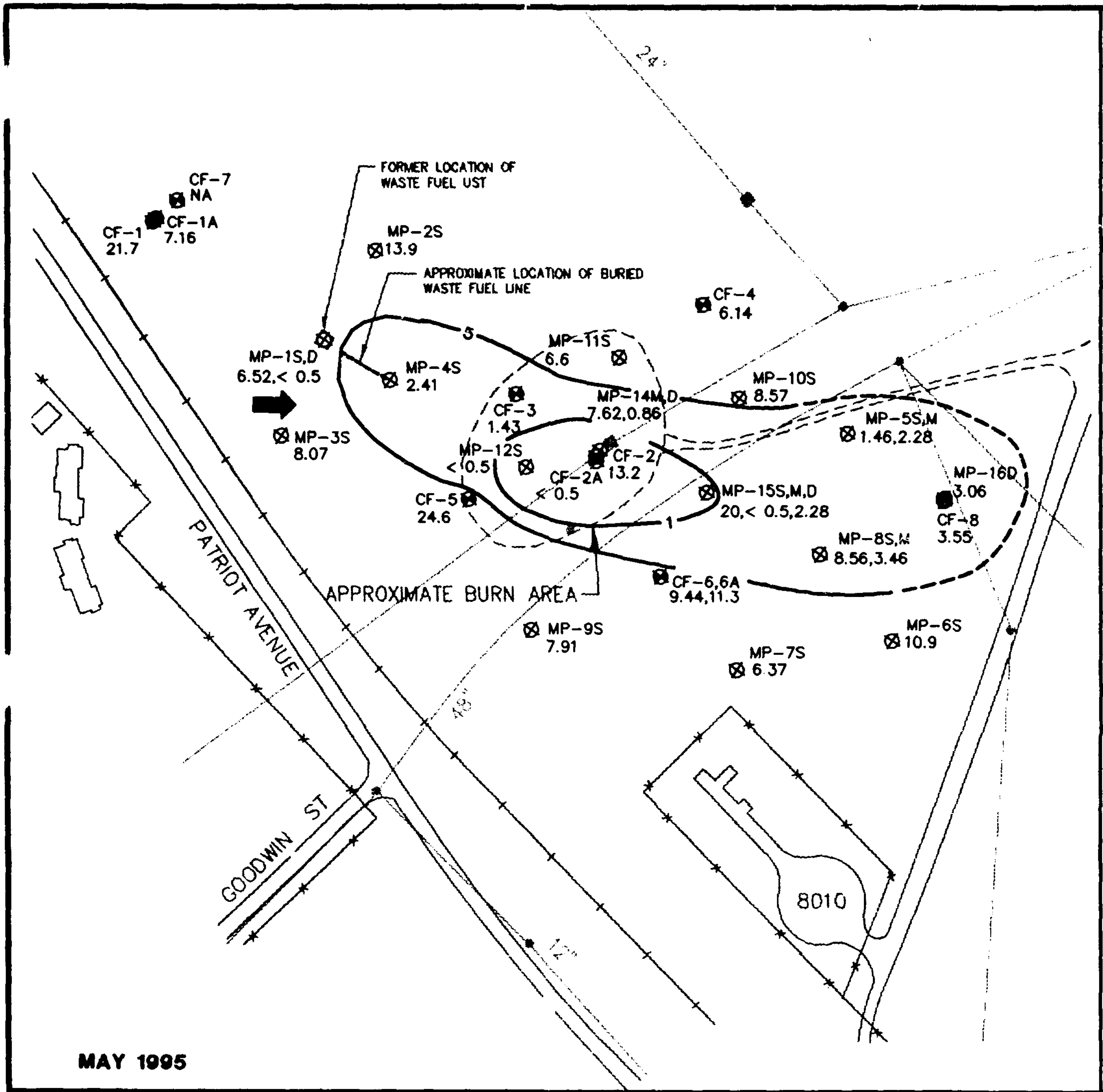
environment, i.e., an environment more favorable to sulfate reduction and methanogenesis.

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 <0.5 mg/L to 24.6 mg/L and from <0.5 mg/L to 76.7 mg/L in May 1995 and July 1996, respectively. Table 4.5 summarizes measured sulfate concentrations. Figure 4.10 presents two isopleth maps illustrating the areal extent of sulfate in groundwater for both sampling events. Comparison of Figures 4.2, 4.6, and 4.10 shows graphically that the area of depleted sulfate concentrations corresponds to the anaerobic portions of the BTEX plume. This is a strong indication that anaerobic biodegradation of the BTEX compounds is occurring at the site via sulfate reduction. In May 1995, the lowest sulfate concentrations were measured in groundwater samples from monitoring locations CF-2A and MP-12S (<0.5 mg/L), which are located in the center of the BTEX plume. In July 1996, sulfate concentrations less than 0.5 mg/L were measured in the following groundwater monitoring locations: MP-4S, CF-3, MP-14D, CF-2A, MP-12S, MP-15M and MP-1D. The increase in the number of sampling locations with low sulfate concentrations suggests that sulfate reduction has become a more favored degradation mechanism between May 1995 and July 1996.

The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water by microbial sulfate reduction is presented in Table 4.4. 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. May 1995 sulfate concentrations at monitoring locations upgradient and at the plume fringe range from 6.52 mg/L to 24.6 mg/L, with an average concentration of 12.1 mg/L. Assuming a background concentration of 12.1 mg/L, the shallow groundwater at this site had the capacity to assimilate 2.54 mg/L (2,540 μg/L) of total BTEX through sulfate reduction. In July1996, sulfate concentrations at upgradient and plume fringe locations ranged from 2.45 mg/L to 76.8 mg/L, with an average concentration of 14.1 mg/L. Assuming a background concentration of 14.1 mg/L, the shallow groundwater in July of 1996 had the capacity to assimilate 2.96 mg/L (2,960 μg/L) of total BTEX through sulfate reduction. Because biomass accumulation is not considered, the actual assimilative capacities attributable to sulfate reduction could be somewhat higher.



LEGEND

MP-3S ⊗ 8.0	MONITORING POINT, WITH SULFATE CONCENTRATION (mg/L) (S=SHALLOW, M=INTERMEDIATE, D=DEEP)	➡	GROUNDWATER FLOW DIRECTION
		NA	NOT ANALYZED
		—+—+—	RAILROAD TRACK
CF-5 ⊠ 24.6	MONITORING WELL, WITH SULFATE CONCENTRATION (mg/L)	—×—×—	FENCE
		········	STORM SEWER WITH PIPE DIAMETER
—1.0—	LINE OF EQUAL SULFATE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)		

NOTE: AT WELL CLUSTERS, THE MINIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS

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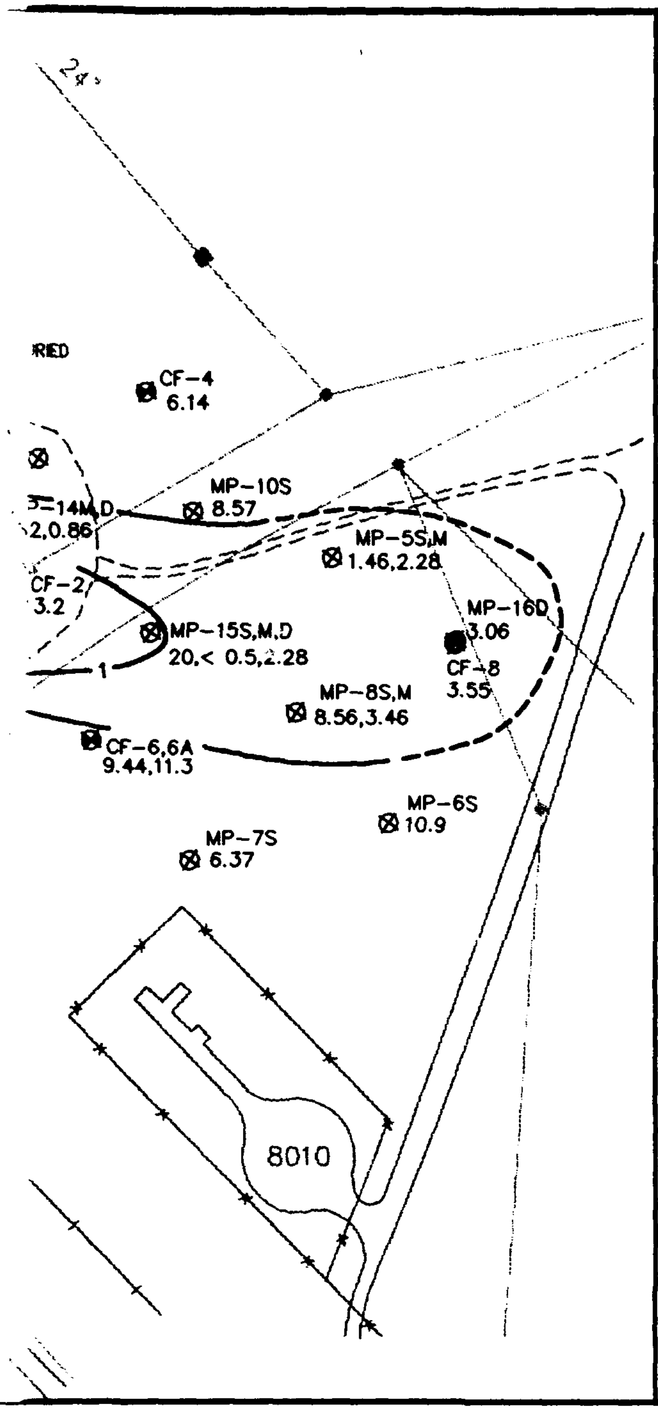

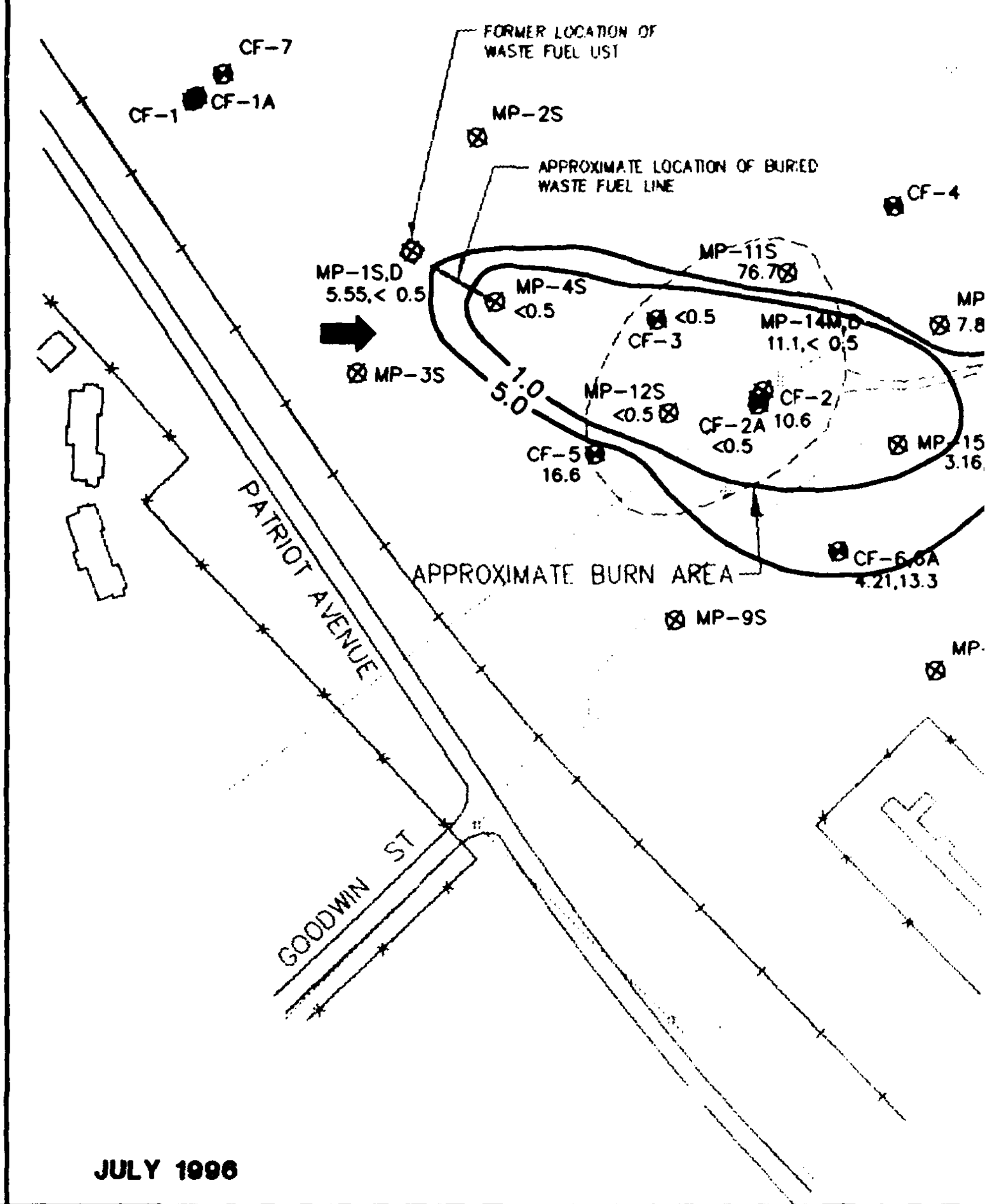

JULY 1996

➡	GROUNDWATER FLOW DIRECTION
NA	NOT ANALYZED
——+——	RAILROAD TRACK
——×——	FENCE
·········	STORM SEWER WITH PIPE DIAMETER

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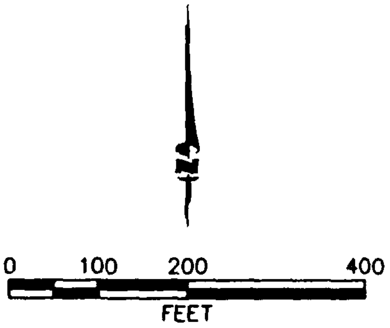

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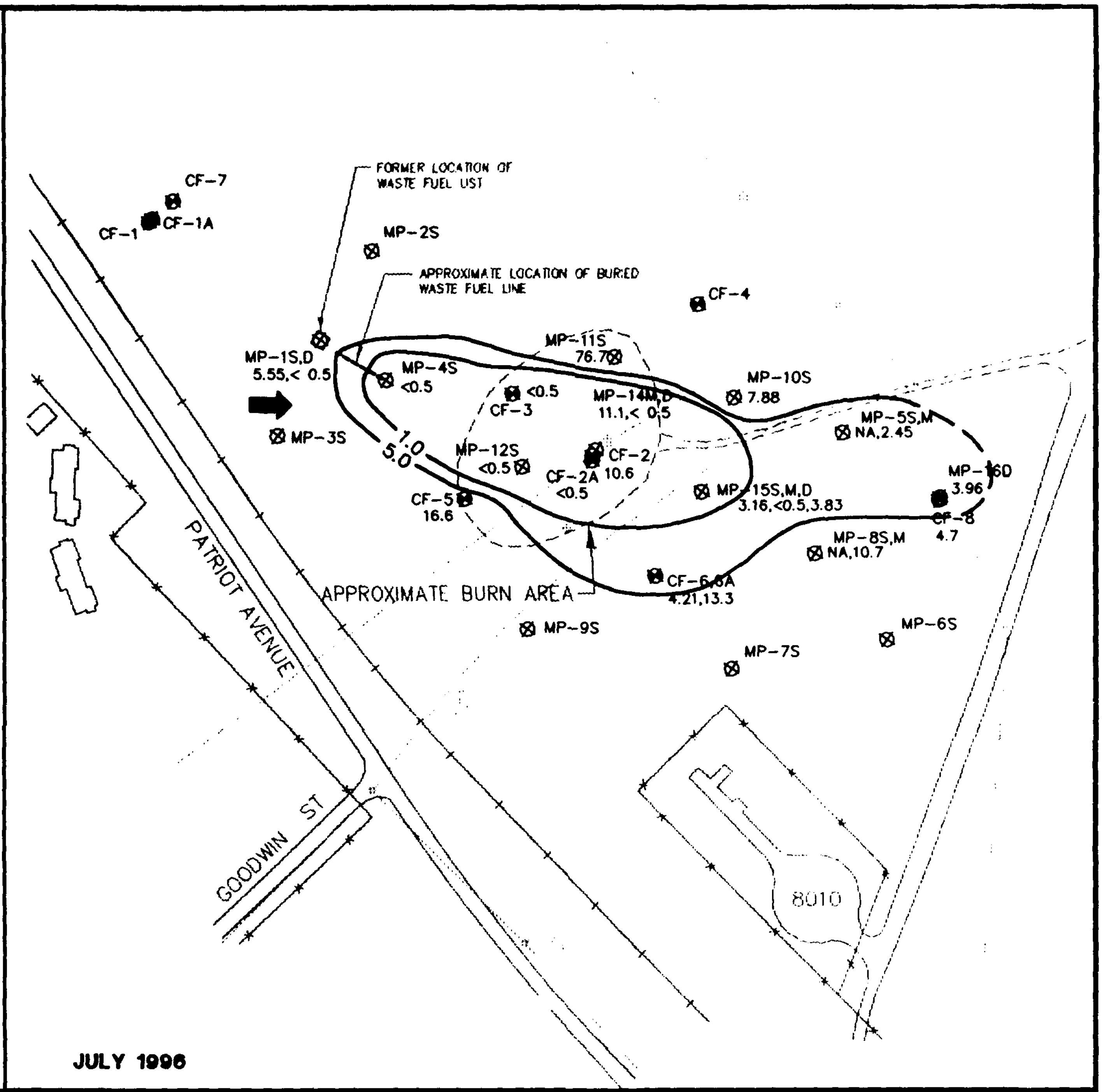

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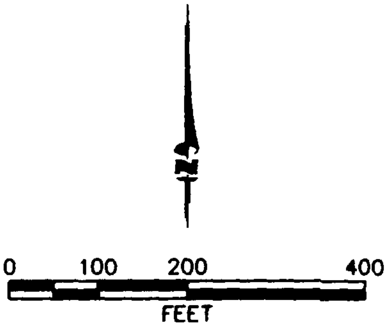


FIGURE 4.10

SULFATE ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intriusic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

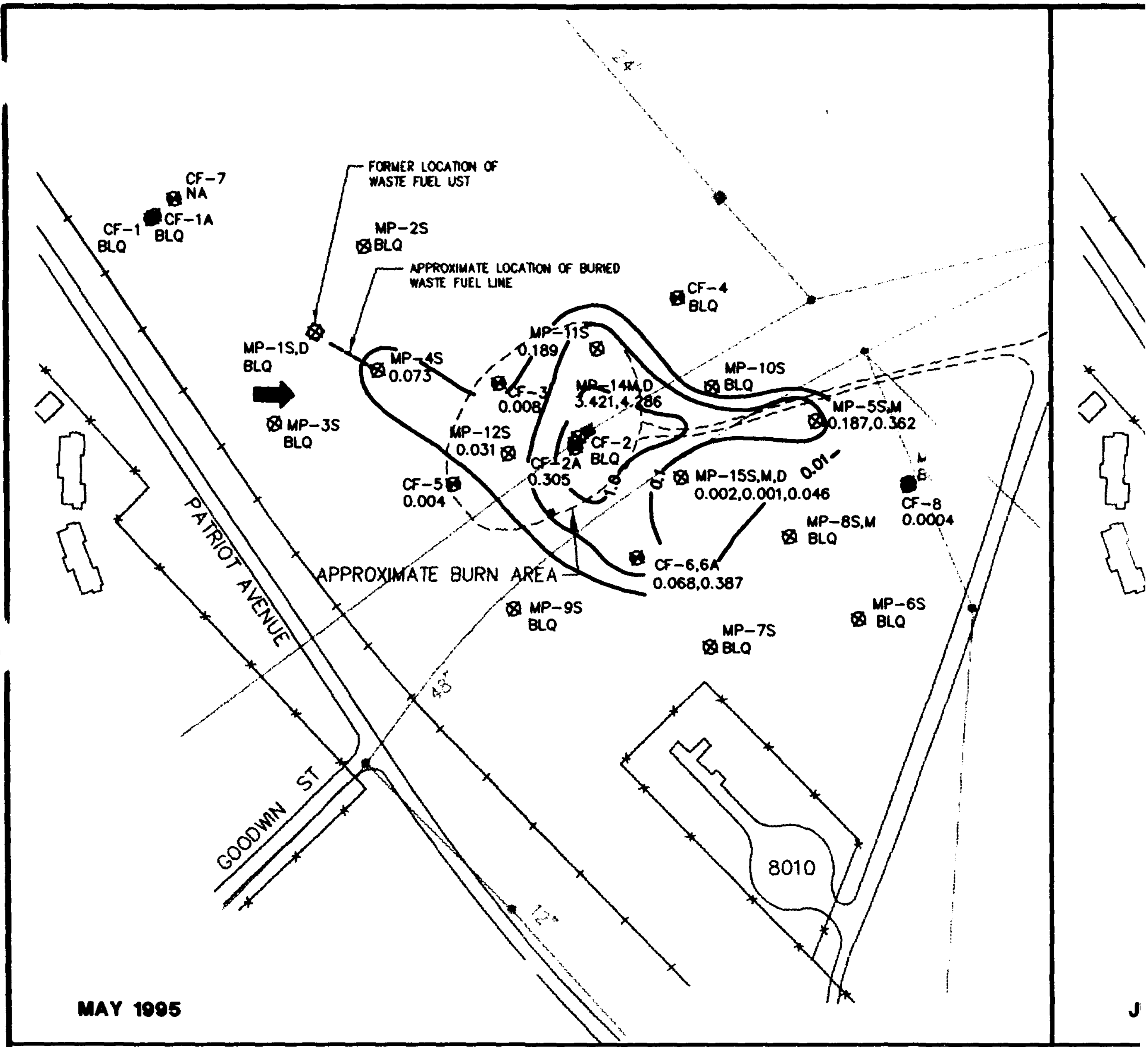
4.3.2.5 Methane

Methane concentrations were measured in groundwater samples collected in May 1995 and July 1996. Table 4.5 summarizes methane concentrations, which ranged from below 0.001 mg/L to 4.286 mg/L and from below 0.001 mg/L to 14.63 mg/L in May 1995 and July 1996, respectively. Figure 4.11 presents two isopleth maps showing the distribution of methane in groundwater for both sampling events. Comparison of Figures 4.2 and 4.11 illustrates that the areas with elevated total BTEX concentrations correlate with elevated methane concentrations. Outside of the BTEX plume, the methane concentrations are <0.001 mg/L (the analytical quantitation limit). The highest methane concentration was detected in the center of the plume, at monitoring point MP-14D in May 1995 and July 1996. The vertical distribution of methane is presented on Figures 4.12a and 4.12b. The lack of methane at depths greater than 50 feet bgs indicates that the BTEX plume is within the shallow to middle depth zones of the surficial aquifer.

The stoichiometry of BTEX oxidation to carbon dioxide and methane by methanogenesis is presented in Table 4.4. 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 4.286 mg/L in May 1995, the shallow groundwater had the capacity to assimilate approximately 5.50 mg/L (5,500 μg/L) of total BTEX through methanogenesis. In July 1996, the maximum detected methane concentration of 14.63 mg/L corresponds to an assimilative capacity of approximately 18.8 mg/L (18,800 μg/L). These are conservative estimates of the assimilative capacity of methanogenesis because these calculations are based on observed methane concentrations and not on the amount of carbon dioxide (the electron acceptor for methanogenesis) available in the aquifer. Because methanogenesis produces more carbon dioxide than it consumes, an unlimited supply of carbon dioxide is theoretically available once the process of methanogenesis has been initiated. Therefore, methanogenesis is limited by the rate of reaction rather than the source of electron acceptors. The significant increase in the assimilative capacity of methanogenesis from May 1995 to July 1996 corresponds with the decrease in iron reduction over the same period of time. The groundwater system is most likely responding to the decrease in bioavailable iron in the surrounding soils and the continued presence of high concentrations of dissolved contaminants.

4.3.2.6 Reduction/Oxidation Potential

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. Redox potentials were measured at groundwater monitoring wells in May 1995 and July 1996. These measurements are summarized in Table 4.5. The redox potential at the site ranged from -105.1 millivolts (mV) to 249.5 mV in May 1995, and from -125 mV to 280 mV in 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 and methane concentrations. Overall areas with dissolved BTEX contamination exhibited a decrease in redox from May 1995 to July 1996. This



LEGEND

MP-3S BLQ	MONITORING POINT, WITH METHANE CONCENTRATION (mg/L) (S=SHALLOW, M=INTERMEDIATE, D=DEEP)	➡	GROUNDWATER FLOW DIRECTION
		NA	NOT ANALYZED
CF-5 0.004	MONITORING WELL, WITH METHANE CONCENTRATION (mg/L)	—+—+—	RAILROAD TRACK
		—×—×—	FENCE
—0.1—	LINE OF EQUAL METHANE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)	······	STORM SEWER WITH PIPE DIAMETER

NOTE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS

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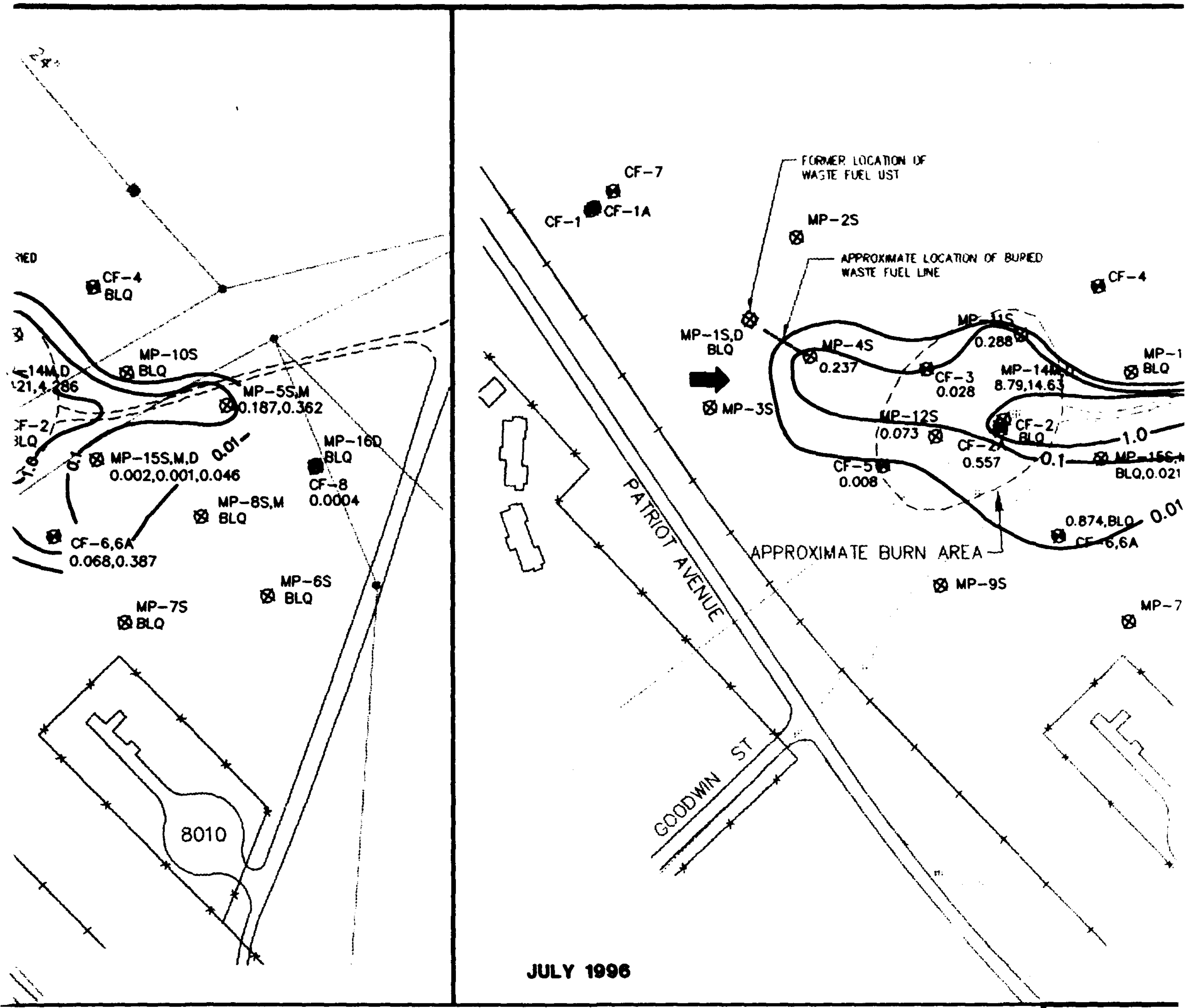
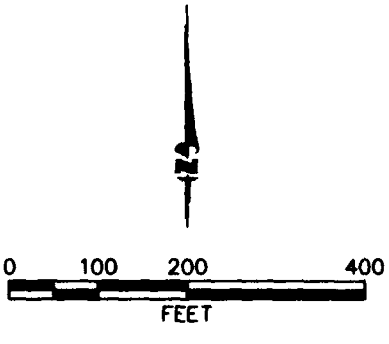


JULY 1996

➡	GROUNDWATER FLOW DIRECTION
NA	NOT ANALYZED
——+——	RAILROAD TRACK
——×——	FENCE
············	STORM SEWER WITH PIPE DIAMETER

TE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS
ED FOR THE CONSTRUCTION OF ISOPLETHS



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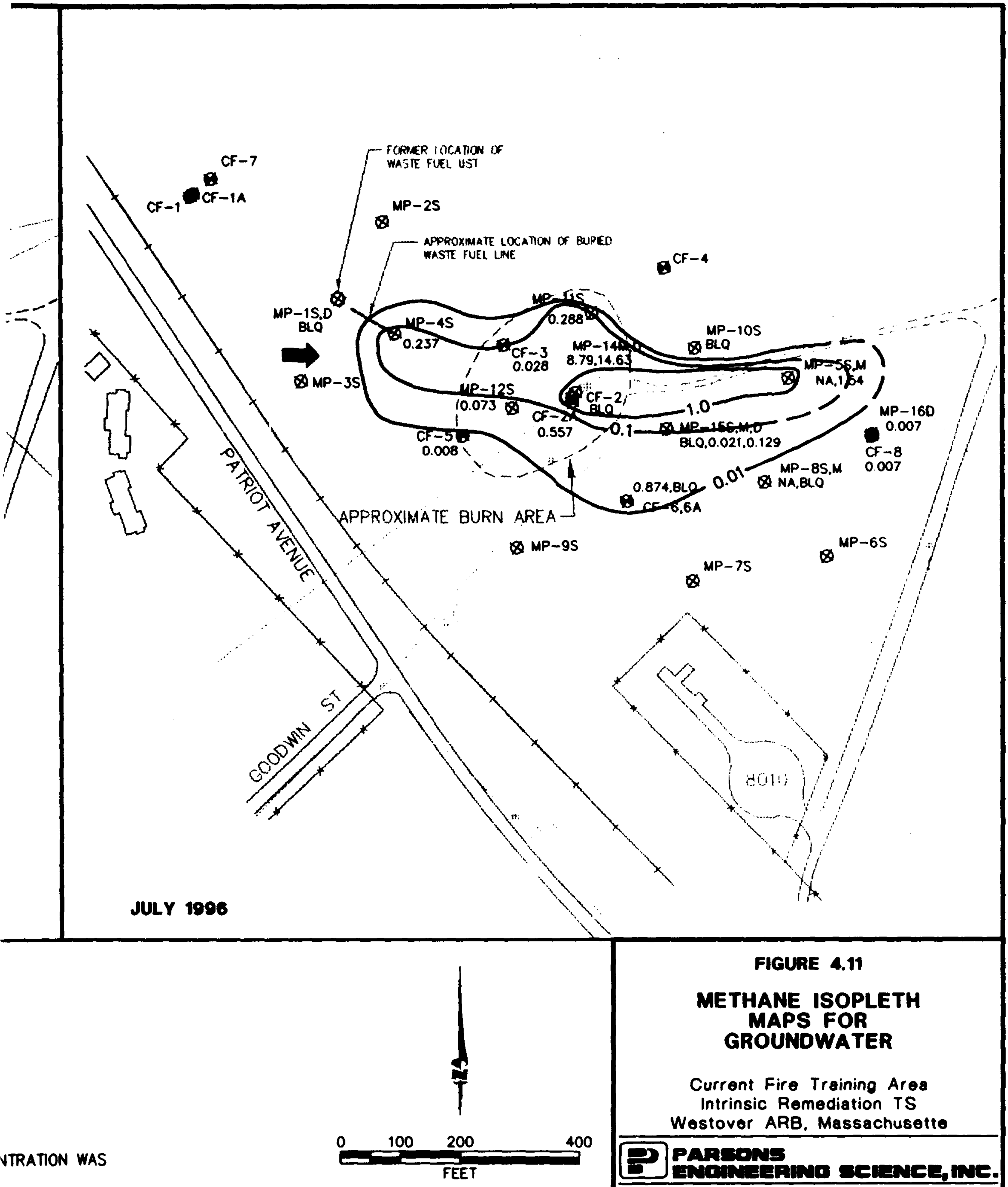

JULY 1996

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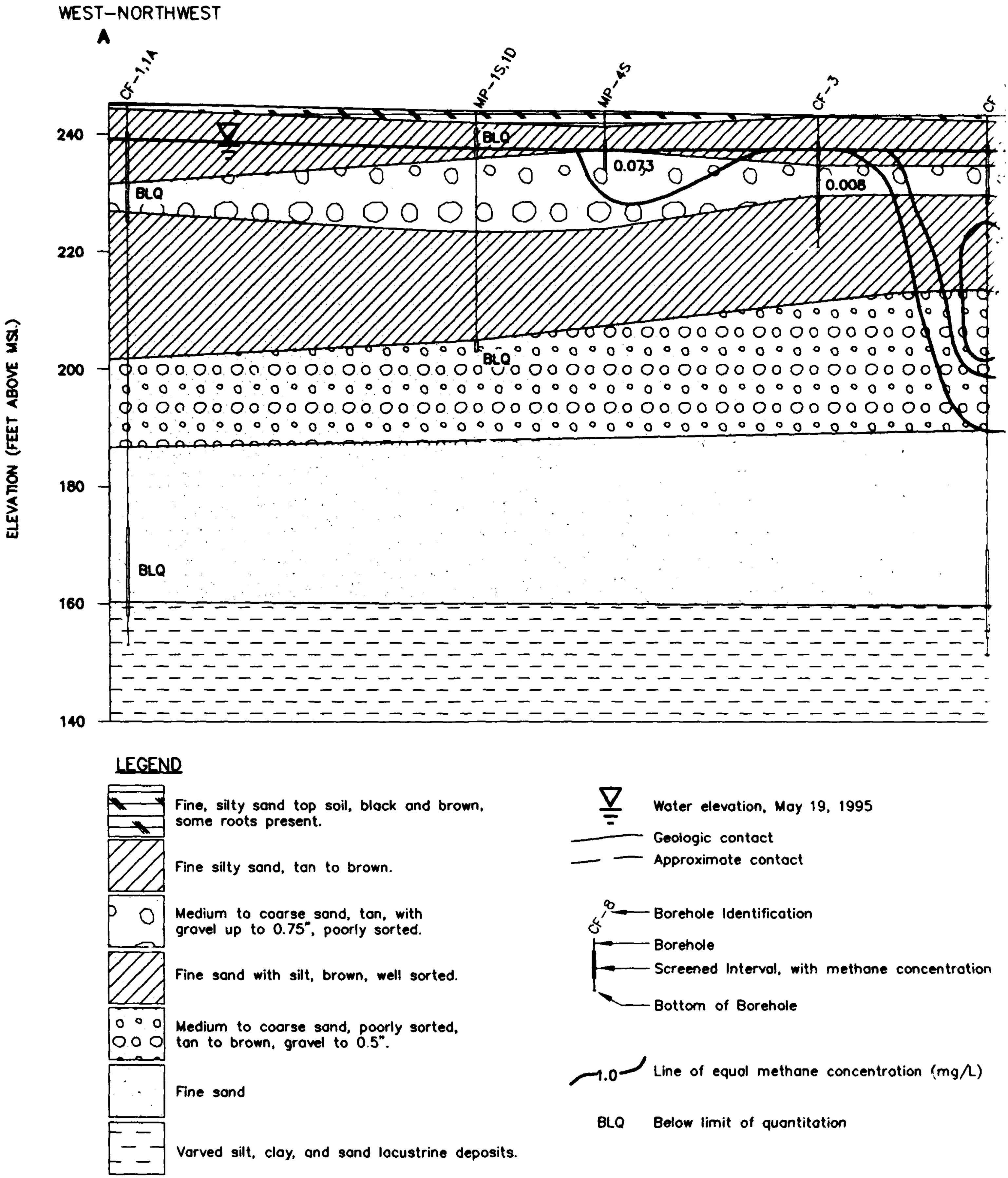
FIGURE 4.11

METHANE ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusette

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



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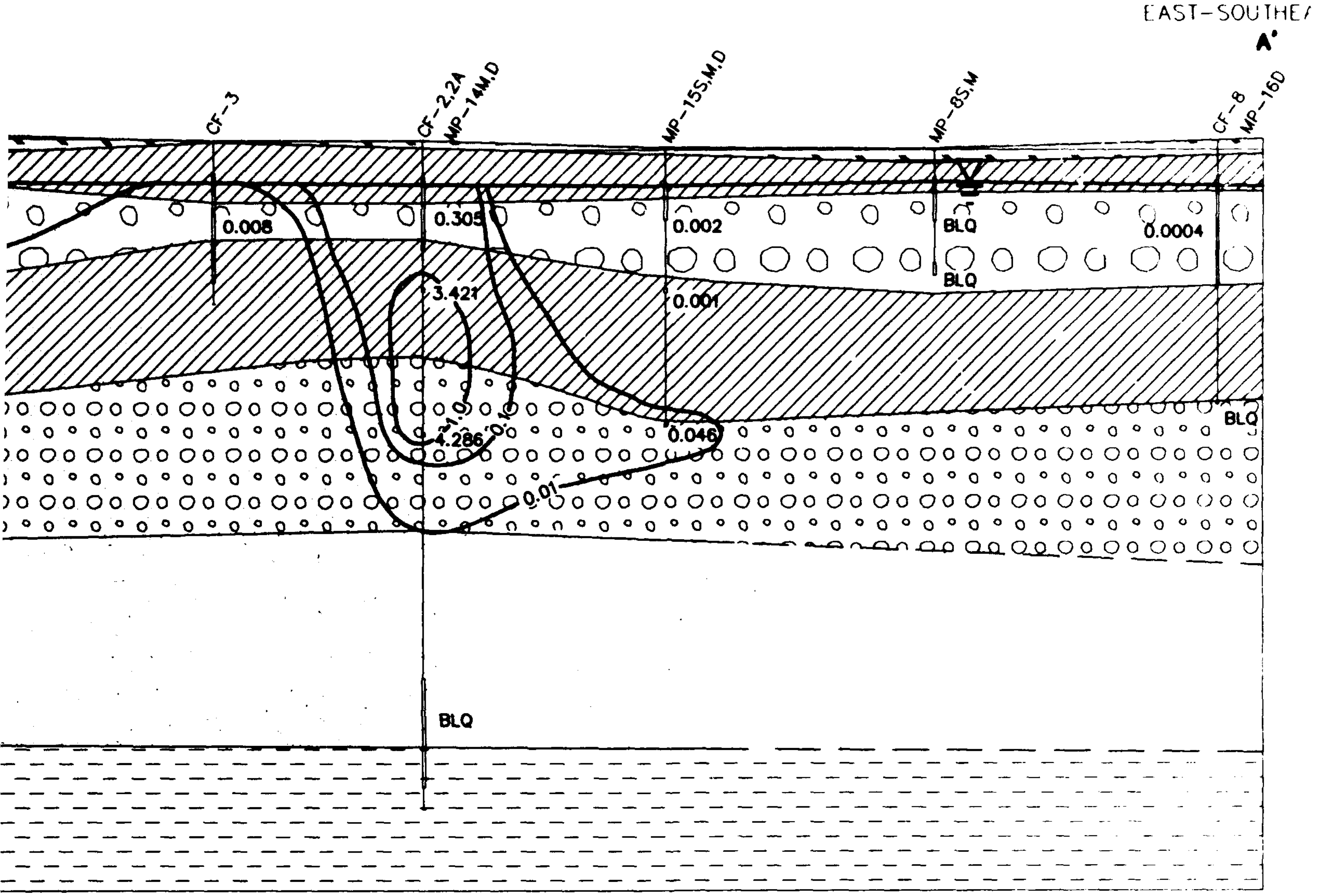

Water elevation, May 19, 1995

Geologic contact

Approximate contact

Borehole Identification

Borehole

Screened Interval, with methane concentration (mg/L)

Bottom of Borehole

Line of equal methane concentration (mg/L)

Below limit of quantitation

VERTICAL EXAGGERATIO

0 25 50 100

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FIGURE 4.12a

VERTICAL PROFI
METHANE ISOPL
FOR GROUNDW
MAY 1995

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Intrinsic Remediat
Westover ARB, Massc

PARSONS
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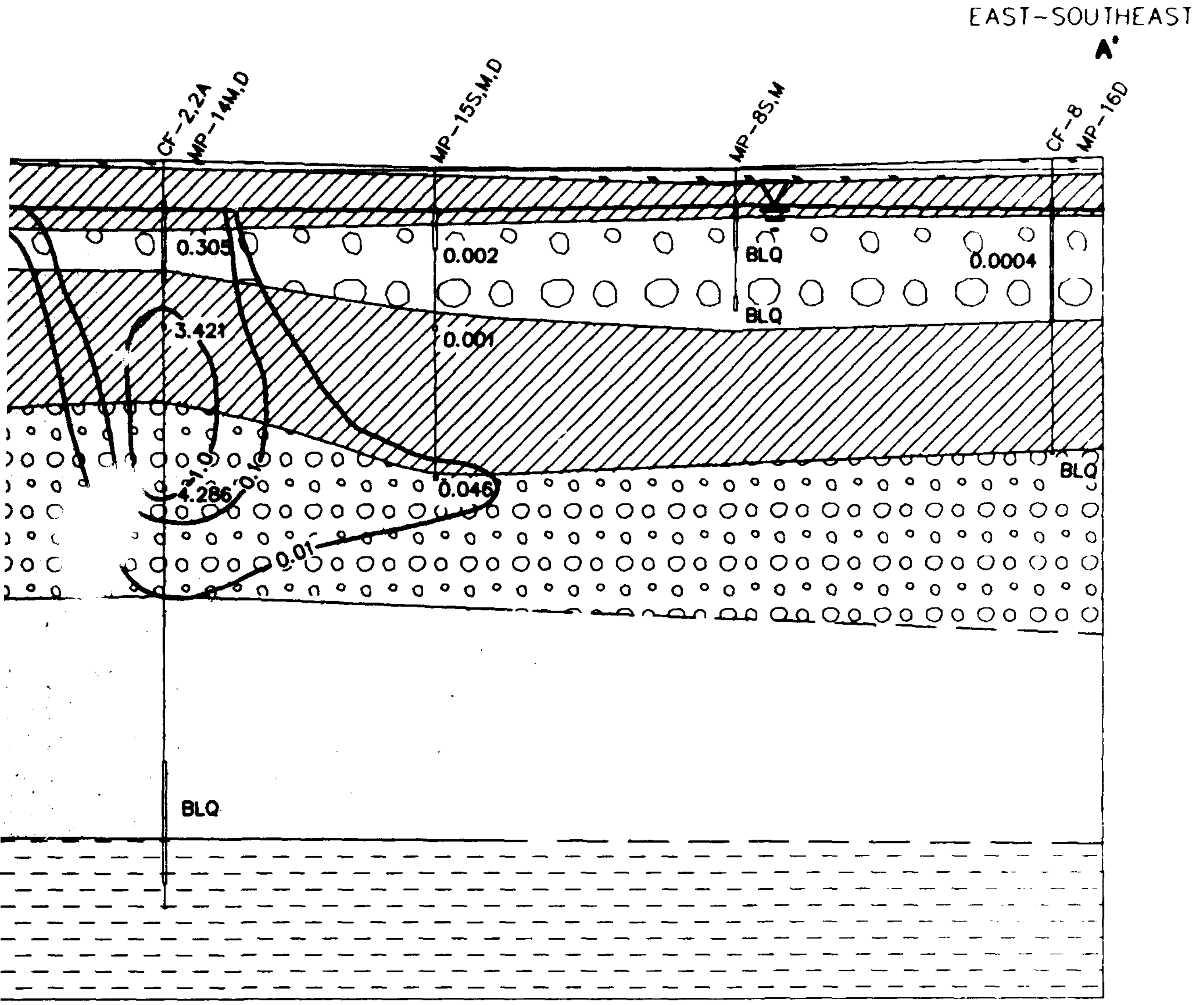
Denver, Colora



5

ne concentration (mg/L)

ntration (mg/L)

VERTICAL EXAGGERATION = 5x

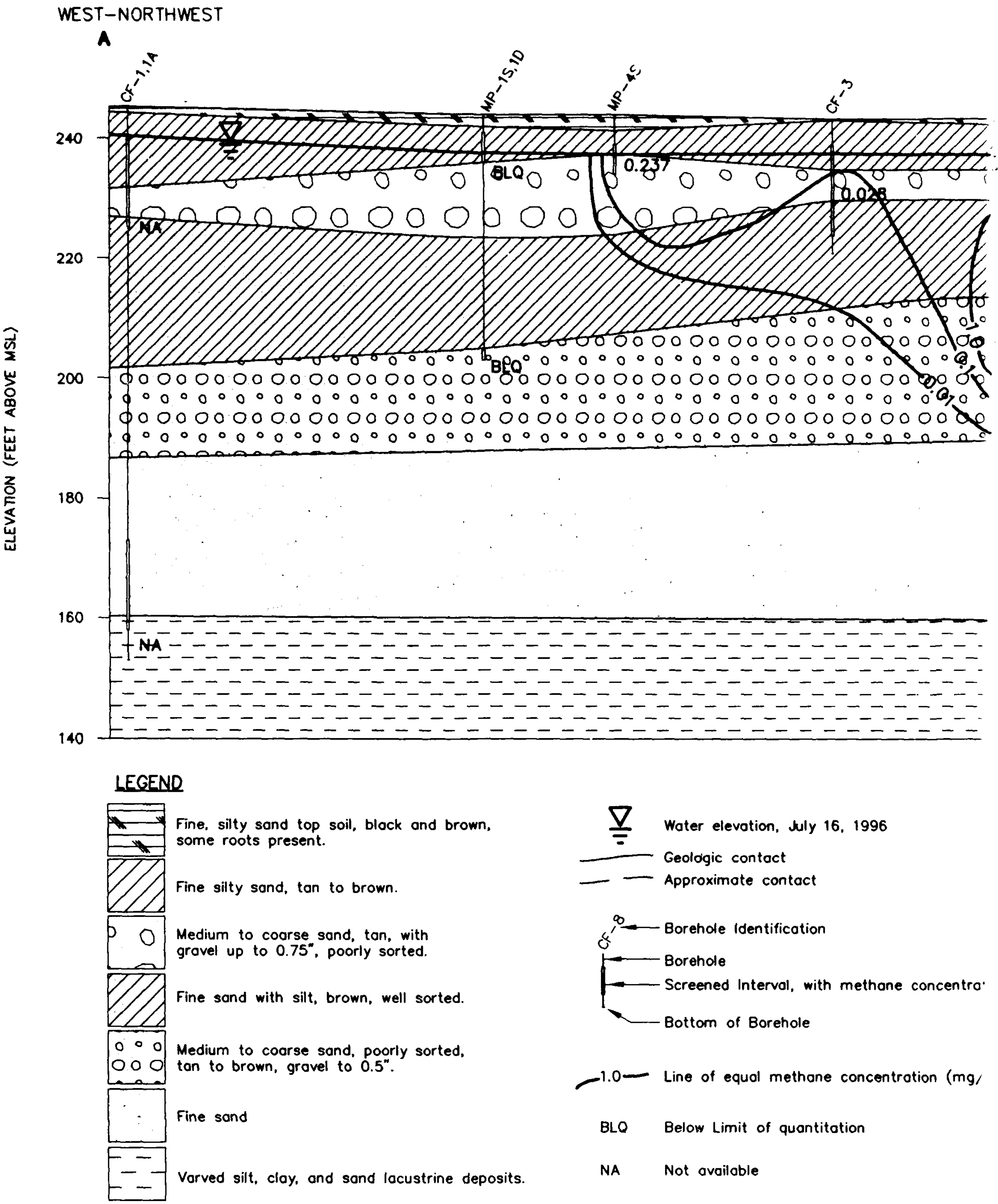
FIGURE 4.12a

VERTICAL PROFILE OF METHANE ISOPLETHS FOR GROUNDWATER MAY 1995

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado



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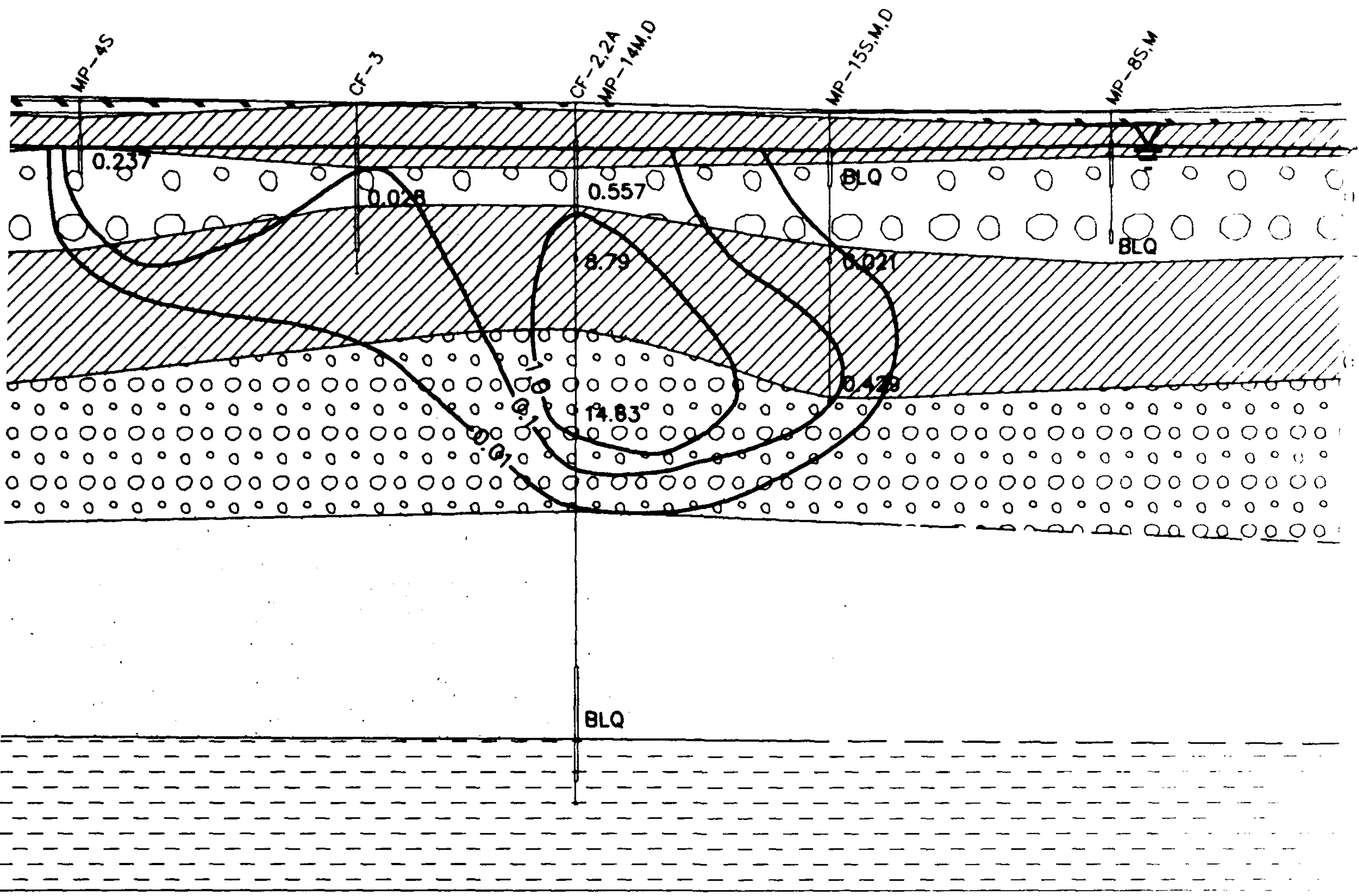

Water elevation, July 16, 1996

Geologic contact

Approximate contact

Borehole Identification

Borehole

Screened Interval, with methane concentration (mg/L)

Bottom of Borehole

1.0 Line of equal methane concentration (mg/L)

BLQ Below Limit of quantitation

NA Not available

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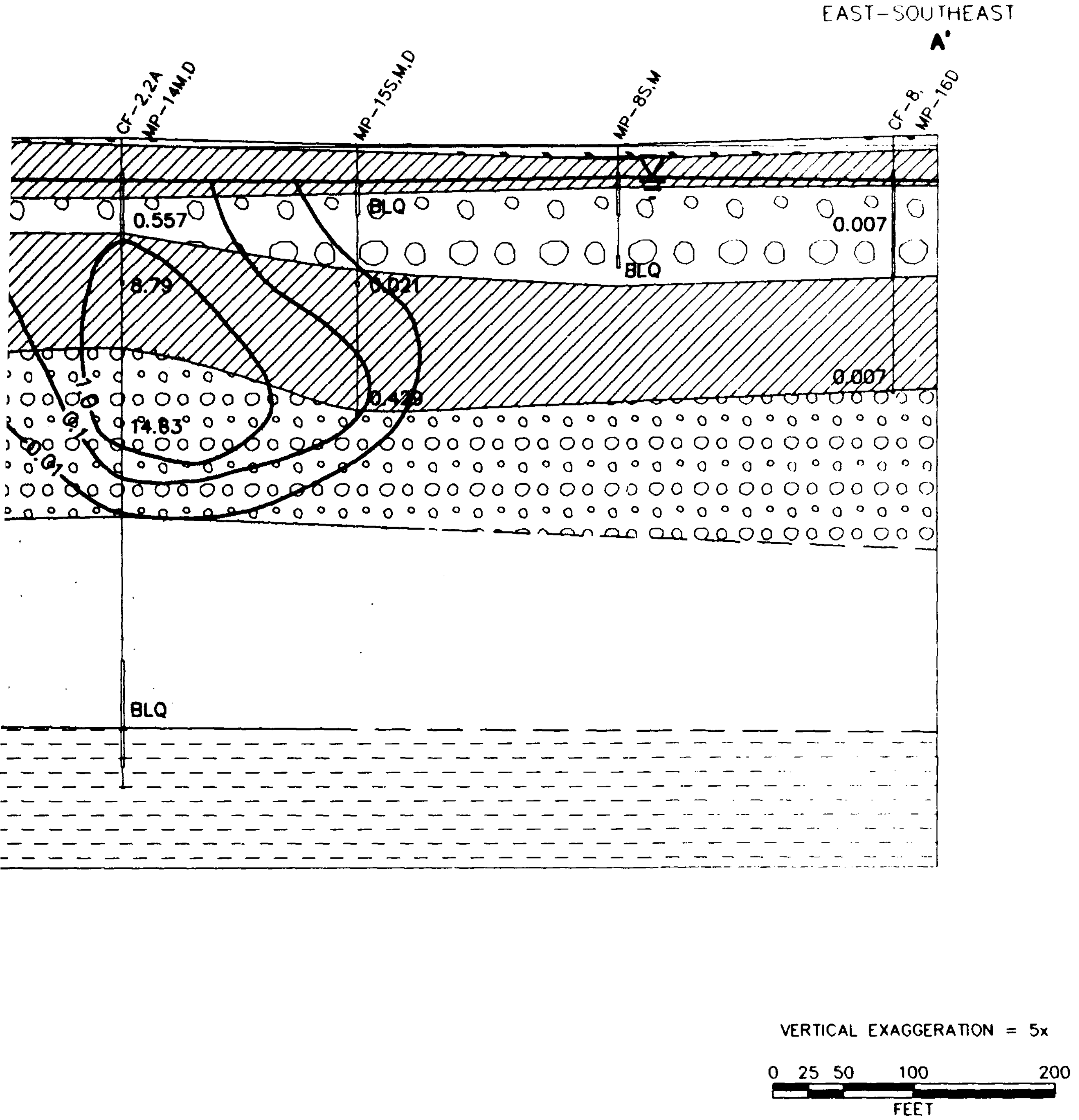


e concentration (mg/L)

ration (mg/L)

FIGURE 4.12b

VERTICAL PROFILE OF METHANE ISOPLETHS FOR GROUNDWATER JULY 1996

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

decrease in the redox potential of the groundwater corresponds to the decrease in iron reduction and the increase in surface reduction and methanogenesis at the site.

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.

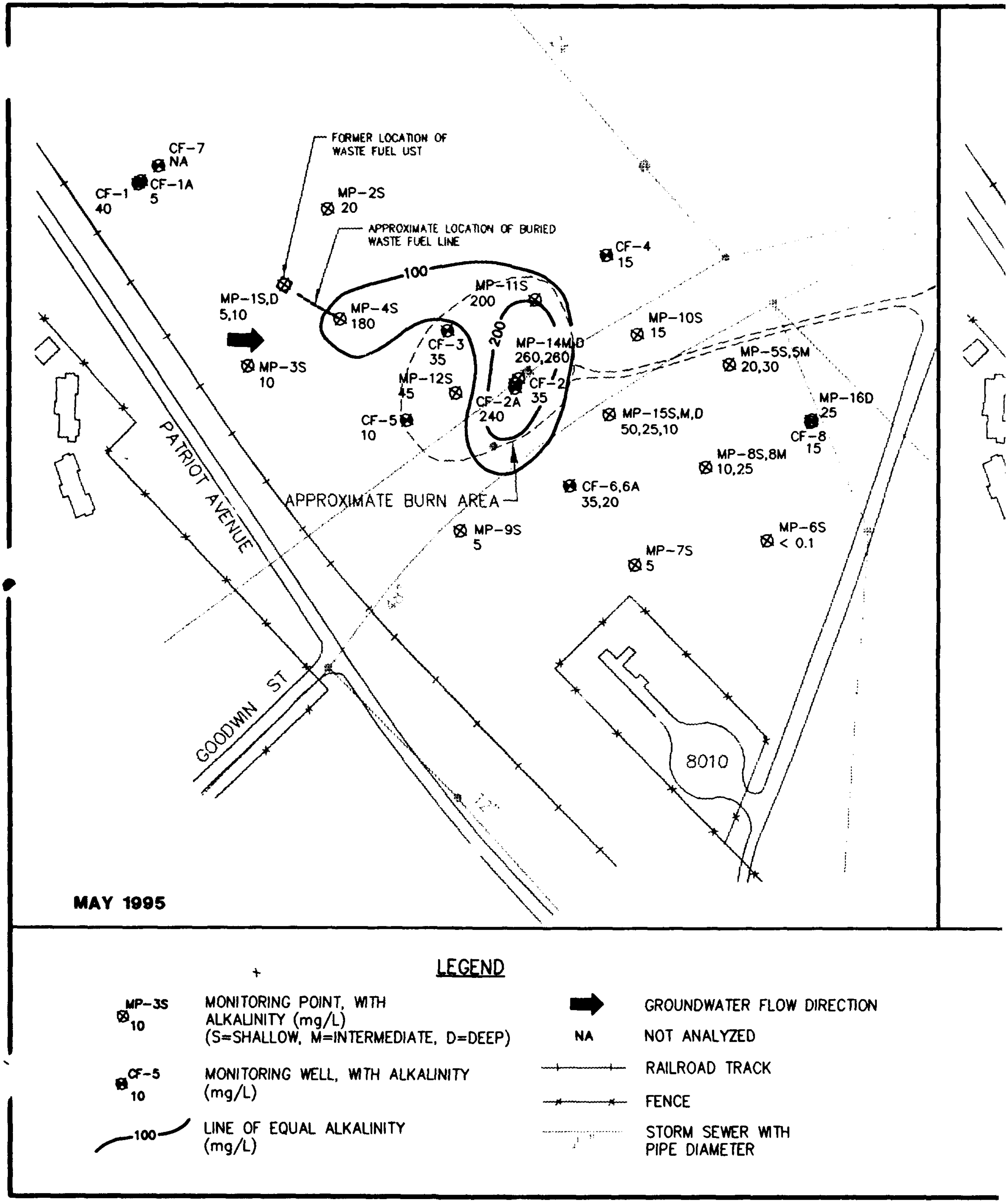
4.3.2.7 Volatile Fatty Acids

Groundwater samples were collected and analyzed for volatile fatty acids in both May 1995 and July 1996. Fatty acids are synthesized by microorganisms to be used in the production of lipids necessary for incorporation into various membranes. A portion of these fatty acids are volatile. Volatile fatty acids (VFAs) are produced when the bacterial cell has obtained the required energy for metabolism of a carbon source (i.e., BTEX, CAHs, or naturally occurring organic carbon). After VFAs are secreted form the bacterial cell, they volatilize fairly rapidly; therefore, detection of VFAs in groundwater is a strong indication of recent metabolic activity and possibly biodegradation of BTEX or CAHs. The standard method of VFA analysis performed by EPA researchers is a gas chromatography/mass spectrometry (GC/MS) method in which groundwater samples are compared to a standard mixture containing 58 phenols, aromatic acids, and aliphatic acids.

In May 1995, USEPA researchers reported that the sample from MP-4S contained 38 of the compounds in the standard mixture. However, due to a procedural error, the quantitation of the 12 phenols and creosols was not possible, resulting in a possible maximum of 46 (rather than 58) compounds that could be detected. In July 1996, groundwater samples from MP-14M and MP-14D were also analyzed for volatile fatty acids. EPA results show that of the 58 standard compounds, more than 50 were found in both samples. It is also notable that concentrations of the volatile fatty acids were much higher in the sample taken from MP-14D, where dissolved BTEX concentrations exceeded 20,000 μg/L. Since many of the VFAs were detected at high concentrations, results indicate significant and recent microbial activity in the groundwater at FT-08.

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. In May 1995 and July 1996, total alkalinity (as calcium carbonate) was measured in groundwater samples. These measurements are summarized in Table 4.5. Figure 4.13 presents two isopleth maps illustrating the increase in alkalinity in the areas of high BTEX concentration for May



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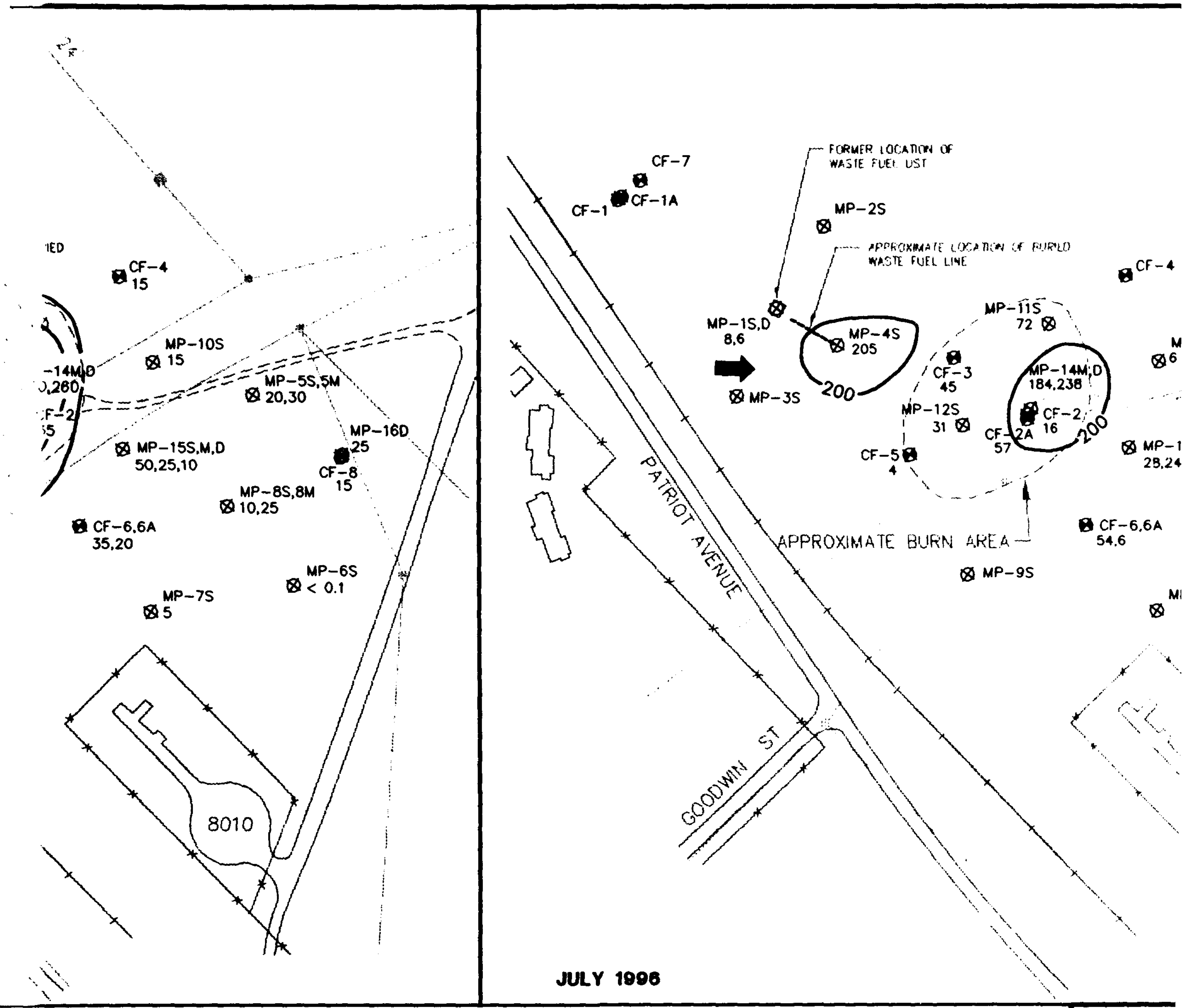

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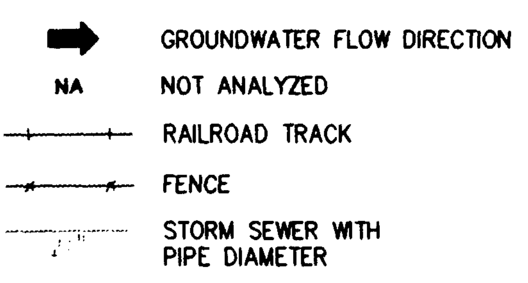

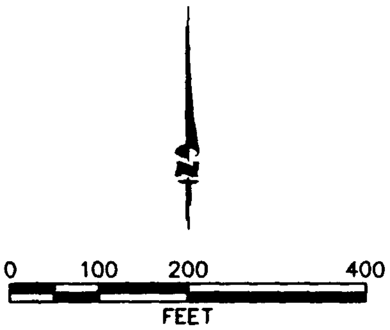

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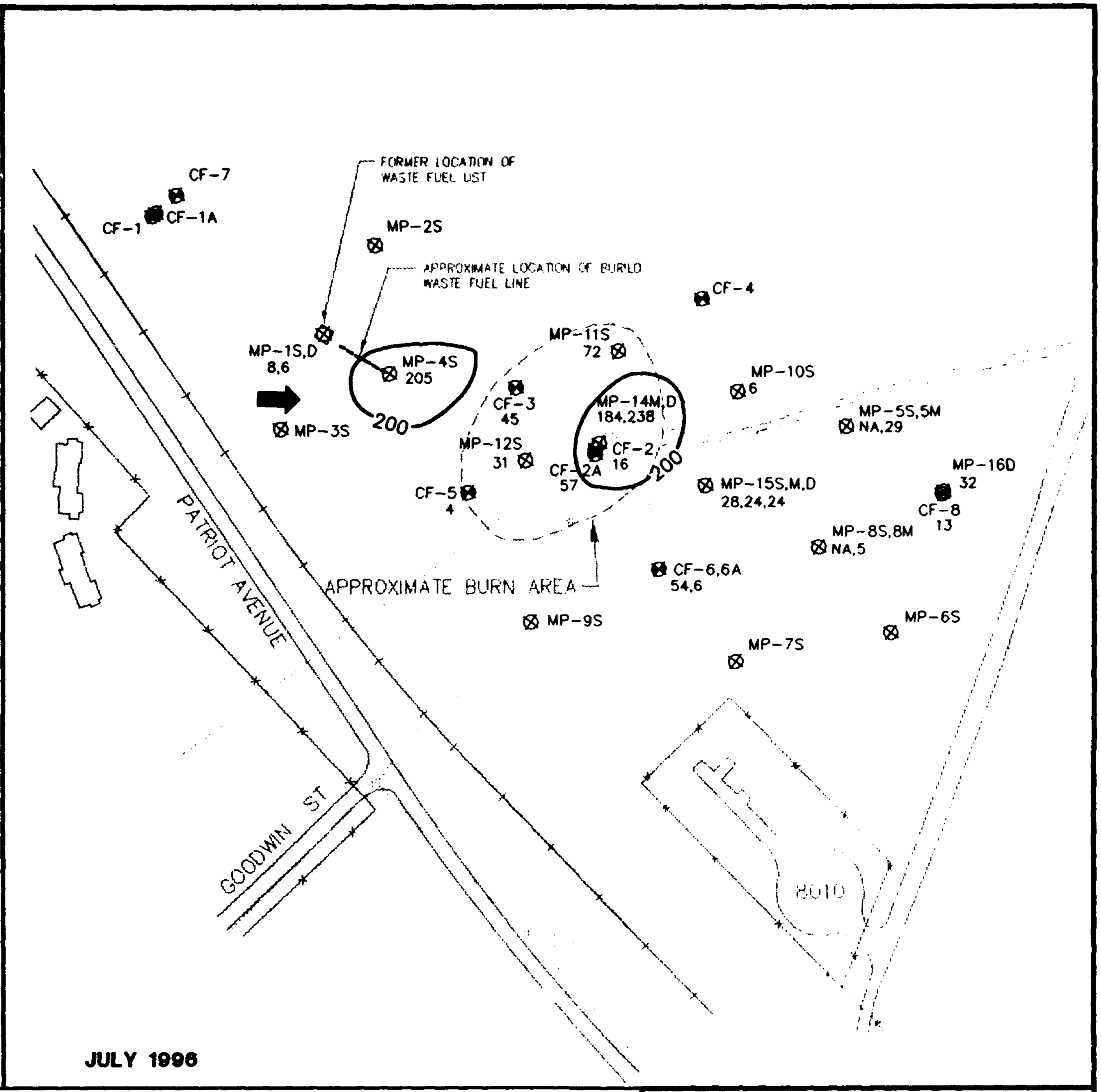


JULY 1996

FIGURE 4.13

ALKALINITY ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

1995 and July 1996. Total alkalinity at the site ranges from 5 mg/L at the site background well to 260 mg/L in May 1995, and from 4 mg/L to 238 mg/L in July 1996. When compared with the 1995 and 1996 BTEX plumes (Figure 4.2) the elevated alkalinity isopleths correlate with the groundwater BTEX plume. The total background alkalinity at FT-08 is in the low range for groundwater. The increase in alkalinity in the areas of groundwater BTEX contamination is in response to increased carbon dioxide levels that result from BTEX biodegradation. Increasing alkalinity acts as a buffer to weakly acidic conditions brought about by an increase in carbon dioxide.

An increase in alkalinity in an area with BTEX concentrations elevated over background conditions can be used to infer the amount of petroleum hydrocarbon destroyed through aerobic respiration, denitrification, iron(III) reduction, and sulfate reduction. Methanogenesis does not cause significant changes in alkalinity in comparison to the other terminal-electron accepting processes. The molar ratio of alkalinity produced during benzene oxidation via aerobic respiration, denitrification, iron(III) reduction, and sulfate reduction is given by:

$$C_6H_6 \rightarrow 6CO_2 \rightarrow 6CaCO_3$$

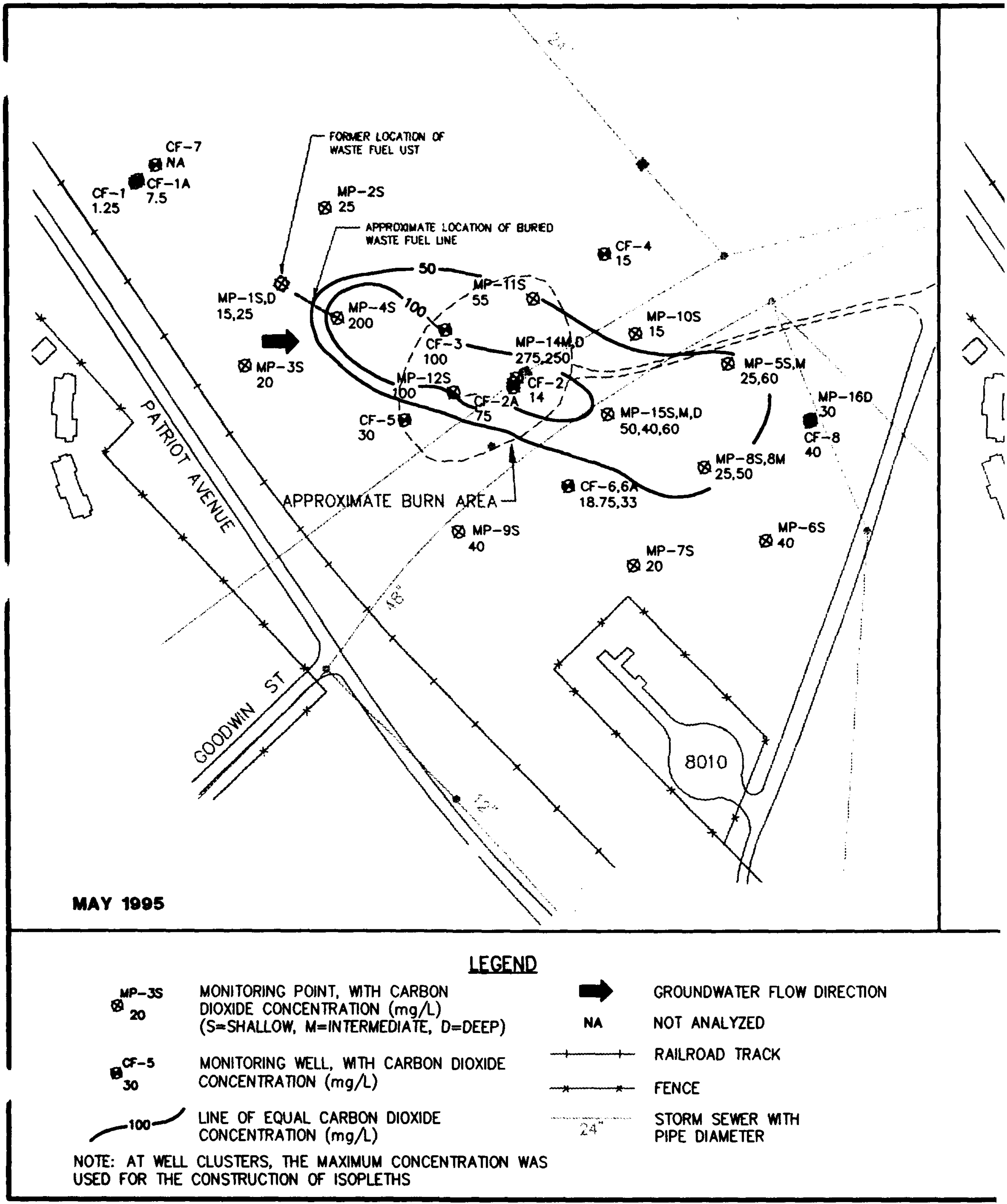
Therefore, 6 moles of $CaCO_3$ are produced during the metabolism of 1 mole of benzene. A mass balance of this reaction demonstrates that for every 1 mg of alkalinity produced, 0.13 mg of benzene is destroyed. Similar calculations can be made for toluene, ethylbenzene, and xylene. Given an average background alkalinity of 10 mg/L and an average source area concentration of approximately 230 mg/L for both sampling events, as much as 28,000 μg/L of BTEX could have been destroyed by aerobic respiration, denitrification, iron (III) reduction, and sulfate reduction. This alone does not demonstrate natural attenuation; however, it does provide additional evidence that natural attenuation of fuel hydrocarbons is occurring within the groundwater BTEX plume.

4.3.2.9 Carbon Dioxide in Groundwater

Carbon dioxide is produced in the plume area as a by product of aerobic respiration, denitrification, iron reduction, sulfate reduction and, methanogenesis (Table 4.4). Groundwater carbon dioxide measurements were collected from site monitoring wells in May 1995 and July 1996. Table 4.5 summarizes the groundwater carbon dioxide measurements. Areal distribution of carbon dioxide in groundwater for both the May 1995 and July 1196 sampling events is presented in Figure 4.14. Comparison of the area of elevated carbon dioxide on Figure 4.14 with Figures 4.6, 4.7, 4.8, and 4.10 further indicates that inferred biodegradation of BTEX compounds is occurring.

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 locations in May 1995 and July 1996. These measurements are summarized in Table 4.5. Groundwater pH measured at the site ranges from 6.33 to 8.30 in May 1995 and from 5.20 to 7.74 in July 1996. These ranges of pH are within the optimal range for BTEX-degrading microbes. In May 1995, a pH of 10.03 was measured in



NOTE: AT WELL CLUSTERS, THE MAXIMUM CONCENTRATION WAS USED FOR THE CONSTRUCTION OF ISOPLETHS

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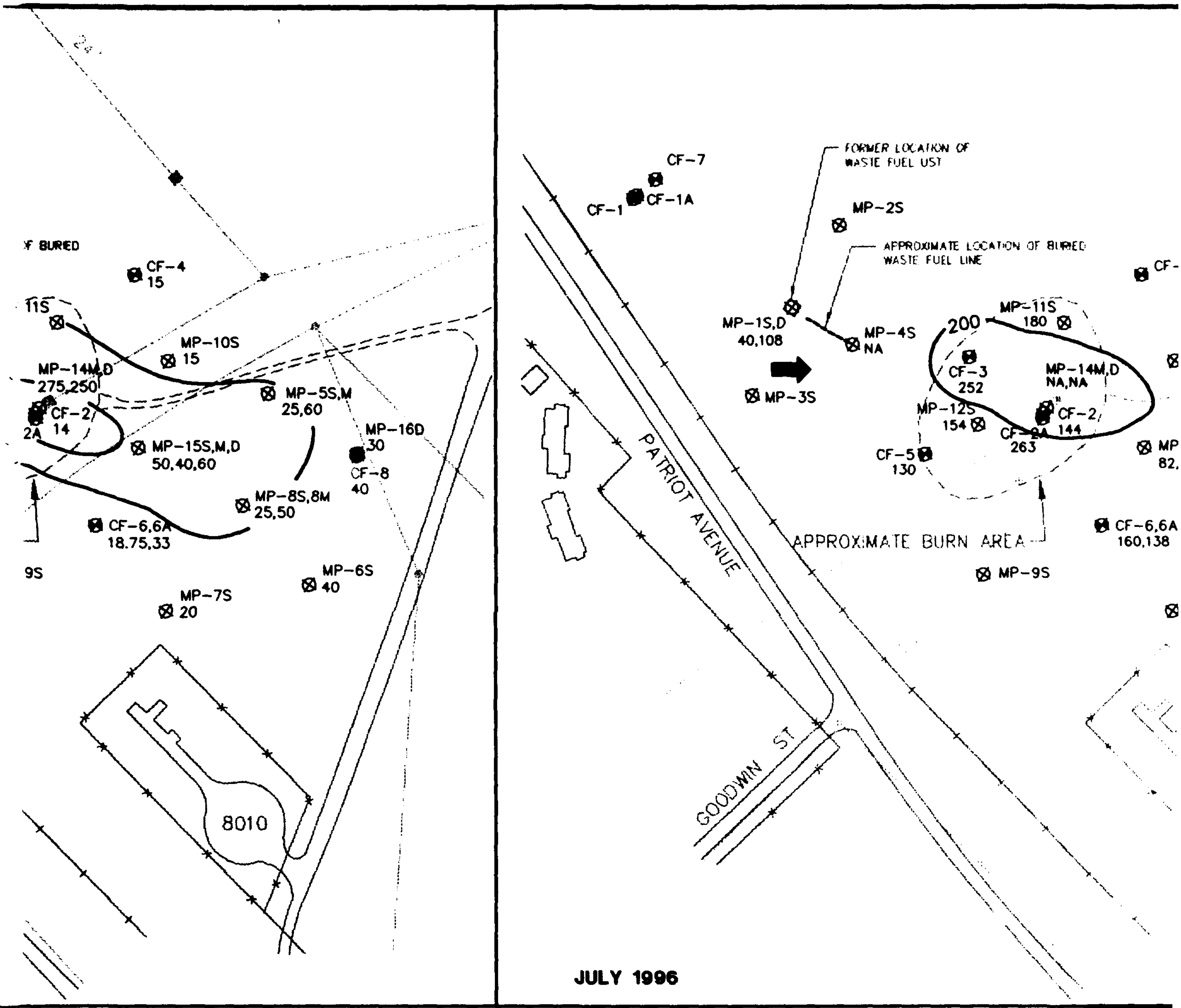

JULY 1996

END

➡	GROUNDWATER FLOW DIRECTION
NA	NOT ANALYZED
—+—+—	RAILROAD TRACK
—×—×—	FENCE
·········· 24"	STORM SEWER WITH PIPE DIAMETER

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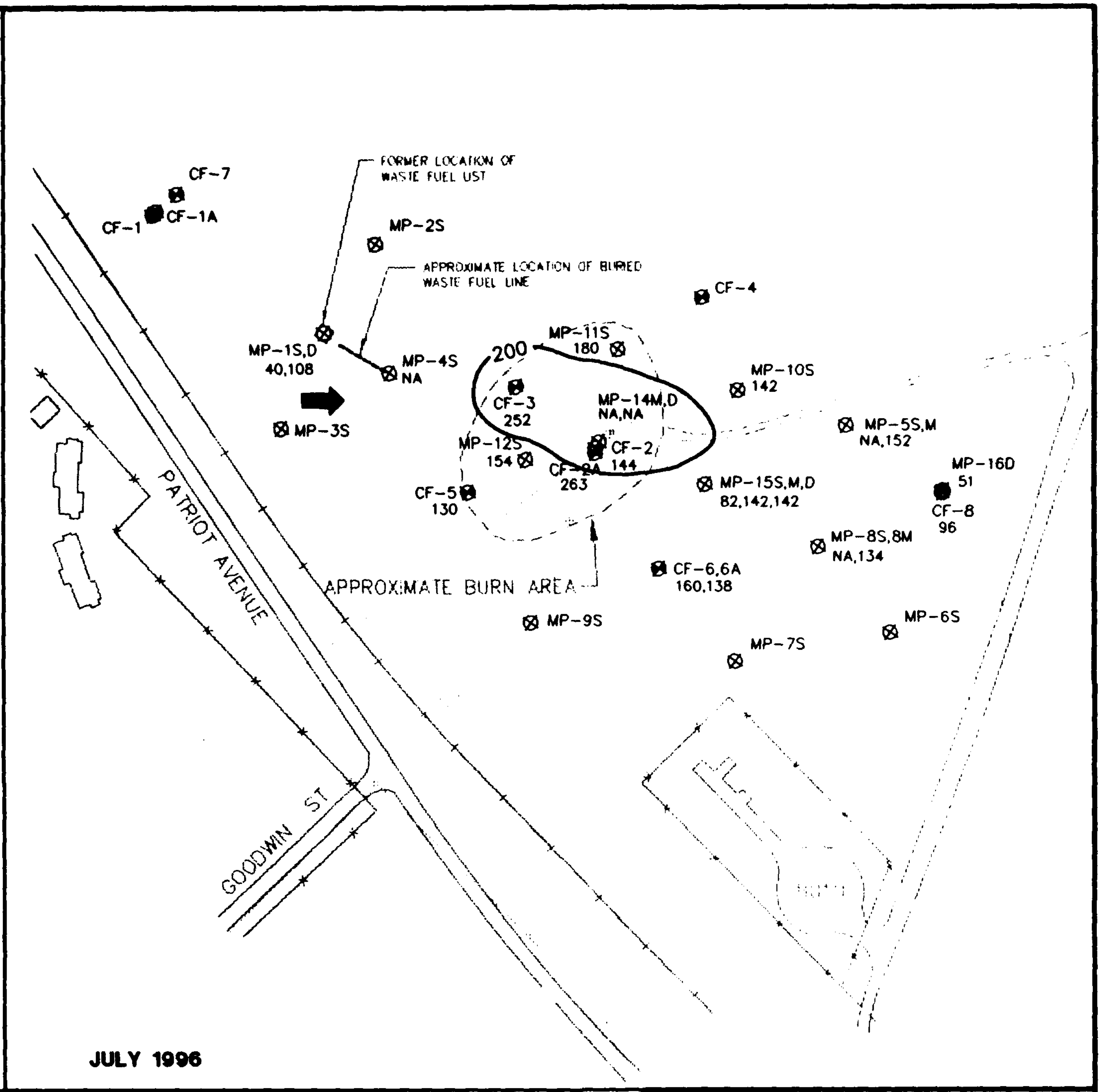

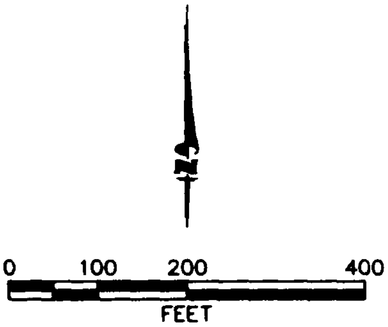

FIGURE 4.14

CARBON DIOXIDE ISOPLETH MAPS FOR GROUNDWATER

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

groundwater from monitoring well CF-1, however, this is most likely an anomalous value. High pH values frequently are caused by grout contamination, which can result from improper well construction.

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 1996 are summarized in Table 4.5. Temperatures in the aquifer varied from 8.5 degrees Celsius (°C) to 12.0 °C and from 10.6°C to 17.0°C in May 1995 and July 1996, respectively. These are relatively moderate temperatures for shallow groundwater, suggesting that bacterial growth rates should not be inhibited.

4.3.3 Expressed Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis. On the basis of the stoichiometry presented in Table 4.4, the expressed BTEX assimilative capacity of groundwater at FT-08 was at least 27,510 μg/L in May 1995 and at least 30,230 μg/L in July 1996 (Table 4.6).

A closed system containing 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*" mg 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*" mg 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*" mg of fuel hydrocarbons were in the second liter of water, only "*x*" mg of fuel hydrocarbons would ultimately degrade.

The groundwater beneath a site is an open system, which continually receives additional electron acceptors from 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 concentrations in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. 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 (Chapelle, 1994). This significant expressed assimilative capacity is a strong indicator that biodegradation is occurring; however, it is not a guarantee that biodegradation will proceed to completion before potential downgradient receptors are impacted.

TABLE 4.6
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
CURRENT FIRE TRAINING AREA
INSTRINSIC REMEDIATION TS
WESTOVER AIR RESERVCE BASE, MASSACHUSETTS

Electron Acceptor or Process	May 1995 Expressed BTEX Assimilative Capacity (μg/L)	July 1996 Expressed BTEX Assimilative Capacity (μg/L)
Dissolved Oxygen	3,140	2,860
Nitrate	3,530	3,530
Iron Reduction	12,800	2,080
Sulfate	2,540	2,960
Methanogenesis	5,500	18,800
Expressed Assimilative Capacity	27,510	30,230

At FT-08, the groundwater appears to provide sufficient assimilative capacity to decrease the dissolved BTEX contaminant mass and limit plume migration over time. In addition, the calculations of assimilative capacity presented in the earlier sections are conservative because they do not account for microbial cell mass production, and the measured concentrations of ferrous iron and methane may not be the maximum achievable. There is also a potential for the influx of electron acceptors (particularly oxygen) through rainwater infiltration at the site. The addition of this water may further enhance the assimilative capacity of the site groundwater.

4.3.4 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 4.3.3; 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.

4.3.4.1 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 as shown in Figure 4.15. 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-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.

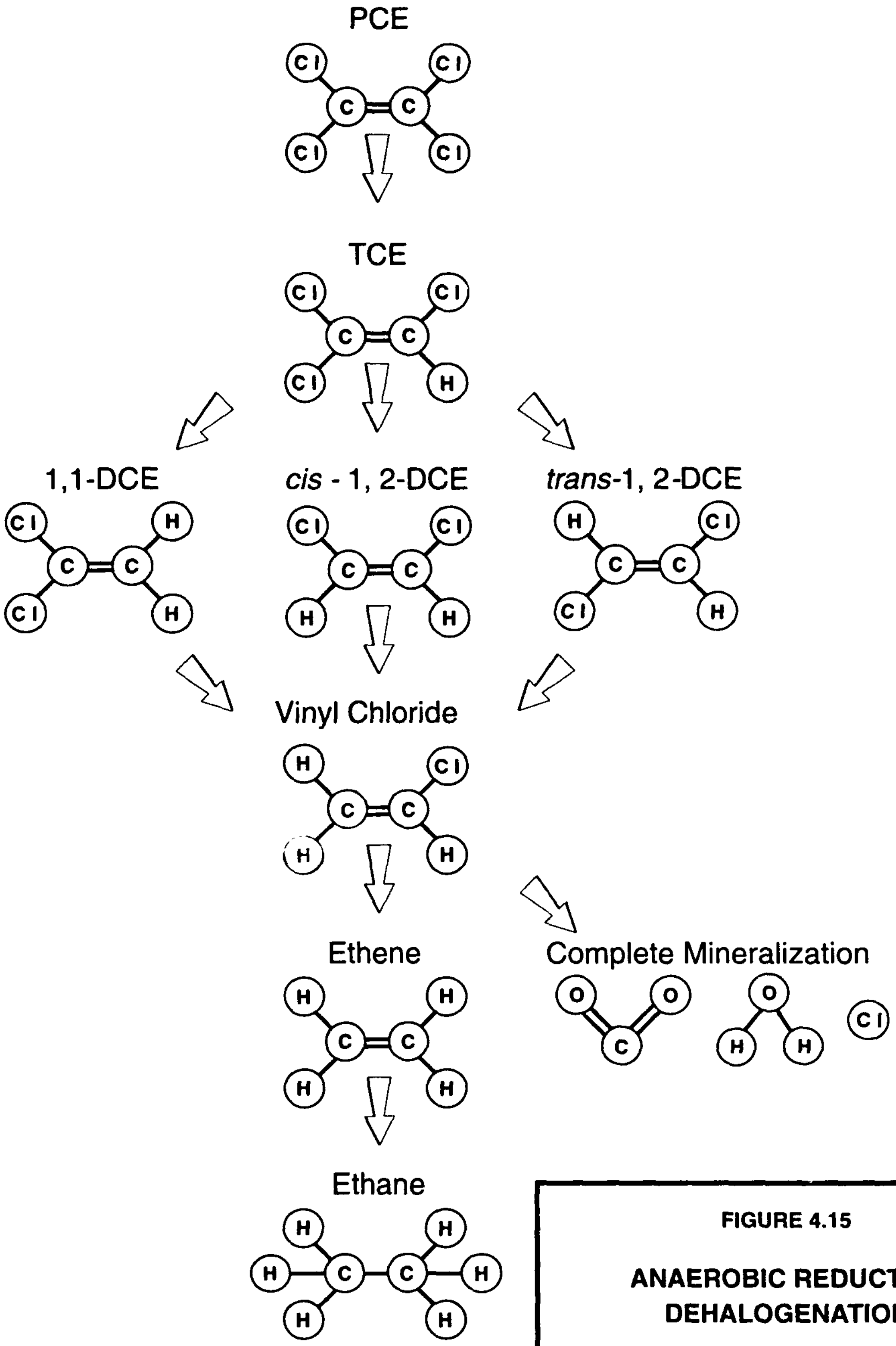

FIGURE 4.15

ANAEROBIC REDUCTIVE DEHALOGENATION

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Messachusetts

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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).

Fortuitously, the degree of sorption of chlorinated solvents to organic matter in soil is proportional to the amount of chlorine in the molecule and consequently, the compounds with more chlorine (e.g., PCE, TCE, and DCE) have slower contaminant velocities due to increased retardation. This results in a longer residence time in the highly reducing anaerobic core for chlorinated solvent compounds containing the most chloride. Once again, this zone is most favorable for the degradation of highly chlorinated compounds. Conversely, solvents with fewer chlorine atoms travel more rapidly through the anaerobic regions of the plume and into the aerobic fringe, thereby bringing these compounds into the region most favorable to their degradation as described in Section 4.3.4.2.

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 increased percentage of cis-DCE to TCE both downgradient from the source area and between May 1995 and July 1996 suggests that TCE is being reductively dehalogented. This is further supported by the absence of significant trans-1,2-DCE concentrations during both sampling events. Sulfate reduction and methanogenesis in the core of contaminant plume also support the probability that reductive dehalogenation is occurring. Redox conditions in the core of the plume also are favorable for the reductive dehalogenation of TCE. The further reductive dehalogentation of cis-DCE is indicated by the presence of vinyl chloride. Because vinyl chloride is not observed frequently at the site, it is likely that the reductive dehalogenation of cis-DCE to vinyl chloride is occurring at a very slow rate and only in the core of the dissolved chlorinated plume.

4.3.4.2 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). 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. Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic oxidation of vinyl chloride and DCE may be characterized by loss of contaminant mass, a decreasing molar ratio of vinyl chloride and DCE to other CAH compounds, and the presence of elevated CO_2 concentrations. Possible biodegradation pathways in aerobic conditions are presented in Figure 4.16.

The disappearance of cis-DCE from the site groundwater between May 1995 and July 1996 without a corresponding accumulation of vinyl chloride suggests that cis-DCE is being metabolized as an electron donor at the contaminant plume fringes where groundwater conditions are more aerobic.

4.3.4.3 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-DCE concentrations are being reduced through cometabolic processes.

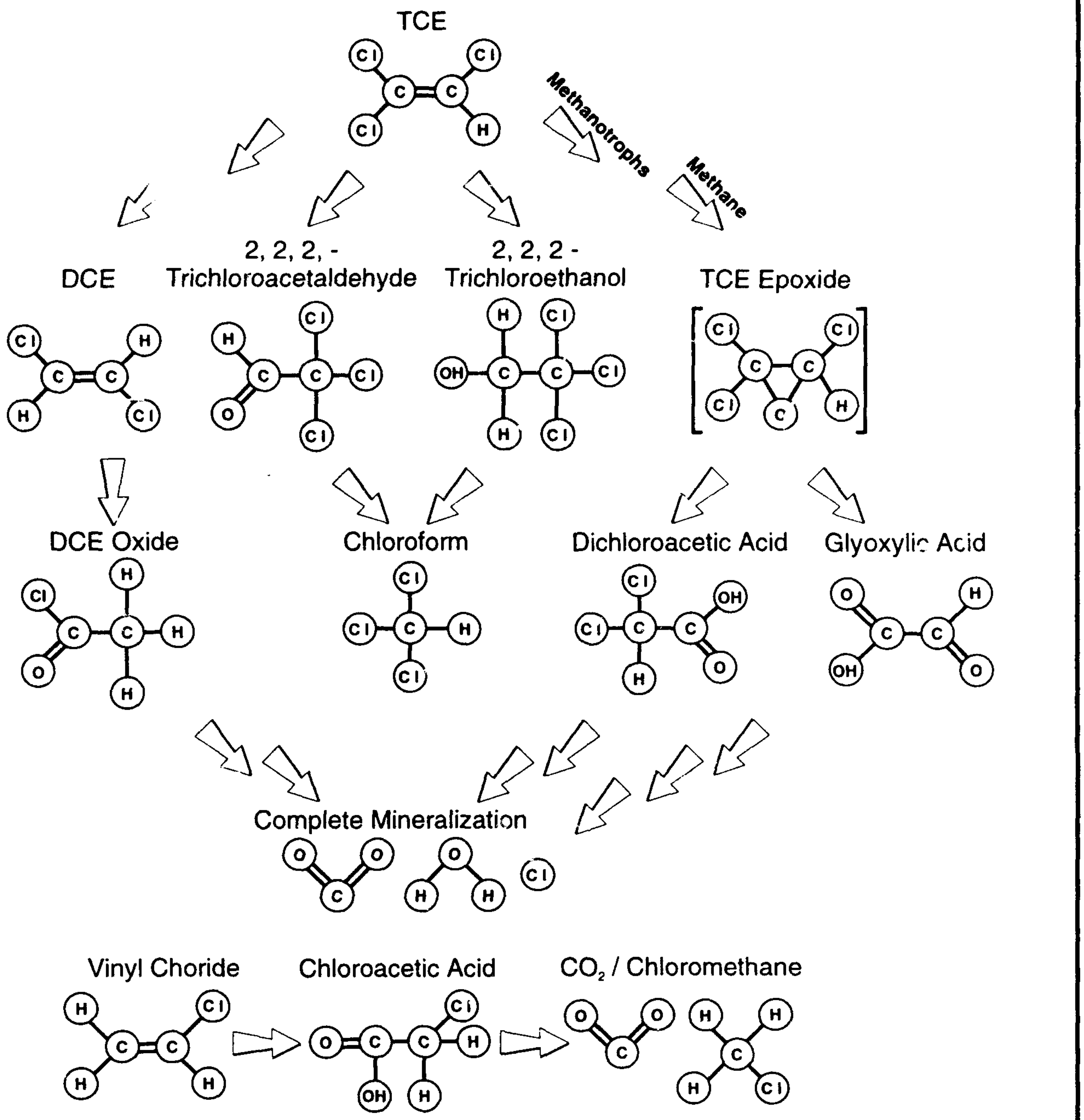

FIGURE 4.16

AEROBIC PATHWAYS

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Messachusetts

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Denver, Colorado

4.3.4.4 Chloride

Chloride concentrations were measured in groundwater samples collected in May 1995 and July 1996. Concentrations at the site ranged from <0.5 mg/L to 150 mg/L and from less than 0.5 mg/L to 131 mg/L in May 1995 and July 1996 respectively. Table 4.5 summarizes measured chloride concentrations. The only significantly elevated chloride concentrations for both the May 1995 and July 1996 sampling events were detected in MP-14M and MP-14D. Concentrations of chloride at these locations were greater than 80 mg/L in both May 1995 and July 1996. All other measured chloride concentrations were less than 10 mg/L. MP-14D and MP-14M also had the second- and third- highest chlorinated solvent concentrations and are immediately downgradient of well CF-3, where the highest chlorinated solvent concentration was measured. The MP-14 cluster contained a higher percentage of daughter products than CF-3; therefore, elevated chloride concentrations would be expected as a result of reductive dechlorination. In summary, the elevated chloride concentrations within the BTEX and chlorinated solvent plumes is a strong indication that reductive dechlorination of chlorinated solvents is occurring in the anaerobic, reducing groundwater at FT-08.

SECTION 5

GROUNDWATER MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved BTEX compounds at the FT-08 site and to help predict the future migration of these compounds, Parsons ES numerically modeled the fate and transport of the dissolved BTEX plume. Contaminant fate and transport models are very sensitive to the magnitude and extent of the source area; therefore, a reliable model for chlorinated solvents could not be generated because neither of these is well defined for chlorinated solvents. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of biodegradation, advection, dispersion, and sorption; 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 evaluation of the intrinsic remediation option at post-modeling regulatory negotiations. The models were developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from the natural attenuation processes is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by natural mechanisms operating at FT-08. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. On the basis of the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous biologically mediated reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic´-Galic´, 1990; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic´-Galic´, 1992; Grbic´-Galic´ and Vogel, 1987; Lovley *et al.*, 1989; Hutchins, 1991). Because geochemical evidence supports the occurrence of anaerobic biodegradation processes at FT-08 (Section 4.3.2), the combined processes of aerobic and anaerobic biodegradation were considered in calculating BTEX fate and transport at the site. The following subsections discuss in detail the input parameters, the model assumptions, the model calibration, and the simulation results.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that oxygen-limited biodegradation is occurring at the site. The Bioplume II model assumes that the limiting factors for biodegradation are: 1) the presence of an indigenous hydrocarbon-degrading microbial population, and 2) sufficient background electron acceptor concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, nitrate, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation.

On the basis of the data presented in Section 3, the shallow aquifer is vertically defined by poorly sorted medium- to coarse-grained sands overlying a silty sand layer. Below the silty sand, a medium to coarse sand defines the lower portion of the aquifer. The majority of dissolved BTEX contamination preferentially migrates from the site in the sands overlying the silty layer. Leakage through the silty sand into the lower coarse sands is occurring and was incorporated into the model. Lithologic data from previous soil borings (Section 3) suggest that the base of the shallow aquifer is defined by an impermeable varved silt and clay layer at approximately 80 feet bgs. Minor changes in site topography and variability in aquifer hydraulic parameters may be responsible for a change in groundwater flow direction across the site. Groundwater enters the site from the northwest. Groundwater elevations suggest that the groundwater at the site flows to the southeast near the source of the plume (near MP-4S), then turns east downgradient of the main burn area (near MP-15S) (Figure 3.5). Groundwater also approaches the site from the southwest and south, but the flow turns east and does not enter the site.

The shallow alluvial layer above the silty layer was conceptualized and modeled as a shallow unconfined aquifer composed of medium- to coarse-grained sand (Figures 3.2, 3.3, and 3.4). The average saturated thickness of this layer was estimated at 10 feet. The use of a 2-D model is appropriate at the FT-08 site because the shallow saturated interval (acting as the dominant transport pathway) is relatively homogeneous. Because contamination detected in the deeper sand layer appears to be under similar hydrologic and geochemical conditions, similar contaminant fate and transport conditions are anticipated.

Dissolved BTEX is known to originate from residual soil contamination present in the shallow soils within the burn pit. An additional source was also found during this investigation at the outfall of a buried pipe that was attached to the removed waste fuel tank. This release at the pipe outfall occurred upgradient from the fire training pit and has migrated into the existing BTEX plume. Contaminated soils at the site have not been remediated, however, the former waste fuel tank located upgradient of the site, was removed in 1986. Given the current site use, additional fuel releases are not expected at the site in the future; therefore, only BTEX contamination leaching from current residual fuel contamination in site soils was considered as a continuing source for the dissolution of BTEX into groundwater over time.

5.3 INITIAL MODEL SETUP

The setup for this model was based on available site data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions for the types of materials that make up the shallow aquifer were made on the basis of widely accepted literature values. The following sections describe the basic model setup. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 30-cell grid was used to model the FT-08 site. Each grid cell was 60 feet long by 60 feet wide. The grid was oriented so that the longest dimension was parallel to the east-southeast groundwater flow direction. The grid includes the existing BTEX plume and encompasses an area of 2.16 million square feet (approximately 50 acres). The full extent of the model grid is indicated on Figure 5.1.

Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (i.e., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

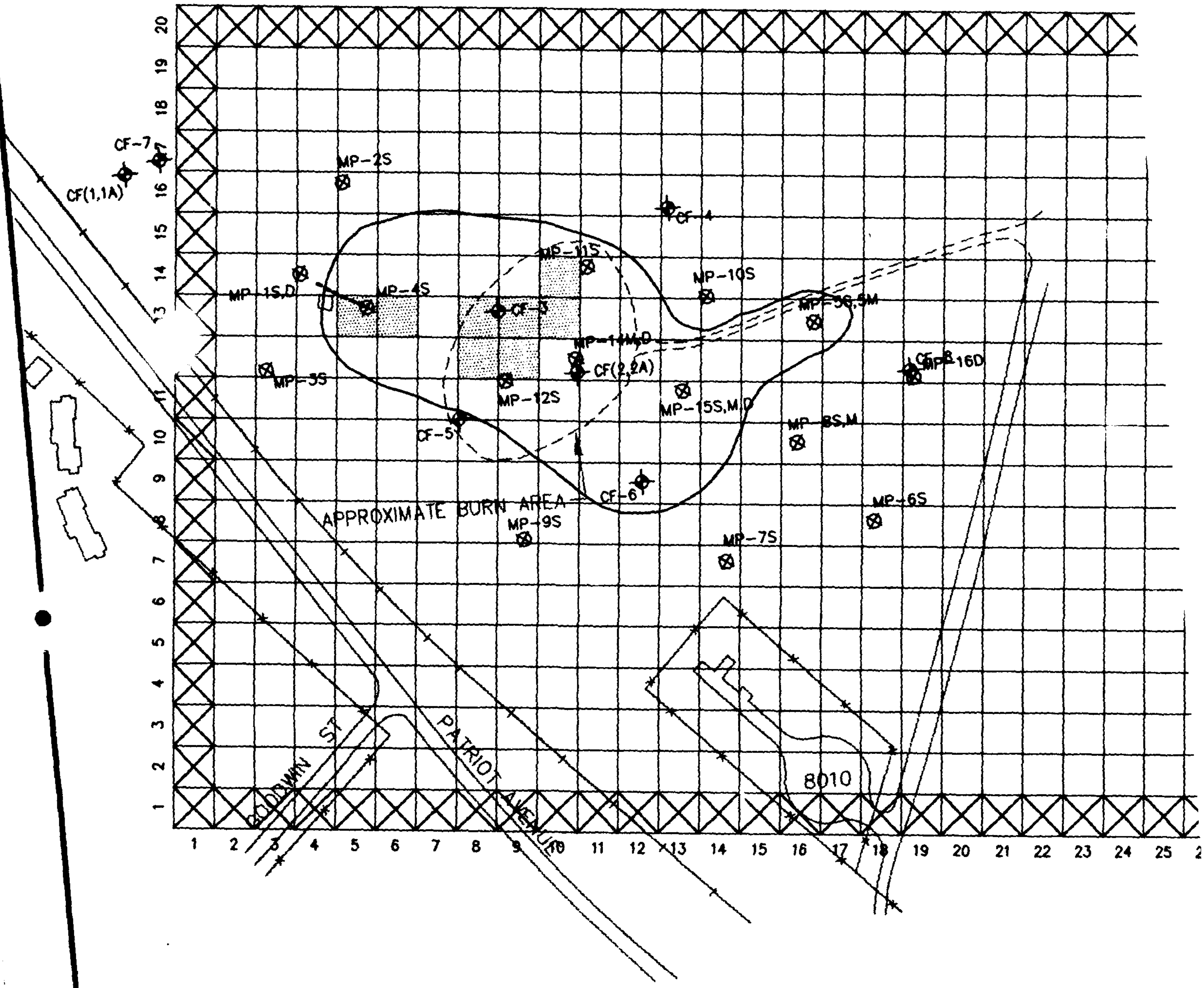
- Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant head conditions. Specified-head boundaries are expressed mathematically as:

  $$Head = f(x,y,z,t)$$

  where f is the function symbol, x, y, and z are position coordinates, and t is time.

- Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (i.e., $ft^3/ft^2/day$). No-flow boundaries are a special type of specified-flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and impermeable hydrostratigraphic units. Specified-flux boundaries are expressed mathematically as:

  $$Flux = f(x,y,z,t)$$



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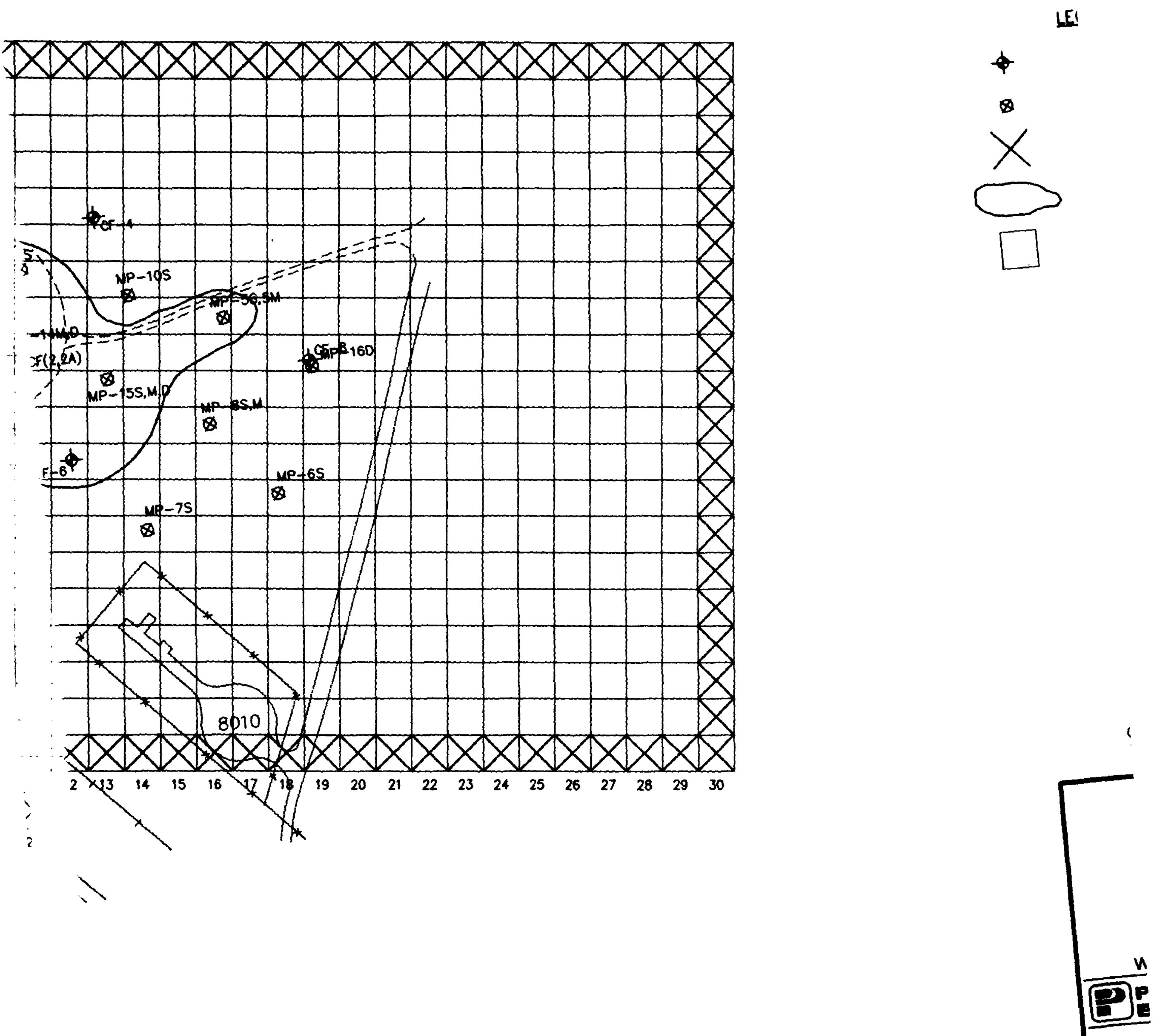
LE
CF-4
5
9
MP-10S
MP-5S,5M
-14M,D
CF(2,2A)
CF-8
MP-16D
MP-15S,M,D
MP-8S,M
F-6
MP-6S
MP-7S
8010
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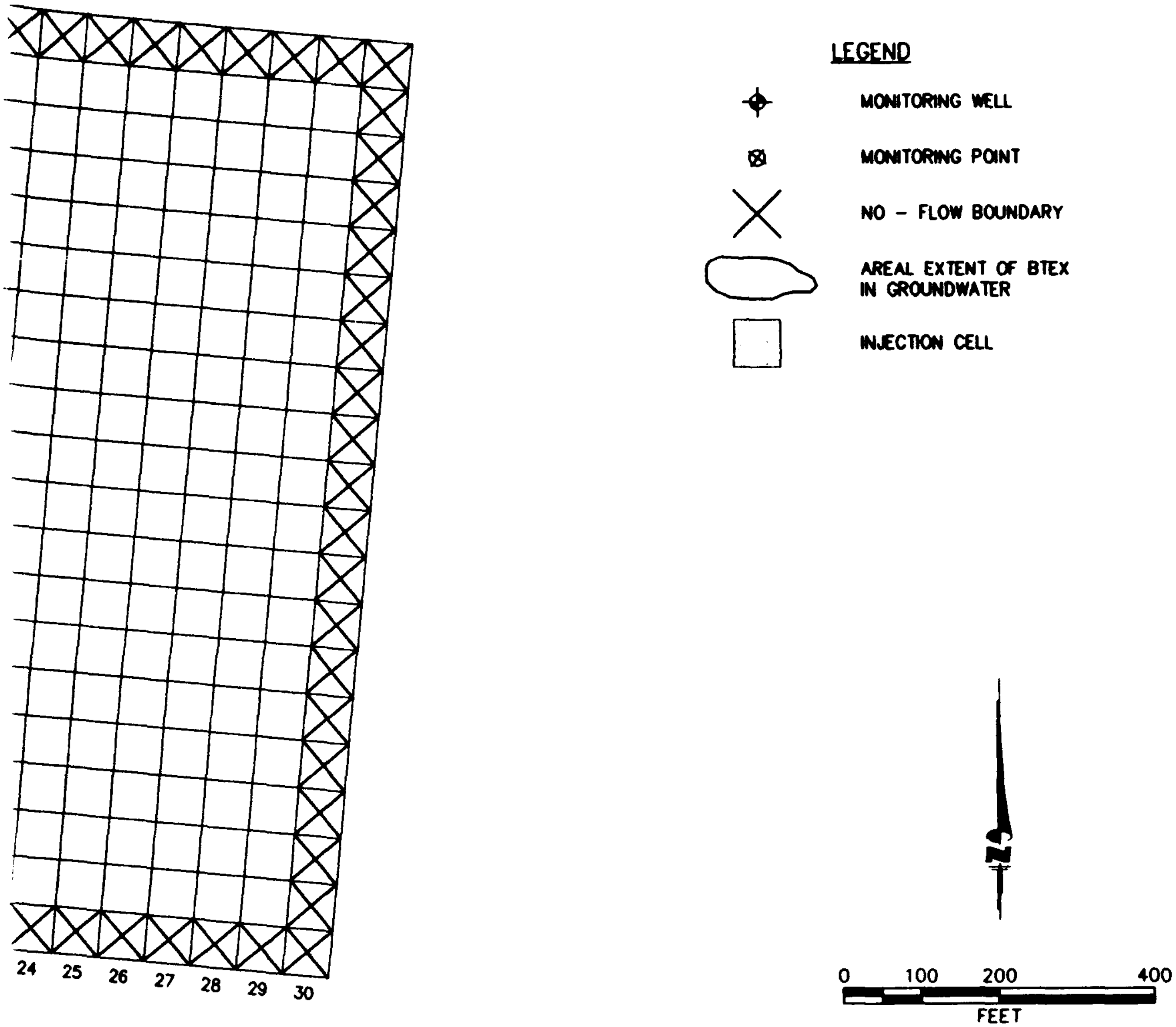

FIGURE 5.1

MODEL GRID

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

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Denver, Colorado

- Head-dependent flow boundaries (Cauchy or mixed-boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model leakage across semipermeable boundaries. Head-dependent flow boundaries are expressed mathematically as (Bear, 1979):

$$Flux = \frac{\left(H_0 - H\right)K'}{B'}$$

Where: H = Head in the zone being modeled (generally the zone containing the contaminant plume),

H_0 = Head in external zone (separated from plume by semipermeable layer),

K' = Hydraulic conductivity of semipermeable layer, and

B' = Thickness of semipermeable layer.

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be specified at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

Specified-head boundaries for the model were set on all sides of the model grid. Typically in two-dimensional models, two rows of specified-head boundaries are sufficient to simulate the flow of groundwater for sites that are not hydrogeologically complex or are bounded by adjacent lakes or streams. However, placement of specified-head cells on all sides of the model grid for the FT-08 site was necessary because of the observed change in groundwater flow direction. The head of the western boundary was estimated to be from 238 to 238.4 feet above msl, and represents the level of groundwater in this portion of the site. The heads of the model grid boundaries coinciding with the north and south boundaries were estimated at 237.1 to 238.4 feet msl and 238 to 238.8 feet msl, respectively. The heads along the eastern model boundary range from 235 to 235.75 feet msl.

The base or lower boundary of the model is assumed to be no-flow, and is defined by the upper surface of the silty sand and clay layer located approximately 20 feet bgs. The upper model boundary is defined by the simulated water table surface.

5.3.2 Groundwater Elevation and Gradient

The water table elevation map presented in Figure 3.5 was used to define the heads used as initial input into the Bioplume II model. Groundwater flow in the vicinity of FT-08 is to the east-southeast with a gradient range over the modeled area of approximately 0.0019 ft/ft to 0.0043 ft/ft. Gradients are lowest in the burn pit and highest near the northeastern model boundary.

5.3.3 BTEX Concentrations

As noted in Section 5.2, dissolved BTEX enters groundwater at FT-08 through two ongoing processes: contact between groundwater and residual LNAPL at or below the water table in the two source areas and migration of recharge (precipitation) through soil containing residual LNAPL above the water table. The total dissolved BTEX concentrations obtained from laboratory analytical results for each well and monitoring point location were used for model development. At well/point nests, the BTEX concentration in the shallowest well was selected to represent concentrations in the shallow aquifer. Table 4.3 presents dissolved BTEX concentration data. Figure 5.1 shows the areal extent of dissolved BTEX compounds in shallow groundwater. Figure 4.3 shows the vertical distribution of dissolved BTEX in groundwater along the preferential groundwater flow pathway.

Modeled BTEX dissolution was approximated using injection wells within 8 model cells situated in the core area of residual soil contamination (Figure 5.1). The estimated source strength was selected to maintain a mass balance without exceeding the constraints of the Bioplume II model. The injection volume for the BTEX injection wells was set at a rate low enough that the hydraulic calibration for the model was not affected.

Initial BTEX mass loading rates were estimated using a groundwater flux calculation. The flux calculation uses aquifer parameters and the known groundwater BTEX concentrations to estimate the strength of the source required to maintain observed BTEX concentrations under measured groundwater flow conditions. The flux calculations account for BTEX dissolution arising from the flushing of groundwater through contaminated soils and the partitioning of total BTEX from contaminated vadose zone soils into downward percolating precipitation. These flux estimates were then varied in order to calibrate the model by reproducing the observed BTEX plume. At the outfall of the abandoned fuel pipe, the loading rates were reduced to 10 and 15 percent of the calculated rate to account for a source of residual contamination that occupies only a small fraction of the total cell area. The flux calculations for each source cell are presented in Appendix C.

5.3.4 Biodegradation Rates

Available data strongly suggest that anaerobic degradation is occurring at the site. Combined anaerobic processes account for over 85 percent of the expressed assimilative capacity of site groundwater (Table 4.6). Anaerobic degradation must therefore be simulated with Bioplume II to make meaningful predictions. The Bioplume II model simulates anaerobic biodegradation by assuming that such degradation follows first-order kinetics. As with a large number of biological processes, anaerobic 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,

C_0 = Initial Contaminant Concentration,

k = Coefficient of Anaerobic Decay (anaerobic rate constant),

t = time.

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 (Bear, 1979). 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, and

k/v_x = slope of line determined from a log-linear plot of contaminant concentration versus distance downgradient along flow path.

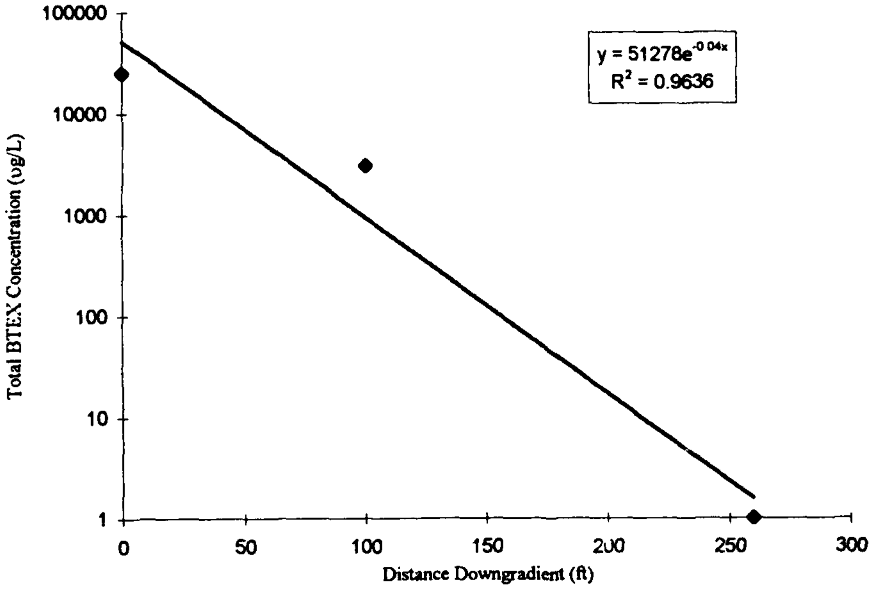
The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Table 5.1 presents a first-order rate constant calculation for BTEX using May 1995 data at FT-08 and the method proposed by Buscheck and Alcantar (1995). An easterly groundwater flow path through wells MP-12S, CF-2A, and MP-15S was used for estimating a biodegradation rate. This flow path represents a groundwater travel path from the anaerobic plume core to the more aerobic downgradient extents. An exponential fit to the data estimates a log-linear slope of 0.04 feet^{-1} (ft^{-1}) which was in turn used to estimate a decay constant of 0.0015 day^{-1}. The loss of BTEX along this flow path can be simulated using a first-order biodegradation decay rate; the calculated R^2 was 0.964.

A review of recent literature indicates that higher anaerobic rate constants generally have been calculated at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic groundwater conditions, the anaerobic rate constants were both approximately 0.01 day^{-1}. Wilson *et al.* (1994) reported first-order anaerobic

TABLE 5.1
FIRST-ORDER RATE CONSTANT CALCULATION USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Point	Distance Downgradient(ft)	Total BTEX (μg/L) May-95
MP-12S	0	25012
CF-2A	100	3020
MP-15S	260	1

PLOT OF TOTAL BTEX CONCENTRATION VERSUS DISTANCE



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

where $v_c =$ 0.029 ft/day
$\alpha_x =$ 8 ft
$k/v =$ 0.04 ft^{-1}
therefore $\lambda =$ 0.0015 day^{-1}

L: 45003\report\calcs FT8BSCH4.XLS

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. An anaerobic rate constant of 0.001 day^{-1} was used in the initial Bioplume II model for this site. It was slightly decreased from the 0.0015 day^{-1} value to account for slightly lower decay rates in the center of the BTEX plume. Furthermore, an anaerobic decay constant of 0.001 day^{-1} is at the low end of the range reported in the literature. Therefore, this selected biodegradation rate is considered to be conservative.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity and constant-head boundary conditions in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by estimating and adjusting source loading and transport parameters in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.2 lists input parameters used for the modeling effort. Model input and output files are included in Appendix D.

5.4.1 Water Table Calibration

The shallow water table at FT-08 was assumed to be influenced by continuous recharge and discharge at the constant-head cells surrounding the model grid. The initial water levels at the constant-head cells and the transmissivity values were varied to calibrate the water table surface. The model was calibrated under steady-state conditions.

Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. According to the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume with a relatively small areal extent and higher average BTEX concentration. Higher values of hydraulic conductivity result in a faster-moving plume that is spread over a larger area and contains lower average BTEX concentrations.

TABLE 5.2
BIOPLUME II MODEL INPUT PARAMETERS
CURRENT FIRE TRAINING AREA
INTRINSIC REMEDIATION TS
WESTOVER ARB, MASSACHUSETTS

Parameter	Description	Calibrated Model Setup	5 % Source Decay	50% Source Decay	Source Removal
NTIM	Maximum number of time steps in a pumping period	5	5	5	5
NPMP	Number of Pumping Periods	4	11	11	11
NX	Number of nodes in the X direction	20	20	20	20
NY	Number of nodes in the Y direction	30	30	30	30
NPMAX	Maximum number of Particles: NPMAX= (NX-2)(NY-2)(NPTPND) + (Ns[a/])(NPTPND) + 250	5344	5344	5344	5344
NPNT	Time step interval for printing data	1	1	1	1
NITP	Number of iteration parameters	7	7	7	7
NUMOBS	Number of observation points	5	5	5	5
ITMAX	Maximum allowable number of iterations in ADIP [b/]	200	200	200	200
NREC	Number of pumping or injection wells	8	8	8	8
NPTPND	Initial number of particles per node	9	9	9	9
NCODES	Number of node identification codes	1	1	1	1
NPNTMV	Particle movement interval (IMOV)	0	0	0	0
NPNTVL	Option for printing computed velocities	1	1	1	1
NPNTD	Option to print computed dispersion equation coefficients	1	1	1	1
NPDELC	Option to print computed changes in concentration	1	1	1	1
NPNCHV	Option to punch velocity data	0	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1	1
PINT	Pumping period (years)	30	80	45	45
TOL	Convergence criteria in ADIP	0.001	0.001	0.001	0.001
POROS	Effective porosity	0.25	0.25	0.25	0.25
BETA	Characteristic length (long. dispersivity; feet)	8	8	8	8
S	Storage Coefficient	0 (Steady-State)	0 (Steady-State)	0 (Steady-State)	0 (Steady-State)
TIMX	Time increment multiplier for transient flow	-	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	60	60	60	60
YDEL	Width of finite difference cell in the y direction (feet)	60	60	60	60
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.1	0.1	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx (1 = isotropic)	1	1	1	1

TABLE 5.2 (Continued)
BIOPLUME II MODEL INPUT PARAMETERS
CURRENT FIRE TRAINING AREA
INTRINSIC REMEDIATION TS
WESTOVER ARB, MASSACHUSETTS

Parameter	Description	Calibrated Model Setup	5 % Source Decay	50% Source Decay	Source Removal
DK	Distribution coefficient	0.3	0.3	0.3	0.3
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.75	1.75	1.75	1.75
THALF	Half-life of the solute	-	-	-	-
DEC1	Anaerobic decay coefficient (day^{-1})	0.00095	0.00095	0.00095	0.00095
DEC2	Reaeration coefficient (day^{-1})	0.0	0.0	0.0	0.0
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.14	3.14	3.14	3.14

[a] Ns = Number of nodes that represent fluid sources (wells or constant head cells).

[b] ADIP = Alternating-direction implicit procedure (subroutine for solving groundwater flow equation).

Saturated thickness data from previous reports, geologic logs, and water level measurements were used in conjunction with the hydraulic conductivity estimates to create an initial transmissivity grid for the entire model. To better match heads in the model to observed values, the transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to selected well locations matched the observed water levels as closely as possible. Figure 5.2 shows the calibrated water table. Calibrated model hydraulic conductivities ranged from 4.3×10^{-3} foot per second (ft/sec) to 1.4×10^{-4} ft/sec (2.6×10^{-1} ft/min to 8.4×10^{-3} ft/min). Hydraulic conductivities were varied through this wide range of values to help achieve a reasonable representation of the observed groundwater table at the site. High hydraulic conductivities were used in the vicinity of MP-15S and MP-5S where hydraulic conductivities are known to be high and were required to simulate the preferential flow of water turning to the east. Lower conductivities were required between MP-9S and MP-7S to divert the groundwater flow to the east.

A precipitation recharge rate of 10.5 inches per year was assumed to enter the aquifer across the entire site. This is equivalent to approximately 25 percent of the annual precipitation at Westover ARB. This rate was considered acceptable due to the shallow groundwater and the highly permeable silty sand soils overlying the surficial aquifer. Nevertheless, surface water recharge was not injected into the model because of the leakage through the silty layer separating the upper and lower zones of the surficial aquifer. The model was calibrated under the assumption that the volume of water entering the aquifer from precipitation infiltration was equivalent to the leakage from the upper zone to the lower zone. Because Bioplume is a 2-D groundwater model and does not have vertical aquifer leakage parameters, groundwater recharge was not included in the model calibration.

Water level elevation data from cells associated with 16 groundwater monitoring locations were used to compare measured and simulated heads for calibration. The 16 selected cell locations each contained one of the following monitoring wells/points: CF-2A, CF-3, CF-4, CF-5, CF-6A, CF-8, MP-1S, MP-2S, MP-4, MP-5S, MP-7S, MP-8S, MP-10S, MP-11S, MP-12S, and MP-15S.

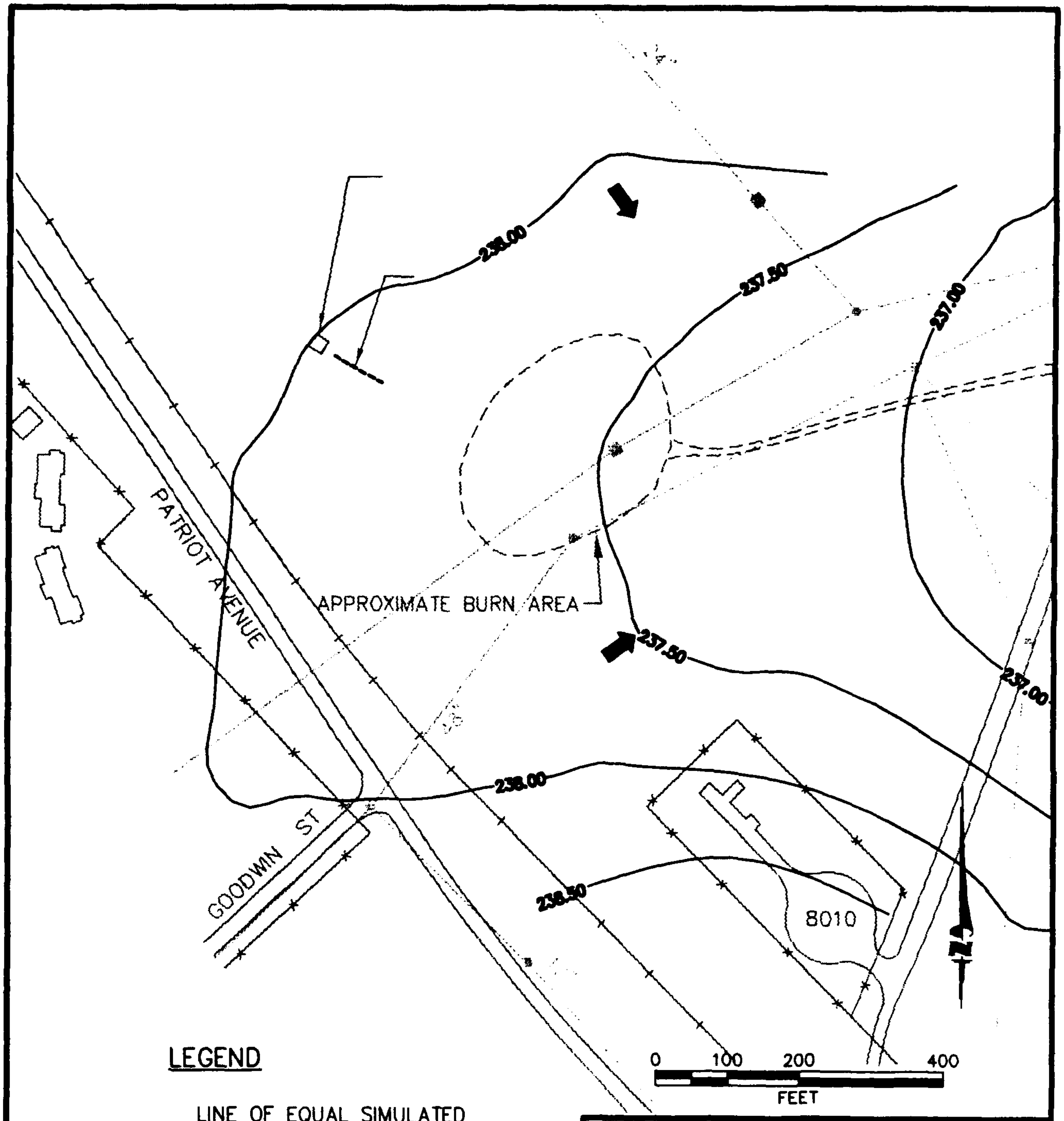
The root mean square (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

$$\mathrm{RMS} = \left[\frac{1}{n} \sum_{i=1}^{n} \left(h_m - h_s \right)_i^2 \right]^{0.5}$$

Where: n = the number of points where heads are being compared,

h_m = measured head value (feet above msl), and

h_s = simulated head value (feet above msl).



LEGEND

—238.00— LINE OF EQUAL SIMULATED GROUNDWATER ELEVATION (ft msl) CONTOUR INTERVAL = 0.5 FT

—+—+— RAILROAD TRACK

—x—x— FENCE

➡ LINE OF EQUAL SIMULATED GROUNDWATER ELEVATION (ft msl)

FIGURE 5.2

CALIBRATED WATER TABLE

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

The RMS error between observed and calibrated values at the 16 comparison points was 0.33 feet, which corresponds to a calibration error of 8.5 percent (water levels dropped 3.8 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured versus calibrated heads shows a random distribution of points around a straight line, as shown in Appendix C. Deviation of points from a straight line should be randomly distributed in such a plot of results from computer simulations (Anderson and Woessner, 1992). Deviations from the straight line occurred in the east of the burn pit where abrupt changes in groundwater elevation and flow direction were observed.

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. Considering the unusual groundwater hydraulics at the site, the hydraulic mass balance for the calibrated model was reasonable, with 99.9 percent of the water flux into and out of the system being numerically accounted for (i.e., a 0.1-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations observed in May 1995. To do this, model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. Because the exact time and frequency of the waste fuel releases at the site is unknown, the model was calibrated to match May 1995 conditions, assuming the groundwater was first impacted 30 years ago, with fire training exercises continuing at regular intervals until 10 years ago. Four leaching periods were used in the calibration to simulate different source areas and rates prior to 1995.

Estimated BTEX source concentrations (Section 5.3.3) were applied to 8 of the simulated injection wells of the model grid to reproduce the configuration and concentrations of the groundwater BTEX plume (Figure 5.2). While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was varied from 1.2×10^{-5} cubic foot per second (ft^3/sec) to 5.0×10^{-5} ft^3/sec, values low enough that the flow calibration and water balance were not affected. Loading rates were varied cell by cell as needed to reproduce the shape of the observed groundwater plume. In this manner, the potential source strength of the residual contamination was maintained while simultaneously obtaining the configuration of the observed plume (Figure 4.3).

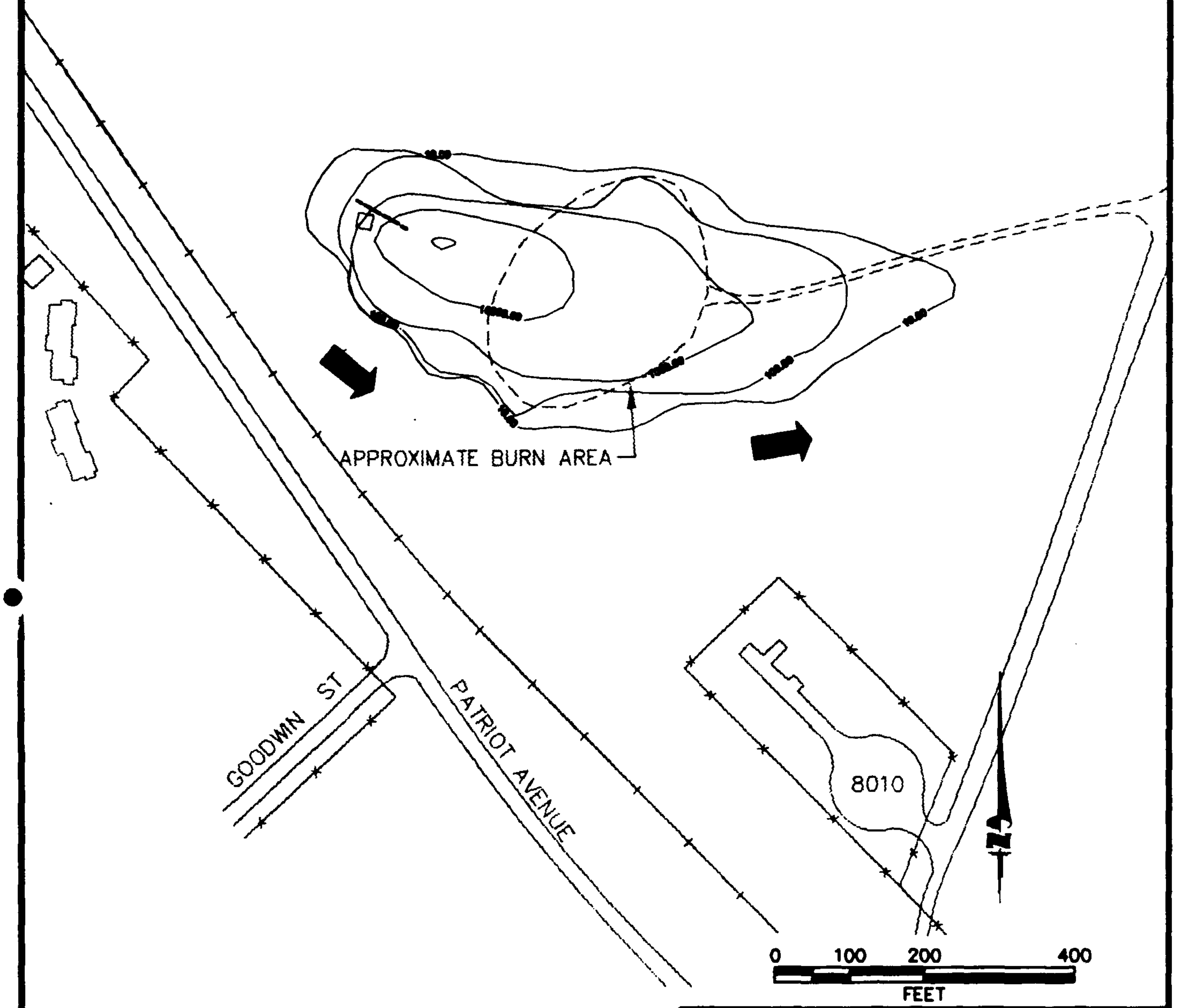
Four leaching periods were used to model the configuration of the BTEX plume beneath the former fire training area. For the first 10 years (1966-1975), moderate amounts of BTEX were injected at 4 injection wells. This represents the start of fire training activities and the buildup of a residual source. For model years 11 to 20 (1976-1985) both the BTEX injection rates and the number of injection wells were increased. These increases were justified because the volume of fuel stored in the soil and the extent of the impacted area are expected to have increased with the continued fire training activities. In 1986, fire training exercises ceased, and the waste oil UST north of the site was removed. During abandonment of the UST and the connected fuel system, it is believed that an additional fuel release may have occurred at the outfall of the buried fuel line abandoned in place near monitoring point MP-4S. Therefore, two additional injection wells were included in the next 5-year pumping period (1986-1990). In addition, BTEX loading rates at the other 6 injection wells were decreased at 5 percent per year to account for natural decay processes (e.g., volatilization, dissolution, or biodegradation) occurring at the inactive fire training area. To obtain the observed configuration of the plume near monitoring point MP-4S, the injection concentrations were applied at approximately 10 percent of the estimated source strength required to sustain measured concentrations of groundwater BTEX over the entire cell. This was done to simulate a point-source release at the pipe outfall rather than a release across the entire grid cell. The final 5 years of the model calibration (1991-1995) consisted of continued 5-percent source decay at all 8 injection wells. The calibrated plume is shown in Figures 5.3 and 5.4. The final calibrated model plume (year 30) was assumed to represent present-day (1995) conditions and compares favorably to the observed BTEX plume (Figure 5.1).

The objective of the calibration was to achieve a modeled plume that equaled or exceeded the observed plume in terms of extent and concentration, and that effectively simulated the preferential flow of BTEX contaminants from the source areas to the observed downgradient locations. The calibrated model successfully meets these objectives, as it reproduces both the observed areal extent and contaminant concentrations. The calibrated plume accurately predicts a preferential flow of contamination from the source area toward the east. In the vicinity of MP-4S, simulated BTEX concentrations are within 2 percent of the observed concentrations. However, because the model cannot simulate a point source within a cell, the calibrated contours extend farther upgradient from MP-4S than indicated by site data. The 10,000-µg/L contour approximated from observed site conditions stretches from the pipe outfall into the source area and ends at MP-12S. In the model, the simulated 10,000-µg/L contour stretches to just upgradient of MP-12S and is approximately 150 feet wide, which is slightly wider than the observed BTEX plume. The downgradient extent of the modeled 10-µg/L contour correlates with the observed conditions.

The fact that the model concentrations in the source area are slightly higher than observed concentrations means that additional BTEX mass is accounted for in the model simulations and that model predictions are conservative. Variations in shape between the model and the observed plume likely are due to subsurface heterogeneities in the hydraulic conductivity, reaeration coefficient, dispersivity, and retardation coefficient that are extremely difficult to identify in the field and to replicate in a discretized model domain.

5.4.2.1 Discussion of Parameters Varied During Plume Calibration

As noted previously, the transport parameters varied during plume calibration were dispersivity, the coefficient of retardation, and the coefficient of anaerobic decay. Those parameters were generally varied with intent of altering plume migration so that the observed plume extent was reproduced. While these parameters were varied with this common intent, each had a slightly different impact on the size and shape of the simulated plume.



LEGEND

——10—— LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)

CONTOUR INTERVAL = VARIABLE

➡ APPROXIMATE GROUNDWATER FLOW DIRECTION

FIGURE 5.3

CALIBRATED BTEX PLUME

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

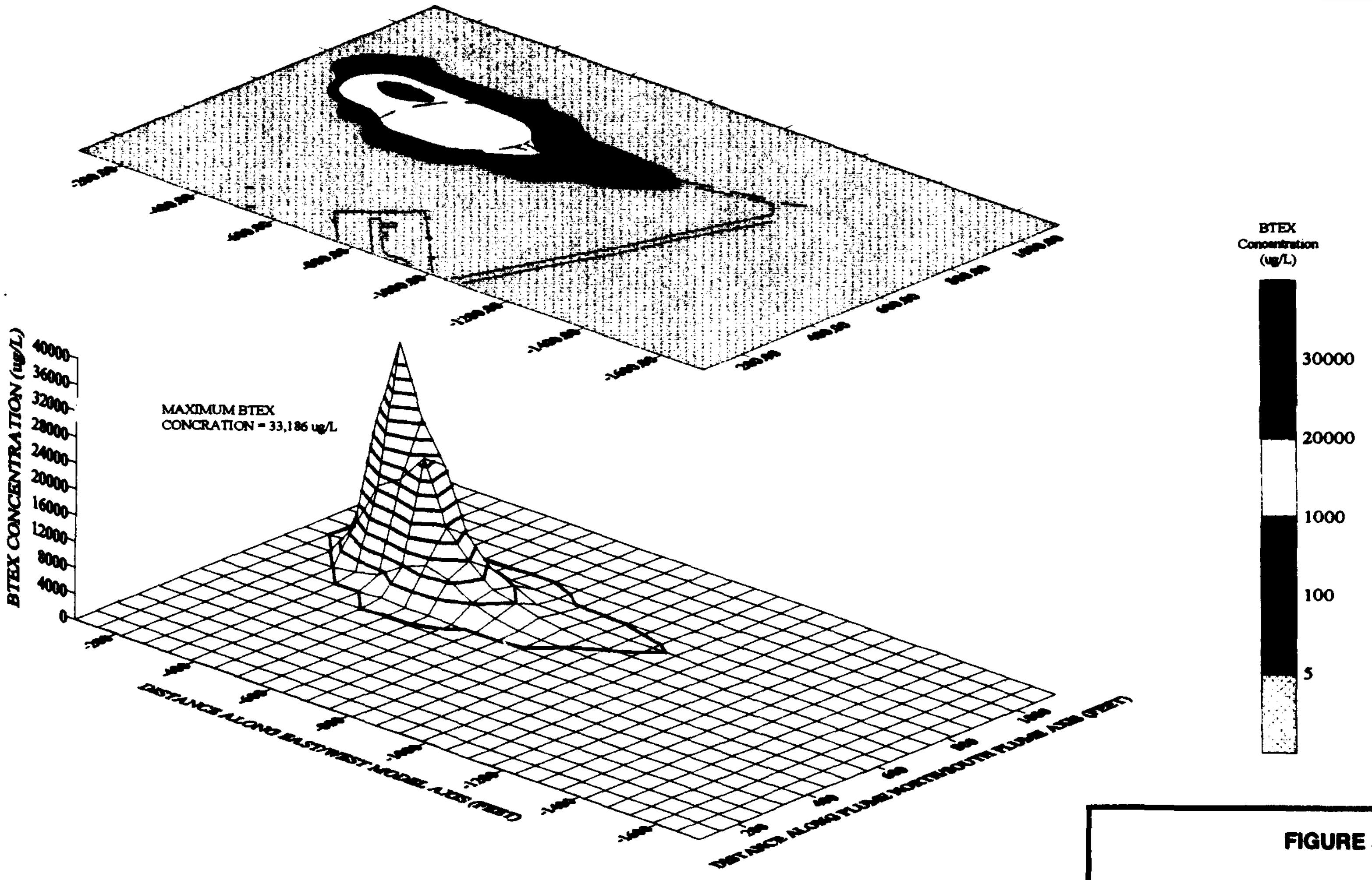


FIGURE 5.4

CALIBRATED
BTEX PLUME

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

5.4.2.1.1 Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for sediments similar to those found at the site range from 0.1 to 200 feet (Walton, 1988). Longitudinal dispersivity was estimated as 8 feet, using approximately one-hundredth (0.01) of the length of the plume from the source (upgradient from MP-12S) to the downgradient extent of the BTEX plume at MP-5S (see Figure 4.3). Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was maintained at 8 feet. This value is low compared to possible values in literature (Walton, 1988). The use of low dispersivity values is a conservative estimate for modeling because low dispersivities cause less BTEX to be lost to dilution. At the same time, the ratio of transverse dispersivity to longitudinal dispersivity was maintained at 0.1 to help reproduce the plume width observed at the site.

5.4.2.1.2 Coefficient of Retardation

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation for the BTEX compounds were calculated on the basis of measured TOC concentrations for soils collected in and near the saturated zone at the site, an assumed bulk density of 1.75 grams per cubic centimeter (g/cc) (Domenico and Schwartz, 1990), and published values of the soil sorption coefficients (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table 5.3.

TOC analyses often are influenced by the presence of soil contamination, which may cause high soil TOC concentrations without necessarily reflecting an increase in the sorptive potential of soil. Therefore, TOC measurements used for retardation estimates should be taken from contaminant-free soils. Furthermore, TOC analysis should be taken across the water table rather than in the vadose zone to best represent the sorptive potential of saturated soils in the aquifer. Fourteen locations were chosen for TOC analyses at the FT-08 site (Table 4.2). Of these 14 sampling locations, 4 TOC samples were collected at the target depth outside of known contamination and include: MP-1-4', MP-3-8', MP-11-4', and MP-16-7' (Figure 4.1). All 4 samples were collected near or below the water table and had TOC concentrations ranging from 0.059 to 0.583 percent. Table 5.3 reflects the use of a TOC average for these 4 samples in the calculation of site specific retardation coefficients. A final value of 2.29 for the retardation coefficient was used for the BTEX compounds. This is intended to correspond to benzene, which is the least sorptive BTEX compound. During plume calibration, the initial coefficient of retardation was slightly increased to achieve a more accurate plume shape. However, the calibrated value (2.29) is lower than the retardation coefficient of the other BTEX compounds and therefore is still a conservative estimate of BTEX retardation.

TABLE 5.3
CALCULATION OF RETARDATION COEFFICIENTS
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Compound	K_{oc} (L/kg [a])	Average Fraction Organic Carbon [b]	Distribution Coefficient K_d (L/kg) Average[c]	Bulk Density (kg/L)[d]	Effective Porosity [a]	Coefficient of Retardation Average	Advective Groundwater Velocity (ft/day) [a]	Contaminant Velocity (ft/day)
Benzene	79	0.00185	0.146	1.75	0.25	2.02	0.0571	0.02821
Toluene	190	0.00185	0.352	1.75	0.25	3.46	0.0571	0.01649
Ethylbenzene	468	0.00185	0.866	1.75	0.25	7.06	0.0571	0.00808
m-xylene	405	0.00185	0.749	1.75	0.25	6.24	0.0571	0.00914
o-xylene	422	0.00185	0.781	1.75	0.25	6.46	0.0571	0.00883
p-xylene	357	0.00185	0.660	1.75	0.25	5.62	0.0571	0.01015
Vinyl Chloride	2.455	0.00185	0.005	1.75	0.25	1.03	0.0571	0.05531
trans-DCE	59	0.00185	0.109	1.75	0.25	1.76	0.0571	0.03235
TCE	95.1	0.00185	0.176	1.75	0.25	2.23	0.0571	0.02558

NOTES:

[a] From technical protocol document (Wiedemeier *et al.*, 1995) and Groundwater Chemical Desk Reference (Mongomery and Welkom, 1990).

[b] From site data (No carbon detected in soil samples from 4-8 ft bgs).

[c] K_d = Average Fraction Organic Carbon x K_{oc}.

[d] Literature values.

5.4.2.1.3 Coefficient of Anaerobic Decay

The coefficient of anaerobic decay is a first-order rate constant used in Bioplume II to simulate the rate of use and replenishment of anaerobic electron acceptors in the groundwater. A decay coefficient of 0.001 day^{-1} was originally selected, following computations using TMB as a conservative tracer and the method of Buscheck and Alcantar (1995). Use of this decay coefficient is justified at this site because anaerobic decay mechanisms account for 85 percent of the biodegradation at the site and because the loss of BTEX compounds at the site appears to be a first-order process (Section 5.3.4). By using a first order biodegradation rate derived from the method of Buscheck and Alcantar (1995), a reaeration coefficient was unnecessary because the rate constant used for anaerobic decay also includes the degradation rate attributable to aerobic processes. The coefficient of anaerobic decay had a significant effect on limiting plume migration, and was also important in controlling the concentrations at the fringes of the plume. This coefficient was changed to 0.00095 day^{-1} during the calibration process to better reproduce the observed plume.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. According to the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of aerobic decay (reaeration coefficient), the coefficient of anaerobic decay, and the hydraulic conductivity of the media, and is less sensitive to changes in the retardation factor, porosity, and dispersivity. To fully evaluate the sensitivity of the calibrated model, the transmissivity, the coefficient of anaerobic decay, the coefficient of retardation, dispersivity, and porosity were all varied. The reaeration coefficient was not used in this model.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually, and then comparing the new model runs to the original calibrated model. The sensitivity models were run for a 30-year period (the same duration used in the original calibrated model) to assess the independent effect of each variable. As a result, 10 sensitivity runs of the calibrated model were made, with the following variations:

1) Transmissivity uniformly increased by a factor of 5;
2) Transmissivity uniformly decreased by a factor of 5;
3) Coefficient of anaerobic decay increased by a factor of 2;
4) Coefficient of anaerobic decay decreased by a factor of 2;
5) Coefficient of retardation increased by 20 percent;
6) Coefficient of retardation decreased by 20 percent;
7) Dispersivity increased by 50 percent;

8) Dispersivity decreased by 50 percent;

9) Porosity increased by 25 percent; and

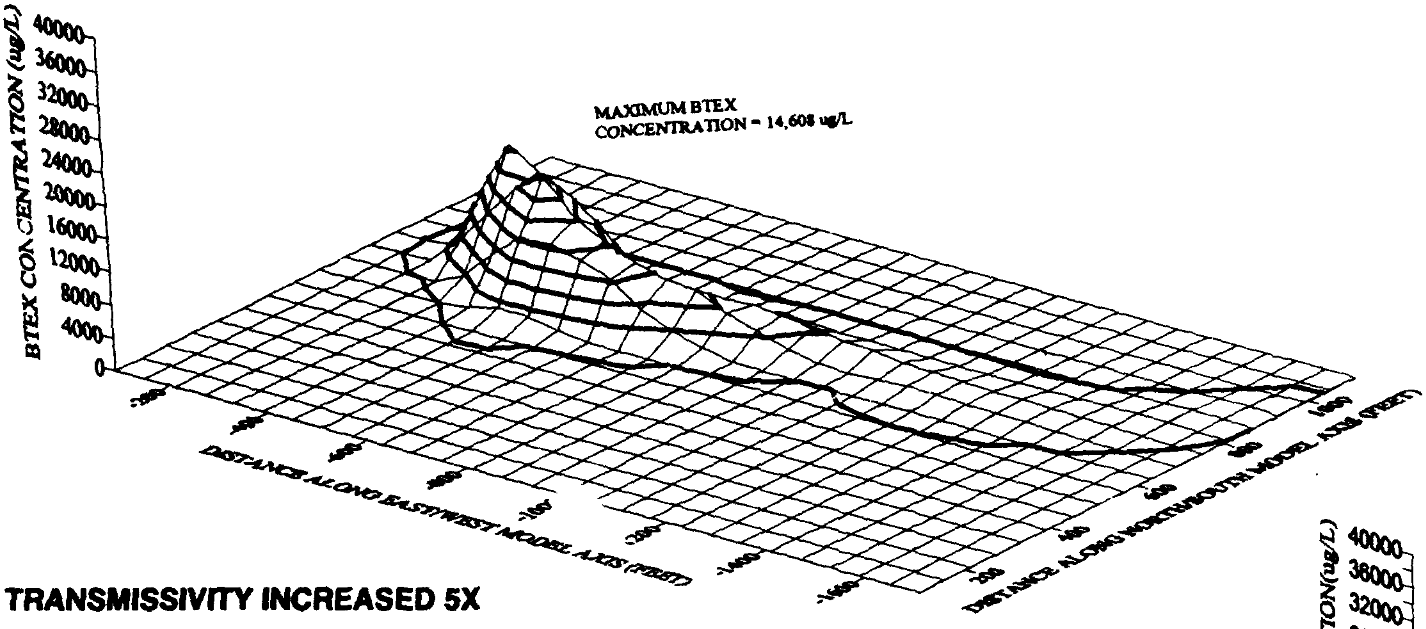
10) Porosity decreased by 25 percent.

The results of the sensitivity analyses are shown graphically in Figures 5.5 through 5.9. These figures display three-dimensional representations of modeled BTEX concentrations over the site. This manner of displaying data is useful because spatial changes in BTEX concentrations can be quickly visualized.

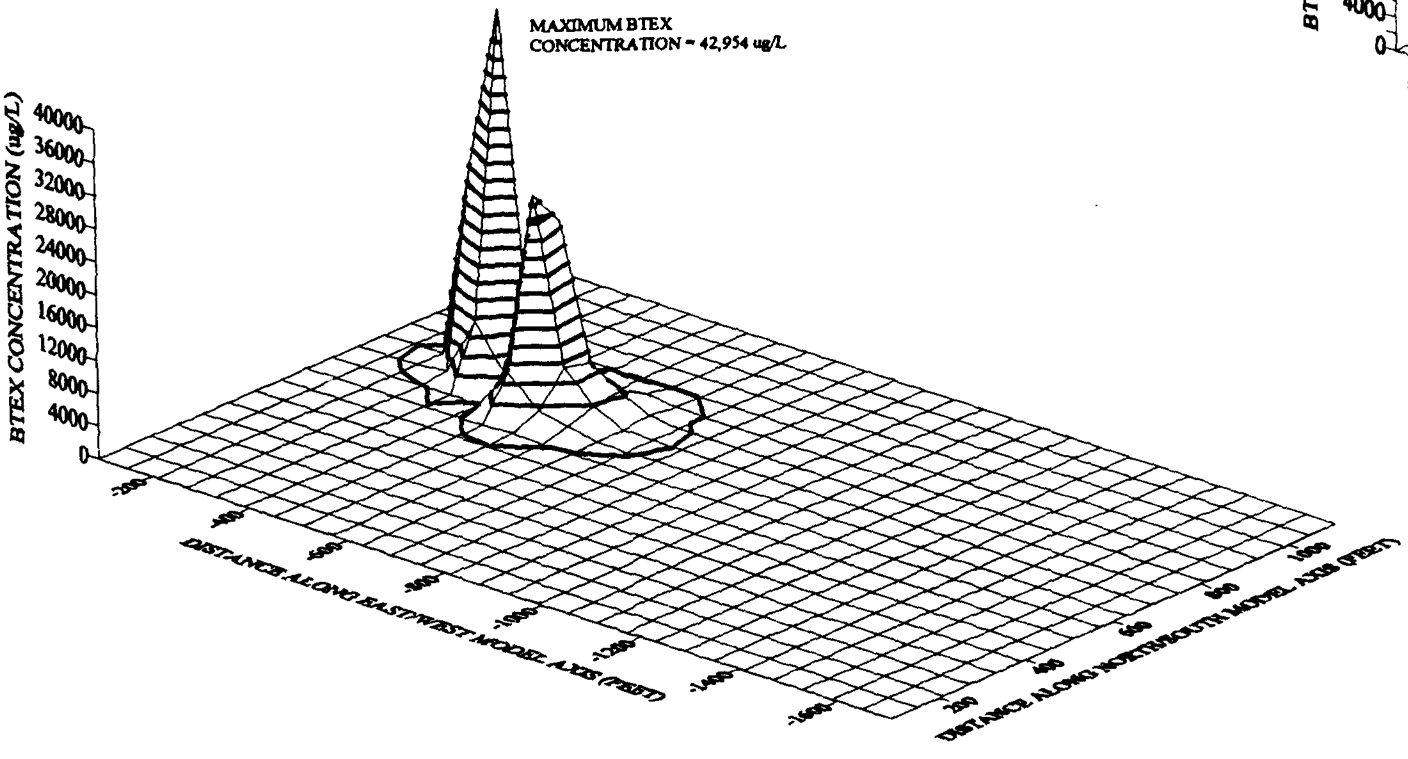
The effects of varying transmissivity are shown on Figure 5.5. Uniformly increasing the transmissivity by a factor of five increased groundwater velocity, and therefore decreased the residence time of groundwater in the aquifer. As a result, BTEX concentrations decreased throughout the plume because of increased dilution of the BTEX compounds. However, the plume is also much longer. BTEX concentrations at the head of the plume biodegrade faster because of the influx of electron acceptors from upgradient sources, but the downgradient portion of the plume migrates further and faster, due to the increased velocity. Under this scenario for transmissivity, the maximum observed BTEX concentration in the source area was 14,608 µg/L, compared to the calibrated 33,186 µg/L. In contrast, decreasing the transmissivity by a factor of five slowed overall plume migration, which increased the maximum BTEX concentrations because of decreased dilution and spreading. The BTEX concentration in the source area increased to approximately 42,954 µg/L, and the BTEX contamination did not extend downgradient from source area. The sensitivity of the model to hydraulic conductivity suggests that an appropriate range of transmissivity values was used in the model calibration.

The effects of varying the coefficient of anaerobic decay are illustrated by Figure 5.6. As expected, increasing this parameter by a factor of two results in a smaller plume with a maximum BTEX concentration of only 22,744 µg/L. In addition, the BTEX plume is approximately 400 feet shorter. Conversely, decreasing the coefficient of anaerobic decay by a factor of two decreases biodegradation and increases plume concentrations. The resultant increase raised computed maximum BTEX concentrations in the source area from 33,186 µg/L to 42,217 µg/L. However, the downgradient extent did not increase relative to the calibrated model. These results show that the calibrated model is sensitive to variations in the coefficient of anaerobic decay and suggest that the selected coefficient of anaerobic decay is a reasonable value for the calibrated model.

The effects of varying the coefficient of retardation (R) are shown on Figure 5.7. Increasing R by 20 percent has a minor effect on the contaminant distribution. An increase in sorptive capacity caused a slight increase of approximately 800 µg/L in the source area, producing a maximum BTEX concentration at 34,000 µg/L. The downgradient extent of the BTEX plume was shorter by about 200 feet. The slight increase in the maximum plume concentration resulted from a slowing of BTEX migration, which allowed for greater BTEX accumulation in the source area and an increased contact period of the sorbed BTEX with electron acceptors throughout the

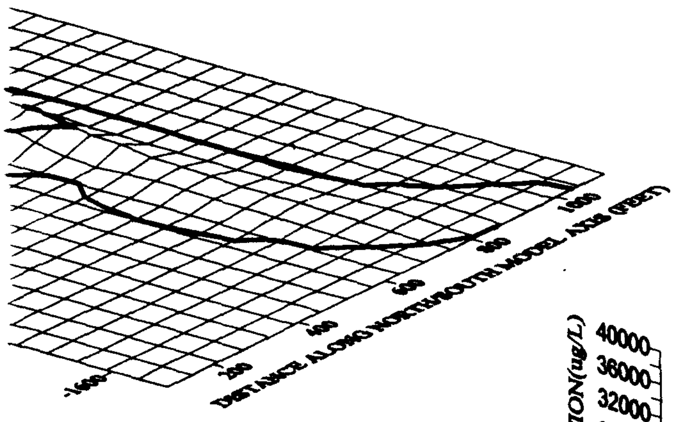


TRANSMISSIVITY INCREASED 5X



TRANSMISSIVITY DECREASED 5X

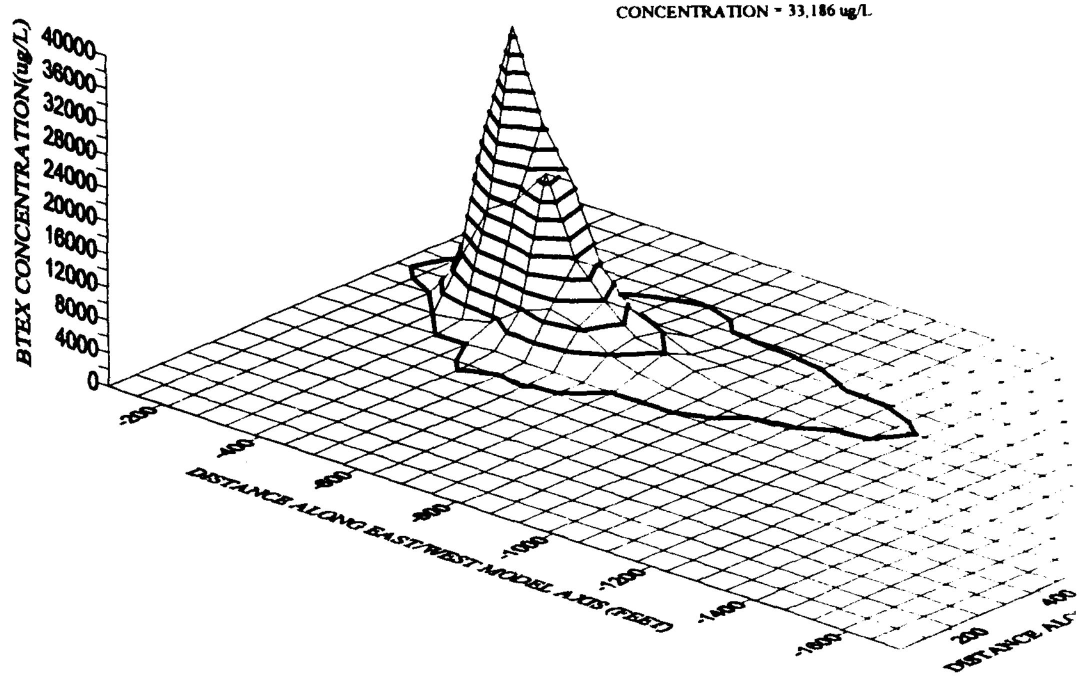
14,608 ug/L

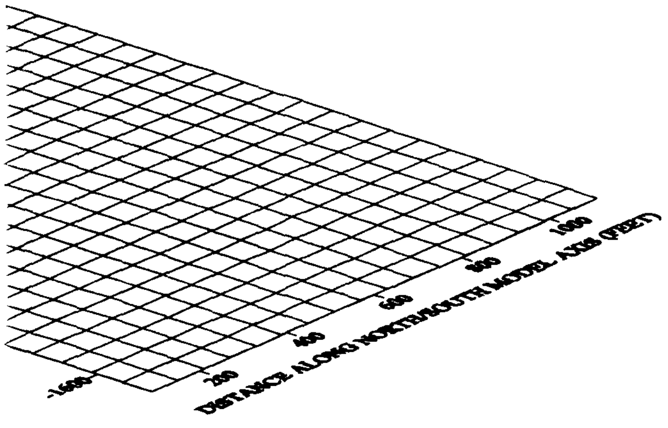


t ug/L

CALIBRATED MODEL

MAXIMUM BTEX
CONCENTRATION = 33,186 ug/L





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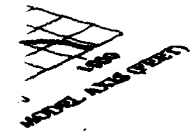
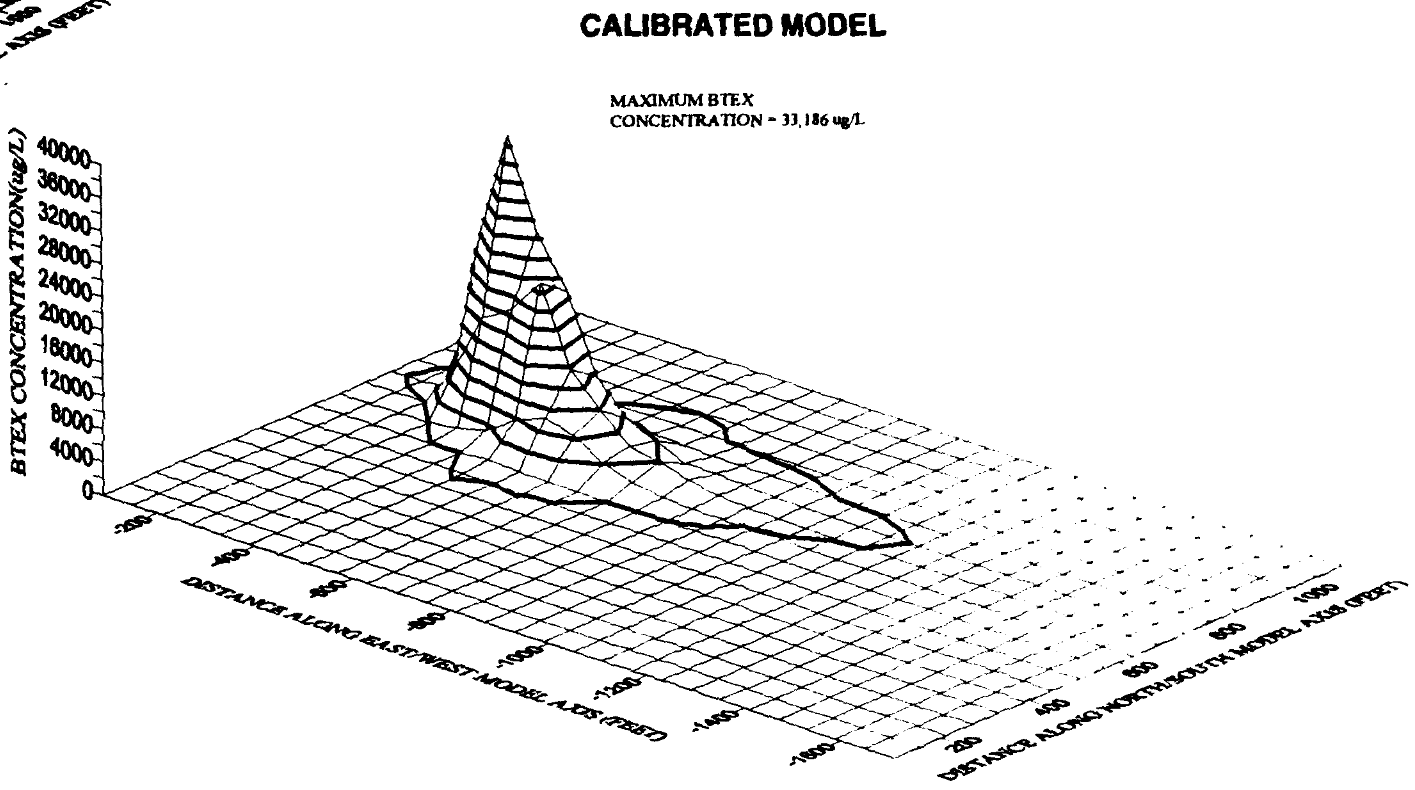




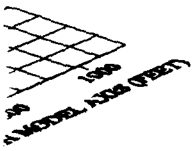
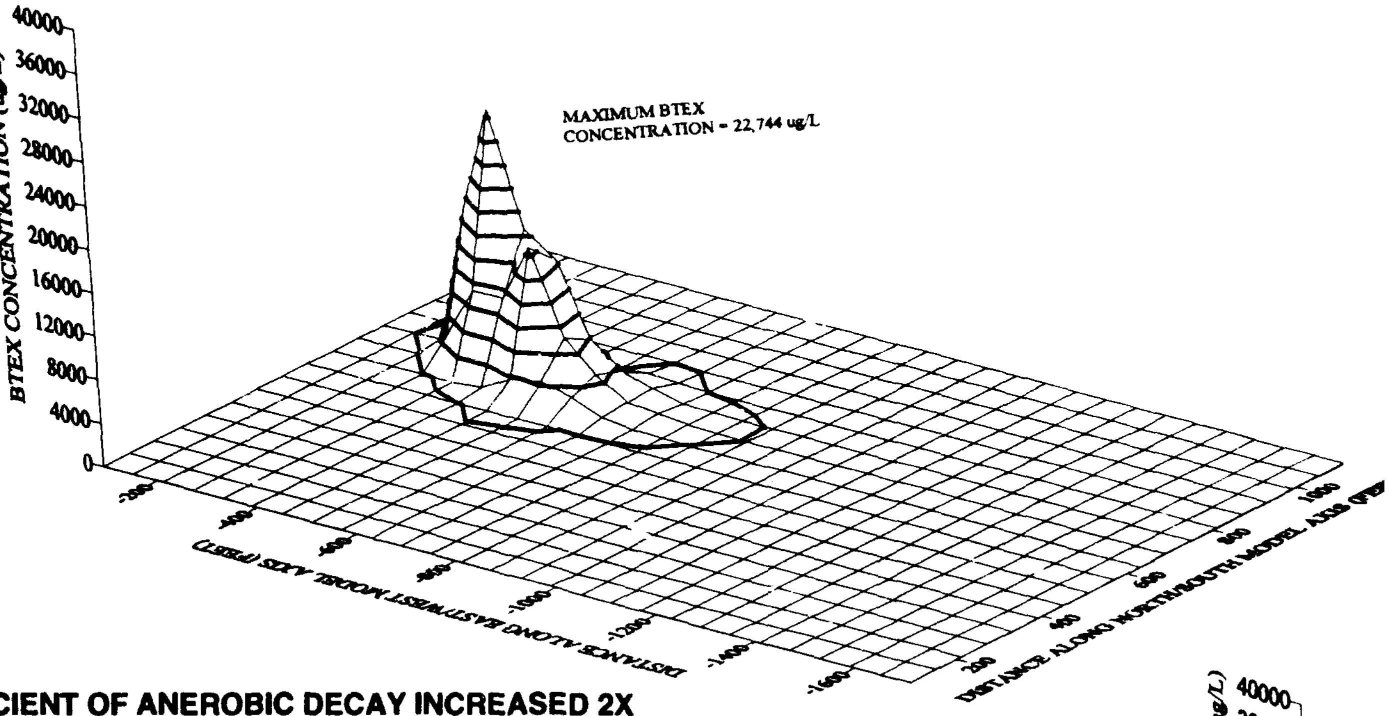


FIGURE 5.5

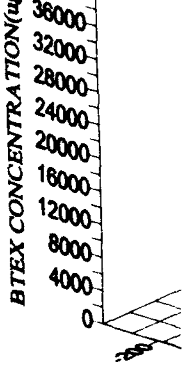
MODEL SENSITIVITY TO VARIATIONS IN TRANSMISSIVITY

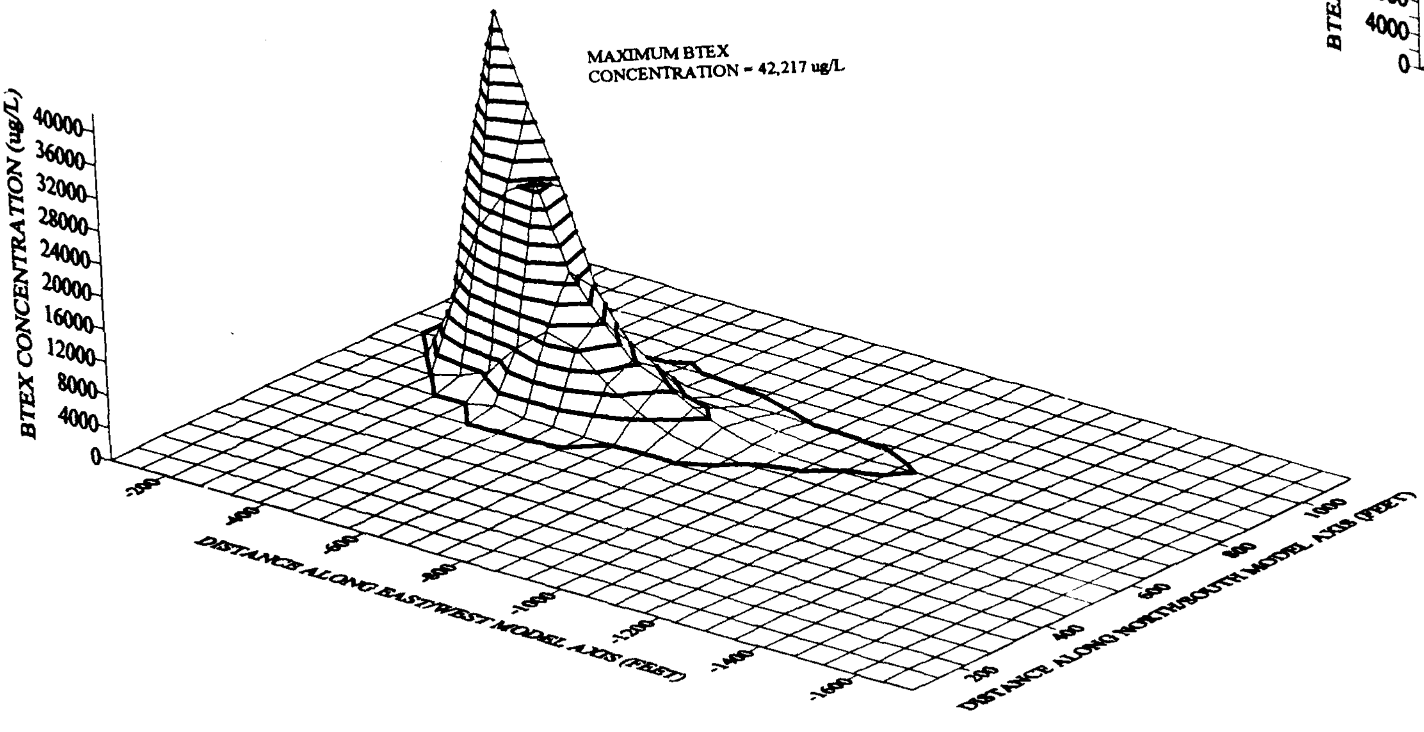
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

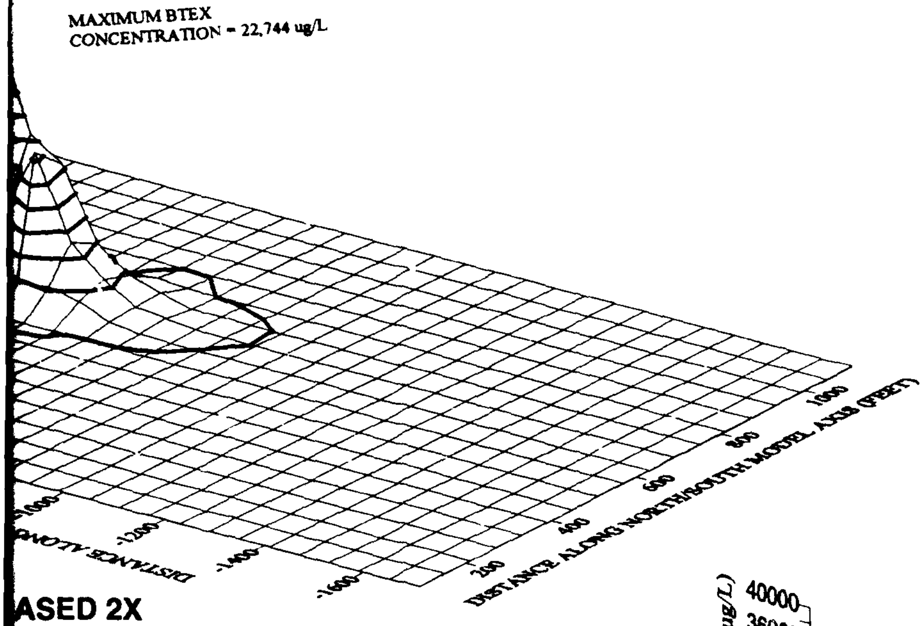


COEFFICIENT OF ANEROBIC DECAY INCREASED 2X

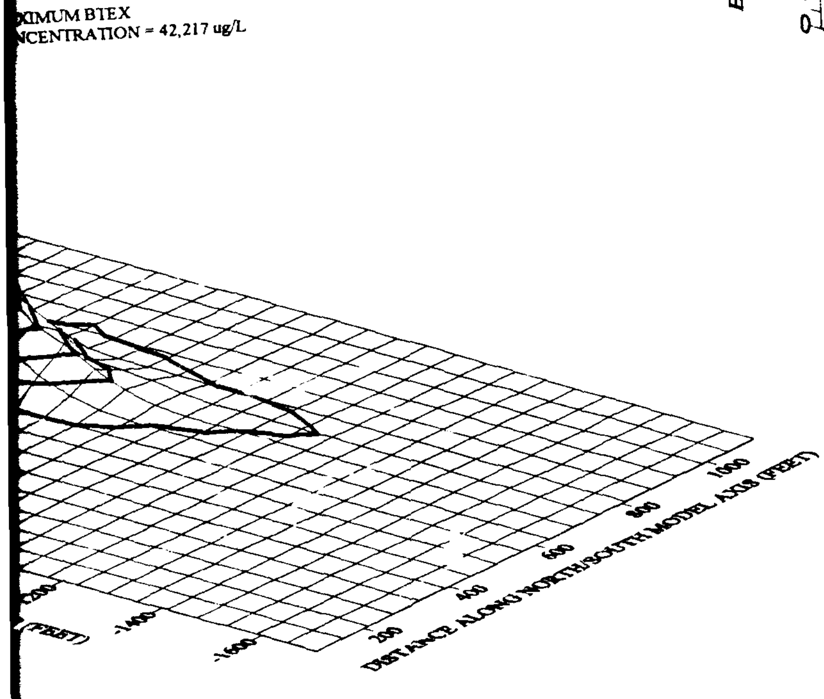




COEFFICIENT OF ANEROBIC DECAY DECREASED 2X

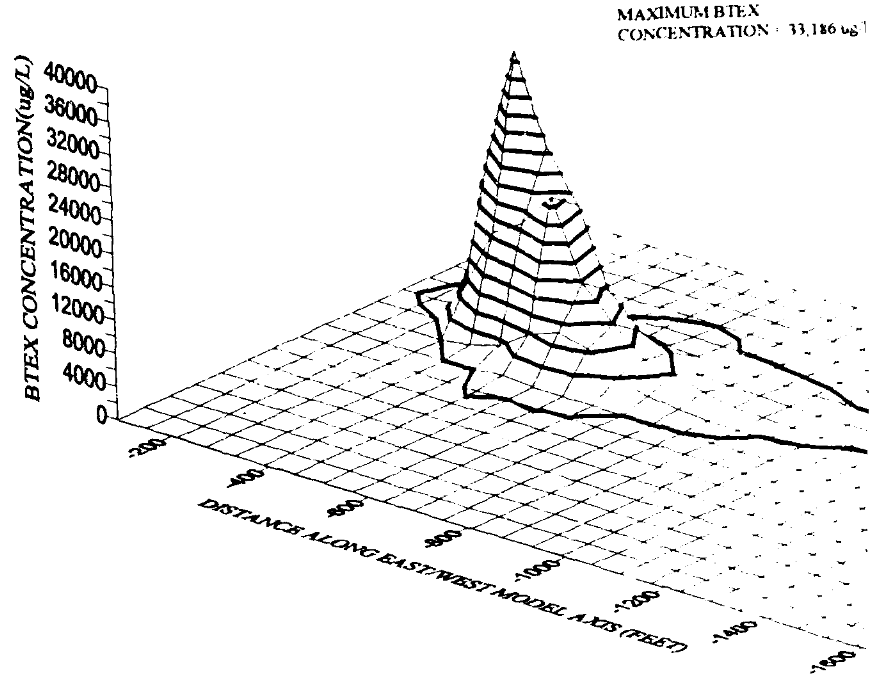


ASED 2X



EASED 2X

CALIBRATED MODE



CALIBRATED MODEL

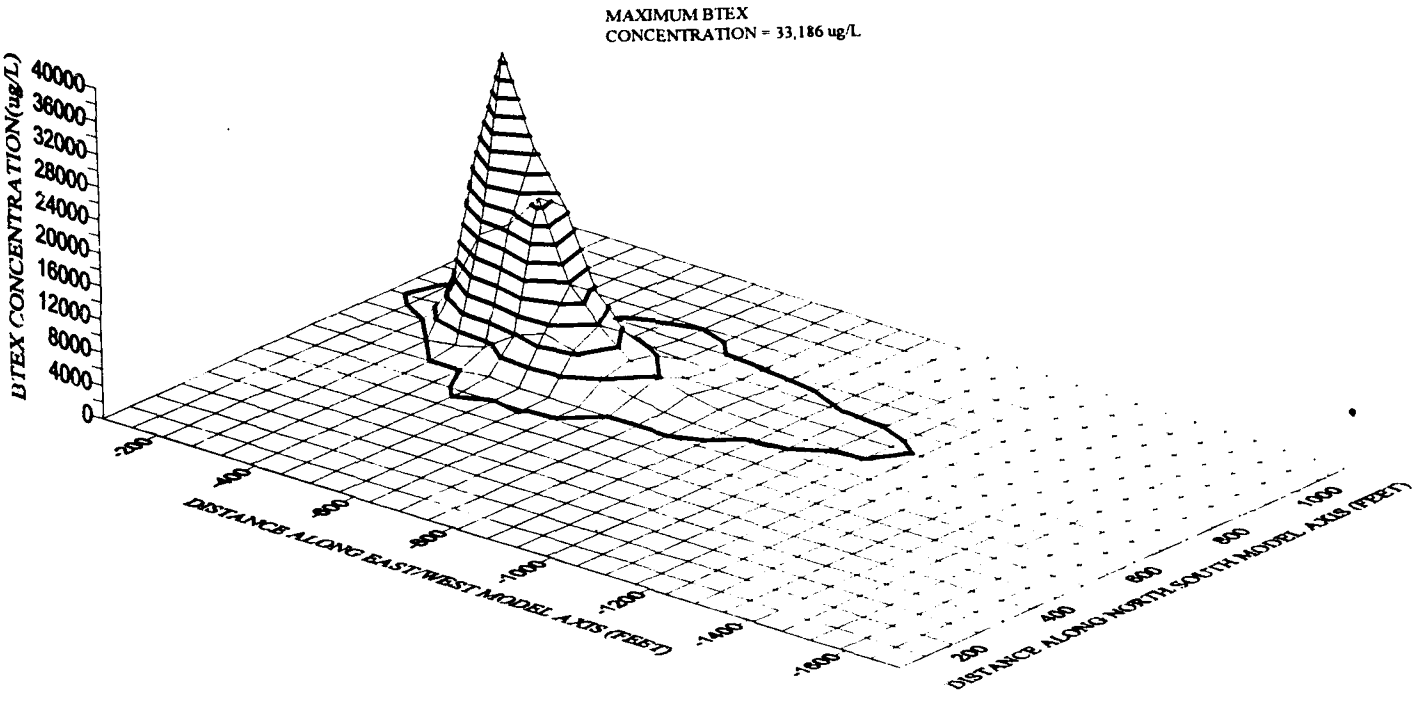
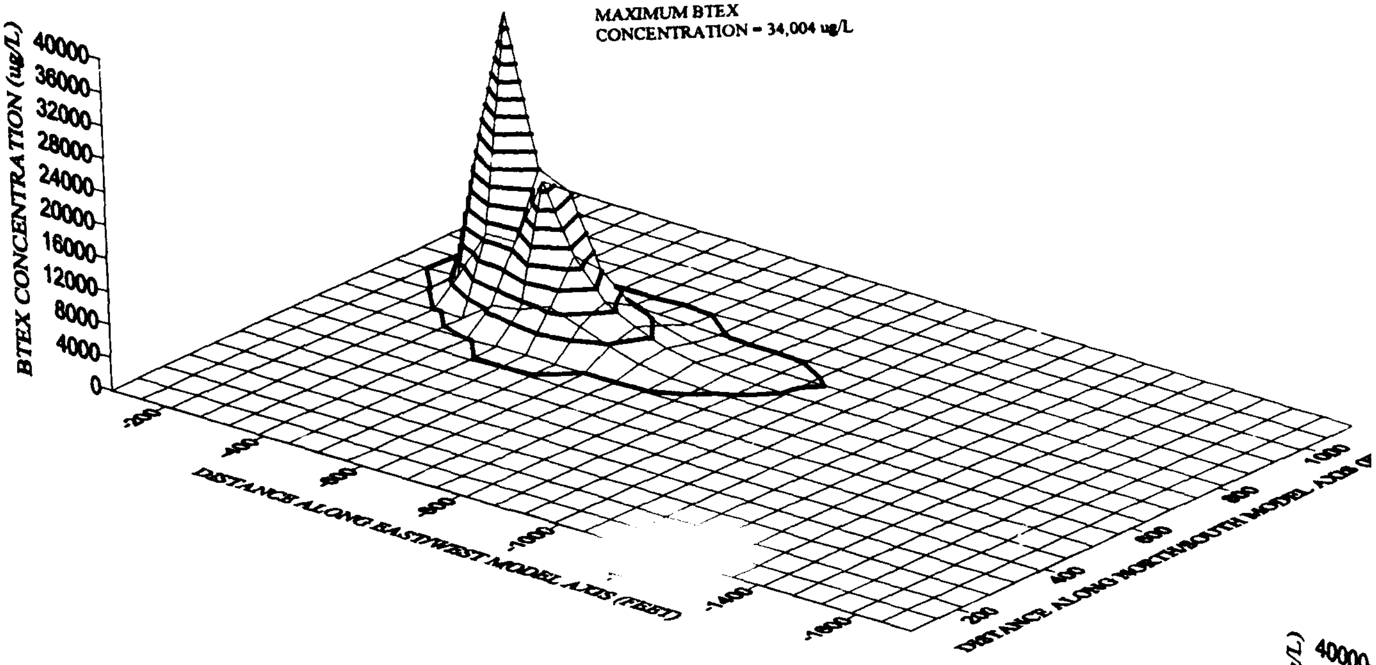


FIGURE 5.6

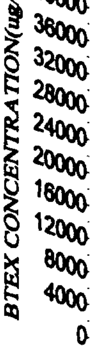
MODEL SENSITIVITY TO VARIATIONS IN THE ANEROBIC DECAY COEFFICIENT

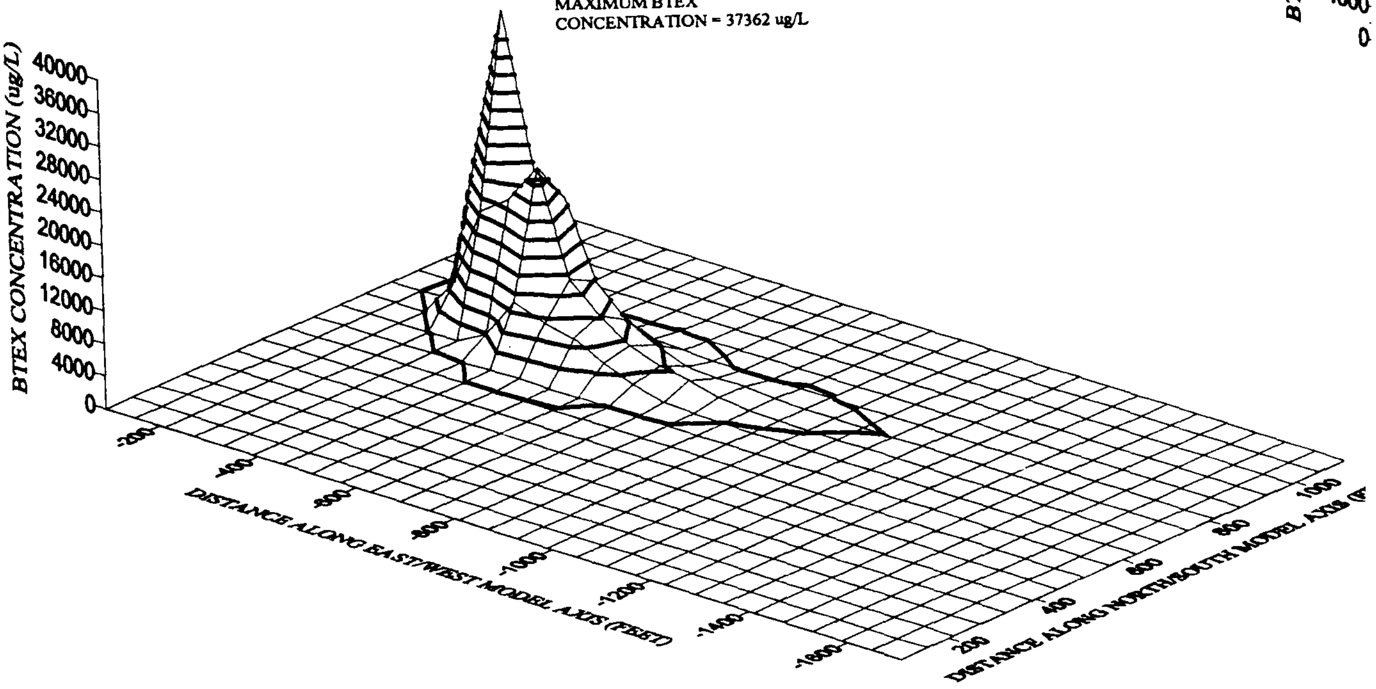
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



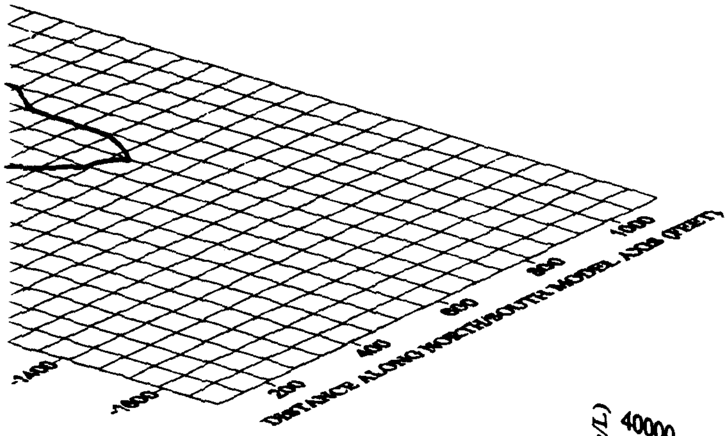
COEFFICIENT OF RETARDATION INCREASED BY 20 PERCENT





COEFFICIENT OF RETARDATION DECREASED BY 20 PERCENT

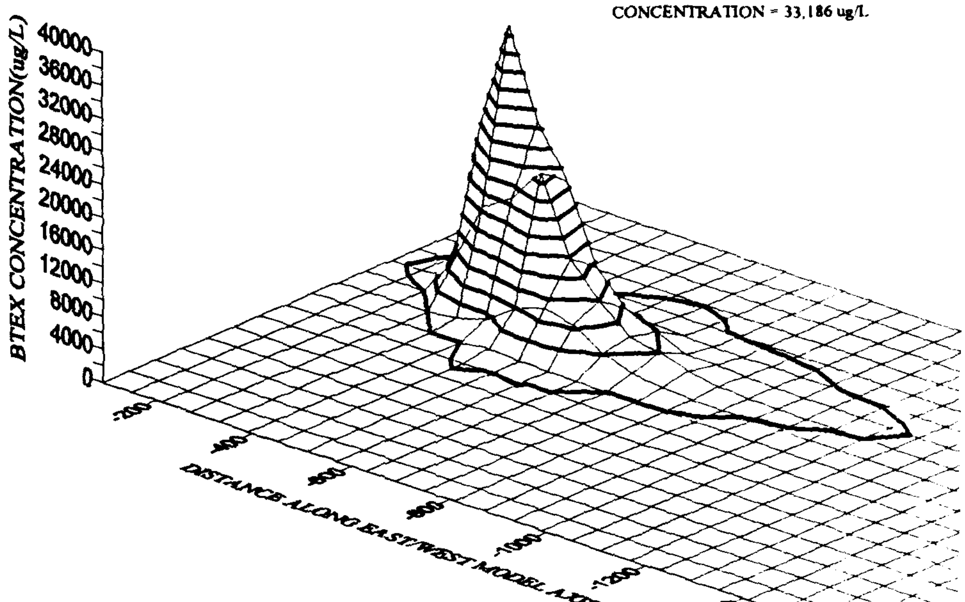
TEX
TION = 34,004 ug/L



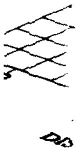
20 PERCENT

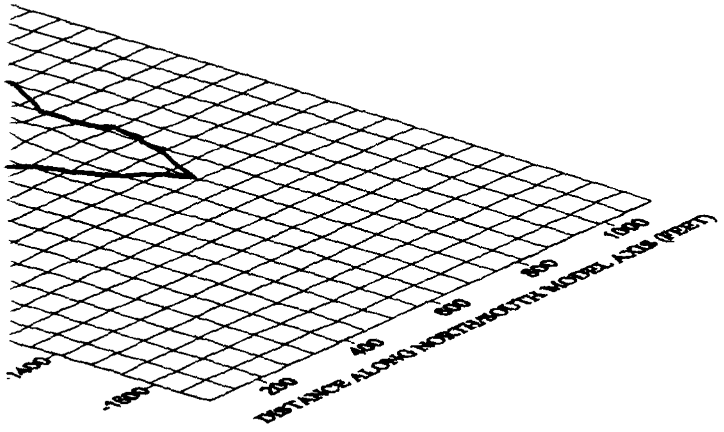
CALIBRATED MODEL

MAXIMUM BTEX
CONCENTRATION = 33,186 ug/L

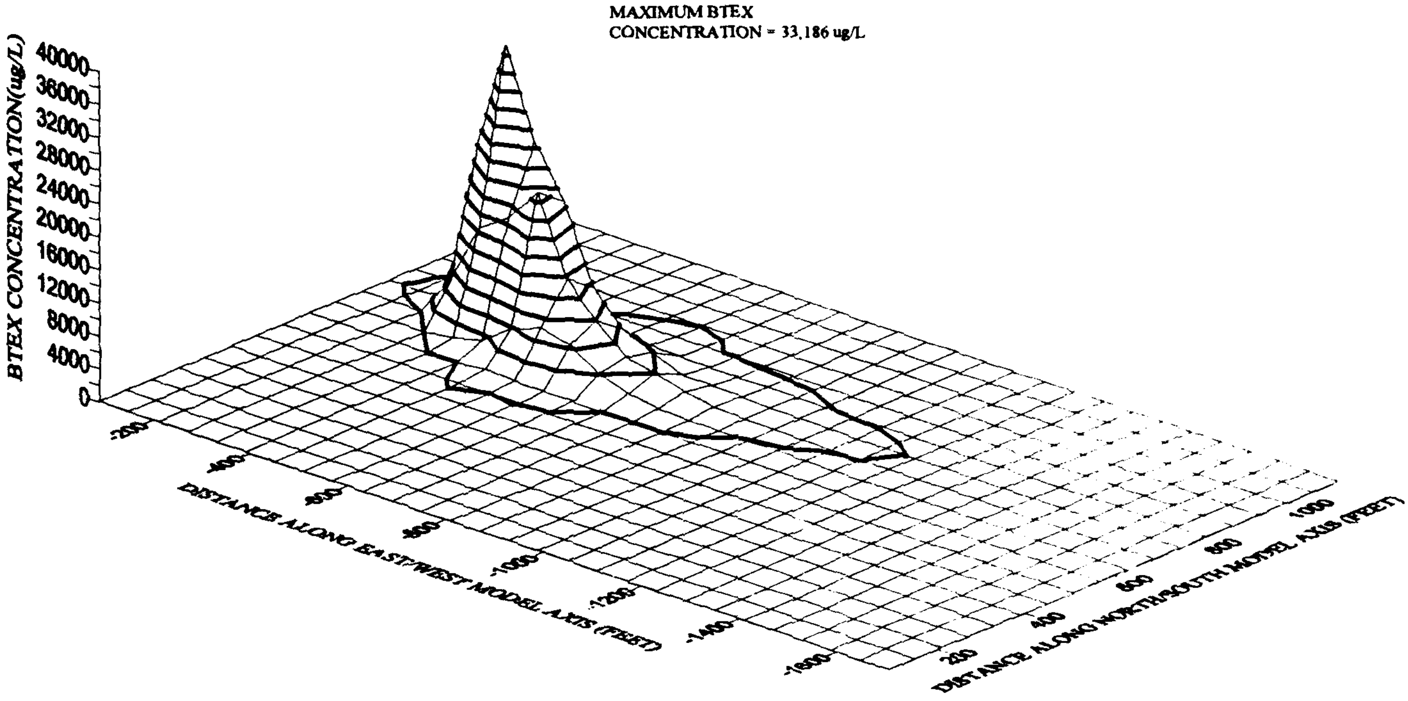


N = 37362 ug/L





/ 20 PERCENT



CALIBRATED MODEL

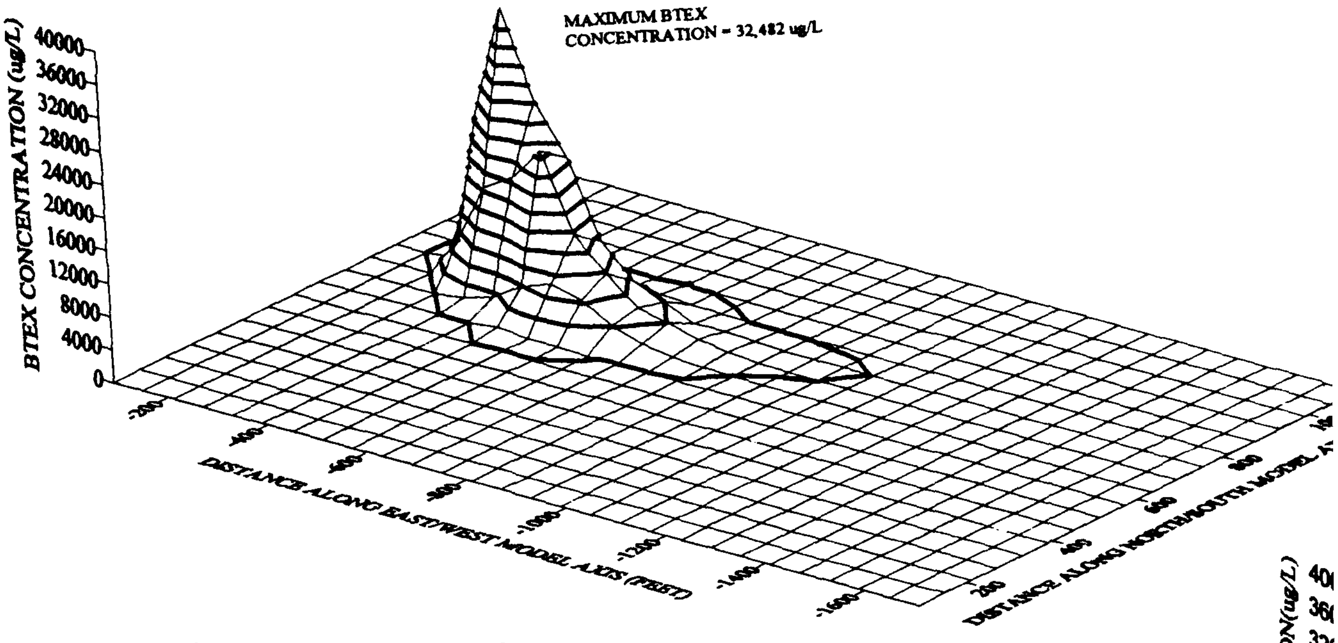
MOD
VA
ETAR
Cur
Int
Westo
PARS
ENGI

FIGURE 5.7

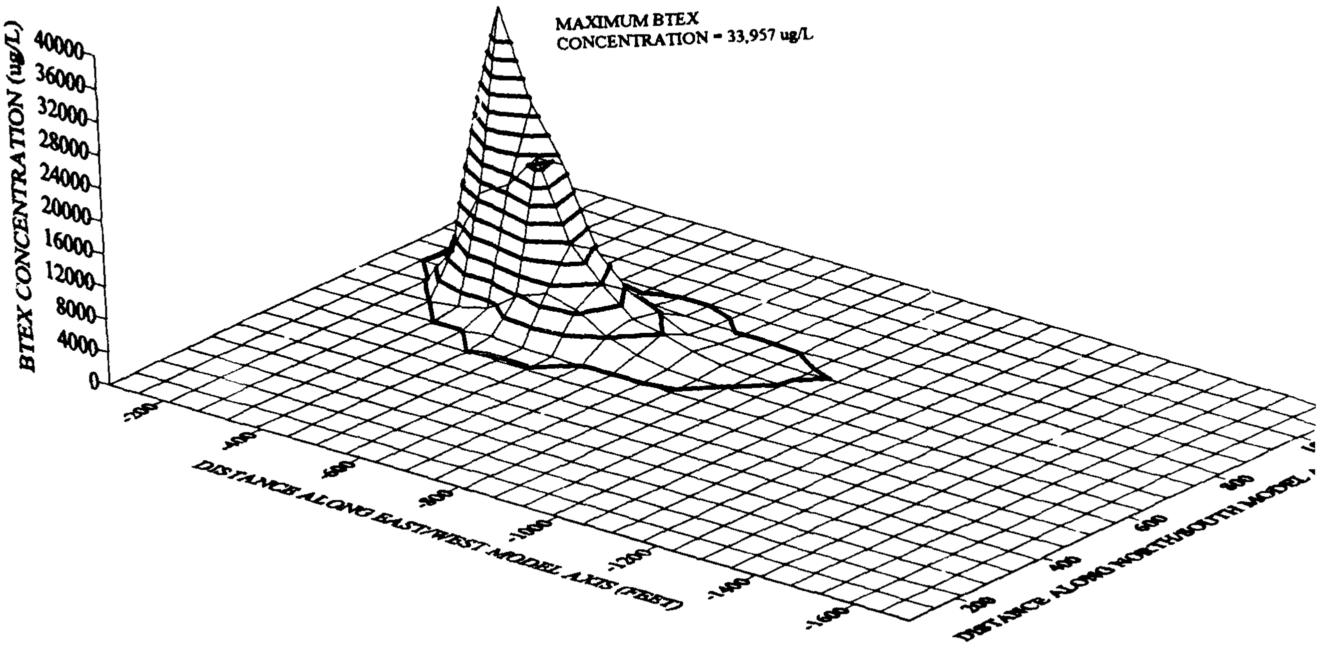
MODEL SENSITIVITY TO VARIATIONS IN THE RETARDATION COEFFICIENT

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

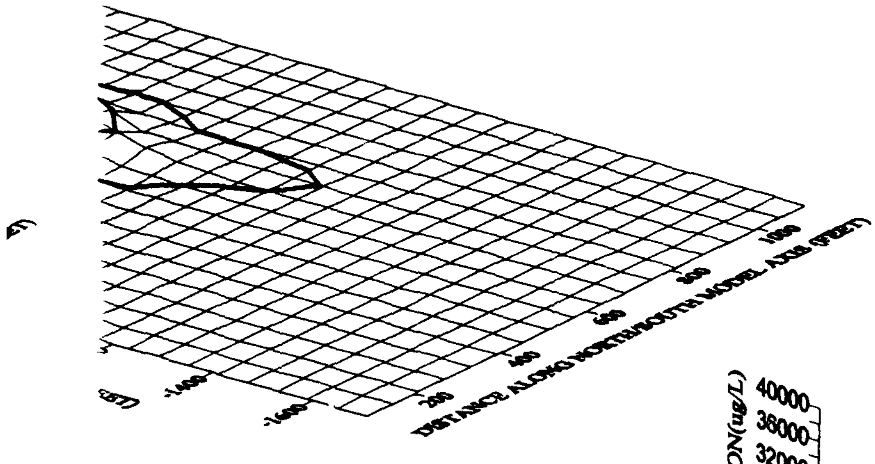


DISPERSIVITY INCREASED BY 50 PERCENT



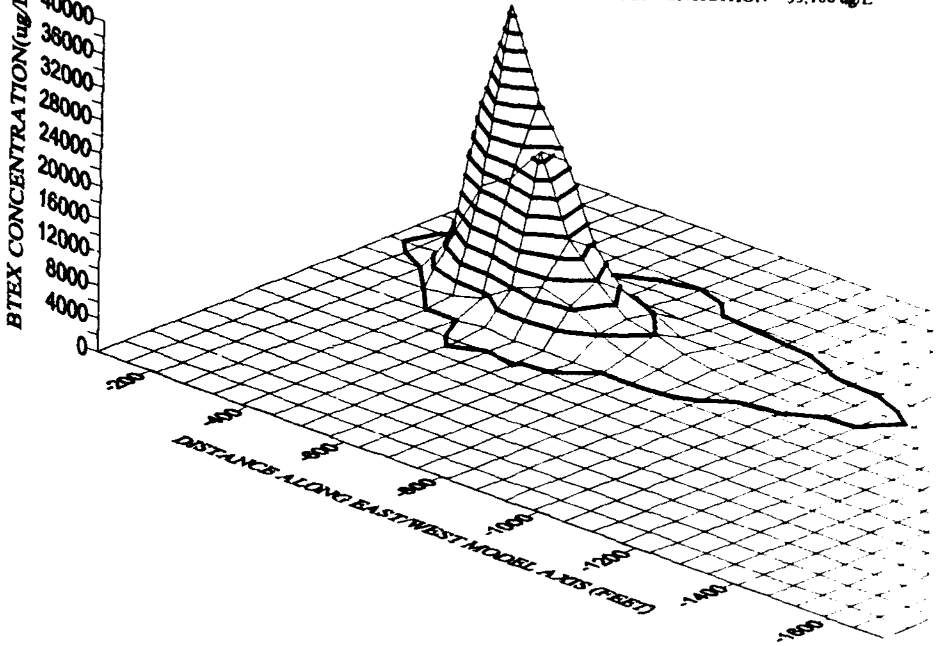
DISPERSIVITY DECREASED BY 50 PERCENT

1 BTEX
RATION = 32,482 ug/L

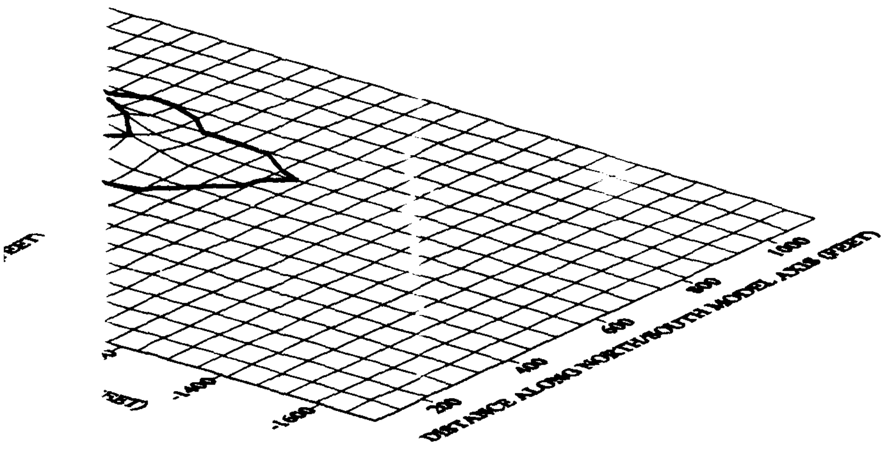


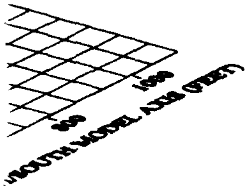
CALIBRATED MODEL

MAXIMUM BTEX
CONCENTRATION = 33,186 ug/L

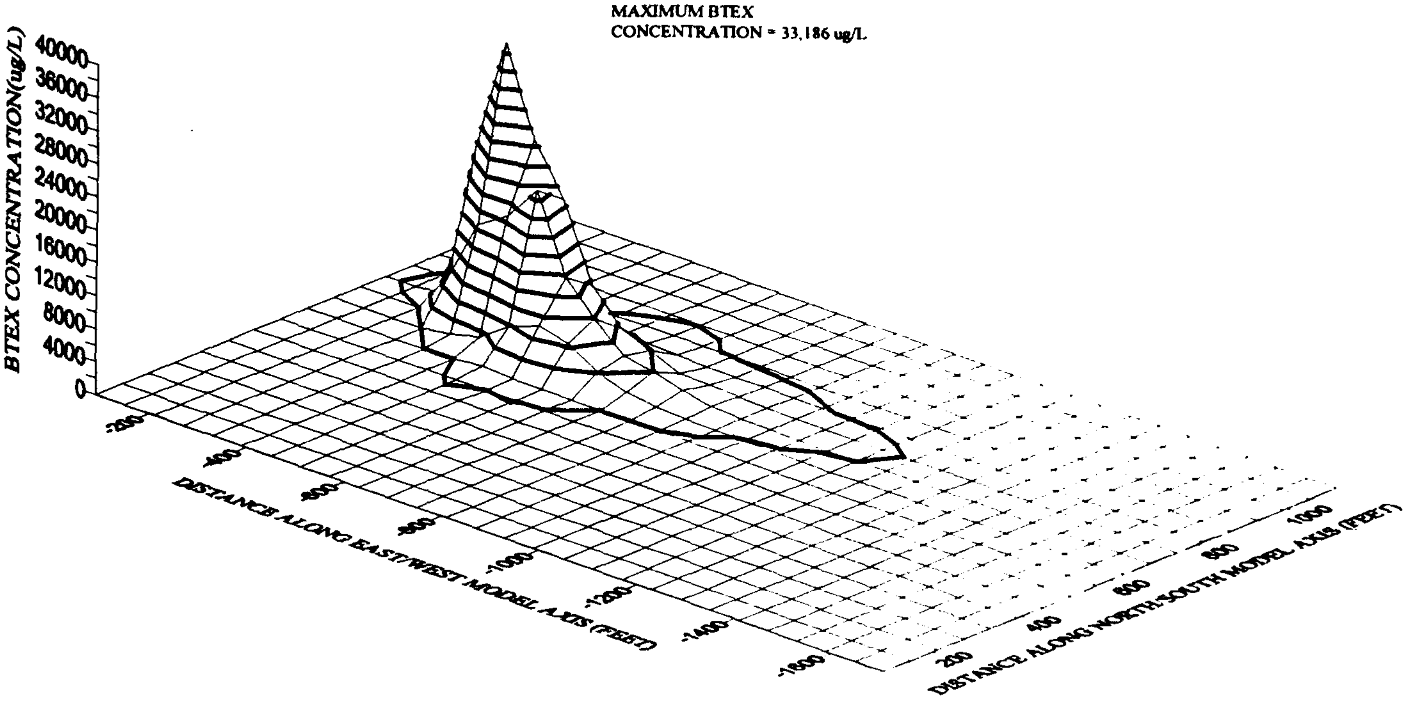


.4 BTEX
RATION = 33,957 ug/L





CALIBRATED MODEL



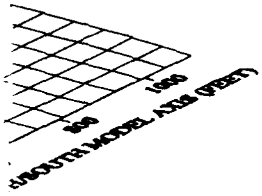
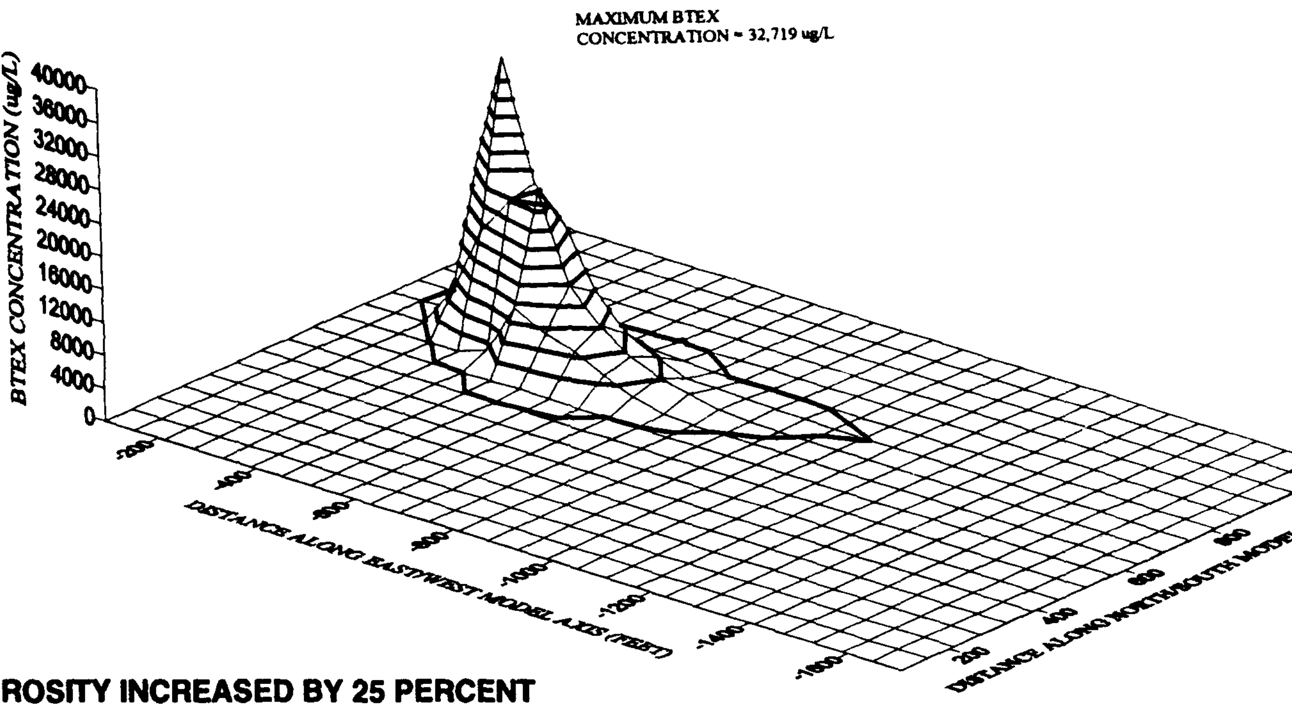


FIGURE 5.8

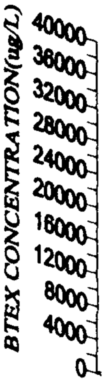
MODEL SENSITIVITY TO VARIATIONS IN DISPERSIVITY

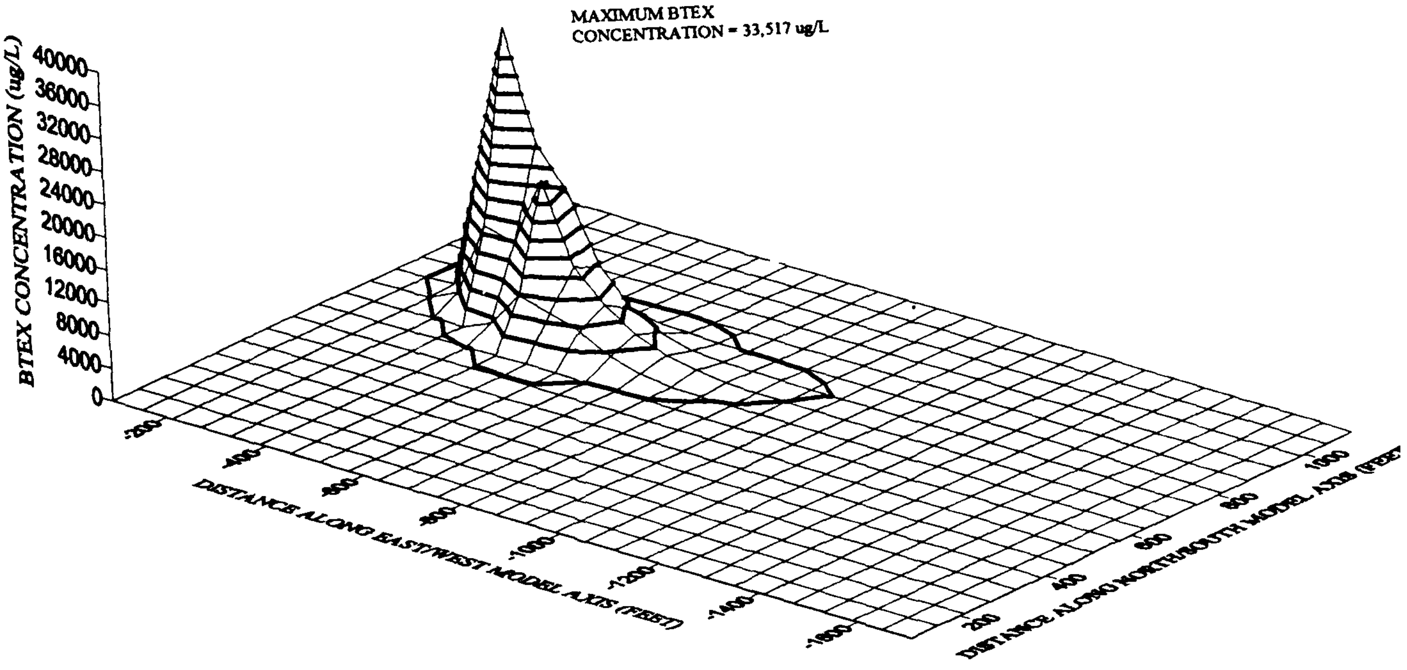
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



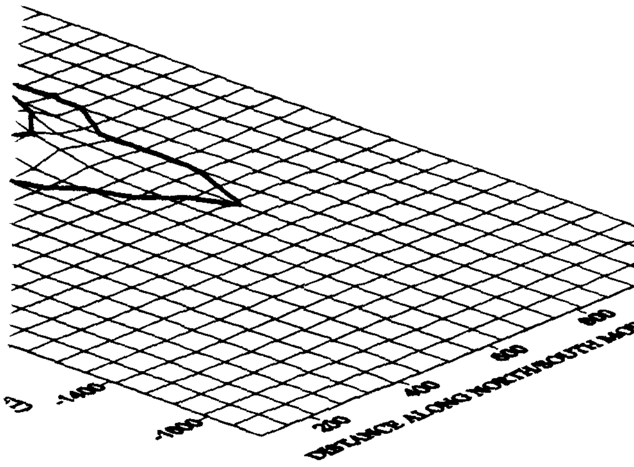
POROSITY INCREASED BY 25 PERCENT





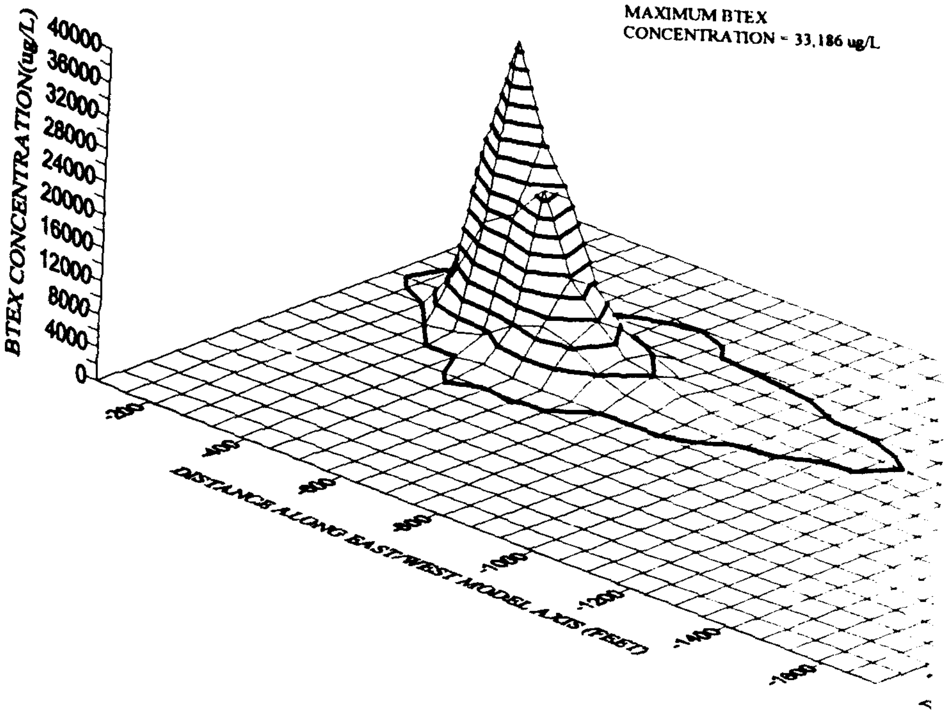
POROSITY DECREASED BY 25 PERCENT

UM BTEX
NTRATION = 32,719 ug/L

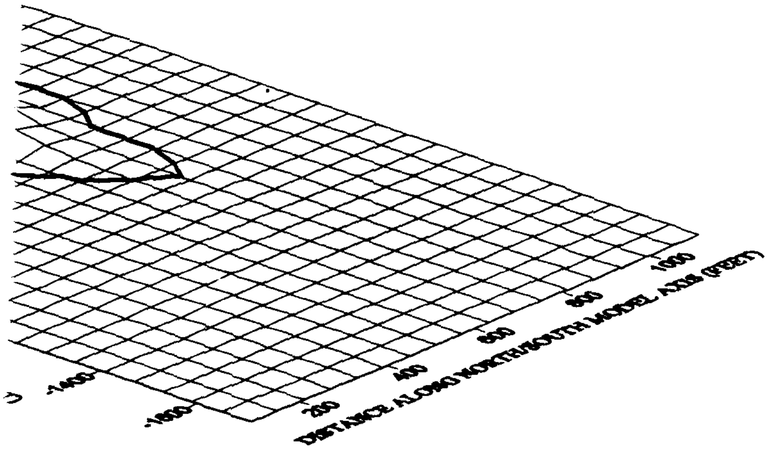


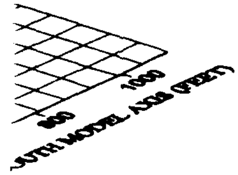
CALIBRATED MODEL

MAXIMUM BTEX
CONCENTRATION = 33,186 ug/L

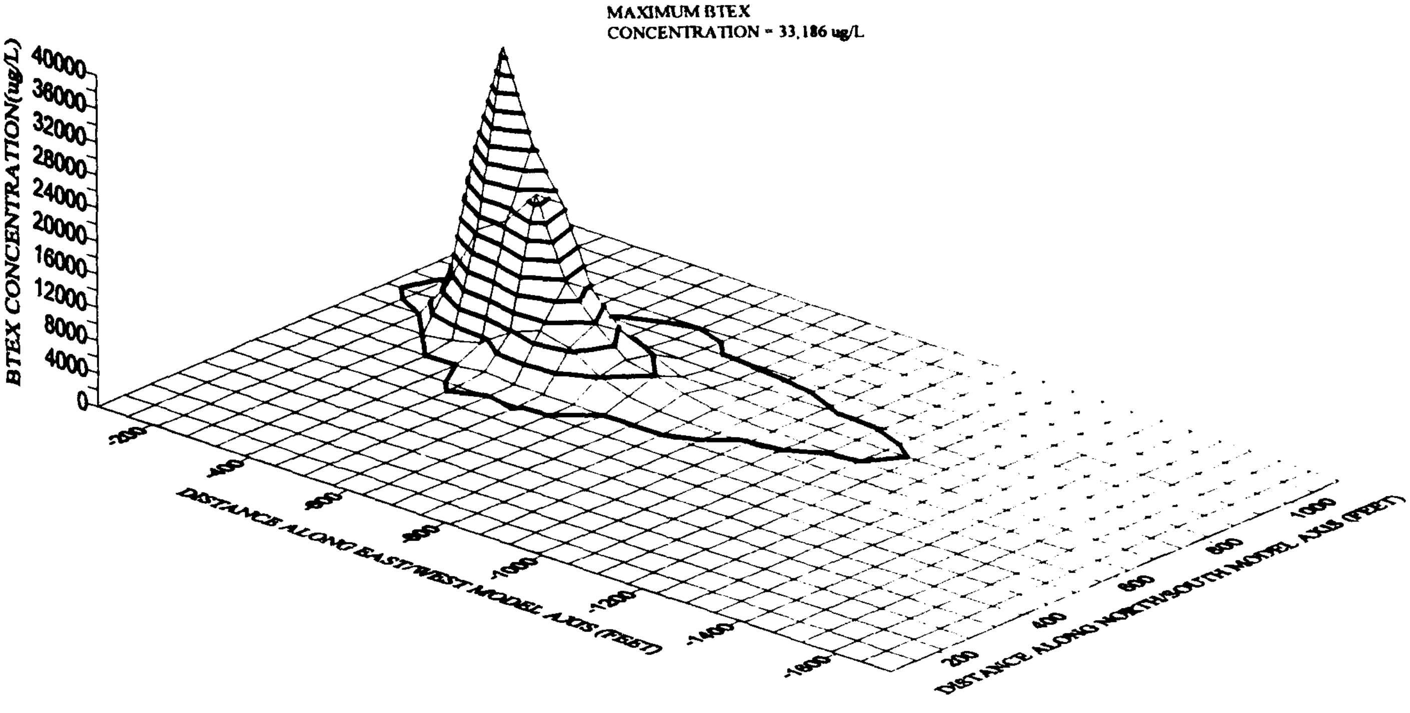


BTEX
RATION = 33,517 ug/L





CALIBRATED MODEL



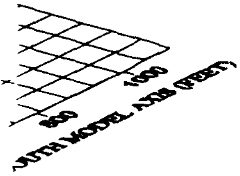


FIGURE 5.9

MODEL SENSITIVITY TO VARIATIONS IN POROSITY

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

plume introduced in infiltration waters flushing into the system. Decreasing R by 20 percent decreases the potential for contact of sorbed BTEX with replenished electron acceptors, thus allowing less biodegradation. As a result, the maximum BTEX concentration in the source area increased to 37,360, without a noticeable change in the downgradient BTEX extent. Because the retardation factor used for the model is low relative to other possible retardation factors (Table 5.3), the R used for the calibrated simulation results in a more conservative prediction of the downgradient plume extent.

The effects of varying dispersivity are illustrated by Figure 5.8. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.1. Increasing the dispersivity by 50 percent resulted in a very minor decrease in the maximum BTEX concentrations (by approximately 600 μg/L) without a noticeable change in areal extent. Decreasing the dispersivity by 50 percent produced a plume with slightly higher BTEX concentrations (by approximately 800 μg/L) without a noticeable change in areal extent. This model appears to be insensitive to dispersivity within the range of values evaluated for this analysis.

The effects of varying effective porosity are illustrated by Figure 5.9. Walton (1988) gives a range of 0.1 to 0.3 for the effective porosity of fine sand. A comparison of the model using effective porosities that were increased and decreased by 25 percent (to 0.31 and 0.19, respectively) around the calibrated value of 0.25 shows a maximum BTEX concentration difference of approximately 800 μg/L at the source and only changes plume extents by about 150 feet. Therefore, the model is moderately insensitive to the range of reasonable effective porosity values.

The results of the sensitivity analyses suggest that the calibrated model parameters used for this report are appropriate. The calibrated model is very sensitive to the transmissivity and the coefficient of anaerobic decay and relatively insensitive to the retardation coefficient, the dispersivity, and the effective porosity. Increasing the transmissivity and the coefficient of anaerobic decay greatly diminishes the predicted maximum BTEX concentrations, although only the coefficient of anaerobic decay results in an actual destruction of (or decrease in) the mass of BTEX. Lowering the transmissivity or the coefficient of anaerobic decay has a reverse effect, and maximum concentrations of BTEX in the aquifer are greatly increased. The model appears relatively insensitive to the retardation factor and dispersivity; however, variation of values for these parameters contributed toward an appropriate plume configuration.

5.6 MODEL RESULTS

To predict fate and transport of dissolved BTEX compounds at the FT-08 site, three Bioplume II simulations (CFTA-IR, CFTA-BV, and CFTA-EX) were run under different sets of conditions. The first simulation (CFTA-IR) assumed the physical processes that currently operate at the site will continue into the future. The second simulation (CFTA-BV) assumed that through the implementation of a soil bioventing system the soil source is reduced and results in a 50 percent decrease in BTEX entering the groundwater per year. The third simulation (CFTA-EX) assumed that loading rates were eliminated at the pipe outfall through excavation of contaminated soil within the upcoming year. The source remaining in the burn area was assumed to be remediated through bioventing. All three models assume that current contamination sources at the site will not increase because the fire training activities at the site ceased over 10 years ago. Input and output files for each simulation are presented in Appendix D. Model results are described in the following sections.

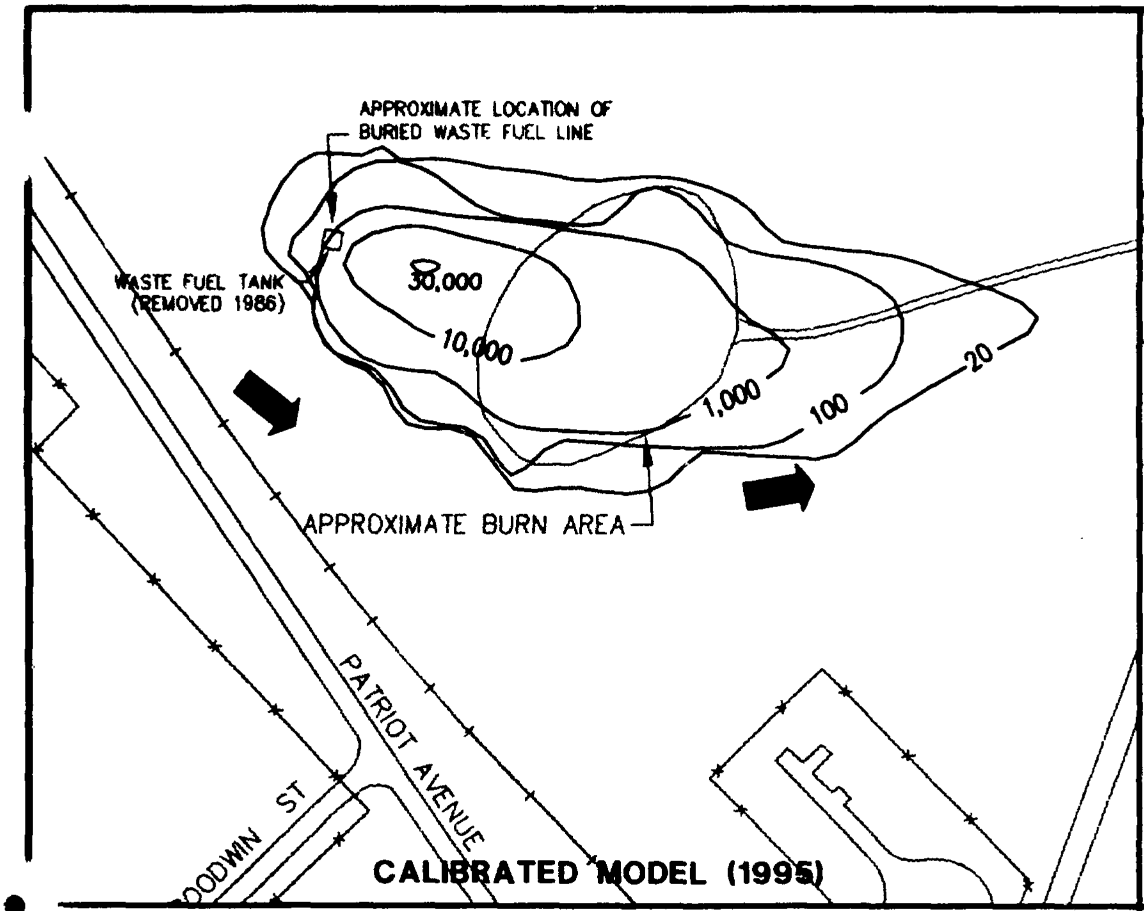
Each model is evaluated with respect to maximum total BTEX concentrations and the extent of the 20 µg/L total BTEX isopleth. The 20-µg/L isopleth was selected on the basis of the federal maximum contaminant level (MCL) for benzene (5 µg/L) and the source area composition of dissolved BTEX. The highest total dissolved BTEX concentration was measured in the sample collected from MP-4S and contained approximately 25 percent benzene. Assuming benzene concentrations account for 25 percent of future dissolved BTEX, an isopleth of 20 µg/L is appropriate for future predictions of plume extent. Using the 20-µg/L isopleth for comparison is believed to be conservative for two reasons. First, benzene accounts for only 20 percent of the total dissolved BTEX mass measured across the entire site. Second, benzene tends to weather more rapidly from source area soils than other BTEX compounds. This means that the percentage of benzene in the source area groundwater is expected to decrease with time as the percentage of benzene remaining in the source area soils decreases with time.

5.6.1 Natural Source Weathering (Model CFTA-IR)

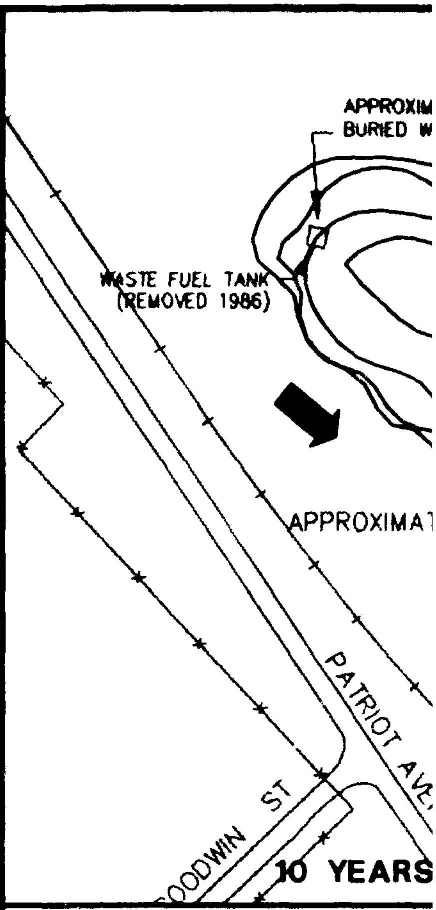
Model CFTA-IR was used to simulate the migration and biodegradation of the BTEX plume assuming that only natural physical weathering decreased BTEX loading in the source areas. Physical weathering included dissolution of BTEX from residual contamination in saturated soil contamination into groundwater and from BTEX dissolution into infiltrating precipitation that contacts residual contamination in the vadose zone. This model does not account for volatilization of BTEX in the vadose zone and chemical or biological degradation of residual product remaining in site soils. Therefore, estimates of source reduction are conservative, which in turn result in conservative model predictions for plume migration.

In order to simulate the anticipated decrease in the source size and composition, model CFTA-IR utilizes 11 pumping periods. The first 4 pumping periods are a copy of the calibrated model. Each of the following pumping periods has a duration of 5, 10, 20, or 30 years and assumes a BTEX injection rate lower than the previous period as a result of weathering. The reduced BTEX injection rate represents a geometric source reduction rate of approximately 5 percent per year. The source reduction rate of 5 percent provided the best calibration in the calibrated model and is an accepted conservative value for natural source weathering. A source decay rate for residual soil BTEX was estimated using a soil sample from MP-4S. The 1995 BTEX compound fractions were compared with assumed "fresh" JP-4 fractions that may have been present during tank removal in 1986. The calculations suggest soil BTEX removal at about 10 percent. The BTEX source weathering estimates are presented in Appendix C. The final pumping period is continued for an additional 30 years to simulate the long-term fate of the groundwater plume.

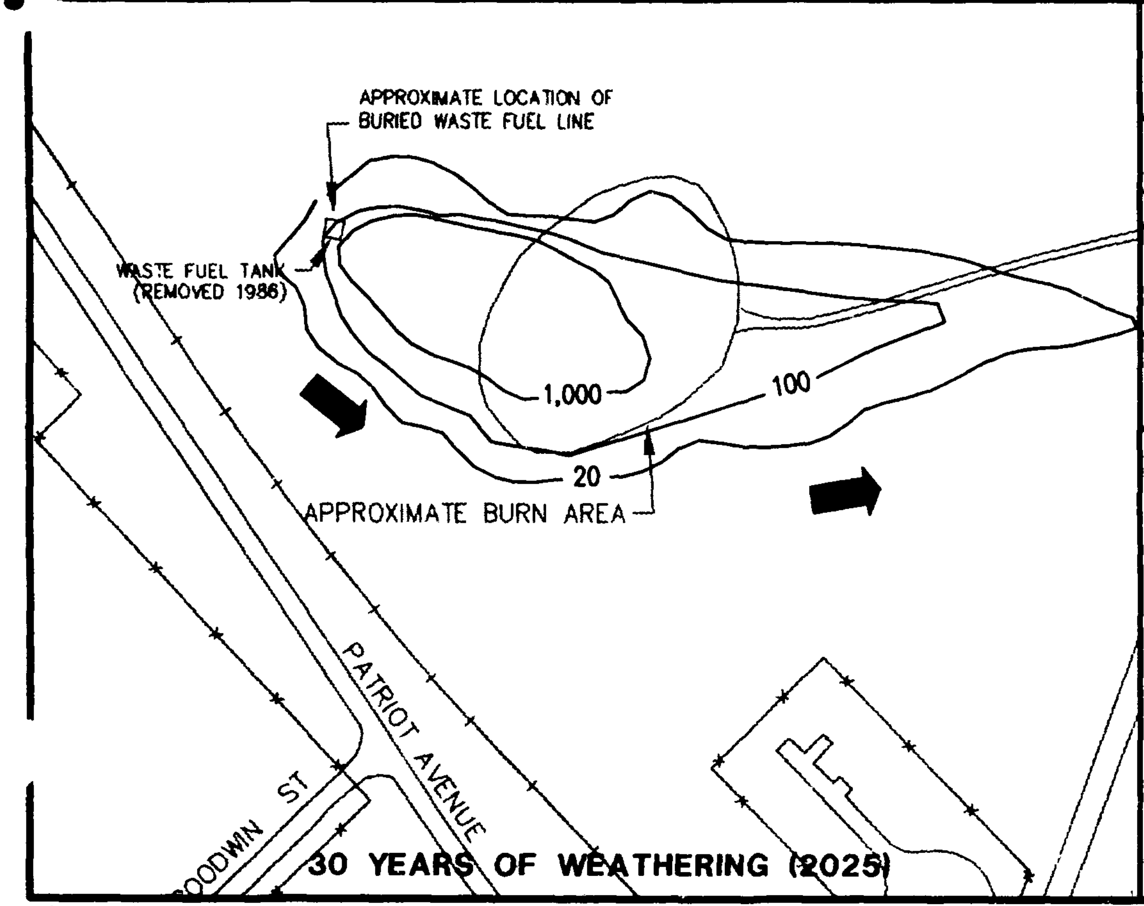
This model predicts declining plume concentrations, with the plume reaching its maximum downgradient extent in approximately 30 years. Figure 5.10 shows the modeled plume for 2005 (10 years of simulated weathering), 2025 (30 years of simulated weathering), and 2057 (62 years of simulated weathering). After 10 years, the modeled downgradient extent of the 20-µg/L BTEX isopleth has migrated



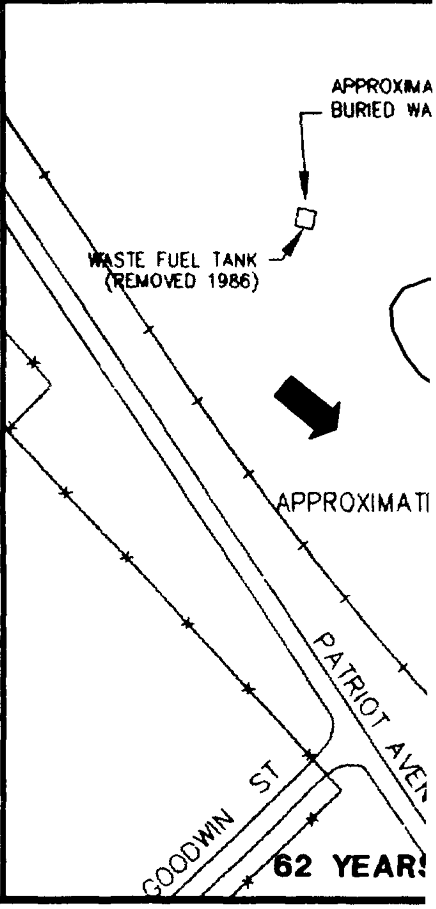
CALIBRATED MODEL (1995)



10 YEARS



30 YEARS OF WEATHERING (2025)



62 YEAR

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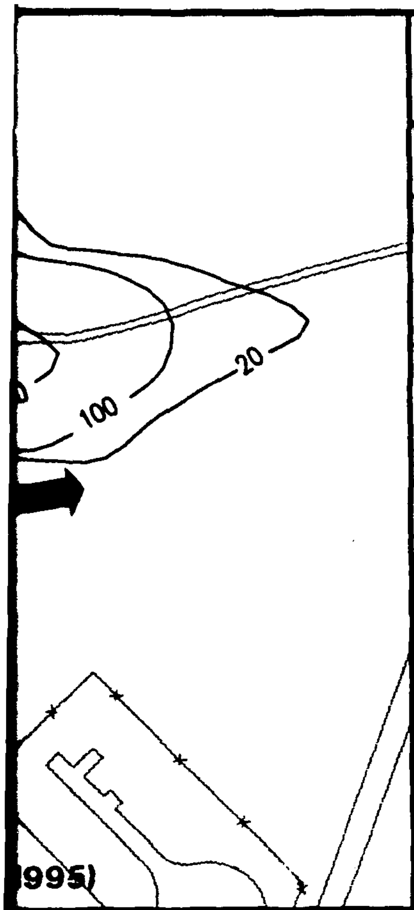
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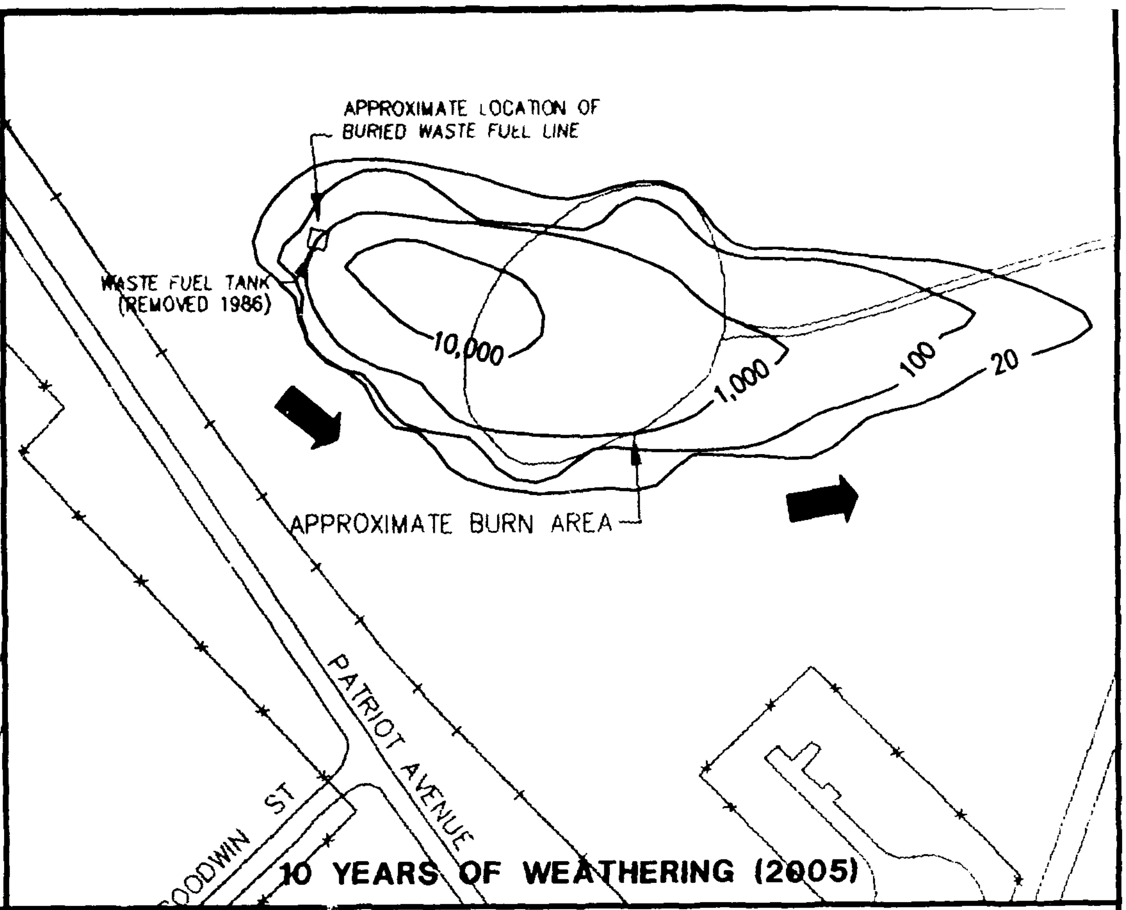
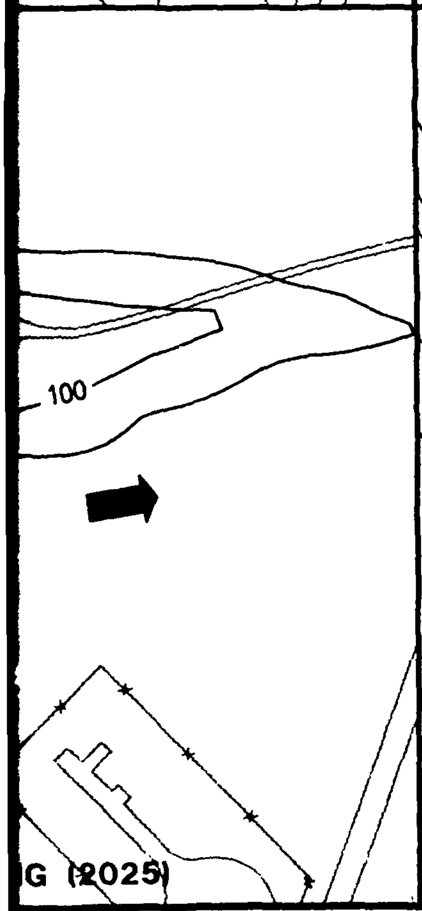
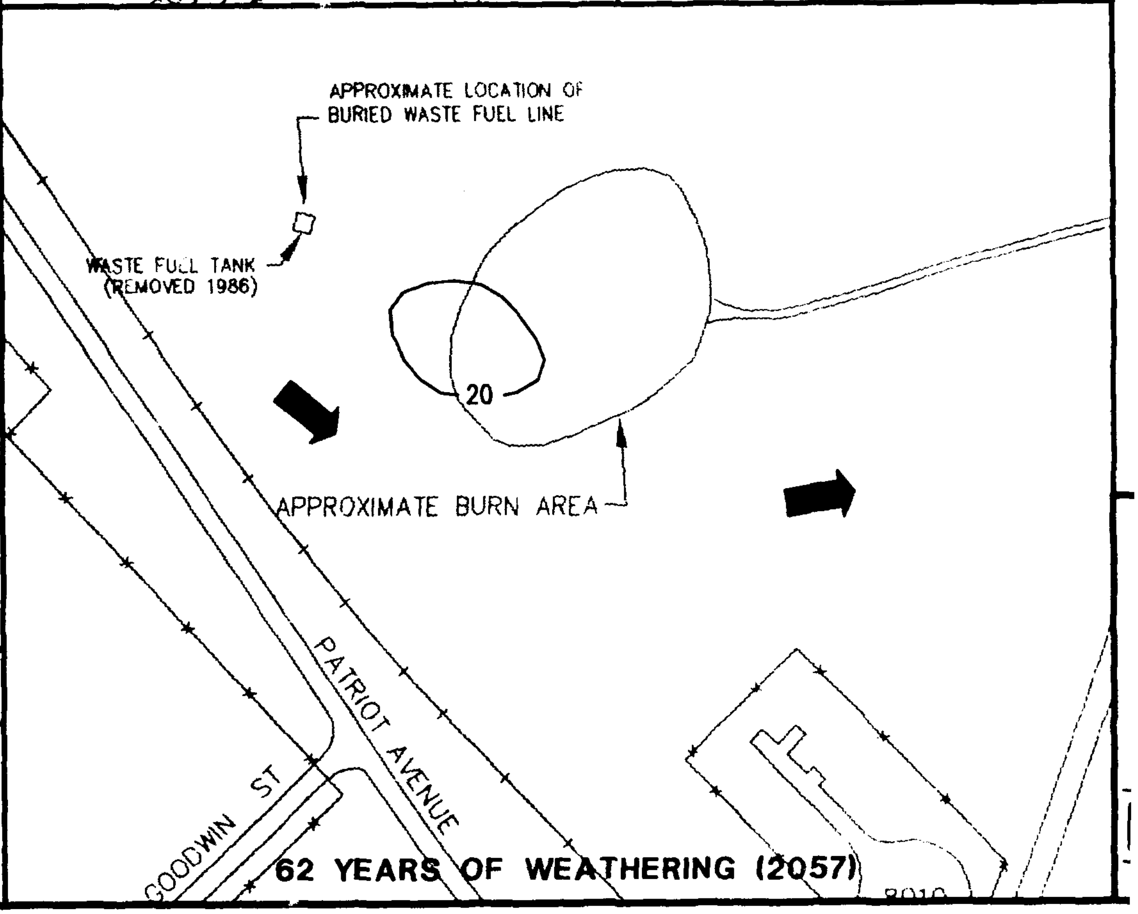

APPROXIMATE LOCATION OF BURIED WASTE FUEL LINE
WASTE FUEL TANK (REMOVED 1986)
10,000
1,000
100
20
APPROXIMATE BURN AREA
PATRIOT AVENUE
GOODWIN ST
10 YEARS OF WEATHERING (2005)


100
G (2025)


APPROXIMATE LOCATION OF BURIED WASTE FUEL LINE
WASTE FUEL TANK (REMOVED 1986)
20
APPROXIMATE BURN AREA
PATRIOT AVENUE
GOODWIN ST
62 YEARS OF WEATHERING (2057)

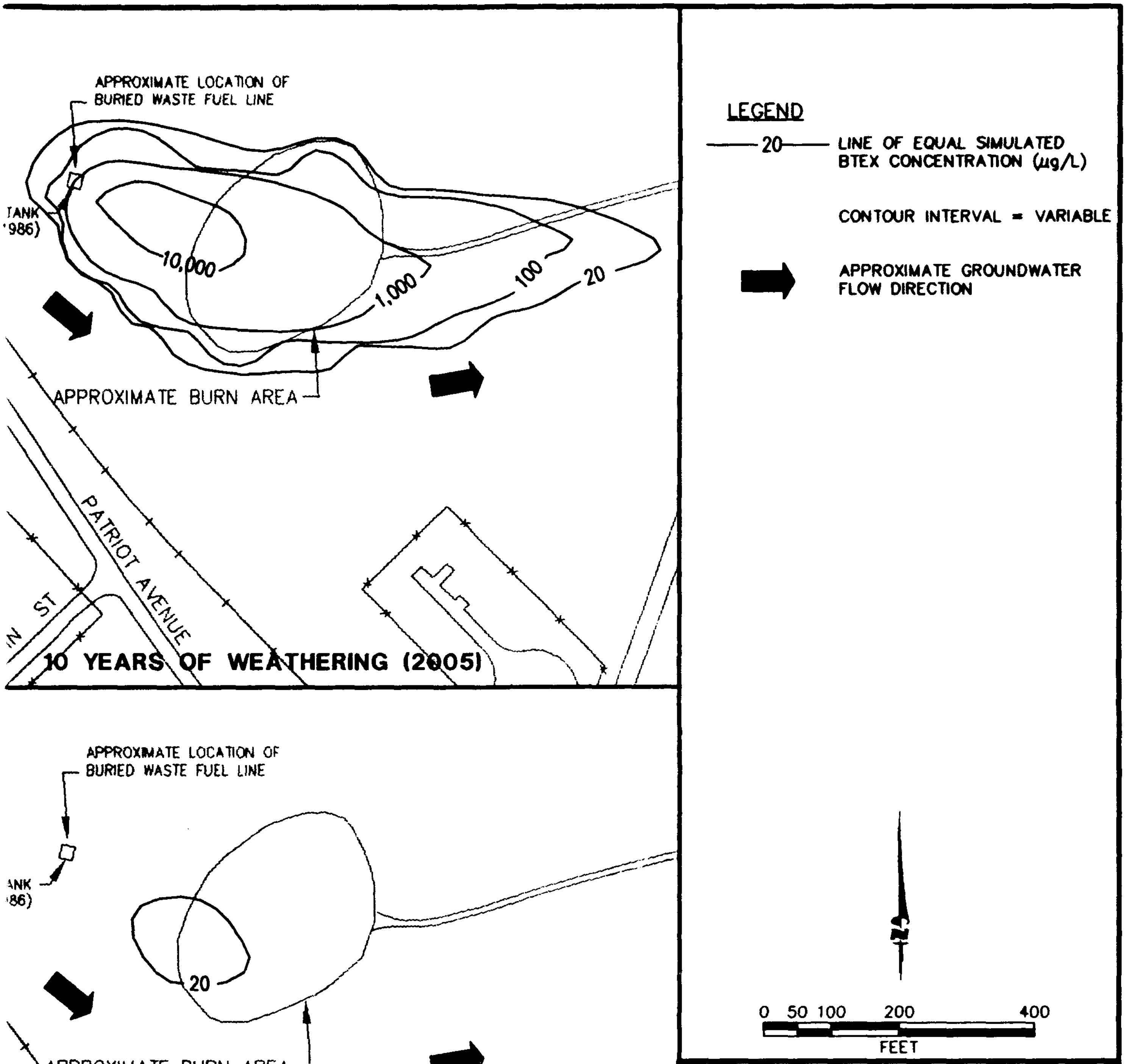


FIGURE 5.10

PREDICTED PLUME MIGRATION CFTA-IR

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

approximately 100 feet downgradient; likewise, the 100-µg/L contour extends further downgradient. Within the source area, the extent of the 1000-mg/L contour remains stable; however, the maximum BTEX concentration decreases by 33 percent from approximately 33,190 µg/L to 22,000 µg/L. (Figure 5.10). After 30 years of weathering (year 2025), the 20 µg/L isopleth reaches the maximum extent, approximately 150 feet downgradient from the calibrated position. At the modeled maximum downgradient extent, the BTEX plume does not leave the site or impact any potential receptors. In addition, although the BTEX plume is at its maximum downgradient extent, the 100-µg/L and 1,000-µg/L isocontours near the center of the plume are both receding. After 30 model years, the maximum BTEX concentration has decreased to approximately 4,550 µg/L, or 14 percent of the calibrated maximum concentration. After 62 years of natural weathering, the model suggests that the groundwater plume will have almost completely attenuated, with a maximum BTEX concentration of 35 µg/L in the source area (Figure 5.10). Further model simulation suggests that after 62 years, the plume is completely degraded to below 20 µg/L.

These results suggest that the maximum observed BTEX concentrations will steadily decrease over the next 65 years without engineered removal. Furthermore, the results suggest that the downgradient extent of the plume will increase by approximately 10 percent over the next 30 years, but that the plume will be completely attenuated within 65 years. Therefore, physical weathering should be sufficient to reduce the BTEX concentrations and limit any future downgradient plume migration.

5.6.2 Engineered Source Reduction (Model CFTA-BV)

To illustrate the impact of engineered source reduction activities upon dissolved BTEX migration, model CFTA-BV incorporates decreasing BTEX loading rates, under the assumption that a bioventing system will be used to remediate the source areas. Bioventing is an *in situ* bioremediation process where low-flow air injection is used to enhance the biodegradation of organic contaminants in the subsurface solid by supplying oxygen to indigenous microbes. Bioventing was simulated in model CFTA-BV through an annual 50 percent reduction in BTEX loading rates over an eight year period.

The CFTA-BV model assumptions are conservative when compared to anticipated removal from bioventing. Implementation of a bioventing soil remediation system has been accompanied by reductions in soil BTEX concentrations averaging over 90 percent per year at a group of 16 other sites (AFCEE, 1994). Therefore, assuming a 50 percent reduction in BTEX loading may underestimate the actual impact of a bioventing system on site groundwater and lengthen the predicted remediation time.

Model CFTA-BV was run with 11 pumping periods. The first four periods are unchanged from the calibrated model. The next 6 pumping periods each last a year and include BTEX loading rates that decrease geometrically, at 50 percent per year. At this point less than 0.1 percent of the original source remains. The final pumping period is continued for an additional 25 years to simulate the long-term fate and transport of the plume. While it is difficult to quantify the actual decrease in the BTEX loading rates that will be brought about by bioventing, a model based on these assumptions can provide a useful indication of the potential effects of source reduction.

This model predicts a rapid decrease in source area BTEX concentrations followed by a slower decrease in the areal extent of the plume. Figure 5.11 presents model results for the years 2000 (5 years after implementation of bioventing), 2005 (10 years after implementation of bioventing), and 2025 (30 years after implementation of bioventing). Five years after implementation of bioventing, the plume (as defined by the 20-µg/L isocontour) has migrated approximately 100 feet downgradient from the downgradient boundary of the calibrated plume. The maximum source-area BTEX concentration has decreased 65 percent, from approximately 33,190 µg/L to 11,290 µg/L. The model predicts that the maximum downgradient plume extent will be reached in the year 2005, with the 20-µg/L contour approximately 150 feet downgradient from its calibrated position. The maximum predicted BTEX concentration, however, is less than 10 percent of that in the calibrated model. After 30 years of active and passive remediation, the plume has detached from the source area and the maximum simulated BTEX concentration (30 µg/L) lies downgradient from the source areas. The model predicts that the plume will disappear entirely 32 years after the initiation of bioventing.

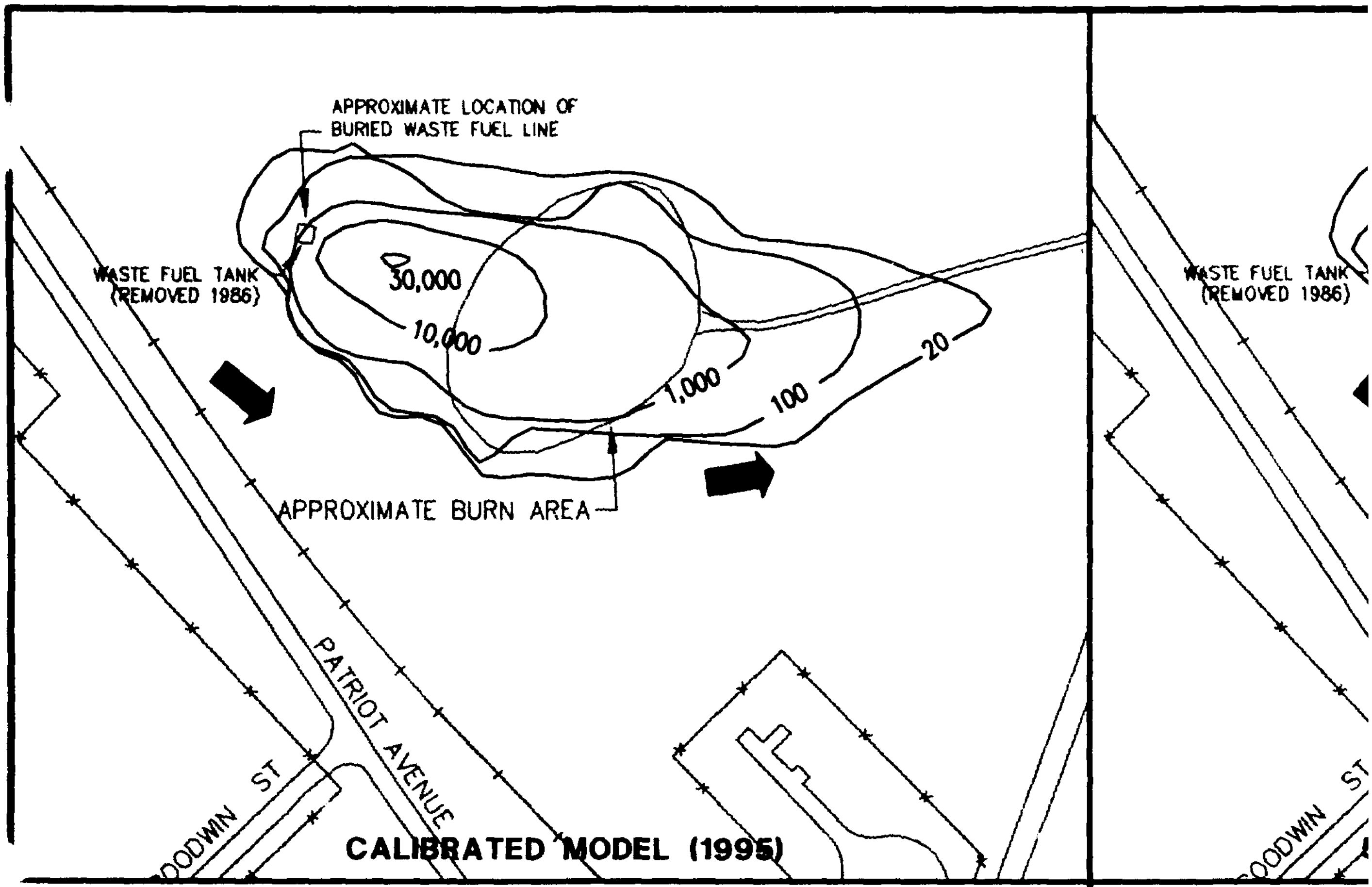
5.6.3 Instantaneous Source Removal (Model CFTA-EX)

Model CFTA-EX was run to illustrate the scenario of a complete source removal (through excavation) at the outfall of the waste fuel pipeline. Instantaneous source removal is the least conservative of the three scenarios modeled for this site. For the first predictive year of this simulation (1996), BTEX loading rates were reduced to zero at the pipe outfall. The bioventing scenario from the previous model was used for the BTEX loading at the 6 cells representing the burn area. As in the two previous models, the first four pumping periods are a copy of the calibrated model. The next pumping period removes source loading at the two model cells representing the waste fuel pipe outfall and reduces BTEX loading in the 6 cells occupying the burn pit by 50 percent. The next 5 pumping periods continue, as in the bioventing simulation, to reduce source loading rates in the burn pit cells by 50 percent annually. The final pumping period is continued an additional 25 years to simulate the long-term fate and transport of the plume.

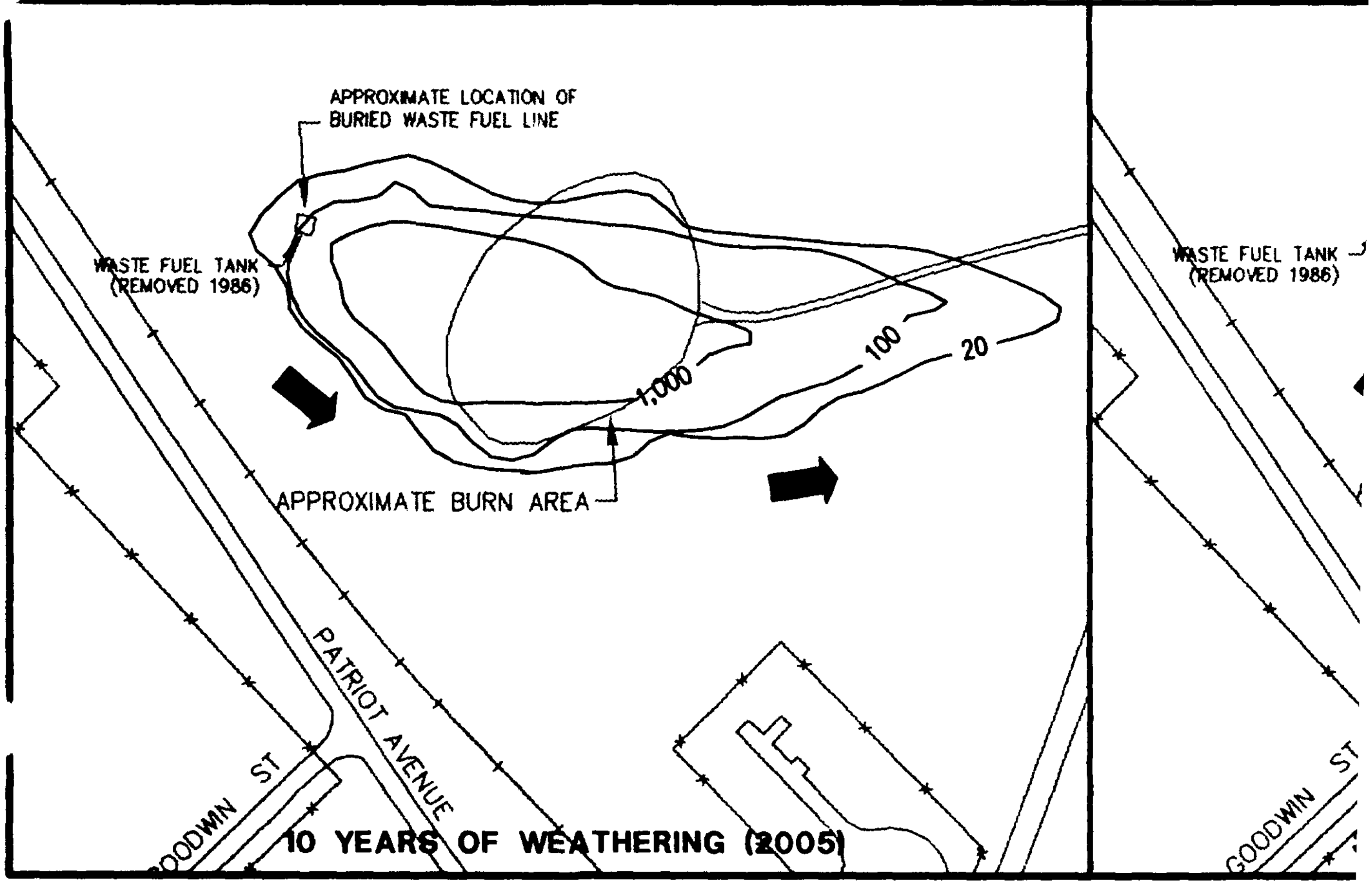
This model predicts a slightly faster decrease in maximum groundwater BTEX concentrations in the source area over a 10-year period. Figure 5.12 presents model predictions for 5, 10, and 30 years of remediation. Simulated maximum BTEX concentrations for this model decrease approximately 75 percent in the first 5 years, from 33,190 µg/L to 8,610 µg/L. The 10-year simulation (year 2005) predicts source-area BTEX concentrations will decrease by over 92 percent to a maximum predicted BTEX concentration of 2,460 µg/L. At this time, the model predicts the plume to be at its maximum downgradient extent of 150 feet beyond the current position. At year 30 (2025) the model suggests that the plume will be detached from the source area, with a maximum BTEX concentration of 27 µg/L. The model predicts the plume will disappear entirely by year 32 (2027).

5.7 CHLORINATED SOLVENT DEGRADATION RATES

Aerobic and anaerobic degradation rates are compound-specific, with highly chlorinated compounds degrading preferentially under highly reducing anaerobic or less-reducing anaerobic conditions and with less-chlorinated compounds degrading



CALIBRATED MODEL (1995)



10 YEARS OF WEATHERING (2005)

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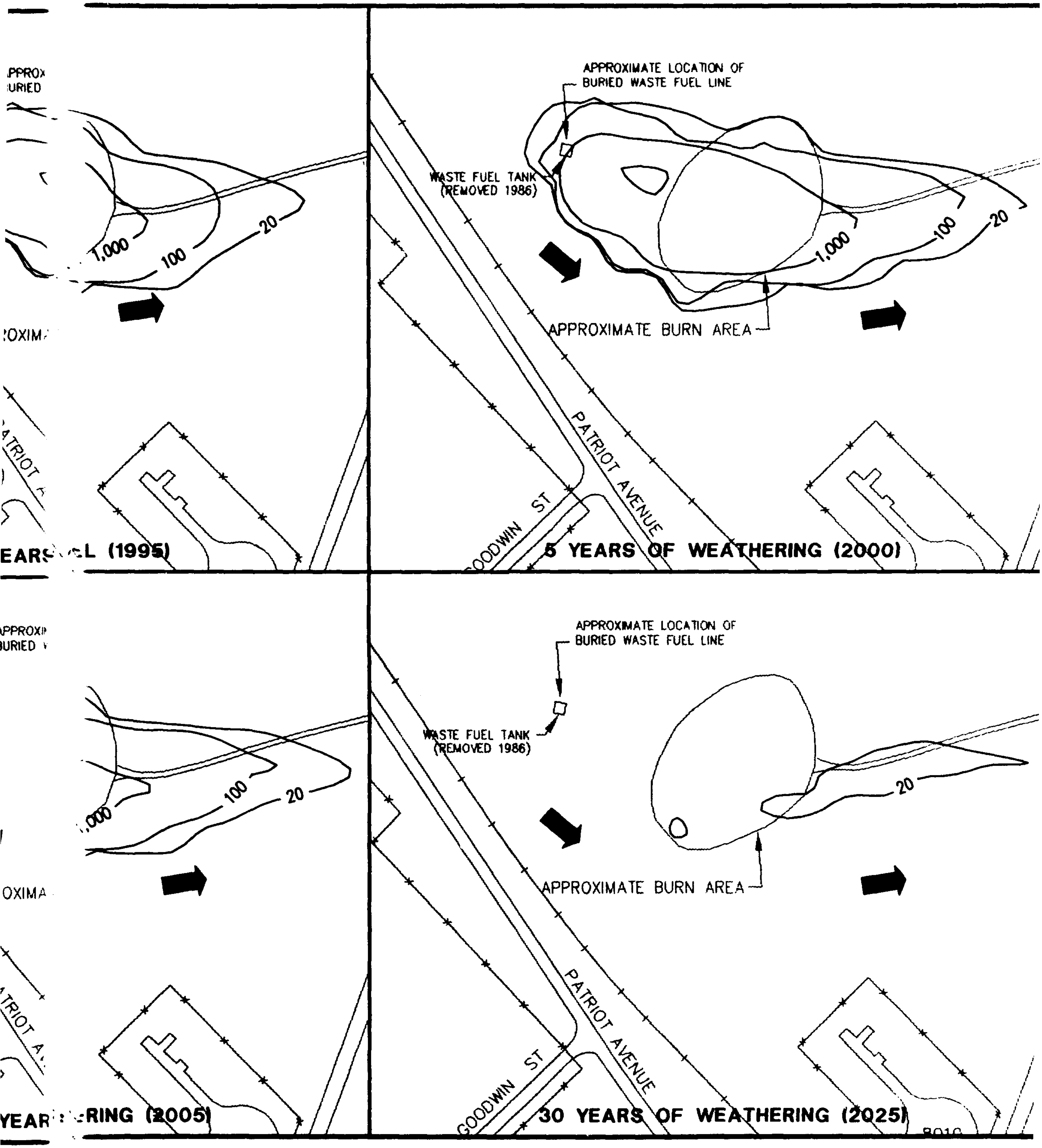
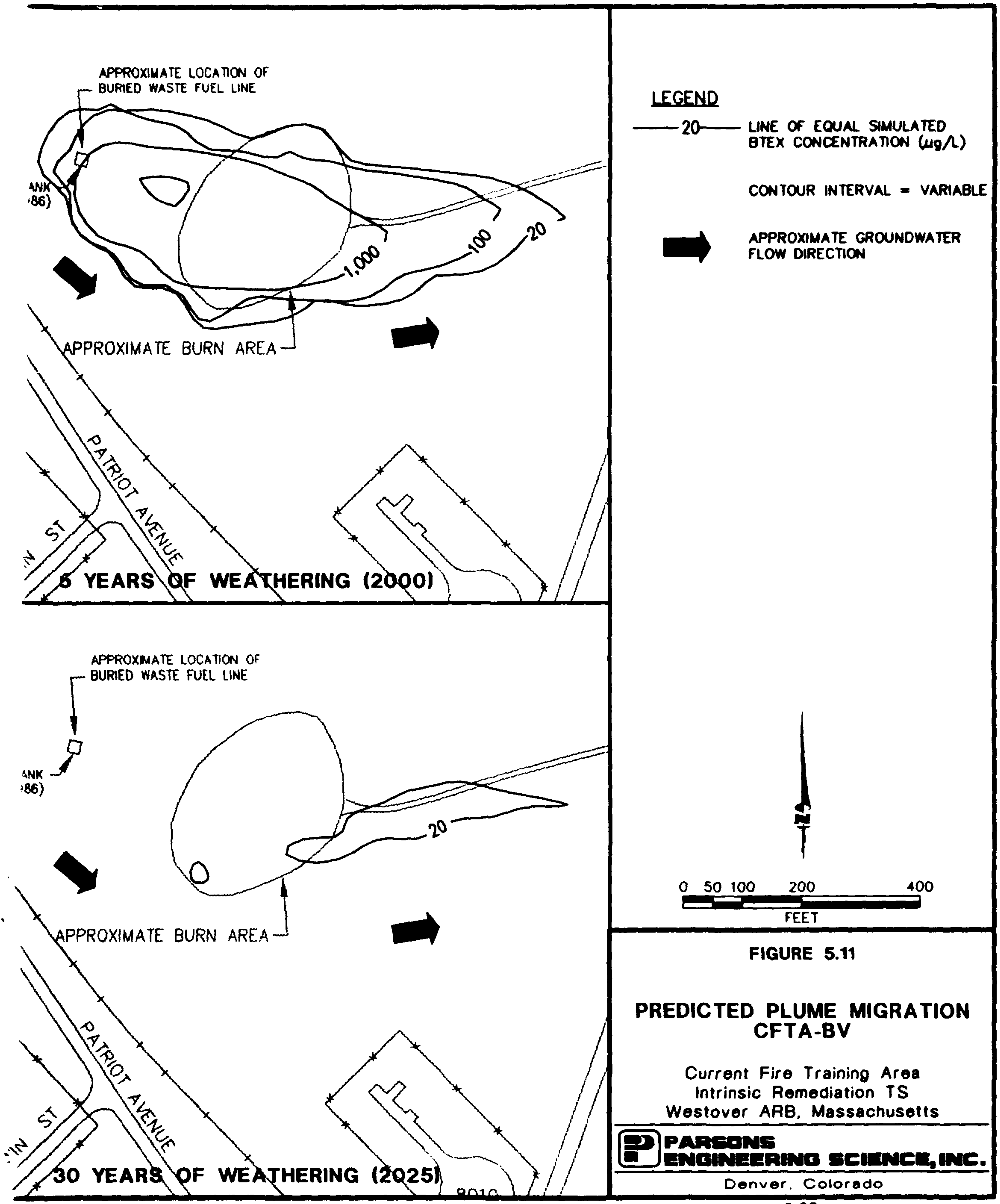


EARS L (1995)

5 YEARS OF WEATHERING (2000)

YEAR RING (2005)

30 YEARS OF WEATHERING (2025)



LEGEND

—20— LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)

CONTOUR INTERVAL = VARIABLE

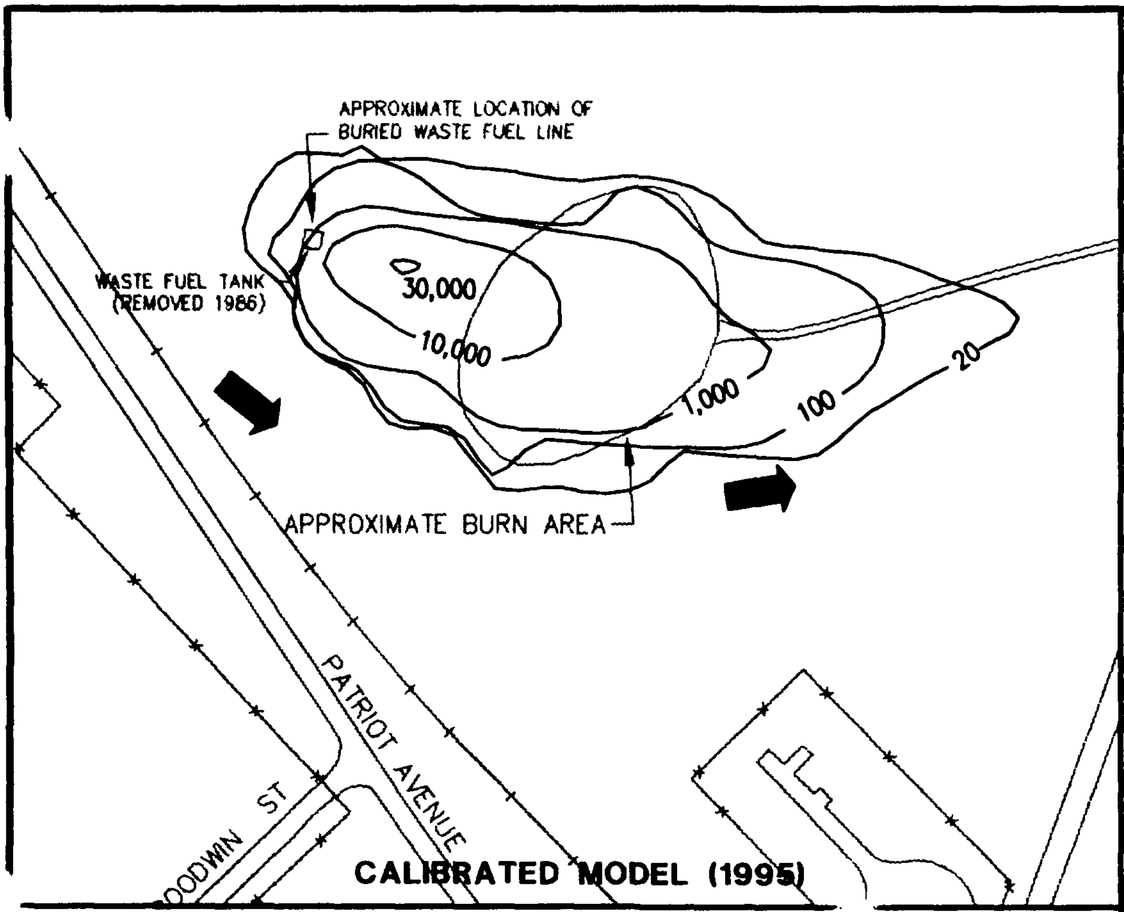
➡ APPROXIMATE GROUNDWATER FLOW DIRECTION

FIGURE 5.11

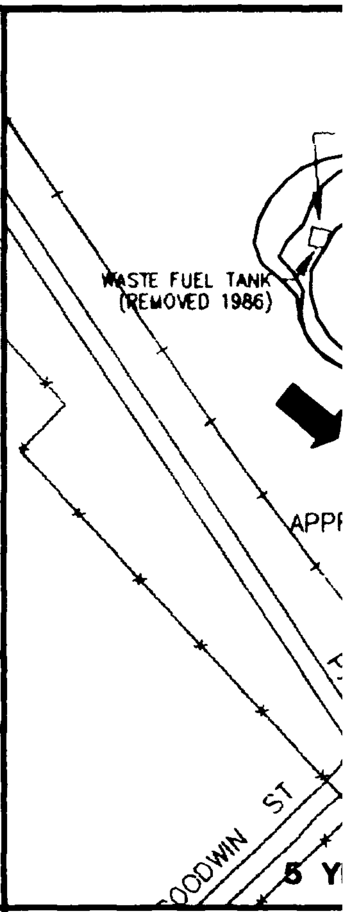
PREDICTED PLUME MIGRATION CFTA-BV

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



CALIBRATED MODEL (1995)



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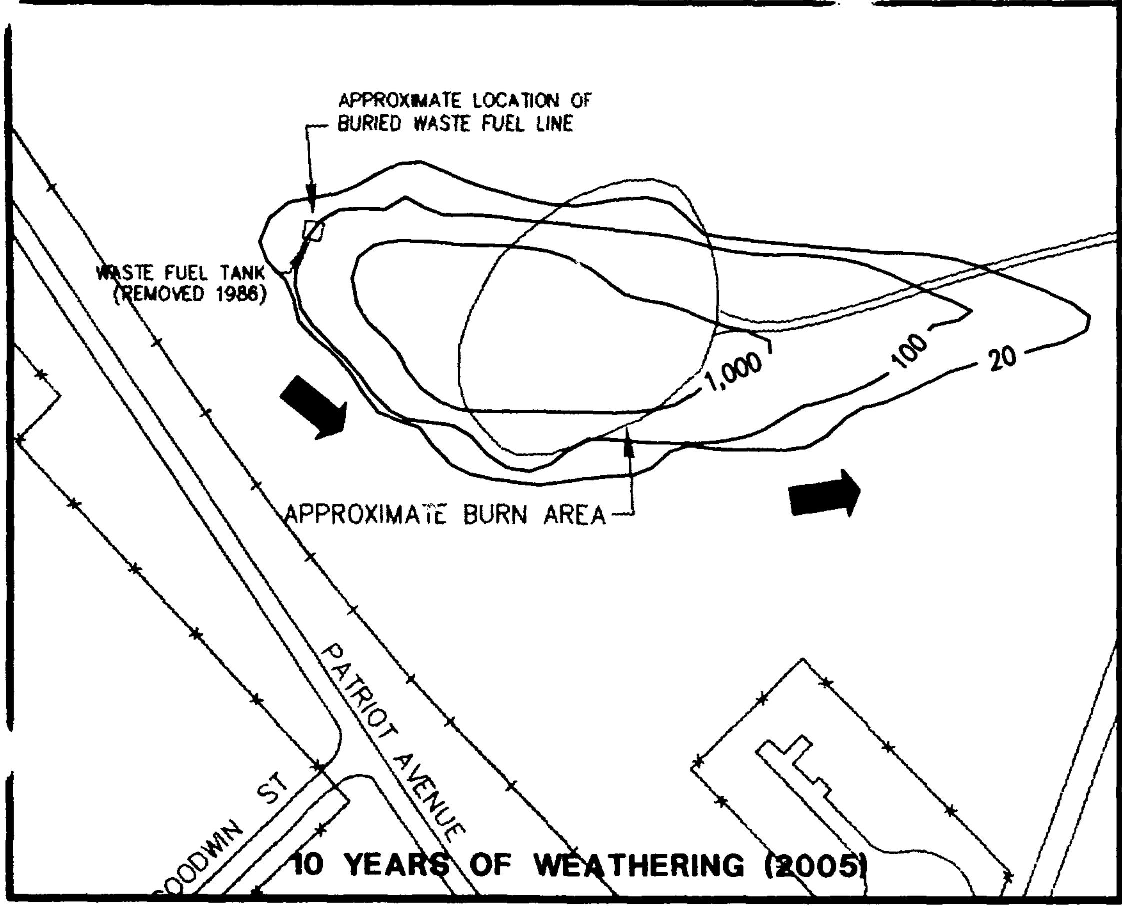
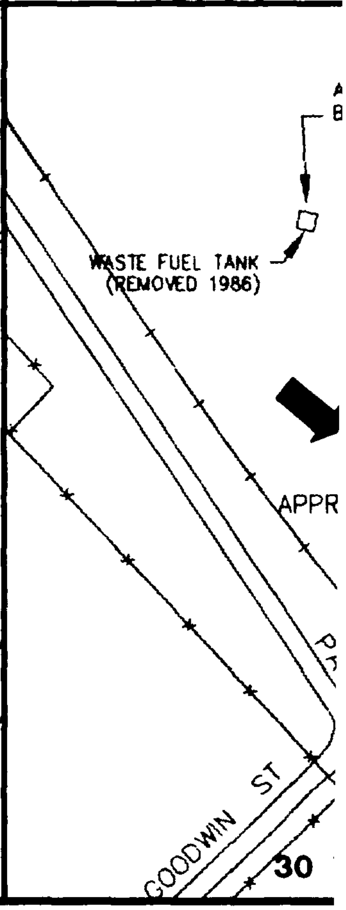


10 YEARS OF WEATHERING (2005)



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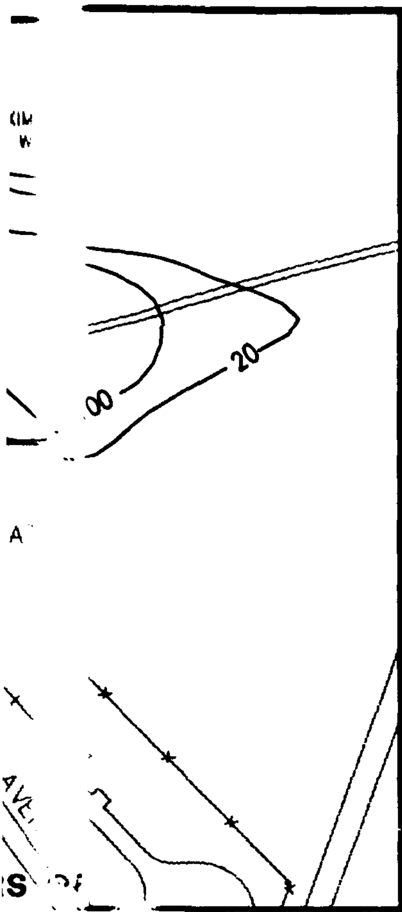
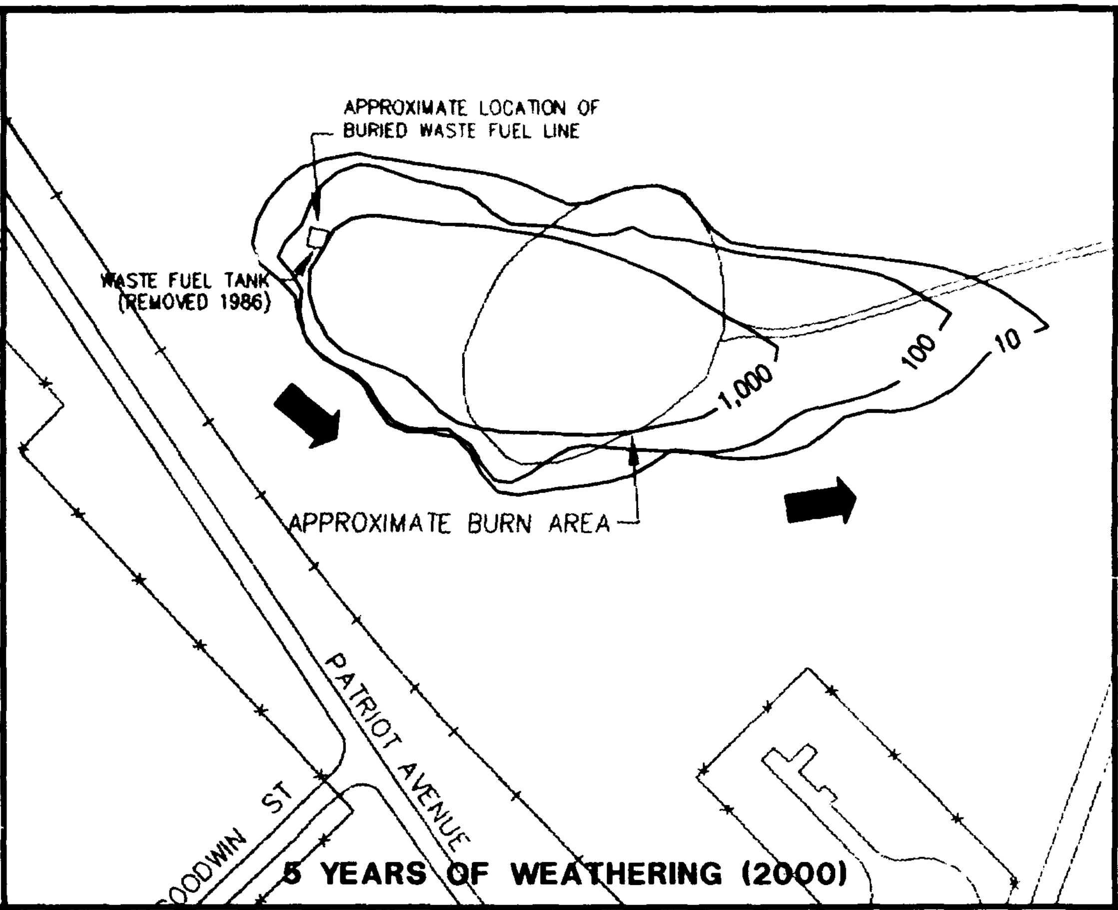
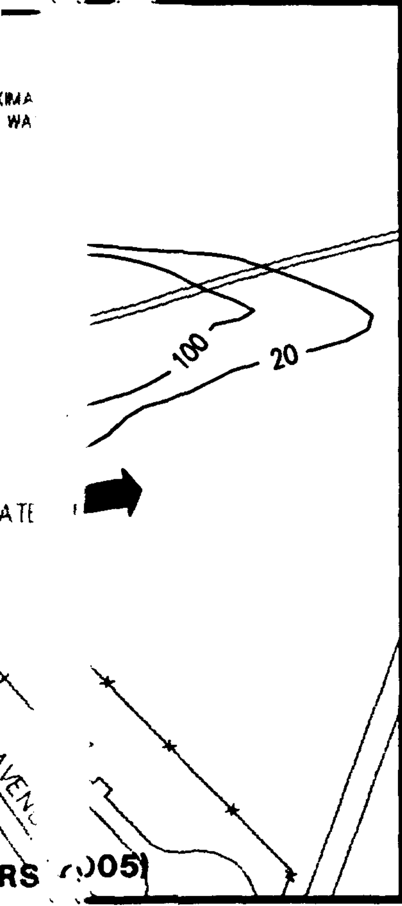
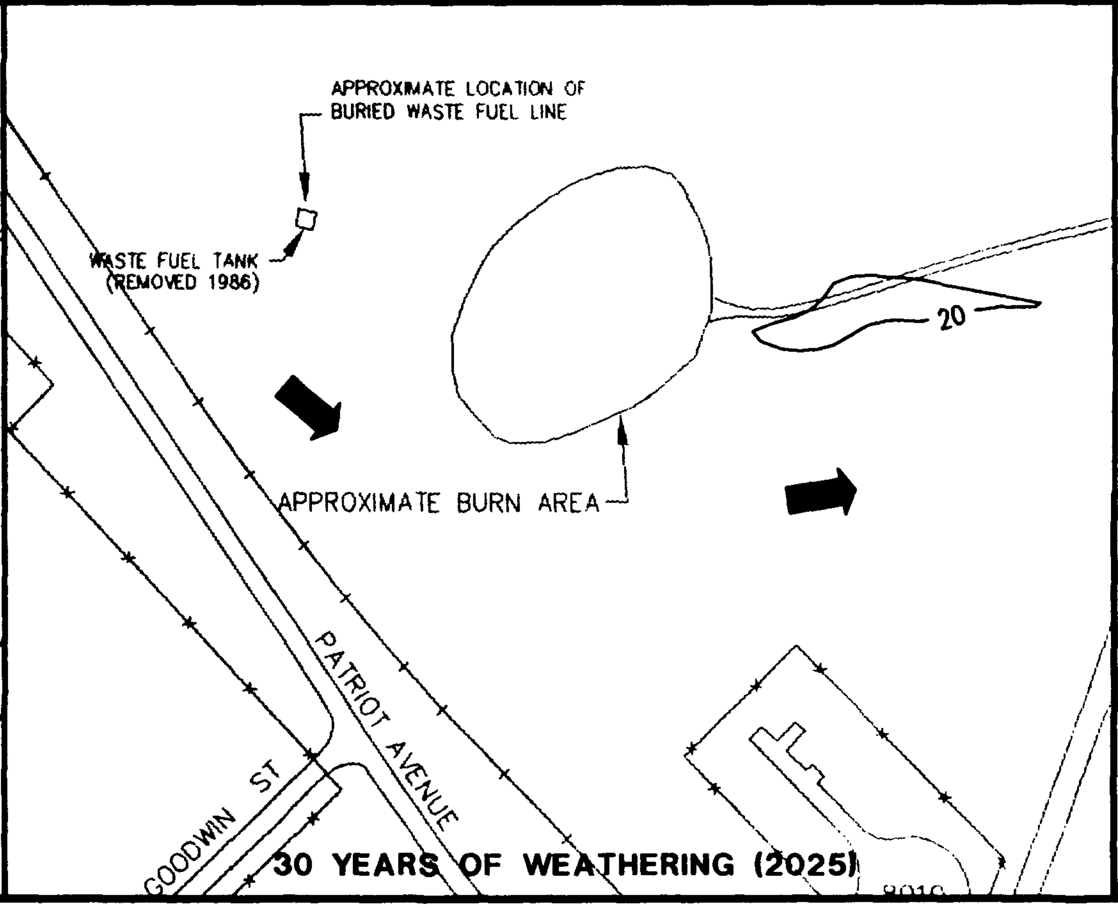




5 YEARS OF WEATHERING (2000)





30 YEARS OF WEATHERING (2025)

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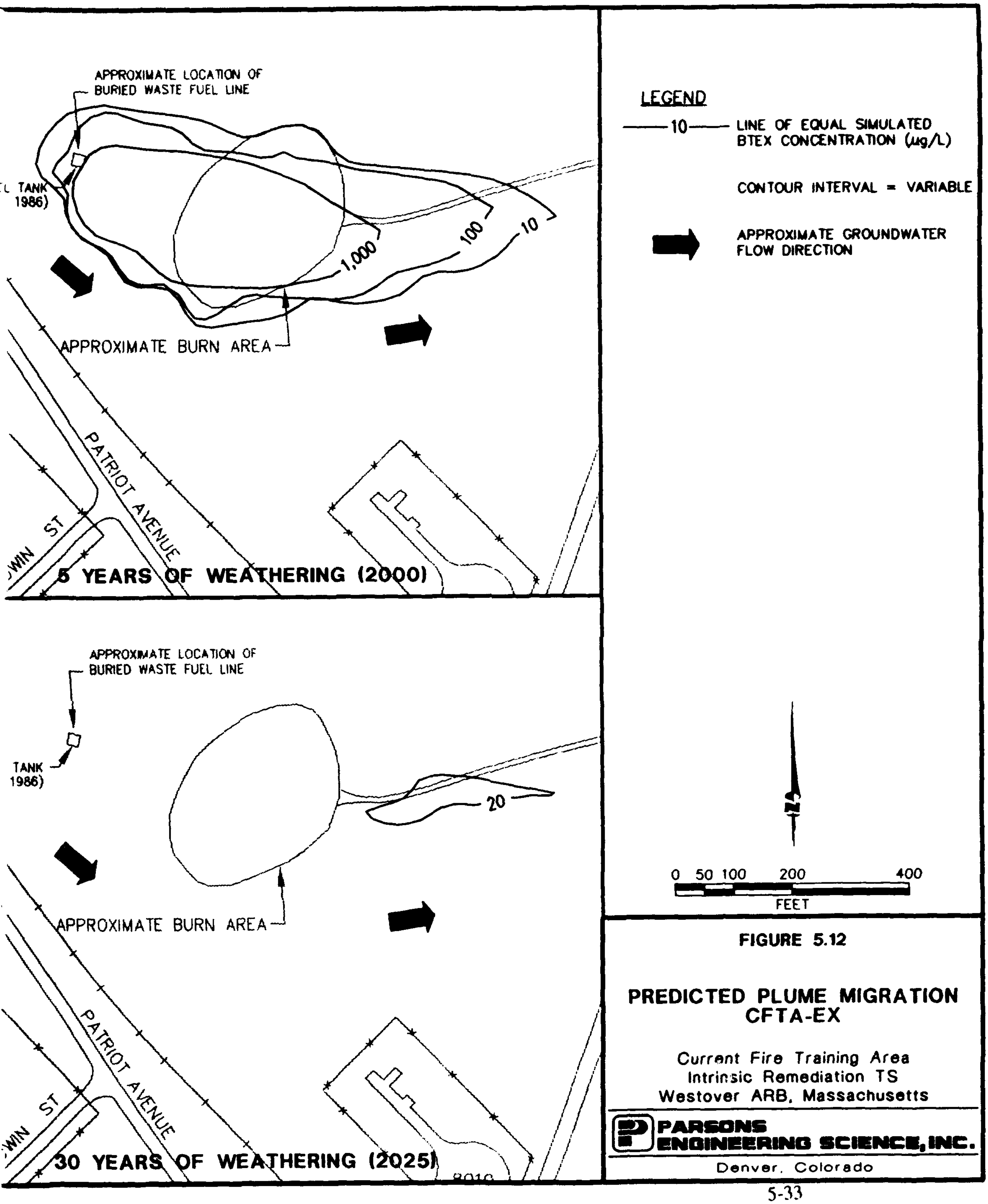


FIGURE 5.12

PREDICTED PLUME MIGRATION CFTA-EX

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

preferentially under aerobic or less-reducing anaerobic conditions (Norris et al., 1994). This situation is advantageous at FT-08 because the burn area coincides with a highly reducing anaerobic zone brought about by the presence of dissolved BTEX compounds. Within this zone, source solvents are degraded under anaerobic conditions to less-chlorinated daughter solvents. Daughter products that degrade slowly under anaerobic conditions are then transported through advective-dispersive processes into the aerobic fringe, where degradation to innocuous products can proceed more rapidly.

The method of Buscheck and Alcantar (1995), as discussed in Section 5.3.4.2, can be used to estimate a degradation rate resulting from both aerobic and anaerobic processes assuming a one-dimensional, steady-state system experiencing first-order decay. Table 5.4 presents a first-order rate constant calculation for TCE using May 1995 data and a retardation coefficient of 2.193 (computed from the soil sorption coefficient for TCE). An easterly groundwater flow path through wells CF-3, MP-14D, and MP-5M was used for estimating a biodegradation rate. This flow path represents a groundwater travel path from the anaerobic plume core to the more aerobic downgradient extents. An exponential fit to the data estimates a log-linear slope of 0.016 ft^{-1}, which was in turn used to estimate a decay constant of 0.0005 day^{-1}. The loss of TCE along this flow path closely approximates a first-order biodegradation decay rate, with a calculated R^2 of 0.987. A decay constant of 0.0005 day^{-1} was also estimated along the same flow path by using total chlorinated solvent concentrations. In this case, R^2 improved slightly to 0.994. A decay constant of 0.0004 day^{-1} was computed for TCE and total chlorinated solvents using July 1996 data along the same flowpath. The R^2 values for both calculations exceeded 0.98.

Although a first-order decay constant could be calculated for the system, the system could not be modeled successfully because source-area constraints are insufficient. The highest chlorinated solvent concentration was detected in a shallow groundwater sample within the burn area; furthermore, the deepest groundwater samples collected immediately above the clay aquitard contained no detected BTEX or chlorinated solvent concentrations. From these results, it can be concluded that the source of dissolved chlorinated solvents lies near the ground surface within the main burn pit rather than from a dense non-aqueous phase liquid (DNAPL) pooled atop an aquitard. Chlorinated solvents, however, were not detected in burn pit soil samples during this investigation, and the highest chlorinated solvent concentration detected in soil samples during previous investigations was only 6.1 μg/kg. Given the volatility and solubility of chlorinated solvents, the sandy site soils, and the 20 years since chlorinated solvents were reportedly last used at the site, the absence of chlorinated solvents in vadose zone soils is not a surprise. It is very likely that chlorinated solvents remaining at the site are dissolved in residual fuel hydrocarbons located at the surface or trapped below the water table. Because models are very sensitive to the magnitude and extent of the source area and neither of these are sufficiently defined, a reliable model for chlorinated organics could not be generated.

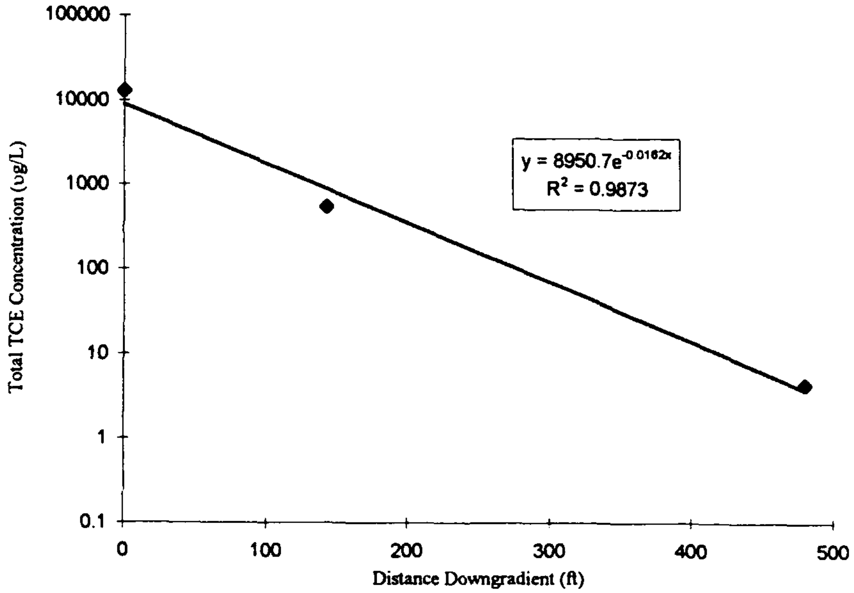
5.8 CONCLUSIONS AND DISCUSSION

Three model scenarios were used to predict BTEX attenuation and migration rates at the FT-08 site. The first scenario, model CFTA-IR, assumed natural physical weathering of the residual soil source contamination. The second scenario, model

TABLE 5.4
FIRST-ORDER RATE CONSTANT CALCULATION FOR TCE USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Point	Distance Downgradient(ft)	Total TCE (μg/L) May-95
CF-3	0	12800
MP-14D	142	541
MP-5M	480	4.4

PLOT OF TCE CONCENTRATION VERSUS DISTANCE



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

where	$v_c =$	0.026	ft/day
	$\alpha_x =$	8	ft
	$k/v =$	0.0162	ft^{-1}
therefore	$\lambda =$	0.0005	day^{-1}

CFTA-BV, assumed that as a result of the operation of a bioventing system, the source of dissolved BTEX would be completely eliminated in 8 years. Model CFTA-EX assumes removal of the BTEX source soils at the pipe outfall along with bioventing in the burn pit soils. The results of all three Bioplume II model scenarios suggest that dissolved BTEX will not migrate more than 150 feet beyond the current plume front.

Model CFTA-IR results suggest that the BTEX plume will be completely degraded by natural processes after approximately 62 years. Using bioventing and a combination of bioventing and excavation, models CFTA-BV and CFTA-EX predict that complete remediation of the dissolved BTEX plume will require approximately 32 years. All three models predict that the leading edge of the plume will not advance more than 150 feet as intrinsic remediation of dissolved groundwater proceeds.

In all model simulations, several conservative assumptions are built into the model. The use of these conservative model assumptions suggests that natural attenuation of BTEX contamination at the site may exceed model predictions. These conservative model assumptions include:

1) Aerobic respiration, iron reduction, sulfate reduction, and methanogenesis all are occurring at this site; however, only the anaerobic processes are effectively simulated in the models. Aerobic processes are effectively simulated within the core of the plume where they potentially account for less than 15 percent of degradation. At the leading edge of the plume, however, the aerobic contribution is more significant and is very likely underestimated by a first order biodegradation rate. In addition, aerobic biodegradation may potentially become more important within the core of the plume as residual BTEX source concentrations are removed, thereby allowing more oxygenated rainwater to percolate through vadose zone soils.

2) The stoichiometry used to determine the ratio between electron acceptors and total BTEX assumed that no microbial cell mass was produced during the reactions. As discussed in Section 4.3.2, this approach may be too conservative by a factor of three.

3) A low coefficient of retardation for benzene (2.29) was used for all the BTEX compounds in the model simulations. Minimum retardation coefficient values for the other BTEX compounds range from 3.46 to 7.06. The use of a conservative retardation coefficient tends to increase the velocity of contaminant migration, but may provide a more accurate estimate of benzene transport. However, realistic retardation coefficients for toluene, ethylbenzene, and xylenes are higher than that for benzene, which will slow the actual migration of these compounds, thereby increasing their susceptibility to biodegradation.

4) The decay constant of 0.00095 day^{-1} is conservative when compared to literature values of 0.001 day^{-1} to 0.185 day^{-1} (see Section 5.3.5.3). The use of a low decay constant increases the travel distance of the contaminant plume, as well as the time required for natural attenuation.

5) Calibrated source concentrations in the models were higher than observed concentrations. This introduction of extra contaminant mass likely results in the predictions being conservative because additional BTEX mass must be biodegraded to produce the observed results.

The three model simulations were run in order to account for uncertainties associated with the assumptions of future site conditions and to provide a framework for any decision-making that might be based on the model results. The patterns of degradation of the plumes shown in models CFTA-IR, CFTA-BV, and CFTA-EX are feasible, given the observed BTEX concentrations, the conservative assumptions made in constructing the simulations, and the strong evidence of biodegradation. Model CFTA-IR is a "worst-case" scenario in that it assumes BTEX dissolution into the aquifer will continue while the source is being naturally weathered. Without source reduction, BTEX contamination in that model remains for more than 60 years. Models CFTA-BV and CFTA-EX are more optimistic predictions which assume active source reduction will rapidly reduce the BTEX in site soils and therefore reduce any further dissolution into the groundwater. This results in more rapid attenuation of the dissolved BTEX plume. All three models predict that the groundwater plume will not leave the Base or impact potential downgradient receptors.

The 1995 and 1996 groundwater analytical results imply that dissolved BTEX and CAH mass is decreasing while plume extent remains relatively unchanged. This combination results in stable isopleths for the lower dissolved concentrations (.e.g., 1 μg/L and 10 μg/L) and shrinking isopleth areas for the higher concentrations (e.g., 100 μg/L, 1,000 μg/L, and 10,000 μg/L). Intrinsic remediation was the only form of site remediation between May 1995 and July 1996; therefore, Model CFTA-IR, which simulates intrinsic remediation without additional engineered remediation, is the most appropriate model for comparison. Model results suggest that source concentrations should decrease; however, the plume should experience increasing concentrations along the plume's leading edge in conjunction with gradual plume expansion for the next 30 years. Comparison of May 1995 and July 1996 groundwater sampling results suggest that RNA at the site appears to be proceeding more rapidly than predicted by the numerical model. First, the dissolved BTEX plume did not expand, and second, the observed source area concentration after only one year lost approximately two-thirds of the total decrease predicted after 10 years. Several conservative assumptions were made during initial groundwater modeling because insufficient contaminant data were available prior to the 1995 investigation. Therefore, the groundwater model was calibrated only on the basis of the 1995 soil and groundwater data. Consequently, the existing groundwater model may be overly conservative. The model however, does suggest a worst-case contaminant fate and transport scenario.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of three groundwater remedial alternatives for FT-08 at Westover ARB. The intent of this evaluation is to determine if intrinsic remediation of groundwater is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the site, especially when combined with other innovative and conventional remedial technologies.

Section 6.1 presents the criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. The results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for shallow groundwater contamination at the site were adapted from those recommended by the USEPA (1988) for selecting remedies for Superfund sites [Office of Solid Waste and Emergency Response (OSWER) Directive 9355.3-01]. These criteria include (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report focuses on the potential use of intrinsic remediation and source reduction technologies to reduce BTEX and chlorinated solvent concentrations in the shallow groundwater to levels that meet regulatory action levels.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial technology or remedial alternative (which can be a combination of remedial approaches and technologies such as intrinsic remediation and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that groundwater quality standards can be achieved at a downgradient POC. The expected technical effectiveness based on case histories from other sites with similar conditions also is evaluated. The ability to minimize potential impacts to surrounding facilities and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential risks associated with potential exposure pathways is qualitatively assessed. This evaluation criterion also included permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and time until protection is achieved are considered. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, is also evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology or remedial alternative was evaluated in terms of technical feasibility and availability. Potential shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls such as LTM and land use restrictions are described. Details on administrative feasibility in terms of the likelihood of public acceptance and the ability to obtain necessary approvals are discussed.

6.1.3 Cost

The total cost (adjusted to present worth) of each remedial alternative was estimated for relative comparison. An estimate of capital costs, and operating and post-implementation costs for site monitoring and controls is included. An annual adjustment factor of 7 percent was assumed in present-worth calculations. The annual adjustment factor is the difference between the rate of inflation and the cost of money (USEPA, 1988).

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at the site. Factors considered included the objectives of the AFCEE natural attenuation demonstration program; contaminant, groundwater, and soil properties; current and future land uses; and potential receptors and exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the final remedial alternatives considered for the Current Fire Training Area.

6.2.1 Program Objectives

The intent of the intrinsic remediation demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting natural subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program and the specific FT-08 demonstration is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons and chlorinated solvents so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies that demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential receptor exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (e.g., soil, soil gas, etc.), technologies have been evaluated primarily on the basis of their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also have been evaluated. Many of the source removal technologies evaluated in this section also will reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not intended to remediate all contaminated media. Additional program objectives set forth by AFCEE include cost effectiveness and minimization of waste. Technologies that may best meet these AFCEE criteria include institutional controls, soil vapor extraction (SVE), bioventing, biosparging, groundwater pump and treat, vertical groundwater circulation, and intrinsic remediation. Soil excavation, slurry walls, sheet piling, carbon adsorption, *ex situ* biological or chemical treatment, and onsite/offsite disposal are generally not considered attractive technologies under this program.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at FT-08 are the BTEX compounds. Other site contaminants considered in the remedial strategy include the chlorinated solvents TCE, DCE, and vinyl chloride. The source of this contamination are the fuels and solvents used during fire training exercises. Residual contamination is concentrated in vadose zone and capillary fringe soils in the former burn area and at the outfall of the abandoned buried waste fuel pipe. The physiochemical characteristics of JP-4 and the individual BTEX and chlorinated solvent compounds will greatly influence the effectiveness and selection of a remedial technology.

Petroleum hydrocarbon mixtures, such as JP-4, are composed of more than 300 compounds with different physiochemical characteristics. JP-4 is classified as an LNAPL with a liquid density of 0.75 g/cc at 20 °C (Smith *et al.*, 1981). Many compounds in JP-4 sorb very well to soil and are concentrated in the capillary fringe because the mixture is less dense than water. JP-4 is slightly soluble in water, with a maximum solubility of approximately 300 mg/L. JP-4 is also a primary substrate for biological metabolism. Simultaneous biodegradation of aliphatic, aromatic, and alicyclic hydrocarbons has been observed. In fact, mineralization rates of hydrocarbons in mixtures such as JP-4 may be faster than mineralization of the individual constituents as a result of cometabolic pathways (Jamison *et al.*, 1975; Perry, 1984).

The BTEX compounds are generally volatile, highly soluble in water, and adsorb less strongly to soil than other hydrocarbons in a petroleum mixture. These characteristics allow the BTEX compounds to leach more rapidly from contaminated soil into groundwater, and to migrate as dissolved contamination (Lyman *et al.*, 1992). All of the BTEX compounds are highly amenable to *in situ* degradation by both biotic and abiotic mechanisms.

Benzene is very volatile, with a vapor pressure of 76 millimeters of mercury (mm Hg) at 20°C and a Henry's Law Constant of approximately 0.0054 atmosphere-cubic meters per mole (atm-m^3/mol) at 25°C (Hine and Mookerjee, 1975; Jury *et al.*, 1984). The solubility of pure benzene in water at 20°C has been reported to be 1,780 mg/L (Verschueren, 1983). Benzene is normally biodegraded to carbon dioxide, with catechol as a short-lived intermediate (Hopper, 1978; Ribbons and Eaton, 1992).

Toluene is also volatile, with a vapor pressure of 22 mm Hg at 20°C and a Henry's Law Constant of about 0.0067 atm-m^3/mol at 25°C (Pankow and Rosen, 1988; Hine and Mookerjee, 1975). Toluen[illegible]bs more readily to soil media relative to benzene, but still is very mobile. T[illegible]lubility of pure toluene in water at 20°C is approximately 515 mg/L at 2[illegible] (Verschueren, 1983). Toluene has been shown to degrade to pyruvate, caetaldehyde, and completely to carbon dioxide via the intermediate catechol (Hopper, 1978; Wilson *et al.*, 1986; Ribbons and Eaton, 1992).

Ethylbenzene has a vapor pressure of 7 mm Hg at 20°C and a Henry's Law Constant of 0.0066 atm-m^3/mol (Pankow and Rosen, 1988; Valsaraj, 1988). Ethylbenzene sorbs more strongly to soils than benzene and toluene (Kanaga and Goring, 1980; Means *et al.*, 1980; Hassett *et al.*, 1983; Fetter, 1993). Pure ethylbenzene is also less soluble than benzene and toluene in water at 152 mg/L at 20°C (Verschueren, 1983; Miller *et al.*, 1985). Ethylbenzene ultimately degrades to carbon dioxide via its intermediate 3-ethylcatechol (Hopper, 1978; Ribbons and Eaton, 1992).

The three isomers of xylene have vapor pressures ranging from 7 to 9 mm Hg at 20°C and Henry's Law Constants of between 0.005 and 0.007 atm-m^3/mol at 25°C (Mackay and Wolkoff, 1973; Hine and Mookerjee, 1[illegible]ankow and Rosen, 1988). A compilation of literature values for sorption coeff[illegible]ggests that xylenes sorb to soil with approximately the same strength as ethylben[illegible] (Wiedemeier *et al.*, 1995). Pure xylenes have water solubilities of 152 to 160 mg/L at 20°C (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Isnard and Lambert, 1988). Xylenes can degrade to carbon dioxide *via* pyruvate carbonyl intermediates (Hopper, 1978; Ribbons and Eaton, 1992).

The chlorinated solvents at FT-08 may be more recalcitrant to biodegradation than the BTEX compounds. The primary mechanisms of attenuation for chlorinated solvents once they reach the groundwater are adsorption, biodegradation, and volatilization to the vadose zone. Chlorinated compounds can be biodegraded via reductive dehalogenation and cometabolic processes (see Section 4). There are also microorganisms that are capable of growth using halogenated aliphatic compounds (e.g., DCE and vinyl chloride) as a primary carbon source (Chapelle, 1993).

TCE is very volatile, with a vapor pressure of 100 mm of Hg at 20°C and a Henry's Law Constant of approximately 0.0099 atm-m^3/mol at 20°C (Roberts and Dandliker, 1983). Although TCE adsorbs to soil, it is only slightly less mobile and more adsorptive than benzene. The solubility of TCE in water is approximately 1,000 mg/L (Arthur D. Little, 1987). Microbial degradation of TCE by dehalogenation can yield the degradation products 1,1-DCE, cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride. Abiotic hydrolysis products include acetic acid and 1,1-DCE (Smith and Dragun, 1984).

DCE is also very volatile, with a vapor pressure of 591 mm of Hg at 25°C (Verschueren, 1983) and a Henry's Law Constant of 0.021 atm-m^3/mol (Schwille, 1988). DCE is slightly more mobile than both TCE and benzene (see Table 5.4). The solubility of DCE in water is approximately 400 mg/L at 20°C. DCE can be biodegraded to vinyl chloride and/or carbon dioxide under methanogenic, anoxic groundwater conditions.

Vinyl chloride is extremely volatile, with a vapor pressure of 2,580 mm of Hg at 20°C (Lyman *et al.*, 1982) and a Henry's Law Constant of 0.056 atm-m^3/mol at 25°C (Hine and Mookerjee, 1975). Vinyl chloride does not adsorb as well as either TCE or DCE (Karickhoff *et al.*, 1979). It is significantly more mobile than TCE, DCE, and benzene in groundwater. The solubility of vinyl chloride is about 1,100 mg/L at 25°C (Verschueren, 1983).

On the basis of these physiochemical characteristics, intrinsic remediation, SVE, bioventing, biosparging, groundwater extraction, vertical groundwater circulation, and air stripping technologies could all be effective options for collecting, destroying, and/or treating BTEX and chlorinated solvent compounds at FT-08. Some of these options are considered less desirable, however, after considering site-specific conditions.

6.2.3 Site-Specific Conditions

Three general categories of site-specific characteristics were considered when identifying remedial approaches for comparative evaluation as part of this demonstration. The first category was physical characteristics such as groundwater depth, hydraulic conductivity, gradient, flow direction, and soil type. The second category was the site geochemistry, or how the site contaminants are interacting with electron acceptors, microorganisms, and other site contaminants. Both of these categories influence the types of remedial technologies most appropriate for the site. The third category involved assumptions about future land use and potential receptor exposure pathways. Each of these site-specific characteristics have influenced the development of remedial alternatives included in the comparative evaluation.

6.2.3.1 Physical Characteristics

Site geology and hydrogeology have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. Estimated hydraulic conductivity values from 5 site wells screened across the water table ranged from 4.3 to 15.3 ft/day, within the range characteristic of sand (Freeze and Cherry, 1979). Plume expansion has been limited by the shallow groundwater gradient (0.0018 ft/ft) and average advective groundwater velocity (0.057 ft/day).

The combination of a moderate hydraulic conductivity and a nearly flat groundwater gradient has both positive and negative impacts on the fate and transport of the contaminant plume and the processes of natural attenuation. On the positive side, expansion of the contaminant plume proceeds slowly. The low estimated groundwater velocity implies that a contaminant plume experiencing no retardation would travel only about 21 feet in a year. Attenuation processes will further limit the migration of the plume. On the negative side, the low groundwater velocity limits the influx of additional electron acceptors into the contaminant plume, even when the retardation of the plume in relation to groundwater flow is considered. Furthermore, the effectiveness of natural biodegradation processes is not improved by exposure to downgradient groundwater enriched with electron acceptors, as the plume is not expanding rapidly into uncontaminated areas. A low velocity also reduces the amount of plume attenuation that can be expected to result from the processes of dilution, dispersion, and adsorption.

The convergent groundwater divide also affects the fate and transport of the contaminant plume and the processes of natural attenuation. On the positive side, the majority of contaminated groundwater flows along a well-defined flow path, which limits the impacted area. Furthermore, the convergent divide also collects groundwater from less contaminated areas upgradient, thereby introducing additional electron acceptors and promoting the natural attenuation mechanisms of biodegradation and dilution. On the negative side, the higher groundwater velocity along the convergent divide can result in increased contaminant travel distances. Channelization of the groundwater can also reduce the impact of dispersion and adsorption on natural attenuation.

Site geology and hydrogeology also impact the types of practical engineered remedial technologies. For example, engineered solutions for plume containment are simplified because the convergent groundwater divide already provides partial plume containment. Furthermore, less expense and time should be required to capture and treat the contaminant plume using a network of extraction wells in the areas of higher hydraulic conductivity that were measured along the convergent divide. However, the required capture volume is increased because the convergent divide also draws in uncontaminated groundwater. In addition, the effectiveness of *in situ* technologies such as biosparging may increase as hydraulic conductivity increases because of reduced entry pressures and an increased radius of influence. Contaminant recovery may also be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil.

6.2.3.2 Geochemical Characteristics

To satisfy the requirements of indigenous microbial activity and intrinsic remediation, the aquifer must also provide an adequate and available carbon or energy source (e.g., the contamination), electron acceptors, essential nutrients, and proper ranges of pH, temperature, and redox potential. Data collected as part of the field work phase of this demonstration project and described in Sections 3 and 4 of this TS indicate that this site is characterized by adequate and available carbon/energy sources and electron acceptors to support measurable biodegradation of fuel hydrocarbon contamination by indigenous microorganisms. DO, nitrate, ferric iron, sulfate, and carbon dioxide (which is utilized during methanogenesis) represent sources of electron acceptor capacity for the biodegradation of BTEX compounds at FT-08. Further, because fuel hydrocarbon-degrading microorganisms have been known to thrive under a wide range of temperature and pH conditions (Chapelle, 1993), the physical and chemical conditions of the groundwater and phreatic soil at the site are not likely to inhibit microorganism growth.

Fuel-hydrocarbon-degrading microorganisms are ubiquitous, and as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (Davies and Westlake, 1979; Jones and Eddington, 1968). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985). Microbe addition was not considered a viable remedial technology for this site.

Although the focus of this demonstration was the BTEX compounds, the fate and transport of the chlorinated solvents in the groundwater must be considered in determining the type of remedial action warranted at the site. As discussed in Section 4, chlorinated solvent degradation is accomplished via both reductive dehalogenation in the contaminant plume core, and direct oxidation at the plume fringes.

Groundwater results presented in Section 4 strongly support the conclusion that biodegradation of both BTEX and chlorinated solvents are occurring at the site with the present geochemical conditions; therefore, remedial technologies that significantly alter the site geochemistry are considered risky. For example, biosparging was not considered a viable option at this site because the process tends to oxygenate the groundwater while stripping volatile contaminants from the groundwater. As reductive dehalogenation is more prevalent in highly reducing conditions, the decrease in reductive dehalogenation of chlorinated solvents could potentially outweigh the benefits of a biosparging system.

6.2.3.3 Potential Exposure Pathways

A pathways analysis identifies the potential human and ecological receptors that could come into contact with site-related contamination and the pathways through which these receptors might be exposed. To have a complete exposure pathway, there must be a source of contamination, a potential mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining the potential for pathway completion. If a completed exposure pathway exists, potential long-term remedial options may still be sufficient to maintain exposure concentrations below regulatory action levels. However, establishing site-specific, risk-based cleanup levels is beyond the scope of this TS.

Assumptions about current and future land uses at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated.

The contaminant source areas at FT-08 consist of vadose zone and phreatic soils containing residual LNAPL within the former burn area and at the terminus of the buried fuel line that was abandoned in place. Open areas lie to the north of the site; residential and industrial portions of the base are located approximately 1,000 feet to the west of the site; an active fire training area is located approximately 750 feet south of FT-08; and a dirt access road is located approximately 650 feet to the east. A secondary runway lies approximately 1,350 feet further to the east. The groundwater plume originating from FT-08 is migrating generally to the east, and has impacted groundwater almost two-thirds of the distance to the dirt access road.

Although it is not within the scope of this demonstration, a risk assessment may be required to evaluate potential risks. Under reasonable current land use assumptions, worker populations are the only potential receptors. Workers could be exposed to site-related contamination in phreatic soils or shallow groundwater if these materials are removed or exposed during future construction excavations or remedial activities. On the basis of Bioplume II model results, BTEX contamination in groundwater will completely degrade prior to reaching the non-potable water supply well located on the base approximately 3,000 feet to the east. As described in Section 5, an effective model could not be developed for chlorinated solvent degradation; however, assuming a conservative migration rate of 25 ft/yr (i.e., a 500-foot plume with chlorinated solvents last used at the site 20 years ago), chlorinated solvents would not reach the non-potable well for at least another 120 years. In the direction of local groundwater flow to the east, the base boundary is approximately 6,500 feet distant, and in the direction of regional groundwater flow to the south, the base boundary is approximately 11,000 feet distant. For the chlorinated solvents to reach these boundaries at a migration rate of 25 ft/yr would require over 250 and 400 years, respectively. Other than the single non-potable water supply well, groundwater from the shallow aquifer is not currently used to meet any demands at Westover ARB. On-Base water demands are met by the city of Chicopee. Exposure pathways involving other environmental media such as shallow soils and soil gas in the source area were not considered as part of this project, but should be considered in overall site remediation decisions. If source reduction technologies such as SVE or bioventing are implemented, they will have some impact on the short- and long-term land use options and some level of institutional control and worker protection during remediation will be required.

6.2.3.4 Remediation Goals for Shallow Groundwater

Model results suggest that BTEX compounds are not likely to move more than 150 feet downgradient from the observed plume front. The ultimate extent for chlorinated solvent migration could not be estimated; however, the predicted rate of migration is not expected to exceed 25 ft/yr. Considering both the chlorinated solvent and BTEX plumes, an area approximately 500 feet beyond the May 1995 plume front has been identified as the POC for groundwater remedial activities. This is a suitable location for monitoring and for demonstrating compliance with protective groundwater quality standards, such as promulgated groundwater maximum contaminant levels (MCLs). A distance of 500 feet represents the maximum distance that the chlorinated solvent plume would be expected to migrate in 20 years and is beyond the maximum extent of future BTEX migration predicted by the models. In addition, the proposed POC location is over a mile from the nearest downgradient base boundary.

This remedial 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). Thus, 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 of FT-08 is limiting plume expansion to prevent exposure of downgradient receptors to concentrations of BTEX or chlorinated solvent compounds in groundwater at levels that exceed regulatory standards. This means that viable remedial alternatives must be able to achieve concentrations that minimize plume migration and/or expansion. The remedial objective for shallow groundwater at the POC is eventual 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 may be appropriate.

In summary, available data suggest that there is no complete potential exposure pathway involving shallow groundwater under current conditions. Moreover, it is unlikely that potential exposure pathways involving shallow groundwater would be complete under future land use assumptions, provided use of shallow groundwater as a potable or industrial source of water is prohibited by institutional controls within the plume area and within an area approximately 500 feet downgradient of the 1995 plume front. Thus, institutional controls are likely to be a necessary component of any groundwater remediation strategy for this site. The required duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentration in the groundwater.

6.2.4 Summary of Remedial Option Screening

Several remedial options have been identified and screened for use in treating the shallow groundwater at the site. Table 6.2 identifies the initial remedial technologies and approaches considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE intrinsic remediation demonstration, physiochemical properties of the BTEX and chlorinated solvent compounds, and other site-specific characteristics such as hydrogeology, geochemistry, land use assumptions, potential exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site.

TABLE 6.1
POINT-OF-COMPLIANCE REMEDIATION GOALS
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Compound	Massachusetts Groundwater Standards		Federal MCL (μg/L)
	GW-1 (μg/L) [a/]	GW-3 (μg/L) [b/]	
Benzene	5	7,000	5
Toluene	1,000	50,000	1,000
Ethylbenzene	700	4,000	700
Total Xylenes	10,000	50,000	10,000
TCE	5	20,000	5
1,1,1-TCA	200	50,000	200
cis-1,2-DCE	70	50,000	70
trans-1,2-DCE	100	50,000	100
Vinyl Chloride	2	600	2

[a/] GW-1 = Standard for sensitive groundwater.
[b/] GW-3 = Standard for ultimate discharge to surface water.

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater Monitoring	Confirmation Wells	Many wells and monitoring points are available to confirm the progress of remediation. Sufficient space for additional.	Necessary for all remediation strategies	Low	Yes
		Point-of-Compliance Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Necessary	Low	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume lies within the base boundary, and land and groundwater use are under base jurisdiction.	Necessary	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	Not required at this site	Low	No
		Point-of-Use Treatment	No shallow groundwater is extracted from the plume area for any use.	Poor	Moderate	No
	Public Education	Meetings/ Newsletters	Base public relations and environmental management offices have many information avenues to workers and residents.	Necessary	Low	Yes
Containment of Plume	Hydraulic Controls	Interceptor Trench Collection	No likely receptors downgradient of site. Groundwater gradients are low. Hydraulic conductivity of site soils favors pumping.	Low	Moderate to High	No
		Minimum Pumping/ Gradient Control	No likely receptors downgradient of site. The rate of plume advance is slow as a result of low site groundwater gradients.	Low	High	No
	Physical Controls	Slurry Wall/Grout Curtains	Although implementable, the technology would be costly and ineffective. Contaminant migration is currently limited by low advective groundwater velocities.	Low	High	No
		Sheet Piling	Although implementable, the technology would be costly and ineffective. Contaminant migration is currently limited by low advective groundwater velocities.	Low	High	No
	Reactive/ Semi-Permeable Barriers	Biologically Active Zones	Degradation of BTEX can be stimulated by allowing groundwater to flow through a nutrient-rich barrier. Although implementable, the technology is new and unproven. Furthermore, contaminant migration rates are limited by the low advective groundwater velocity.	Moderate	High	No

TABLE 6.2 (continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

General Response Action	Technology Type	Process Option	Implementability	Effective-ness	Relative Cost	Retain
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Nutrients are injected downgradient of plume to limit plume migration by enhancing biodegradation and reducing BTEX concentrations. Although implementable, the technology is not proven to be more effective than intrinsic remediation and could negatively affect cometabolism of chlorinated solvents by altering site geochemistry.	Low	Low	No
	Chemical/ Physical	Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at FT-08 site indicates that this is an ongoing remediation process.	High	Low	Yes
		Vertical Groundwater Circulation	Groundwater is moved vertically within an aquifer to recirculate contaminated groundwater through an *in situ* biologic reactor. Can assist with plume containment. Can be combined with secondary technologies such as cosubstrate addition or air stripping.	Unknown, but potentially high	Low	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and vadose zone. Although implementable, could negatively affect cometabolism of chlorinated solvents by altering site geochemistry.	Low	Low	No
Aboveground Groundwater Treatment	Groundwater Extraction	Vertical Pumping Wells	Source area of groundwater plume is pumped by installing submersible pumps in source area wells. Could simultaneously reduce source area contaminant concentrations as well as the length of time required for natural attenuation processes to complete the groundwater restoration.	Moderate	Moderate	No
	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	Moderate	High	No
	Chemical/ Physical	Air Stripping	Cost-effective technology for removing BTEX and chlorinated solvents from groundwater at high flow rates. Potential permitting for air emissions.	High	Moderate	Yes
		Activated Carbon	Cost prohibitive for more concentrated BTEX. Creates a carbon disposal problem. Ineffective for removal of vinyl chloride.	Moderate	High (O&M)	No
		Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Implementable option only when an IWWTP is readily available and capable of handling BTEX, TPH, chlorinated solvent, and hydraulic loading. IWWTP not available for this site.	High	Low	No
		UV/Ozone Reactors	High flow rates require lengthy retention times and large, costly reactors.	Moderate	High	No

TABLE 6.2 (concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Implementable option only when an IWWTP is available and capable of handling hydraulic loading. IWWTP is not available.	High	Low	No
		Sanitary Sewer	Implementable option only when access to a sanitary sewer exists and hydraulic loading is acceptable.	High	Low	Yes
	Treated Groundwater Reinjection	Vertical Injection Wells	Injection wells subject to clogging, high maintenance, and permitting.	Moderate	Moderate	No
		Injection Trenches	Requires large trenches and can be subject to injection well permitting.	Moderate	Moderate	No
	Discharge to Surface Waters	Storm Drains	Viable option. Generally requires NPDES or other discharge permit	High	Low	Yes
Source Removal/Soil Remediation	Excavation/ Treatment	Landfilling	Excavation may be feasible at this site. For reasons of risk and cost reduction, in-situ methods preferable when possible.	Moderate	Moderate	Yes
		Biological Landfarming	Excavation may be feasible at this site. For reasons of risk and cost reduction, in-situ methods preferable when possible.	Moderate	High	No
		Thermal Desorption	Excavation may be feasible at this site. For reasons of risk and cost reduction, in-situ methods preferable when possible.	Moderate	High	No
	In Situ	Bioventing	Air injection/extraction to increase soil oxygen levels and stimulate biodegradation of fuel residuals. It is uncertain how the use of this technology will affect the future biodegradation of dissolved chlorinated solvents.	Moderate to High	Low	Yes
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites. Highly implementable in sandy soils and effective for both BTEX and chlorinated solvents in unsaturated soils. May be subject to air permitting.	High	Low to Moderate	Yes
		Soil Washing	Water and/or surfactant solution are forced through zones of residual contamination to enhance contaminant partitioning into the groundwater. Most effective in homogeneous sandy soils.	Low	High	No

The remedial technologies retained for development of remedial alternatives and comparative analysis include institutional controls, intrinsic remediation, LTM, bioventing, vertical groundwater circulation, and limited soil excavation. Biosparging, though implementable, was not retained for further consideration because by introducing oxygen to the groundwater, it alters the geochemistry in such a way that the rate of chlorinated solvent reductive dehalogenation could decrease. A decreased degradation rate of chlorinated solvents could potentially outweigh the benefits of the remedial technology.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into three remedial alternatives for FT-08. Sufficient information on each remedial alternative is provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1 - Intrinsic Remediation, Vertical Groundwater Circulation, and Institutional Controls with Long-Term Groundwater Monitoring

Intrinsic remediation is achieved when natural attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. Intrinsic remediation results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, intrinsic remediation will reduce dissolved contaminant concentrations below numerical concentration goals intended to be protective of human health and the environment. As indicated by the evidence of intrinsic remediation described in Section 4, these processes are occurring at FT-08 site and will continue to reduce contaminant mass in the plume area.

Model CFTA-IR is intended to predict the fate and transport of dissolved BTEX compounds if engineered source removal is not implemented at FT-08. To accomplish this, the model assumes a gradually weathered source, resulting in a geometric decrease in BTEX mass loading to the groundwater of approximately 5 percent per year. This model predicts that the downgradient extent of the dissolved BTEX plume will advance to a maximum 150 feet further than the present plume in approximately 30 years. After 62 years, the model CFTA-IR predicts that the BTEX plume will completely disappear.

A pilot test for a vertical groundwater circulation system is also proposed under this alternative to address the significant presence of chlorinated solvents dissolved in site groundwater. Vertical groundwater circulation is an *in situ* remediation technique that in this instance would be designed to limit migration and encourage reductive dehalogenation by extracting chlorinated-solvent-contaminated groundwater from a depth of approximately 40 feet and reinjecting it into the upper 10 feet of the aquifer where BTEX is concentrated. It has been determined from other site investigations that when the migration of the dissolved chlorinated solvent plume outpaces the migration of the dissolved BTEX plume, biodegradation of the dissolved chlorinated solvents can effectively cease beyond the influence of the BTEX plume (Parsons ES, 1995b). In the absence of an effective model for the fate and transport of the chlorinated solvent plume at FT-08, it is uncertain whether a separation of the dissolved BTEX and chlorinated solvent plumes is likely to occur in the future. Biodegradation rates estimated in Section 5 suggest, however, that this could occur in the future because the degradation rate for chlorinated solvents is lower than for BTEX. At Site FT-08, the majority of the dissolved chlorinated solvent contamination appears to migrate at a depth of 40 to 50 feet bgs; therefore, the proposed vertical groundwater circulation system is intended to recirculate groundwater contaminated with chlorinated solvents from the deeper zones of the surficial aquifer back through the core of the BTEX plume to promote additional reductive dehalogenation.

If the pilot testing shows that simple recirculation through the core of the BTEX plume is insufficient to contain and biodegrade the majority of the chlorinated solvent plume, recirculated groundwater can be enhanced with nutrients or additional organic carbon substrate or treated through subsurface air stripping. Neither of these alternatives has been considered for the initial pilot test because there is no indication that the nutrients or organic substrate are insufficient. Also aeration/oxygenation caused by in well air stripping could reduce the rate of reductive dehalogenation as well as produce an off-gas that would require treatment prior to atmospheric release.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation within the source area and long-term restrictions on groundwater well installations within and downgradient from the plume area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination.

Long-term monitoring would be conducted every second year as part of this remedial technology to evaluate the progress of natural attenuation processes. Because there are no apparent downgradient receptors, three POC well clusters should be placed downgradient of the modeled maximum BTEX extent (i.e., approximately 500 feet downgradient of the current plume front). In addition, 12 LTM wells within, upgradient, and immediately downgradient from the existing contaminant plume would be used to monitor the effectiveness of intrinsic remediation at multiple depths within the surficial aquifer. LTM and POC wells are further described in Section 7.2. Detection of benzene or TCE in excess of 5 μg/L, or vinyl chloride in excess of 2 μg/L at the furthest downgradient LTM well cluster, any well screened immediately above the clay aquitard, or the POC wells may require additional evaluation to assess BTEX and/or chlorinated solvent migration and to determine the probable extent of migration, or to determine if additional corrective action would be necessary. Regulatory standards for other detected chlorinated solvent and BTEX compounds are much higher; therefore, it is unlikely that these standards would be exceeded before the benzene, TCE, and vinyl chloride standards. If total chlorinated solvent concentrations exceed 70 μg/L or total BTEX concentrations exceed 700 μg/L, then contaminant concentrations for the other detected compounds should be checked against regulatory standards. In either case, land use restrictions would also require reevaluation.

Public education on the selected alternative would be developed to inform Base personnel and residents of the scientific principles underlying source reduction and intrinsic remediation. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews could also be conducted every year using data collected from the long-term groundwater monitoring program. The purpose of these periodic reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and/or institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 - Horizontal Bioventing, Intrinsic Remediation, Vertical Groundwater Circulation, and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is identical to Alternative 1 except that a bioventing system with horizontal wells would be used to reduce the volume of residual fuels within the source area. This would be accomplished through the installation and operation of horizontal bioventing wells in the former burn area and at the terminus of the abandoned waste fuel pipe. Bioventing is an *in situ* bioremediation technique that is applicable for the remediation of fuel hydrocarbon compounds in vadose zone soils. A bioventing system consists of wells screened within contaminated vadose zone soils. A regenerative blower is used to inject a small volume of air into each well. This process promotes aerobic biodegradation of fuel constituents through the introduction of oxygenated air into contaminated soils. By reducing the quantity of residual fuel hydrocarbons within the source area, bioventing would reduce the predicted future dissolution of BTEX into the surficial aquifer and therefore shorten the predicted length of time required for intrinsic remediation to degrade dissolved BTEX.

A bioventing pilot test was previously performed at the site; however, results were unavailable. The pilot test results should be considered during design of a full-scale system. Specifically, the pilot test would help to establish an air injection rate to establish blower size and the radius of oxygen influence to determine an appropriate number of horizontal injection wells. A radius of oxygen influence in excess of 40 feet was estimated from results of a bioventing pilot test conducted at Building 7705 in similar sandy soils using vertical injection wells (Engineering-Science, 1993). For the purpose of this remedial alternative comparison, air injection wells with a 40-foot radius of influence were assumed with an injection rate of approximately 1 pore volume per day have been assumed. Figure 6.1 shows a proposed 3-well system with 2 150-foot horizontal wells in the burn pit and one 60-foot horizontal well at the end of the buried waste fuel pipe. Bioventing systems frequently result in BTEX removal efficiencies in vadose zone soils of greater than 90 percent during the first year of operation (AFCEE, 1994); therefore, for the purposes of modeling and costing, the system was estimated to operate for approximately 3 years.

Bioventing is generally preferred over SVE because it uses a low rate of air injection that significantly reduces emissions into the atmosphere while maximizing *in situ* biodegradation of fuel constituents. Bioventing, however, is not a proven technology in the remediation of chlorinated-solvent-contaminated soils. Therefore, if significant

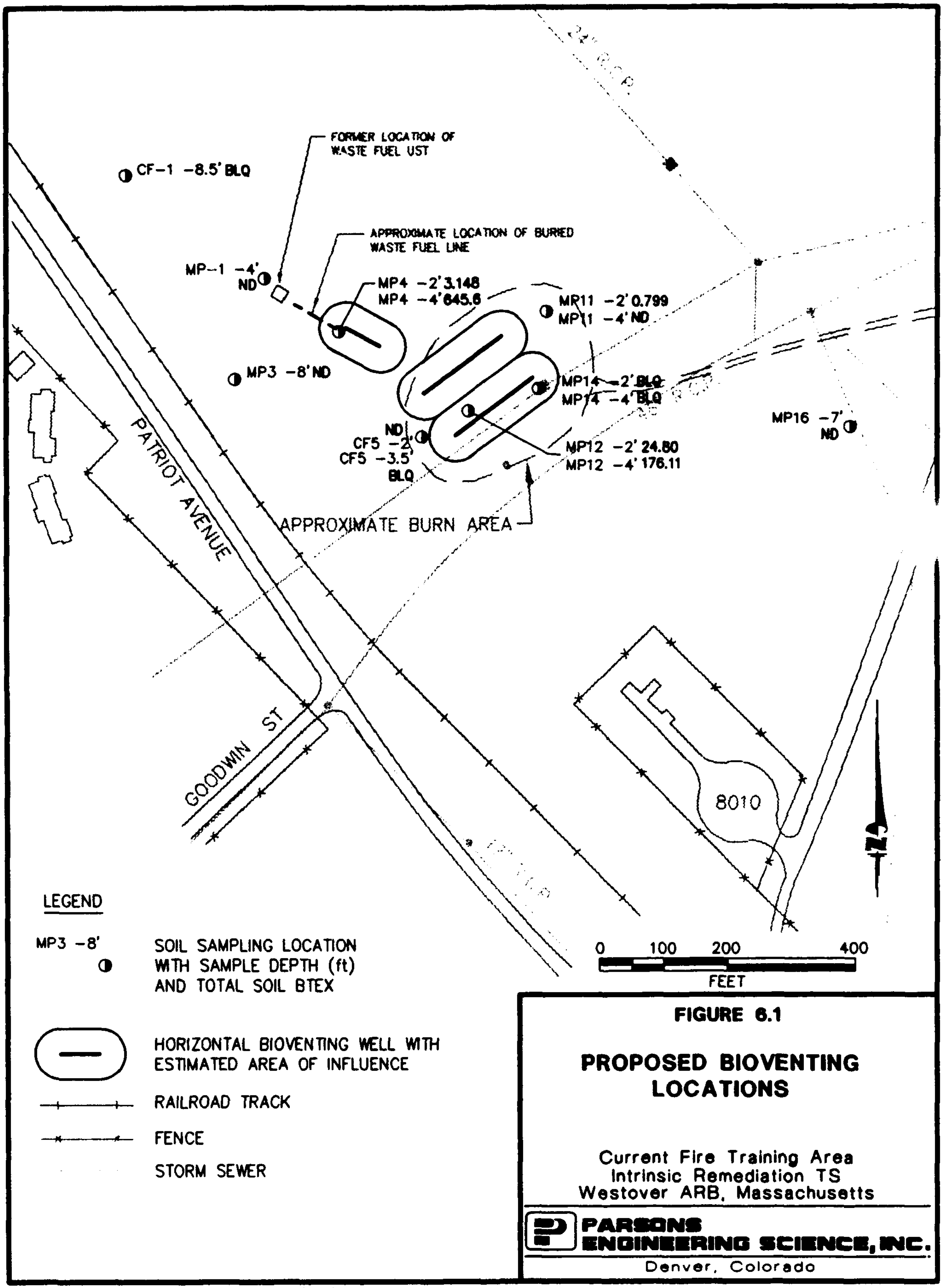


FIGURE 6.1

PROPOSED BIOVENTING LOCATIONS

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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levels of chlorinated solvents are detected in the soil or soil gas, SVE would be recommended to insure removal of chlorinated solvents from the soil.

To estimate the impact of bioventing on the fate and transport of dissolved BTEX in the shallow groundwater, model CFTA-SVE incorporated a decaying BTEX injection rate of 50 percent per year for 8 years. This rate is intended to be a conservative reflection of the 90-percent source reduction in the vadose zone soils in combination with a much lower source reduction in the phreatic soils. Results suggest that maximum dissolved BTEX concentrations will rapidly decrease in the source area, with downgradient concentrations decreasing at a slightly slower rate. Five years after the implementation of bioventing, the maximum dissolved BTEX concentration is predicted to have fallen to approximately one-third of the current maximum concentration. The downgradient extent of the dissolved BTEX plume is predicted to extend a maximum of 100 feet beyond the current observed plume approximately 10 years after the implementation of bioventing. The model predicts the complete degradation of the dissolved BTEX plume in just over 30 years. The effect of bioventing on the fate and transport of the dissolved chlorinated solvent plume is unknown.

As with Alternative 1, institutional controls and LTM would be required. POC and LTM wells would be installed in the same locations alluded to in the previous subsection and detailed in Section 7. Groundwater monitoring also would follow the same schedule as Alternative 1.

6.3.3 Alternative 3 - Limited Soil Excavation, Horizontal Bioventing, Intrinsic Remediation, Vertical Groundwater Circulation, and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is identical to Alternative 2 except that soil excavation would replace the horizontal bioventing well at the end of the abandoned waste fuel pipe. This option has been evaluated because the soil at this location is nearly saturated with fuel and because the extent of soil contamination is believed to be very limited. For the purposes of estimating cost, the area of contamination is estimated to cover an area of 100 square feet and extend to a depth of 6 feet bgs.

Model CFTA-EX was designed to estimate the impact of bioventing with limited soil excavation on the fate and transport of dissolved BTEX in the shallow groundwater. To account for source removal through excavation, BTEX mass loading was immediately eliminated at the buried waste fuel pipe outfall. In the main burn area, BTEX mass loading was reduced 50 percent per year to account for bioventing (See Alternative 2). Results suggest that maximum dissolved BTEX concentrations will rapidly decrease in the source area, with downgradient concentrations decreasing at a slightly slower rate. Five years after the implementation of bioventing, the maximum dissolved BTEX concentration is predicted to have fallen to approximately one-quarter of the current maximum concentration. The downgradient extent of the dissolved BTEX plume is predicted to move a maximum of 100 feet beyond the current observed plume about 10 years after the implementation of bioventing. The model predicts the complete degradation of the dissolved BTEX plume in just over 30 years.

As with Alternatives 1 and 2, institutional controls and LTM would be required. POC and LTM wells would be installed in the same locations alluded to under Alternative 1 and discussed in Section 7. Groundwater monitoring would also follow the same schedule as Alternative 1.

6.4 Evaluation of Alternatives

This section provides a comparative analysis of each of the remedial alternatives on the basis of effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - Intrinsic Remediation, Vertical Groundwater Circulation, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.1.1 Effectiveness

Section 5 of this document presents the results of the Bioplume II modeling of intrinsic remediation at FT-08. Model results predicted that natural attenuation mechanisms will significantly limit BTEX migration and reduce contaminant mass and toxicity. BTEX (and specifically benzene) concentrations should not exceed state and federal criteria at the POC wells. Chlorinated solvents are not expected to reach the POC for at least 20 years. A pilot test is recommended to evaluate the use of vertical groundwater circulation technology to slow or halt the future migration as well as to increase the rate of reductive dehalogenation for dissolved chlorinated solvents . Groundwater monitoring at the LTM and POC wells will allow for continued evaluation of chlorinated solvent and BTEX migration and ensure the continued safety of this alternative. While this alternative would not cease to be protective if the benzene or chlorinated solvent plumes were intercepted by the POC wells, such an instance would indicate that site conditions should be reevaluated.

The effectiveness of this remedial alternative requires that excavations or drilling within the source area be conducted only by properly protected site workers. Reasonable land use assumptions for the plume area indicate that exposure is unlikely unless excavation or drilling activities bring saturated soil to the surface. Long-term land use restrictions would be required to ensure that shallow groundwater is not pumped or removed for potable use within a radius of approximately 500 feet from the margins of the existing BTEX and chlorinated solvent plumes. Existing health and safety plans should be enforced to reduce risks from additional excavation or from installing and monitoring additional wells.

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 would satisfy program objectives designed to promote intrinsic remediation as a component of site remediation and to scientifically document natural processes. This alternative also satisfies program goals for cost effectiveness and waste minimization.

Alternative 1 is based on the effectiveness of natural processes that minimize contaminant migration and reduce contaminant mass over time, and the effectiveness of institutional controls. As described earlier, an investigation of the potential effectiveness of natural processes at FT-08 using field data and the Bioplume II model demonstrated that the BTEX plume migration will be limited and the extent eventually reduced. Furthermore, investigation results suggest that biodegradation of chlorinated solvents is occurring.

Apart from the administrative concerns associated with enforcement of long-term land use restrictions and long-term groundwater monitoring programs, this remedial alternative should provide reliable, continued protection. It is assumed for cost comparison purposes that dissolved benzene concentrations will exceed state and federal criteria throughout the plume for approximately 60 years under Alternative 1. Furthermore, it is assumed that sampling will be performed every second year for 60 years to demonstrate that intrinsic remediation will uniformly reduce all BTEX and chlorinated solvent compounds to levels below regulatory criteria.

6.4.1.2 Implementability

Alternative 1 is not technically difficult to implement. Installation of wells and groundwater monitoring are standard procedures. Long-term management efforts would be required to ensure proper sampling procedures are followed. Following installation, the vertical groundwater circulation well pump(s) would require periodic maintenance. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and verify the effectiveness of this remediation approach. There may also be administrative concerns associated with long-term enforcement of groundwater use restrictions. Future land use within the source area may be impacted by leaving contaminated soil and groundwater in place. It is possible that over the next 60 years this site may change ownership; therefore, long-term deed restrictions would be required to limit land and groundwater uses. Regulators and the public would have to be informed of the benefits and limitations of the intrinsic remediation option. Educational programs are not difficult to implement. Where the effectiveness of this option has been scientifically supported, the initial regulatory reaction to this alternative has been positive.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3. Capital costs are limited to the construction of 13 new monitoring wells and one pilot test circulation well with circulation pump. Included in the $304,200 total present worth cost estimate for Alternative 1 are the costs for maintaining institutional controls and long-term groundwater monitoring for a total of 60 years. The cost also includes an estimated cost for a one-year vertical groundwater circulation treatability test and report.

6.4.2 Alternative 2 - Horizontal Bioventing, Intrinsic Remediation, Vertical Groundwater Circulation, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.2.1 Effectiveness

The effectiveness of the intrinsic remediation, vertical groundwater circulation, institutional controls, and LTM components of this alternative have been described

TABLE 6.3
ALTERNATIVE 1 - COST ESTIMATE
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Capital Costs	**Cost**
Design/Construct 7 LTM wells	$22,640
Design/Construct 1 Vertical Groundwater Circulation Well with Circulation Pump	$15,620
Future Costs	
Design/Construct 6 POC wells (in 3 years)	$19,400
Annual Costs (per Sampling Event)	**Cost per Event**
Conduct Groundwater Sampling at 12 wells (1 year)	$11,190
Conduct Groundwater Sampling at 18 wells (every second year for 58 years)	$16,780
Conduct a Vertical Groundwater Circulation Treatability Study, Including Report (1 year)	$20,120
Maintain Institutional Controls/Public Education (every second year for 60 years)	$5,000
Project Management and Reporting (every second year for 60 years)	$13,690
Present Worth of Alternative 1 [a]	**$304,200**

[a] Based on a discount rate of 7 percent.

under Alternative 1. Bioventing is an established technology for reducing source contamination and controlling plume migration. The goal of bioventing would be to effect the removal of BTEX from the source area soils so that intrinsic remediation of dissolved contaminants in the groundwater could proceed without the continual infusion of additional contaminants. The model CFTA-SVE suggests that reduction of the source would enhance the effectiveness of intrinsic remediation and expedite the decrease in the size of the BTEX plume.

Alternative 2 should provide reliable, continuous protection with little risk from temporary system failures. This alternative also complies with AFCEE program goals because intrinsic remediation remains the predominant remediation method for fuel hydrocarbons and chlorinated solvents dissolved in groundwater at the site. This remedial alternative, however, will result in the generation of drill cuttings and soil gas, which may require treatment and/or disposal. Furthermore, it is uncertain how BTEX removal resulting from a bioventing system would affect the fate and transport the dissolved chlorinated solvent plume.

.4.2.2 Implementability

Installing and operating a horizontal bioventing system to reduce residual fuel hydrocarbons in the source areas is more complex than Alternative 1; however, major obstacles are not anticipated. In order to design an effective system, results from the previously conducted bioventing pilot test will be required. If high chlorinated solvent concentrations are detected in extracted soil gas during system installation, it may be advisable to operate the system in an SVE mode in order to remediate residual chlorinated solvents more rapidly. If SVE is used, soil gas treatment using a system such as a modified internal combustion engine could be required. Installation of the bioventing system involves standard engineering design and construction, including the installation of air injection wells, a regenerative blower system, electrical supply, and system integration.

Installation and operation of a bioventing system would require an increased commitment of labor hours and other resources to maintain and monitor the system. Periodic maintenance would be required for the regenerative blower. Weekly system checks are recommended, and operating data such as injection pressures and flow rates would be manually recorded. It is estimated that the bioventing system would be operational for 3 years. The technical and administrative implementability concerns associated with the vertical groundwater circulation, intrinsic remediation and LTM components of this remedial alternative are similar to those discussed in Alternative 1.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. The total present worth cost of Alternative 2 is $396,800. The cost of Alternative 2 is increased from the costs of Alternative 1 by the addition of the bioventing system, including system design, construction, operation, and maintenance. It is assumed that the bioventing system would operate for 3 years after installation. LTM is assumed to occur every second year for 30 years to ensure that intrinsic remediation is reducing

TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
Current Fire Training Area
Intrinsic Remediation, TS
Westover ARB, Massachusetts

Capital Costs	**Cost**
Design/Construct 7 LTM Wells	$22,640
Design/Construct 1 Vertical Groundwater Circulation Well with Pump	$15,620
Design/Construct 3-Well Horizontal Bioventing System	$84,524
Future Costs	
Design/Construct 6 POC Wells (in 3 years)	$19,400
Operation, Maintenance, and Monitoring Costs	**Cost per annum or event**
Operate and Maintain Bioventing System (3 years)	$11,480
Bioventing Annual Report (3 years)	$4,350
Conduct a Vertical Groundwater Circulation Treatability Study, Including Report (1 year)	$20,120
Conduct *Groundwater Sampling at 12 wells (1 year)*	$11,190
Conduct Groundwater Sampling at 18 wells (every second year for 28 years)	$16,780
Maintain Institutional Controls/Public Education (every second year for 30 years)	$5,000
Project Management and Reporting (every second year for 30 years)	$13,690
Present Worth of Alternative 2 [a]	**$396,800**

[a] Based on a discount rate of 7 percent.

BTEX and chlorinated solvent concentrations to below regulatory criteria throughout the plume and to verify that contamination does not reach the POC wells. The capital expense and annual costs for the vertical groundwater circulation treatability study, LTM, and institutional controls are assumed to be the same as for Alternative 1; however, the present worth of LTM is slightly lower than for Alternative 1 because of the reduction from 60 years of monitoring to 30 years.

6.4.3 Alternative 3 - Limited Soil Excavation, Horizontal Bioventing, Intrinsic Remediation, Vertical Groundwater Circulation, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.3.1 Effectiveness

The effectiveness of the intrinsic remediation, vertical groundwater circulation, institutional controls, LTM, and bioventing components of this alternative have been described under Alternatives 1 and 2. Soil excavation is an established technology for reducing source contamination and controlling plume migration. The goal of limited soil excavation would be to target the removal of a small volume of highly contaminated soil at the outfall of the buried waste fuel pipe. This would instantaneously eliminate one of the largest sources of continuing groundwater BTEX contamination. The model CFTA-EX suggests that reduction of the source would enhance the effectiveness of intrinsic remediation and expedite the decrease in the size of the BTEX plume.

Alternative 3 should provide reliable, continuous protection with little risk from temporary system failures. This alternative, however, does not comply well with all of the AFCEE program goals because of the generation of soil waste. In defense of the alternative, an effort has been taken to limit the volume of generated waste (approximately 22 cubic yards). Also, intrinsic remediation and bioventing remain the predominant remediation methods for fuel hydrocarbons and chlorinated solvents for most of the site.

6.4.3.2 Implementability

Limited soil excavation would be simple to implement. The option would require one-time excavation and disposal with no future operations and maintenance commitments. The technical and administrative implementability concerns associated with the bioventing, intrinsic remediation, vertical groundwater circulation, LTM, and institutional control components of this remedial alternative are similar to those discussed in Alternatives 1 and 2.

6.4.3.3 Cost

The estimated capital and operating costs of Alternative 3 are shown in Table 6.5. The total present worth cost of Alternative 3 is $394,400. The cost of Alternative 3 is varied from the costs of Alternative 2 by the addition of soil excavation and disposal costs and the elimination of installation, operation, and maintenance costs for one horizontal bioventing well. As in Alternative 2, the bioventing system would operate

TABLE 6.5
ALTERNATIVE 3 - COST ESTIMATE
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Capital Costs	**Cost**
Design/Construct 7 LTM Wells	$22,640
Design/Construct 1 Vertical Groundwater Circulation Well with Pump	$15,620
Design/Construct 2-Well Horizontal Bioventing System	$76,383
Excavate and Dispose of 22 cubic yards of fuel contaminated soil	$6,640
Future Costs	
Design/Construct 6 POC Wells (in 3 years)	$19,400
Operation, Maintenance, and Monitoring Costs	**Cost per annum or event**
Operate and Maintain Bioventing System (3 years)	$11,080
Bioventing Annual Report (3 years)	$4,350
Conduct a Vertical Groundwater Circulation Treatability Study, Including Report (1 year)	$21,120
Conduct Groundwater Sampling at 12 wells(1 year)	$11,190
Conduct Groundwater Sampling at 18 wells (every second year for 28 years)	$16,780
Maintain Institutional Controls/Public Education (every second year for 30 years)	$5,000
Project Management and Reporting (every second year for 30 years)	$13,690
Present Worth of Alternative 3 [a/]	**$394,400**

[a/] Based on a discount factor of 7 percent.

for 3 years, the vertical groundwater circulation treatability study would last 1 year, and the LTM program would continue every second year for 30 years. The cost of the bioventing system is somewhat lower than for Alternative 2 because only 2 150-foot horizontal wells would be installed, operated, and maintained. The cost for vertical groundwater circulation, LTM, and institutional controls are assumed to be the same as for Alternative 2.

6.5 RECOMMENDED REMEDIAL APPROACH

Three remedial alternatives have been evaluated for remediation of the shallow groundwater at FT-08. Components of the alternatives evaluated include limited soil excavation/disposal, bioventing, vertical groundwater circulation, intrinsic remediation with LTM, and institutional controls. Table 6.6 summarizes the results of the evaluation on the basis of effectiveness, implementability, and cost criteria. On the basis of this evaluation, the Air Force recommends Alternative 2 as achieving the best combination of risk reduction and cost effectiveness.

All three alternatives make maximum use of intrinsic remediation mechanisms to reduce plume migration and toxicity. In addition, Alternatives 2 and 3 would limit further BTEX plume migration by reducing the magnitude of continuing sources. All three options continue to rely on intrinsic remediation mechanisms to reduce plume toxicity in the groundwater. Implementation of Alternatives 2 and 3 would substantially decrease the time frame for BTEX remediation, but it is unclear on how this reduction would impact reductive dehalogenation of the chlorinated solvent plume. Both alternatives also would require a greater capital expenditure. Alternative 3 is considered the least favorable of the three evaluated alternatives because soil excavation simply transfers contamination rather than reducing contaminants to innocuous products. Furthermore, the transfer process could potentially result in higher risks to potential receptors.

All three remedial alternatives are implementable and effectively reduce potential hydrocarbon migration and toxicity in the groundwater. In addition, a vertical groundwater circulation treatability study is included as a part of all three alternatives in an attempt increase rates of biodegradation and reduce future migration of dissolved chlorinated solvents. All three alternatives should be acceptable to the public and regulatory agencies because they are protective of human health and the environment and reduce soil and groundwater contamination; however, none of the alternatives completes the groundwater restoration in a short time frame. Implementation of any of the three alternatives will require land use and groundwater use controls to be enforced for at least 30 years and perhaps longer depending on the alternative selected and the effectiveness of the selected remedial alternative. Groundwater monitoring would be required for the same period.

The final evaluation criterion used to compare each of the remedial alternatives was cost. It is the opinion of the Air Force that the additional cost of Alternative 2 over Alternative 1 is justified by the reduced risk resulting from the decrease in the time required to remediate the dissolved BTEX plume and the residual soil contamination. Adverse effects on dissolved chlorinated solvent degradation caused by bioventing operations are simply unknown at this time. Therefore, Alternative 2 is still recommended.

TABLE 6.6
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION FOR GROUNDWATER REMEDIATION
Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			
- Intrinsic Remediation - Vertical Circulation - Long-Term Monitoring - Institutional Controls	Contaminant mass, volume, and toxicity will be significantly reduced and plume migration should be halted. MCLs for BTEX are not likely to be exceeded at POC wells. Biodegradation and containment of the chlorinated solvent plume will be enhanced.	Readily implementable. Long-term management, groundwater use controls and monitoring required for an estimated 60 years. Minimal exposure of site workers if excavation is carefully controlled in source area. If MCLs are exceeded at POC, additional remedial work may be required.	$304,200
Alternative 2			
- Bioventing - Intrinsic Remediation - Vertical Circulation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of a bioventing system. BTEX mass, volume, and toxicity will be reduced more rapidly than in Alternative 1. Future impact on the rate of reductive dehalogenation for the chlorinated solvent plume is uncertain.	Readily implementable. Installation of bioventing system should present no problems. Bioventing estimated to continue for 3 years. Long-term management, groundwater controls, and monitoring required for an estimated 30 years. If MCLs are exceeded at POC, additional remedial work may be required.	$396,800
Alternative 3			
- Limited Source Soil Excavation - Bioventing - Intrinsic Remediation - Vertical Circulation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 2, with excavation of BTEX contaminated soil at the outfall of the buried waste fuel pipe instead of bioventing. Contaminant mass, volume, and toxicity will be reduced at a comparable rate to Alternative 2. Creates soil waste requiring additional treatment or disposal.	Readily implementable. Soil excavation should present no technical problems and the other components are the same as above. Bioventing estimated to continue for 3 years. Long-term management, groundwater controls, and monitoring required for an estimated 30 years. If MCLs are exceeded at POC, additional remedial work may be required.	$394,400

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for FT-08 at Westover ARB (bioventing, vertical groundwater circulation, and intrinsic remediation with LTM), a long-term groundwater monitoring plan must be developed. The purpose of this component of the preferred remedial alternative for the site is to assess site conditions over time, confirm the effectiveness of natural processes at reducing contaminant mass and minimizing contaminant migration, assess compliance with regulatory cleanup goals, and evaluate the need for additional remediation.

The LTM plan consists of identifying the location of two separate groundwater monitoring networks and developing a groundwater sampling and analysis strategy to demonstrate attainment of site-specific remediation goals and to verify the predictions of the Bioplume II model developed for FT-08. 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. In the event that data collected under this 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.

7.2 MONITORING NETWORKS

Two separate sets of wells will be utilized at the site as part of the LTM component of the remedial alternative. The first set will consist of twelve LTM wells located in, upgradient, and downgradient from the observed contaminant plume to verify that natural attenuation is occurring at rates sufficient to minimize plume expansion and reduce BTEX concentrations. This network of wells will consist of six monitoring wells screened across the water table (shallow wells) to provide short-term confirmation of the effectiveness of intrinsic remediation. The remaining six wells will be screened in deeper saturated intervals of the surficial aquifer. Three of these wells will be screened immediately below the silty sand layer (intermediate wells), while the remaining three wells will be screened immediately above the lacustrine clay aquitard at approximately 85 feet bgs (deep wells). The second set of wells will consist of six POC wells clustered at three locations along a line perpendicular to the general direction of groundwater flow, approximately 500 feet east of monitoring well CF-8. The purpose of the POC wells is to verify that no BTEX and chlorinated solvent concentrations exceeding state criteria migrate beyond the area under institutional control. Conservative model results suggest that the BTEX plume front should not reach the POC wells.

The proposed LTM and POC well locations are presented on Figure 7.1. The LTM and POC wells will be sampled for analysis of the parameters listed in Tables 7.1 and 7.2, respectively.

7.2.1 Long-Term Monitoring Wells

At six locations, groundwater wells within, upgradient, and downgradient from the current BTEX and chlorinated solvent contaminant plumes will be used to monitor the effectiveness of intrinsic remediation in reducing total contaminant mass and minimizing contaminant migration at FT-08. Of the 12 wells proposed for the LTM network, 5 have been installed during previous investigations. The remaining 7 wells would be installed upon implementation of this plan. Figure 7.1 identifies the proposed locations of the wells to be used for LTM. This network will supplement the POC wells to provide evidence of continuing intrinsic remediation and to allow additional response time if site conditions change.

Wells CF-1 and CF-1A are proposed for monitoring the background groundwater quality in the upper and lower intervals of the surficial aquifer. A new well is proposed for installation in the shallow saturated interval at the current location of monitoring point MP-4S to continue to evaluate the impact of the source area at the terminus of the buried waste fuel pipe. Well CF-3 is proposed for use in monitoring the shallow groundwater within the core of the former burn area. Typically, downgradient wells are installed within the anaerobic and aerobic treatment zones; however, the aerobic treatment zone appears to be minimal at this site. Therefore, well clusters are proposed for the anaerobic core, the anaerobic fringe, and the aerobic zone downgradient of the current leading edge of the plume. The well cluster CF-2 and CF-2A is proposed for monitoring the shallow and deep groundwater of the surficial aquifer at the downgradient edge of the former burn area within the anaerobic core of the plume. A third well is proposed for installation at this location to monitor intermediate depth groundwater. A new well cluster consisting of two wells (shallow and intermediate depths) is proposed for installation within the anaerobic fringe of the plume between monitoring point locations 5, 10, and 15. A three-well cluster (shallow, intermediate, and deep) is proposed for downgradient of the leading edge of the plume, where the shallow groundwater conditions are returning to aerobic. Because the well cluster is beyond the contaminant plume's leading edge, it will double as a sentry (or advance warning) location for all three depths.

The seven new monitoring wells will have 10-foot screened intervals. Shallow wells will be screened across the water table with approximately 8 feet of the 10-foot screen positioned below the water table. Intermediate wells will be screened in the gravelly sand immediately below the sandy silt at a depth of approximately 40 feet. The two largest lobes of the BTEX and chlorinated solvent contaminant plumes are located in the same hydrogeologic intervals monitored by the shallow and intermediate depth wells. Deep wells will be screened in the fine sand overlying the lacustrine clays at a depth of approximately 85 feet. At least one foot of screen will be installed in the clay unit to ensure that the deepest portion of the surficial aquifer is within the screened interval.

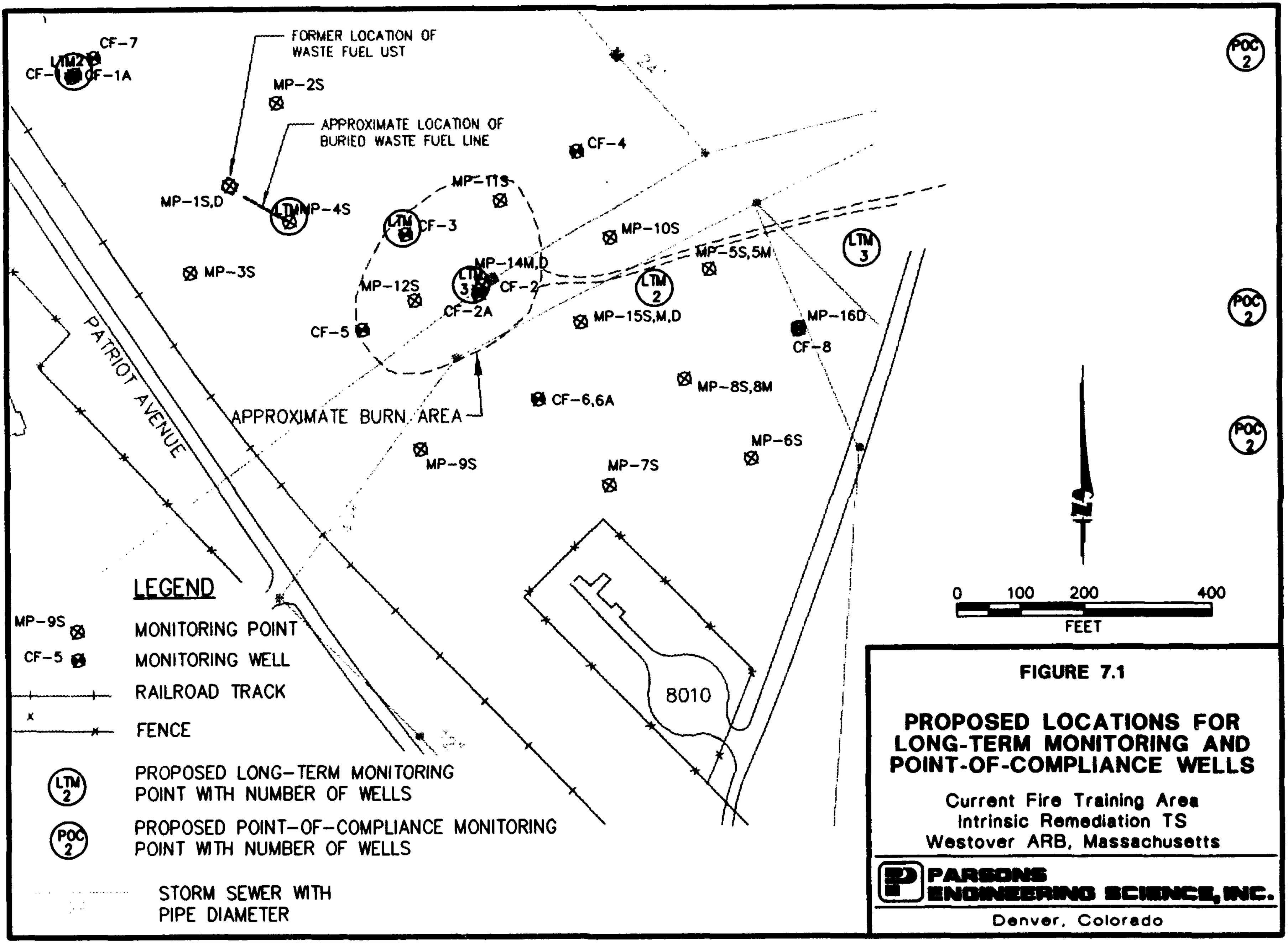

FIGURE 7.1

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

Current Fire Training Area
Intrinsic Remediation TS
Westover ARB, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 7.1
LONG-TERM MONITORING ANALYTICAL PROTOCOL
Current 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 Second Year for 30 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 Second Year for 30 Years	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Every Second Year for 30 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Every Second Year for 30 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 Second Year for 30 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 Second Year for 30 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 Second Year for 30 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 7.1 (concluded)
LONG-TERM MONITORING ANALYTICAL PROTOCOL
Current 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 Second Year for 30 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 Second Year for 30 Years	*Collect 100–250 mL of water in a* glass container, filling container from bottom; analyze immediately	*Field*
Methane, Ethane, and Ethene	*RSKSOP-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). The presence of ethane and ethene suggest that cometabolism of vinyl chloride is occurring.	Every Second Year for 30 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
Halogenated compounds	Purge and trap GC method SW8010. Alternately, GC/MS method SW8240.	Handbook method	Chlorinated solvent concentrations must be measured for regulatory compliance	Every Second Year for 30 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
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 Second Year for 30 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

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

TABLE 7.2
POINT-OF-COMPLIANCE MONITORING ANALYTICAL PROTOCOL
Current 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 Second Year for 30 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Every Second Year for 30 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 Second Year for 30 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 Second Year for 30 Years	Collect 100–250 mL of water in a glass or plastic container	Field
Halogenated compounds	Purge and trap GC method SW8010. Alternately, GC/MS method SW8240.	Handbook method	Chlorinated solvents concentrations must be measured for regulatory compliance	Every Second Year for 30 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
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 Second Year for 30 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

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

7.2.2 Point-of-Compliance Wells

Three POC monitoring well clusters are proposed for installation at the site. Figure 7.1 shows proposed locations for these clusters. These locations, however, should be considered tentative because the groundwater flow direction to the east of FT-08 is not well established. To the east of FT-08 it is unclear whether the easterly flowing convergent divide system will persist or whether the southerly regional flow system will control local downgradient flow. It is recommended that the POC wells be installed two years after the LTM wells to allow for at least a year of quarterly groundwater elevations prior to final placement of the POC wells. The locations presented on Figure 7.1 are approximately 500 feet downgradient of the current leading edge of the BTEX plume. These locations are approximately 3,000 feet upgradient of the non-potable groundwater well located on the eastern side of the Base. The POC wells are over a mile from the eastern and southern base boundaries.

The purpose of POC wells is to verify that no contaminated groundwater exceeding state criteria migrates beyond the area under institutional control. Although model results strongly suggest that the contaminant plume will not migrate beyond this area at concentrations exceeding chemical-specific federal or state MCLs, these POC wells are the technical mechanisms used to demonstrate protection of human health and the environment and compliance with site-specific numerical RAOs. These wells will be installed and monitored for the parameters listed in Table 7.2 to assure that the selected remedy 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 units as the contaminant plumes. 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 in the shallow groundwater at this site. Intermediate-depth POC wells will be screened across the first 10 feet of gravelly sand, immediately beneath the silty sand layer.

7.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at FT-08 to meet site-specific remediation goals, the long-term groundwater monitoring plan includes a comprehensive sampling and analysis plan. Because the rate of groundwater flow is low at FT-08, groundwater samples will be collected and analyzed from LTM and POC wells every second year for 30 years to verify that natural processes are effectively reducing contaminant mass and mobility. Reductions in toxicity will be implied by mass reduction. The sampling and analysis plan is also aimed at assuring intrinsic remediation can achieve site-specific concentration goals for BTEX and chlorinated solvent compounds.

7.3.1 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. Water level measurements will be made during each sampling event. Groundwater samples will be analyzed for the parameters listed in Tables 7.1 and 7.2. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating the LTM program.

7.3.2 Sampling Frequency

Each of the LTM and POC wells will be sampled once every other year for 30 years. POC wells will first be monitored during the second LTM sampling event because they will not be installed at the time of the first event. If the data collected during these 30 years supports the anticipated effectiveness of the proposed remedial alternative at this site, the sampling frequency could be reduced to once every five years for all wells in the LTM program, 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.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of intrinsic remediation for remediation of fuel-hydrocarbon and chlorinated-solvent-contaminated groundwater in the vicinity of site FT-08 at Westover ARB, Massachusetts. Specifically, the finite-difference groundwater model Bioplume II was used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation 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-08: The loss of contaminant mass at the field scale and geochemical evidence. Decreases in contaminant concentrations between May 1995 and July 1996, as well as rates of biodegradation estimated from flow path analyses using the method of Buscheck and Alcantar (1995) indicate the loss of contaminant mass. Comparison of BTEX, chlorinated solvent, electron acceptor, and biodegradation byproduct isopleth maps for May 1995 and July 1996 provides strong 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 TCE is being degraded via reductive dehalogenation. The lack of significant concentrations of vinyl chloride suggest that cis-1,2-DCE is being degraded aerobically near the fringes of the contaminant plume.

Site-specific geologic, hydrologic, and laboratory analytical data collected in May 1995 were then used in the Bioplume II numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the dissolved BTEX plume. Previous 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 Bioplume II model for this study, and therefore, the model results presented herein represent very conservative scenarios, given the other modeling assumptions regarding source removal.

For one simulation (model CFTA-IR), it was assumed that conditions that produced the calibrated model would persist for the duration of the simulation. This scenario suggests that the plume would migrate a maximum of 150 feet beyond the May 1995 plume front before BTEX migration halts and the plume stabilizes as a result of natural attenuation. The model predicts complete attenuation of the dissolved BTEX plume in 62 years. Model CFTA-SVE assumed a contaminant source reduction through bioventing or SVE, using a geometric source decay rate of 50 percent per year for 8 years. Results for this model suggest that the plume will migrate approximately 100 feet beyond the May 1995 plume front before natural attenuation mechanisms effectively halt migration and shrink the plume. Model CFTA-SVE predicts that the BTEX plume will completely attenuate in just over 30 years. The third model (CFTA-EX) assumed complete removal of the contaminated soil source at the outfall of the buried waste fuel pipe with bioventing or SVE treatment in the main burn area. The model predicted nearly identical plume expansion and attenuation as model CFTA-SVE.

Data collected in July 1996 suggest that model predictions are overly conservative, and biodegradation rates are occurring faster than original predictions. In fact, two-thirds of the decrease in source area concentrations predicted for the first 10 years was observed after only 14 months. Although there is no guarantee that this plume attenuation rate will be maintained, it is clear that natural attenuation processes are occurring and are sufficient to continue to reduce the dissolved contaminant mass and limit plume migration over time.

The results of this study suggest that natural attenuation of BTEX and chlorinated solvent compounds is occurring at FT-08. Given that the models predict no impact to known receptors at the modeled rates of BTEX plume migration, and that chlorinated solvents are also being biodegraded, the Air Force is recommending natural attenuation, vertical groundwater circulation, institutional controls, and LTM to remediate site groundwater impacted by BTEX and chlorinated solvents. However, to reduce the anticipated length of cleanup and to further reduce risk, the Air Force also recommends that a bioventing system be installed to remediate fuel-contaminated vadose zone soils. The estimated rates of biodegradation, when coupled with sorption, dispersion, and dilution, should be sufficient to reduce and maintain dissolved BTEX and chlorinated solvent concentrations to levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected. Construction activities in the plume area and groundwater use in and downgradient from the plume area should be restricted for a period of at least 30 years.

To continue to verify the results of the Bioplume II modeling effort, and to ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, groundwater from 12 LTM wells should be sampled and analyzed for the parameters listed in Table 7.1. In addition, six POC groundwater monitoring wells should be installed downgradient from the predicted maximum travel distance of the BTEX plume and sampled for the parameters listed in Table 7.2. Figure 7.1 shows suggested locations for the POC and LTM wells. These wells should be sampled every second year for 30 years. At this time, sampling will cease, will decrease in frequency, or will continue at the rate of every second year as dictated by the analytical results. 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 9

REFERENCES

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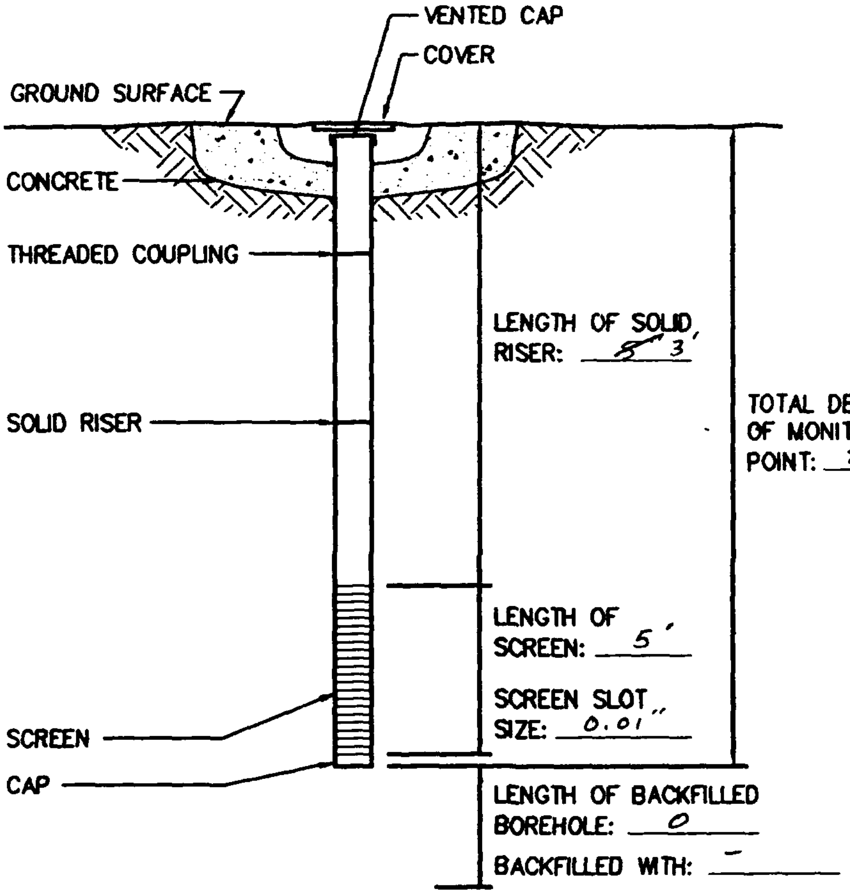
APPENDIX A

APPENDIX A-1

MONITORING POINT INSTALLATION RECORDS

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-15
JOB NUMBER 722450.28 INSTALLATION DATE MAY 10, 1995 LOCATION FT-08
DATUM ELEVATION 243.79 GROUND SURFACE ELEVATION 243.96
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: ~~8~~ 3'
TOTAL DEPTH OF MONITORING POINT: 8'
LENGTH OF SCREEN: 5'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL 6.16' FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 8' FEET BELOW DATUM.

APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\fign 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-1D

JOB NUMBER 722450.28 INSTALLATION DATE MAY 10, 1995 LOCATION FT-08

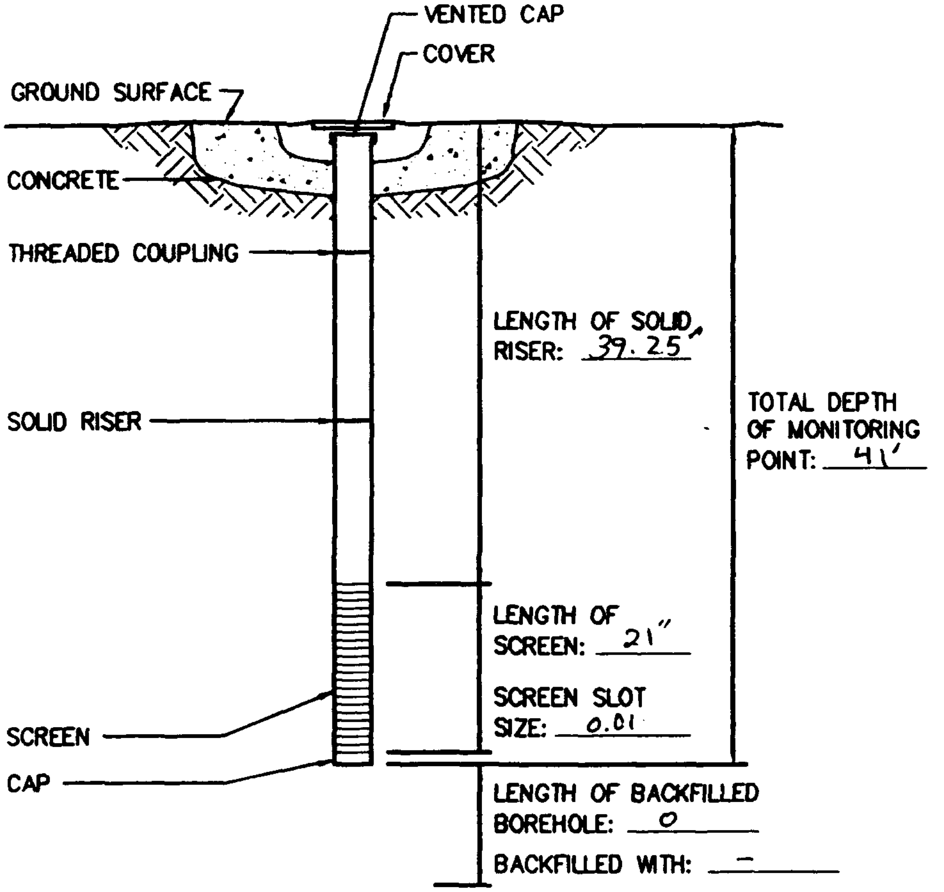
DATUM ELEVATION 243.96 GROUND SURFACE ELEVATION 243.96

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.375 WIRE MESH SLOT SIZE 0.010

RISER DIAMETER & MATERIAL 0.375 Teflon Lined HDPE BOREHOLE DIAMETER 1"

GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 39.25'

TOTAL DEPTH OF MONITORING POINT: 41'

LENGTH OF SCREEN: 21"

SCREEN SLOT SIZE: 0.01

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 39.25' FEET BELOW DATUM.

APPENDIX A

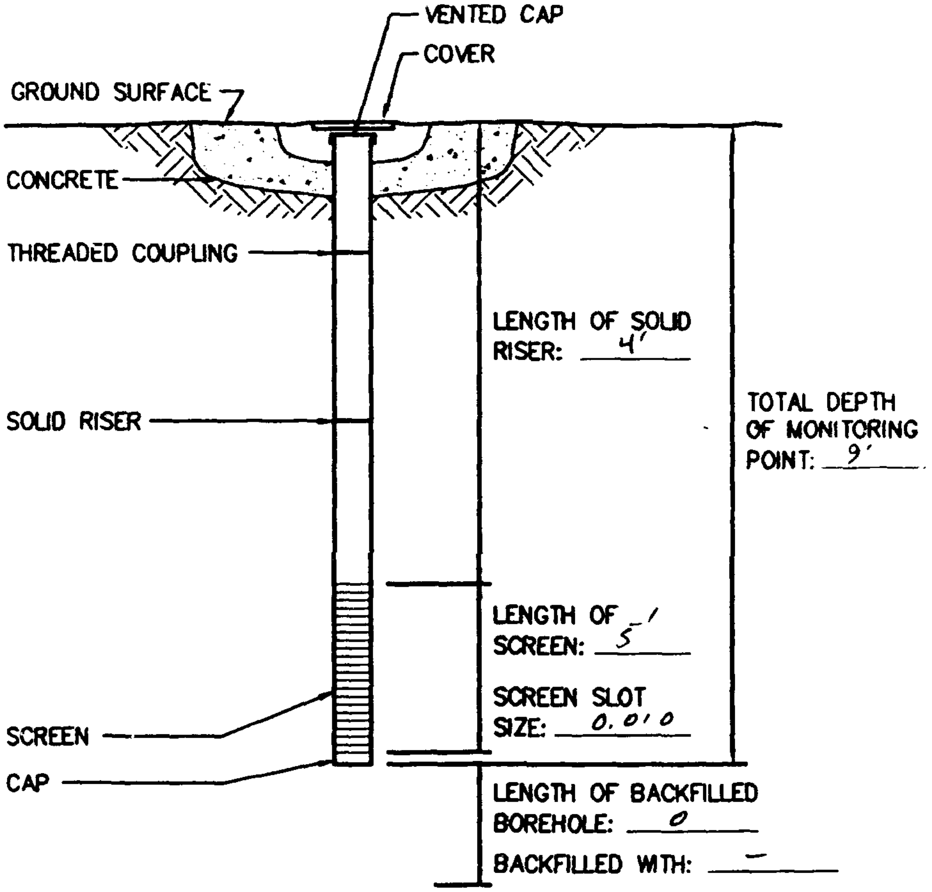
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\fign 4 5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-25
JOB NUMBER 722450.28 INSTALLATION DATE MAY 10, 1995 LOCATION FT-08
DATUM ELEVATION 243.83 GROUND SURFACE ELEVATION 243.96
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 4'
TOTAL DEPTH OF MONITORING POINT: 9'
LENGTH OF SCREEN: 5'
SCREEN SLOT SIZE: 0.010
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.68 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 9' FEET BELOW DATUM.

APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-3S

JOB NUMBER 722450.28 INSTALLATION DATE MAY 10, 1995 LOCATION FT-08

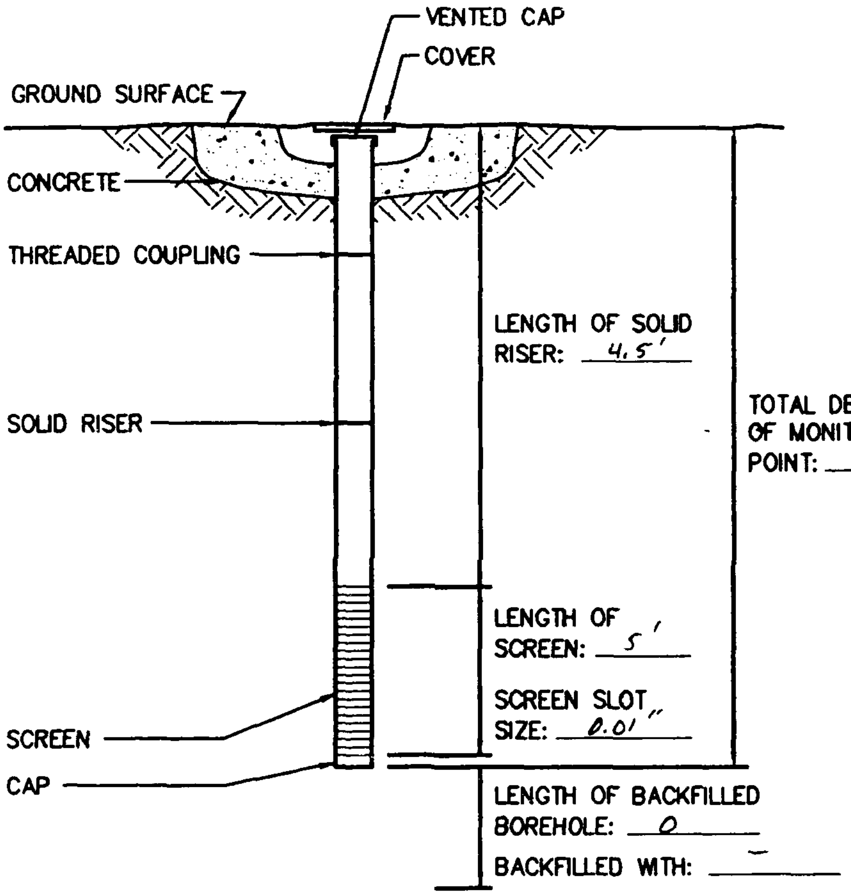
DATUM ELEVATION 243.32 GROUND SURFACE ELEVATION 243.42

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 10

RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"

GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 4.5'

TOTAL DEPTH OF MONITORING POINT: 9.5'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL 7.78 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 9.5' FEET BELOW DATUM.

APPENDIX A

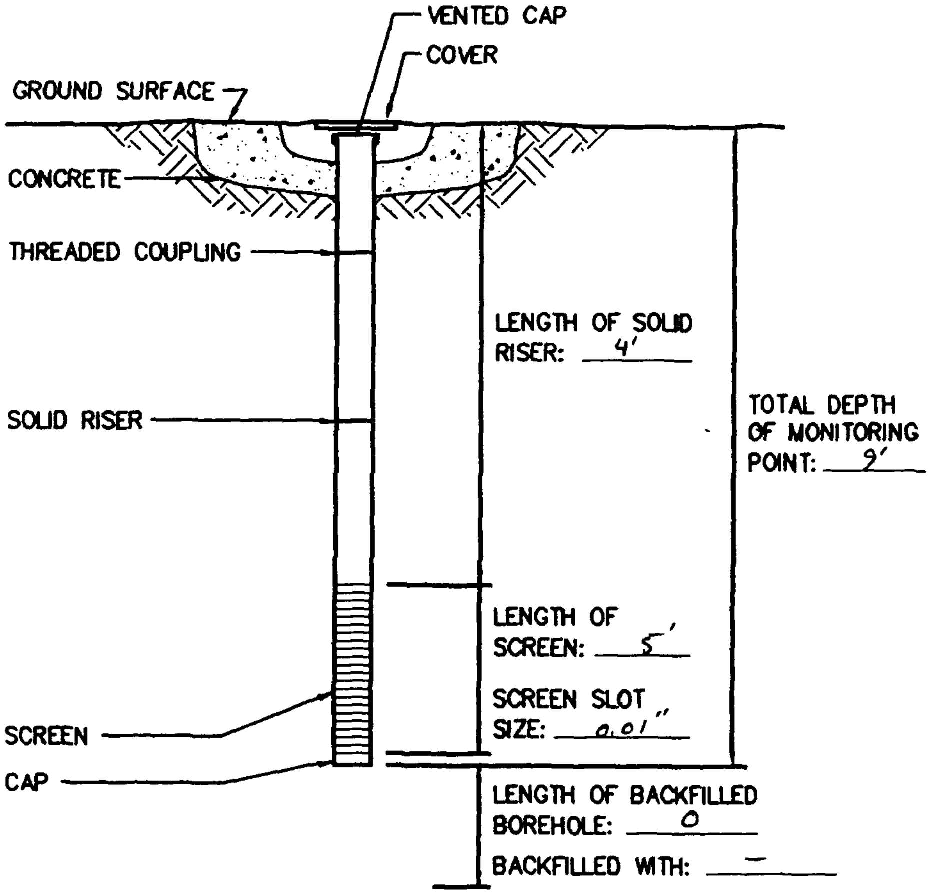
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\fig 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-4S
JOB NUMBER 722450.28 INSTALLATION DATE MAY 10, 1995 LOCATION FT-08
DATUM ELEVATION 243.88 GROUND SURFACE ELEVATION 243.92
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 4'
TOTAL DEPTH OF MONITORING POINT: 9'
LENGTH OF SCREEN: 5'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL 6.51 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 9' FEET BELOW DATUM.

APPENDIX A

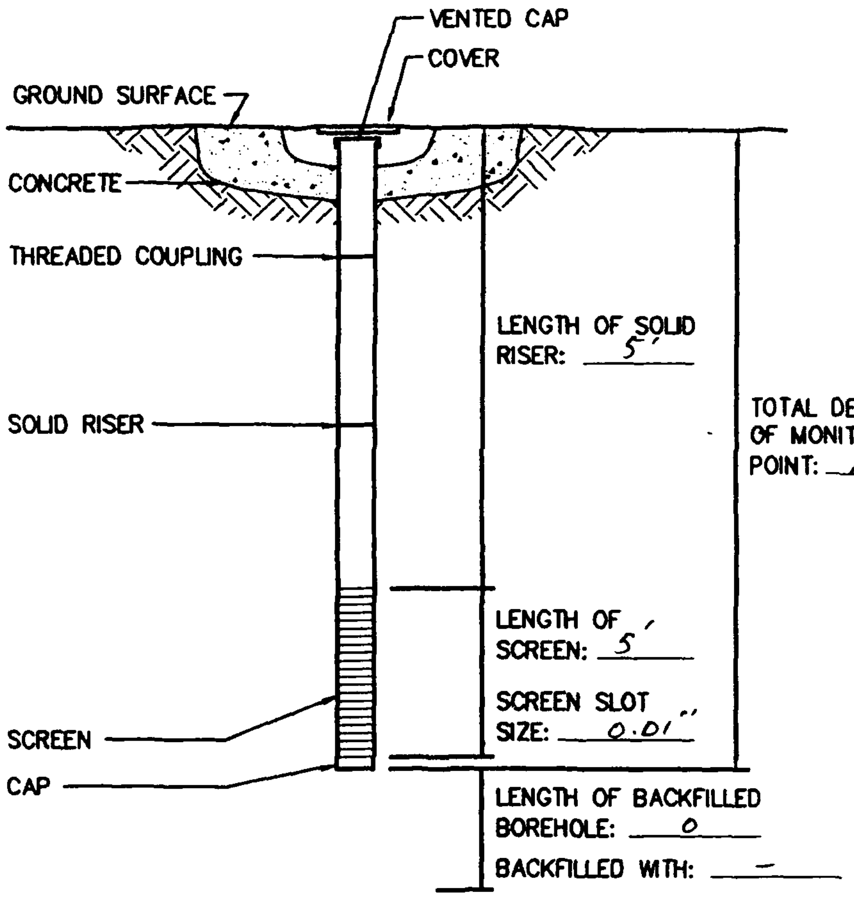
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

L:\FIGURES\fig 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-58
JOB NUMBER 722450.28 INSTALLATION DATE MAY 11, 1995 LOCATION FT-08
DATUM ELEVATION 241.58 GROUND SURFACE ELEVATION 241.58
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 5'

TOTAL DEPTH OF MONITORING POINT: 10'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.26 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 10 FEET BELOW DATUM.

APPENDIX A

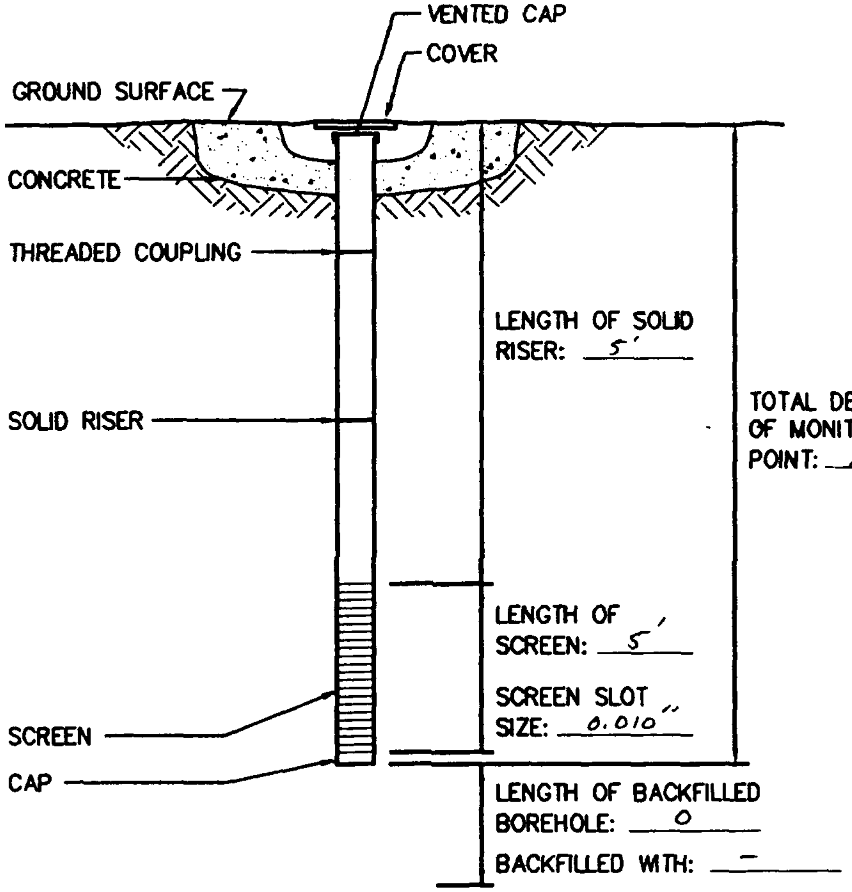
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\figp 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB
MONITORING POINT NUMBER MP-65
JOB NUMBER 722450.28
INSTALLATION DATE MAY 11, 1995
LOCATION FT-08
DATUM ELEVATION 243.07
GROUND SURFACE ELEVATION 243.09
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC
SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC
BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES
ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 5'

TOTAL DEPTH OF MONITORING POINT: 10'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.010"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.03 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 10 FEET BELOW DATUM.

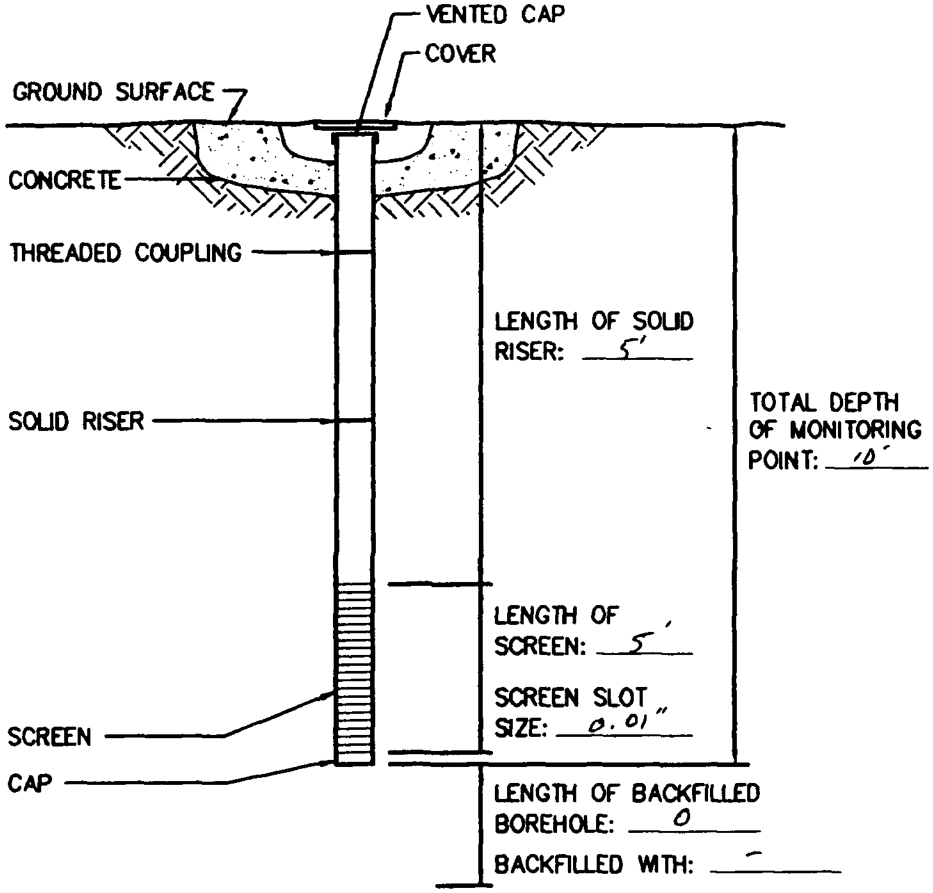
APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-7S
JOB NUMBER 722450.28 INSTALLATION DATE MAY 11, 1995 LOCATION FT-08
DATUM ELEVATION 242.84 GROUND SURFACE ELEVATION 242.92
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL PVC - 0.5" SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 5'
TOTAL DEPTH OF MONITORING POINT: 10'
LENGTH OF SCREEN: 5'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.01 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 10' FEET BELOW DATUM.

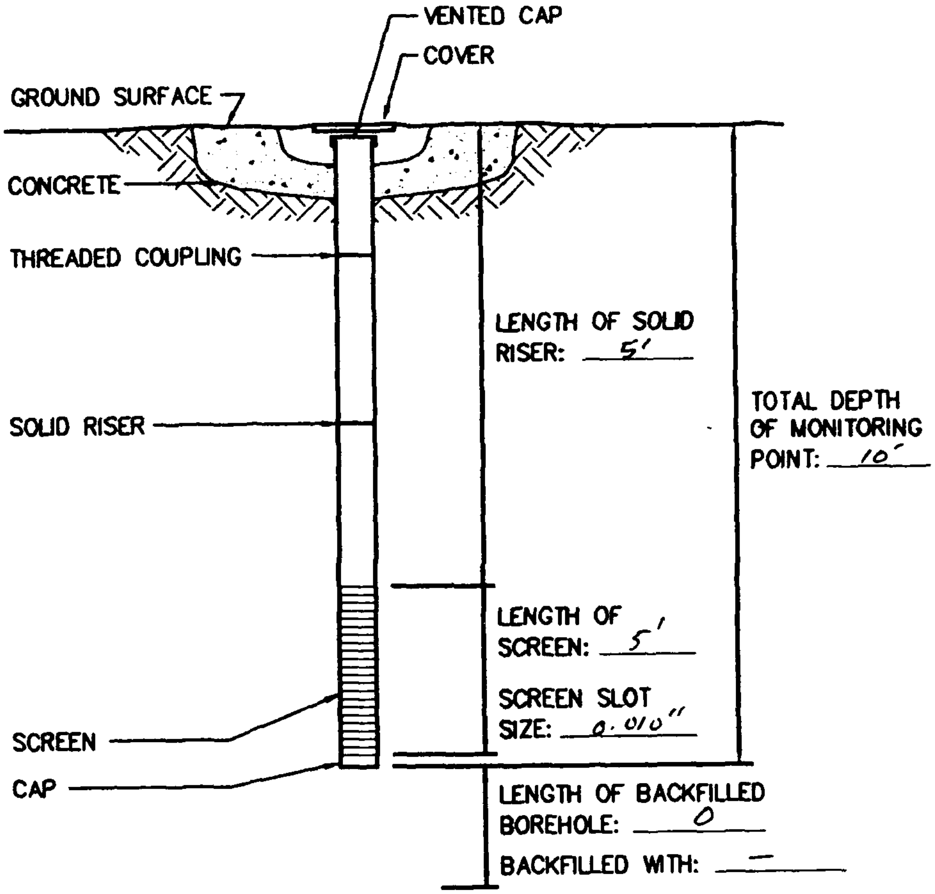
APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-85
JOB NUMBER 722450.28 INSTALLATION DATE MAY 11, 1995 LOCATION FT-08
DATUM ELEVATION 241.94 GROUND SURFACE ELEVATION 242.10
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 5'

TOTAL DEPTH OF MONITORING POINT: 10'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.010"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL 4.41 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 10 FEET BELOW DATUM.

APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

\FIGURES\fig 4 5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-8M

JOB NUMBER 722450.28 INSTALLATION DATE MAY 11, 1995 LOCATION FT-08

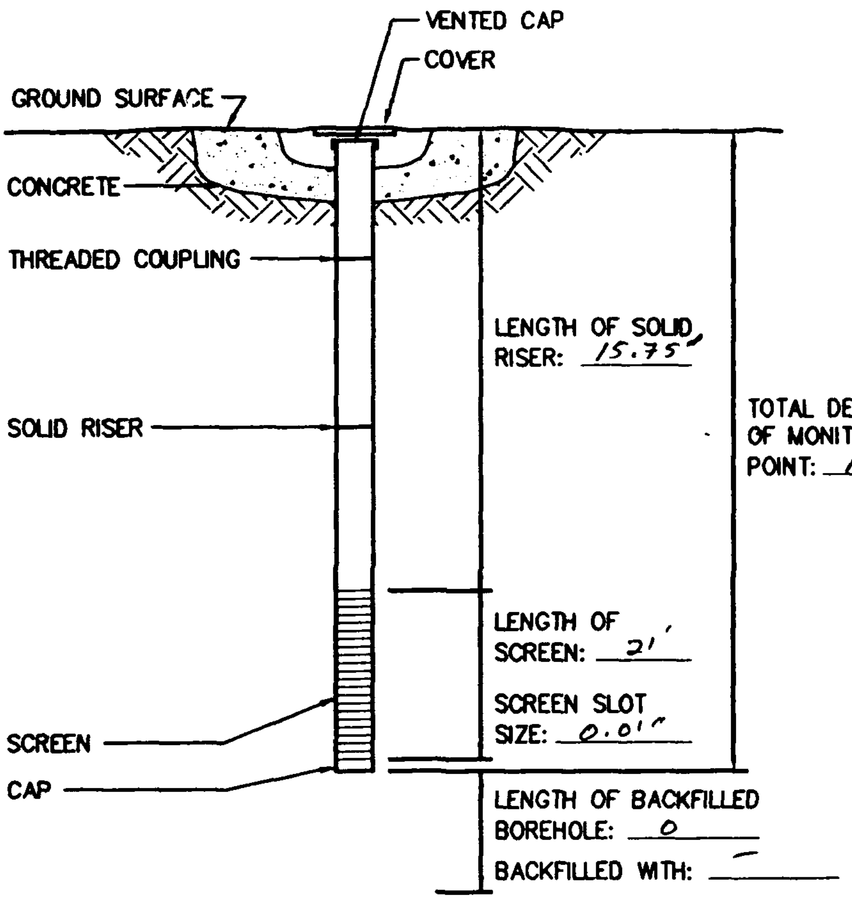
DATUM ELEVATION 242.10 GROUND SURFACE ELEVATION 242.10

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.375 Steel mesh SLOT SIZE 0.010

RISER DIAMETER & MATERIAL 0.375 Teflon Lined HDPE BOREHOLE DIAMETER 1"

GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 15.75'

TOTAL DEPTH OF MONITORING POINT: 17.5'

LENGTH OF SCREEN: 2'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 17.5 FEET BELOW DATUM.

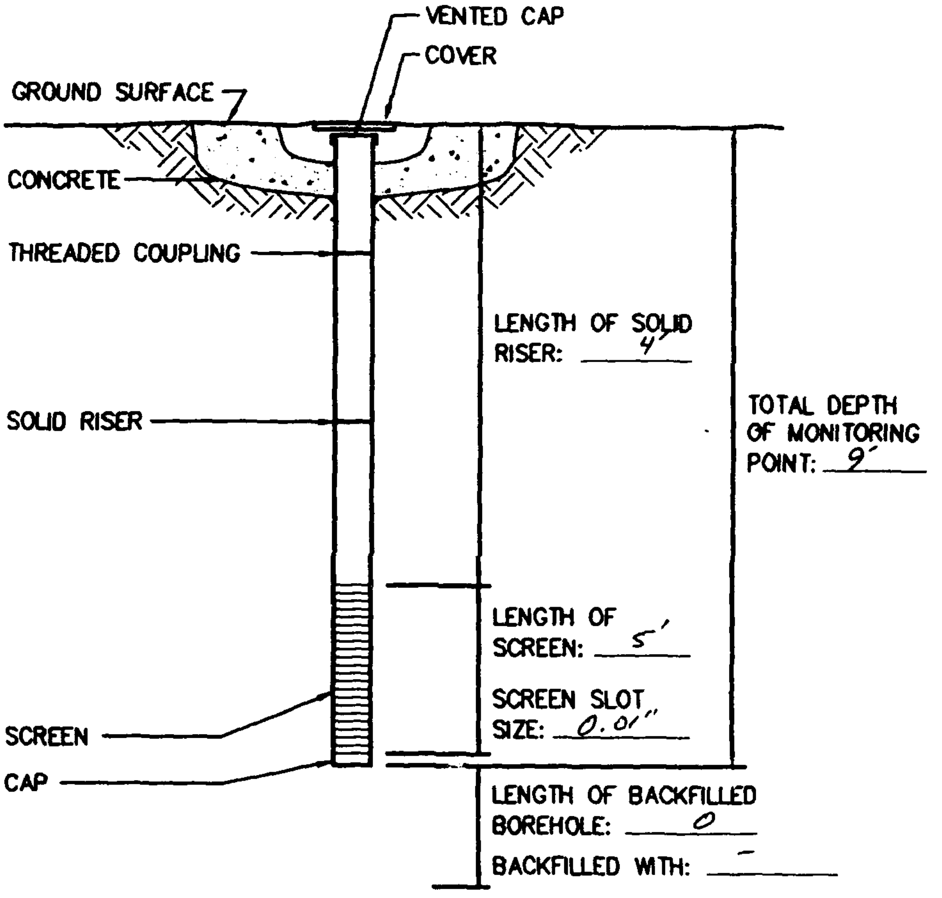
APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-95
JOB NUMBER 722450.28 INSTALLATION DATE MAY , 1995 LOCATION FT-08
DATUM ELEVATION 243.64 GROUND SURFACE ELEVATION 243.85
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 4'
TOTAL DEPTH OF MONITORING POINT: 9'
LENGTH OF SCREEN: 5'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL 6.68 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 9 FEET BELOW DATUM.

APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

L:\FIGURES\figs 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-10 S

JOB NUMBER 722450.28 INSTALLATION DATE MAY 11, 1995 LOCATION FT-08

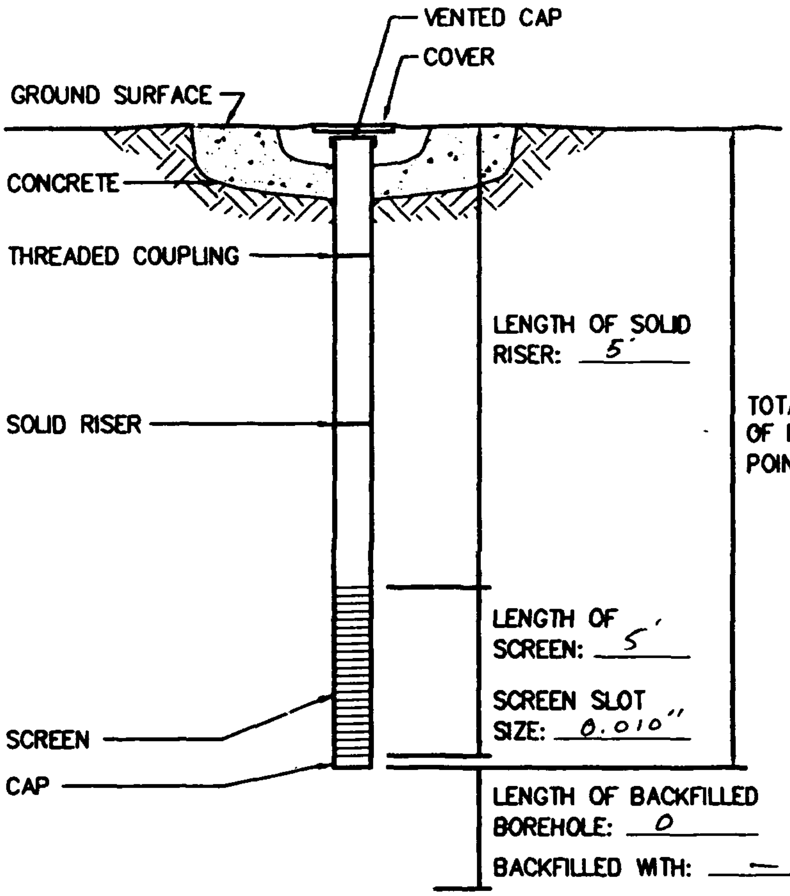
DATUM ELEVATION 243.27 GROUND SURFACE ELEVATION 243.44

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010

RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"

GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 5'

TOTAL DEPTH OF MONITORING POINT: 10'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.010"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.97 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 10 FEET BELOW DATUM.

APPENDIX A

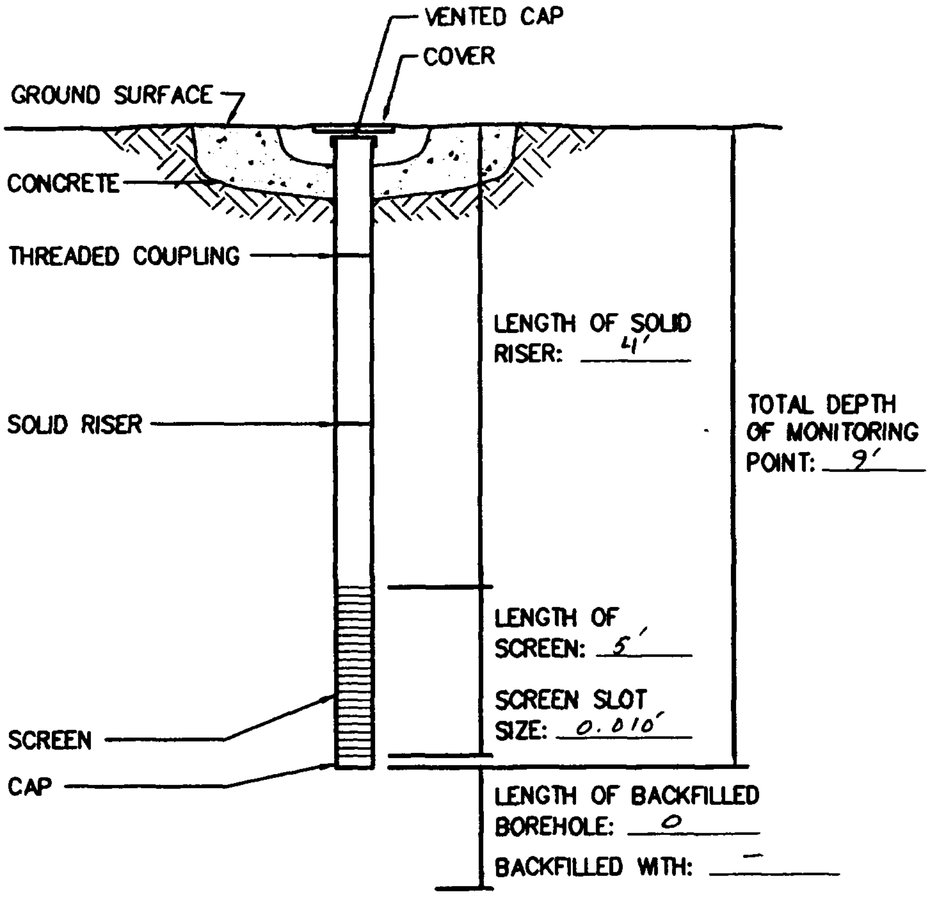
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

\FIGURES\fign 4 5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-11S
JOB NUMBER 722450.28 INSTALLATION DATE MAY 11, 1995 LOCATION FT-08
DATUM ELEVATION 242.80 GROUND SURFACE ELEVATION 242.97
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 4'

TOTAL DEPTH OF MONITORING POINT: 9'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.010'

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.10 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 10 FEET BELOW DATUM.

APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\figg 4 5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-12S

JOB NUMBER 722450.28 INSTALLATION DATE MAY 12, 1995 LOCATION FT-08

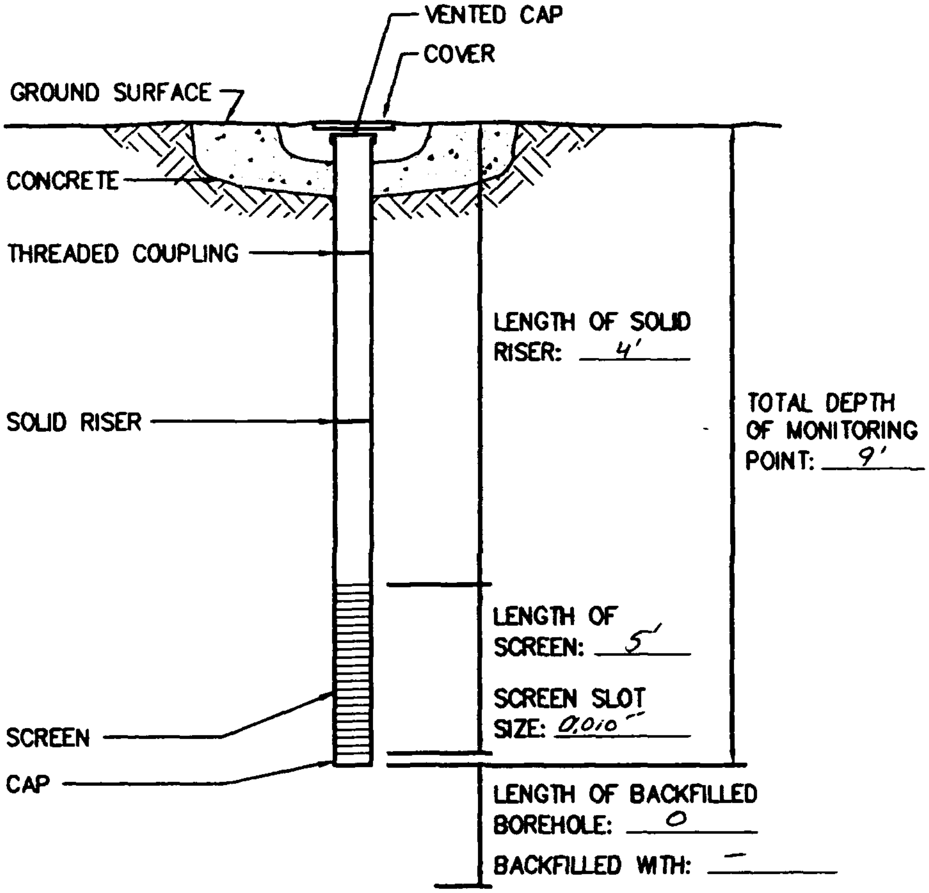
DATUM ELEVATION 242.94 GROUND SURFACE ELEVATION 243.34

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010"

RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"

GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 4'

TOTAL DEPTH OF MONITORING POINT: 9'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.010"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.66 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 9' FEET BELOW DATUM.

APPENDIX A

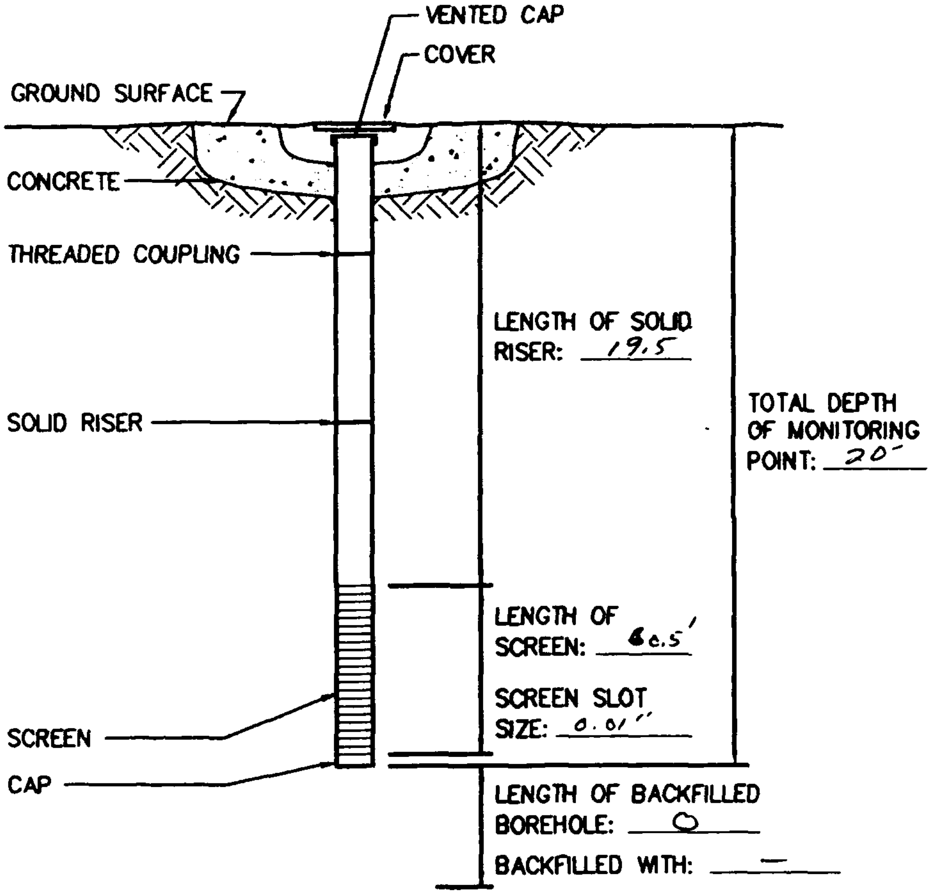
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

\FIGURES\fign 4 5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER mP-14M
JOB NUMBER 722450.28 INSTALLATION DATE MAY 12, 1995 LOCATION FT-08
DATUM ELEVATION 243.36 GROUND SURFACE ELEVATION 243.36
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.375" WIRE MESH SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 0.378" TEFLON LINED HDPE BOREHOLE DIAMETER 1"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 19.5
TOTAL DEPTH OF MONITORING POINT: 20'
LENGTH OF SCREEN: 0.5'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 20' FEET BELOW DATUM.

APPENDIX A

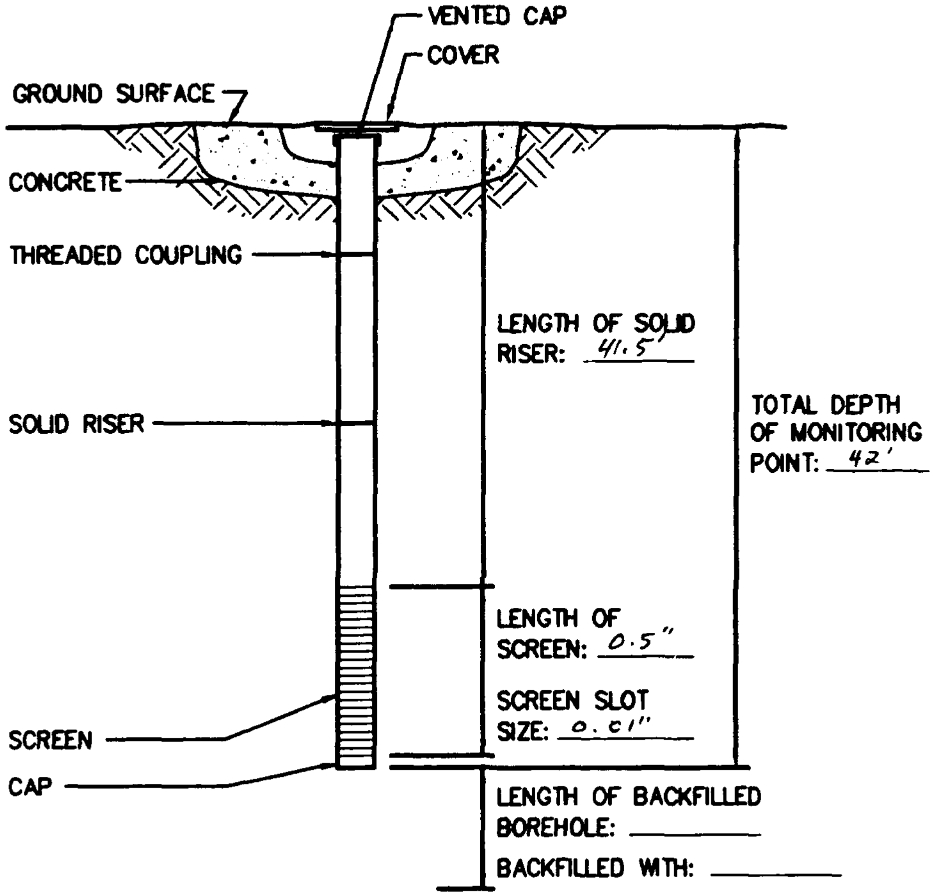
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

L:\FIGURES\fig 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB
MONITORING POINT NUMBER 140
JOB NUMBER 722450.28
INSTALLATION DATE MAY , 1995
LOCATION FT-08
DATUM ELEVATION 243.36
GROUND SURFACE ELEVATION 243.36
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.375" wire mesh
SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 0.375" Teflon Lined HDPE
BOREHOLE DIAMETER 1"
GEOPROBE CONTRACTOR PARSONS ES
ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 41.5'
TOTAL DEPTH OF MONITORING POINT: 42'
LENGTH OF SCREEN: 0.5"
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: ________
BACKFILLED WITH: ________

(NOT TO SCALE)

STABILIZED WATER LEVEL ________ FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH ______ FEET BELOW DATUM.

APPENDIX A

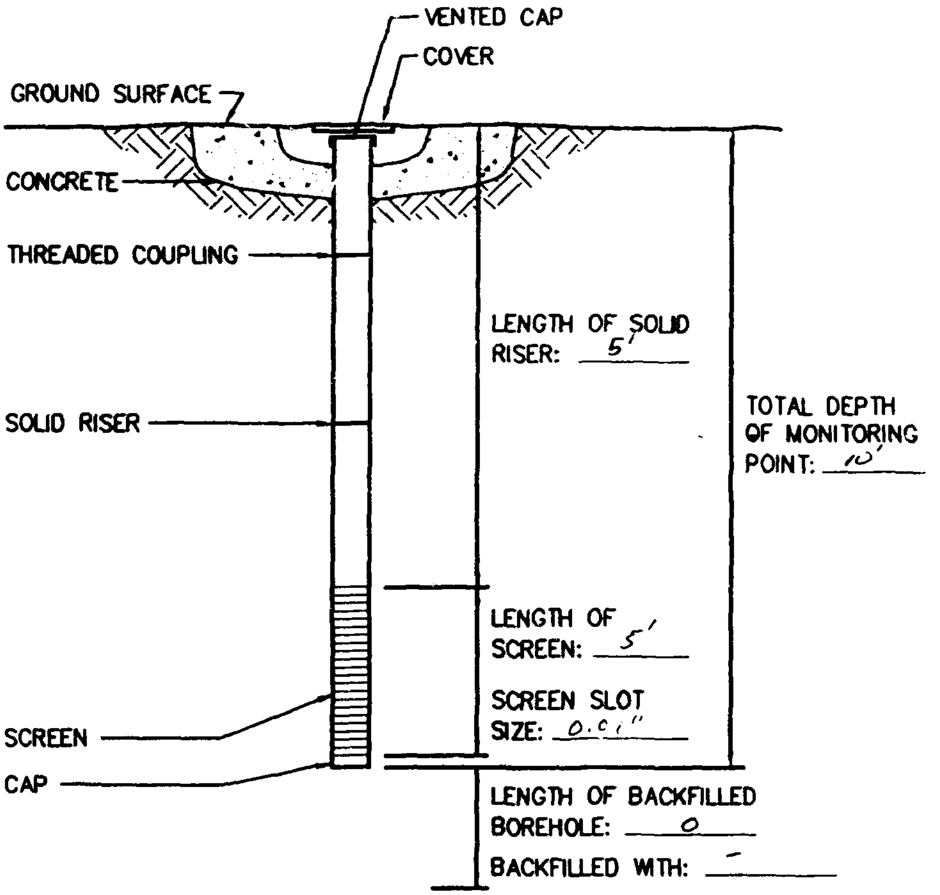
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

L: \FIGURES\figa_4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER 15 5
JOB NUMBER 722450.28 INSTALLATION DATE MAY 12, 1995 LOCATION FT-08
DATUM ELEVATION 242.03 GROUND SURFACE ELEVATION 242.25
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 5'
TOTAL DEPTH OF MONITORING POINT: 10'
LENGTH OF SCREEN: 5'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL 5.04 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 10 FEET BELOW DATUM.

APPENDIX A

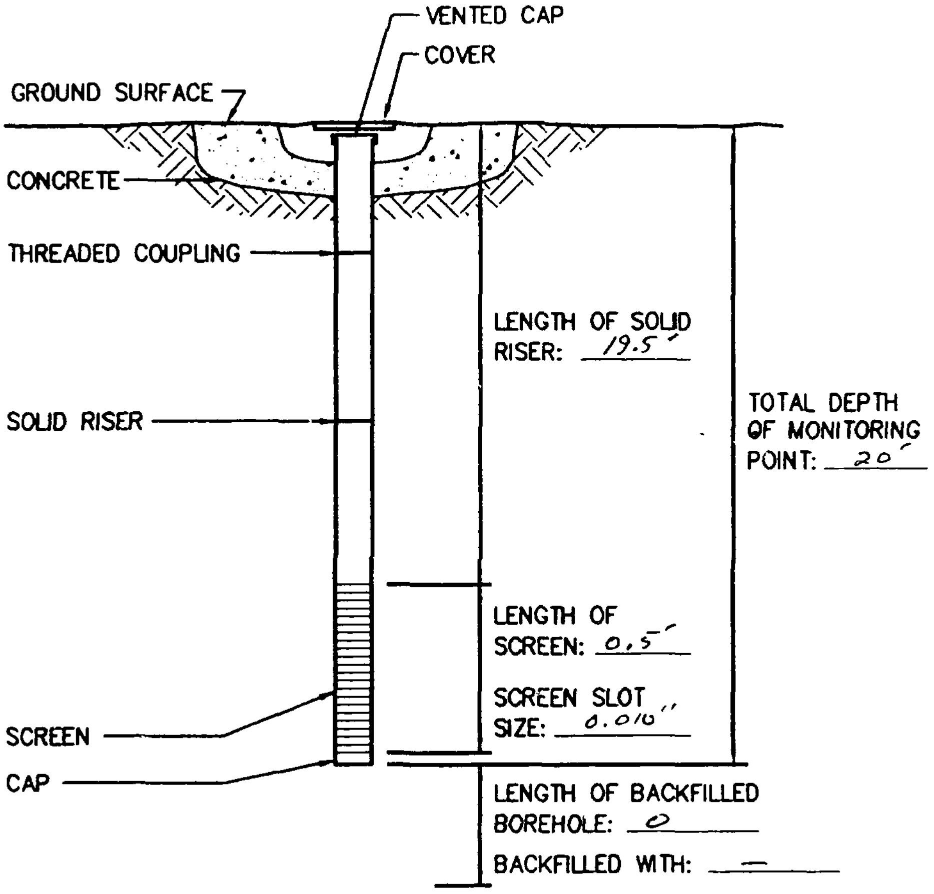
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\figo_4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-15m
JOB NUMBER 722450.28 INSTALLATION DATE MAY 12, 1995 LOCATION FT-08
DATUM ELEVATION 242.25 GROUND SURFACE ELEVATION 242.25
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.375" wire mesh SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 0.375" TEFLON LINED HDPE BORFHOLE DIAMETER 1"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENT TIVE MJV



LENGTH OF SOLID RISER: 19.5'

TOTAL DEPTH OF MONITORING POINT: 20'

LENGTH OF SCREEN: 0.5'

SCREEN SLOT SIZE: 0.010"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 20' FEET BELOW DATUM.

APPENDIX A

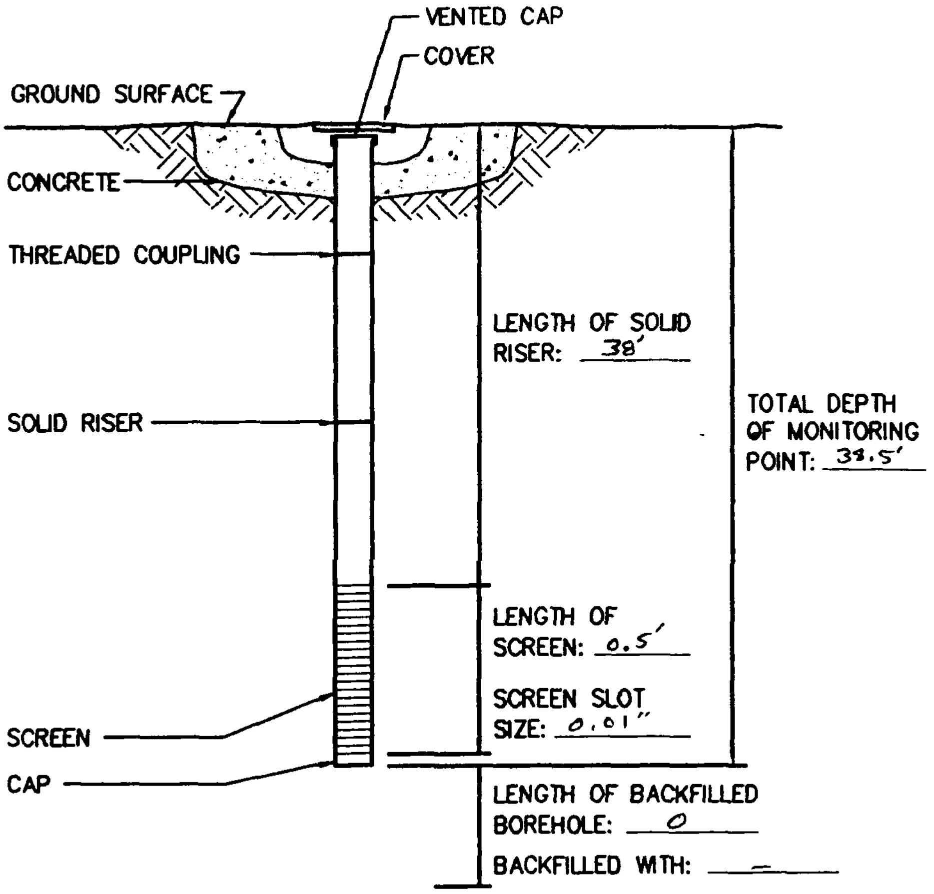
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I·\FIGURES\figo. 4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-15D
JOB NUMBER 722450.28 INSTALLATION DATE MAY 12, 1995 LOCATION FT-08
DATUM ELEVATION 242.25 GROUND SURFACE ELEVATION 242.25
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.375" wire mesh SLOT SIZE 0.010
RISER DIAMETER & MATERIAL 0,375" TEFLON LINED HDPE BOREHOLE DIAMETER 1"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 38'

TOTAL DEPTH OF MONITORING POINT: 38.5'

LENGTH OF SCREEN: 0.5'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: 0

BACKFILLED WITH: –

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 38.5 FEET BELOW DATUM.

APPENDIX A

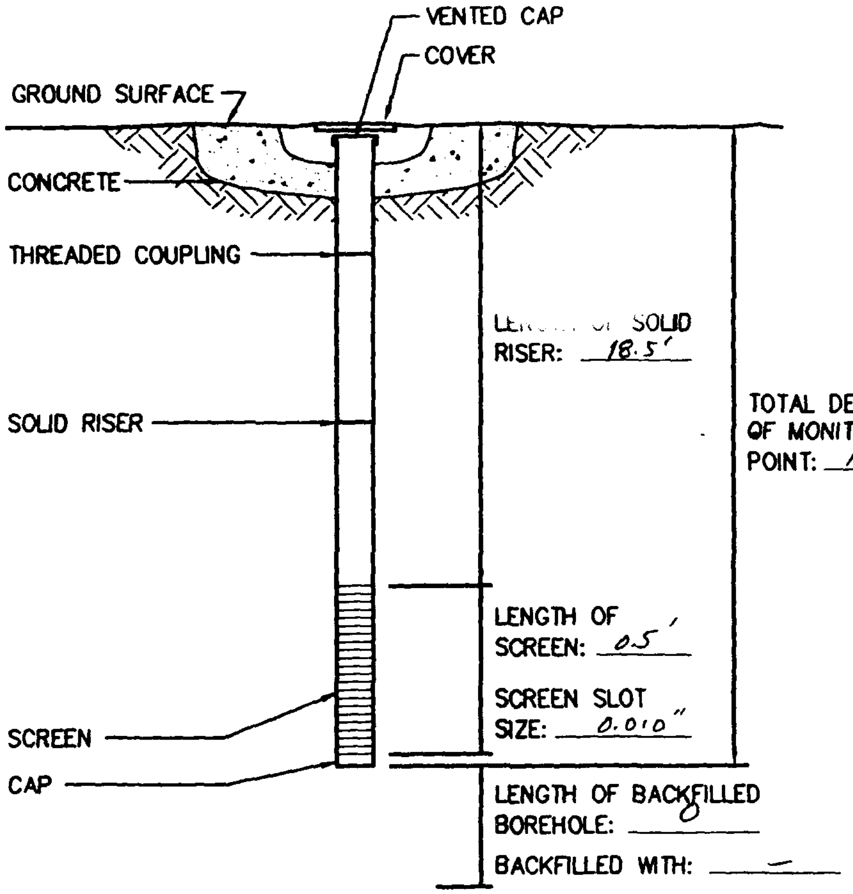
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\figa_4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER mP-5m
JOB NUMBER 722450.28 INSTALLATION DATE MAY 13, 1995 LOCATION FT-08
DATUM ELEVATION 241.58 GROUND SURFACE ELEVATION 241.58
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.375" Screen mesh SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 0.375" Teflon Lined HDPE BOREHOLE DIAMETER 1"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 18.5'
TOTAL DEPTH OF MONITORING POINT: 19'
LENGTH OF SCREEN: 0.5'
SCREEN SLOT SIZE: 0.010"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 19' FEET BELOW DATUM.

APPENDIX A

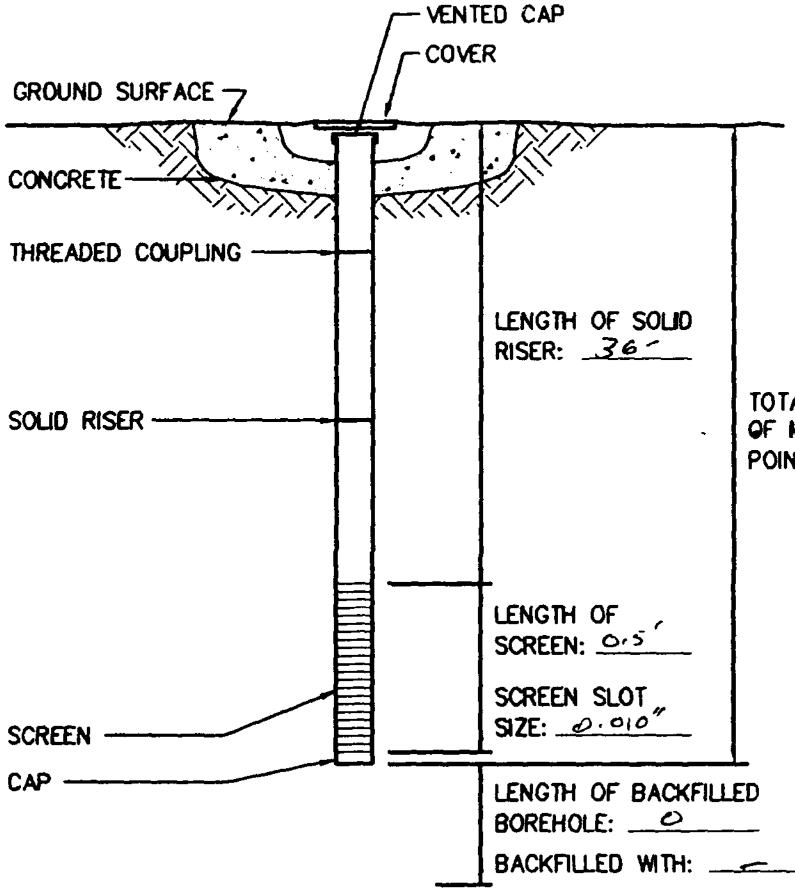
MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

I:\FIGURES\figo_4_5 on 5/1/95 @ 6:45

MONITORING POINT INSTALLATION RECORD

JOB NAME WESTOVER ARB MONITORING POINT NUMBER MP-16 D
JOB NUMBER 722450.28 INSTALLATION DATE MAY 13, 1995 LOCATION FT-08
DATUM ELEVATION 243.22 GROUND SURFACE ELEVATION 243.22
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 0.375" WIRE MESH SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 0.375" TEFLON LINED HDPE BOREHOLE DIAMETER 1"
GEOPROBE CONTRACTOR PARSONS ES ES REPRESENTATIVE MJV



LENGTH OF SOLID RISER: 36'
TOTAL DEPTH OF MONITORING POINT: 36.5'
LENGTH OF SCREEN: 0.5'
SCREEN SLOT SIZE: 0.010"
LENGTH OF BACKFILLED BOREHOLE: 0
BACKFILLED WITH: -

(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 36.5' FEET BELOW DATUM.

APPENDIX A

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation TS
Westover ARB, Massachusetts

APPENDIX A-2

GEOLOGIC BORING LOGS

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-15 ID	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 10, 1995
CLIENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 15, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.96
LOCATION:	WESTOVER ARB	BORING DIA.:	2" & 1"	TEMP:	60° F
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Rainy
COMENTS:					

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Top soil, Brown, Some roots & other organics								
				Blk carbon rich layer - Peat?								
			Sm	Fine to medium sand TAN, moist at Bottom							ND	
▼	5											
			SP	water @ 6' Medium to Course, poorly Sorted sand; gravel to 0.5"								
	10											
				medium grained, some iron Staining								
	15			SAS								
	20											
			Sm	Fine Sand, Brown, well Sorted w/ silt								
	25			same								
				Same								
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 2

BORING NO.:	MP-15, 1D (cont)	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 10, 1995
IENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 10, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.96
LOCATION:	WESTOVER ARB	BORING DIA.:	1"	TEMP:	60°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Rainy
COMENTS:					

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
	[illegible]		SM	Fine SAND, Brown, well Sorted w/ silt								
	40		SP	Course SAND, Tan Brown, Poorly Sorted, gravel <.5"		X						
				Bottom @ 41' bgs								
	45											

NOTES
- bgs – Below Ground Surface
- GS – Ground Surface
- TOC – Top of Casing
- NS – Not Sampled
- SAA – Same As Above

SAMPLE TYPE
- D – DRIVE
- C – CORE
- G – GRAB
- ▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-25	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 10, 1995
IENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 10, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.75
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	60°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	RAIN
COMENTS:					

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Top Soil, Brown, Fine to Course Sand								
				BIK carbon Peat - 16 - 22"								
			SM	Sand, Fine to medium, some Silt, well sorted								
	5											
▼			SP	Medium to Course tan Sand, poorly sorted gravel ≤ 0.25"								
	10			BOTTOM @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	mP-35	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 10, 1995
IENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 10, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.42
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	60°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Cloudy
COMENTS:					

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Fine to Course grained, Brown Blk Topsoil w/ roots		☒						
	5		SM	well sorted Fine grained medium Sand w/ silt		☒						
▼			SP	Medium to Coarse Sand, TAN poorly sorted, gravel / <0.5"		☒					ND	
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-4S	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 10, 1995
LIENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 10, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.92
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	55°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Cloudy

COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Black Fine-coarse grained Sand Top soil ; Some organics		☒					3.15	
	5		Sm	Fine grained SAND, Brown Some Silt, well sorted, Strong fuel smell		☒			134		6456	
▼			SP	Medium-Coarse SAND, Gray, Strong fuel odor		☒ ☒			134 389			
	10			BOTTOM @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB
▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-55, 5m	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 11, 1995
ENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 11, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	241.58
LOCATION:	WESTOVER ARB	BORING DIA.:	2" / 1"	TEMP:	55°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Cloudy
COMENTS:					

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	ILV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
				Black Top Soil		☒						
	1–5		Sm	Fine grained, Brown, Sand w/ silt		☒						
▼	5–10		SP	Medium to Coarse grained Sand, poorly Sorted, Tan gravel < 0.5"		☒						
	15											
	20			→ Approximate boundary w/ Coarse Sand and Silt, Geoprobe resistance significantly decreased - no Recovery Bottom @ 19'		no Recovery						
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

?ORING NO.:	MP-65	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 11, 1995
IENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 11, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.09
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	55°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Cloudy
COMENTS:					

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Black Fine to Coarse Top Soil		☒						
	5		SM	Fine brown Sand w/ Silt		☒						
	10		SP	Medium to Corse grained Sand w/ gravel ≤ 0.5"		☒						
				Bottom @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-7S	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY //, 1995
ENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY //, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	242.92
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	55°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Rainy
COMENTS:					

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
				Black Top Soil								
	1		sm	Fine grained, Brown Sand w/ silt								
	5											
			SP	medium to Coarse Sand w/ gravel ≤ 0.75", TAN								
	10			Bottom @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB
▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-8M	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 11, 1995
IENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 11, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	242.10
LOCATION:	WESTOVER ARB	BORING DIA.:	2" Ø 1"	TEMP:	70°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Rainy
COMENTS:					

Elev (ft)	Depth (ft)	Profile	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
	1			Black, Fine to Course Top Soil		☒						
			SM	Fine, Brown Sand, Some Silt		☒						
	5			Black F. grained peat layer		☒						
			SP	Medium to Coarse Sand, poorly sorted w/ gravel ≤ 0.5"		☒						
	10											
	15											
			SM	Approximate Contact with Silty Sand, no Recovery Resistance decreased		no recovery						
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	mp. 95	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 11, 1995
[illegible]ENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 11, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.85
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	55°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Rainy
COMENTS:					

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
				Black Top Soil								
	1		SM	Brown, Fine Sand, w/ Silt								
	5											
			SP	Medium to Course Sand, GRAY, gravel < 0.5"								
	10			Bottom @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	MP-10S	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 11, 1995
IENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 11, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.44
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	55°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Rainy

COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample		Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
					No.	Depth (ft)						
	1			Black, organic Top Soil								
			SM	Fine Brown Sand w/ silt								
	5		SP	Medium to Course Sand, Tan with gravel < 0.5"								
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: mP-11 S
IENT: AFCEE
JOB NO.: 722450.28
LOCATION: WESTOVER ARB
GEOLOGIST: MJV
COMENTS:

CONTRACTOR: PARSONS ES
RIG TYPE: GEOPROBE
DRLG METHOD: GEOPROBE
BORING DIA.: 2"
DRLG FLUID: NONE

DATE SPUD: MAY 11, 1995
DATE CMPL.: MAY 11, 1995
ELEVATION: 242.97
TEMP: 55°
WEATHER: Rainy

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample		Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
					No.	Depth (ft)						
				Black Top Soil w/ organics								
	1			Fine Brown Sand with silt. MODERATE SOLVENT SMELL							0.8	
											ND	
	5			Medium to Course Sand, tan, gravel ≤ 0.5" moderate odor								
	10			Bottom @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB
▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: MP-12S
CONTRACTOR: PARSONS ES
DATE SPUD: MAY 12, 1995
LIENT: AFCEE
RIG TYPE: GEOPROBE
DATE CMPL.: MAY 12, 1995
JOB NO.: 722450.28
DRLG METHOD: GEOPROBE
ELEVATION: 243.34
LOCATION: WESTOVER ARB
BORING DIA.: 2"
TEMP: 65
GEOLOGIST: MJV
DRLG FLUID: NONE
WEATHER: Cloudy
COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
				Black Top Sac								
	1		SM	Find Brown Sand w| silt					731		24.9	
				Black peat layee, Strong odr								
	5		SM	Fine Brown silty Sand strong Solvent odor					597		176.1	
			SP	Medium to Course Sand, TAN WITH GRAVEL ≤0.5" Strong odor					696			
									120			
	10			Bottom @ 10'								
	15											
	20											
	25											
	30											
	35											

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.:	mP 14 m	CONTRACTOR:	PARSONS ES	DATE SPUD:	MAY 12, 1995
ENT:	AFCEE	RIG TYPE:	GEOPROBE	DATE CMPL.:	MAY 12, 1995
JOB NO.:	722450.28	DRLG METHOD:	GEOPROBE	ELEVATION:	243.36
LOCATION:	WESTOVER ARB	BORING DIA.:	2"	TEMP:	65°
GEOLOGIST:	MJV	DRLG FLUID:	NONE	WEATHER:	Cloudy

COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Black Top soil								
			SM	Fine Brown Sand, Some Silt, no odor							BLQ BLQ	
	5		SP	Coarse to Medium Sand, TAN, gravel ≤ 0.5" no odor								
	10											
	15						no Recovery					
	20			BOTTOM @ 20 PROBABLY Silty layer- no recovery, Decrease in geoprobe resistance								
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB
▼ Water level drilled

APPENDIX A
GEOLOGIC BORING LOG

Intrinsic Remediation TS
Westover ARB, Massachusetts

APPENDIX A-3

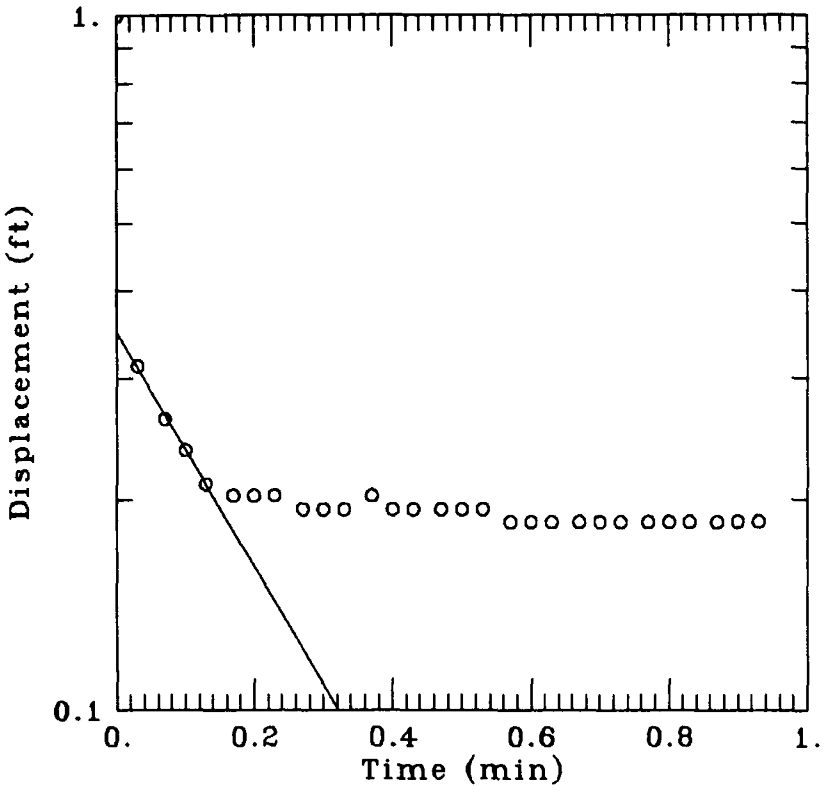
AQUIFER SLUG TEST RESULTS

Aquifer Slug Test Data Sheet

Location Westover ARB
Client AFCEE
Well No. CF 1A
Job No. 722450.28020
Field Scientist DM/MV
Date 5/19/95
Water Level 10.18
Total Well Depth 90.5'
Measuring Datum Toc
Elevation of Datum Toc
Weather Cloudy
Temp 60°
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
16^{00}	16^{04}	13.143	13.229	Fall	CF1AF1	
16^{05}	16^{08}	13.231	13.028	rise	CF1AR1	
16^{09}	16^{12}	13.045	13.214	Fall	CF1AF2	
16^{13}	16^{15}	13.197	12.995	rise	CF1AR2	

FT-08, WELL CF-01A(Falling Head Test-1)



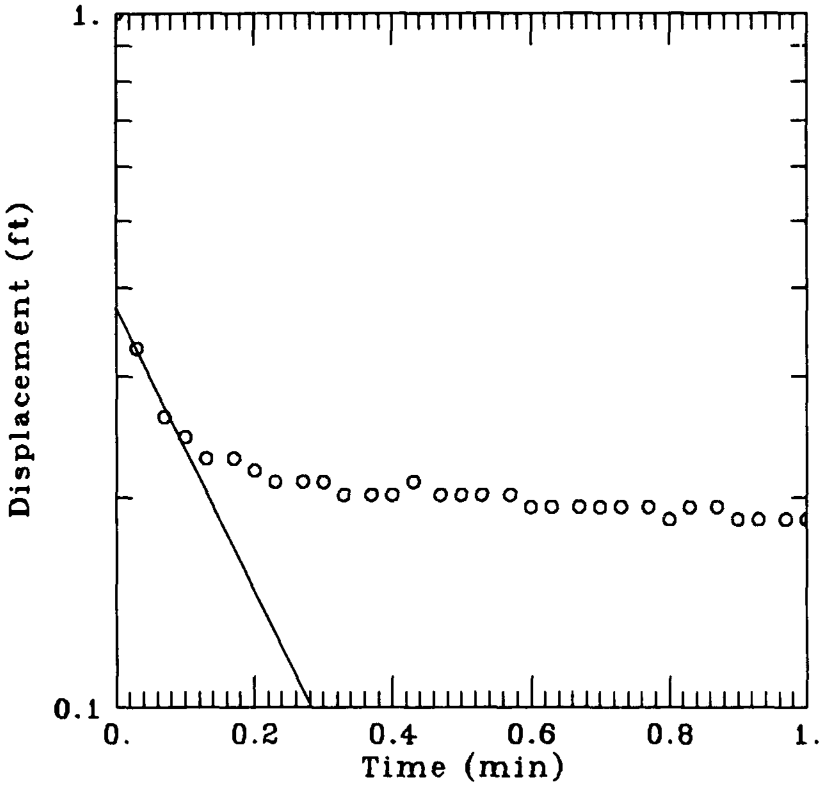
DATA SET:
cf1af1
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002539 ft/min
y0 = 0.3483 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.65 ft
H = 13.65 ft

FT-08, WELL CF-1A (Falling Head Test-2)



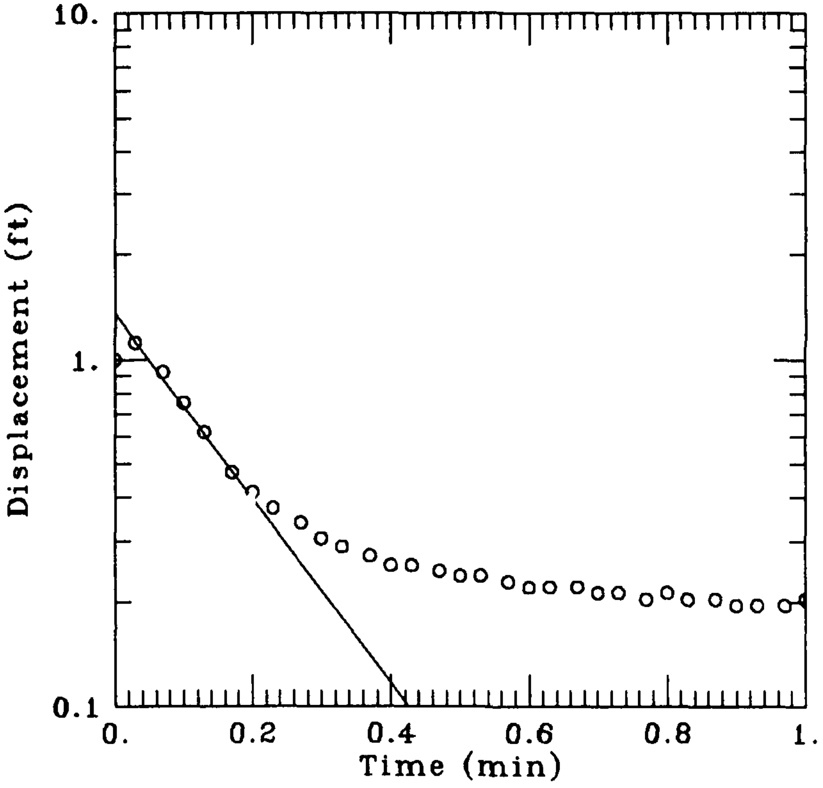
DATA SET:
cf1af2.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.00307 ft/min
y0 = 0.3751 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.65 ft
H = 13.65 ft

FT-08, WELL CF-01A(Rising Head Test-1)



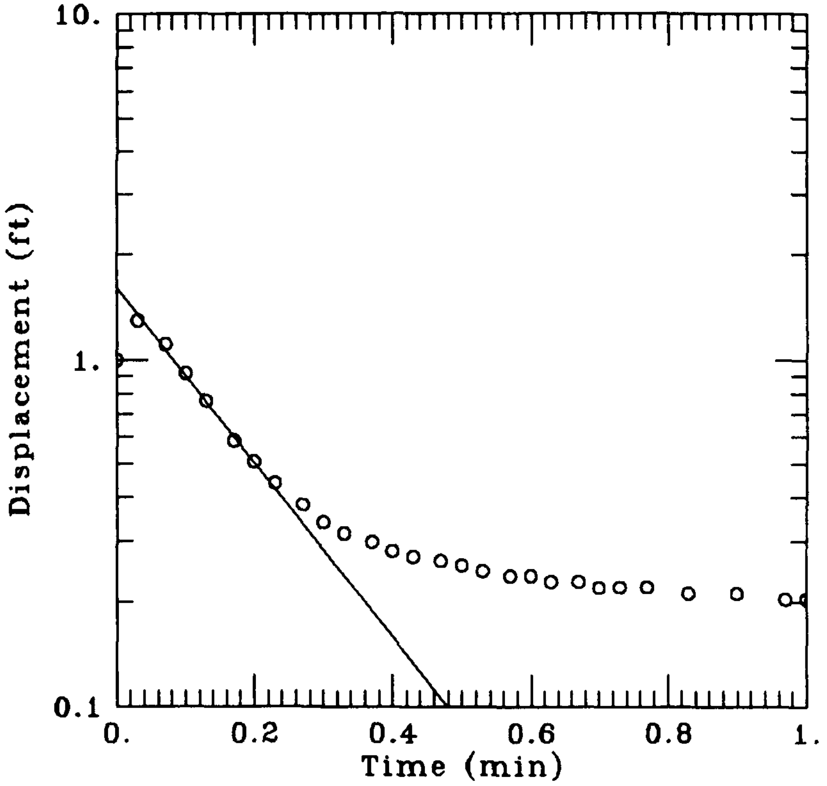
DATA SET:
cf1ar1.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.00402 ft/min
y0 = 1.349 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.65 ft
H = 13.65 ft

FT-08, WELL CF-01A (Rising Head Test-2)



DATA SET:
cf1ar2
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.00381 ft/min
y0 = 1.608 ft

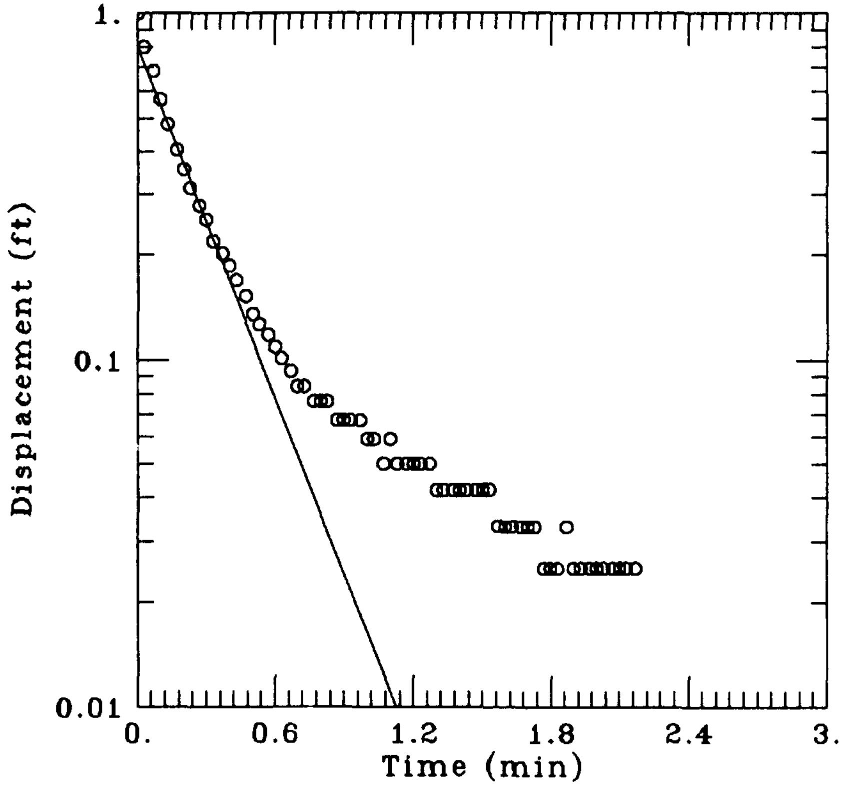
TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.65 ft
H = 13.65 ft

Aquifer Slug Test Data Sheet

Location Westover ARB
Client AFCEE
Well No. CF-4
Job No. 722450.28020
Field Scientist DM/MV
Date 5/19/95
Water Level 6.24
Total Well Depth 22.36
Measuring Datum TOC
Elevation of Datum
Weather Cloudy
Temp 55°
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
1737	1739	12.572	12.589	Fall	CF4F1	
1740	1742	12.581	12.521	Rise	CF4R1	
1743	1745	12.538	12.589	Fall	CF4F2	
1746	1748	12.581	12.521	Rise	CF4R2	

FT-08, WELL CF-4 (Falling Head Test-1)



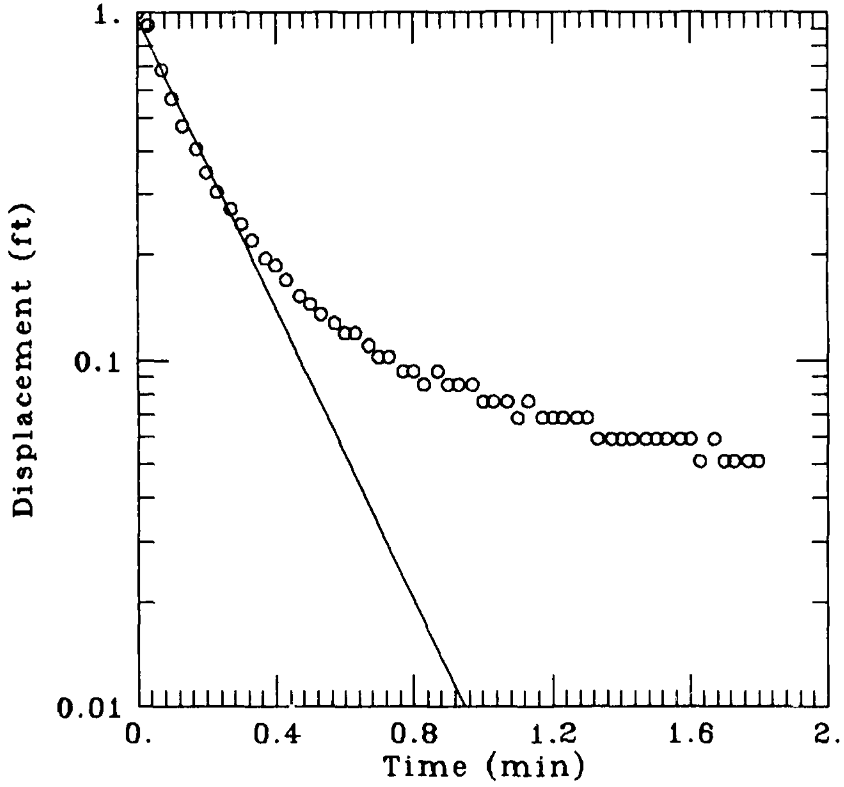
DATA SET:
cf4f1.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002642 ft/min
y0 = 0.7996 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 16.12 ft
H = 16.12 ft

FT-08, WELL CF-4 (Falling Head Test-2)



DATA SET:
cf4f2.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.003285 ft/min
y0 = 0.9597 ft

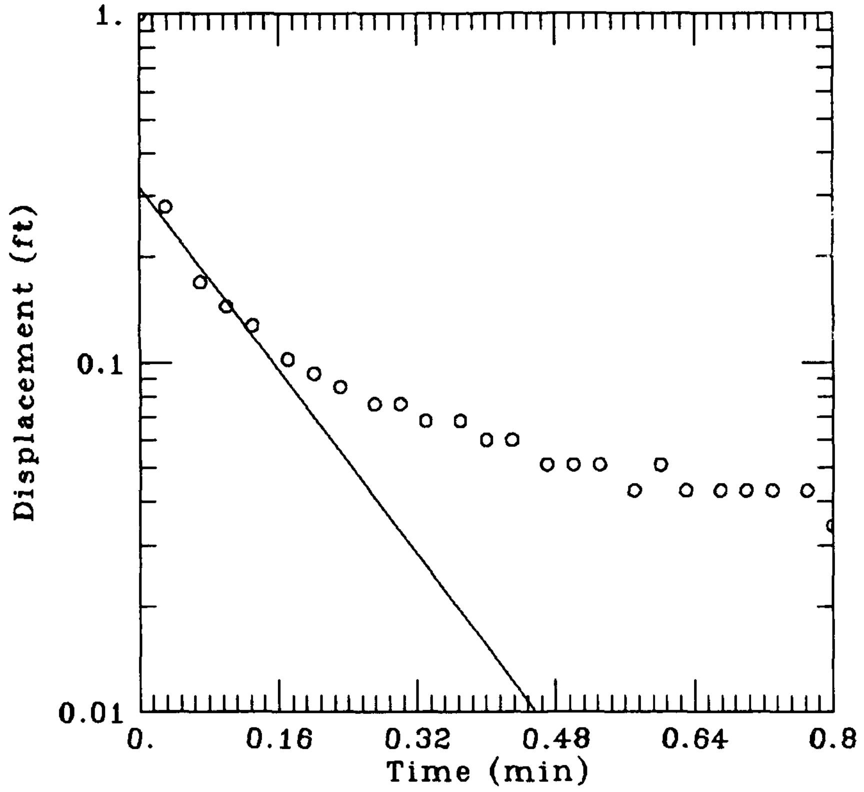
TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 16.12 ft
H = 16.12 ft

Aquifer Slug Test Data Sheet

Location Westover ARB
Client AFCEE
Well No. CF-5
Job No. 722450.28020
Field Scientist DM/MV
Date 5/19/95
Water Level 8.76
Total Well Depth 22.62
Measuring Datum TOC
Elevation of Datum
Weather Cloudy cool
Temp 60°
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
16^{27}	16^{29}	11.026	11.060	FALL	CF5 F1	
16^{30}	16^{31}	11.043	11.043	Rise	CF5 R1	
16^{32}	16^{34}	11.068	11.119	FALL	CF5 F2	
16^{35}	16^{36}	11.110	11.102	Rise	CF5 R2	

FT-08, WELL CF-5 (Falling Head Test-1)



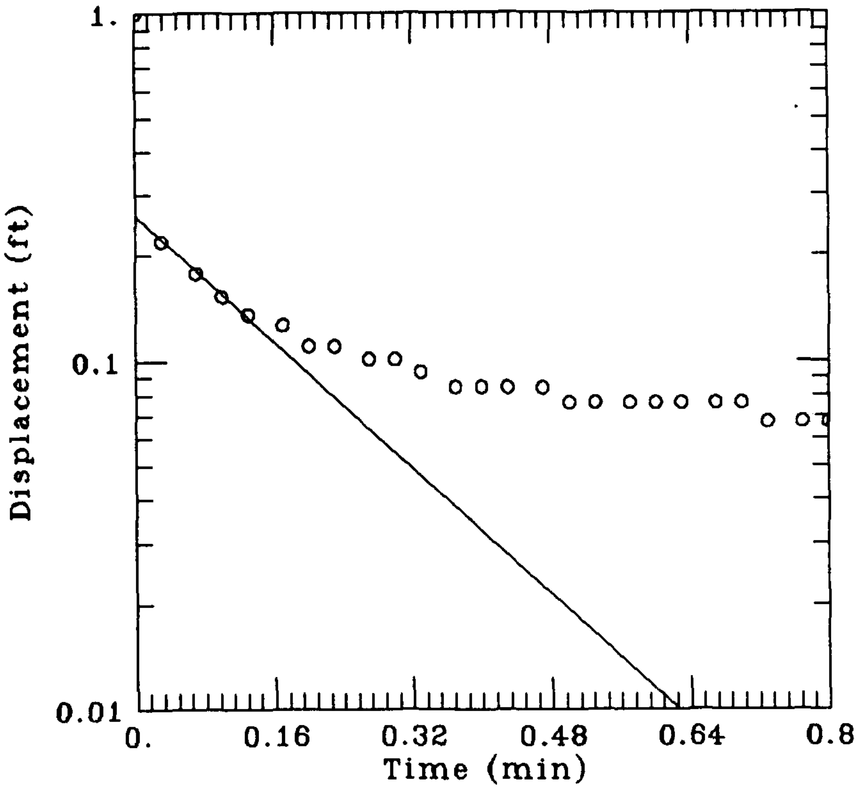
DATA SET:
cf5f1
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.004971 ft/min
y0 = 0.317 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.86 ft
H = 13.86 ft

FT-08, WELL CF-5 (Falling Head Test-2)



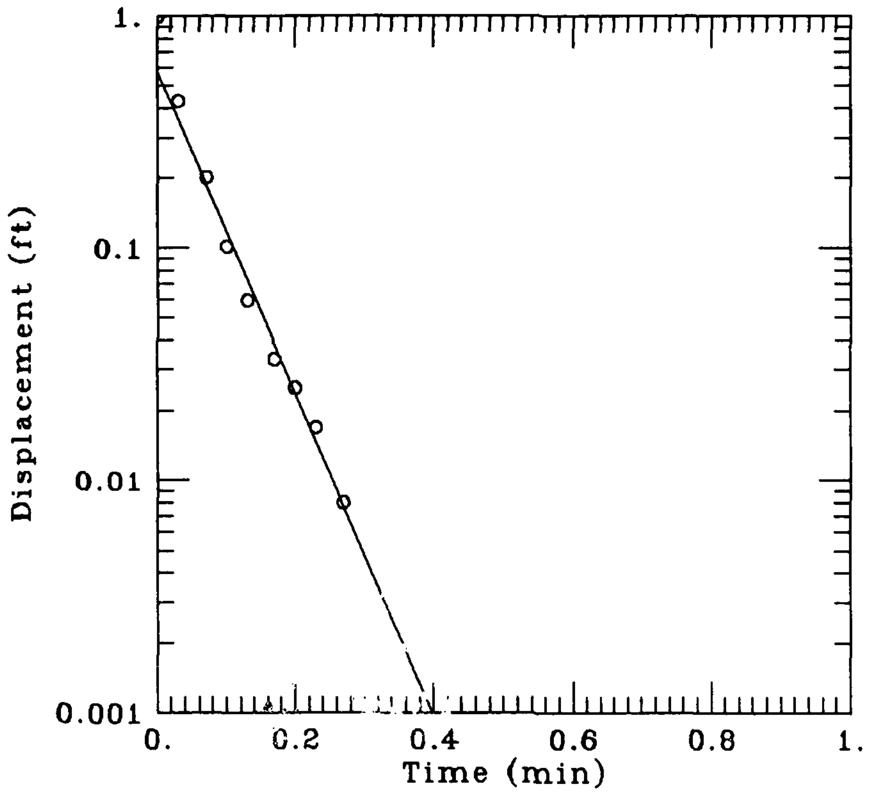
DATA SET:
cf5f2
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.00343 ft/min
y0 = 0.2605 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.86 ft
H = 13.86 ft

FT-08, WELL CF-5 (Rising Head Test-1)



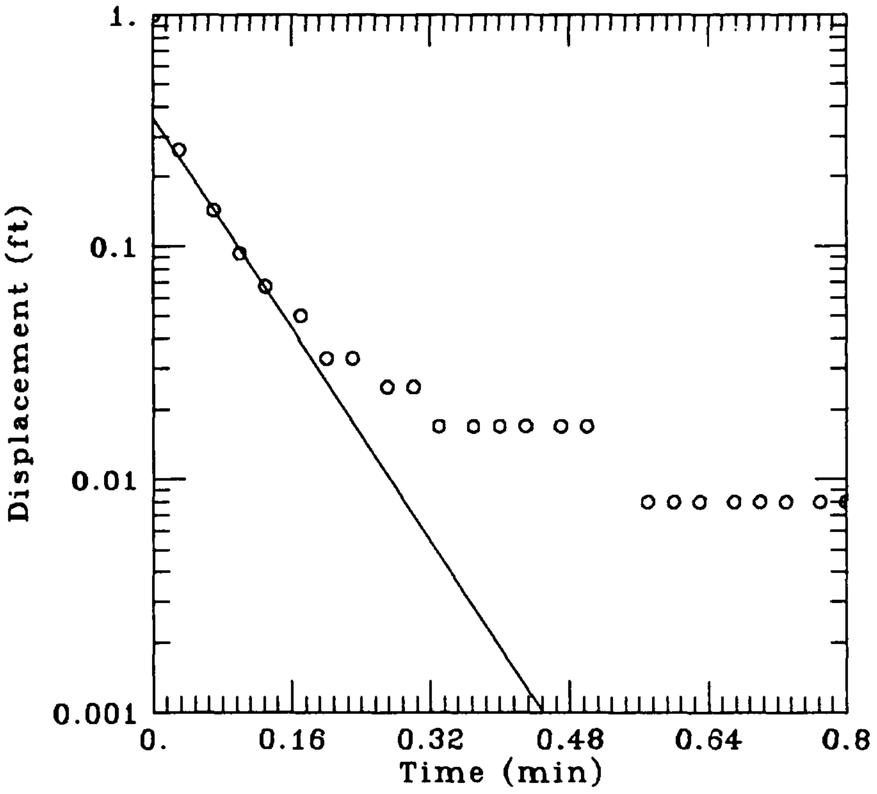
DATA SET:
cf5r1.dat
05/23/95

AQUIFER
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.01052 ft/min
y0 = 0.5783 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.86 ft
H = 13.86 ft

FT-08, WELL CF-5 (Rising Head Test-2)



DATA SET:
cf5r2.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.008636 ft/min
y0 = 0.3615 ft

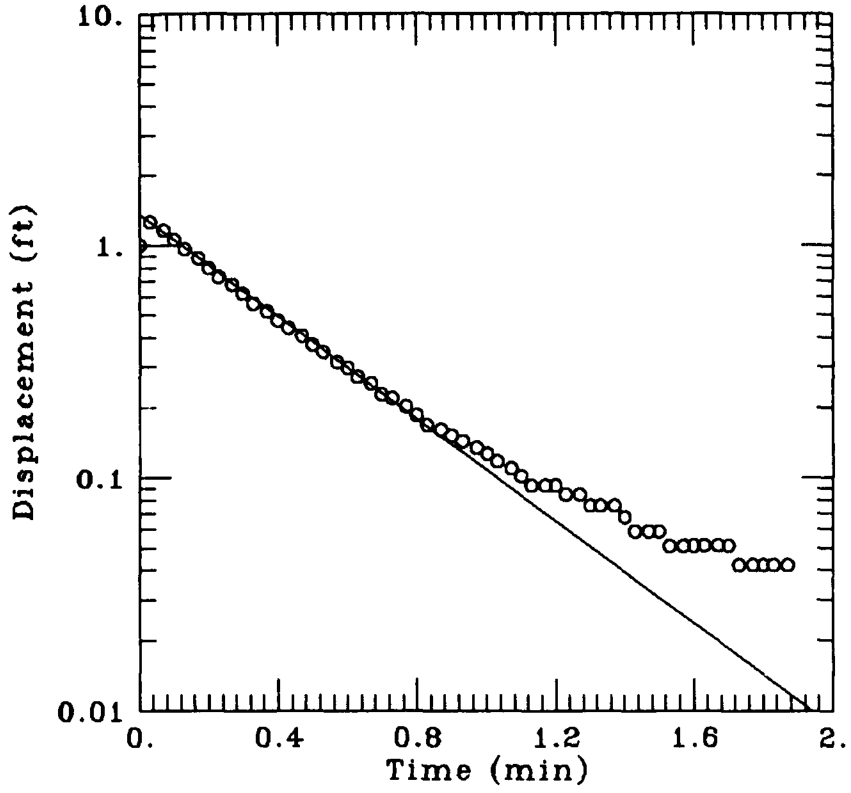
TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.86 ft
H = 13.86 ft

Aquifer Slug Test Data Sheet

Location Westover ARB
Client AFCEE
Well No. CF-6 SL-t
Job No. 722450.28020
Field Scientist DM/MV
Date 5/19/95
Water Level 6.60
Total Well Depth 87.34
Measuring Datum TVC
Elevation of Datum
Weather Cloudy 60's
Temp 60°
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
1644	1646	13.406	13.451	F	CF6F1	
1648	1650	13.434	13.425	R	CF6R1	
1651	1653	13.442	13.468	F	CF6F2	
1655	1658	13.459	13.442	R	CF6R2	

FT-08, WELL CF-6 (Falling Head Test-1)



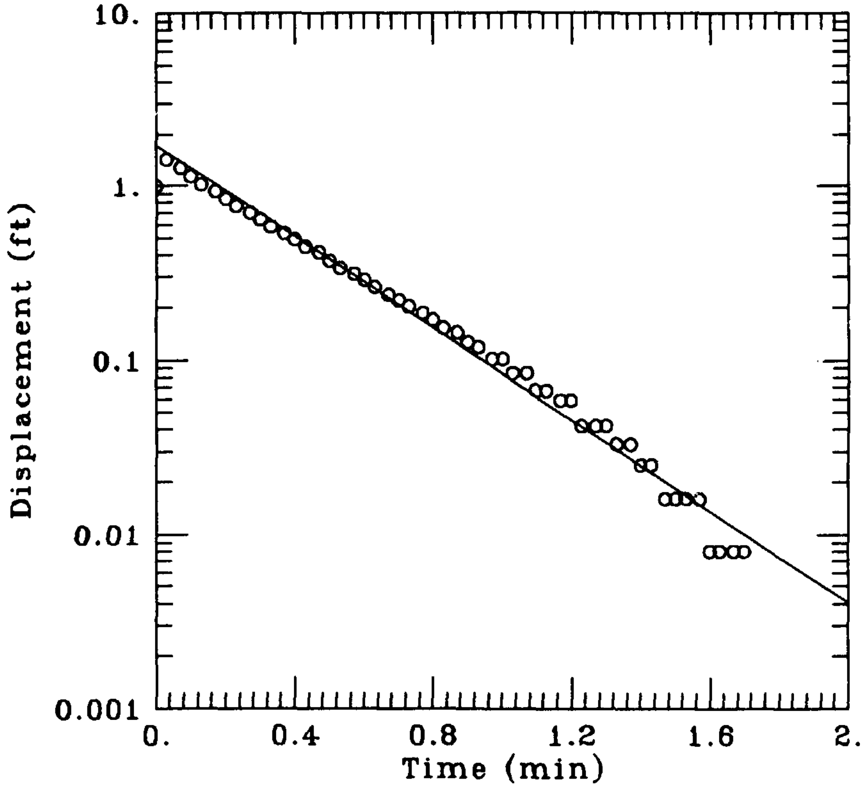
DATA SET:
cf5f1.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002282 ft/min
y0 = 1.358 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 80.74 ft
H = 80.74 ft

FT-08, WELL CF-6 (Falling Head Test-2)



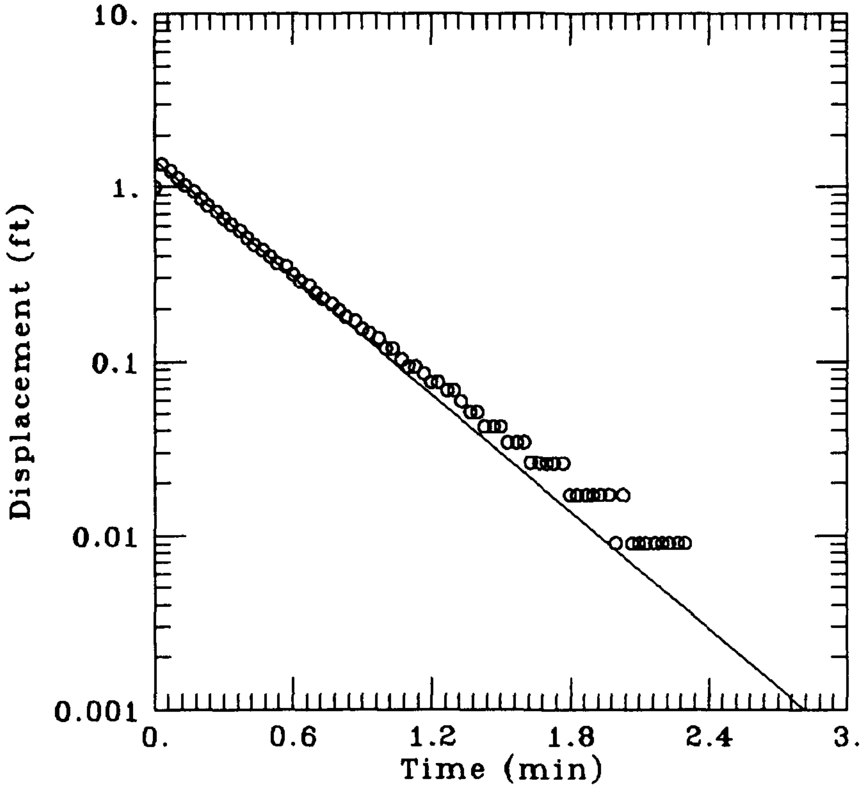
DATA SET:
cf6r1.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002731 ft/min
y0 = 1.719 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 80.74 ft
H = 80.74 ft

FT-08, WELL CF-6 (Rising Head Test-2)



DATA SET:
cf6r2.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002328 ft/min
y0 = 1.431 ft

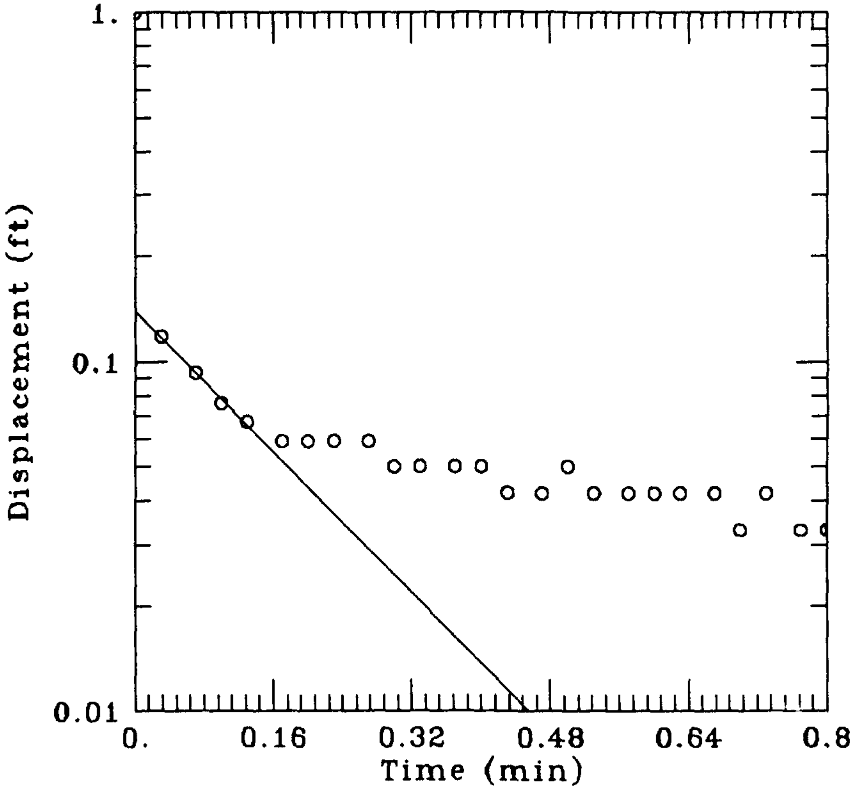
TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 80.74 ft
H = 80.74 ft

Aquifer Slug Test Data Sheet

Location Westover ARB
Client AFCEE
Well No. CF-6A Tall
Job No. 722450.28020
Field Scientist DM/MV
Date 5/19/95
Water Level 7.56
Total Well Depth 22.52
Measuring Datum TOC
Elevation of Datum
Weather Rain/Cloudy
Temp 60°
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
17^{01}	17^{02}	11.905	11.947	Fall	CF6AF1	
17^{04}	17^{05}	11.930	11.913	R	CF6AR1	
17^{06}	17^{07}	11.922	11.951	F	CF6AF2	
17^{08}	17^{09}	11.964	11.938	R	CF6AR2	

FT-08, WELL CF-6A (Falling Head Test-1)



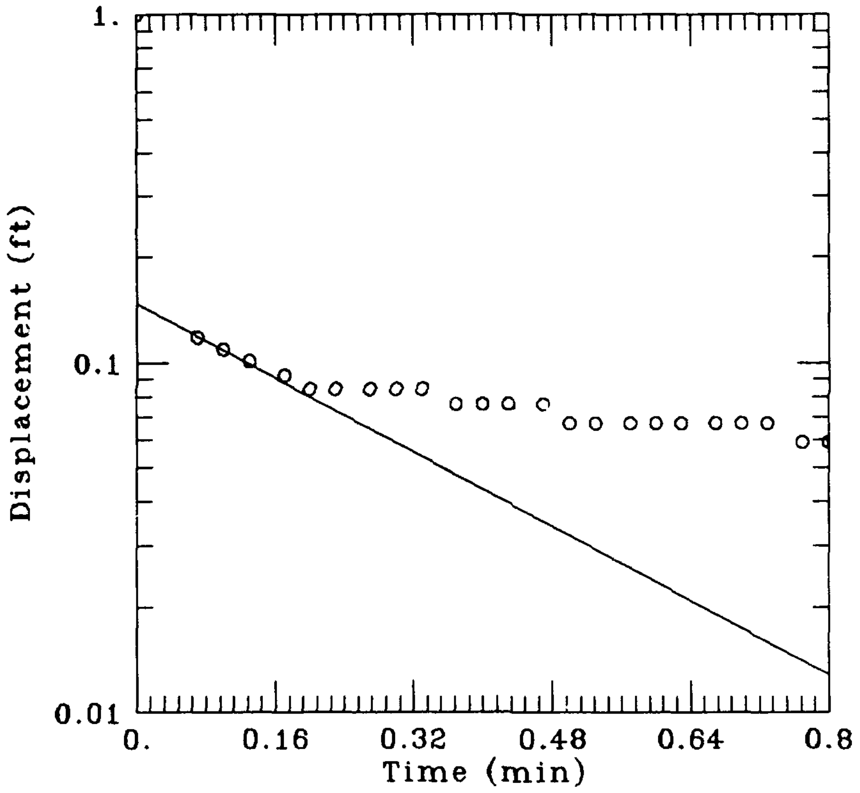
DATA SET:
cf6af1.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.003881 ft/min
y0 = 0.1393 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 14.96 ft
H = 14.96 ft

FT-08, WELL CF-6A (Falling Head Test-2)



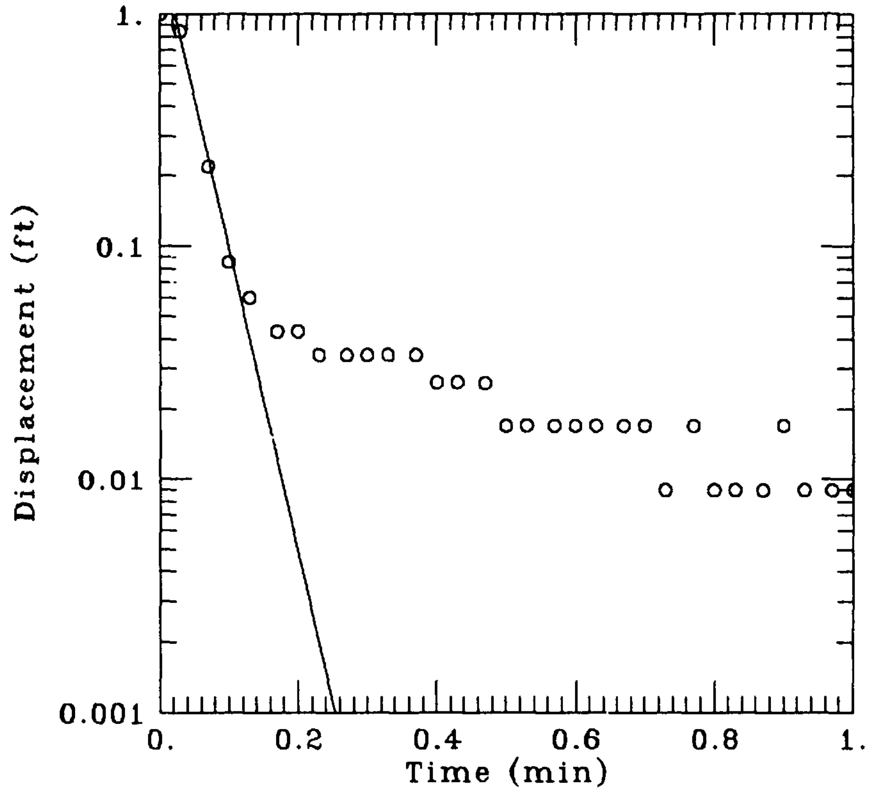
DATA SET:
cf6af2.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.002043 ft/min
y0 = 0.1463 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 14.96 ft
H = 14.96 ft

FT-08, WELL CF-6A (Rising Head Test-1)



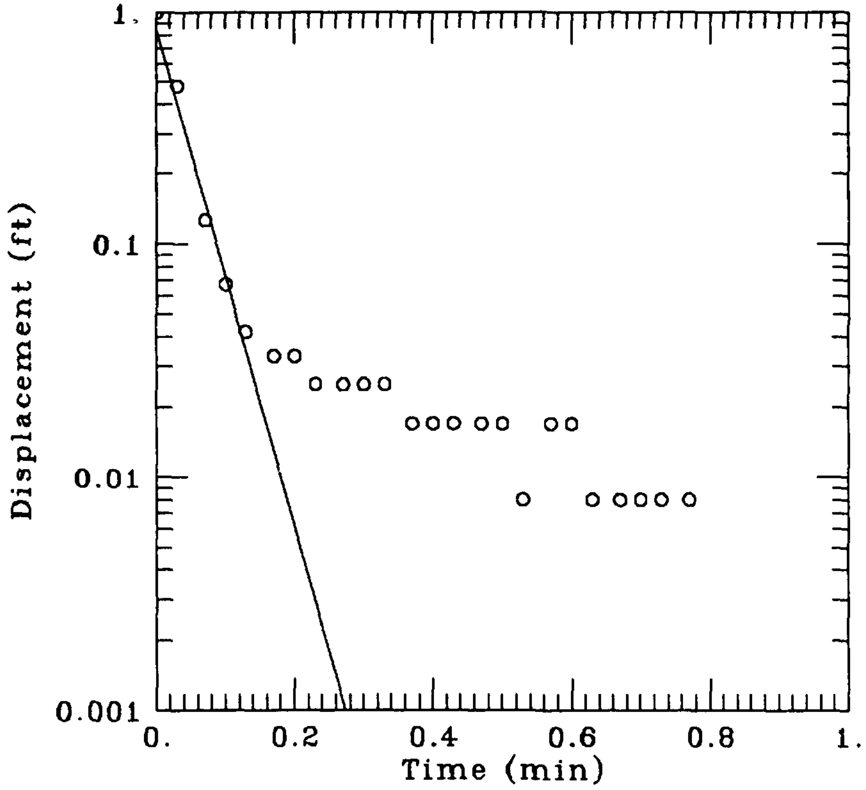
DATA SET:
cf6ar1.dat
05/24/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.01998 ft/min
y0 = 1.942 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 14.96 ft
H = 14.96 ft

FT-08, WELL CF-6A (Rising Head Test-2)



DATA SET:
cf6ar2.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.01646 ft/min
y0 = 0.8538 ft

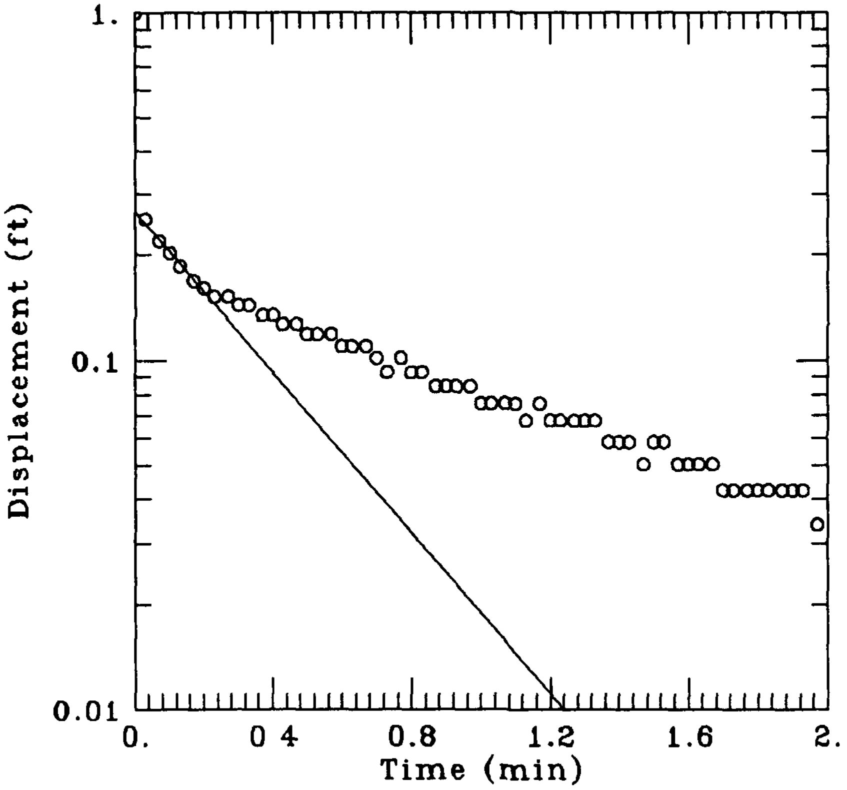
TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 14.96 ft
H = 14.96 ft

Aquifer Slug Test Data Sheet

Location Westover ARB
Client AFCEE
Well No. CF-8
Job No. 722450.28020
Field Scientist DM/MV
Date 5/19/95
Water Level 8.46
Total Well Depth 22.33
Measuring Datum Toc
Elevation of Datum
Weather Cloudy / Rainy
Temp 60
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
		~~[illegible]~~		~~Fall~~		
				~~Rise~~		
				~~Fall~~		
				~~Rise~~		
			10.004			
17^{16}	17^{18}	9.9617	~~[illegible]~~	FALL	CF8-F1	
~~17^{19}~~		~~9.96[illegible]~~				
17^{23}	17^{25}	9.97[illegible]	9.9533	Rise	CF8R1	
17^{26}	17^{28}	9.9617	10.012	Fall	CF8F2	
17^{30}	17^{32}	10.004	9.9617	Rise	CF8R2	

FT-08, WELL CF-8 (Falling Head Test-1)



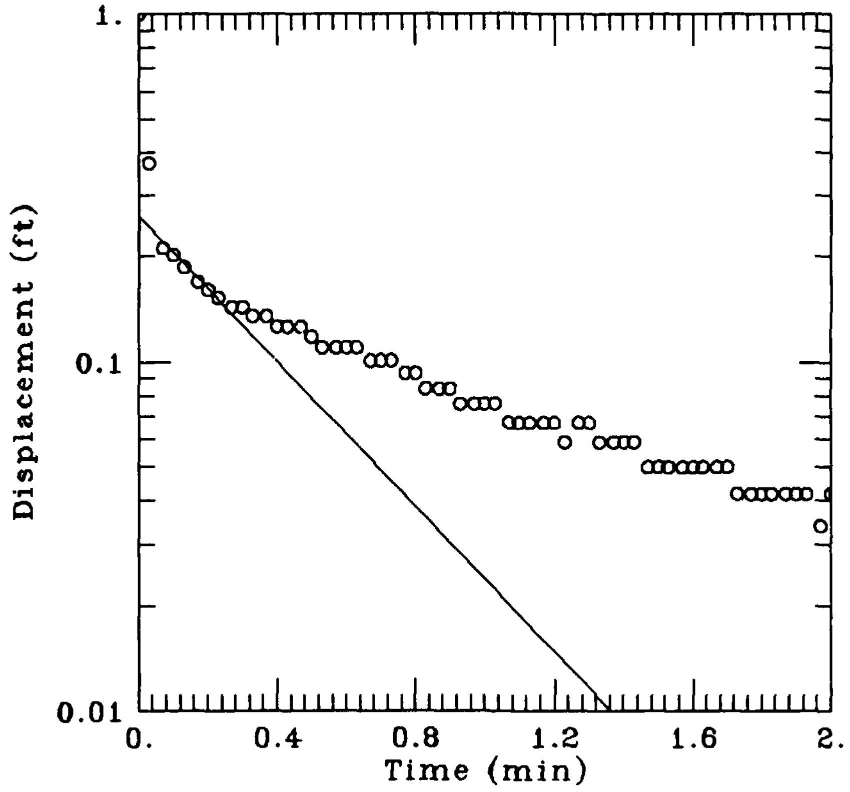
DATA SET:
cf8f1.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.001743 ft/min
y0 = 0.2675 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15 ft
b = 13.87 ft
H = 13.87 ft

FT-08, WELL CF-8 (Falling Head Test-2)



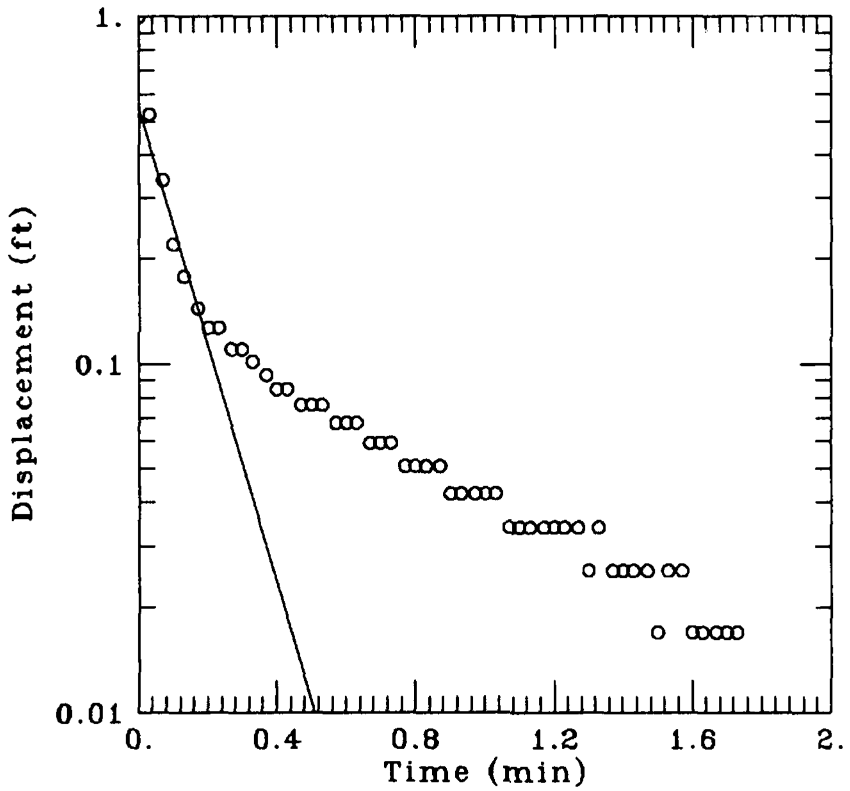
DATA SET:
cf8f2.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.001573 ft/min
y0 = 0.2594 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.87 ft
H = 13.87 ft

FT-08, WELL CF-8 (Rising Head Test-1)



DATA SET:
cf8r1.dat
05/23/95

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.005162 ft/min
y0 = 0.5431 ft

TEST DATA:
H0 = 1. ft
rc = 0.083 ft
rw = 0.33 ft
L = 15. ft
b = 13.87 ft
H = 13.87 ft

APPENDIX B
SOIL AND GROUNDWATER RESULTS

MANAGEMENT
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

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 Field Dup	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	6.4	6.0	^ ^ ^	ND	ND	2.6
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	2.1	1.8	^ ^ ^	ND	ND	1.3
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	732	676	692	ND	7.6	2.5
TRICHLOROETHENE	ND	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 Field Dup	WETF-1A	WETF-1	WETF-2A	WETF-2	WETF-3	WETF-4	WETF-5
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	ND	ND	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	---

	WETF-7	WETF-8	WETF-11	WETF-11 Lab Dup	WETF-12	WETF-13	WETF-14	WETF-14 Field Dup	WETF-15	WETF-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	ND	1.1	1.6	1.5	---	ND
TRICHLOROETHENE	---	1.8	ND	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 Field Dup 1/2 Dil	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 Lab Dup	WEMP-14D	WEMP-14M	WEMP-14M Lab Dup
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	2.2	ND	ND
.1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	2.7	---	---
2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	3.0	---	---
DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	158	86.7	86.3
OETHENE	ND	ND	ND	ND	ND	4.1	4.1	541	25.8	25.9
OETHENE	ND	ND	ND	ND	ND	ND	ND	1.4	ND	ND

Table 2. Quantitation Report for S.R. # SF−1− from Westover AFB.

Concentration = ppb

Compound	WEMP−14M Field Dup	WEMP−15D	WEMP−15M	WEMP−15S	WEMP−16D	QC0605A 20 ppb	QC0605B 200 ppb	QC0605C 20 ppb	QC0605D 200 ppb	QC0605E 20 ppb
VINYL CHLORIDE	ND	ND	ND	ND	ND	20.5	191	20.7	191	19.2
1,1−DICHLOROETHENE	−−−	ND	ND	ND	ND	20.9	199	19.6	193	18.9
T−1,2−DICHLOROETHENE	−−−	ND	ND	ND	ND	19.1	184	19.2	186	18.8
C−1,2−DICHLOROETHENE	88.5	ND	ND	ND	ND	20.1	203	21.0	197	20.5
TRICHLOROETHENE	25.6	−−−	ND	ND	ND	21.3	186	21.4	183	20.3
TETRACHLOROETHENE	ND	ND	ND	ND	ND	22.8	198	20.6	201	19.2

	QC0605F 200 ppb	QC0605G 20 ppb	QC0605H 200 ppb	QC0605I 20 ppb	QC0605J 200 ppb	QC0608A 20 ppb	QC0608B 200 ppb	BL0605A	BL0605B
VINYL CHLORIDE	209	19.8	201	20.4	206	20.9	203	ND	ND
1,1−DICHLOROETHENE	208	19.7	195	21.0	201	20.9	199	ND	ND
T−1,2−DICHLOROETHENE	181	19.5	189	19.2	179	19.4	193	ND	ND
C−1,2−DICHLOROETHENE	196	20.4	207	19.9	207	19.6	201	ND	ND
TRICHLOROETHENE	190	20.4	178	21.8	186	20.9	186	ND	ND
TETRACHLOROETHENE	204	21.6	199	20.6	185	21.3	200	ND	ND

ND = None Detected −−− = Below Calibration Limit(1.0 ppb) QC = Quality Control Std. BL = Blank

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 H_2SO_4. For a water blank without Na_3PO_4 added, a pH of 2 is reached with ten drops. For 100 ml of water sample preserved with Na_3PO_4, 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.

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

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 $1.0\text{x}10^{-5}$ 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 banks, 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
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

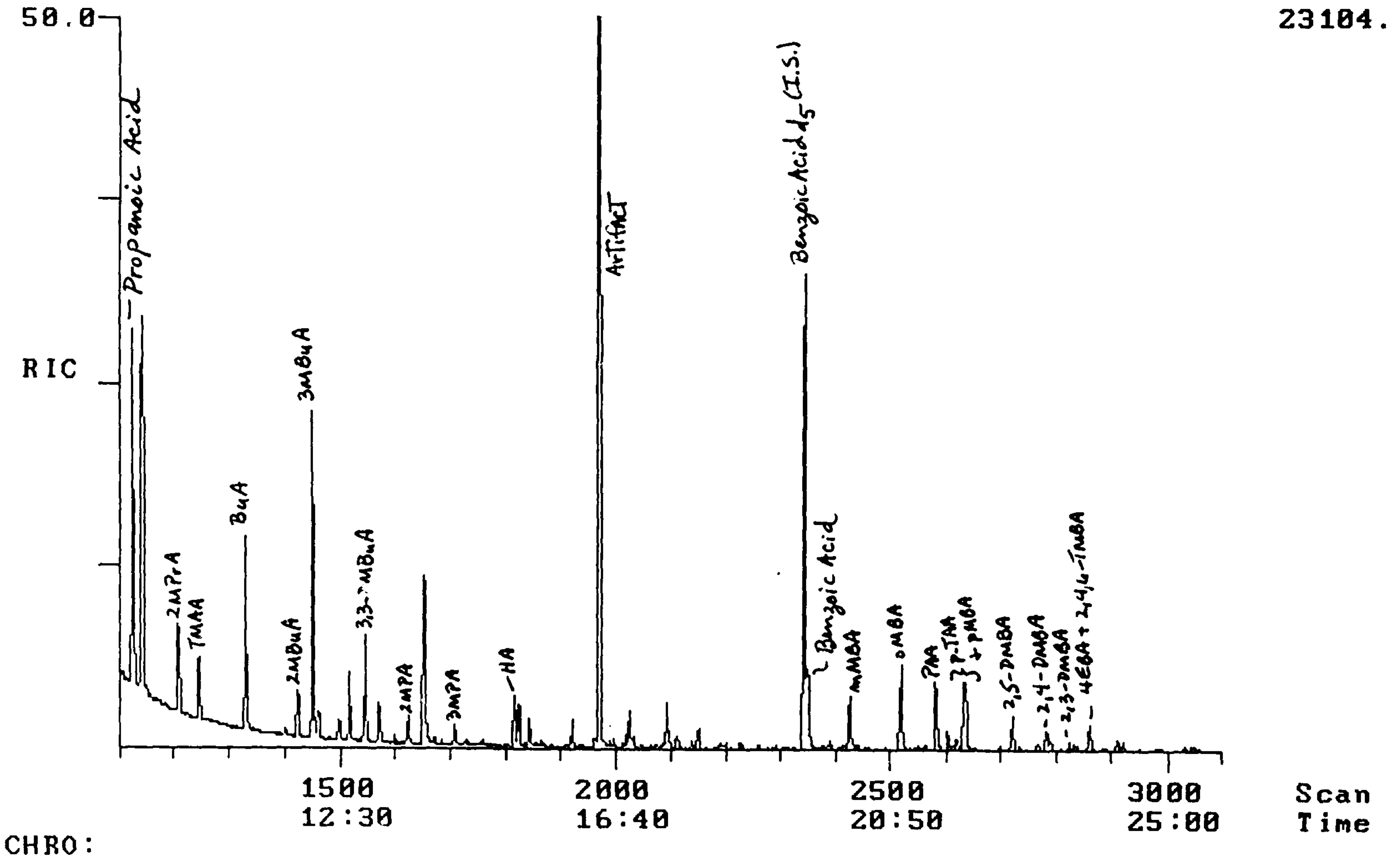
		WEMP-4S	WETF-2A	Extraction Blank	50 ppb Extr. Recovery	10 ppb Chk. Std.	50 ppb Chk. Std.	100 ppb Chk. Std.	500 ppb Chk Std.
1	PROPANOIC ACID - PFB	214	19	***	9	12	53	94	732
2	2-METHYLPROPANOIC ACID - PFB	57	***	***	23	10	52	91	653
3	TRIMETHYL ACETIC ACID - PFB	35	***	***	59	10	51	90	679
4	BUTYRIC ACID - 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	9	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	6	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 Data: 746WEMP4S #1967 Scans 1100 to 3100
06/07/95 0:12:00 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



MANAGEMENT
TECHNOLOGY

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
Lisa R. Black

xc: R.L.Cosby
G.B. Smith
J. L. Seeley

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

Printed 5/26/95 SF-1-133 DP-PT/GC-PID:FID Analyses for Dr. Kampbell Units = ng/mL Analyst: L. Black

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
0 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
[illegible]CF-6A	ND	ND	ND	ND	ND	ND	42.88
[illegible]ECF-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
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

Printed 5/26/95 SF-1-133 DP-PT/GC-PID:FID Analyses for Dr. Kampbell Units = ng/mL Analyst: L. Black

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE
PPB	102.58	101.76	102.01	101.32	102.15	103.44
, 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
CF-6A	25.30	ND	ND	ND	ND	ND
CF-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
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

MANAGEMENT
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 SV

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

Mark White

Cherri Heard

Cherri Heard

xc: R.L. Cosby
J.L. Seeley
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	mg/l Cl^-	mg/l SO_4^{-2}	mg/l $NO_2^- + NO_3^- (N)$	mg/l $NH_3 (N)$
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

Sample	mg/l Cl^-	mg/l SO_4^{-2}	mg/l $NO^-_2+NO^-_3(N)$	mg/l $NH_3(N)$
WEMP-14D Dup	149	.80	----	----
WEMP-14M	146	7.62	.09	5.84
WEMP-15D	9.77	2.28	<.05	.50
WEMP-15M	2.88	<.5	<.05	.29
WEMP-15S	3.21	20.0	.07	.44
WEMP-16D	2.25	3.06	<.05	.34
Blanks	<.5	<.5	<.05	<.05
	<.5	<.5	<.05	<.05
AQC	59.1	21.1	.75	6.24
	59.4	22.1	----	----
True Value	59.0	22.0	.86	6.30
Spike Rec.	100%	103%	101%	102%

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
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

TC, TOC, AND TIC RESULTS FOR DON KAMPBELL (SF-1-133)

SAMPLE	MG/L TC	MG/L TOC	MG/L TIC
WETF-1	23.1	16.6	6.5
WETF-1A	20.7	6.4	14.3
WETF-2	40.9	16.6	24.3
WETF-2A	96.0	26.0	70.0
WETF-3	42.8	7.2	35.6
WETF-4	37.8	8.7	29.1
WETF-5	39.9	6.1	33.8
WETF-7	47.5	4.2	43.3
WETF-8	70.3	6.2	64.1
WETF-11	114.7	15.5	99.2
WETF-11 DUP	114.3	15.4	98.9
WETF-12	39.6	6.8	32.8
WETF-13	54.3	6.5	47.8
WETF-14	90.6	9.7	80.9
WETF-15	45.6	5.5	40.1
WETF-16	20.4	5.7	14.7
WECF-1	5.6	1.0	4.6
WECF-1A	2.3	1.2	1.1
WECF-2	4.7	0.8	3.9
WECF-2A	114.3	52.5	61.8
WECF-3	41.8	25.8	16.0
WECF-3 DUP	41.2	25.0	16.2
WECF-4	7.0	5.6	1.4
WECF-5	11.0	3.9	7.1
WECF-6	8.8	1.1	7.7
WECF-6A	16.4	4.1	12.3
WECF-8	10.2	1.7	8.5
WEMP-1D	7.1	1.0	6.1
WEMP-1S	3.3	1.8	1.5
WEMP-2S	12.0	3.8	8.2
WEMP-3S	6.2	2.7	3.5
WEMP-4S	77.1	60.2	16.9
WEMP-5D	22.5	4.3	18.2
WEMP-5D DUP	21.8	4.4	17.4
WEMP5S	16.0	3.0	13.0
WEMP-6S	11.2	4.5	6.7
WEMP-7S	3.1	2.4	0.7
WEMP-8S	10.7	1.3	9.4
WEMP-9S	8.2	3.1	5.1
WEMP-10S	5.7	3.4	2.3
WEMP-11S	65.8	24.0	41.8
WEMP-12S	85.7	67.8	17.9
WEMP-14D	115.0	94.4	20.6
WEMP-14M	108.1	53.3	54.8
WEMP-14M DUP	107.0	53.3	53.7
WEMP-15D	18.2	2.0	16.2

TRUE VALUES: WPO33-II = 35.0 MG/L

SAMPLE	MG/L TC	MG/L TOC	MG/L TIC
WEMP-15M	14.4	1.6	12.8
WEMP-15S	20.3	7.1	13.2
WEMP-16D	13.9	3.7	10.2
WEMP-8M	5.0	2.0	3.0
WPO33-II		35.1	
		35.1	
		35.1	
		35.7	
		34.9	
		35.0	
		35.2	
		35.0	
		35.3	
		35.2	
		35.4	
		35.0	
		35.4	
		35.4	
		35.9	

MANAGEMENT
TECHNOLOGY

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 (μS/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

RECEIVED
JUL 06 1995

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

Westover AFB 051795 filename=051795.wk1 range=A1.K55

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

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
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

SR# SF-1-133

ANALYSIS PERFORMED 6-20-95

SAMPLE	METHANE
LAB BLANK	BLQ
WECF-2A	0.305
WECF-3	0.008
WECF-4	BLQ
WECF-5	0.004
* FIELD DUP	0.004
10 PPM CH4	10.00
100 PPM CH4	104.59
1000 PPM CH4	1036.26
1% CH4	1.02 %
10% CH4	10.00 %

ANALYSIS PERFORMED 6-22-95

SAMPLE	METHANE
LAB BLANK	BLQ
WECF-6	0.068
WECF-6A	0.387
WECF-8	0.0004
WEMP-1D	BLQ
* FIELD DUP	BLQ
WEMP-1S	BLQ
WEMP-2S	BLQ
WEMP-3S	BLQ
WEMP-4S	0.073
WEMP-5D	0.362
* LAB DUP	0.342
WEMP-5S	0.187
WEMP-6S	BLQ
WEMP-7S	BLQ
WEMP-8M	BLQ
WEMP-8S	BLQ
* FIELD DUP	BLQ
WEMP-9S	BLQ
WEMP-10S	BLQ
WEMP-11S	0.139
WEMP-12S	0.031
WEMP-14D	4.286
* LAB DUP	4.398
10 PPM CH4	10.18
100 PPM CH4	107.49
1000 PPM CH4	1000.62
1% CH4	1.02 %
10% CH4	9.67 %
20% CH4	20.16 %

MANAGEMENT
TECHNOLOGY

Ref: 95-DK18/vg

June 12, 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:

This report contains the results of my GC/MSD analysis of core extracts from Westover AFB for quantitation of benzene, toluene, ethylbenzene, p-Xylene, m-Xylene, o-Xylene, 1,3,5-trimethylbenzene (1,3,5-TMB), 1,2,4-trimethylbenzene (1,2,4-TMB) and 1,2,3-trimethylbenzene (1,2,3-TMB) performed under Service Request #SF-1-133.

The analytical method was a modification of RSKSOP-124. Cool (38°C) on-column injection (0.5 µl) was used with electronic pressure control set for a constant flow of 0.9 ml/min. A 30M X 0.25 mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5 µm film) capillary GC column with 9 inch long X 0.53 mm ID uncoated capillary precolumn was used. Quantitation was based on low level (0.05-5.0 µg/ml) and high level (5.0-250 ug/ml) calibration curves of selected target ions (1 to 3 ions, total area) for each compound. Complete reports detailing the acquisition method and calibration curves have been recorded. The samples were extracted by Mark Blankenship on May 30, 1995 and analyzed June 2-3, 1995.

If I can be of further assistance, please feel free to contact me.

Sincerely,

David A. Kovacs

David A. Kovacs

xc: R.L. Cosby
J.L. Seeley
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

SF-1-133 Westover AFB D. Kampbell GC/MSD ... core extracts Units = mg/kg

Sample	Benzene	Toluene	Ethylbenzene	p-Xylene	m-Xylene	o-Xylene	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
WECF-1-8.5'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
WECF-5-2'	ND	ND	ND	ND	ND	ND	ND	ND	ND
WECF-5-3.5' *	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
WEMP-1-4'	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-3-8'	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-4-2'	9.44E-01	2.57E-01	3.82E-01	4.64E-01	6.75E-01	4.26E-01	1.83E-01	5.14E-01	2.78E-01
WEMP-4-4'	1.88E+01	1.87E+02	9.26E+01	6.82E+01	1.76E+02	1.03E+02	6.61E+01	1.71E+02	7.43E+01
WEMP-11-2'	1.99E-01	BLQ	9.76E-02	1.06E-01	2.66E-01	1.30E-01	5.44E-02	1.23E-01	9.61E-02
WEMP-11-4'	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-12-2'	2.45E-01	7.51E+00	2.79E+00	3.07E+00	7.25E+00	4.02E+00	3.87E+00	8.31E+00	4.18E+00
WEMP-12-4'	2.11E+00	5.66E+01	2.08E+01	1.98E+01	5.02E+01	2.66E+01	2.32E+01	4.99E+01	2.41E+01
WEMP-14-2'	ND	ND	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
WEMP-14-4'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
WEMP-16-7'	ND	ND	ND	ND	ND	ND	ND	ND	ND

* Vial leaked during shipping

Check Standards

Method Blank	ND	ND	BLQ	ND	ND	ND	ND	ND	ND
50 ug/ml	4.75E+01	4.83E+01	4.80E+01	4.96E+01	5.03E+01	4.96E+01	5.03E+01	5.06E+01	5.04E+01
50 ug/ml	4.61E+00	4.58E+00	4.56E+00	4.97E+00	4.61E+00	4.72E+00	4.71E+00	4.74E+00	4.77E+00
5 ug/ml	4.74E+00	4.86E+00	4.75E+00	4.70E+00	4.81E+00	4.73E+00	4.64E+00	4.74E+00	4.75E+00
5 ug/ml	4.99E-01	4.59E-01	4.97E-01	4.96E-01	4.79E-01	4.92E-01	5.19E-01	5.01E-01	4.73E-01
0.5 ug/ml	5.48E-02	5.37E-02	5.12E-02	5.34E-02	4.71E-02	4.85E-02	4.54E-02	4.44E-02	5.00E-02
0.05 ug/ml	4.76E+01	4.99E+01	4.86E+01	4.41E+01	5.38E+01	5.06E+01	4.74E+01	4.89E+01	4.82E+01
50 ug/ml QC	5.43E+01	5.12E+01	5.04E+01	5.42E+01	4.98E+01	5.06E+01	5.15E+01	5.14E+01	5.14E+01

Analyst: D.A. Kovacs BLQ < 0.05 ug/ml Printed: 6/12/95 Page 1 of 1

Received
7/10/95
Dm/mv

Westover AFB

Total Petroleum Hydrocarbons

Sample	mg TPH/Kg soil
CF-1-8.5'	43
CF-5-2.0'	59
CF-5-3.5'	45
MP-1-4.0'	40
MP-3-8.0'	47
MP-4-2.0'	55
MP-4-4.0'	9950
MP-11-2.0'	43
MP-11-4.0'	46
MP-12-2.0'	5890
MP-12-4.0'	12800
MP-14-2.0'	41
MP-14-4.0'	38
MP-16-7.0'	38

Don Kampbell 7/5/95

MAN
TECH

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
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

Pr /12/96 SF-2-223 Westover AFB G' ples for Dr. Don Kampbell Units = ng/mL st: L Black

SampleName	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	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
1 PPB	1.1	1.1	1.0	0.9	1.0	1.0	1.0	1.1	1.0	N/A
WEMP-12S	2220	13150	1090	880	2350	1520	180	521	314	20600
WEMP-14D	252	540	106	97.7	173	85.4	18.6	49.2	32.0	1540
WEMP-14M	85.3	1.2	35.2	48.6	1.3	1.0	8.9	21.4	14.1	333
WEMP-15D	2.0	ND	3.9	7.1	4.7	3.1	1.3	3.4	3.5	32.1
WEMP-15M	BLQ	ND	ND	BLQ	ND	ND	ND	ND	ND	BLQ
WEMP-15S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WEMP-16D	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
WECF-2	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
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	ND	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

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. 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
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
WEMP ~~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

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
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	WE− Trip Blnk	WEMP−1D	WEMP−1S	WEMP−4S	WEMP−5M	WEMP−8M	WEMP−10S	WEMP−10S Field Dup	WEMP−12S	WEMP−14D
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.7
1,1−DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.7
T−1,2−DICHLOROETHENE	ND	ND	ND	ND	−−−	ND	ND	ND	ND	3.1
1,1−DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C−1,2−DICHLOROETHENE	ND	ND	ND	ND	−−−	ND	ND	ND	−−−	288
CHLOROFORM	ND	ND	ND	1.1	ND	ND	ND	ND	1.5	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	ND	ND	ND	3.2	ND	ND	ND	6.8	289
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	−−−
CHLOROBENZENE	ND	ND	ND	−−−	ND	ND	ND	ND	ND	ND

	WEMP−14D Lab Dup	WEMP−14D Field Dup	WEMP−14M	WEMP−15D	WEMP−15M	WEMP−15S	WEMP−16D	WECF−2	WECF−2A	WECF−3
VINYL CHLORIDE	1.9	1.6	ND	ND	ND	ND	ND	ND	ND	ND
1,1−DICHLOROETHENE	2.7	2.6	−−−	ND	ND	ND	ND	ND	ND	3.7
T−1,2−DICHLOROETHENE	3.1	2.9	−−−	ND	ND	ND	ND	ND	ND	ND
1,1−DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C−1,2−DICHLOROETHENE	298	323	50.6	ND	ND	ND	ND	ND	ND	434
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	297	283	10.1	ND	ND	ND	ND	ND	ND	1660
TETRACHLOROETHENE	−−−	−−−	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	WECF−3 Field Dup	WECF−5	WECF−6	WECF−6 Lab Dup	WECF−6A	WECF−8	WEFT−1	WEFT−1A	WEFT−2	WEFT−2 Field Dup
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1−DICHLOROETHENE	3.5	−−−	−−−	−−−	ND	ND	ND	ND	ND	ND
T−1,2−DICHLOROETHENE	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	435	35.0	3.0	3.1	ND	ND	ND	ND	ND	ND
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	1632	94.6	13.8	14.2	ND	ND	ND	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	−−−	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

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	---	---	---	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-15	WEFT-16	QC0809A 20 ppb	QC0809B 200 ppb	QC0809C 20 ppb	QC0809D 200 ppb	QC0809E 20 ppb	QC0809F 200 ppb	QC0809G 20 ppb
VINYL CHLORIDE	ND	ND	ND	20.3	207	20.7	209	22.7	216	22.1
1,1-DICHLOROETHENE	ND	ND	ND	21.7	217	22.0	224	22.4	229	22.0
T-1,2-DICHLOROETHENE	ND	ND	ND	22.5	221	23.1	223	22.7	223	21.8
1,1-DICHLOROETHANE	ND	ND	ND	22.2	200	23.5	199	24.1	195	23.5
C-1,2-DICHLOROETHENE	ND	ND	ND	22.3	229	22.3	219	23.2	209	21.6
CHLOROFORM	ND	ND	ND	21.6	213	22.3	212	23.0	204	21.1
1,1,1-TRICHLOROETHANE	ND	ND	ND	20.3	203	21.4	205	21.7	220	21.4
CARBON TETRACHLORIDE	ND	ND	ND	19.3	187	20.4	191	20.5	209	20.1
1,2-DICHLOROETHANE	ND	ND	ND	22.6	222	23.5	203	23.6	195	22.3
TRICHLOROETHENE	ND	ND	---	17.9	180	19.1	181	18.3	186	18.4
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	20.5

Compound	QC0809H 200 ppb	QC0809I 20 ppb	QC0809J 200 ppb	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

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 NO_2 and NO_3, and 350.1 for NH_3 and Waters capillary electrophoresis Method N-601 for Cl and SO_4. 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 for
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 Cl^-	mg/L $SO_4^=$	mg/L $NO_2^- + NO_3^-$ (N)	mg/L NH_3
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 Cl^-	mg/L $SO_4^=$	mg/L $NO_2^- + NO_3^-$ (N)	mg/L NH_3
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%

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	56	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-11 S	7-18-96	137	6.1	318	180	72	3.0	
WE FT-15	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	

MAN
TECH

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,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
G.B. Smith
J.L. Seeley SV for
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
" FIELDDUP	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
WEMP ~~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.

MANTECH

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 C_8 aliphatic acids. These acids were most abundant in sample WEMP-14D. C_7, C_9 and C_{10} aliphatic acids were also found in this sample.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D Fine

Dennis D. Fine

xc: J. Wilson
J. Seeley JS
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

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids from Water Samples from Westover AFB (Service Request SF-2-223)

Concentration ppb

		WEMP-14M	WEMP-14D	WEFT-2A	Extraction Blank	[illegible] ppb Extraction Recovery	100 ppb Check Standard
	PROPANOIC ACID - PFB	24	33	21	13	5	115
	2-METHYLPROPANOIC ACID - PFB	7	14	9	***	19	112
3	TRIMETHYL ACETIC ACID - PFB	79	150	21	***	50	109
4	BUTYRIC ACID - PFB	39	22	***	32	30	121
5	2-METHYLBUTYRIC ACID - PFB	***	21	***	***	44	104
6	3-METHYLBUTYRIC ACID - PFB	***	16	18	***	42	105
7	3,3-DIMETHYLBUTYRIC ACID - PFB	355	465	226	***	62	110
8	PENTANOIC ACID - PFB	***	***	***	***	50	111
9	2,3-DIMETHYLBUTYRIC ACID - PFB	312	460	22	***	66	104
10	2-ETHYLBUTYRIC ACID - PFB	N.F.	444	***	***	65	111
11	2-METHYLPENTANOIC ACID - PFB	***	6	***	***	65	105
12	3-METHYLPENTANOIC ACID - PFB	***	114	***	***	65	99
13	4-METHYLPENTANOIC ACID - PFB	***	***	N.F.	***	60	97
14	HEXANOIC ACID - PFB	6	6	5	6	70	123
15	2-METHYLHEXANOIC ACID - PFB	N.F.	***	N.F.	N.F.	70	111
16	PHENOL - PFB	***	21	***	9	74	119
17	CYCLOPENTANECARBOXYLIC ACID - PFB	***	37	***	***	56	106
18	5-METHYLHEXANOIC ACID - PFB	***	25	***	***	67	121
19	o-CRESOL - PFB	***	6	N.F.	N.F.	81	121
20	2-ETHYLHEXANOIC ACID - PFB	60	2406	234	***	58	103
21	HEPTANOIC ACID - PFB	***	***	***	***	65	100
22	m-CRESOL - PFB	N.F.	62	N.F.	***	79	121
23	p-CRESOL - PFB	N.F.	1400	N.F.	***	75	129
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID - PFB	***	***	***	N.F.	50	100
25	o-ETHYLPHENOL - PFB	N.F.	***	N.F.	***	62	124
26	CYCLOPENTANEACETIC ACID - PFB	***	9	***	***	63	102
27	2,6-DIMETHYLPHENOL - PFB	***	5	N.F.	***	64	132
28	2,5-DIMETHYLPHENOL - PFB	***	6	N.F.	***	61	132
	CYCLOHEXANECARBOXYLIC ACID - PFB	***	***	***	***	64	105
	3-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	***	N.F.	N.F.	***	62	103
31	2,4-DIMETHYLPHENOL - PFB	N.F.	***	N.F.	N.F.	62	125
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL - PFB	***	6	N.F.	***	82	123
33	OCTANOIC ACID - PFB	***	***	***	***	66	102
34	2,3-DIMETHYLPHENOL - PFB	***	7	N.F.	***	72	128
35	p-ETHYLPHENOL - PFB	***	N.F.	N.F.	N.F.	70	106
36	BENZOIC ACID - PFB	39	39	44	44	36	92
37	3,4-DIMETHYLPHENOL - PFB	***	***	N.F.	N.F.	60	129
38	m-METHYLBENZOIC ACID - PFB	***	914	***	***	52	95
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	***	***	N.F.	***	66	100
40	CYCLOHEXANEACETIC ACID - PFB	***	22	***	***	66	100
41	2-PHENYLPROPANOIC ACID - PFB	***	21	***	N.F.	65	94
42	o-METHYLBENZOIC ACID - PFB	***	66	16	***	62	97
43	PHENYLACETIC ACID - PFB	***	90	12	N.F.	63	96
44	m-TOLYLACETIC ACID - PFB	130	159	31	N.F.	69	90
45	o-TOLYLACETIC ACID - PFB	5	49	***	***	60	101
46	2,6-DIMETHYLBENZOIC ACID - PFB	9	6	9	N.F.	55	[illegible]
47	p-TOLYLACETIC ACID - PFB	103	172	123	***	63	[illegible]
48	p-METHYLBENZOIC ACID - PFB	***	95	22	***	60	67
49	3-PHENYLPROPANOIC ACID - PFB	N.F.	357	N.F.	***	59	63
50	2,5-DIMETHYLBENZOIC ACID - PFB	57	61	16	***	63	66
51	DECANOIC ACID - PFB	6	6	8	6	61	93
52	2,4-DIMETHYLBENZOIC ACID - PFB	60	65	15	***	63	101
53	3,5-DIMETHYLBENZOIC ACID - PFB	19	33	10	7	63	89
54	2,3-DIMETHYLBENZOIC ACID - PFB	25	32	***	N.F.	56	89
55	4-ETHYLBENZOIC ACID - PFB	***	50	12	***	N.F.	87
56	2,4,6-TRIMETHYLBENZOIC ACID - PFB	62	75	20	***	N.F.	102
	3,4-DIMETHYLBENZOIC ACID - PFB	52	90	13	***	N.F.	84
	2,4,5-TRIMETHYLBENZOIC ACID - PFB	24	32	6	***	N.F.	99

*** indicates concentration of extract was below lowest calibration standard (5 ppb).

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

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

```
                                   ELEMENTAL CONSTITU[illegible] ANALYSIS BY: ICAP (DATA.DAT)
            THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;4535) WAS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3082

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                   WECF-2A                   WECF 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/RSKERL/ADA, OK
```

```
                              ELEMENTAL CONSTITUENT ANALYSIS BY: ICAP (DATA.DAT)
                THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;4535) WAS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3082

PROJECT: AQ FILTERED FIELD DIRECT READING  WESTOVER AFB
         KAMPBELL
         SR65

CONCENTRATION IN: MG/L

TAG NO.  14556                      14557                      ZSTD5                      IECCHK2
STATION  WEMP-14D                   WEMP-12S                   ----------                 ----------
TIME        09:21                      09:23                      15:38                      15:40
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      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         0.0550      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
  Ti        <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.
  RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS                                                   EPA/RSKERL/ADA, OK
```

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                         ELEMENTAL CONSTITUENT ANALYSIS BY: ICAP (DATA.DAT)
        THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;4535) WAS GENERATED FROM USER$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$DISK:[CLARK.ICAP]DATA.DAT;281          (INSTRUMENT RAW DATA)
         USER$DISK:[CLARK.ICAP]IC0001.DAT;3913       (INSTRUMENT CALC. DATA)
         USER$DISK:[CLARK.ICAP]TAG.DAT;4847          (ORIGINAL TAG FILE)
         USER$DISK:[CLARK.ICAP]TAG.DAT;4848          (TAG FILE FOR CALC.)
         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
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```
                         ELEMENTAL CONSTITUEN[illegible]NALYSIS 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        SAD   STATION      MACHINE   PRIMARY   REGULAR       FINAL
                NUMBER       #     IDENT       READING   DILUTION  DILUTION   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
```

APPENDIX C

BIOPLUME II MODEL INPUT PARAMETERS AND CALCULATIONS

MEAN ERROR, MEAN AVERAGE ERROR, AND ROOT-MEAN-SQUARE ERROR FOR THE CALIBRATED FLOW MODEL

Current Fire Training Area

Intrinsic Remediation TS

Westover ARB, Massachusetts

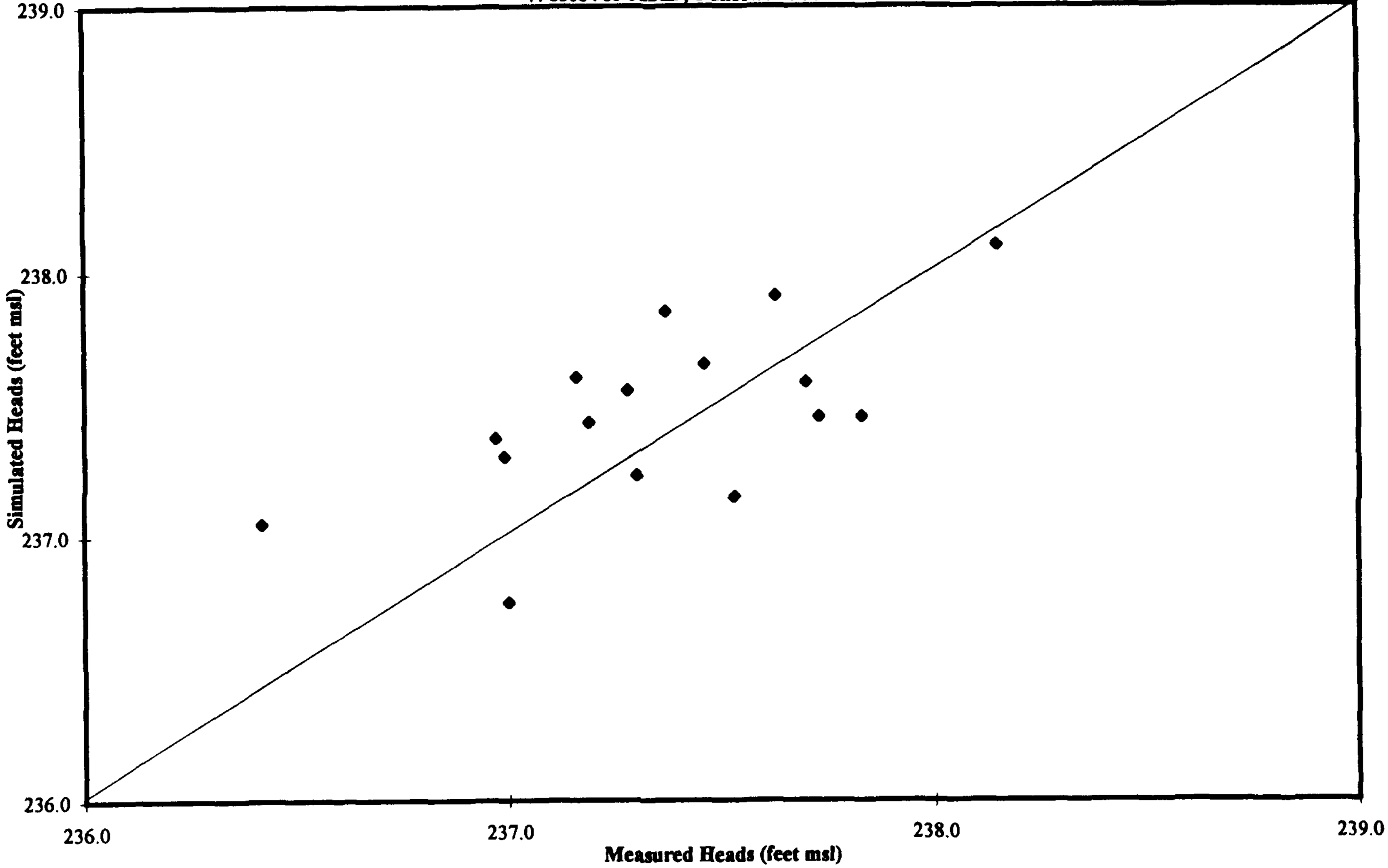
Location	Actual Water Level (h_m)[a]	Calibrated Water Level (h_s)[a]	h_m-h_s	abs(h_m-h_s)	$(h_m-h_s)^2$
MP-4S	237.4	237.9	0.48	0.48	0.23
CF-2A	237.2	237.4	0.24	0.24	0.06
CF-6A	237.0	237.4	0.40	0.40	0.16
MP-7S	237.8	237.5	-0.38	0.38	0.14
MP-5S	236.4	237.1	0.63	0.63	0.40
MP-1S	237.6	237.9	0.28	0.28	0.08
CF-5	237.2	237.6	0.44	0.44	0.19
CF-3	237.5	237.7	0.19	0.19	0.04
CF-4	237.7	237.5	-0.28	0.28	0.08
CF-8	237.0	236.8	-0.25	0.25	0.06
MP-2S	238.2	238.1	-0.05	0.05	0.00
MP-11S	237.7	237.6	-0.12	0.12	0.01
MP-12S	237.3	237.6	0.27	0.27	0.07
MP-10S	237.3	237.2	-0.07	0.07	0.00
MP-15S	237.0	237.3	0.31	0.31	0.10
MP-8S	237.5	237.2	-0.38	0.38	0.14
Total:	3797.7	3799.4	1.71	4.77	1.77
			ME[b] =	0.11	
			MAE[c] =	0.30	
			RMS[d] =	0.33	8.536719

[a] Water levels are in feet mean-sea-level.

[b] ME = Mean Error =1/n x (h_m-h_s).

[c] MAE = Mean Average Error = 1/n x |(h_m-h_s)|.

[d] RMS = Root-Mean-Square (RMS) Error = $(1/n \times (h_m-h_s)^2)^{0.5}$.


Measured Heads vs. Simulated Heads
Westover ARB, Massachusetts

L:\45011\tables\naknek\WATSTAT2.XLS

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE / WESTOVER
Job No. 722450.28050
Sheet 1 of 1
Subject BTEX Source WEATHERING ESTIMATION.
By M. Vessely
Date 11/16/95
Checked
Rev.

① MP-45 → Saturated Soil Sample = 646 $\frac{mg}{Kg}$ total BTEX

② CALCULATE unit mass

PARTICLES: BULK density 2.7 x .65 (volume)
= 1.755 is solid MATERIAL

WATER: 1 x .15 (15% volume is H_2O)
= 0.15 is water

FUEL: 0.75 x 0.1 (10% fuel)
= 0.075 is fuel

REMAINING 10% of Pore Space is Air

③ CALCULATE INDIVIDUAL BTEX FRACTION

% in Fresh JP-4

Benzene = 0.075 x 0.005 = 0.00038
Toluene = 0.075 x 0.0133 = 0.0010
Ethylbenzene = 0.075 x 0.0037 = 0.00028
Xylenes = 0.075 x 0.0232 = 0.0017
BTEX TOTAL = 0.00336

④ Divide TOTAL "Fresh" BTEX Fraction by total unit weight

$$\frac{0.00336}{(1.755 + 0.15 + 0.075)} = 0.0017$$

⑤ There fore, Saturated "Fresh" JP-4 SOIL Should have a CONCENTRATION OF 1700 $\frac{mg}{Kg}$. Assume 10yrs decay

AND Therefore: $1700(1-.095)^{10} \doteq 630$ mg/Kg ← 9.5% decay for 10yrs

∴ APPROXIMATELY 10% Source decay ⇐ Use 5% to be conservative

PESI-COR-8 (12/94)

"BATCH FLUSH"
- MV -

BTEX flux calculation:
Injection Well = 13, 5 & 13, 6

STEP				
1	I=	0.0019		
2	x=	60	feet	
3	T=	0.0043	sq ft/sec	
	Q=	0.0005	cfs	Q = I*x*T
	Q=	0.0139	L/sec	unit conversion
4	GW BTEX=	32	mg/L	
		0.4442	mg/sec of contamination must enter cell to maintain X BTEX concentration	
5	injection rate=	0.000010	cfs	
		0.00028	L/sec	
		1568.6	mg/L to get X BTEX in the groundwater	
		44424	mg/cubic ft to get X BTEX in the groundwater	

x 10 & 15% to account for point source loading

BTEX flux calculation:
Injection Well = 12, 8

STEP				
1	I=	0.0019		
2	x=	60	feet	
3	T=	0.0007	sq ft/sec	
	Q=	0.0001	cfs	Q = I*x*T
	Q=	0.0022	L/sec	unit conversion
4	GW BTEX=	10	mg/L	
		0.0223	mg/sec of contamination must enter cell to maintain X BTEX concentration	
5	injection rate=	0.000010	cfs	
		0.00028	L/sec	
		78.7	mg/L to get X BTEX in the groundwater	
		2228	mg/cubic ft to get X BTEX in the groundwater	

BTEX flux calculation:
Injection Well = 13, 8

STEP				
1	I=	0.0019		
2	x=	60	feet	
3	T=	0.0006	sq ft/sec	
	Q=	0.0001	cfs	Q = I*x*T
	Q=	0.0019	L/sec	unit conversion
4	GW BTEX=	10	mg/L	
		0.0187	mg/sec of contamination must enter cell to maintain X BTEX concentration	
5	injection rate=	0.000010	cfs	
		0.00028	L/sec	
		66.1	mg/L to get X BTEX in the groundwater	
		1873	mg/cubic ft to get X BTEX in the groundwater	

BTEX flux calculation:
Injection Well = 13, 10

STEP				
1	I=	0.0019		
2	x=	60	feet	
3	T=	0.0007	sq ft/sec	
	Q=	0.0001	cfs	Q = I*x*T
	Q=	0.0022	L/sec	unit conversion
4	GW BTEX=	1	mg/L	
		0.0025	mg/sec of contamination must enter cell to maintain X BTEX concentration	
5	injection rate=	0.000010	cfs	
		0.00028	L/sec	
		8.7	mg/L to get X BTEX in the groundwater	
		245	mg/cubic ft to get X BTEX in the groundwater	

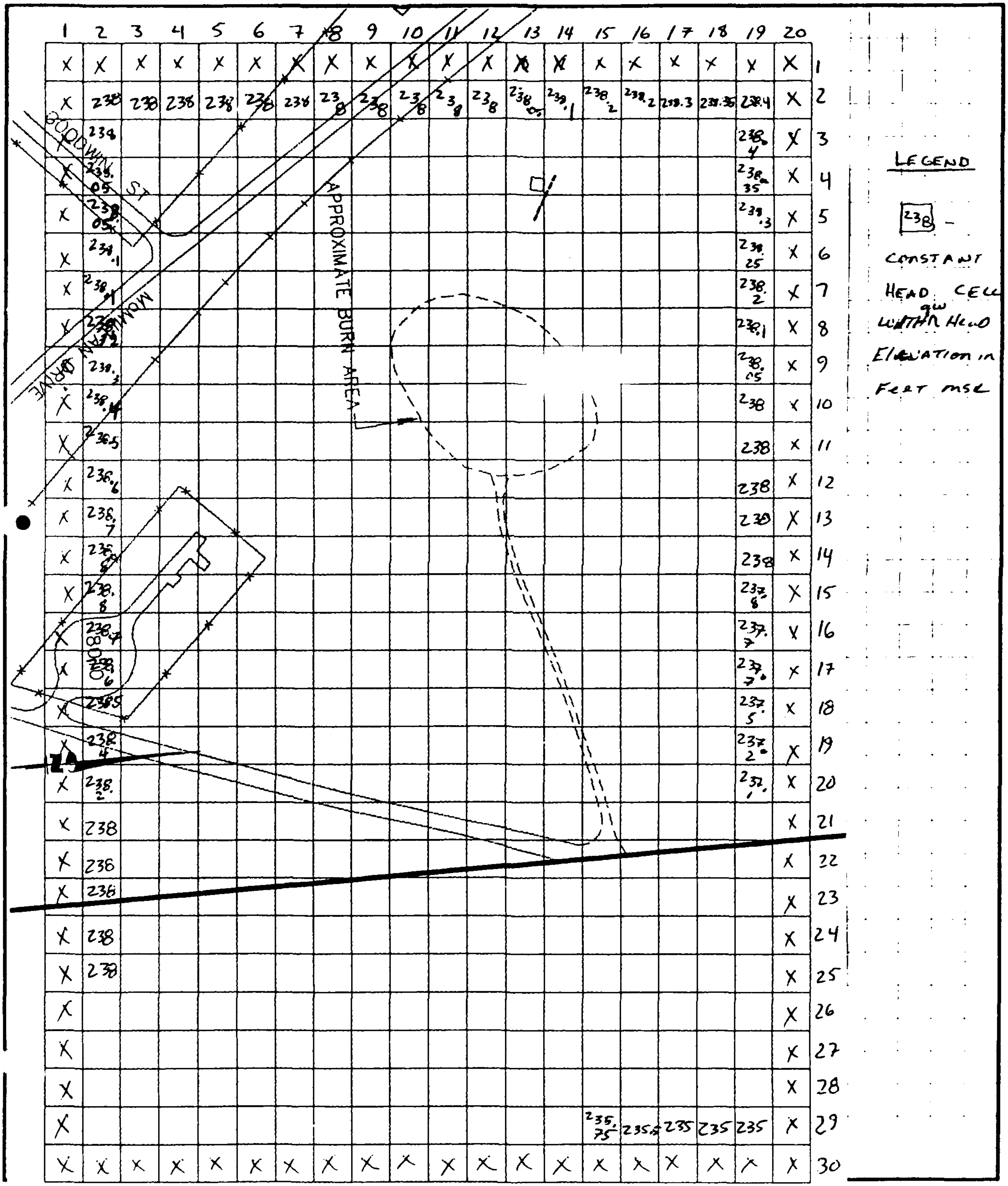
BTEX flux calculation:
Injection Well = 12, 9
STEP
1 I= 0.0019
2 x= 60 feet
3 T= 0.0043 sq ft/sec
Q= 0.0005 cfs Q = I*x*T
Q= 0.0139 L/sec unit conversion
4 GW BTEX= 5 mg/L
0.0694 mg/sec of contamination must enter cell to maintain X BTEX concentration
5 injection rate= 0.000010 cfs
0.00028 L/sec
245.1 mg/L to get X BTEX in the groundwater
6941 mg/cubic ft to get X BTEX in the groundwater

BTEX flux calculation:
Injection Well = 13, 9
STEP
1 I= 0.0019
2 x= 60 feet
3 T= 0.0006 sq ft/sec
Q= 0.0001 cfs Q = I*x*T
Q= 0.0019 L/sec unit conversion
4 GW BTEX= 1 mg/L
0.0021 mg/sec of contamination must enter cell to maintain X BTEX concentration
5 injection rate= 0.000010 cfs
0.00028 L/sec
7.3 mg/L to get X BTEX in the groundwater
206 mg/cubic ft to get X BTEX in the groundwater

BTEX flux calculation:
Injection Well = 14, 10
STEP
1 I= 0.0019
2 x= 60 feet
3 T= 0.0007 sq ft/sec
Q= 0.0001 cfs Q = I*x*T
Q= 0.0022 L/sec unit conversion
4 GW BTEX= 1 mg/L
0.0018 mg/sec of contamination must enter cell to maintain X BTEX concentration
5 injection rate= 0.000010 cfs
0.00028 L/sec
6.3 mg/L to get X BTEX in the groundwater
178 mg/cubic ft to get X BTEX in the groundwater

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE / WESTOVER ARB
Job No. 722450.28
Sheet 1 of 1
Subject CONSTANT HEAD CELLS
By MV
Date
Checked
Rev.



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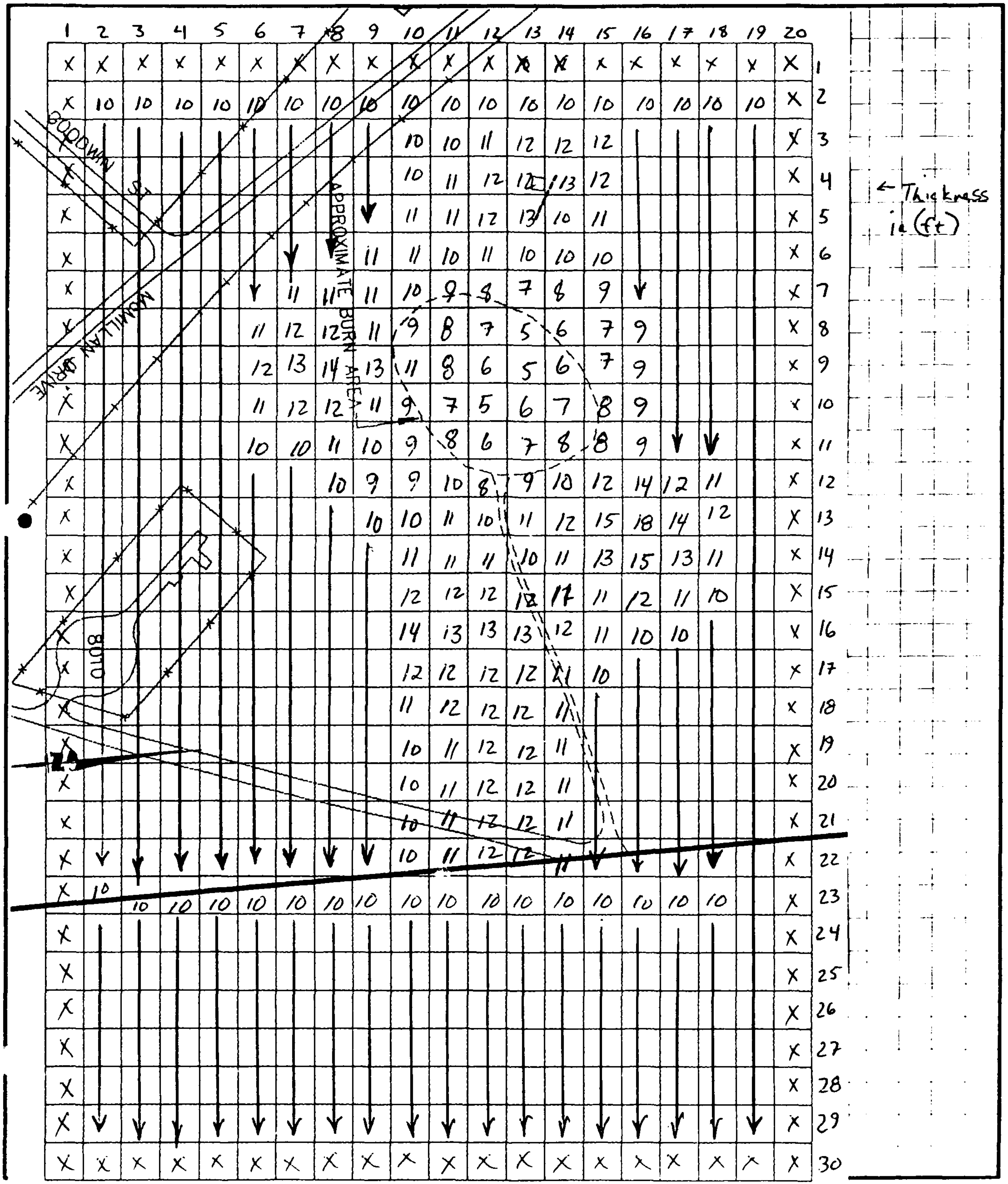
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	238	238	238	238	238	238	238	238	238	238	238	238.05	238.1	238.2	238.2	238.3	238.35	238.4	X
3		238																	238.4	X
4	X	238.05																	238.35	X
5	X	238.05																	238.3	X
6	X	238.1																	238.25	X
7	X	238.1																	238.2	X
8	X	238.2																	238.1	X
9		238.3																	238.05	X
10	X	238.4																	238	X
11	X	238.5																	238	X
12	X	238.6																	238	X
13	X	238.7																	238	X
14	X	238.8																	238	X
15	X	238.8																	237.8	X
16	X	238.7																	237.7	X
17	X	238.6																	237.7	X
18	X	238.5																	237.5	X
19	X	238.4																	237.2	X
20	X	238.2																	237.1	X
21	X	238																		X
22	X	238																		X
23	X	238																		X
24	X	238																		X
25	X	238																		X
26	X																			X
27	X																			X
28	X																			X
29	X														235.75	235.5	235	235	235	X
30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

LEGEND

238 – CONSTANT HEAD CELL WITH GW HEAD ELEVATION IN FEET MSL

PARSONS ENGINEERING SCIENCE, INC.

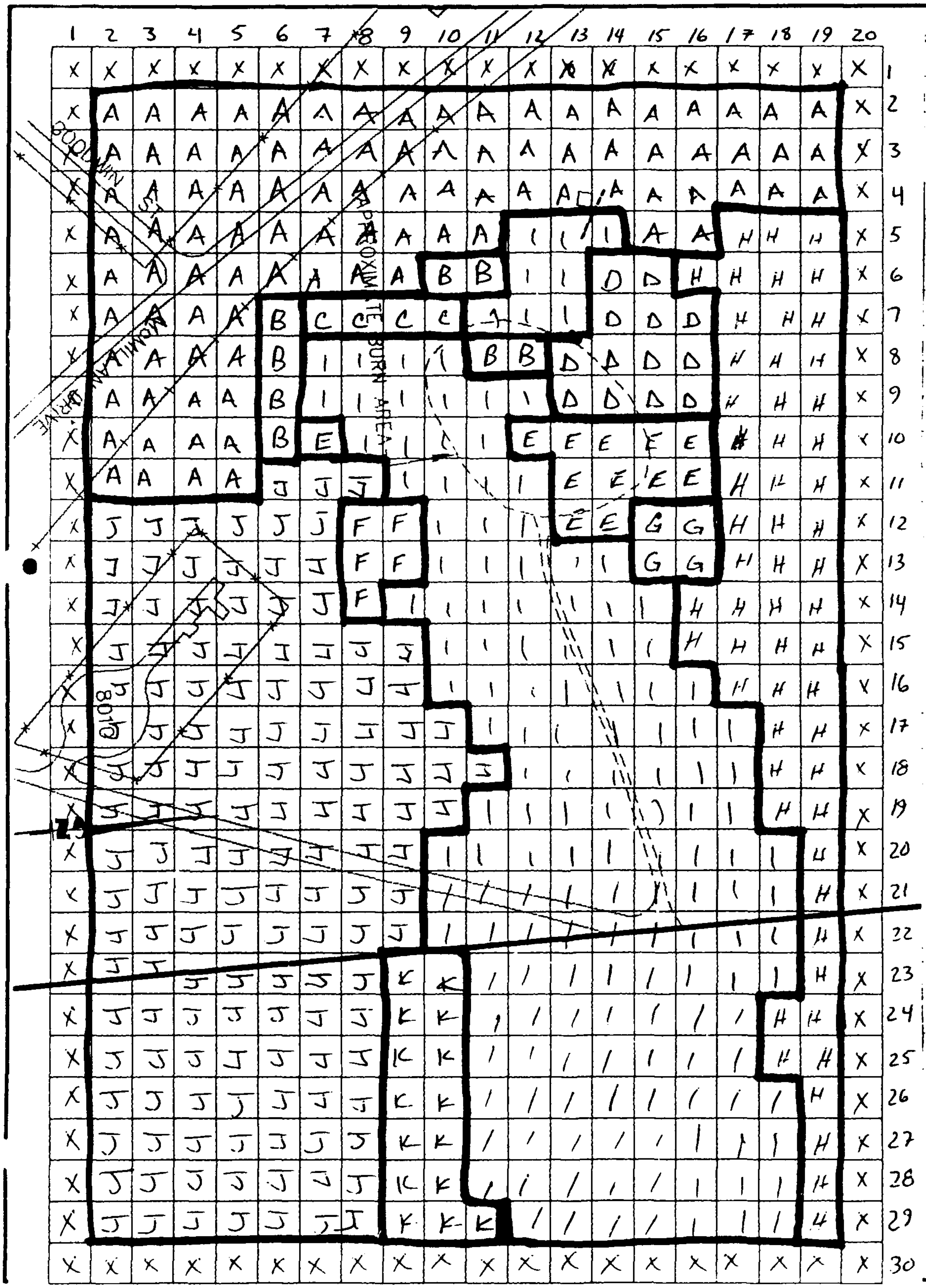
Client AFCEE
Job No. 722450.
Sheet 1 of 1
Subject WESTOVER - FT-08
By MV
Date
Aquifer Thickness Grid
Checked
Rev.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	X
3	X									10	10	11	12	12	12					X
4	X									10	11	12	12	13	12					X
5	X									11	11	12	13	10	11					X
6	X								11	11	10	11	10	10	10					X
7	X						11	11	11	10	9	8	7	8	9					X
8	X					11	12	12	11	9	8	7	5	6	7	9				X
9						12	13	14	13	11	8	6	5	6	7	9				X
10	X					11	12	12	11	9	7	5	6	7	8	9				X
11	X					10	10	11	10	9	8	6	7	8	8	9				X
12	X							10	9	9	10	8	9	10	12	14	12	11		X
13	X								10	10	11	10	11	12	15	18	14	12		X
14	X									11	11	11	10	11	13	15	13	11		X
15	X									12	12	12	12	17	11	12	11	10		X
16	X									14	13	13	13	12	11	10	10			X
17	X									12	12	12	12	11	10					X
18	X									11	12	12	12	11						X
19	X									10	11	12	12	11						X
20	X									10	11	12	12	11						X
21	X									10	11	12	12	11						X
22	X									10	11	12	12	11						X
23	X	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		X
24	X																			X
25	X																			X
26	X																			X
27	X																			X
28	X																			X
29	X																			X
30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE / Westover
Job No. 722450.28
Sheet 1 of 1
Subject Transmisivity Grid
By MV
Date
Checked
Rev.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	X
3	X	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	X
4	X	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	X
5	X	A	A	A	A	A	A	A	A	A	A	I	I	I	A	A	H	H	H	X
6	X	A	A	A	A	A	A	A	A	B	B	I	I	D	D	H	H	H	H	X
7	X	A	A	A	A	B	C	C	C	C	I	I	I	D	D	D	H	H	H	X
8	X	A	A	A	A	B	I	I	I	I	B	B	D	D	D	D	H	H	H	X
9	X	A	A	A	A	B	I	I	I	I	I	I	D	D	D	D	H	H	H	X
10	X	A	A	A	A	B	E	I	I	I	I	E	E	E	E	E	H	H	H	X
11	X	A	A	A	A	J	J	J	I	I	I	I	E	E	E	E	H	H	H	X
12	X	J	J	J	J	J	J	F	F	I	I	I	E	E	G	G	H	H	H	X
13	X	J	J	J	J	J	J	F	F	I	I	I	I	I	G	G	H	H	H	X
14	X	J	J	J	J	J	J	F	I	I	I	I	I	I	I	H	H	H	H	X
15	X	J	J	J	J	J	J	J	J	I	I	I	I	I	I	H	H	H	H	X
16	X	J	J	J	J	J	J	J	J	I	I	I	I	I	I	I	H	H	H	X
17	X	J	J	J	J	J	J	J	J	J	I	I	I	I	I	I	I	H	H	X
18	X	J	J	J	J	J	J	J	J	J	J	I	I	I	I	I	I	H	H	X
19	X	J	J	J	J	J	J	J	J	J	I	I	I	I	I	I	I	H	H	X
20	X	J	J	J	J	J	J	J	J	I	I	I	I	I	I	I	I	I	H	X
21	X	J	J	J	J	J	J	J	J	I	I	I	I	I	I	I	I	I	H	X
22	X	J	J	J	J	J	J	J	J	I	I	I	I	I	I	I	I	I	H	X
23	X	J	J	J	J	J	J	J	K	K	I	I	I	I	I	I	I	I	H	X
24	X	J	J	J	J	J	J	J	K	K	I	I	I	I	I	I	I	H	H	X
25	X	J	J	J	J	J	J	J	K	K	I	I	I	I	I	I	I	H	H	X
26	X	J	J	J	J	J	J	J	K	K	I	I	I	I	I	I	I	I	H	X
27	X	J	J	J	J	J	J	J	K	K	I	I	I	I	I	I	I	I	H	X
28	X	J	J	J	J	J	J	J	K	K	I	I	I	I	I	I	I	I	H	X
29	X	J	J	J	J	J	J	J	K	K	K	I	I	I	I	I	I	I	H	X
30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

LEGEND

X - No Flow
A = 4.4×10^{-4}
B = 6.88×10^{-4}
C = 8.0×10^{-4}
D = 5.79×10^{-4}
E = 7.41×10^{-4}
F = 8.85×10^{-4}
G = 3.98×10^{-4}
H = 1.0×10^{-3}
I = 4.3×10^{-3}
J = 1.4×10^{-4}
K = 7.7×10^{-4}

APPENDIX D
BIOPLUME II MODEL INPUT AND OUTPUT

APPENDIX E

REMEDIAL OPTION DESIGN AND COSTING CALCULATIONS

Present Worth Analysis Discount Factor = 7%

Alternative 1: IR and Vertical Circulation with Institutional Controls and		Present Worth	Cost ($) at Year Indicated										
Long-Term Groundwater Monitoring	years	($)	Year: 1	2	3	4	5	10	11	20	21	29	30
Vertical Circulation Treatability Study	1	$33,406	$35,744	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintain Institutional Controls	60	$33,911	$5,000	$0	$5,000	$0	$5,000	$0	$5,000	$0	$5,000	$5,000	$0
Long-term Monitoring													
Install New LTM Wells	1	$21,156	$22,637	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Install New POC Wells	3	$15,839	$0	$0	$19,403	$0	$0	$0	$0	$0	$0	$0	$0
Goundwater Sampling/LTM	1	$10,455	$11,187	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Groundwater Sampling/LTM and POC	58	$113,516	$0	$0	$16,780	$0	$16,780	$0	$16,780	$0	$16,780	$16,780	$0
Reporting/Project Mgmt	60	$75,859	$11,185	$0	$11,185	$0	$11,185	$0	$11,185	$0	$11,185	$11,185	$0
Subtotal Present Worth ($)		$304,141											

Total Present Worth Cost ($): $304,141

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Present Worth Analysis Discount Factor = 7%

Alternative 2: IR, Vertical Circulation, and Bioventing with Institutional Controls and Long-Term Monitoring		Present Worth	Cost ($) at Year Indicated										
	years	($)	Year: 1	2	3	4	5	10	11	20	21	29	30
Bioventing													
Bioventing System Installation	1	$78,995	$84,524	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
System Maintenance	3	$30,127	$11,480	$11,480	$11,480	$0	$0	$0	$0	$0	$0	$0	$0
Annual Report	3	$11,405	$4,346	$4,346	$4,346	$0	$0	$0	$0	$0	$0	$0	$0
Subtotal Present Worth ($)		$120,527											
Vertical Circulation Treatability Study	1	$33,406	$35,744	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintain Institutional Controls	30	$29,974	$5,000	$0	$5,000	$0	$5,000	$0	$5,000	$0	$5,000	$5,000	$0
Long-term Monitoring													
Install New LTM Wells	1	$21,156	$22,637	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Install New POC Wells	3	$15,839	$0	$0	$19,403	$0	$0	$0	$0	$0	$0	$0	$0
Goundwater Sampling/LTM	1	$10,455	$11,187	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Groundwater Sampling/LTM and POC	28	$98,387	$0	$0	$16,780	$0	$16,780	$0	$16,780	$0	$16,780	$16,780	$0
Reporting/Project Mgmt	30	$67,051	$11,185	$0	$11,185	$0	$11,185	$0	$11,185	$0	$11,185	$11,185	$0
Subtotal Present Worth ($)		$276,266											

Total Present Worth Cost ($): $396,793

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Present Worth Analysis

Discount Factor = 7%

Alternative 3: IR, Vertical Circulation, Limited Soil Excavation, and Bioventing with Institutional Controls and Long-Term Monitoring		Present Worth	Cost ($) at Year Indicated										
	years	($)	Year: 1	2	3	4	5	10	11	20	21	29	30
Bioventing													
Bioventing System Installation	1	$71,386	$76,383	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
System Maintenance	3	$29,077	$11,080	$11,080	$11,080	$0	$0	$0	$0	$0	$0	$0	$0
Annual Report	3	$11,405	$4,346	$4,346	$4,346	$0	$0	$0	$0	$0	$0	$0	$0
Subtotal Present Worth ($)		$111,869											
Vertical Circulation Treatability Study	1	$33,406	$35,744	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintain Institutional Controls	30	$29,974	$5,000	$0	$5,000	$0	$5,000	$0	$5,000	$0	$5,000	$5,000	$0
Long-term Monitoring													
Install New Wells	1	$21,156	$22,637	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Install New POC Wells	3	$15,839	$0	$0	$19,403	$0	$0	$0	$0	$0	$0	$0	$0
Goundwater Sampling/LTM	1	$10,455	$11,187	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Groundwater Sampling/LTM and POC	28	$98,387	$0	$0	$16,780	$0	$16,780	$0	$16,780	$0	$16,780	$16,780	$0
Reporting/Project Mgmt	30	$67,051	$11,185	$0	$11,185	$0	$11,185	$0	$11,185	$0	$11,185	$11,185	$0
Subtotal Present Worth ($)		$276,266											
Limited Soil Excavation													
Excavation	1	$6,206	$6,640	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		$6,206											

Total Present Worth Cost ($): $394,341

lternatives 1, 2, and 3: Long-Term Monitoring and Institutional Controls

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Install New LTM/POC Wells ($)	Task 2 (hrs)	Sampling ($)	Task 3 (hrs)	Reporting & PM ($)
Word Processor 88/(15)	$30	0	$0	0	$0	30	$900
CADD Operator 58/(25)	$47	4	$188	0	$0	30	$1,410
Technician 42/(50)	$40	5	$200	60	$2,400	30	$1,200
Staff Level 16/(65)	$57	144	$8,208	60	$3,420	60	$3,420
Project Level 12/(70)	$65	12	$780	6	$390	40	$2,600
Senior Level 10/(80)	$85	3	$255	0	$0	3	$255
Principal 02/(85)	$97	0	$0	0	$0	0	$0
Total Labor (hrs|$)		168	$9,631	126	$6,210	193	$9,785
ODCs							
Phone			$40		$0		$50
Photocopy			$50		$0		$200
Mail			$100		$400		$100
Computer			$200		$0		$400
CAD			$20		$0		$450
WP			$0		$0		$200
Travel			$1,000		$2,000		$0
r Diem			$1,284		$1,070		$0
qpt. & Supplies			$400		$200		$0
Total ODCs			$3,094		$3,670		$1,400
Outside Services							
LTM/POC Well Installation Costs [a/]			$28,600		$0		$0
Laboratory Fees [b/]		Soils	$715	12 LTM, 6 POC,	$6,900		$0
Other: Maintain Institutional Controls			$0	and 2qa/qc,	$0		$5,000
Total Outside Services			$29,315		$6,900		$5,000

Proposal Estimate	Task 1	Task 2	Task 3
Labor	$9,631	$6,210	$9,785
ODC's	$3,094	$3,670	$1,400
Outside Services	$29,315	$6,900	$5,000
Total by Task	$42,040	$16,780	$16,185

Total Labor	$25,626
Total ODCs	$8,164
Total Outside Services	$41,215
Total Project	$75,005

ask 1: Install New LTM/POC Wells

ask 2: Sampling per Event

Task 3: Reporting and PM per Sampling Eve

[a/] 13 Wells, 520ft @ $50/ft, $2000mob, $600 soil handling for 2 wells (Assumes soils for the other 11 wells can be spread on-site.)

[b/] BTEX/VOC @ $120ea, Electron receptors at LTM wells @ $150ea

Alternatives 1, 2, and 3: Vertical Circulation Treatability Study

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1	Work Plan ($)	Task 2	Pilot Studies ($)	Task 3	Reporting ($)
Word Processor 88/(15)	$30	16	$480	0	$0	16	$480
CADD Operator 58/(25)	$47	10	$470	0	$0	12	$564
Technician 42/(50)	$40	0	$0	60	$2,400	20	$800
Staff Level 16/(65)	$57	32	$1,824	0	$0	40	$2,280
Project Level 12/(70)	$65	4	$260	80	$5,200	8	$520
Senior Level 10/(80)	$85	0	$0	4	$340	2	$170
Principal 02/(85)	$97	1	$97	0	$0	0	$0
Total Labor (hrs | $)		63	$3,131	144	$7,940	98	$4,814
ODCs							
Phone			$20		$30		$40
Photocopy			$100		$0		$100
Mail			$45		$100		$50
Computer			$100		$0		$100
CAD			$75		$0		$90
WP			$100		$0		$100
Travel			$0		$2,690		$0
Eqpt. & Supplies			$0		$500		$0
Total ODCs			$440		$3,320		$480
Outside Services							
Well Installation			$0		$5,400		$0
Electrical Costs			$0		$0		$0
Product Hauling/Disposal			$0		$1,000		$0
Laboratory Fees			$0		$1,000		$0
Equipment Costs			$0		$4,000		$0
Construction Costs			$0		$4,219		$0
Total Outside Services			$0		$15,619		$0

Proposal Estimate	Task 1	Task 2	
Labor	$3,131	$7,940	$4,814
ODC's	$440	$3,320	$480
Outside Services	$0	$15,619	$0
Total by Task	$3,571	$26,879	$5,294

Total Labor	$15,885
Total ODCs	$4,240
Total Outside Services	$15,619
Total Project	$35,744

Task 1: Work Plan Development
Task 2: Vertical Circulation Pilot Study
Task 3: Report Preparation

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Alternative 2: Bioventing

dard Rate Schedule

ng Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Design & Install Biovent System ($)	Task 2 (hrs)	System Monitoring/ Maintenance (2x per yr)($)	Task 3 (hrs)	End of Year Report ($)
Word Processor 88/(15)	$30	40	$1,200	0	$0	8	$240
CADD Operator 58/(25)	$47	100	$4,700	0	$0	8	$376
Technician 42/(50)	$40	240	$9,600	80	$3,200	8	$320
Staff Level 16/(65)	$57	280	$15,960	20	$1,140	40	$2,280
Project Level 12/(70)	$65	100	$6,500	10	$650	8	$520
Senior Level 10/(80)	$85	8	$680	0	$0	2	$170
Principal 02/(85)	$97	1	$97	0	$0	0	$0
Total Labor (hrs|$)		769	$38,737	110	$4,990	74	$3,906
ODCs							
Phone			$400		$120		$20
Photocopy			$500		$60		$100
Mail			$200		$240		$40
Computer			$500		$0		$200
CAD			$500		$0		$40
WP			$200		$0		$40
Travel			$2,000		$2,000		$0
Per Diem			$4,578		$1,070		$0
Eqpt. & Supplies			$2,000		$400		$0
l ODCs			$10,878		$3,890		$440
Outside Services							
Well Installation			$6,400		$0		$0
System Installation			$11,009		$0		$0
Equipment Costs			$2,500		$0		$0
Product Hauling/Disposal (Soil)			$12,000		$0		$0
Electrical Costs			$0		$200		$0
Laboratory Fees			$3,000		$2,400		$0
Other			$0		$0		$0
Total Outside Services			$34,909		$2,600		$0

Estimate	Task 1	Task 2	Task 3
Labor	$38,737	$4,990	$3,906
ODC's	$10,878	$3,890	$440
Outside Services	$34,909	$2.600	$0
Total by Task	$84,524	$11,480	$4,346

Total Labor	$47,633
Total ODCs	$15,208
Total Outside Services	$37,509
Total Project	$100,350

1: SVE System Design and Construction
sk 2: Monthly Site Time and Travel Costs (per year)
Task 3: Report Preparation

Alternative 3: Bioventing System

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Design & Install Biovent System ($)	Task 2 (hrs)	System Monitoring/ Maintenance (2x per yr)($)	Task 3 (hrs)	End of Year Report ($)
Word Processor 88/(15)	$30	40	$1,200	0	$0	8	$240
CADD Operator 58/(25)	$47	100	$4,700	0	$0	8	$376
Technician 42/(50)	$40	240	$9,600	80	$3,200	8	$320
Staff Level 16/(65)	$57	280	$15,960	20	$1,140	40	$2,280
Project Level 12/(70)	$65	100	$6,500	10	$650	8	$520
Senior Level 10/(80)	$85	8	$680	0	$0	2	$170
Principal 02/(85)	$97	1	$97	0	$0	0	$0
Total Labor (hrs|$)		769	$38,737	110	$4,990	74	$3,906
ODCs							
Phone			$400		$120		$20
Photocopy			$500		$60		$100
Mail			$200		$240		$40
Computer			$500		$0		$200
CAD			$500		$0		$40
WP			$200		$0		$40
Travel			$2,000		$2,000		$0
Per Diem			$4,142		$1,070		$0
Eqpt. & Supplies			$2,000		$400		$0
Total ODCs			$10,442		$3,890		$440
Outside Services							
Well Installation			$5,600		$0		$0
Recovery System Installation			$8,604		$0		$0
Equipment Costs			$2,500		$0		$0
Product Hauling/Disposal (Soil)			$8,000		$0		$0
Electrical Costs			$0		$200		$0
Laboratory Fees			$2,500		$2,000		$0
Other			$0		$0		$0
Total Outside Services			$27,204		$2,200		$0
Estimate			Task 1		Task 2		Task 3
Labor			$38,737		$4,990		$3,906
ODC's			$10,442		$3,890		$440
Outside Services			$27,204		$2,200		$0
Total by Task			$76,383		$11,080		$4,346

Total Labor	$47,633
Total ODCs	$14,772
Total Outside Services	$29,404
Total Project	$91,809

Task 1: Bioventing System Design and Construction
Task 2: Monthly Site Time and Travel Costs (per year)
Task 3: Report Preparation

Alternative 3: Limited Soil Excavation

Standard Rate Schedule

Billing Category Cost Code/(Billing Category)		Billing Rate	Task 1	Excavation ($)
Word Processor	88/(15)	$30	2	$60
CADD Operator	58/(25)	$47	2	$94
Technician	42/(50)	$40	8	$320
Staff Level	16/(65)	$57	8	$456
Project Level	12/(70)	$65	2	$130
Senior Level	10/(80)	$85	1	$85
Principal	02/(85)	$97	0	$0
Total Labor (hrs | $)			23	$1,145

ODCs	
Phone	$10
Photocopy	$10
Mail	$10
Computer	$20
CAD	$10
WP	$10
Travel (Included with SVE)	$0
Eqpt. & Supplies	$20
Total ODCs	$90

Outside Services	
Excavation Costs	$2,405
Soil Hauling/Disposal	$3,000
Total Outside Services	$5,405

Proposal Estimate	Task 1
Labor	$1,145
ODC's	$90
Outside Services	$5,405
Total by Task	$6,640
Total Labor	$1,145
Total ODCs	$90
Total Outside Services	$5,405
Total Project	$6,640

Task 1: Work Plan Development

Task 2: Vapor Extraction/Bioventing/Air Sparging Pilot Study

Task 3: Report Preparation

Westover ARB Backup Calculations for FT-08

Alternatives 1 and 2: Long-term Monitoring

Misc calculations

Number of new LTM and POC wells:
Number of wells: 13
Average depth each: 40 ft

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 28,600	
Mobilization	ea	1	$ 2,000	$ 2,000		
Well Installation	ln ft	520	$ 50	$ 26,000		
Soil Disposal	drum	6	$ 100	$ 600		

Westover ARB Backup Calculations for FT-08

Alternatives 1, 2, and 3: Vertical Circulation

Misc calculations

Number of soil vapor extraction wells:		
Number of wells:	1	
Number of MPs:	-	
Depth each:	50	ft
Trench Volume/Area		
Width:	12	in
Depth:	1	ft
Length:	200	ft
Volume:	200	cf
	7	cy
Surface Area:	200	sf
	22	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 5,400	
Mobilization	ea	1	$ 1,000	$ 1,000		
Well Installation	ln ft	50	$ 80	$ 4,000		
MP Installation	ln ft	-	$ 30	$ -		
Soil Disposal	drum	4	$ 100	$ 400		
Equipment Costs					$ 4,000	
Pump	ea	1	$ 2,000	$ 2,000		Recovery Equipment Supply
Pump Controller	ea	1	$ 2,000	$ 2,000		
System Installation					$ 4,219	
Mob/Demob	ea	1	$ 500	$ 500		
Trenching	cy	7	$ 5.05	$ 35		Means 022 254 0050
Backfill	cy	7	$ 17.20	$ 120		Means 022 204 0600
Compaction	cy	7	$ 5.10	$ 36		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Reseeding	sy	44	$ 1.91	$ 84		Means 029 304 0310
Mechanical	man hr	32	$ 38.83	$ 1,243		Means Q-1 crew
Electrical	ls	1	$ 2,000	$ 2,000		
Slab	cy	-	$ 97.00	$ -		Means 033 130 4700
Contingency	%	5%	$ 4,018	$ 201		
Product Hauling /Disposal (Soil)	load	1	$ 1,000	$ 1,000	$ 1,000	

Westover ARB Backup Calculations for FT-08

Alternative 2: Bioventing System

Misc calculations

Number of soil vapor extraction wells:		
Number of wells:	3	
Number of MPs:	4	
Depth each:	10	ft
Trench Volume/Area		
Width:	12	in
Depth:	5	ft
Length:	600	ft
Volume:	3,000	cf
	111	cy
Surface Area:	600	sf
	67	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 6,400	
Mobilization	ea	1	$ 2,000	$ 2,000		
Well Installation	ln ft	30	$ 60	$ 1,800		
MP Installation	ln ft	40	$ 40	$ 1,600		
Soil Disposal	drum	5	$ 200	$ 1,000		
Equipment Costs					$ 2,500	
Blower	ea	1	$ 2,000	$ 2,000		Recovery Equipment Supply
Blower House	ea	1	$ 500	$ 500		
System Installation					$ 11,009	
Mob/Demob	ea	1	$ 1,000	$ 1,000		
Trenching	cy	111	$ 5.05	$ 561		Means 022 254 0050
Pipe laying	ln ft	720	$ 2.50	$ 1,800		
Backfill	cy	111	$ 17.20	$ 1,909		Means 022 204 0600
Compaction	cy	111	$ 5.10	$ 566		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Reseeding	sy	134	$ 1.91	$ 256		Means 029 304 0310
Piping	lf	840	$ 1.00	$ 840		Means 151 551 1880
Mechanical	man hr	40	$ 38.83	$ 1,553		Means Q-1 crew
Electrical	ls	1	$ 2,000	$ 2,000		
Slab	cy	-	$ 97.00	$ -		Means 033 130 4700
Contingency	%	5%	$ 10,485	$ 524		
Product Hauling /Disposal (Soil)	load	12	$ 1,000	$ 12,000	$ 12,000	

Westover ARB Backup Calculations for FT-08

Alternative 3: Bioventing System

Misc calculations

Number of soil vapor extraction wells:		
Number of wells:	2	
Number of MPs:	4	
Depth each:	10	ft
Trench Volume/Area		
Width:	12	in
Depth:	5	ft
Length:	400	ft
Volume:	2,000	cf
	74	cy
Surface Area:	400	sf
	44	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 5,600	
Mobilization	ea	1	$ 2,000	$ 2,000		
Well Installation	ln ft	20	$ 60	$ 1,200		
MP Installation	ln ft	40	$ 40	$ 1,600		
Soil Disposal	drum	4	$ 200	$ 800		
Equipment Costs					$ 2,500	
Blower	ea	1	$ 2,000	$ 2,000		Recovery Equipment Supply
Blower House	ea	1	$ 500	$ 500		
System Installation					$ 8,604	
Mob/Demob	ea	1	$ 1,000	$ 1,000		
Trenching	cy	74	$ 5.05	$ 374		Means 022 254 0050
Pipe laying	ln ft	480	$ 2.50	$ 1,200		Means 151 701 0550/026 686 2800
Backfill	cy	74	$ 17.20	$ 1,273		Means 022 204 0600
Compaction	cy	74	$ 5.10	$ 377		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Reseeding	sy	88	$ 1.91	$ 168		Means 029 304 0310
Piping	lf	560	$ 1.00	$ 560		Means 151 551 1880
Mechanical	man hr	32	$ 38.83	$ 1,243		Means Q-1 crew
Electrical	ls	1	$ 2,000	$ 2,000		
Slab	cy	-	$ 97.00	$ -		Means 033 130 4700
Contingency	%	5%	$ 8,195	$ 410		
Product Hauling /Disposal (Soil)	load	8	$ 1,000	$ 8,000	$ 8,000	

Westover ARB Backup Calculations for FT-08

Alternative 3: Limited Soil Excavation

Misc calculations

Excavation Volume/Area	
Width:	10 ft
Depth:	10 ft
Length:	6 ft
Volume:	600 cf
	22 cy
Surface Area:	60 sf
	7 sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Excavation					$ 2,405	
Mob/Demob	ea	1	$ 1,000	$ 1,000		
Trenching	cy	22	$ 5.05	$ 111		Means 022 254 0050
Backfill	cy	22	$ 17.20	$ 378		Means 022 204 0600
Compaction	cy	22	$ 5.10	$ 112		Means 022 204 0600
Reseeding	sy	14	$ 1.91	$ 27		Means 029 304 0310
Mechanical	man hr	20	$ 38.83	$ 777		Means Q-1 crew
Product Hauling /Disposal (Soil)	load	3	$ 1,000	$ 3,000	$ 3,000	