FINAL

Treatability Study in Support of Intrinsic Remediation for Fire Protection Training Area 3

Offutt Air Force Base
Omaha, Nebraska

Prepared For

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

and

55 CES/CEVR
Offutt Air Force Base
Omaha, Nebraska

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30 November 1999

Mr. Jerry Hansen
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Subject: Submittal of the Final Treatability Study in Support of Intrinsic Remediation for Fire Protection Training Area 3, Offutt Air Force Base, Nebraska (Contract F41624-92-D-8036-0006)

Dear Mr. Hansen:

Enclosed please find two copies of the November 1999 Final Treatability Study in Support of Intrinsic Remediation for Fire Protection Training Area 3, Offutt Air Force Base, Nebraska. This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and Offutt Air Force Base (AFB).

The intent of the treatability study (TS) was to determine the role of natural attenuation in remediating fuel hydrocarbon and chlorinated solvent contamination in groundwater at Fire Protection Training Area 3 (FPTA-3). The draft TS was submitted to AFCEE in May 1995. Comments on the draft TS were received from AFCEE as reviewed by Chung Yen (date unknown). Responses to these comments were prepared by Parsons ES and are contained in Appendix F.

In addition, sample data collected by the US Environmental Protection Agency (USEPA) National Risk Management Research laboratory (NRMRL) in June 1996 and June 1998 has been incorporated into this report as an addendum (Appendix G). Conclusions and recommendations from the addendum have been added to the Final TS Executive Summary, and revisions have been made to Section 7, Long-Term Monitoring.

If you have any questions or comments regarding this package please do not hesitate to contact me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry

Bruce M. Henry, P.G.
Project Manager

Enclosures
c.c. Mr. Phil Cork – Offutt AFB (two copies)
Mr. Don Kampbell – USEPA NRMRL

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FINAL

TREATABILITY STUDY IN SUPPORT OF INTRINSIC REMEDIATION FOR FIRE PROTECTION TRAINING AREA 3

at

OFFUTT AIR FORCE BASE
OMAHA, NEBRASKA

November 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
µg/L	micrograms per liter
1,1-DCA	1,1-dichloroethane
2-D	2-dimensional
55 CES/CEVR	55th Civil Engineering Squadron-Environmental
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AST	aboveground storage tank
B&V	Black and Veatch
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
cis-1,2-DCE	*cis*-1,2-dichloroethene
cm/s	centimeters per second
CPT	cone penetrometer testing
DO	dissolved oxygen
ES	Engineering-Science, Inc. (now Parsons Engineering, Science, Inc.)
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron
FPTA3	Fire Protection Training Area 3
ft/day	feet per day
ft/ft	foot per foot
ft/min	feet per minute
ft^2/day	square feet per day
ft^2/sec	square feet per second
ft^3/s	cubic feet per second
ΔG_R^0	Gibbs free engery
g/cc	grams per cubic centimeter
GC/MS	gas chromatography/mass spectrometry
HAZWRAP	Hazardous Waste Remedial Actions Program
HDPE	high-density polyethylene
ID	inside diameter
JP-4	jet fuel no. 4
K_{oc}	sorption coefficient
LIF	laser-induced fluorometry
LNAPL	light nonaqueous-phase liquid
LTM	long-term monitoring
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/kg/year	milligrams per kilogram per year
mgd	million gallons per day
mm Hg	millimeters of mercury
MOC	method of characteristics
msl	mean sea level
MUD	Municipal Utilities District
mV	millivolts

N	nitrogen
NRMRL	National Risk Management Research Laboratory
OD	outside diameter
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
POC	point of compliance
PVC	polyvinyl chloride
QC	quality control
R	coefficient of retardation
RAO	remedial action objective
redox	reduction oxidation
RMS	root mean squared
RSKERL	Robert S. Kerr Environmental Research Laboratory
SAC	Strategic Air Command
STRATCOM	Strategic Command
TCE	trichloroethene
TMBs	trimethylbenzenes
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TS	Treatability Study
USACE	United States Army Corps of Engineers
USEPA	United Stated Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
W-C	Woodward-Clyde Consultants

EXECUTIVE SUMMARY

This report presents the results of a treatability study performed by Parsons Engineering Science, Inc. (Parsons ES) at Fire Protection Training Area 3 (FPTA3), Offutt Air Force Base, Nebraska to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) as a remedial option for dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) contamination in the shallow groundwater. Residual light nonaqueous-phase liquid (LNAPL) is present within the soil, and dissolved contamination is present in the groundwater. There is no evidence of mobile LNAPL (free product) at this site. This study focused on the impact of dissolved BTEX on the shallow groundwater system at the site. Dissolved chlorinated solvents also are present in the shallow groundwater; therefore, the impact of the dissolved chlorinated solvents was studied 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 for FPTA3 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 the anaerobic processes of 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, the ratio of source chlorinated solvents to their anaerobic decay products suggests that chlorinated solvents in the groundwater also are being degraded through reductive dechlorination and/or cometabolism.

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 estimate the rate and direction of dissolved BTEX movement through the shallow groundwater under the influence of advection, dispersion, sorption, and biodegradation. A one-dimensional analytical model was used to estimate the fate of chlorinated solvent compounds in the shallow groundwater aquifer. Input parameters for the Bioplume II and analytical models were obtained from available site characterization data, supplemented with data collected by Parsons ES. Model parameters that were not measured at the site were estimated using reasonable literature values. The results of this study suggest that dissolved BTEX and chlorinated solvent contamination present in groundwater poses no significant risk to human health or the environment in its present, or predicted future, concentration and distribution.

Results from additional groundwater monitoring performed in June 1996 and June 1998 further support the occurrence of natural biodegradation of fuel hydrocarbons and chlorinated solvents at FPTA3. Geochemical data indicate that fuel hydrocarbon biodegradation continues to occur at the site primarily via the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis. Although natural attenuation appears to have stabilized the BTEX plume, the continued presence of residual fuel contamination in source area soils, combined with rising water levels, have caused dissolved BTEX concentrations beneath the main burn pit to persist and increase in some areas. The additional data also suggests that the easterly extent of the BTEX plume may be receding.

However, this may be due at least in part to temporal changes in groundwater flow directions. Considering the low hydraulic gradient at the site, it is unlikely that the BTEX plume will migrate a significant distance in any direction from its current position. As BTEX concentrations in the source area decrease due to the continued effects of weathering, the plume is expected to recede back towards the source area. As a result of the low groundwater flow velocity at the site, the electron acceptor supply in the plume core is replenished slowly. This may limit the rate at which dissolved BTEX is degraded, and support the persistence of the BTEX plume.

The chlorinated solvent plume exhibits conditions of anaerobic reductive dechlorination, where the primary source of biologically available organic carbon is anthropogenic fuel hydrocarbons (BTEX). Typical of these conditions is a decrease in concentrations of trichloroethene (TCE), an increase in *cis*-1,2-dichloroethene (*cis*-1,2-DCE), and the accumulation of vinyl chloride (VC). These characteristics are observed at the FPTA3 site. Most of the TCE has been effectively degraded to *cis*-1,2-DCE by reductive dechlorination. With time, *cis*-1,2-DCE has been reduced to VC. Within the source area, VC is accumulating because the anaerobic degradation rate of VC is slow relative to TCE and *cis*-1,2-DCE. The presence of ethene at MP-5M suggests that VC also is degrading, at least within the highly reducing core of the BTEX plume.

In addition, observed BTEX and chlorinated solvent plume behavior in June 1996 and June 1998 have not exceeded the conservative predictions made using the numerical and analytical models developed in this TS report. Given the rates of BTEX and chlorinated solvent plume migration and degradation predicted by the models, and considering that there are no impacted receptors at or downgradient from the site; natural attenuation, institutional controls, and continued LTM are recommended as the remedial option for BTEX- and chlorinated solvent-impacted groundwater. Because anaerobic conditions at the site are effectively limiting the migration of chlorinated solvents, remedial actions that induce aerobic conditions (e.g., air sparging) are not recommended. However, if shortening of the remedial time-frame becomes desirable, engineered source reduction (soil remediation) could be considered.

To ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, it is recommended that groundwater be sampled biennially (every other year) for 20 years to monitor the long-term migration and degradation of the dissolved BTEX and chlorinated solvent plumes. Biennial sampling should be sufficiently protective given the very low groundwater migration rate. The need for additional sampling and the appropriate sampling interval should be re-evaluated after 20 years, at a minimum. In addition to analyses used to verify the effectiveness of intrinsic remediation, the groundwater samples should be analyzed for BTEX and chlorinated solvents by United States Environmental Protection Agency (USEPA) Method SW8260B.

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 (natural attenuation) for remediation of fuel-hydrocarbon-contaminated groundwater at Fire Protection Training Area 3 (FPTA3), Offutt Air Force Base (AFB), Omaha, Nebraska. Previous investigations indicate that fuel hydrocarbons and chlorinated solvents have been released into the soil and groundwater at the site as a result of past site activities.

The main emphasis of the work described herein was to evaluate the potential for natural degradation mechanisms to reduce dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations in groundwater to levels that are protective of human health and the environment. The potential for these mechanisms to effectively reduce the concentration of chlorinated solvents at the site, which is outside the scope of this program, was also qualitatively considered.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers of the United States Environmental Protection Agency (USEPA) Robert S. Kerr Environmental Research Laboratory (RSKERL), was retained by the United States Air Force Center for Environmental Excellence (AFCEE) 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 FPTA3.

Performance of numerous tasks was required in order to fulfill the project objective. These tasks included:

- Reviewing previously reported hydrogeologic and soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of 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;
- Designing and preparing the Bioplume II model for site hydrogeologic conditions;
- Simulating the fate and transport of fuel hydrocarbons in groundwater under the influence of advection, dispersion, adsorption, and biodegradation using the Bioplume II model;
- 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 downgradient point of compliance (POC);
- Developing remedial action objectives (RAOs) and reviewing available remedial technologies;
- Using the results of modeling to recommend the most appropriate remedial option on the basis of specific effectiveness, implementability, and cost criteria; and
- Providing a LTM plan (if appropriate) that includes LTM and POC well locations and a sampling and analysis plan.

Site characterization activities in support of intrinsic remediation included cone penetrometer testing (CPT) in conjunction with laser-induced fluorometry (LIF); aquifer testing; static groundwater level measurement; soil sample collection and analysis; monitoring point installation; and groundwater sample collection and analysis from newly installed monitoring points and previously-installed monitoring wells. Additional groundwater sampling was performed by the USEPA National Risk Management Research Laboratory (NRMRL, formerly the RSKERL) in June 1996 and June 1998. Data for these events were not available for analysis in preparation of this TS, but have been evaluated in an addendum to this TS (Appendix G). Results of the addendum have been incorporated into the Executive Summary and Section 7, Long-Term Monitoring.

Site-specific data were used to develop a fate and transport model for the site using Bioplume II, and to conduct a preliminary exposure pathways analysis. The modeling effort was used to predict the future extent and concentration of the dissolved BTEX plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation. Site-specific data also were used to qualitatively evaluate the potential fate and transport of trichloroethene (TCE), cis-1,2-dichloroethene (c-1,2-DCE), trans-1,2-dichloroethene (t-1,2-DCE), and vinyl chloride in the presence of fuel hydrocarbons. Potential biological degradation of these chlorinated solvents via cometabolic processes was addressed qualitatively.

Results of the model and of the qualitative investigation of cometabolic biodegradation were used to assess the potential for completion of exposure pathways involving groundwater and to identify whether intrinsic remediation with LTM is an

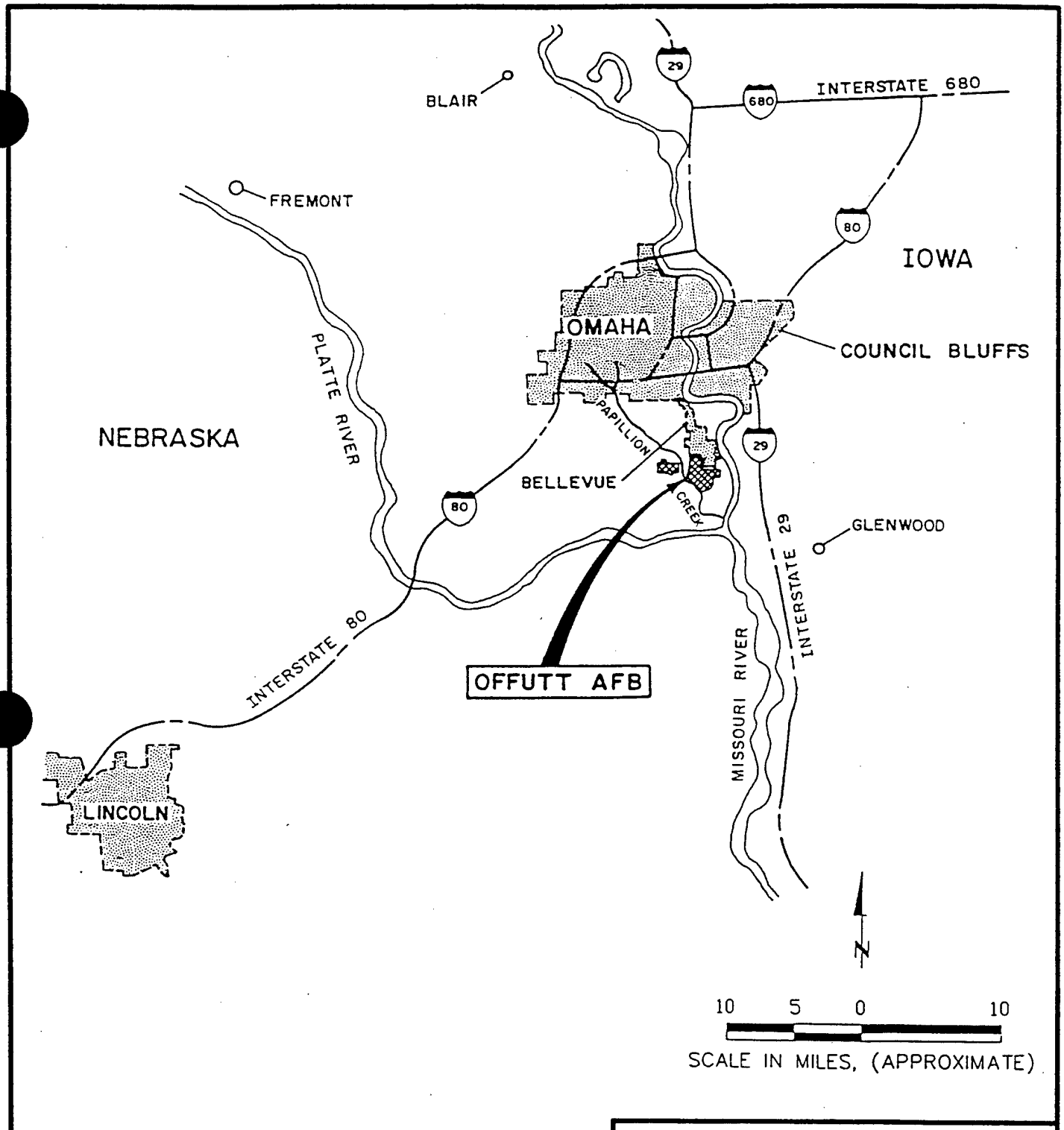
appropriate and defensible remedial option for contaminated groundwater at FPTA3. The model results will be used to provide technical support for the intrinsic remediation with LTM remedial option during regulatory negotiations, as appropriate.

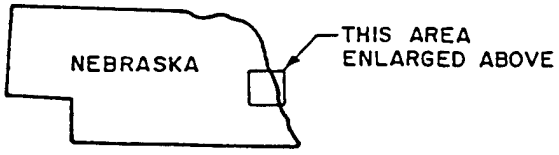
Alternate remedial options were considered to identify the major advantages and disadvantages associated with different groundwater remedial strategies. These options included groundwater extraction and treatment coupled with natural contaminant attenuation, LTM, and institutional controls. All hydrogeologic and groundwater chemical data necessary to evaluate these remedial options either were collected under this program or were available from previous investigations at this site, from investigations at other Offutt AFB sites with similar characteristics, or in the technical literature. Field work conducted under this program, however, was oriented toward the collection of hydrogeologic data to be used as input into the Bioplume II groundwater model in support of intrinsic remediation with LTM for restoration of fuel-hydrocarbon-contaminated groundwater.

This report contains nine sections, including this introduction, and seven 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 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 CPT logs, borehole logs, monitoring point installation records, and slug test results. Appendix B presents soil and groundwater analytical results. Appendix C contains analytical models, Bioplume II model input parameters, and calculations related to model calibration. 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. Appendix F contains responses to comments on the draft TS, and Appendix G contains the Final Intrinsic Remediation Treatability Study Addendum.

1.2 FACILITY BACKGROUND

The Base occupies approximately 2,750 acres in eastern Sarpy County, Nebraska. It is bordered by the cities of Bellevue and Omaha to the north, the city of Papillion to the west, and agricultural land along the Missouri and Platte rivers to the east and south, respectively (Figure 1.1). The Base was originally established by the United States Army in 1891 as Fort Crook, and was continuously operated by the Army until transferred to the Air Force in 1948. From 1948 through 1992, the Base served as the headquarters for the Strategic Air Command (SAC). Since 1992, the Base has served as the Strategic Command (STRATCOM) Headquarters. The Base presently employs approximately 11,000 military and civilian personnel [Woodward-Clyde Consultants (W-C), 1992a].





Source: Woodward-Clyde Consultants,1992b.

FIGURE 1.1

BASE LOCATION

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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Denver, Colorado

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FPTA3 is located west of Harlan-Lewis Road in the southeastern corner of the Base (Figure 1.2). Fire protection training exercises were conducted at the site from 1960 until the spring of 1990. From 1960 to 1974, exercises were conducted at a frequency of approximately once per week and used up to 2,000 gallons of waste fuels and solvents per training day. After 1974, exercises were conducted with approximately 300 gallons of jet fuel (JP-4) at a frequency of approximately twice per calendar quarter (ES, 1990a).

The central training area at FPTA3 is a bermed burn pit surrounding a mock aircraft fuselage. The berm is topped by a gravel track, circumscribes a circular area approximately 200 feet in diameter, and stands roughly 3 feet higher than the interior of the burn pit. The flat interior area within the berm is approximately 100 feet in diameter and will be referred to as the main burn pit. Main burn pit soils are visibly contaminated and support very little vegetation. Disturbance of these surficial soils releases a strong odor of hydrocarbons and unidentified chemicals. A drain pipe on the north side of the main burn pit was used to discharge contaminated water from the main burn pit into a pond north of the main burn pit.

The only remaining portion of the discharge pond is located within a small circular stand of trees approximately 25 feet in diameter. The main body of the discharge pond was formerly located north-northwest of the remaining discharge pond; however, it now lies beneath the southern portion of Hardfill 6 and is filled with construction rubble. A slight surface depression leads from the location of the remaining discharge pond to the suspected location of the former discharge pond. It is believed to trace the path of the drain pipe that connected the two ponds.

Building 654, located west of the main burn pit, is a cinder block shell which appears to have also been used for training exercises (Figure 1.2). Historic aerial photographs are reported to indicate a fire training area where Building 654 currently stands (ES, 1990a). A semi-circular gravel path north, south, and west of Building 654 may help define the extent of the former fire training area. The gravel track is similar in appearance to the gravel track that runs along the crest of the main burn pit berm. Soils surrounding Building 654 are not visibly contaminated; however, the area is sparsely vegetated, and disturbance of subsurface soils releases an odor similar to that of the main burn pit.

Another burn pit is located between Building 654 and the drainage pond. This secondary burn pit is surrounded by a 1-foot-high berm and is approximately 45 feet in diameter. The berm is breached on the eastern side. At the center of the bermed area stands a structure resembling a barbecue grill constructed of a barrel split lengthwise and mounted on legs.

Under the Hazardous Waste Remedial Actions Program (HAZWRAP), investigations were conducted at FPTA3 in 1988 and 1989 by ES (1990a, 1990b) and reported in the *Site Inspection Report for Offutt Air Force Base.* Following the site inspection, B&V Waste Science and Technology Corporation (B&V) was contracted by the Air Force to perform a corrective measures study (B&V, 1990) and prepare a remedial action program for contaminated site soils (B&V, 1992); however, plans for soils remediation have not been implemented to date. During 1992, quarterly groundwater monitoring was

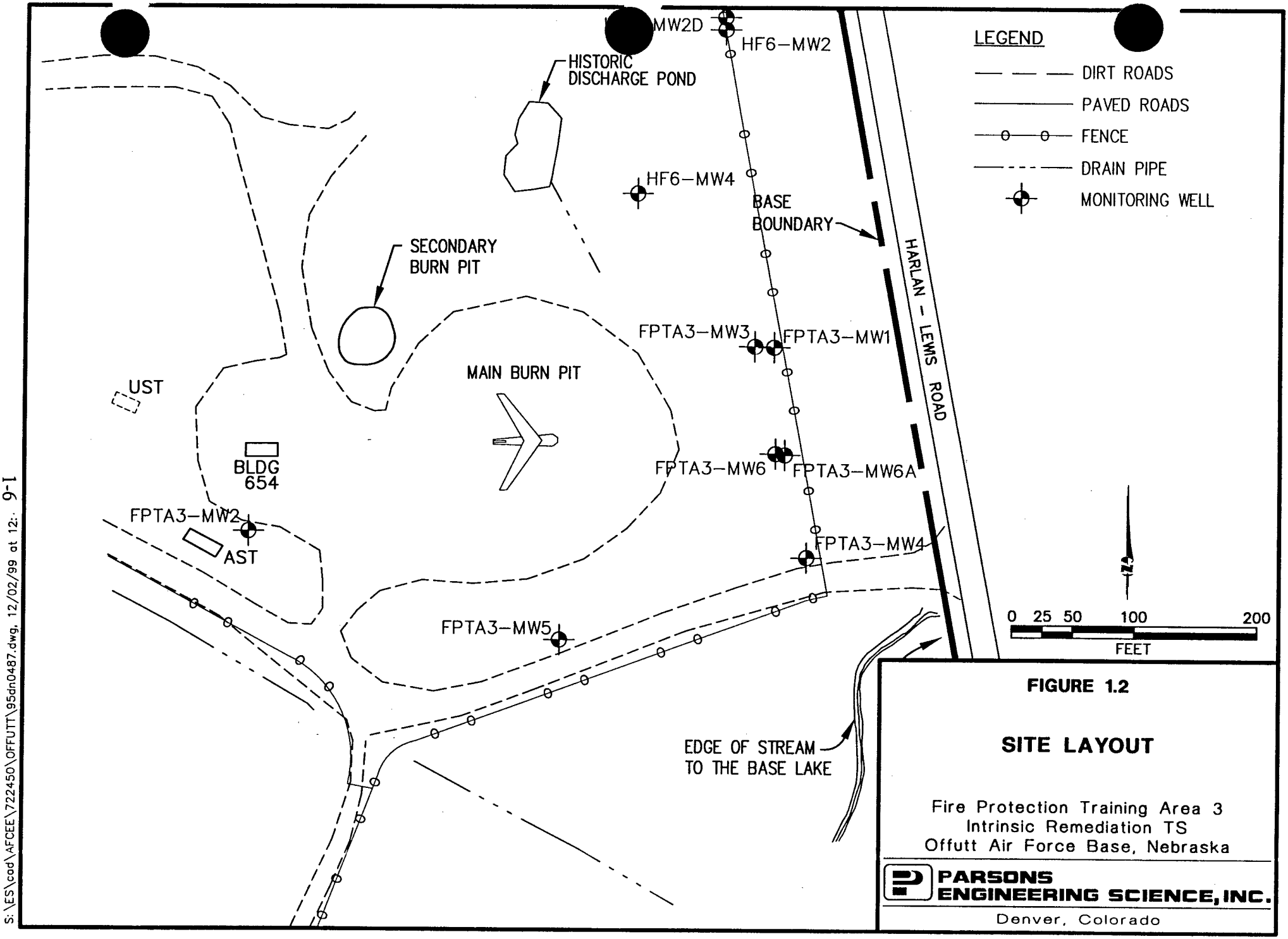

FIGURE 1.2

SITE LAYOUT

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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conducted by W-C as part of the Base groundwater monitoring program (W-C, 1992b). The field portions of the current investigation were conducted between September 22 and 28, 1994 and November 13 and 20, 1994.

The results of these investigations suggest that the soil and groundwater associated with and downgradient of FPTA3 are contaminated with JP-4 related compounds and chlorinated solvents. Fuel mixtures not burned during fire training exercises seeped into the soils and contaminated the soil column and groundwater underlying source areas. At some locations, the soil is saturated with fuel; however, free-phase fuel has not been detected floating on the groundwater. The site-specific data presented in Sections 3, 4, and 5 are derived from a review of previous investigation reports and the Parsons ES field investigations under this program.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

To meet the requirements of the intrinsic remediation demonstration, additional data were required to evaluate near-surface geology, aquifer properties, and the nature and extent of soil and groundwater contamination. Site characterization activities included performing CPT with LIF; sampling and analyzing soils from CPT pushes and hand-augered boreholes; installing monitoring points; sampling and analyzing groundwater from newly installed monitoring points and previously installed monitoring wells; and measuring and estimating hydrogeologic parameters (static groundwater levels, groundwater gradient, groundwater flow direction, and hydraulic conductivity). Locations of site activities are presented on Figures 2.1 and 2.2.

CPT pushes were performed at the locations labeled CPT-1 through -22 to characterize subsurface stratigraphy. LIF was performed simultaneously at these locations to evaluate the presence of residual- or free-phase hydrocarbons in the soils and groundwater. Pushes at locations CPT-1 through CPT-5 were performed on September 27, 1994. Pushes at locations CPT-5 through CPT-22 were performed November 15 through 17, 1994. As a push was performed at location CPT-5 in both September and November, it serves in part as a field duplicate for the CPT/LIF. Push statistics are summarized in Table 2.1.

The CPT was used to collect a total of two soil samples on September 27, 1994. The samples were collected from 4.5 to 5.3 feet below ground surface (bgs) at Location CPT-2 and 4.8 to 5.6 feet bgs at Location CPT-5. Both samples were analyzed for BTEX, trimethylbenzenes (TMBs), TCE, tetrachloroethene (PCE), and total organic carbon (TOC) by the USEPA/RSKERL.

On November 18, a total of 14 soil samples were collected from hand-augered boreholes SS-1 and SS-2 (Figure 2.1). Borehole SS-2 was installed approximately 20 feet south of CPT-2 to a depth of 9.5 feet. Borehole SS-1 was installed to a depth of 11 feet near monitoring wells FPTA3-MW6 and FPTA3-MW6A. Borehole logs are included in Appendix A. Samples were collected from ground surface to the total borehole depth at intervals of approximately 1.5 feet. Soil samples collected from hand-augered boreholes were analyzed by the USEPA/RSKERL for BTEX, TMBs, TCE, PCE, naphthalenes, total petroleum hydrocarbons (TPH), TOC, moisture, and dehydrogenase activity.

Groundwater samples were collected from the 11 monitoring wells identified on Figure 2.2. Groundwater samples were also collected from 22 of the 25 newly installed,

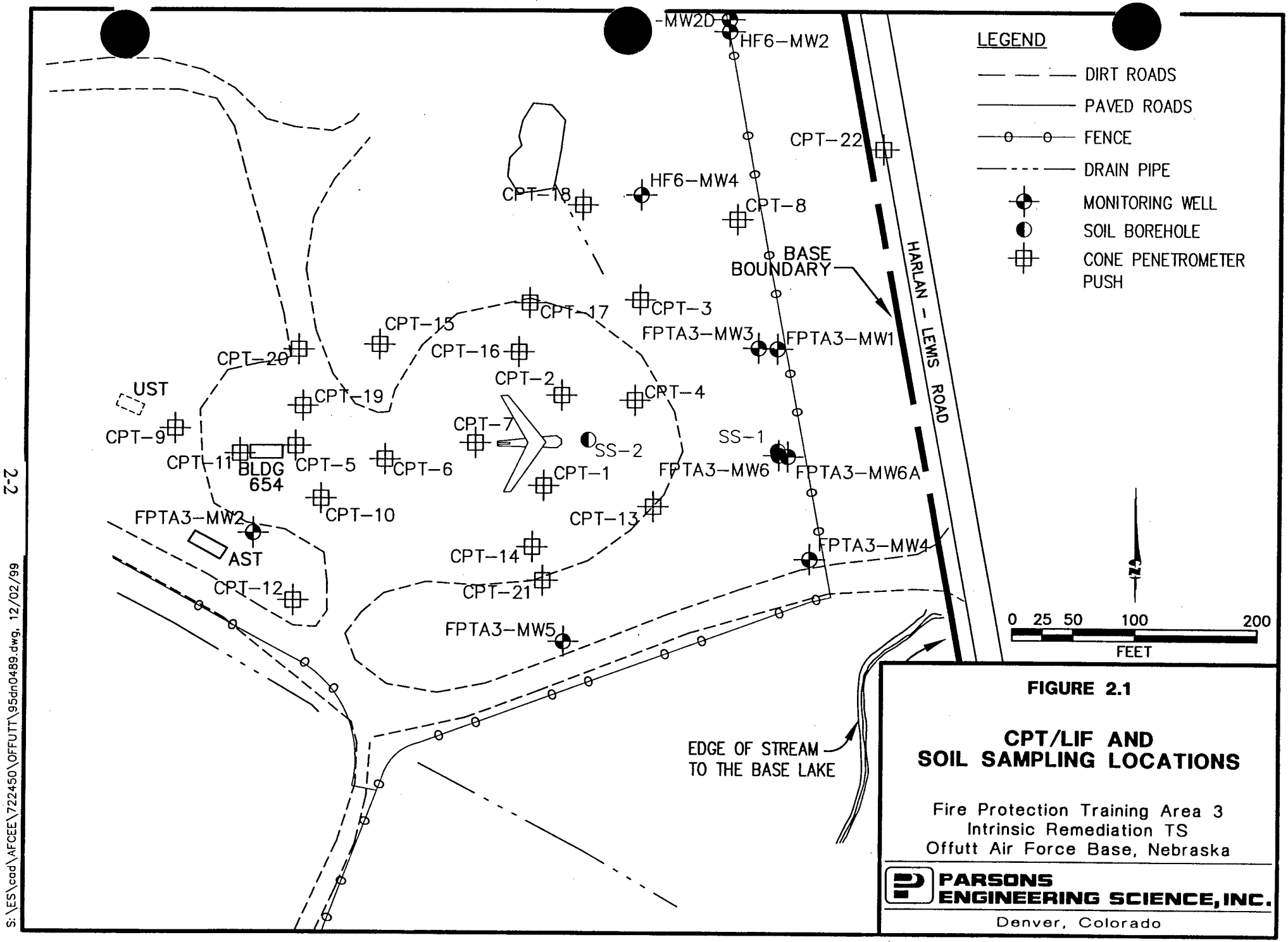

FIGURE 2.1

CPT/LIF AND SOIL SAMPLING LOCATIONS

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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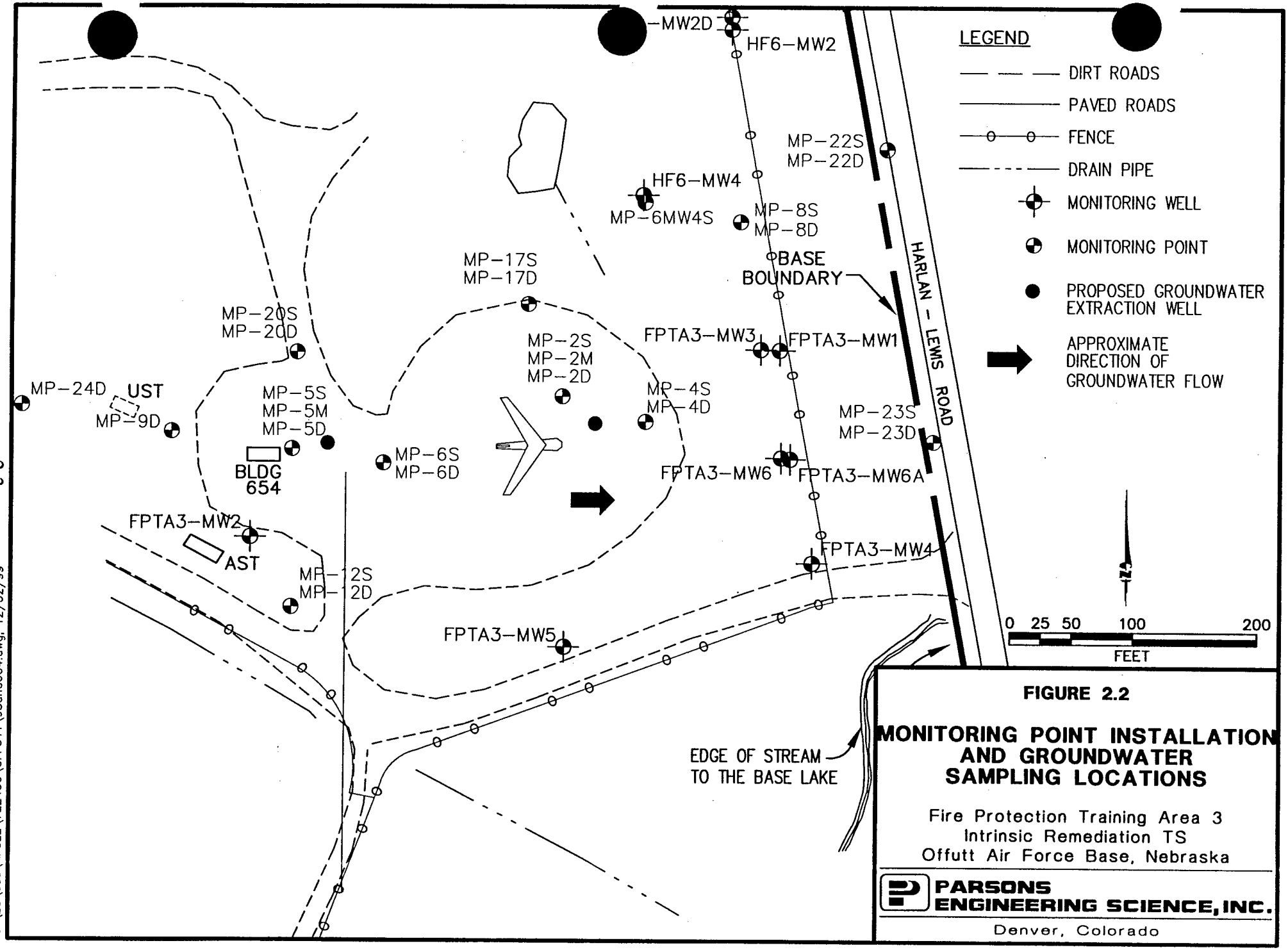

FIGURE 2.2

MONITORING POINT INSTALLATION AND GROUNDWATER SAMPLING LOCATIONS

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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TABLE 2.1
CPT ACTIVITY AND MONITORING POINT COMPLETION SUMMARY
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Location	CPT/LIF Profile Available[a/] (Y/N)	Ground Elevation (ft msl)[b/]	Total Depth (ft bgs)[c/]	Soil Sample Interval (ft msl)	Depth to Screen Top (ft bgs)	Depth to Screen Bottom (ft bgs)	Screen Elevation Top (ft msl)	Screen Elevation Bottom (ft msl)	Midpoint (ft msl)
CPT-1	Y	961.9	16.9	NS[d/]	-[e/]	-			
CPT-2	Y	962.0	16.9	4.0-4.8	-	-			
MP-2S	N	962.0	8.0	NS	4.55	7.75	957.5	954.3	955.9
MP-2M	N	962.0	18.0	NS	14.55	17.75	947.5	944.3	945.9
MP-2D	N	962.0	28.0	NS	24.55	27.75	937.5	934.3	935.9
CPT-3	Y	963.2	13.3	NS	-	-			
CPT-4	Y	964.9	16.9	NS	-	-			
MP-4S	N	964.9	12.5	NS	9.05	12.25	955.9	952.7	954.3
MP-4D	N	964.9	22.5	NS	19.05	22.25	945.9	942.7	944.3
CPT-5	Y	964.6	14.4	4.8-5.6	-	-			
CPT-5	Y	964.6	29.9	NS	-	-			
MP-5S	N	964.6	11.0	NS	7.55	10.75	957.1	953.9	955.5
MP-5M	N	964.6	21.0	NS	17.55	20.75	947.1	943.9	945.5
MP-5D	N	964.6	31.0	NS	27.55	30.75	937.1	933.9	935.5
CPT-6	Y	964.7	26.5	NS	-	-			
MP-6S	N	964.7	11.0	NS	7.55	10.75	957.2	954.0	955.6
MP-6D	N	964.7	21.0	NS	17.55	20.75	947.2	944.0	945.6
CPT-7	Y	961.7	29.9	NS	-	-			
CPT-8	Y	963.4	25.9	NS	-	-			
MP-8S	N	963.4	11.0	NS	7.55	10.75	955.9	952.7	954.3
MP-8D	N	963.4	21.0	NS	17.55	20.75	945.9	942.7	944.3
CPT-9	Y	962.9	72.6	NS	-	-			
MP-9D	N	962.9	21.0	NS	17.55	20.75	945.4	942.2	943.8
CPT-10	Y	964.3	23.4	NS	-	-			
CPT-11	Y	964.5	20.1	NS	-	-			
CPT-12	Y	963.3	20.0	NS	-	-			
MP-12S	N	963.3	11.0	NS	7.55	10.75	955.8	952.6	954.2
MP-12D	N	963.3	21.0	NS	17.55	20.75	945.8	942.6	944.2
CPT-13	Y	965.2	23.0	NS	-	-			
CPT-14	Y	963.9	23.2	NS	-	-			
CPT-15	Y	963.4	20.0	NS	-	-			

TABLE 2.1 (Continued)
CPT ACTIVITY AND MONITORING POINT COMPLETION SUMMARY
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Location	CPT/LIF Profile Available[a/] (Y/N)	Ground Elevation (ft msl)[/b]	Total Depth (ft bgs)[c/]	Soil Sample Interval (ft msl)	Depth to Screen Top (ft bgs)	Depth to Screen Bottom (ft bgs)	Screen Elevation Top (ft msl)	Screen Elevation Bottom (ft msl)	Midpoint (ft msl)
CPT-16	Y	963.4	23.2	NS	-	-			
CPT-17	Y	965.0	23.2	NS	-	-			
MP-17S	N	965.0	13.0	NS	9.55	12.75	955.5	952.3	953.9
MP-17D	N	965.0	22.9	NS	19.45	22.65	945.6	942.4	944.0
CPT-18	Y	963.4	20.0	NS	-	-			
CPT-19	Y	963.9	20.0	NS	-	-			
CPT-20	Y	963.5	20.0	NS	-	-			
MP-20S	N	963.5	11.5	NS	8.05	11.25	955.5	952.3	953.9
MP-20D	N	963.5	21.5	NS	18.05	21.25	945.5	942.3	943.9
CPT-21	Y	964.7	19.8	NS	-	-			
CPT-22	Y	967.3	29.9	NS	-	-			
MP-22S	N	967.3	16.5	NS	13.05	16.25	954.3	951.1	952.7
MP-22D	N	967.3	26.5	NS	23.05	26.25	944.3	941.1	942.7
MP-23S	N	967.9	17.0	NS	13.55	16.75	954.4	951.2	952.8
MP-23D	N	967.9	27.0	NS	23.55	26.75	944.4	941.2	942.8
MP-24D	N	962.2	21.0	NS	17.55	20.75	944.7	941.5	943.1
MP-6MW4S	N	963.4	10.9	NS	7.45	10.65	956.0	952.8	954.4

[a/] CPT/LIF = Cone Penetrometer Test/Laser-Induced Fluoresence.

[b/] ft msl = Feet above mean sea level.

[c/] ft bgs = Feet below ground surface.

[d/] NS = Not Sampled.

[e/] - = Not Applicable

0.5-inch monitoring points. Samples were not collected from points MP-2S, MP-5S, MP-6S, MP-12S, and MP-17S because they produced an insufficient volume of groundwater. Groundwater samples were analyzed by USEPA personnel in the field for pH, conductivity, temperature, dissolved oxygen (DO), reduction/oxidation (redox) potential, total alkalinity, free carbon dioxide, ferrous iron, sulfide, phenols, and soluble manganese. Analyses for BTEX, TMBs, chlorinated solvents, nitrate/nitrite, ammonia, chloride, sulfate, methane, ethene, TOC, total inorganic carbon, fuel carbon, and metals were performed at the RSKERL in Ada, Oklahoma.

Static groundwater levels were measured in all site wells prior to purging for groundwater sampling and at the conclusion of the field effort. Two rising head slug tests were performed at each of two monitoring wells: FPTA3-MW6 and HF6-MW4. Monitoring wells FPTA3-MW6 and HF6-MW4 were selected for slug tests based upon a lack of free product, and a determination from borehole logs that the screened intervals for these wells were representative of the shallow aquifer.

The investigation activities were used to collect the following physical and chemical hydrogeologic data:

- Depth from measurement datum to the water table or potentiometric surface in monitoring wells;
- Rate of change of water elevation following rapid depression or elevation of water level in a monitoring well;
- Location of potential groundwater recharge and discharge areas;
- Stratigraphy of subsurface media;
- Extent of residual petroleum hydrocarbon contamination in soils;
- Concentrations of chlorinated solvents, fuel carbon, DO, nitrate, ferrous iron, sulfate, methane, chloride, and ammonia in groundwater;
- Temperature, specific conductance, redox potential, total alkalinity, and pH of groundwater;
- Concentrations of BTEX, TMB, and TOC in groundwater and soil samples; and
- TCE, PCE, and TOC concentrations in soil samples.

In addition to the work conducted under this program, complementary site characterization data were previously collected by ES, W-C, and B&V. These activities included soil gas surveys, soil sampling for chemical and geophysical analysis; groundwater sampling for laboratory analysis on at least 5 occasions from site monitoring wells; slug testing; and measuring static groundwater levels. Previously collected data and data collected under this program were integrated to develop the conceptual site model and to aid with interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

The remainder of section 2 describes the procedures followed during the field work phase of the TS. Additional details regarding investigative activities are presented in the draft work plan (Parsons ES, 1994).

2.1 CONE PENETROMETRY

Subsurface conditions at the site were characterized using CPT coupled with LIF on September 27, and from November 15 through 17, 1994. The purpose of the CPT/LIF sampling at the site was to determine subsurface stratigraphy and to help delineate the extent of petroleum hydrocarbon contamination.

2.1.1 Determination of Stratigraphy

Cone penetrometry is an expeditious and effective means of analyzing the stratigraphy of a site by measuring the resistance against the conical probe of the penetrometer as it is pushed into the subsurface. Stratigraphy is determined from a correlation of the point stress at the probe tip and frictional stress on the side of the cone. Stratigraphy as determined from the CPT is checked against previous soil data or to soil samples collected to correlate the CPT readings to the lithologies present at the site. Methodologies for the collection of soil samples are described in Section 2.1.3.

CPT was conducted using the US Army Corps of Engineers' (USACE's) cone penetrometer truck. This equipment consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck, with the weight of the truck providing the necessary reaction mass. The penetrometer equipment is housed in a stainless steel, dual-compartment body mounted on a 43,000-pound, triple-axle Kenworth® truck chassis powered by a turbo-charged diesel engine. The weight of the truck and equipment is used as ballast to achieve the overall push capability of 39,000 pounds. This push capacity may be limited in tight soils by the structural bending capacity of the 1.8-inch outside-diameter (OD) push rods, rather than by the weight of the truck. (Some applications use 1.4-inch OD push rods). The current 39,000-pound limitation is intended to minimize the possibility of push-rod buckling. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

The penetrometer probe is of standard dimensions, having a 1.8-inch OD, 60-degree conical point with sacrificial tip, and an 8.0-inch-long by 1.8-inch-OD friction sleeve. Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross-section which is instrumented with four strain gauges in a full-bridge circuit. Forces are sensed by the load cells, and the data are transmitted from the probe assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometry truck. A grout tube also runs down the push cylinder to allow the introduction of cement grout into the hole in order to seal the CPT hole. The USACE CPT is not equipped to monitor pore pressure; therefore, the location of the water table was not measured using the CPT apparatus. Evaluation of point and sleeve stresses can often provide an estimated depth to groundwater. The penetrometer is usually advanced vertically into the soil at a constant rate of 2 centimeters per second (cm/s), although this rate must sometimes be reduced, such as when hard layers are encountered.

2.1.2 Investigation of Residual and Free-Phase Hydrocarbons

The known propensity of aromatic hydrocarbons to fluoresce under ultraviolet wavelengths has allowed the use of LIF technology, in conjunction with CPT technology, to detect soil characteristics and hydrocarbon contamination simultaneously. The LIF is not capable of detecting chlorinated solvents. The LIF system has a 0.25-inch sapphire window in the side of the cone that allows a laser to scan the soil for fluorescent compounds as the LIF penetrometer rod pushes through soil. Assuming that aromatic hydrocarbons are simultaneously solvenated with other fuel-hydrocarbon constituents, the magnitude of aromatic fluorescence is indicative of hydrocarbon contamination in a soil matrix. Fiber optic cables connected to the laser spectrometer and a 6-pair electrical conductor connected to the CPT data acquisition system, are routed through the interior of the push tubes to the CPT probe.

The basic components of the LIF instrument are a nitrogen laser, a fiber optic probe, a monochromator for wavelength resolution of the return fluorescence, a photomultiplier tube to convert photons into an electrical signal, a digital oscilloscope for waveform capture, and a control computer. The fiber optic probe for the cone penetrometer consists of delivery and collection optical fibers, a protective sheath, a fiber optic mount within the cone, and a 0.25-inch sapphire window (Figure 2.3). The wavelength used in the USACE CPT LIF system gives the strongest fluorescence signal (attributable to the presence of contamination) for naphthalene and heavier long-chained hydrocarbons. Thus, while the LIF is not entirely appropriate for detecting the fluorescence of BTEX, it is useful for defining soil contamination because the heavier long-chained hydrocarbons are more likely to sorb to the soil matrix.

Graphical results of each LIF/CPT push were plotted by USACE staff at the conclusion of each penetration and were available minutes after the completion of each hole. The graphs showed cone resistance, sleeve friction, soil classification, fluorescence intensity, and maximum fluoresced wavelength. The real-time availability of the CPT information allowed the Parsons ES field scientist to make investigative decisions based on the most current information. Final CPT logs are presented in Appendix A.

2.1.3 Soil Sample Collection

Single soil samples were obtained using a Hoggen-Toggler® sampling device at CPT-2 and -5. A Hoggen Toggler® sampler generally can be used to collect undisturbed soil samples at any desired depth within the range of the driving apparatus. The sampler is coupled to the penetrometer rod and pushed into the soil with the CPT truck. With the Hoggen Toggler® cone in the closed position, soil is prevented from entering the sampling tube until the desired depth is achieved. When the sampler has been pushed to the depth at which the soil sample is to be taken, the sampling unit is raised a few inches and the Hoggen Toggler® apparatus is opened. The open Hoggen Toggler® is pushed to

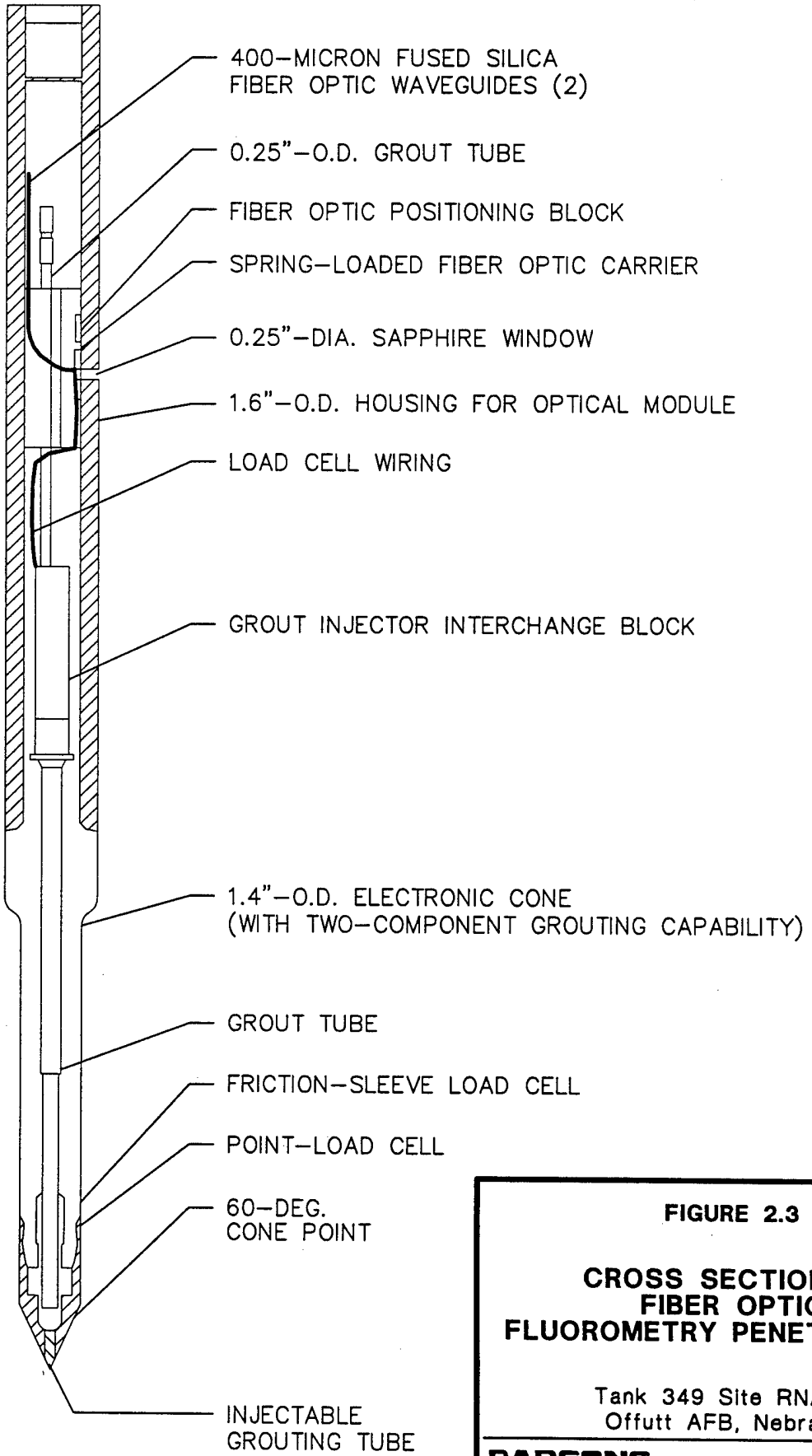

FIGURE 2.3

CROSS SECTION OF FIBER OPTIC FLUOROMETRY PENETROMETER

Tank 349 Site RNA TS
Offutt AFB, Nebraska

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Denver, Colorado

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fill with soil, then pulled from the ground as quickly as possible. The Hoggen Toggler® sampling apparatus allows collection of 8-inch-long by 1-inch inside-diameter (ID) continuous samples. Recovery efficiencies for samples in saturated or sandy soils are often reduced, or the samples are compromised, because of spillage of the soil from the device after extraction. To mitigate this problem, soil samples will be compressed *in situ* with the penetrometer and Hoggen Toggler® assembly to expel the pore water before extraction.

For sampling that occurred on September 27, recovered soil was placed in clean 2-ounce glass jars with Teflon®-lined caps and shipped to the USEPA/RSKERL for analysis of BTEX, TCE, PCE, and TOC. For each sample, the Parsons ES field scientist recorded the following information:

- Sample interval (top and bottom depth);
- Presence or absence of contamination;
- Lithologic description, including major textural constituents, minor constituents, porosity, color, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and
- Any unusual conditions.

2.1.4 Monitoring Point Installation

The USACE staff installed 25 0.5-inch ID monitoring points at 13 locations in the vicinity of the site. Clusters of 3 monitoring points were installed at CPT-2 and -5. Clusters of 2 monitoring points were installed at CPT-4, -6, -8, -12, -17, -20, -22, and -23. Single monitoring points were installed at CPT-9 and -24 and in a cluster with monitoring well HF6-MW4. Where monitoring points were installed in clusters, the shallowest screen was placed across or just below the water table. Screens for deeper monitoring points within the same cluster were placed approximately 10 feet below the next shallowest point in the cluster. Within each monitoring point cluster, the point with the shallowest screened interval was designated with the suffix "S", while the point with the deepest screened interval was designated with the suffix "D". The intermediate depth point in the three-point clusters was designated with the suffix "M". All installed monitoring points are shown on Figure 2.2. A summary of monitoring point construction details is provided in Table 2.2. Monitoring point completion diagrams are provided in Appendix A.

2.1.4.1 Materials

Monitoring points were constructed of flush threaded 0.5-inch ID/0.75-inch OD polyvinyl chloride (PVC) casing and screen. Installed screens were 3.3 feet in length with factory-slotted 0.010-inch openings. The sacrificial stainless steel CPT tip was screwed into the PVC screen and served as the bottom cap of the monitoring point when the push was completed. Each monitoring point was fitted with a PVC top cap upon completion. Monitoring point materials were inspected for cleanliness prior to use. If not factory-sealed, casing, screen, and sacrificial tips were cleaned prior to use with a

high-pressure, steam/hot-water cleaner. No glue or solvents were used with monitoring point materials.

2.1.4.2 Installation

Monitoring points were pressed into the ground through the inside of 1.8-inch-OD CPT pushrods. This method protects the monitoring point screen and casing until the monitoring point has been pushed to the desired depth and the pushrods are removed. To accomplish this, the PVC screen was threaded through the bottom CPT pushrod. A sacrificial tip was screwed into the bottom of the screen and pressed into the bottom of the CPT pushrod. As the pushrod was pressed into the ground, CPT pushrods and new PVC casing were continuously attached until the desired depth was reached. Upon removal of the pushrods, a fully-cased monitoring point remained. Data collection devices such CPT and LIF could not be used during monitoring point placement; however, CPT tests were generally performed prior to monitoring point installation in order to select desired depths.

2.1.4.3 Development

Prior to sampling, 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 CPT apparatus to place monitoring points minimizes the amount of fine sediment that might accumulate in the casing.

Monitoring point development was accomplished using a peristaltic pump with new dedicated or decontaminated (Section 2.1.6) high-density polyethylene (HDPE) tubing. The pump tubing was regularly lowered to the bottom of the well so that fines were agitated and removed from the well in the development water. Development was continued until a minimum of 10 casing volumes of water were removed from the well and the temperature and DO concentrations of the groundwater had stabilized.

All development water was contained and transferred into 55-gallon drums. The drums were labeled with the date, contents, generation location, and generators. Drums were removed from site daily and stored in a secured barrel storage area identified by Civil Engineering Squadron-Environmental (55 CES/CEVR) personnel.

2.1.4.4 At-Grade Completion

Each monitoring point was completed with an at-grade protective cover. Along Harlan-Lewis Road, the at-grade cover was installed in a cement pad flush with the surrounding road shoulder to prevent damage to the monitoring points during snow removal or other such road maintenance activities. At all other FPTA3 locations, the concrete immediately surrounding the monitoring point was sloped gently away from the protective casing to facilitate runoff during precipitation. Because the points were finished at grade, the monitoring point top caps were not vented.

2.1.5 CPT Hole Abandonment

The CPT/LIF probe is equipped with a grout tube and sacrificial tip; therefore, CPT/LIF holes were sealed with a Portland® cement grout as the CPT pushrod was withdrawn. Collection of samples with the Hoggen-Toggler® sampler did not allow for grouting during pushrod withdrawal; therefore, these holes were abandoned with Portland® cement from the ground surface after sample collection.

2.1.6 Equipment Decontamination

After sampling at each CPT location, CPT push rods were cleaned with the CPT steam-cleaning system (rod cleaner) as the rods were withdrawn from the ground. A vacuum system located beneath the CPT truck was used to recover cleaning water. Use of this system resulted in nearly 100-percent recovery of steam-cleaning rinseate from the rod cleaner. Rinseate was generated only as the rods moved past the cleaner, thereby minimizing liquid waste generation.

Rinseate was collected in 55-gallon drums provided by USACE. The filled 55-gallon drums were labeled and transported to a secure drum storage location designated by 55 CES/CEVR personnel. The three drums of decontamination water collected between September 23 and September 28, were analyzed in the field for pH, alkalinity, chloride, hardness, iron, and volatile organic compounds (VOCs) in the headspace. The drum contents were also checked for odor, sheen, and discoloration. The results and observations were provided to 55 CES/CEVR personnel for drum disposal.

All soil sampling tools were cleaned onsite with a steam/hot-water spray prior to use and between each sampling location.

Potable water used in CPT equipment cleaning, decontamination, or grouting was obtained from one of the Base water supplies. Water use approval was verified by contacting the appropriate facility personnel. Precautions were taken to minimize any impact to the surrounding area that might result from decontamination operations.

2.2 GROUNDWATER SAMPLING

Groundwater samples were collected at 11 monitoring wells and 22 of 25 newly-installed monitoring points during November 1994 (Figure 2.2). Groundwater samples were not collected at monitoring points MP-2S, MP-5S, MP-6S, MP-12S, and CPT-17S due to insufficient groundwater production. Groundwater sampling forms were used to document the specific details of the sampling event for each well. In addition to the sampling events conducted under this program, ES and W-C have conducted groundwater sampling at the site.

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, 1994) and summarized in the following sections were followed.

2.2.1 Preparation for Sampling

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

2.2.1.1 Equipment Decontamination

All portions of sampling and test equipment that contacted the sample were thoroughly cleaned before use. The sampling pump, pump tubing, and water level indicator were the only reusable pieces of equipment which came in contact with groundwater samples or were used down the well. The following protocol was used to clean all surfaces of the Grundfos Redi-Flo 2® pump and water level indicator that contacted the groundwater or was lowered downhole:

- Cleaned with potable water and Alconox® detergent; and
- Rinsed with potable water until detergent was removed; and
- Air dried prior to use.

Generally, cleaning was not required with the HDPE tubing used for the peristaltic pump because a new length of tubing was dedicated to the well or monitoring point; however, when the HDPE tubing was reused, it was cleaned inside and out with acetone and rinsed with deionized water. Decontaminated tubing was dedicated to a particular monitoring point for development, purging, and sampling so that by the time sampling occurred, a large volume of groundwater had passed through the tubing. Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form.

All cleaning fluids were contained and transferred to 55-gallon drums. The drums were labeled with the date, contents, generation location, and generators. Drums were removed from site daily and stored in a secured barrel storage area identified by 55 CES/CEVR personnel.

2.2.1.2 Equipment Calibration

Field analytical equipment was calibrated according to the manufacturers' specifications prior to field use, and as required. As the majority of physical and chemical analyses were performed by USEPA/RSKERL personnel, this requirement applied specifically to the Orion® DO meter.

2.2.1.3 Preparation of Location

Prior to proceeding with sampling, the area around the well or monitoring point was cleared of foreign materials, such as brush, rocks, and debris to prevent 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.

2.2.1.4 Water Level and Total Depth Measurements

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

Static groundwater levels were also measured on November 19, 1994, near the conclusion of the field activities. Measurements were obtained at all site wells and monitoring points.

2.2.2 Well Purging and Sample Collection

Well purging consisted of removing at least three casing volumes of water prior to sample collection. At all groundwater sampling locations except the deep wells FPTA3-MW1 and HF6-MW2D, a peristaltic pump was used to purge and sample the wells and monitoring points. A Grundfos Redi-Flo 2® pump was used to purge and sample the two deep monitoring wells. Once three casing volumes of water were removed from the well or monitoring point, purging continued until the temperature and DO concentrations had stabilized.

Within 24 hours of the purge, groundwater samples were extracted with either a peristaltic pump or Grundfos Redi-Flo 2® pump as specified in the preceding paragraph. Sample containers were filled directly from the pump discharge tubes. The groundwater was directed towards the bottle wall near the top and allowed to run down the inner walls of the sample bottle in order to minimize aeration of the sample. Sample bottles for BTEX plus TMB and dissolved gas analyses were filled so that there was no headspace or air bubbles within the container.

All groundwater derived from purging and sampling was contained and transferred to 55-gallon drums. The drums were labeled with the date, contents, generation location, and generators. Drums were removed from site daily and stored in a secured drum storage area identified by 55 CES/CEVR personnel.

2.2.3 Onsite Chemical Parameter Measurement

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

2.2.3.1 Dissolved Oxygen Measurements

DO measurements were taken using an Orion® model 840 DO meter in a flow-through cell at the outlet of the peristaltic pump or Grundfos Redi-Flo 2® pump. DO

concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

2.2.3.2 Temperature Measurements

Because the temperature changes significantly within a short time following sample acquisition, it was measured at the time of sample collection, in the same flow-through cell in which DO was measured. The temperature was recorded in the groundwater sampling record.

2.2.4 Sample Handling

2.2.4.1 Sample Preservation

The USEPA/RSKERL personnel provided appropriately preserved sample bottles. Samples were delivered to the USEPA mobile laboratory within minutes of sample collection. Samples for those analyses not performed by the mobile laboratory were shipped by the USEPA field personnel to the RSKERL in Ada, Oklahoma for analysis.

2.2.4.2 Sample Containers and Labels

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

- Facility name;
- Sample identification;
- Sample type (groundwater);
- Sampling date;
- Sampling time;
- Preservatives added; and,
- Sample collector's initials.

2.2.4.3 Sample Shipment

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory. The following packaging and labeling procedures were followed:

- Samples were packaged to prevent leakage or vaporization from their container; and
- Samples were cushioned to avoid breakage.

As the November 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. Sample shipment to the RSKERL and associated chain-of-custody documentation was the responsibility of the USEPA/RSKERL field personnel.

2.3 HAND-AUGERED BOREHOLES AND SOIL SAMPLING

Hand-augered boreholes were advanced at two locations at FPTA3 for the purpose of collecting 14 soil samples. The boreholes were advanced within the main burn pit at location SS-2 and approximately 150 feet downgradient of the main burn pit at the FPTA3-MW6 well cluster (Figure 2.1). Soil samples were collected in each borehole at intervals of approximately 1.5 feet from ground surface to the termination of the borehole below the water table. Sampling was accomplished by transferring soil from the hand auger bucket to analyte-appropriate sampling containers. Samples were labeled and delivered to the USEPA mobile laboratory. Soil samples were analyzed for BTEX, TMBs, TCE, PCE, naphthalenes, TPH, TOC, moisture, and dehydrogenase activity. All field analyses and sample shipment were performed by on-site USEPA/RSKERL personnel.

2.4 AQUIFER TESTING

Slug tests were conducted in two monitoring wells at the site. Slug tests are single-well hydraulic tests used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. 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. At this site, two rising head tests were performed on each well. Slug tests were performed in monitoring wells FPTA3-MW6 and HF6-MW4 (Figure 2.2). Detailed slug testing procedures are presented in the *Draft Technical Protocol for Implementing the Intrinsic Remediation with Long-Term Monitoring Option for Natural Attenuation of Dissolved-Phase Fuel Contamination in Ground Water* (Wiedemeier *et al.*, 1994), hereafter referred to as the Technical Protocol document.

Data obtained during slug testing were analyzed using AQTESOLV software and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3.

2.5 SURVEYING

All site monitoring wells, monitoring points, CPT locations, soil sampling locations, and selected site reference points were surveyed by Louis Surveying of Omaha, Nebraska during the week of November 21, 1994, following completion of all field activities. All horizontal coordinates and ground surface elevations were measured to the nearest 0.1 foot relative to a Base datum. In addition, the top of casing elevation (measurement datum) for wells and monitoring points was surveyed to the nearest 0.01 foot.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of FPTA3 using information collected by Parsons ES in September and November 1994, in conjunction with data documented in previous reports on Offutt AFB. Investigative techniques used to determine the physical characteristics of the site are discussed in Section 2.

3.1 SURFACE FEATURES

3.1.1 Topography and Surface Water Hydrology

Offutt AFB is located in the dissected till plains section of the Central Lowland province, a region characterized by rolling uplands, broad gently-sloping terrace plains, and nearly flat valleys. Moderate slopes developed on eroded glacial till cover the northern half of the main base. The southeastern parts of the Base, including FPTA3, lie on an alluvial terrace of the Missouri River with very gentle to flat slopes (ES, 1990a). Base elevations range from approximately 1,150 to 960 feet above mean sea level (msl) (USGS, 1984a and 1984b). A topographic map of the Base and the surrounding area is presented on Figure 3.1.

Major surface water features in the area include the Missouri River, located 0.5 to 2 miles east of the Base boundary, and the Platte River, located approximately 3 miles south of the Base boundary. The western half of the main body of the Base is drained by storm sewers or topography to Big Papillion Creek, which flows between the Cape Hart Housing Area and the main body of the Base. Big Papillion Creek enters the Missouri River southeast of the Base. The eastern half of the main Base is drained by the Bellevue Drain that flows eastward into the Missouri River, and by unnamed streams that lead to the Base Lake, which occupies the southeast corner of the Base (Figure 3.1). The Base Lake has no surface outlet and reportedly maintains the same stage as the Missouri River. Thick permeable deposits of sand and gravel beneath the lake reportedly allow direct hydraulic connection between the lake and the river (ES, 1990a).

3.1.2 Manmade Features

FPTA3 is located in a relatively undeveloped portion of the Base that is mostly vegetated. Manmade features at the site include a small abandoned building (Building 654), two fire training pits, an above-ground storage tank (AST), an underground storage tank (UST), a perimeter fence, and a several gravel roads (Figure 1.2). At the boundaries of the site lie Hardfill 6 to the north and Harlan-Lewis Road to the east. Other significant

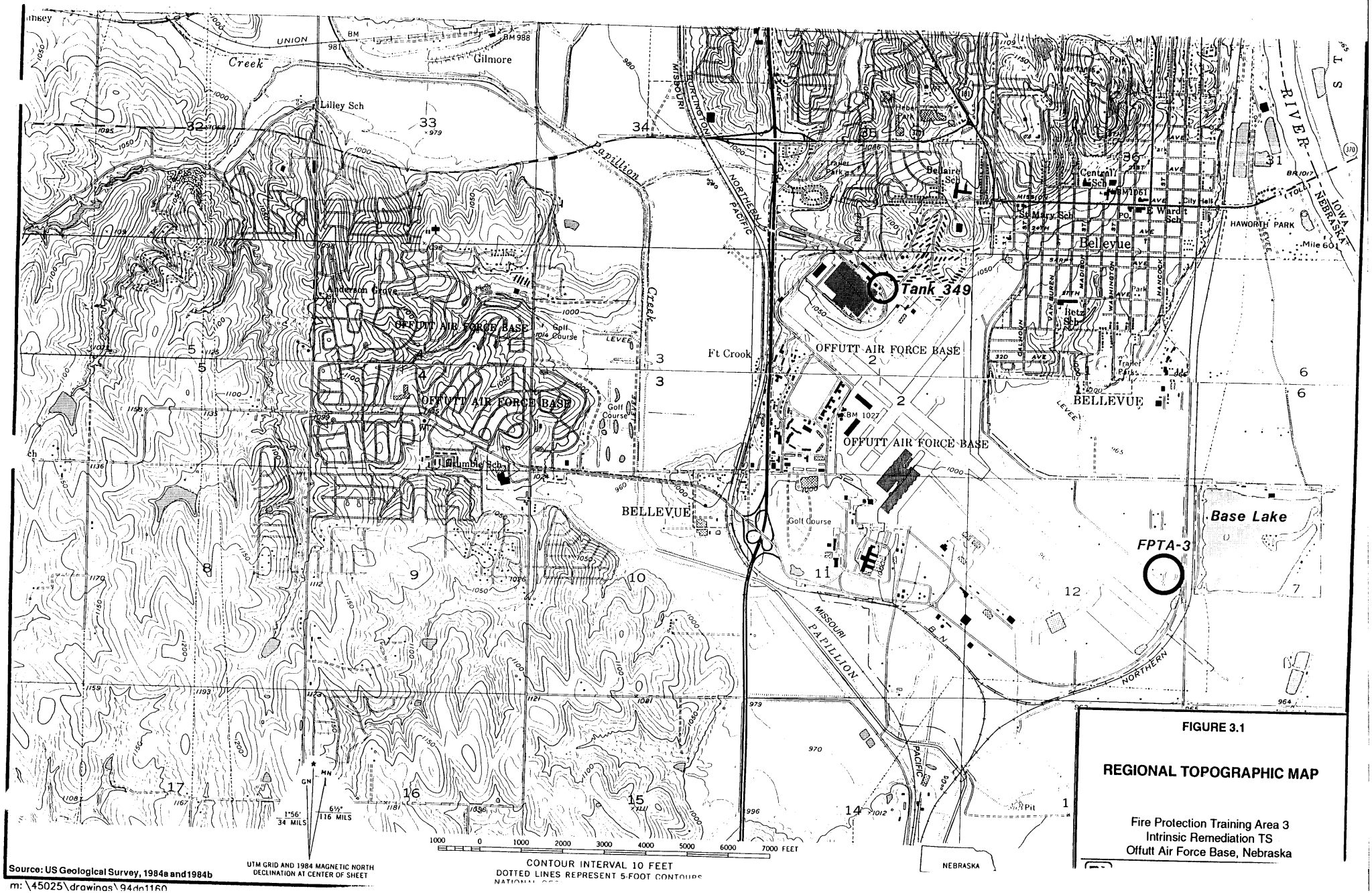

FIGURE 3.1

REGIONAL TOPOGRAPHIC MAP

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

nearby manmade constructions include the runway located approximately 1,000 feet west and southwest of the site, and the manmade base lake located approximately 700 feet east of the site.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Regionally, bedrock is composed of interbedded shale and limestone of Pennsylvanian age. Valleys in the bedrock surface represent the drainage pattern in preglacial times. With the exception of the Missouri River Valley, these valleys have been completely filled with glacial deposits. Present day topography and drainage do not reflect the presence of the buried valleys.

In the rolling upland areas, bedrock is overlain by as much as 200 feet of glacial and periglacial deposits. These deposits consist of thin, moderately permeable beds of sand and gravel, deposited during interglacial periods, alternating with thick beds of clay-rich glacial till. Three cycles of sand/gravel and till deposits are present in the region, representing glacial advances of Nebraskan, Kansan, and Illinoian Age. A mantle of periglacial loess at least 25 feet thick overlies most of the glacial till in the upland areas. The loess is a clayey silt deposited by wind following the retreat of the glaciers (ES, 1990a).

Lowland areas are occupied by alluvial and glacial fluvial sediments that range in thickness from less than 10 feet near the upland areas to greater than 100 feet near the Missouri River. The glacial fluvial deposits consist of fine to coarse sand and gravel, grading upward to alluvial fine sand and silty sand and covered by up to 20 feet of alluvial organic silt and clay (ES, 1990a). In some areas of the Base, fill materials, typically loose sands, are present at thicknesses of up to 10 feet (W-C, 1992b).

The groundwater surface generally reflects the surface topography. Hydraulic gradients in the upland areas are relatively steep where hydraulic conductivities are low, and depth to groundwater can exceed 50 feet. In lowland areas, hydraulic gradients are relatively flat, hydraulic conductivities are higher, and the depth to groundwater is frequently 10 feet or less. Base-wide hydraulic conductivities have been measured from 0.03 feet per day (ft/day) in shallow fill and alluvial clay/silt, to 270 ft/day in deep glacial outwash sand. Hydraulic conductivities in the deeper groundwater zones are almost always higher than near the groundwater surface. The highest measured shallow hydraulic conductivity was 9.5 ft/day, in alluvial silty sand. Regionally, groundwater flow is predominantly toward Papillion Creek and the Missouri River. Locally, groundwater flow may be influenced by site features such as drainage ditches, paved surfaces, and buried utilities (W-C, 1992b).

The bedrock aquifers in the Offutt AFB region are generally not used for groundwater withdrawal, and little information is available on the occurrence, yield, and quality of groundwater in the bedrock (ES, 1990a).

3.3 SITE GEOLOGY AND HYDROGEOLOGY

Characterization of the vadose zone and alluvial aquifer system at FPTA3 has been the objective of several investigations. A site inspection, supplemental site inspection, and

soil sampling investigation were conducted by ES in 1988 and 1989. These investigations included the completion of two soil gas surveys, 16 soil boreholes, and 6 monitoring wells (5 at FPTA3 and 1 at Hardfill 6). Subsequent investigations by B&V (1990) leading to remedial design included installation of 7 geotechnical soil boreholes and an additional 2 monitoring wells. Remedial investigations conducted by W-C (1992c) at Hardfill 6 included the installation of 2 additional monitoring wells which can also be used for characterization of FPTA3. As a part of the current investigation, CPT/LIF pushes were performed at 22 locations, and 2 additional soil boreholes were installed.

3.3.1 Lithology and Stratigraphic Relationships

The shallow sediments underlying FPTA3 are comprised of 1.5 to 9 feet of a silt, clay, and sand mixture in shades of olive, gray, and brown. The shallow sediments are underlain by a poorly-graded sand which frequently contains a trace or more of silt, clay, or gravel. At CPT-9, a very clayey and silty layer was identified from 54 to 68 feet bgs. A sandy gravel layer was observed from 85 to 90 feet bgs at the location of the deepest borehole, FPTA3-MW1. The depth to bedrock has not been determined.

In order to illustrate these stratigraphic relationships, hydrogeologic sections have been developed from subsurface data derived from logs of previously installed monitoring wells and from the fall 1994 CPT 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 Grain-Size Distribution

Grain-size analyses were performed by B&V (1990) on soil samples collected at 14 to 15.5 feet bgs and 39 to 40.5 feet bgs from geophysical borehole B-7. Both of these samples are representative of the poorly graded sands. The 14- to 15.5-foot sample is described as a fine silty sand, with approximately 23 percent of the soil passing through the #200 sieve. The 39- to 40.5-foot sample is classified as a fine to coarse sand, with none of the sample passing the #200 sieve. The #200 size represents the break between fine sand and silt.

3.3.3 Groundwater Hydraulics

3.3.3.1 Flow Direction and Gradient

Groundwater is first encountered in the poorly graded sands and silty sands in the vicinity of FPTA3. Depth to groundwater is approximately 8 to 10 feet bgs across the majority of the site. Generally, groundwater flow is to the east-southeast with an average

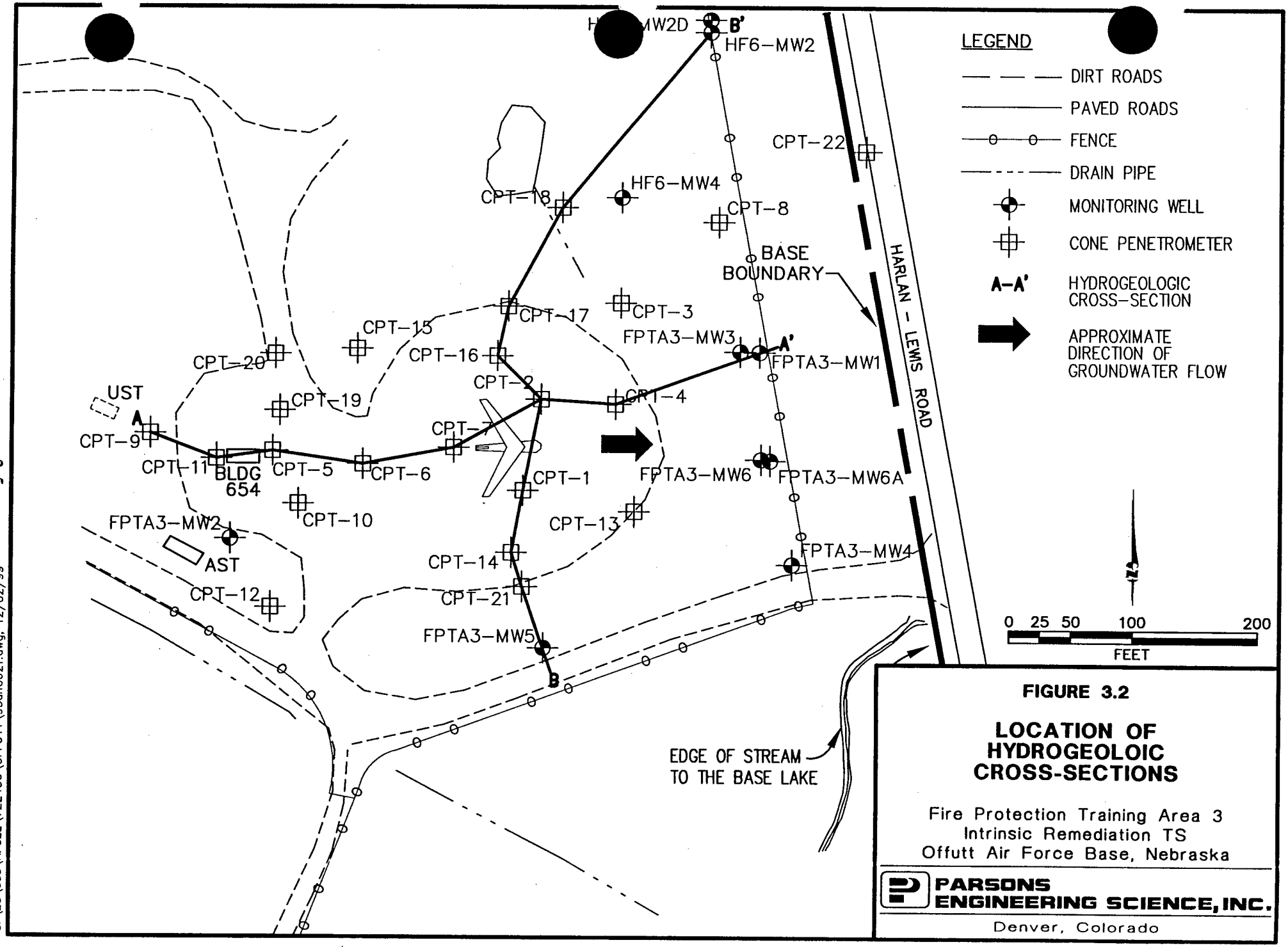

FIGURE 3.2

LOCATION OF HYDROGEOLOIC CROSS-SECTIONS

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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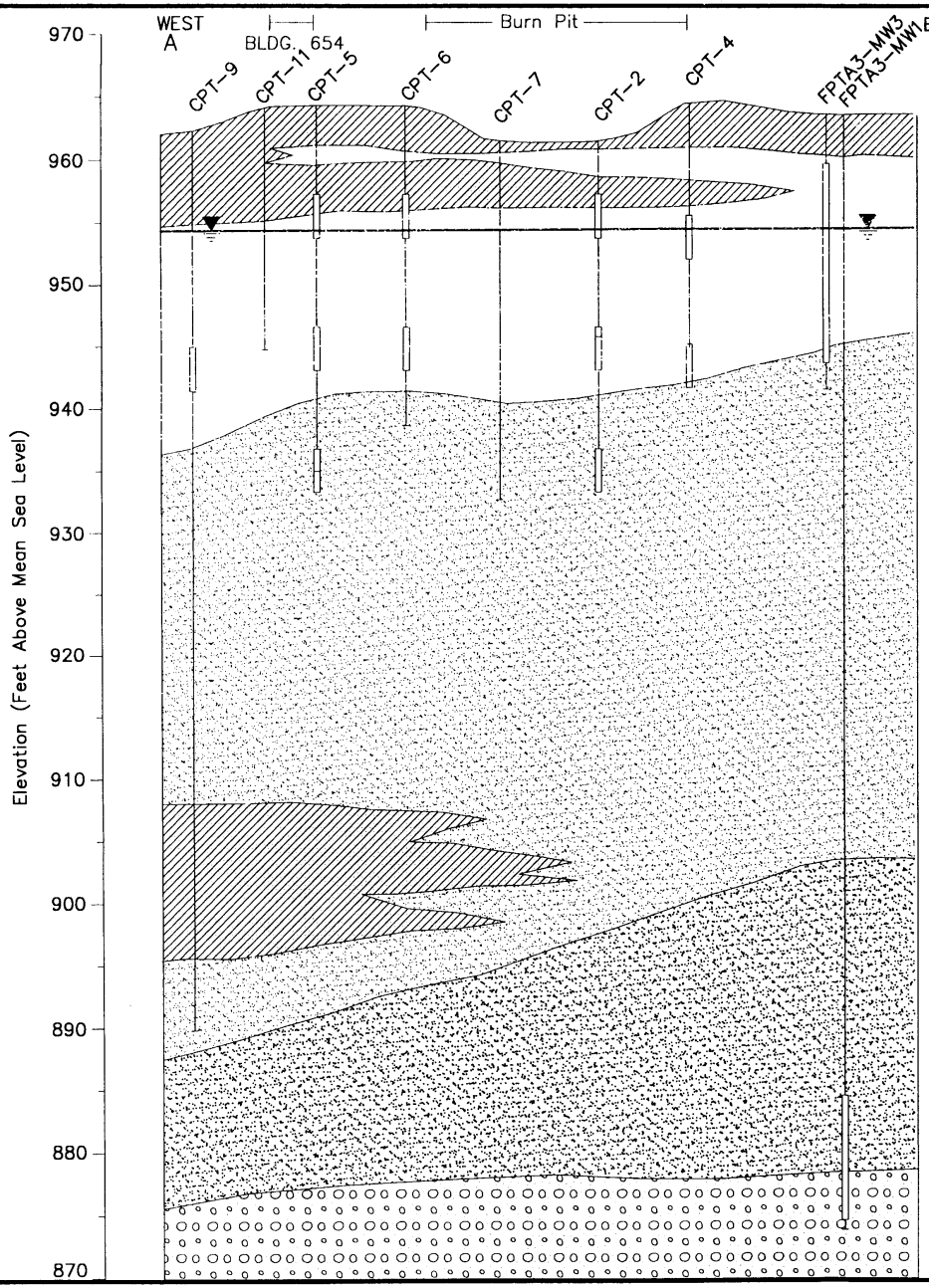

LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 — Well Identification
- Well Borehole Screen
- Bottom of Borehole
  Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 3.3

HYDROGEOLOGIC CROSS-SECTION A-A'

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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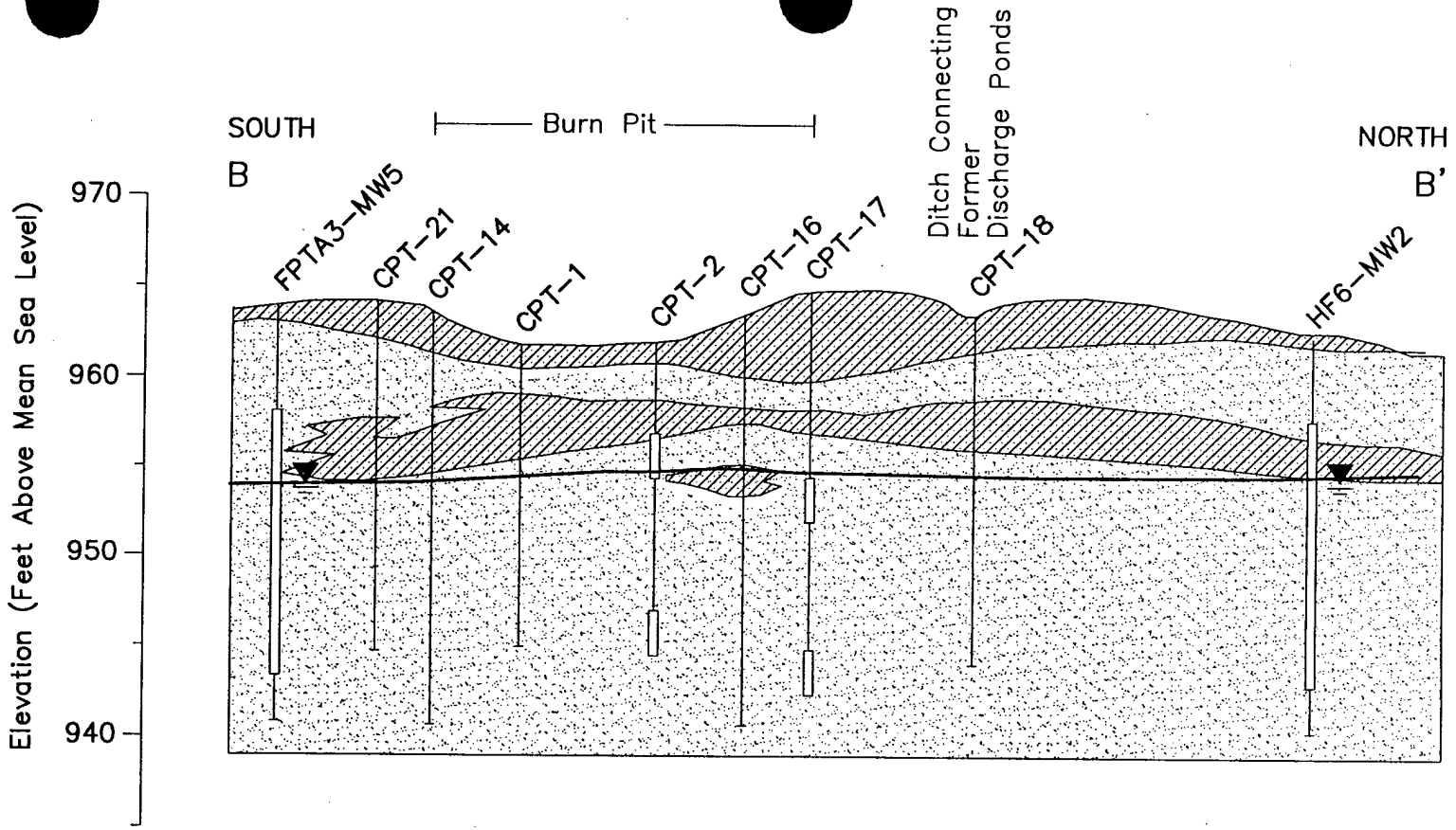

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

LEGEND

Contact
(Dashed where inferred)

CPT-17

Well Identification

Well Borehole Screen

Bottom of Borehole
Multiple screened intervals are pictured where clusters were installed at a CPT location.

Approximate Location of Water Table

SILT and/or fine to very fine SAND.

SAND, fine to very fine, trace silt and/or clay.

FIGURE 3.4

HYDROGEOLOC CROSS-SECTION B-B'

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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gradient of 0.0004 foot per foot (ft/ft) (Figure 3.5). Historically, groundwater gradients are steeper in the spring; therefore, a gradient of 0.0006 was used for modeling to account for yearly fluctuations. A summary of historical groundwater measurements is presented in Table 3.1.

A groundwater mound, as shown on Figure 3.5, disrupts the east-southeasterly groundwater flow in the vicinity of the main burn pit. The mound is believed to be the result of groundwater recharge from surface water infiltration in the main burn pit. As the top few feet of soil at the site consist of clayey silt and silty clay, groundwater recharge resulting from precipitation is believed to be negligible across the majority of the site. The only areas where recharge is expected to occur are those low-lying areas where water accumulates and remains standing for a significant length of time. The largest recharge areas include the main burn pit, the remaining discharge pond, and the drainage ditch between the eastern Base boundary fence and Harlan-Lewis Road. Groundwater recharge as a result of these features has been incorporated into the site model. As a result of the size and geometry of the main burn pit, and the density of groundwater monitoring points surrounding the main burn pit, the groundwater mound at this location is readily apparent. There are insufficient data points surrounding the discharge pond and the drainage ditch to establish whether either of these features contributes to groundwater mounding.

Evidence suggests that significant vertical flow gradients within the shallow aquifer are not present at this site. Two monitoring well clusters had shallow wells screened across the water table and deep wells screened at least 70 feet below the water table. Vertical gradients were computed at 0.00013 ft/ft up and 0.0004 ft/ft down. As these gradients are relatively small and in opposing directions, the vertical gradient averaged across the upper 70 to 90 feet of the aquifer is believed to be negligible. Vertical gradients were also computed across the upper 10 to 20 feet of the aquifer at 10 monitoring point clusters. Magnitudes ranged from 0.003 ft/ft up to 0.008 ft/ft down with downward gradients at 8 of the 10 clusters. The average vertical gradient for the 10 monitoring points clusters was measured at 0.003 ft/ft down. In conclusion, a downward vertical gradient exists in the upper portion of the aquifer; however, the gradient is believed to dissipate with depth. This can be observed in the vertical profile of the potentiometric surface presented on Figure 3.6.

3.3.2.2 Hydraulic Conductivity

Hydraulic conductivities ranging from 7.7 to 9.5 feet per day (ft/day) were reported for wells screened across the water table within silty sand at FPTA3 (W-C, 1992b). The hydraulic conductivities were estimated from rising head slug tests performed on site wells. The same range was reported for water table wells at the adjacent site, Hardfill 6. W-C (1992b) reported a range of 42 to 58 feet per day for sands at the base of the aquifer at Hardfill 6.

Parsons ES estimated the hydraulic conductivity at wells FPTA3-MW6 and HF6-MW4 using rising head slug tests and the methods of Bouwer and Rice (1976) as described in Section 2. The results of these slug tests are summarized in Table 3.2. The average hydraulic conductivity of the sands in the shallow saturated zone as determined

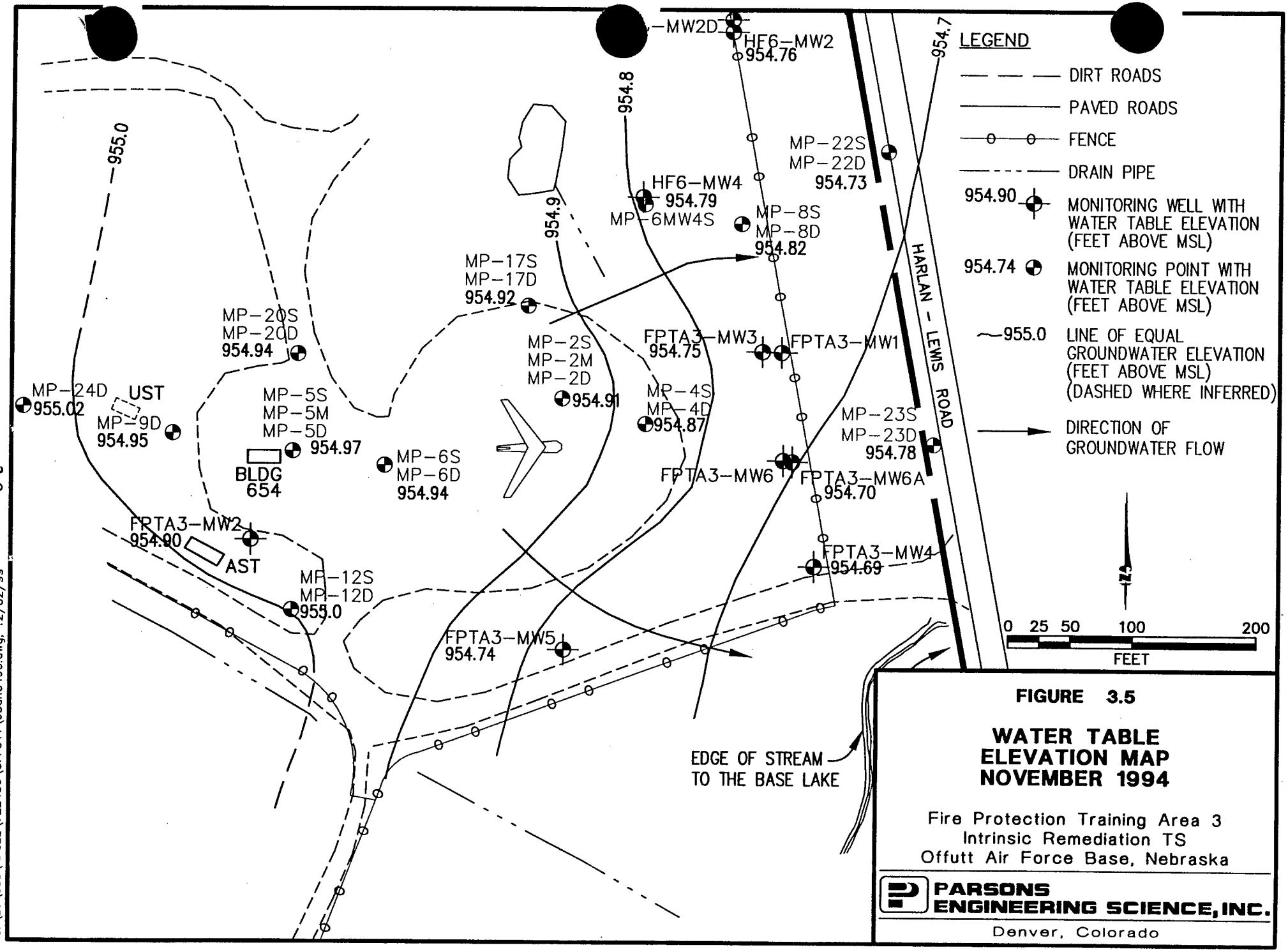

FIGURE 3.5

WATER TABLE ELEVATION MAP NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 3.1
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Location	Measurement Date	Datum Elevation (ft msl) [a/]	Depth to Water (ft TOC) [b/]	Groundwater Elevation (ft msl)
HF6-MW1	Nov-94	962.89	7.66	955.23
HF6-MW2	Aug-91	964.82	11.28	953.54
	Oct-91	964.82	11.89	952.93
	Dec-91	964.82	11.88	952.94
	Mar-92	964.82	11.57	953.25
	Apr-92	964.82	11.27	953.55
	May-92	964.82	10.24	954.58
	Aug-92	964.82	10.17	954.65
	Nov-94	964.47	9.71	954.76
HF6-MW2D	Nov-94	965.17	10.40	954.77
HF6-MW4	Aug-91	966.14	12.54	953.60
	Oct-91	966.14	13.13	953.01
	Dec-91	966.14	13.11	953.03
	Mar-92	966.14	12.80	953.34
	Apr-92	966.14	12.51	953.63
	May-92	966.14	11.43	954.71
	Aug-92	966.14	11.44	954.70
	Nov-94	965.79	11.00	954.79
MP-6MW4S	Nov-94	963.34	8.51	954.83
FPTA3-MW1	Aug-91	965.77	12.25	953.52
	Oct-91	965.77	12.89	952.88
	Dec-91	965.77	12.88	952.89
	Mar-92	965.77	12.61	953.16
	Apr-92	965.77	12.31	953.46
	May-92	965.77	11.23	954.54
	Aug-92	965.77	11.16	954.61
	Nov-94	965.42	10.70	954.72
FPTA3-MW2	Aug-91	964.98	11.22	953.76
	Oct-91	964.98	11.79	953.19
	Dec-91	964.98	7.68	957.30
	Mar-92	964.98	11.14	953.84
	Apr-92	964.98	10.89	954.09
	May-92	964.98	9.85	955.13
	Aug-92	964.98	10.09	954.89
	Nov-94	964.66	9.76	954.90

TABLE 3.1 (Continued)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Location	Measurement Date	Datum Elevation (ft msl) [a/]	Depth to Water (ft TOC) [b/]	Groundwater Elevation (ft msl)
FPTA3-MW3	Aug-91	964.37	10.86	953.51
	Oct-91	964.37	11.48	952.89
	Dec-91	964.37	11.44	952.93
	Mar-92	964.37	11.17	953.20
	Apr-92	964.37	10.88	953.49
	May-92	964.37	9.75	954.62
	Aug-92	964.37	9.75	954.62
	Nov-94	964.02	9.27	954.75
FPTA3-MW4	Aug-91	966.17	12.65	953.52
	Oct-91	966.17	13.29	952.88
	Dec-91	966.17	13.29	952.88
	Mar-92	966.17	13.04	953.13
	Apr-92	966.17	12.74	953.43
	May-92	966.17	11.65	954.52
	Aug-92	966.17	11.60	954.57
	Nov-94	965.81	11.12	954.69
FPTA3-MW5	Aug-91	966.43	12.79	953.64
	Oct-91	966.43	13.39	953.04
	Dec-91	966.43	13.37	953.06
	Mar-92	966.43	13.02	953.41
	Apr-92	966.43	12.72	953.71
	May-92	966.43	11.63	954.80
	Aug-92	966.43	11.72	954.71
	Nov-94	966.06	11.32	954.74
FPTA3-MW6	Aug-91	966.01	12.49	953.52
	Oct-91	966.01	13.10	952.91
	Dec-91	966.01	13.10	952.91
	Mar-92	966.01	12.84	953.17
	Apr-92	966.01	12.55	953.46
	May-92	966.01	11.40	954.61
	Aug-92	966.01	11.42	954.59
	Nov-94	965.65	10.97	954.68

TABLE 3.1 (Continued)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Location	Measurement Date	Datum Elevation (ft msl) [a/]	Depth to Water (ft TOC) [b/]	Groundwater Elevation (ft msl)
FPTA3-MW6A	Aug-91	966.01	12.5	953.51
	Oct-91	966.01	13.12	952.89
	Dec-91	966.01	13.11	952.90
	Mar-92	966.01	13.87	952.14
	Apr-92	966.01	12.56	953.45
	May-92	966.01	11.45	954.56
	Aug-92	966.01	11.43	954.58
	Nov-94	965.65	10.95	954.70
MP-2S	Nov-94	961.83	6.91	954.92
MP-2M	Nov-94	961.91	7.00	954.91
MP-2D	Nov-94	961.92	7.09	954.83
MP-4S	Nov-94	964.81	9.87	954.94
MP-4D	Nov-94	964.84	9.97	954.87
MP-5S	Nov-94	964.37	9.35	955.02
MP-5M	Nov-94	964.27	9.30	954.97
MP-5D	Nov-94	964.28	9.41	954.87
MP-6S	Nov-94	964.32	9.41	954.91
MP-6D	Nov-94	964.35	9.41	954.94
MP-8S	Nov-94	963.33	8.43	954.90
MP-8D	Nov-94	963.32	8.50	954.82
MP-9D	Nov-94	962.81	7.86	954.95
MP-12S	Nov-94	963.11	8.11	955.00
MP-12D	Nov-94	963.16	8.16	955.00
MP-17S	Nov-94	964.88	9.95	954.93
MP-17D	Nov-94	964.82	9.90	954.92
MP-20S	Nov-94	963.42	8.44	954.98
MP-20D	Nov-94	963.35	8.41	954.94

TABLE 3.1 (Continued)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Location	Measurement Date	Datum Elevation (ft msl) [a/]	Depth to Water (ft TOC) [b/]	Groundwater Elevation (ft msl)
MP-22S	Nov-94	967.01	12.26	954.75
MP-22D	Nov-94	967.05	12.32	954.73
MP-23S	Nov-94	967.72	12.92	954.80
MP-23D	Nov-94	967.70	12.92	954.78
MP-24D	Nov-94	962.34	7.32	955.02

[a/] Feet Above Mean Sea Level

[b/] Feet Below Top of Casing

TABLE 3.2
SLUG TEST RESULTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

WELL	HYDRAULIC CONDUCTIVITY (ft/min)	HYDRAULIC CONDUCTIVITY (ft/day)
FPTA3-MW6	0.0036	5.1
FPTA3-MW6	0.0043	6.2
HF6-MW4	0.00093	1.3
HF6-MW4	0.00083	1.2
AVERAGE	0.0024	3.5

from these tests is 3.5 ft/day. An average of the historic and current hydraulic conductivity measurements was used in groundwater models (approximately 6.1 ft/day).

3.3.3.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil comprising the shallow saturated zone were used. Walton (1988) gives ranges of effective porosity for fine sand of 0.1 to 0.3. Because the presence of fines tends to decrease the effective porosity, and because lower effective porosities result in higher computed advective groundwater velocities, an effective porosity of 0.2 was assumed for this project.

3.3.3.4 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] (6.1 feet per day)

dH/dL = Gradient [L/L] (0.0006 ft/ft)

n_e = Effective porosity (0.2).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at the site in November 1994, was 0.018 ft/day, or approximately 6.7 feet per year.

3.3.3.5 Preferential Flow Paths

No preferential contaminant migration pathways were identified during the field work phase of this project. Relatively few manmade features such as utility trenches or storm sewers are present at the site, and only a single drain line is known to enter the source area. A CPT/LIF push performed immediately downgradient from this line did not encounter residual or free-phase product. The relatively high hydraulic conductivity of the aquifer materials might also prevent the few manmade features on site from providing preferential flow paths.

3.3.4 Groundwater Use

Groundwater in the Offutt AFB region is used for public water supply, for industrial use, and for irrigation. Groundwater is obtained primarily from wells in the alluvial aquifer; all pumping wells identified near the Base are located in the valley of Papillion Creek, the Missouri River, and the Platte River south of Offutt AFB (Figure 3.7). The largest groundwater user in the area is the Municipal Utilities District (MUD). Its well field is located on Cedar Island in the Platte River Valley, about 4 miles southwest of Offutt AFB. The well field consists of 38 wells screened in the alluvial aquifer; the plant draws approximately 60 million gallons per day (mgd). About 17 mgd are withdrawn from 19 wells by the Arcadia Fertilizer facility located in the Platte River Valley, about 2.5 miles due south of the Base. The city of Bellevue owns and operates five public water supply wells north of the Base Lake and northeast of the main Base. These wells have a capacity of about 2, mgd but are pumped at considerably lower rates. The city of Bellevue purchases most of its water from MUD.

Formerly, the Base operated six water supply wells at Offutt AFB. When the Base began purchasing water from MUD in 1976, three of these wells were abandoned, and the remaining three are maintained for fire control. They are not connected to the Base water supply system or pumped on a regular basis.

3.4 CLIMATE

The climate at Offutt AFB is continental, characterized by cold winters, hot summers, and moderate rainfall. Average daily maximum temperatures range from 29 degrees Fahrenheit (°F) in January to 87 °F in July. Precipitation occurs primarily as slow, steady rainstorms during spring; as scattered thunderstorms (often with high wind) during late spring and summer; and as snow during the winter. The mean annual precipitation is approximately 32 inches, with about 75 percent occurring between April and September. The 1-year, 24-hour rainfall event is reported to be 2.5 inches (ES, 1990a).

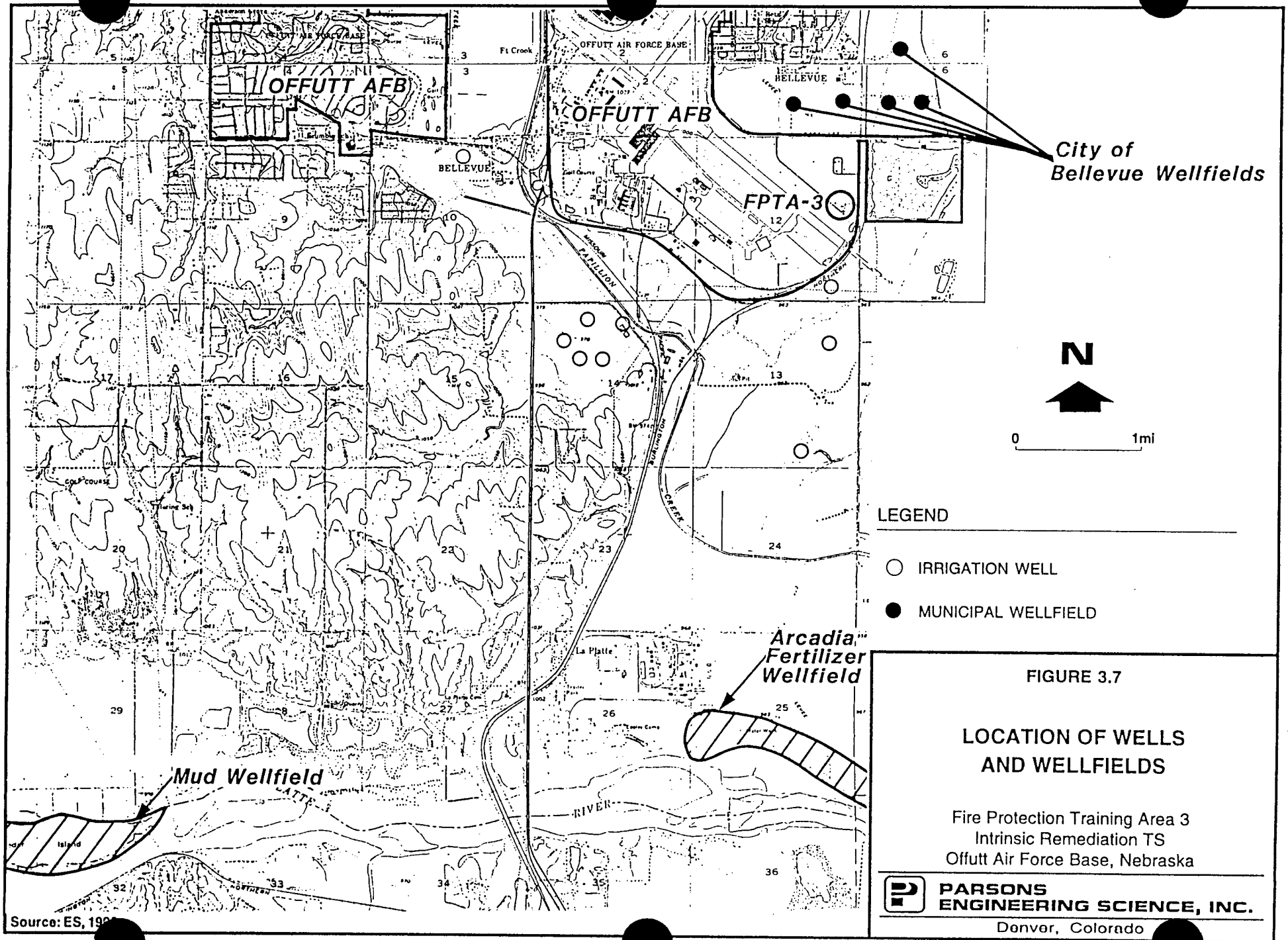

FIGURE 3.7

LOCATION OF WELLS AND WELLFIELDS

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCE OF CONTAMINATION

Three sources of contamination have been positively identified at FPTA3. These include the main burn pit, the area around Building 654, and the former water discharge pond. Plans have been developed for the excavation and treatment of approximately 5,000 cubic yards of soils from these three areas (B&V, 1992); however, the plans have not been implemented. A UST and second evident burn pit may contribute to the overall site contamination; however, investigations have not identified these locations as major sources.

The main burn pit consists of a mock aircraft fuselage surrounded by a 4-foot berm, 200 feet in diameter. No liners or other devices were used within the burn pit to prevent the fuels and waste solvents used during fire training exercises from percolating into the soils to groundwater. Main burn pit soils are visibly contaminated and support very little vegetation. Disturbance of these surficial soils releases a strong, unidentified chemical odor.

Building 654, also referred to as the smokehouse, is located west of the main burn pit within a second area of contamination. Where Building 654 currently stands, a fire training area has been identified in historic aerial photographs (ES, 1990a). Soils surrounding Building 654 are not visibly contaminated; however, the area is sparsely vegetated and disturbance of subsurface soils releases an odor similar to that of the main burn pit.

Two ponds located north-northeast of the main burn pit were used for the discharge of water/fuel/foam mixtures following fire protection training activities. An investigation conducted in November 1988, identified floating JP-4 in the ponds following a fire training exercise (ES, 1990a). The northern pond has since been filled with debris from the encroachment of Hardfill 6. The smaller southern pond and a trace of the channel which connected the two ponds are still present at the site.

4.2 SOIL CHEMISTRY

4.2.1 Residual Contamination

Residual light nonaqueous-phase liquid (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 and will not flow 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 that 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; mobile-phase LNAPL has not been identified at FPTA3.

4.2.1.1 LIF Data

LIF and analytical soil data collected during CPT activities indicate that petroleum hydrocarbons are present in soil in the shaded areas depicted on Figure 4.1. LIF profiles collected at all of the locations within the shaded areas show significantly elevated fluorescence intensity (>800 counts). The majority of the zones of elevated fluorescence extend to the water table and are from 0.5 to 5.5 feet thick. The water table is approximately 6 to 9 feet bgs.

At five locations along the projected boundary of the residual hydrocarbon contamination (CPT-6, -10, -17, -20, and -21), the results of the LIF profiles are unclear. Each of these locations exhibited a slightly elevated fluorescence intensity; however, it is unknown whether these responses are the result of residual hydrocarbon contamination. As all soils fluoresce at varying background levels, a varying soil matrix can result in a fluctuating fluorescence intensity. When a fluctuation occurs gradually or is not elevated much above background soil levels, the fluctuation can be difficult to distinguish from a small increase in fluorescence caused by hydrocarbons. Also, near the surface (approximately the top 2 feet of soil), anomalous fluorescence intensities can result from surficial light intrusion.

A slightly elevated fluorescence intensity was identified from the LIF profile conducted at CPT-18, along the remnant channel that formerly connected the remaining discharge pond to the debris-filled discharge pond. The fluorescence intensity of approximately 250 counts was detected over an interval of approximately 2 feet at the top of the water table (6 to 8 feet bgs). At this depth, light intrusion from the surface is no longer a factor. The count of 250 is approximately three times greater than the background count, which had been decreasing at a very steady rate. The elevated fluorescence intensity at this location is believed to be attributable to the presence of hydrocarbons.

4.2.1.2 Soil BTEX and Fuel Hydrocarbon Contamination

Sixteen soil samples were collected at four locations at FPTA3 and analyzed for BTEX by the USEPA/RSKERL. With the exception of one sample collected from 0 to 0.5 foot at SS-2, BTEX compounds were detected in all samples collected at the three locations located within the area of residual-phase hydrocarbon contamination. At borehole SS-2, due west of the nose of the mock aircraft, eight soil samples were collected over 0.5-foot intervals from the surface to 9.5 feet bgs. The highest BTEX concentration at borehole S-2 was 13.8 milligrams per kilogram (mg/kg) in the 1- to 1.5-foot sample. The four samples collected at depths of 4.5 feet or greater all had total BTEX concentrations below 1 mg/kg. BTEX compounds were detected in the single soil samples collected approximately 2 feet above the water table at CPT-2 and CPT-5. Total BTEX concentrations were 331 and 0.3 mg/kg, respectively. CPT-2 is located within the

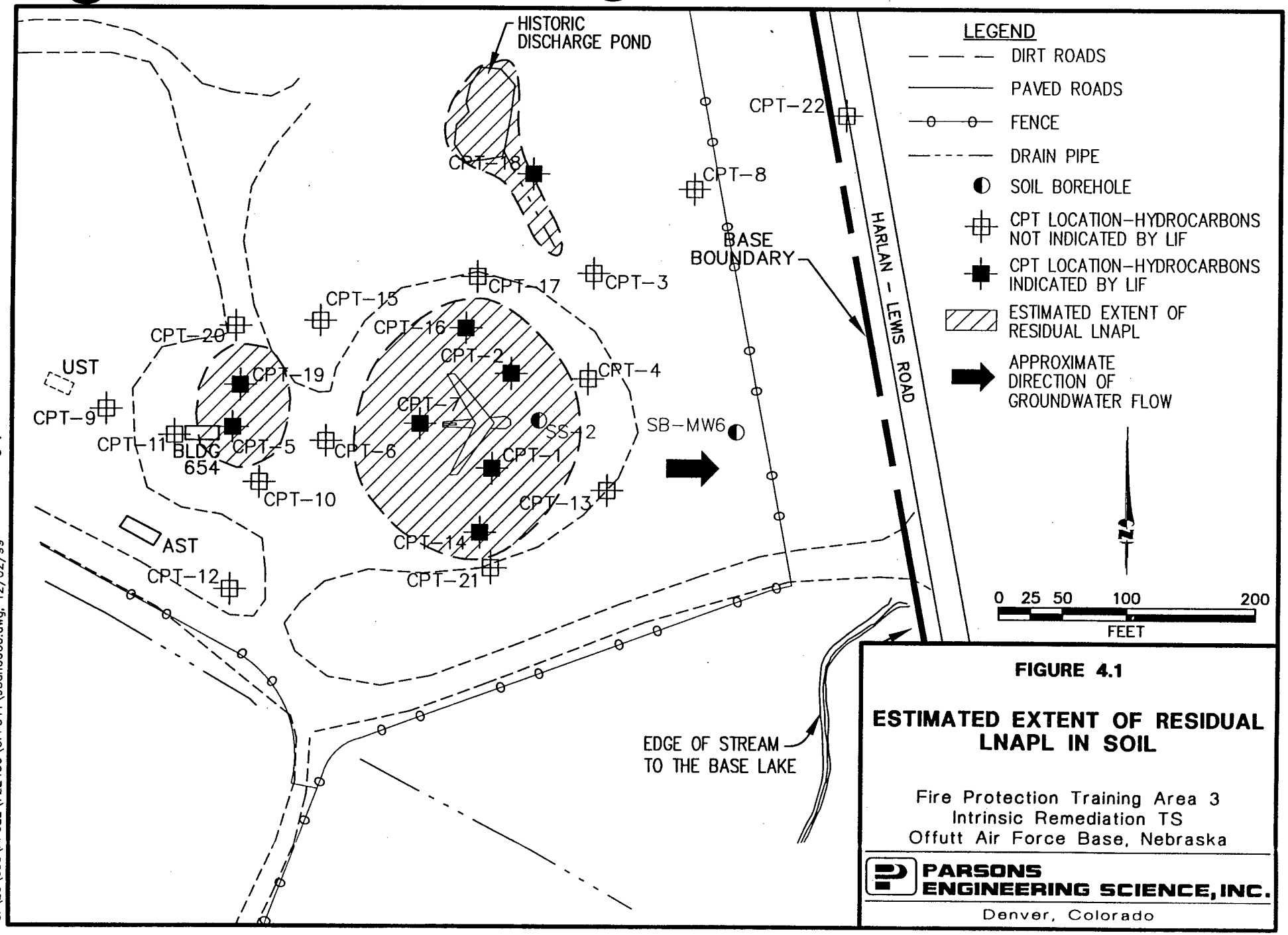

FIGURE 4.1

ESTIMATED EXTENT OF RESIDUAL LNAPL IN SOIL

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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main burn pit, and CPT-5 is located due west of Building 654. Table 4.1 presents soil BTEX data.

BTEX compounds were not detected in the six soil samples collected at borehole SS-1. The six samples were collected over 0.5-foot intervals from the surface to 11 feet bgs. Borehole SS-1 is located east of the main burn pit near the monitoring well cluster of FPTA3-MW6 and -MW6A.

Historically, BTEX compounds have been detected in the areas identified as contaminated by the CPT/LIF at concentrations similar to results of the current investigation. During site investigations performed in 1988, 1989, and 1990, soil samples were collected from eight boreholes within the main burn pit. The maximum detected BTEX concentration was 387 mg/kg. Soil samples were also collected from five boreholes in the vicinity of Building 654. The maximum detected BTEX concentration was 3.1 mg/kg. BTEX were not detected in soil samples collected from two boreholes near the remaining discharge pond (ES, 1990a and 1990b).

Fourteen site soil samples from two boreholes were analyzed for fuel hydrocarbons. Petroleum hydrocarbons were detected only in samples collected from borehole SS-2, located in the main burn pit. The five samples collected above the water table had TPH concentrations of 450 to 23,400 mg/kg. The three soil samples collected below the water table had TPH concentrations of <50 to 150 mg/kg. Table 4.1 presents fuel hydrocarbon data.

4.2.1.3 Soil Chlorinated Solvent Contamination

Sixteen soil samples were collected at 4 locations at FPTA3 and analyzed for TCE and PCE by the USEPA/RSKERL. Neither compound was detected above the quantitation limit in any of the 16 samples. Historically, chlorinated solvents were detected in soil samples from all 5 soil boreholes in the vicinity of Building 654. Maximum concentrations included 5.2 mg/kg TCE and 0.016 mg/kg PCE. 1,1-Dichloroethane, 1,2-dichloroethane, t-1,2-DCE, and 1,1,1-trichloroethane also have been detected in soil samples at concentrations up to 0.2 mg/kg. Within the main burn pit, the only chlorinated solvent detected in a soil sample was a single detection of TCE at 0.134 mg/kg. TCE (0.004 mg/kg) also was detected in one of the six samples collected from two boreholes near the remaining discharge pond (ES, 1990a and 1990b).

4.2.2 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 relative to the average advective groundwater velocity.

Five samples for TOC analysis collected in sandy material below the water table were used in the computation of contaminant retardation as a result of sorption. Had these samples contained high concentrations of TPH, they would not have been used in order to

TABLE 4.1
SOIL ANALYTICAL RESULTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Sample Location	Sample Depth (ft bgs)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	p-Xylene (mg/kg)	m-Xylene (mg/kg)	o-Xylene (mg/kg)	Total Xylenes (mg/kg)	Total BTEX (mg/kg)	Total TMB (mg/kg)	TPH (mg/kg)	TOC (percent)	Dehydrogenase Activity (mg/kg)
CPT-2	4.5-5.3	2.84	0.0418	127	61.8	136	3.54	201	331	737	NA[a/]	2.6	NA
CPT-2	(dup)	3.04	0.0619	134	66	144	3.98	214	351	800	NA	NA	NA
CPT-5	4.8-5.6	ND[b/]	0.0339	0.0549	0.0491	0.107	0.0381	0.194	0.283	0.420	NA	0.359	NA
SS-1	0.0-0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	<50	2.35	52
	2.5-3.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<50	0.198	0.5
	4.5-5.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<50	0.333	0.5
	6.5-7.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	50	0.308	0.2
	8.5-9.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<50	0.068	0.8
	10.5-11.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	<50	0.072	0.5
SS-2	0.0-0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	7,200	1.35	65
	1.0-1.5	0.138	0.0412	2.41	5.76	5.43	ND	11.2	13.8	60.4	20,600	0.444	16
	2.5-3.0	ND	ND	0.0944	0.227	0.223	ND	0.450	0.544	2.80	700	0.165	16
	3.5-4.0	0.0748	0.0321	0.8	0.696	0.614	0.502	1.81	2.72	5.95	23,400	0.854	130
	4.5-5.0	0.0206	ND	0.0969	0.0621	0.0601	0.0539	0.176	0.294	0.634	450	0.543	300
	6.5-7.0	0.0552	ND	0.107	0.0604	0.0577	0.027	0.145	0.307	0.590	<50	0.051	ND
	8.5-9.0	0.125	ND	0.186	0.0874	0.066	0.0359	0.189	0.500	0.585	150	0.109	235
	9.0-9.5	0.13	0.0153	0.305	0.199	0.141	0.0996	0.440	0.890	1.96	82	0.059	230

[a/] NA = Not analyzed.
[b/] ND = Not detected.

avoid interference from fuel carbons. The samples had a range of 0.051 to 0.11 percent TOC, with an average concentration 0.07 percent TOC (Table 4.1).

4.3 GROUNDWATER CHEMISTRY

Three lines of evidence can be used to document the occurrence of natural attenuation: 1) geochemical evidence; 2) documented loss of contaminant mass at the field scale; and 3) laboratory microcosm studies. The first two lines of evidence (geochemical evidence and documented loss of contaminants) are used herein to support the occurrence of natural attenuation at FPTA3, as described in the following sections. Because these two lines of evidence strongly suggest that natural attenuation is occurring at this site, laboratory microcosm studies were not deemed necessary.

4.3.1 Dissolved Hydrocarbon and Chlorinated Solvent Contamination

During previous site investigations, groundwater samples were collected on at least six occasions. Fuel hydrocarbons and chlorinated solvents were detected irregularly at low concentrations. The highest detected total BTEX concentration was 344 micrograms per liter (µg/L) at well HF6-MW4 (W-C, 1992b). Monitoring well HF6-MW4 is the only site well where BTEX has been consistently detected. Monitoring well FPTA3-MW2 has had the next highest BTEX concentrations. During the second quarter of a quarterly groundwater sampling program, total BTEX was detected at 103 µg/L; however, during the preceding quarter only 1 µg/L of total BTEX was detected, and the following quarter no BTEX was detected (W-C, 1992b). 1,2-DCE (total) was the only chlorinated solvent detected in a groundwater sample collected from a site monitoring well. It was detected twice during the quarterly groundwater sampling at concentrations of 1.6 and 1.5 µg/L in samples from well FPTA3-MW6A (W-C, 1992b).

Both the low contaminant concentrations and the irregularity of detections are believed to be a function of the distance between the source areas and the monitoring wells. Four groundwater samples were collected within the source areas during a soil gas survey in 1989, and analyzed by a mobile laboratory. BTEX were detected in all four samples, and chlorinated solvents were detected in the three samples at and immediately downgradient from Building 654.

Groundwater samples collected in November 1994, by Parsons ES personnel at monitoring wells and newly installed monitoring points confirmed these historical observations. Tables 4.2 and 4.3 summarize groundwater contaminant data for these samples. Analytical results of the current investigation are discussed in the following subsections.

4.3.1.1 Dissolved BTEX and Fuel Hydrocarbon Contamination

The areal distribution of total dissolved BTEX in groundwater for November 1994 is presented on Figure 4.2. Where nested wells are present, isopleths are drawn based on the maximum concentration detected in the top 20 feet of the saturated zone at each location. As indicated by the 1-µg/L isopleth, the BTEX plume is about 650 feet long and 450 feet wide. The main body of the plume is slightly elongated parallel to the direction of groundwater flow as a result of both the groundwater flow and the alignment

TABLE 4.2
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Sample Location	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylene (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Fuel Carbon (µg/L)
HF6-MW1	ND[a/]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1[b/]
HF6-MW2	ND	ND	<1	<1	<1	ND	<1	<1	ND	ND	ND	<1
HF6-MW2D	19.8	50.8	5.3	4.0	9.7	4.7	18.5	94.3	ND	2.0	ND	162
HF6-MW2D (dup)	11.0	27.7	3.0	2.4	5.5	3.1	11.0	52.7	ND	1.7	ND	105
HF6-MW4	3.7	ND	<1	<1	ND	<1	<1	3.7	2.2	2.4	2.2	81.3
HF6-MW4 (dup)	3.3	ND	<1	ND	<1	ND	<1	3.3	1.8	<1	<1	70.2
HF6-MW4 (dup)	3.3	ND	ND	ND	ND	ND	ND	3.3	2.7	2.1	<1	74.1
MP-6MW4S	1.7	40.0	<1	ND	ND	ND	ND	41.7	ND	ND	ND	38.6
FPTA3-MW1	6.4	19.8	2.6	2.2	4.7	2.4	9.3	38.2	ND	1.8	ND	61.3
FPTA3-MW2	3.5	ND	2.6	1.3	0.9	ND	2.2	8.3	9.1	9.2	5.3	176
FPTA3-MW3	ND	ND	<1	<1	<1	ND	<1	<1	ND	ND	ND	<1
FPTA3-MW4	ND	ND	<1	<1	<1	ND	<1	<1	ND	ND	ND	<1
FPTA3-MW5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW5 (dup)	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND	<1
FPTA3-MW6	<1	ND	ND	ND	<1	ND	<1	<1	ND	ND	ND	<1
FPTA3-MW6A	5.4	ND	ND	ND	<1	ND	<1	5.4	1.8	ND	ND	98.4
MP-2M	775	4.1	991	441	1020	2.2	1460	3230	57.9	ND	<1	3300
MP-2D	55.0	13.1	4.8	4.4	4.5	3.1	12.0	84.9	5.5	4.0	3.4	250
MP-4S	234	206	117	95.2	293	196	584	1140	34.7	137	80.9	1630
MP-4D	1.1	<1	3.3	2.1	4.1	ND	6.1	10.5	ND	ND	1.0	40.7
MP-5M	56.6	29.3	20.7	15.3	25.3	41.9	82.5	189	ND	ND	1.8	172
MP-5M (dup)	54.2	28.8	19.3	14.6	23.1	39.8	77.5	180	ND	ND	1.7	165
MP-5D	<1	1.1	<1	<1	1.0	ND	1.0	2.1	ND	ND	ND	4.1
MP-6D	2.8	4.9	<1	<1	<1	<1	<1	7.7	ND	ND	ND	16.3
MP-8S	1.5	43.7	<1	ND	1.4	ND	1.4	46.6	ND	ND	ND	58.1
MP-8D	2.9	1.9	ND	ND	ND	<1	ND	4.8	ND	2.0	3.6	285

TABLE 4.2 (Continued)
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Sample Location	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylene (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Fuel Carbon (µg/L)
MP-9D	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND	<1
MP-12D	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND	<1
MP-17D	1.1	1.2	<1	0.9	0.9	ND	1.9	4.2	1.3	1.6	466	7.5
MP-17D (dup1)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-17D (dup2)	<1	<1	ND	ND	ND	ND	<1	<1	ND	ND	ND	<1
MP-20S	<1	3.2	ND	ND	<1	ND	<1	3.2	ND	ND	ND	10.1
MP-20D	ND	ND	<1	<1	<1	ND	<1	<1	ND	ND	ND	<1
MP-22S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-22D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-23S	ND	2.2	ND	ND	ND	ND	ND	2.2	ND	ND	ND	2.3
MP-23D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-24D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
UST1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	<1

[a/] ND = Not Detected.
[b/] <1 = Below Quantitation Level.

TABLE 4.3
DETECTED CHLORINATED SOLVENTS AND ETHENE CONCENTRATIONS IN GROUNDWATER
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Sample Location	Vinyl Chloride (µg/L)	trans-1,2-DCE (µg/L)	cis-1,2-DCE (µg/L)	1,1,1-TCA (µg/L)	TCE (µg/L)	Total Chlorinated Solvents (µg/L)	Ethene (µg/L)
HF6-MW1	ND[a/]	ND	ND	ND	ND	ND	ND
HF6-MW2	ND	ND	ND	ND	ND	ND	ND
HF6-MW2D	ND	ND	ND	ND	ND	ND	ND
HF6-MW2D (dup)	ND	ND	ND	ND	ND	ND	ND
HF6-MW4	ND	ND	ND	ND	ND	ND	ND
HF6-MW4 (dup)	ND	ND	ND	ND	ND	ND	ND
MP-6MW4S	ND	ND	ND	ND	ND	ND	NA[b/]
FPTA3-MW1	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW1 (dup)	ND	ND	ND	ND	ND	ND	NA
FPTA3-MW2	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW3	2.6	ND	ND	ND	ND	2.6	3.0
FPTA3-MW4	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW5	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW6	ND	ND	ND	ND	ND	ND	<3[c/]
FPTA3-MW6A	6.2	ND	2.7	ND	ND	8.9	<3
MP-2M	2.6	ND	ND	ND	ND	2.6	<3
MP-2D	ND	ND	ND	ND	ND	ND	3.0
MP-4S	40.7	2.4	273	ND	8.6	325	NA
MP-4D	ND	ND	ND	ND	ND	ND	ND
MP-5M	817	1.6	ND	ND	ND	819	895
MP-5M (dup)	766	1.5	ND	ND	ND	768	NA
MP-5D	ND	ND	2.2	ND	ND	2.2	ND
MP-6D	51.9	1.7	93.3	ND	ND	147	17.0
MP-8S	ND	ND	ND	ND	ND	ND	ND
MP-8D	ND	ND	ND	ND	ND	ND	ND
MP-9D	ND	ND	ND	ND	ND	ND	ND
MP-12D	ND	ND	ND	ND	ND	ND	ND
MP-17D	6.7	ND	ND	ND	ND	6.7	3.0
MP-17D (dup)	6.4	ND	ND	ND	ND	6.4	4.0
MP-20S	ND	ND	ND	3.1	6.7	9.8	ND
MP-20S (dup)	ND	ND	ND	3.3	7.6	10.9	NA
MP-20D	ND	ND	ND	ND	ND	ND	ND
MP-22S	ND	ND	ND	ND	ND	ND	ND
MP-22D	ND	ND	ND	ND	ND	ND	<3
MP-23S	ND	ND	ND	ND	ND	ND	ND
MP-23D	ND	ND	ND	ND	ND	ND	ND
MP-24D	ND	ND	ND	ND	ND	ND	ND
UST1	ND	ND	ND	ND	ND	ND	ND

[a/] ND = Not Detected
[b/] NA = Not Analyzed
[c/] <3 = Below Quantitation Limit

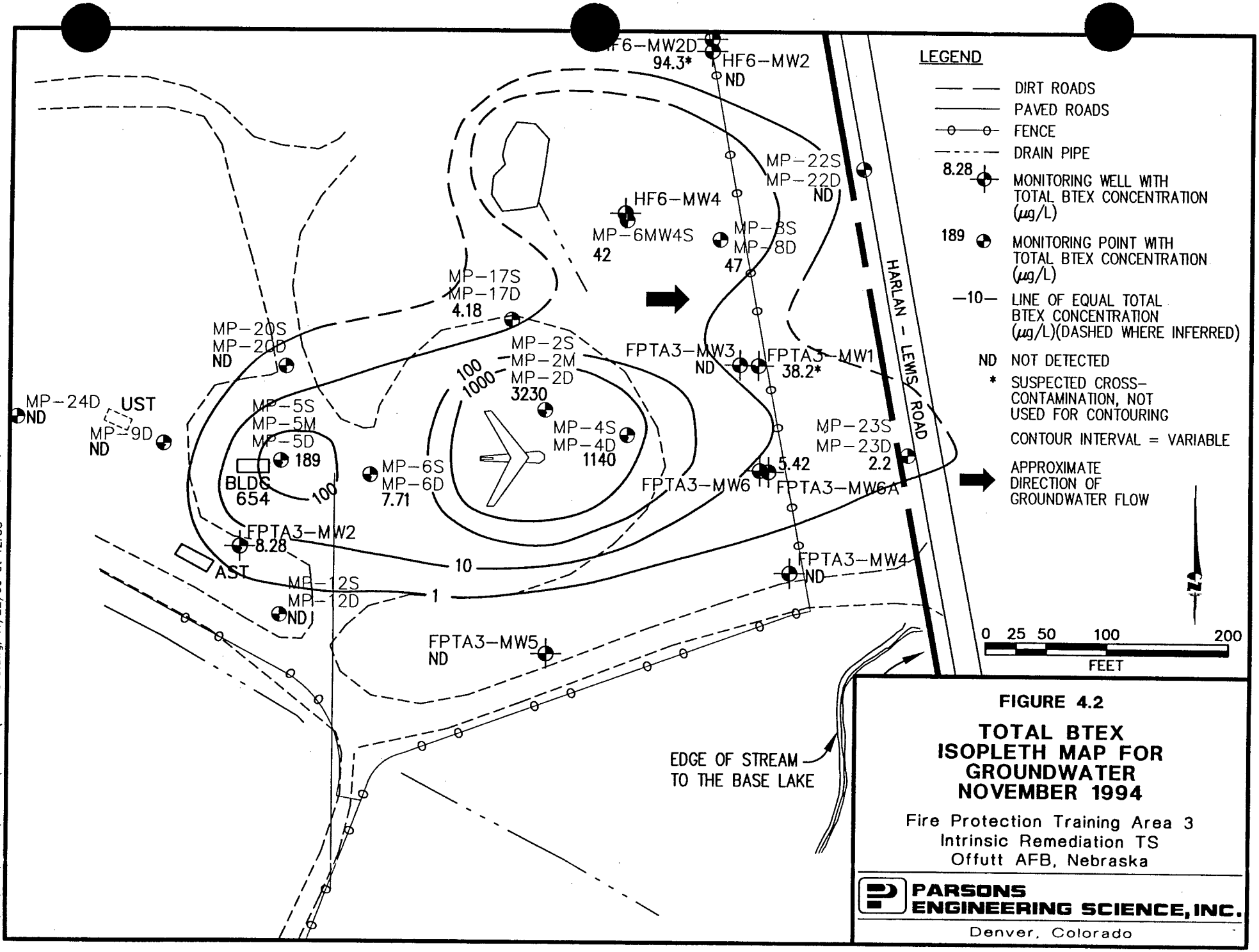

FIGURE 4.2

TOTAL BTEX ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt AFB, Nebraska

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Denver, Colorado

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of the main burn pit and Building 654 source areas. A second plume associated with the former discharge pond merges with the main plume and increases the overall plume width. The estimated extent of the plume is approximately has a total area of approximately 170,000 square feet, or approximately 3.9 acres.

The vertical distribution of contaminants along the main axis of the plume parallel to the direction of groundwater flow is presented on Figure 4.3. The maximum depth of the 1-µg/L isopleth is estimated at approximately 30 feet bgs in the main burn pit area. A second lobe of contamination is estimated to reach a depth of approximately 23 feet beneath the Building 654 source area.

The maximum observed total BTEX concentration was 3,230 µg/L, in the sample collected from monitoring point MP-2M. At this location, the benzene concentration was 775 µg/L. In the sample collected from MP-2D, the total BTEX concentration was 85 µg/L, with a benzene concentration of 55 µg/L. The shallow monitoring point immediately downgradient from MP-2M and the main burn pit (MP-4S) contained the second highest total BTEX and benzene concentrations (1,140 and 234 µg/L, respectively). Elsewhere, total BTEX concentrations ranged from 2.1 µg/L to 189 µg/L, with benzene concentrations from 1.06 µg/L to 57 µg/L. BTEX were not detected above quantitation limits in groundwater samples collected at MP-9D, MP-12D, MP-20D, MP-22S, MP-22D, MP-23D, MP-24D, FPTA3-MW3, FPTA3-MW4, FPTA3-MW5, FPTA3-MW6, HF6-MW1, and HF6-MW2.

Total BTEX at concentrations of 94 and 38 µg/L were detected in groundwater samples collected from the two deep site wells, HF6-MW2D and FPTA3-MW1, respectively. Historically, BTEX have not been detected in groundwater samples collected from either well. It is believed that the concentrations measured during the November 1994, investigation are erroneous and result from pump contamination. These two wells were purged and sampled using a Grundfos Redi-Flo 2® pump, whereas all of the other groundwater samples at the site were collected using a peristaltic pump. The Grundfos® pump was used to collect heavily contaminated samples at the Tank 349 site prior to its use at FPTA3. It is believed that either the decontamination procedure used to clean the pump and tubing was inadequate, or that the pump was contaminated as a result of transport in the sampling truck. The generator and fuel for the generator were also transported in the truck. As BTEX concentrations for these two wells are considered inaccurate, they were not included in the BTEX distribution maps. Parsons ES intends to resample monitoring wells HF6-MW2D and FPTA3-MW1 with a peristaltic pump and dedicated tubing in order to support the exclusion of these data from the investigation. Resampling will occur when further investigations are performed at the Tank 349 site, currently anticipated to occur in the fall of 1995.

The distribution of total fuel hydrocarbons in site groundwater is presented on Figure 4.4. Where nested wells are present, isopleths are drawn based on the maximum concentration detected in the top 20 feet of the saturated zone at each location. The distribution of fuel hydrocarbons is similar to the distribution of BTEX compounds presented on Figure 4.2. Dissolved fuel hydrocarbons were detected at the same locations where dissolved BTEX compounds were detected. At no location were fuel hydrocarbons detected and BTEX compounds not detected. Total fuel hydrocarbon concentrations ranged from 2.3 to 3,300 µg/L. For the same reasons given for BTEX, the

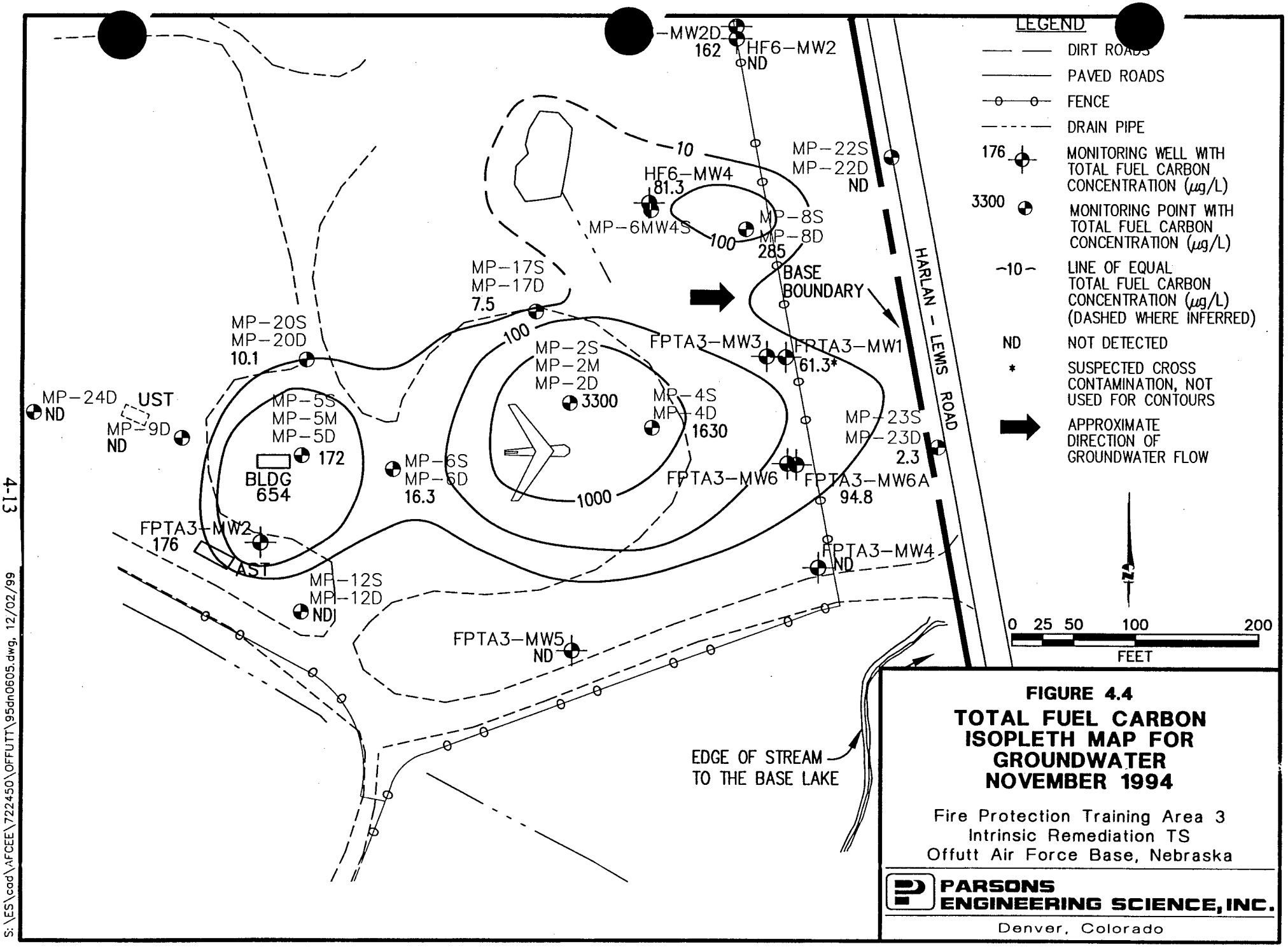

FIGURE 4.4

TOTAL FUEL CARBON ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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fuel hydrocarbon concentrations are considered suspect for the two deep wells, FPTA3-MW1 and HF6-MW2D.

4.3.1.2 Dissolved Chlorinated Solvent Contamination

The areal extent of total dissolved chlorinated solvents in groundwater for November 1994 is presented on Figure 4.5. The concentrations of individual chlorinated solvents and ethene are presented in Table 4.3 and on Figure 4.6. Where nested wells are present, isopleths are drawn based on the maximum detected concentration at each location. As indicated by the 1-µg/L isopleth, the chlorinated solvent plume is approximately 520 feet in long and 220 feet wide. The plume is slightly elongated parallel to the direction of groundwater flow, with the apparent source in the Building 654 area. The estimated extent of the plume has a total area of approximately 90,000 square feet, or approximately 2.1 acres. The vertical distribution of contaminants along the axis of the plume parallel to the direction of groundwater flow is presented on Figure 4.7. The maximum depth of the 1-µg/L isopleth is estimated at approximately 23 feet bgs below the Building 654 area.

The maximum observed total chlorinated solvent concentration was 819 µg/L, in the sample collected from monitoring point MP-5M. Only 2.2 µg/L of total chlorinated solvents was detected in the adjacent cluster point MP-5D, which is screened 10 feet deeper in the saturated zone. Elsewhere, total chlorinated solvent concentrations ranged from 2.6 µg/L to 325 µg/L in groundwater samples collected at MP-2M, MP-4S, MP-6D, MP-17D, MP-20S, FPTA3-MW3, and FPTA3-MW6A. Chlorinated solvents were not detected above quantitation limits in samples collected from the remaining groundwater sampling locations.

4.3.2 Inorganic Chemistry and Geochemical Indicators of BTEX Biodegradation

Microorganisms obtain energy for cell production and maintenance by facilitating 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 the site are 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 oxygen, 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 use

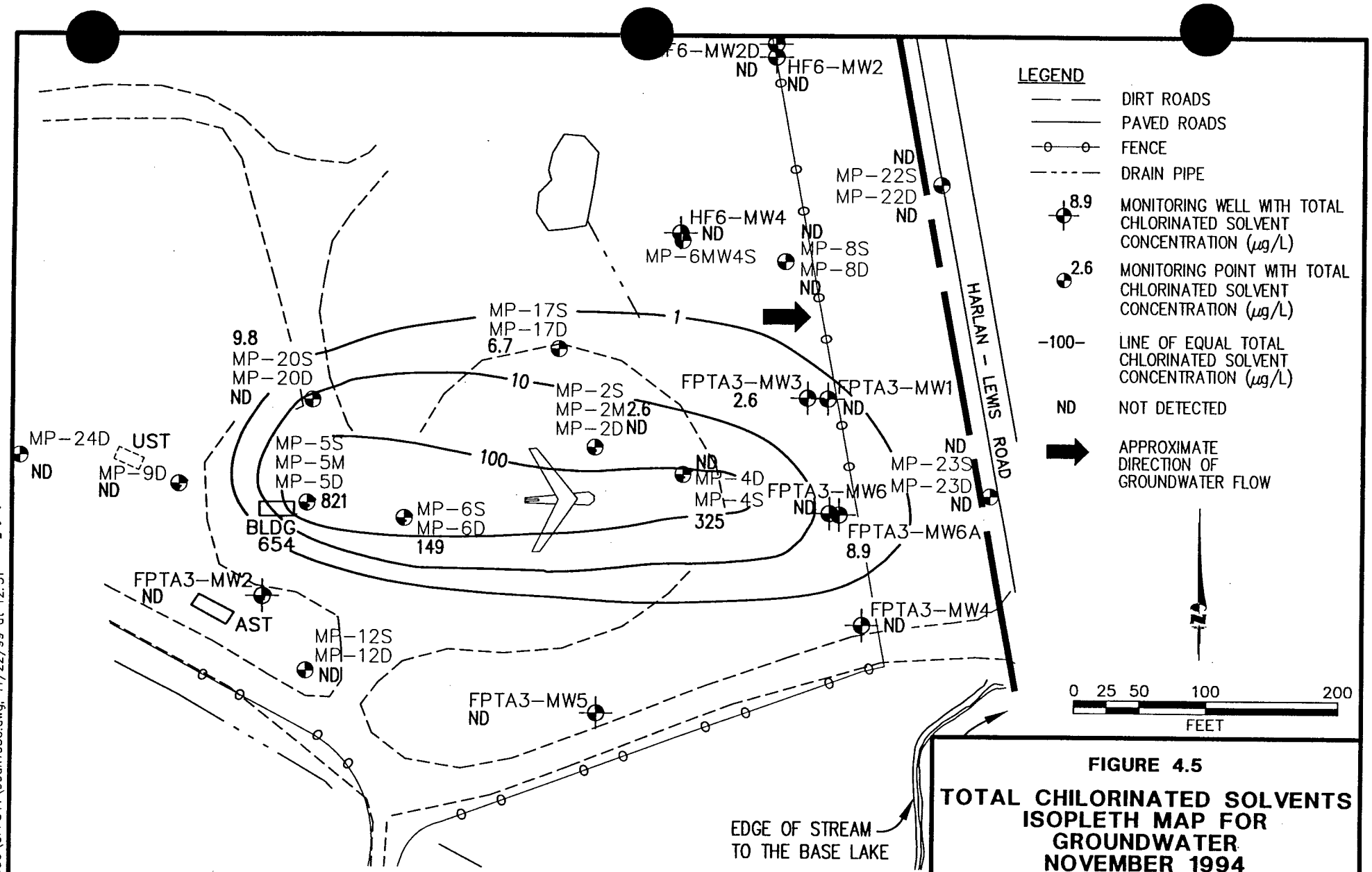

FIGURE 4.5

TOTAL CHLORINATED SOLVENTS ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt AFB, Nebraska

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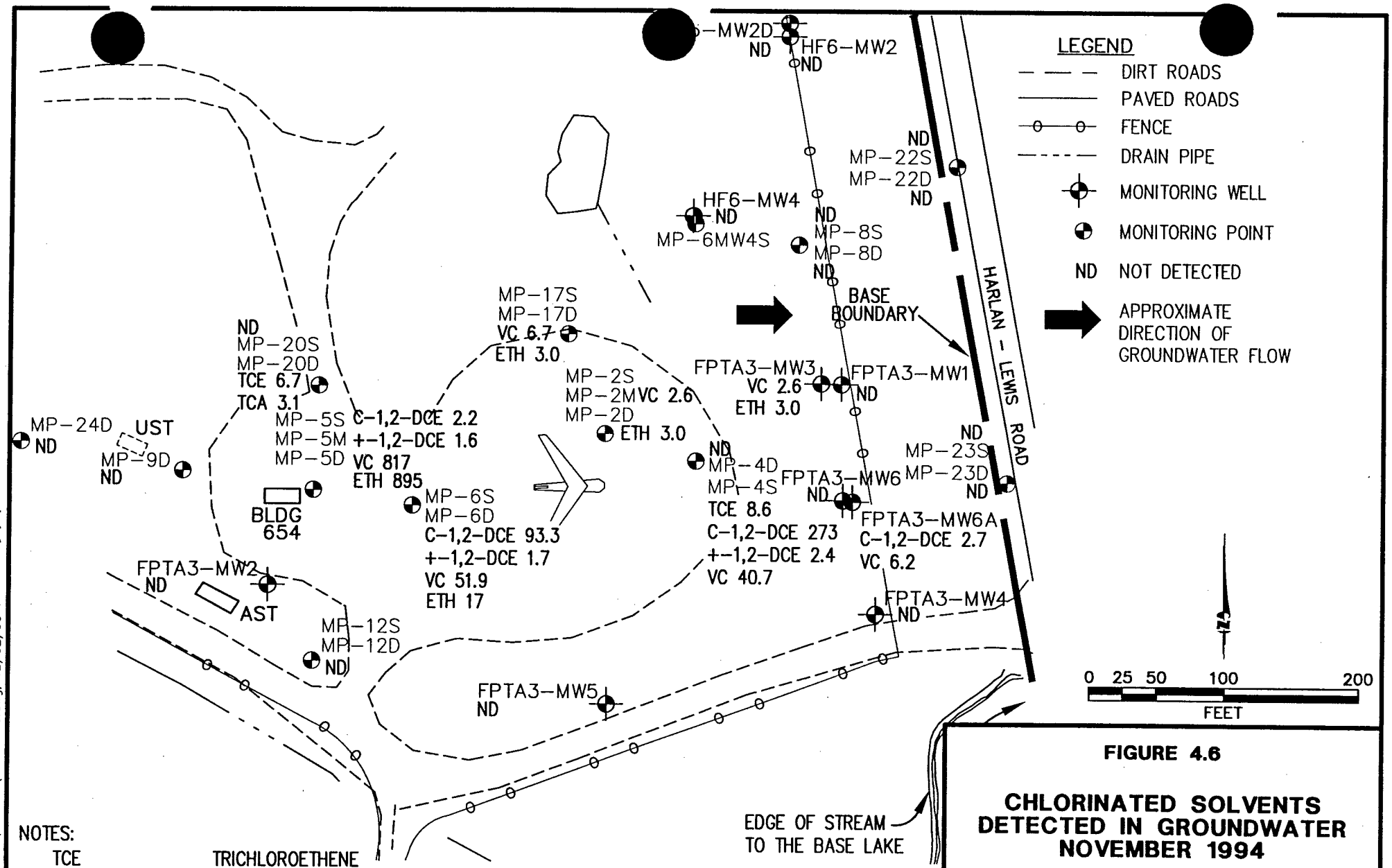

NOTES:

TCE	TRICHLOROETHENE
C-1,2-DCE	CIS-1,2-DICHLOROETHENE
+-1,2-DCE	TRANS-1,2-DICHLOROETHENE
VC	VINYL CHLORIDE
TCA	1,1,1-TRICHLOROETHANE
ETH	ETHENE

CONCENTRATIONS IN µg/L

FIGURE 4.6

CHLORINATED SOLVENTS DETECTED IN GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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TABLE 4.4
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Coupled Benzene Oxidation Reactions	$\Delta G°_r$ (kcal/mole Benzene)	$\Delta G°_r$ (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
$60H^+ + 30Fe(OH)_{3,a} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *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	$\Delta G°_r$ (kcal/mole Toluene)	$\Delta G°_r$ (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
$72H^+ + 36Fe(OH)_{3,a} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ *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 (CONTINUED)
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Coupled Ethylbenzene Oxidation reactions	$\Delta G°_r$ (kcal/mole Ethyl-benzene)	$\Delta G°_r$ (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
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *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	$\Delta G°_r$ (kcal/mole *m*-xylene)	$\Delta G°_r$ (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
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *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.

electron acceptors in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of the 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 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 such as sulfate suggest that intrinsic remediation of hydrocarbons in the shallow aquifer by sulfate reduction is occurring. In addition, data for ferrous iron (Fe^{2+}) and methane suggest that anaerobic degradation via ferric iron reduction and methanogenesis is occurring. Because both site and background concentrations of DO and nitrate are almost nonexistent, aerobic degradation and denitrification are not believed to contribute significantly to the attenuation of BTEX in site groundwater. Geochemical parameters for site groundwater are discussed in the following sections.

4.3.2.1 Dissolved Oxygen

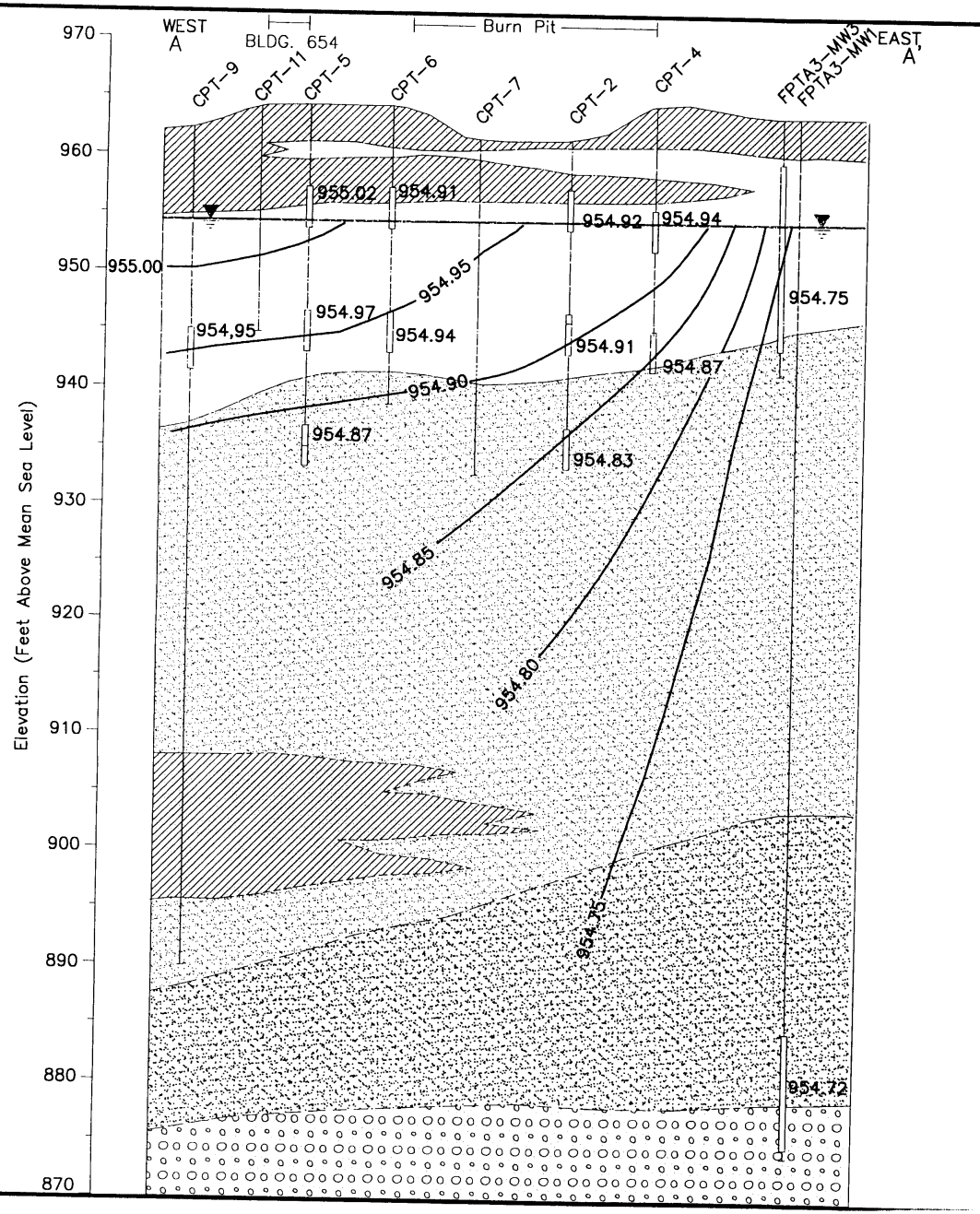
DO concentrations were measured at monitoring wells and points at the time of groundwater sampling during the November 1994 sampling event. Table 4.5 summarizes measured DO concentrations. Generally, DO concentrations were measured at 0.3 mg/L or less in site wells and monitoring points, and no DO was detected in the groundwater at either background monitoring point. The only DO concentration greater than 0.6 mg/L was measured in well FPTA3-MW6 at 3.3 mg/L. It is suspected that this concentration may be the result of surface water/groundwater interaction, as this well is located within 100 feet of the inlet to the Base Lake. As a result of the overall lack of DO in groundwater, DO is not considered to be an important electron acceptor at this site.

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 of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With an average site DO concentration of approximately 0.2 mg/L (excluding well FPTA3-MW4), the shallow groundwater at this site has the capacity to assimilate 0.06 mg/L (60 µg/L) of total BTEX through aerobic biodegradation. This is a conservative estimate of the assimilative capacity of DO because microbial cell mass production was not taken into account by the stoichiometry presented in Table 4.4.

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

TABLE 4.5
GROUNDWATER GEOCHEMICAL DATA
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Sample Location	Dissolved Oxygen (mg/L)	NO_2+NO_3 Nitrogen (mg/L)	NH_3 Nitrogen (mg/L)	Soluble Manganese (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)
HF6-MW1	0	<0.05	0.68	NA[a/]	NA	67.5	NA
HF6-MW1 (dup)	NA	<0.05	0.71	NA	NA	66.6	NA
HF6-MW2	0.1	<0.05	<0.05	0.3	8.3	175	0.01
HF6-MW2D	0.3	<0.05	0.46	<0.1	3.9	48.5	0.008
HF6-MW2D (dup)	NA	NA	NA	NA	NA	48.3	NA
HF6-MW2D (dup)	0	<0.05	0.41	<0.1	4.1	49.4	0.017
HF6-MW4	0.1	<0.05	<0.05	NA	24	391	7.91
HF6-MW4 (dup)	NA	<0.05	<0.05	0.4	24.3	387	8.09
FPTA3-MW1	0.2	<0.05	0.59	<0.1	7.5	45.8	NA
FPTA3-MW1 (dup)	NA	<0.05	0.53	NA	NA	NA	NA
FPTA3-MW2	0.1	<0.05	<0.05	0.2	20	17.8	0.17
FPTA3-MW2 (dup)	NA	NA	NA	NA	NA	17.9	NA
FPTA3-MW3	0.1	<0.05	0.22	<0.1	23.3	3.72	4.32
FPTA3-MW4	3.3	1.52	<0.05	0.2	<0.5	15.6	0.007
FPTA3-MW5	0.2	<0.05	<0.05	<0.1	<0.5	24	0.01
FPTA3-MW6	0.1	<0.05	0.45	0.4	9.4	17.6	0.978
FPTA3-MW6A	0.1	<0.05	0.66	0.4	8.7	5.75	2.29
FPTA3-MW6A (dup)	NA	<0.05	0.64	NA	NA	NA	NA
MP-FPTA3-2M	0.1	<0.05	1.18	<0.1	26.3	<0.5	17.6
MP-FPTA3-2D	0.3	<0.05	1.27	0.2	18.1	2.35	8.41
MP-FPTA3-4D	0.6	<0.05	1.71	0.1	22.5	2.83	2.93
MP-FPTA3-5M	0.1	<0.05	1.38	<0.1	17.5	23.2	22.5
MP-FPTA3-5D	0.2	<0.05	0.93	0.4	16.3	46	0.013
MP-FPTA3-6D	0.2	<0.05	0.56	0.5	18.4	8.35	2.26
MP-FPTA3-6D (dup)	NA	<0.05	0.57	NA	NA	NA	NA
MP-FPTA3-8S	NA	NA	NA	NA	NA	NA	0.037
MP-FPTA3-8D	0.3	<0.05	<0.05	0.6	8.7	<0.5	0.384
MP-FPTA3-9D	0	<0.05	<0.05	0.2	7.5	65	0.008
MP-FPTA3-12D	0.1	<0.05	<0.05	<0.1	1.7	42.2	0.001
MP-FPTA3-12D (dup)	NA	NA	NA	NA	NA	42.6	NA
MP-FPTA3-17D	0.1	<0.05	0.39	<0.1	24.7	35.5	1.33
MP-FPTA3-17D (dup)	NA	<0.05	0.45	<0.1	25.8	36.1	1.32
MP-FPTA3-20D	0.2	<0.05	1.07	<0.1	27	4.72	0.096
MP-FPTA3-20S	NA	NA	NA	NA	NA	NA	0.008
MP-FPTA3-20D (dup)	NA	<0.05	0.99	NA	NA	NA	NA
MP-FPTA3-22S	0.3	<0.05	0.31	<0.1	1.2	41.3	0.05
MP-FPTA3-22D	0.2	<0.05	<0.05	0.1	2.2	6.75	1.18
MP-FPTA3-23S	NA	0.2	<0.05	NA	NA	27.9	0.005
MP-FPTA3-23D	0.2	<0.05	0.75	0.1	6.3	24.5	0.014
MP-FPTA3-24D	0	<0.05	<0.05	0.1	4.3	21.5	0.106
MP-FTPA3-UST1	0.1	<0.05	<0.05	0.1	<0.05	117	0.008



LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 — Well Identification; Well Borehole Screen With Groundwater Potentiometric surface (Feet msl); Bottom of Borehole. Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- −954.80− Line of Equal Groundwater Potentiometric surface (Feet msl)

CONTOUR INTERVAL = 0.05 Foot

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 3.6

GROUNDWATER POTENTIOMETRIC SURFACE NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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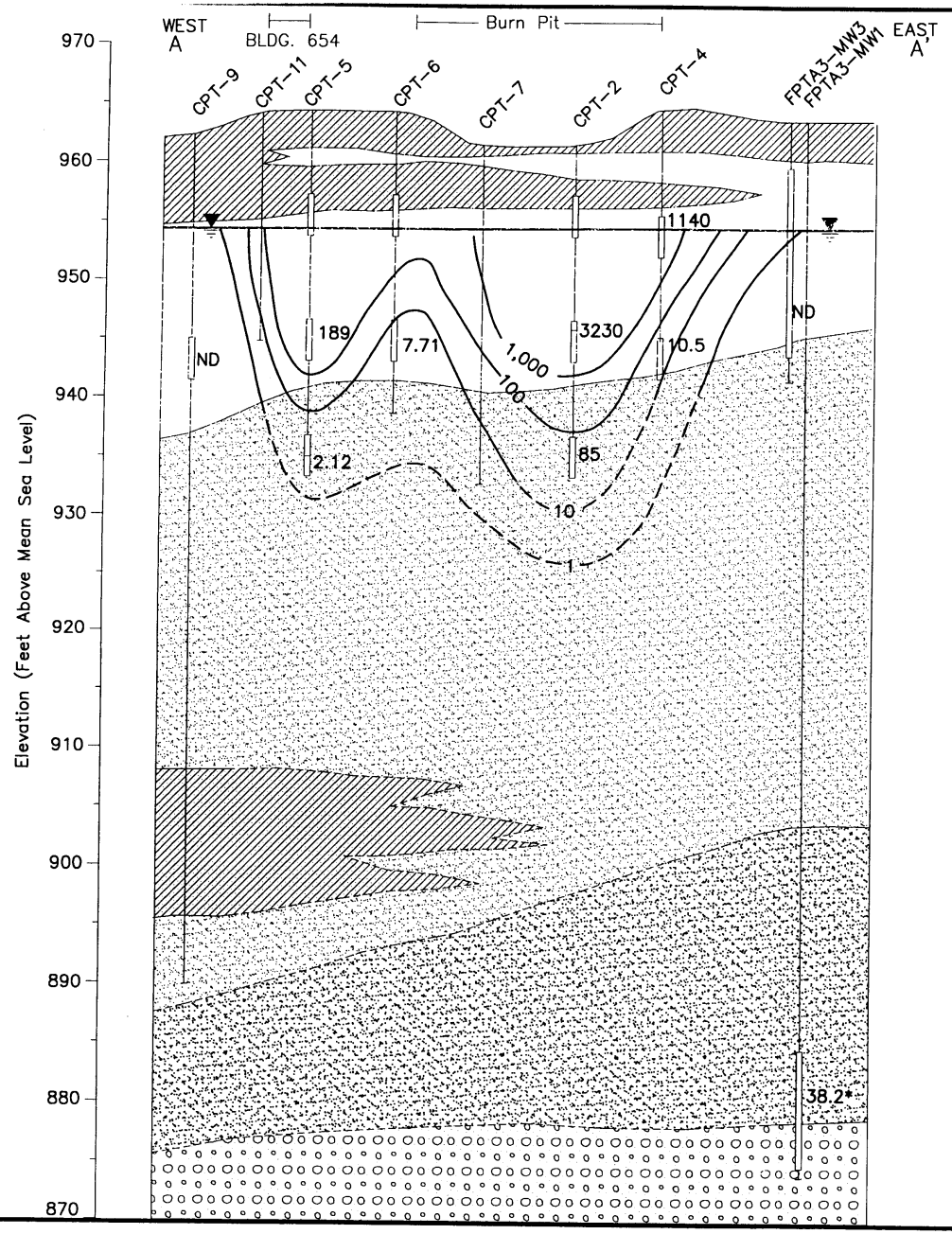

LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 — Well Identification; Well Borehole Screen Total BTEX With Concentration Mictograms Per Liter (µg/L)
- Bottom of Borehole. Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- —100— Line of Equal BTEX Concentration (µg/L)

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 4.3

VERTICAL PROFILE OF TOTAL BTEX ISOPLETHS FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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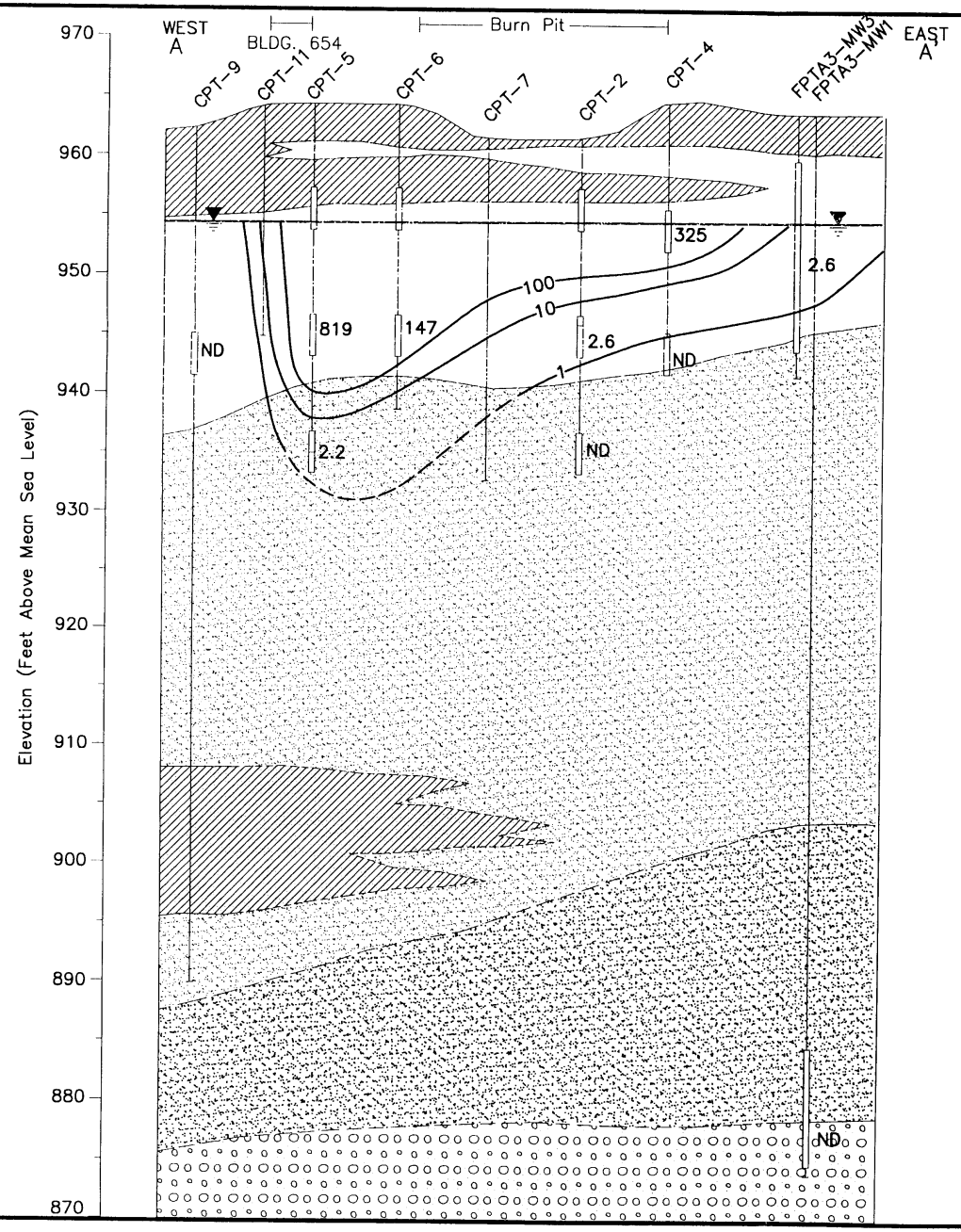

LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 — Well Identification
- 147 — Well Borehole Screen With Total Chlorinated Solvent Concentration (µg/L)
- Bottom of Borehole Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- 10 — Line of Equal Chlorinated Solvent Concentration (µg/L) (Dashed where inferred)
- ND — NOT DETECTED
- CONTOUR INTERVAL = VARIABLE

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 4.7

VERTICAL PROFILE OF TOTAL CHLORINATED SOLVENT ISOPLETHS FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 4.5 (CONTINUED)
GROUNDWATER GEOCHEMICAL DATA
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Sample Location	Redox Potential (mV)	Alkalinity (mg/L)	Free CO_2 (mg/L)	pH	Temp. (°C)	Conduc-tivity	Chloride (mg/L)	Phenols (mg/L)
HF6-MW1	NA	NA	NA	NA	12.3	NA	4.27	NA
HF6-MW1 (dup)	NA	NA	NA	NA	NA	NA	4.07	NA
HF6-MW2	-60	460	440	6.8	13.1	1490	20.4	0.3
HF6-MW2D	-100	500	230	7.2	13.5	1060	4.85	<0.1
HF6-MW2D (dup)	NA	NA	NA	NA	NA	NA	4.88	NA
HF6-MW2D (dup)	-105	520	240	7.2	12.8	1050	5.59	<0.1
HF6-MW4	-90	678	600	7.0	12.9	1860	25.2	NA
HF6-MW4 (dup)	-91	670	630	7.0	NA	1860	25.3	0.8
FPTA3-MW1	-120	502	282	6.9	13.5	1050	4.53	0.2
FPTA3-MW1 (dup)	NA	NA	NA	NA	NA	NA	NA	NA
FPTA3-MW2	-86	784	652	6.8	13.8	1440	3.6	0.3
FPTA3-MW2 (dup)	NA	NA	NA	NA	NA	NA	3.7	NA
FPTA3-MW3	-145	760	522	7.0	13.8	1170	17.2	0.2
FPTA3-MW4	90	446	160	7.3	13.8	820	4.61	0.3
FPTA3-MW5	30	428	132	7.1	13.3	849	2.98	<0.1
FPTA3-MW6	-50	600	300	7.1	12	1150	22.8	0.3
FPTA3-MW6A	-100	675	440	7.2	11.3	1270	19.5	0.3
FPTA3-MW6A (dup)	NA	NA	NA	NA	NA	NA	NA	NA
MP-FPTA3-2M	-165	640	424	7.3	14.3	1230	16.2	0.4
MP-FPTA3-2D	-140	632	476	7.2	14.3	1210	10.5	0.3
MP-FPTA3-4D	-120	712	540	7.2	13.7	1300	18.1	0.1
MP-FPTA3-5M	-170	520	460	7.3	13.5	1470	129	0.2
MP-FPTA3-5D	-160	480	450	7.2	12.6	926	5.57	0.3
MP-FPTA3-6D	-130	654	580	7.1	13.8	1790	213	0.3
MP-FPTA3-6D (dup)	NA	NA	NA	NA	NA	NA	NA	NA
MP-FPTA3-8S	NA	NA	NA	NA	NA	NA	NA	NA
MP-FPTA3-8D	-130	518	304	7.2	12.3	871	5.31	0.4
MP-FPTA3-9D	-98	514	182	7.2	12.1	1020	7.19	0.2
MP-FPTA3-12D	-60	570	260	7.2	11.7	1120	7	<0.1
MP-FPTA3-12D (dup)	NA	NA	NA	NA	NA	NA	6.94	NA
MP-FPTA3-17D	-111	630	560	6.9	12.8	1370	65.9	0.2
MP-FPTA3-17D (dup)	NA	614	NA	7.0	NA	1360	165	0.2
MP-FPTA3-20D	-120	766	780	6.9	12.8	1390	22.9	<0.1
MP-FPTA3-20S	NA	NA	NA	NA	NA	NA	NA	NA
MP-FPTA3-20D (dup)	NA	NA	NA	NA	NA	NA	NA	NA
MP-FPTA3-22S	-37	464	212	7.0	12.4	944	13	NA
MP-FPTA3-22D	-80	470	266	7.0	12.5	903	7.87	NA
MP-FPTA3-23S	NA	NA	NA	NA	NA	NA	15.9	NA
MP-FPTA3-23D	-127	492	342	7.1	13.2	964	11.1	NA
MP-FPTA3-24D	-70	412	104	7.2	11.6	820	3.74	<0.1
MP-FTPA3-UST1	82	142	100	7.3	11.8	693	49.4	<0.1

NA=Not available.

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

This equation indicates that 5.0 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) + 1(6) = 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 are required to mineralize 1 mg of benzene. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. On the basis of these calculations, approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed. With an average site DO concentration of approximately 0.2 mg/L (excluding well FPTA3-MW4), the shallow groundwater at this site has the capacity to assimilate 0.2 mg/L (200 µg/L) of total BTEX if microbial cell mass production is taken into account.

4.3.2.2 Nitrate/Nitrite

Concentrations of nitrate/nitrite [as nitrogen (N)] were measured in groundwater samples collected in November 1994. Table 4.5 summarizes measured nitrate/nitrite (as N) concentrations. Nitrate/nitrite (as N) concentrations were not detected above 0.05 mg/L except at two sampling locations, including background locations. The highest nitrate/nitrite (as N) concentration was measured in the groundwater sample collected from well FPTA3-MW4 at 1.5 mg/L. It is suspected that this concentration may be the result of surface water/groundwater interaction as this well is located within 100 feet of the inlet to the Base Lake. An anomalously high DO concentration for the site was also measured in a groundwater sample collected from this well. As a result of the overall lack of nitrate/nitrite (as N) in groundwater, nitrate is not considered to be an important electron acceptor at this site.

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 to the mineralization of approximately 0.20 mg of BTEX for every 1.0 mg of nitrate consumed. As nitrate/nitrite (as N) was not detected above quantitation limits at all but two wells, the shallow groundwater at this site has a negligible capacity to assimilate BTEX through denitrification.

4.3.2.3 Ferrous Iron

Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected in November 1994. Table 4.5 summarizes ferrous iron concentrations. Measured ferrous iron concentrations range from <0.05 mg/L to 26.3 mg/L. Figure 4.8 is an isopleth map showing the areal extent of ferrous iron in groundwater. Comparison of Figures 4.2 and 4.8 shows graphically that most of the area with elevated total BTEX

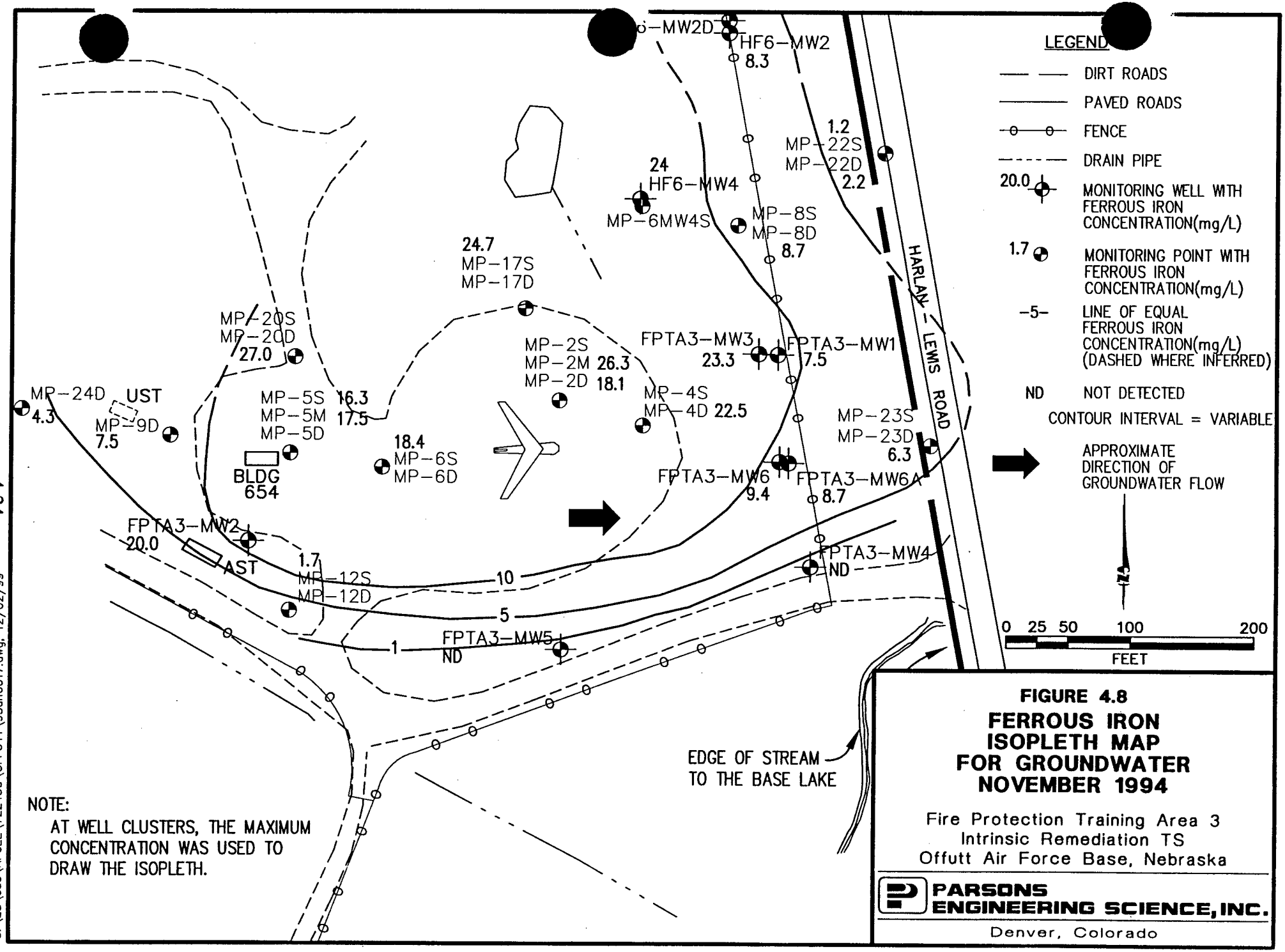

FIGURE 4.8

FERROUS IRON ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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Denver, Colorado

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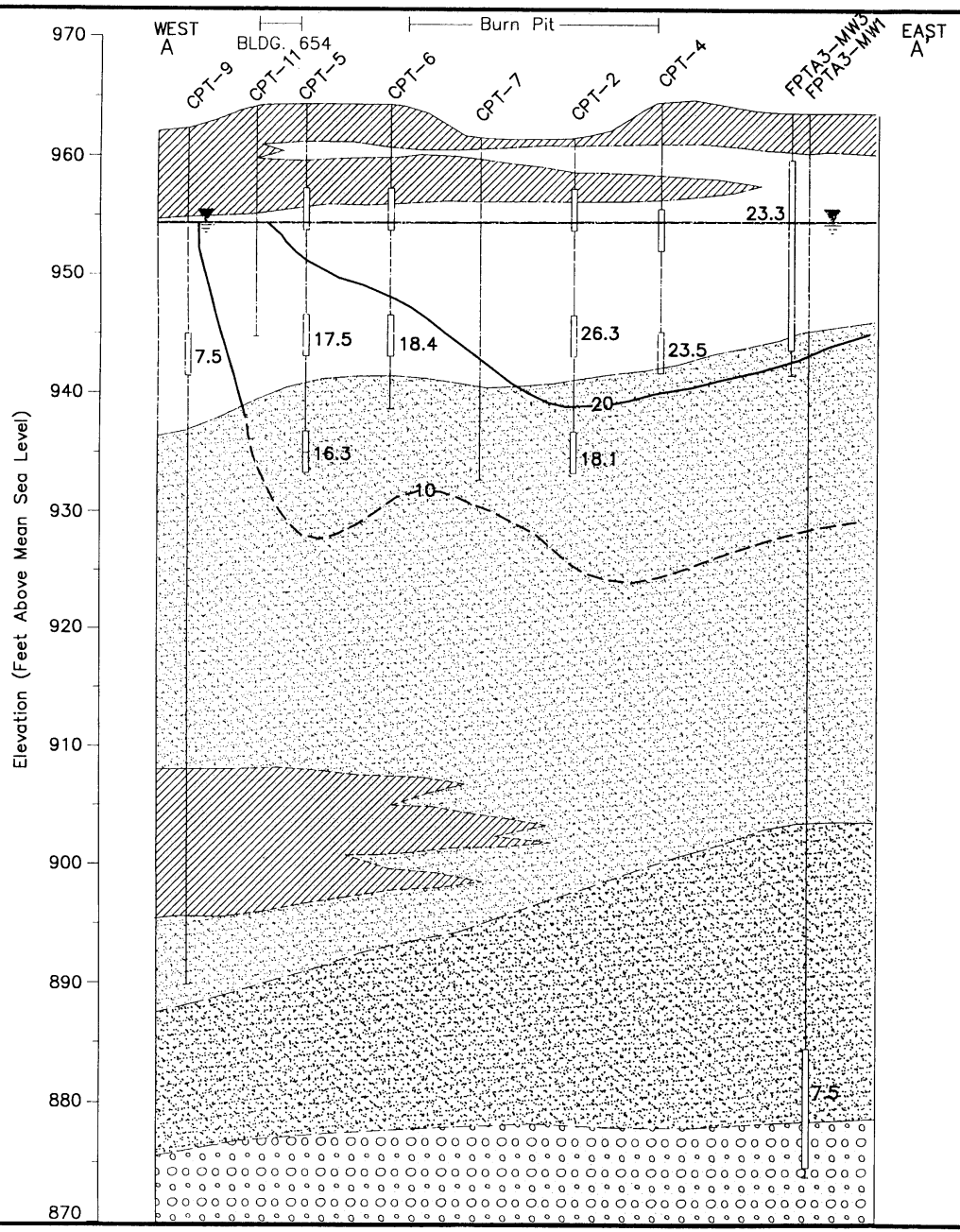
concentrations has elevated ferrous iron concentrations. This suggests that ferric iron hydroxide (Fe^{3+}) is being reduced to ferrous iron during biodegradation of BTEX compounds. All but one groundwater sample with a ferrous iron concentration greater than 10 mg/L was collected from a well where BTEX also were detected. Background levels of ferrous iron are generally at or below 8 mg/L, as measured at wells with little or no BTEX contamination. Similar to the distribution of dissolved BTEX, concentrations of ferrous iron decrease with depth in the shallow water table. The vertical distribution of ferrous iron in groundwater is pictured on Figure 4.9.

The stoichiometry of BTEX oxidation to carbon dioxide, ferrous iron, and water by iron reduction through anaerobic microbial biodegradation 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 approximately 8 mg/L and a maximum detected ferrous iron concentration of 27 mg/L, the shallow groundwater has the capacity to assimilate approximately 0.87 mg/L (870 µg/L) of total BTEX through iron reduction. This is a conservative estimate of the assimilative capacity of iron because microbial cell mass production was not taken into account by the stoichiometry shown in Table 4.4. In addition, this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, iron assimilative capacity could be much higher.

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 November 1994. Sulfate concentrations at the site range from <0.5 mg/L to 391 mg/L. Table 4.5 summarizes measured sulfate concentrations. Figure 4.10 is an isopleth map showing the areal extent of sulfate in groundwater. Comparison of Figures 4.2 and 4.10 shows graphically that the area of depleted sulfate concentrations occupies much of the same area as the BTEX plume. One of the two sulfate concentrations of <0.5 mg/L was measured in the groundwater sample from monitoring point MP-2M, which is located at the center of the main burn pit and has the highest BTEX concentration. In addition, sulfate concentrations increase with depth in the shallow water table. The vertical distribution of sulfate in groundwater is pictured on Figure 4.11. These relationships are a strong indication that anaerobic biodegradation of BTEX compounds is occurring in the shallow groundwater through the microbially mediated process of sulfate reduction.



LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 — Well Identification
- 26.3 — Well Borehole Screen With Ferrous Iron Concentration (mg/L) Bottom of Borehole Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- −20− Line of Equal Ferrous Iron Concentration (mg/L) (Dashed Where Inferred)

CONTOUR INTERVAL = 10 mg/L

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 4.9

VERTICAL PROFILE OF FERROUS IRON ISOPLETHS FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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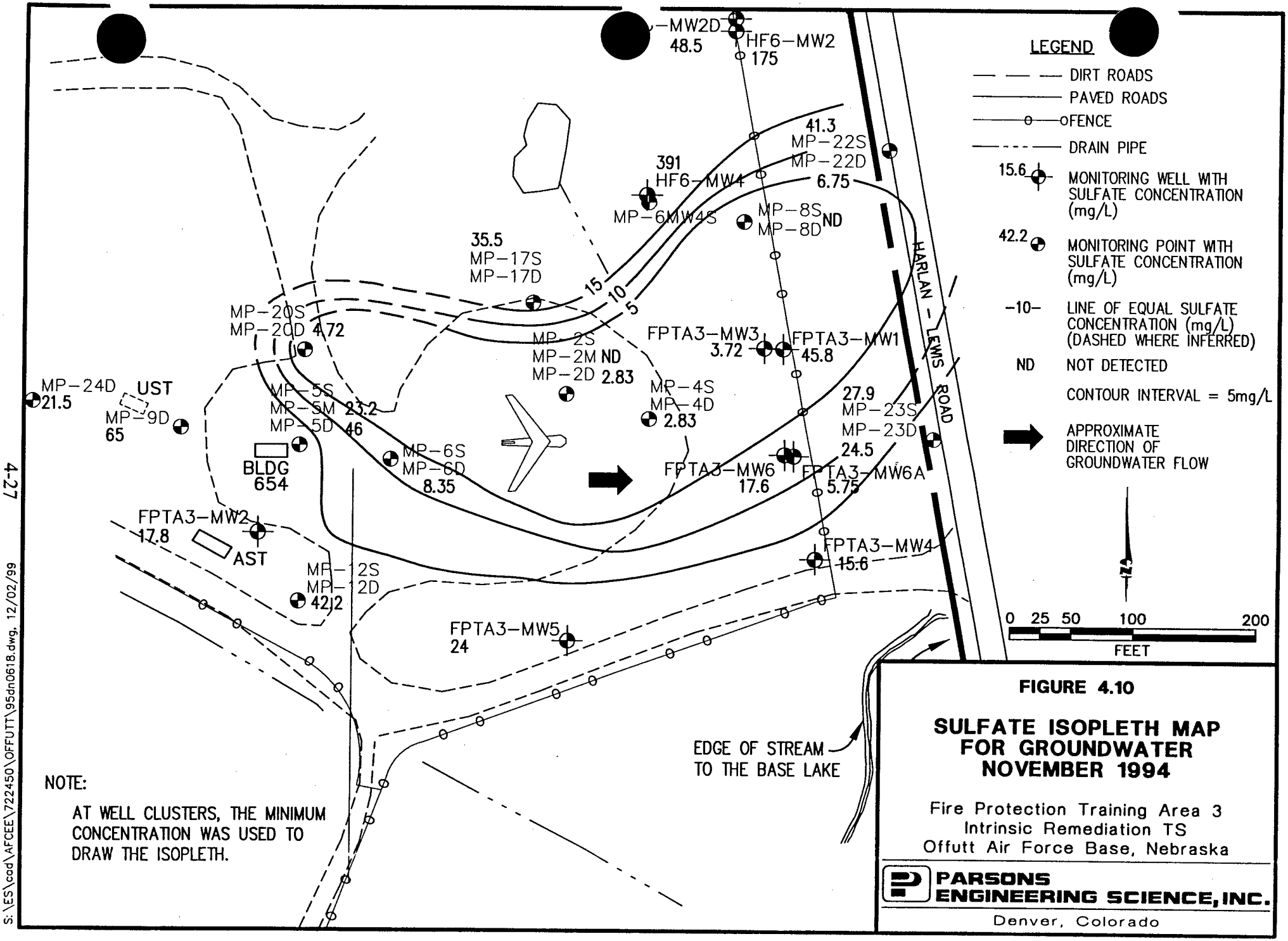

NOTE:

AT WELL CLUSTERS, THE MINIMUM CONCENTRATION WAS USED TO DRAW THE ISOPLETH.

FIGURE 4.10

SULFATE ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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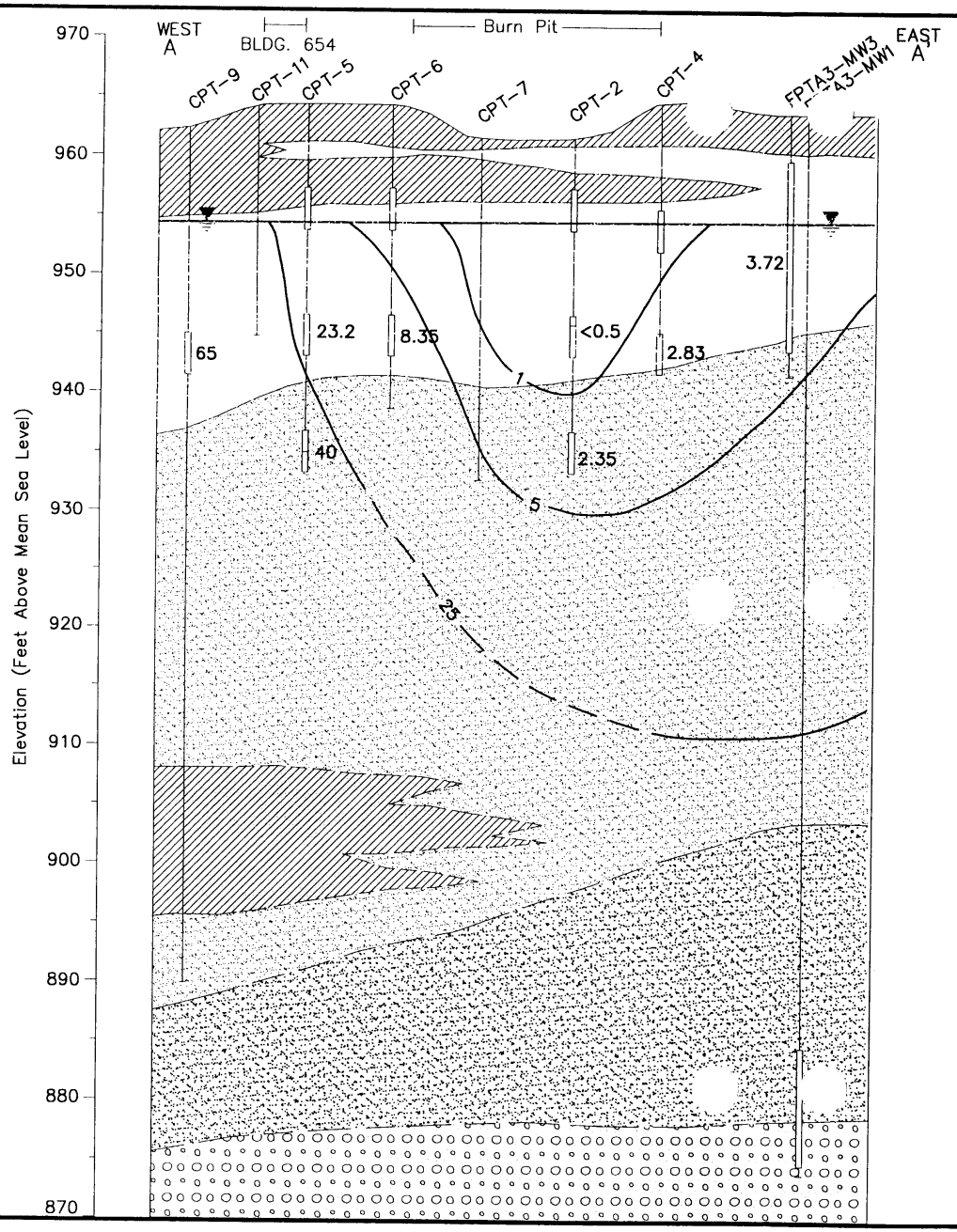

LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 / 2.35 — Well Identification; Well Borehole Screen With Sulfate Concentration (mg/L); Bottom of Borehole. Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- –5– Line of Equal Sulfate Concentration (mg/L) (Dashed Where Inferred)

CONTOUR INTERVAL = VARIABLE

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 4.11

VERTICAL PROFILE OF SULFATE ISOPLETHS FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water by sulfate reduction through anaerobic microbial biodegradation 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. Sulfate concentrations at eight shallow locations outside of the BTEX plume range from 6.7 mg/L to 65 mg/L, with an average concentration of 33.1 mg/L. Assuming a background sulfate concentration of 33.1 mg/L, the shallow groundwater at this site has the capacity to assimilate 6.95 mg/L (6,950 µg/L) of total BTEX through sulfate reduction. Again, this is a conservative estimate of the assimilative capacity of sulfate because microbial cell mass production has not been taken into account by the stoichiometry presented in Table 4.4.

4.3.2.5 Methane in Groundwater

Methane concentrations were measured in groundwater samples collected in November 1994. Table 4.5 summarizes methane concentrations which range from below the quantitation level to 22.5 mg/L at the site. Figure 4.12 is an isopleth map showing the distribution of methane in groundwater. Comparison of Figures 4.2 and 4.12 shows graphically that areas with elevated total BTEX concentrations correlate with elevated methane concentrations. The majority of the methane concentrations in areas of low or no BTEX concentrations were below 0.01 mg/L. In addition, the two highest methane concentrations were detected within the main burn pit and Building 654 source areas: 17.6 mg/L at MP-2M and 22.5 mg/L at MP-5M. Furthermore, vertical distributions of BTEX and methane concentrations are nearly identical, as can be observed through a comparison of Figures 4.3 and 4.13. These relations are a strong indication that anaerobic biodegradation of BTEX is occurring at the site. This is consistent with other electron acceptor data for this site, with the area having elevated methane concentrations corresponding with the areas with depleted sulfate and elevated ferrous iron concentrations.

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 22.5 mg/L, the shallow groundwater has the capacity to assimilate approximately 28.8 mg/L (28,800 µg/L) of total BTEX through methanogenesis. This is a conservative estimate of the assimilative capacity through methanogenesis because microbial cell mass production was not taken into account by the stoichiometry shown in Table 4.4. In addition, these calculations are based on observed methane concentrations and not on the amount of carbon dioxide available in the aquifer. As 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, methanogenic assimilative capacity could be much higher.

4.3.2.6 Reduction/Oxidation Potential

Redox potentials were measured at groundwater monitoring wells and points in November 1994. Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during BTEX oxidation. The

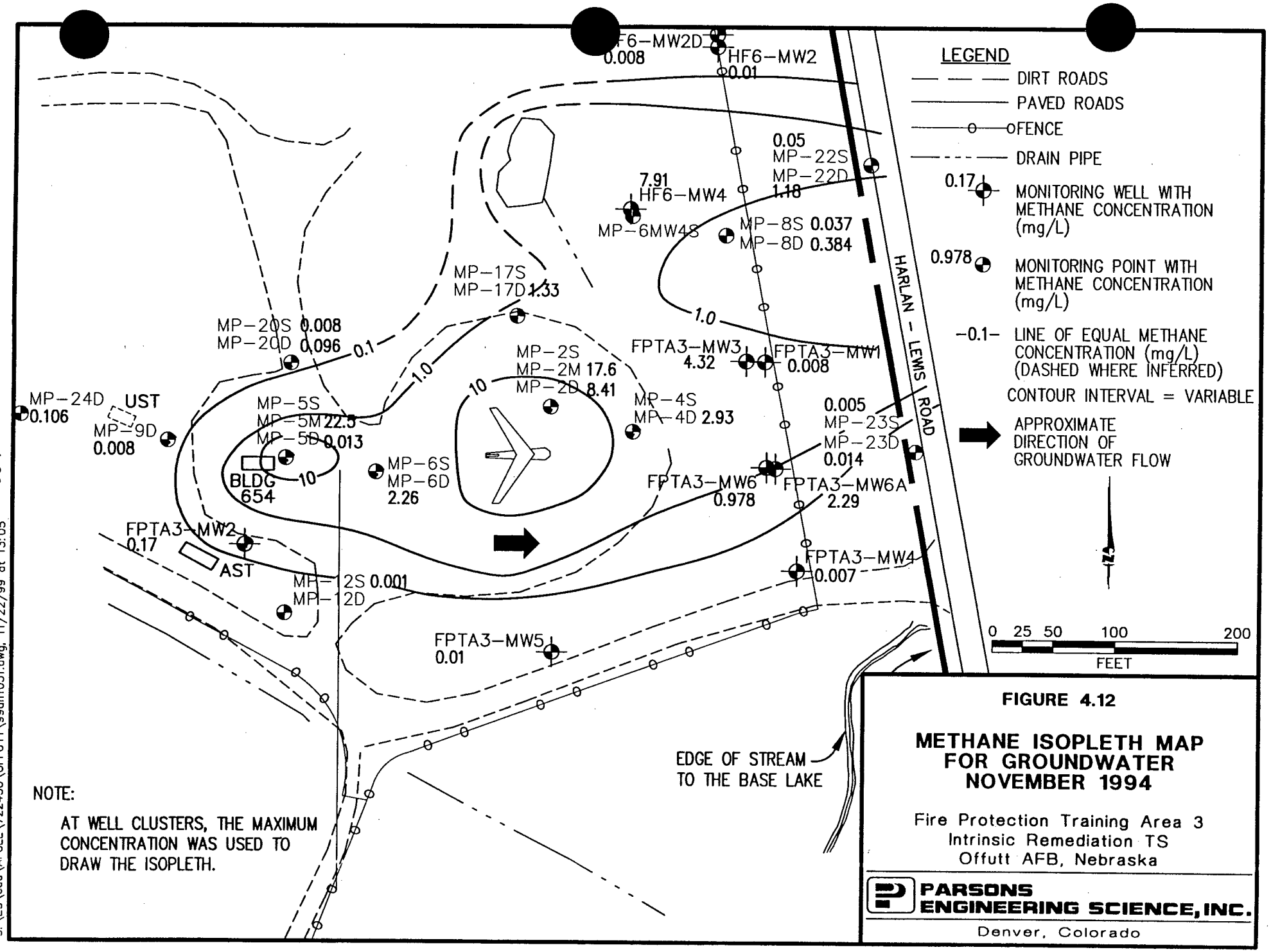

FIGURE 4.12

METHANE ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt AFB, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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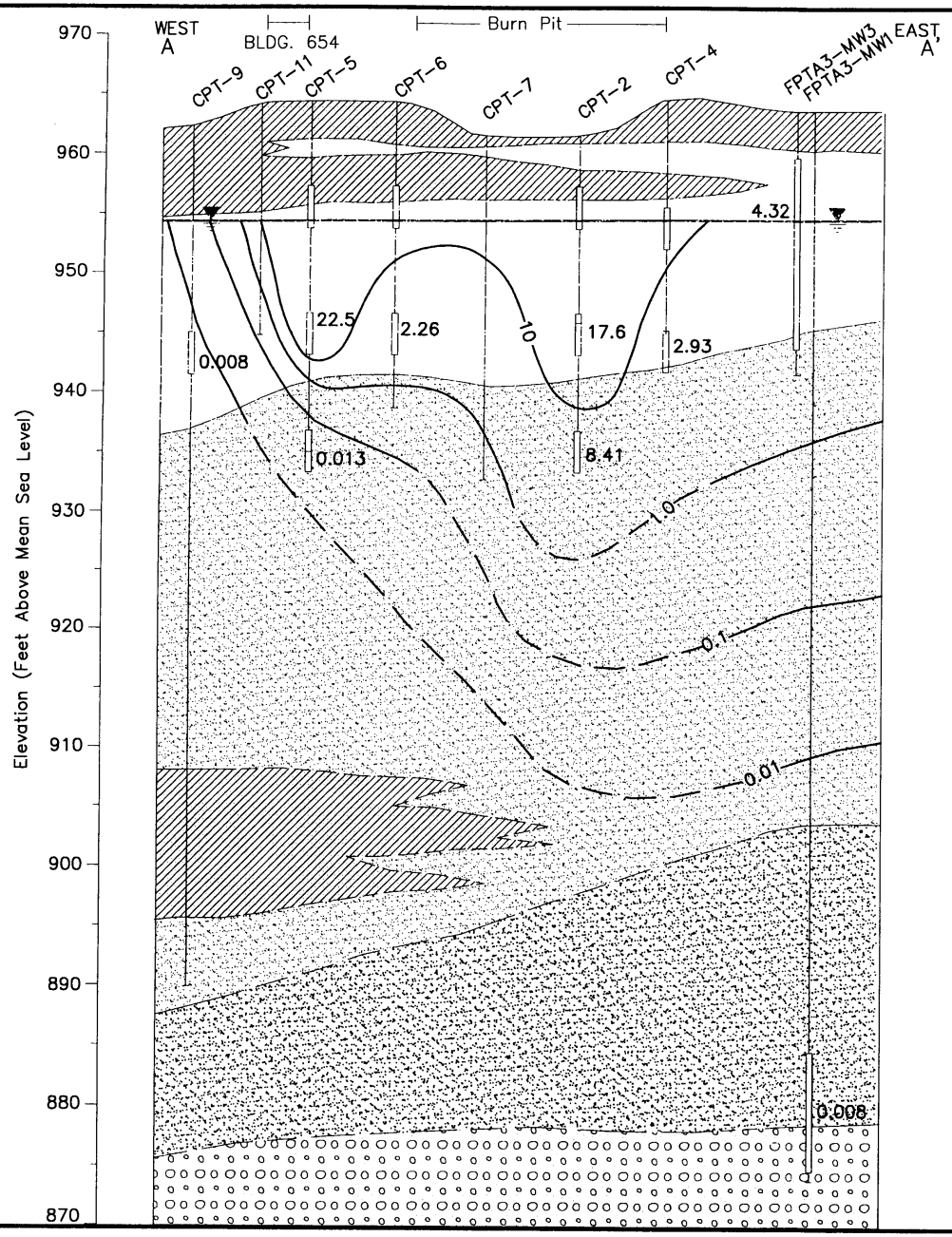

LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 — Well Identification
- 8.41 — Well Borehole Screen With Methane Concentration (mg/L)
- Bottom of Borehole Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- −1.0− Line of Equal Methane Concentration (mg/L) (Dashed Where Inferred)

CONTOUR INTERVAL = VARIABLE

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 4.13

VERTICAL PROFILE OF METHANE ISOPLETHS FOR GROUNDWATER NOVEMBER 1994

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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redox potential at the site ranges from 90 millivolts (mV) to -170 mV. Table 4.5 summarizes available redox potential data. The areal extent of redox potentials is illustrated graphically on Figure 4.14. As expected, areas at the site with low redox potentials appear to coincide with areas of high BTEX contamination, low sulfate concentrations, and elevated ferrous iron and methane concentrations (compare Figure 4.14 with Figures 4.2, 4.8, 4.10, and 4.12). Redox potential is below -150 mV within the main burn pit and Building 654 source areas. Likewise, the vertical distribution of low redox potentials is comparable to the distribution of high BTEX contamination, low sulfate concentrations, and elevated ferrous iron and methane concentrations (compare Figure 4.15 with Figures 4.3, 4.9, 4.11, and 4.13).

4.3.2.7 Dehydrogenase Activity

The 14 soil samples collected from soil boreholes SS-1 and SS-2 were analyzed for dehydrogenase activity. The dehydrogenase test is a qualitative method used to determine if aerobic bacteria are present in an aquifer in quantities capable of biodegrading fuel hydrocarbons. If the test gives a positive result, a sufficient number of microorganisms capable of aerobic metabolism and/or denitrification are present in the aquifer. If the test is negative, sufficient numbers of microorganisms capable of aerobic respiration or denitrification are not present in the aquifer. A negative result for the dehydrogenase test gives no indication of the relative abundance of anaerobic microorganisms capable of utilizing sulfate, iron III, or carbon dioxide during biodegradation. Positive results were obtained from samples collected from both boreholes. At borehole SS-1, which is located outside of the source area, hydrogenase activity was highest in the surface soil sample at 52 µg of formazan per gram of soil. Dehydrogenase activity was detected in 7 of the 8 soil samples collected at borehole SS-2 in the main burn pit. Detected activity levels ranged from 16 to 300 µg of formazan per gram of soil. Measurements are presented in Table 4.1.

4.3.2.8 Volatile Fatty Acids

At monitoring wells FPTA3-MW3 and FPTA3-MW6, USEPA researchers collected groundwater samples for volatile fatty acids analysis. This test is a gas chromatography/mass spectrometry (GC/MS) method wherein the samples are compared to a standard mixture containing a total of 58 phenols, aliphatic acids, and aromatic acids. Compounds in the standard mixture are generally associated with microbial processes that break down petroleum hydrocarbons. USEPA researchers reported that the sample from FPTA3-MW3 contained 20, and the sample from FPTA3-MW6 contained 23 of the compounds in the standard mixture. Both sample locations are near the downgradient boundary of the dissolved BTEX plume.

4.3.2.9 Alkalinity

Total alkalinity (as calcium carbonate) was measured in groundwater samples collected in November 1994. These measurements are summarized in Table 4.5. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site is in the moderate range for groundwater, varying from 412 mg/L at MP-24D to 784 mg/L at FPTA3-MW2.

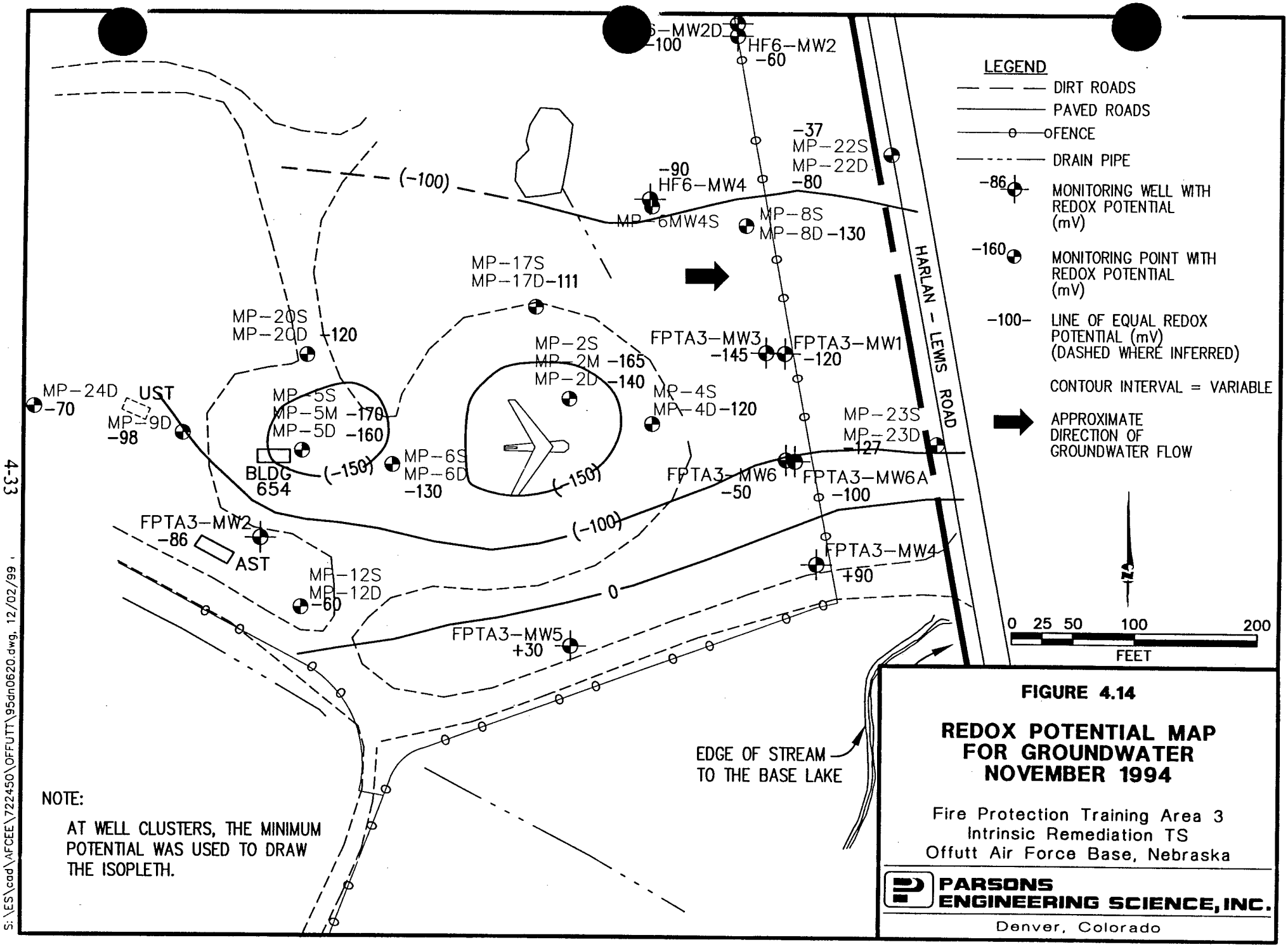

FIGURE 4.14

REDOX POTENTIAL MAP FOR GROUNDWATER NOVEMBER 1994

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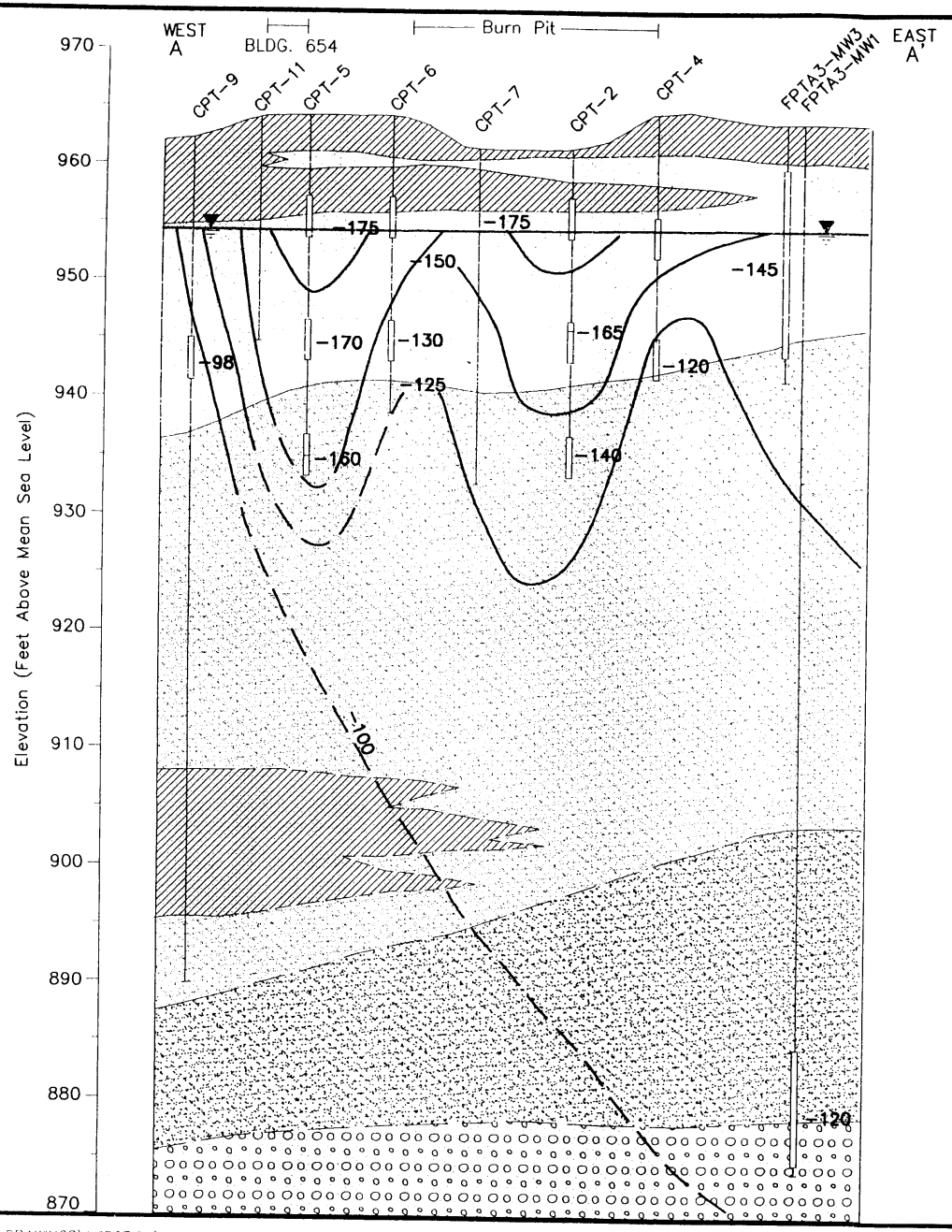

LEGEND

- SILT and fine to very fine SAND.
- SAND, fine to very fine, trace silt and/or clay.
- SAND, fine (shallow) to coarse (deep), clean.
- SAND, medium to coarse, no fines, trace well rounded gravel increasing with depth.
- Sandy GRAVEL, well rounded, no fines.
- Contact (Dashed where inferred)
- CPT-2 / -140: Well Identification; Well Borehole Screen With Redox Potential (mV)
- Bottom of Borehole Multiple screened intervals are pictured where clusters were installed at a CPT location.
- Approximate Location of Water Table
- --125-- Line of Equal Redox Potential (mV)(Dashed Where Inferred)

CONTOUR INTERVAL = 25mV

VERTICAL EXAGGERATION 10x

0 50 100 200

FEET

FIGURE 4.15

VERTICAL PROFILE OF REDOX POTENTIAL FOR GROUNDWATER NOVEMBER 1994

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This amount of alkalinity should be sufficient to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions.

4.3.2.10 pH

pH was measured for groundwater samples collected from groundwater monitoring points and monitoring wells in November 1994. These measurements are summarized in Table 4.5. The pH of a solution is the negative logarithm of the hydrogen ion concentration [H^+]. Groundwater pH measured at the site ranges from 6.8 to 7.3. This range of pH is within the optimal range for BTEX-degrading microbes.

4.3.2.11 Temperature

Groundwater temperature was measured at groundwater monitoring points and monitoring wells in November 1994. Table 4.5 summarizes groundwater temperature readings. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the shallow aquifer varied from 11.3 degrees Celsius (°C) to 14.3°C. These are moderate temperatures for shallow groundwater, suggesting that bacterial growth rates should not be inhibited.

4.3.3 Cometabolism of Chlorinated Solvents

Although the focus of this demonstration was on natural attenuation of 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. Chlorinated solvents can be transformed 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 Gosset, 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; Hartsman and deBont, 1992; McCarty and Semprini, 1994). However, the transformation differs from BTEX degradation because microorganisms do not obtain free energy from the transformation of chlorinated solvents. Instead, chlorinated solvent degradation is accomplished through cometabolism. Microorganisms in the groundwater produce enzymes or cofactors during the degradation of BTEX. These enzymes and/or cofactors then participate in the degradation of the chlorinated solvents. Chlorinated solvents are usually only partially transformed during cometabolic processes (McCarty and Semprini, 1994). Either hydrolysis or dehalogenation is generally required to complete the transformation.

There also appears to be a correlation between cometabolism reaction rates and reducing conditions; the more reducing the conditions, the faster dechlorination occurs. Bouwer and Wright (1988) documented that reaction rates of cometabolism tend to proceed faster under reducing conditions associated with methanogenesis than under less reducing conditions associated with denitrification. At FPTA3, the principal BTEX degradation processes include methanogenesis, iron reduction, and sulfate reduction. All three processes occur under conditions more reducing than those associated with denitrification.

Historically, soils in the vicinity of Building 654 at FPTA3 have been contaminated with chlorinated solvents, most notably TCE (Section 4.2.1.3). Previous studies have shown that TCE can be anaerobically reduced to either c- or t-1,2-DCE, both of which can be further transformed to vinyl chloride (Miller and Guengerich, 1982; Wilson and Wilson, 1985; Mayer *et al.*, 1988; Nelson, *et al.*, 1988; Freedman *et al.*, 1989; Henson *et al.*, 1989; Tsien *et al.*, 1989; Henry, 1991; McCarty, 1994; Wilson *et al.*, 1994). Vinyl chloride may be subsequently reduced to ethene or carbon dioxide. The following equation describes the cometabolic degradation of TCE to the first intermediate product (c- or t-1,2-DCE):

$$C_6H_6 + 4.5H_2O \rightarrow 2.25CO_2 + 3.75CH_4 + \text{cofactor} \rightarrow \text{TCE} + \text{cofactor} \rightarrow \text{DCE} + Cl^-$$

This relationship demonstrates how the reduction of BTEX via methanogenesis may result in the dechlorination of TCE to DCE via cometabolic processes. Similar relationships can be developed for each of the intermediate products. TCE is indirectly transformed by the hydrocarbon-degrading bacteria as BTEX is used to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX, nor interfere with the use of electron acceptors involved in the oxidation of BTEX. It is possible, however, that the cometabolic degradation of TCE or one of the intermediate products could have toxic side effects on the microorganisms involved in the BTEX degradation.

4.3.3.1 Chlorinated Solvents and Ethene

TCE, TCA, c- and t-1,2-DCE, vinyl chloride, and ethene were measured in groundwater samples collected from site monitoring wells and monitoring points in November 1994. Results are presented in Table 4.3 and on Figure 4.6. Total chlorinated solvents consisted of approximately 70 percent vinyl chloride, 28 percent c-1,2-DCE, 1 percent TCE, and 1 percent all others. As TCE has been historically documented as the source solvent in soils, and vinyl chloride is the final chlorinated solvent in the anaerobic degradation sequence, it can be concluded that heavier chlorinated solvents (TCE and PCE) are being degraded anaerobically to lighter chlorinated solvents (DCE and vinyl chloride).

Equally as important, vinyl chloride is apparently undergoing a final transformation to ethene. The two highest ethene concentrations were detected in the groundwater samples from monitoring points MP-5M and MP-6D (Table 4.3). These two groundwater samples also contained the two highest concentrations of vinyl chloride.

4.3.3.2 Chloride

Chloride concentrations also were measured in groundwater samples collected in November 1994. Concentrations at the site range from <0.5 mg/L to 213 mg/L. Table 4.5 summarizes measured chloride concentrations. Figure 4.16 is an isopleth map showing the areal extent of chloride in groundwater. Comparison of Figures 4.2, 4.5, and 4.16 shows graphically that the area of elevated chloride concentrations occupies much of the same area as the chlorinated solvent and BTEX plumes. Furthermore, the two highest chloride concentrations were detected in groundwater samples from the two monitoring points which also contained the highest concentrations of vinyl chloride and ethene: MP-5M and MP-6D. These relationships are a strong indication that dechlorination of

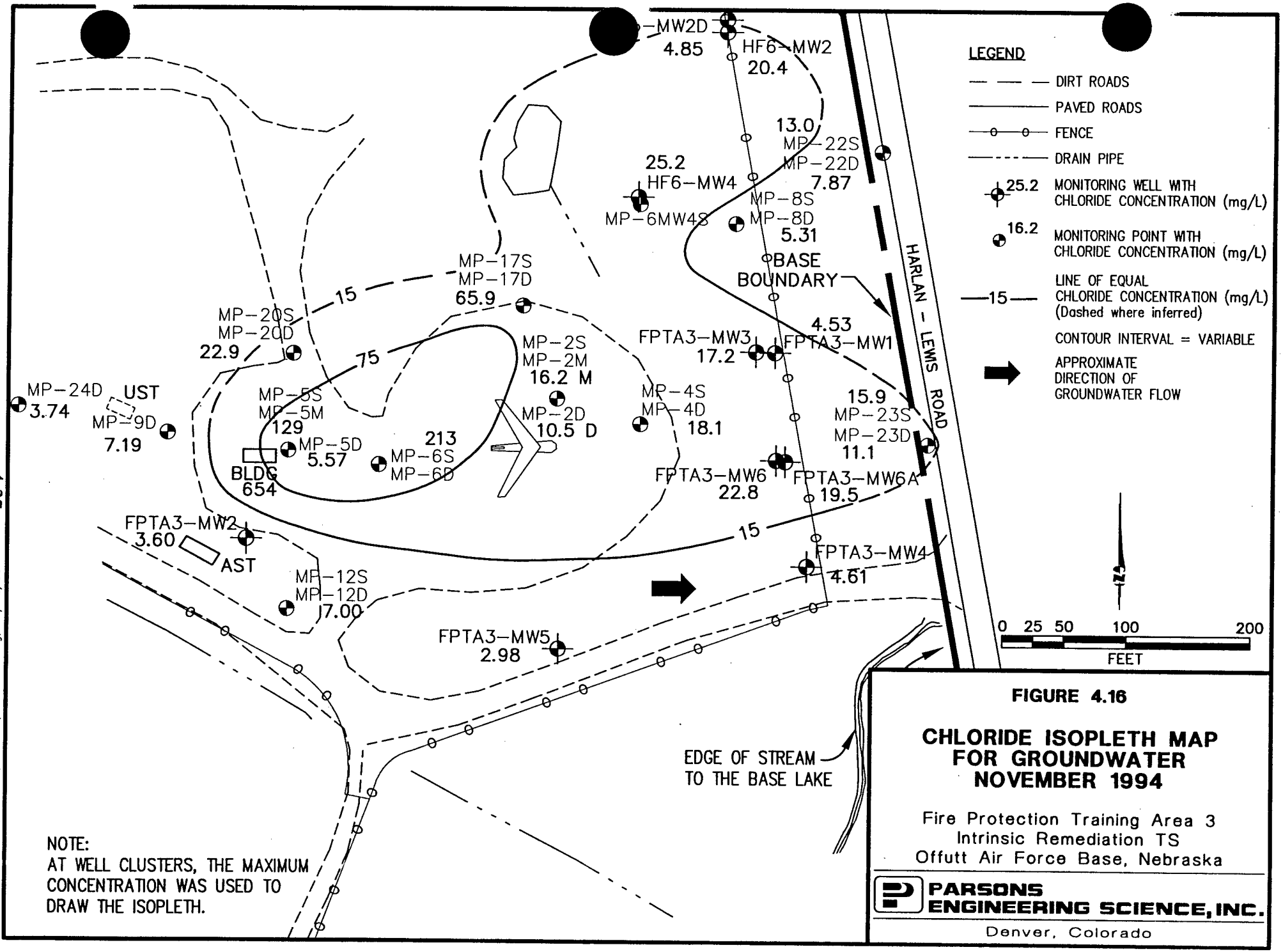

FIGURE 4.16

CHLORIDE ISOPLETH MAP FOR GROUNDWATER NOVEMBER 1994

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chlorinated solvents is occurring in the highly reducing shallow groundwater, particularly near the source area at Building 654.

4.3.4 Discussion

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.

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps provides strong qualitative evidence of biodegradation of BTEX compounds. Other observations and patterns in the data provide further evidence that biodegradation is reducing hydrocarbon concentrations at the site.

As benzene is typically more recalcitrant to biodegradation than toluene, ethylbenzene, and xylene isomers, an apparent enrichment of dissolved benzene relative to toluene, ethylbenzene, and xylenes in site groundwater is another indicator of biodegradation (Barker *et al.*, 1987; Cozzarelli *et al.*, 1990). GC studies of JP-4 and Jet-A fuels show that those petroleum mixtures contain 0.3 to 0.5 percent (by weight) benzene and between 2.9 and 4.4 percent total BTEX (Arthur D. Little, Inc., 1987; Dunlap and Beckmann, 1988). Therefore, benzene originally accounts for approximately 7 to 17 percent of the total BTEX concentration of these fuels. Approximately 24 percent of all dissolved BTEX detected at FPTA3 was identified as benzene. The enriched concentrations of benzene are one additional indicator of biodegradation. Furthermore, with a 35-year old source that has not received fresh product in over 5 years, the fraction of benzene in the source soils is likely to have decreased below the original range of 7 to 17 percent of total BTEX because benzene has a higher solubility and higher susceptibility to weathering in the source soils than toluene, ethylbenzene, or xylenes. The higher solubility of benzene can account for enriched benzene concentrations early in the history of a spill; however, this is mitigated by the more rapid reduction of benzene in the source soils resulting from the higher dissolution rate and susceptibility to weathering.

4.3.5 Expressed Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of 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 FPTA3 is at least 36,800 µg/L (Table 4.6). The highest dissolved total BTEX concentration observed at the site was 3,230 µg/L, at MP-2M.

The groundwater appears to have more than sufficient assimilative capacity to degrade the observed dissolved BTEX and limit plume migration. 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 through rainwater infiltration at the main burn pit, discharge pond, and drainage ditch east of the site. The addition of this water may further increase the assimilative capacity of the groundwater at this site.

The large difference between the expressed assimilative capacity and the maximum detected BTEX concentration implies that natural processes will eventually biodegrade the BTEX remaining in the system; however, because of mass transfer, kinetic, and other chemical and biological limitations, the total reservoir of electron acceptors is not available for immediate biodegradation of the BTEX. In addition, other hydrocarbons (such as naphthalene) and natural organic carbons are dissolved in the groundwater, further increasing the demand on the assimilative capacity. Furthermore, the present day

TABLE 4.6
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
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Electron Acceptor or Process	Expressed BTEX Assimilative Capacity (µg/L)
Dissolved Oxygen	200
Nitrate	0
Iron Reduction	870
Sulfate	6,950
Methanogenesis	28,780
Expressed Assimilative Capacity	36,800
Highest observed Total BTEX Concentration	3,230

maximum total BTEX concentration may be a small fraction of the original maximum concentration. During fire training exercises, mobile LNAPL may have been present on the groundwater surface and dissolved total BTEX concentrations as high as 30,000 to 35,000 µg/L may have been present in the groundwater. Such a concentration would have been nearly equivalent to the expressed assimilative capacity.

SECTION 5

GROUNDWATER MODELING

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved BTEX at FPTA3 and to help predict the future migration of these compounds, Parsons ES modeled the fate and transport of the dissolved BTEX plume. The modeling effort has three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible risk to potential downgradient receptors; and 3) to provide technical support for the natural attenuation remedial option at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Because of the conservative nature of model input, the reduction in contaminant mass caused by natural attenuation is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by natural mechanisms operating at the site. 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; Lovely *et al.*, 1989; Hutchins, 1991). Because there is evidence that anaerobic biodegradation processes are occurring at the site, these processes were accounted for during Bioplume II modeling using a first-order anaerobic decay coefficient. The following subsections discuss in more detail the model setup, input parameters and assumptions, model calibration, and 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 ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for anaerobic biodegradation. Due to the limited DO concentrations in the area, aerobic processes are expected to have a minimal contribution to the overall BTEX degradation.

On the basis of the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a shallow unconfined aquifer composed of very fine- to fine-grained sand with a trace of silt and/or clay (Figures 3.4 and 3.5). The use of a 2-dimensional model is appropriate at this site because the saturated interval is relatively homogenous, and water level data suggest that the local groundwater flow system does not have a significant vertical component at depths below the top 20 feet of the saturated zone. Available evidence suggests that mobile LNAPL is not present at the site, but this evidence is inconclusive. The contaminated soils at the site have not been remediated and provide a continuing source of dissolved BTEX contamination in the vicinity of the main burn pit, Building 654, and the former discharge pond.

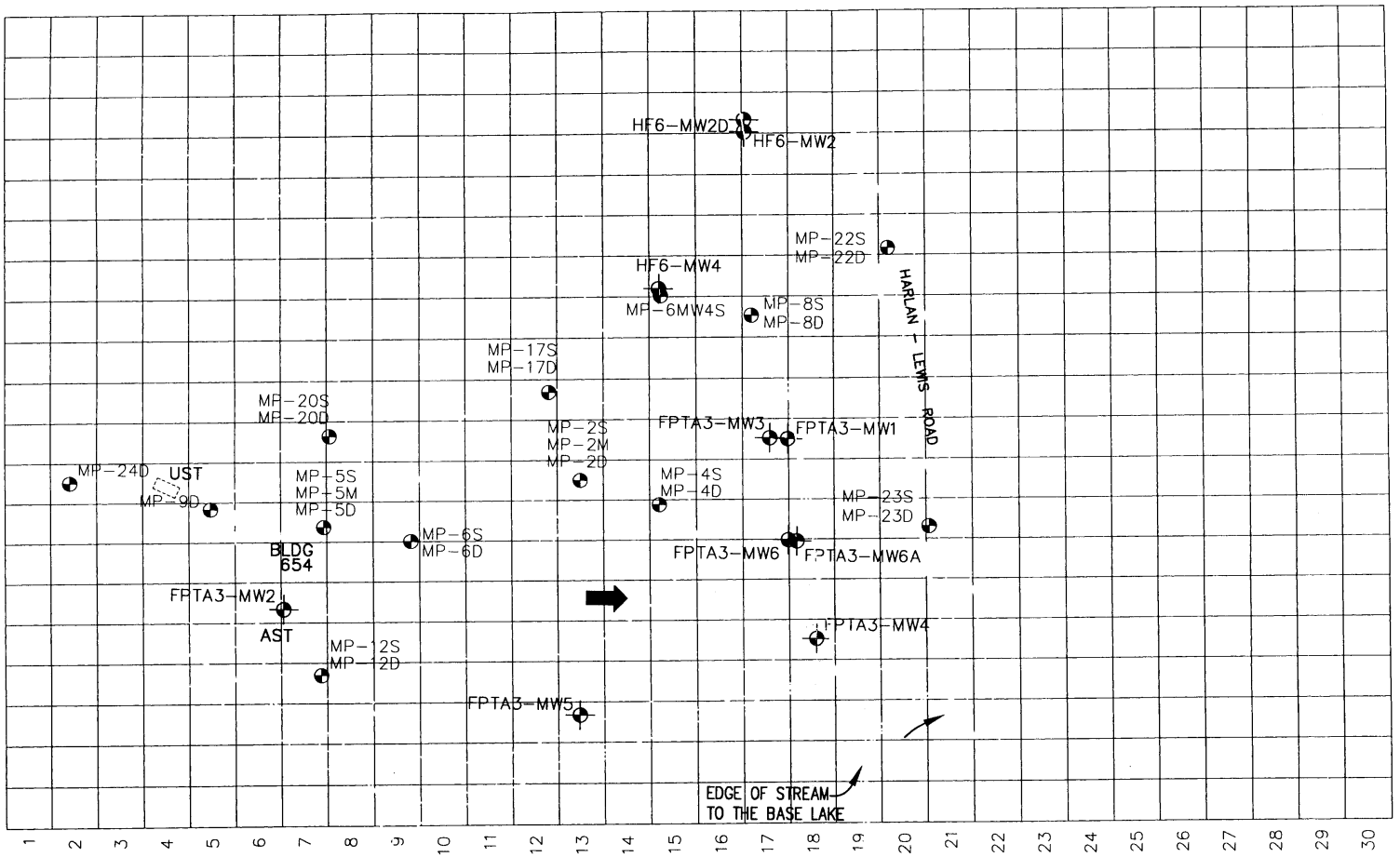
5.3 INITIAL MODEL SETUP

Where possible, the initial setup for this model was based on site data. Where site-specific data were not available (e.g., for effective porosity), reasonable assumptions for the types of materials comprising the shallow aquifer were made based on 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 FPTA3. Each grid cell was 40 feet long by 35 feet wide. The grid was oriented so that the longest dimension was parallel to the overall direction of groundwater flow. The model grid covers an area of 840,000 square feet, or approximately 19.3 acres. The full extent of the model grid is presented on Figure 5.1.

Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (e.g., surface water bodies or contour lines of



LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.1

MODEL GRID

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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 (e.g., $ft^3/ft^2/day$). 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:

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

- 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):

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

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
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 the western and eastern perimeters of the model grid to simulate the easterly groundwater flow observed at the site. Both boundaries were set in the approximate location of the water table indicated by water level data. The head of the western boundary was estimated to be 955.00 to 955.01 feet above msl. The eastern (downgradient) model boundary was estimated at 954.50 to 954.56 feet above msl from available water table elevation and flow gradient data. Part of the eastern boundary lies along the Base Lake. These cells were assigned a constant head of 954.50 feet above msl. The upgradient and downgradient constant-head cells were placed far enough away from the BTEX plume to avoid potential boundary interferences.

Specified-head boundaries were also set along the creek leading to the Base Lake in the southwestern part of the model grid. The constant-head values were selected such that the surface water flowed toward the lake and in order to achieve the best match between observed groundwater elevation data and the calibrated groundwater flow model. Constant-head values were gradually increased from 954.50 feet above msl at the creek's terminus at the Base Lake to 954.68 feet above msl at the creek's furthest upgradient model cell.

The northern model boundary and the southern model boundary to the west of the creek were configured as no-flow (specified flux) boundaries. In this case, the flux through these boundaries is assumed to be zero because flow is generally parallel to these boundaries. The base or lower boundary of the model is also assumed to be no-flow, and is assumed to be 30 feet below the water table. The upper model boundary is defined by the simulated water table surface.

The model cells to the south of the Base Lake creek were made inactive. This was accomplished by setting the head and transmissivity to zero. The cells were turned off to reduce the chance of introducing errors to the model.

A model grid that provides an identification of boundary cells is presented in Appendix C. A second model grid with values for the constant head cells is also presented in Appendix C.

5.3.2 Groundwater Elevation and Gradient

The water table elevation map presented on Figure 3.6 was used to define the starting heads input into the Bioplume II model. Groundwater flow in the vicinity of the site is to the east southeast with an average gradient of approximately 0.0004 ft/ft. Data quantifying seasonal variations in groundwater flow direction and gradient at the site were collected, compiled, and presented by W-C (1992b). Elevations measured at these locations suggested a comparable flow direction as predicted from the same wells in November 1994; however, slightly higher groundwater gradients were predicted throughout most of the year based on the groundwater elevations. To account for seasonal groundwater gradient fluctuations an average gradient of 0.0006 ft/ft was used.

Although the historic groundwater elevation data suggested a slightly steeper groundwater gradient than the November 1994 groundwater elevation data, historic data were available only for monitoring wells located at the periphery of the site. These historic data sets were not sufficiently complete to define unique site groundwater features such as the mound beneath the main burn pit. Therefore, it was assumed that the November 1994 water levels were representative of steady-state conditions. As described in Section 5.4.1, the model was calibrated to the water table as observed in November 1994.

5.3.3 BTEX Concentrations

The total dissolved BTEX concentrations obtained from laboratory analytical results for each well location were used for model development. At nested monitoring points and well nests, the highest BTEX concentration detected in groundwater samples collected within the upper 30 feet of the water table was used. Table 4.2 presents dissolved BTEX concentration data. Figure 4.2 and 4.3 show the lateral and vertical distribution of dissolved BTEX in November 1994.

The BTEX plume observed in November 1994 covered an area of approximately 170,000 square feet (3.9 acres). The shape and distribution of the total BTEX plume is the result of advective-dispersive transport and biodegradation of dissolved BTEX contamination originating from source areas at the main burn pit, Building 654, and the former discharge pond. As described in Section 5.4.2, the simulated BTEX plume was calibrated to match the observed BTEX plume.

5.3.4 Dissolved Oxygen

As discussed previously, the Bioplume II model assumes an instantaneous reaction between the BTEX plume and the DO plume. The discussion presented in Section 4 suggests that DO, ferric iron, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for biodegradation of BTEX compounds at the site. To be conservative, the total BTEX plume at the site was modeled assuming that DO was the only electron acceptor being utilized at a rate that is instantaneous relative to the advective groundwater flow velocity for the biodegradation of the BTEX compounds. As described in Section 5.3.5, anaerobic biodegradation, which is not instantaneous relative to the advective groundwater velocity, was accounted for using a rate constant.

Groundwater samples collected in uncontaminated portions of the aquifer indicate that DO concentrations at the site are as high as 3.3 mg/L (observed at FPTA3-MW4). However, immediately upgradient of the plume (at MP-9D and MP-24D), DO was not detected. The average DO concentration for groundwater at all site monitoring points and monitoring wells was 0.2 to 0.3 mg/L. As low DO concentrations were observed upgradient and crossgradient from the site as well as within the site, it was assumed that DO concentrations have historically been low. Therefore, a uniform starting DO concentration of 0.2 mg/L was used for Bioplume II model development. Table 4.5 contains DO data for the site.

The constant-head cells in the Bioplume II model require background DO concentrations to be input as constant concentrations to simulate incoming electron

acceptors. A background DO concentration of 0.2 mg/L was used for the constant-head cells along the upgradient (western) model boundary. Constant-head cells along the creek and eastern model boundary (adjacent to the Base Lake) were assigned DO concentrations of 5.0 mg/L.

5.3.5 Anaerobic Degradation Rates

Available data strongly suggest that anaerobic degradation is occurring at the site. Combined anaerobic processes account for over 99 percent of the assimilative capacity of site groundwater (Table 4.6). Anaerobic degradation must therefore be simulated with Bioplume II to make meaningful predictions. Although a first-order rate assumption may provide a reasonable approximation of how BTEX compounds are degrading in groundwater systems, these reactions may be more appropriately approximated by a second-order rate expression. Unfortunately, currently available fate and transport models (i.e., BIOPLUME II) are incapable of using second-order rates.

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

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

5.3.5.1 Trimethylbenzene Tracer Method

In order to calculate anaerobic rate constants, the apparent degradation rate must be normalized for the effects of dilution caused by advective-dispersive processes and sorption. This can be accomplished by normalizing the concentration of each contaminant to the concentration of a component of jet fuel (a tracer) that has similar sorptive properties but that is fairly recalcitrant. Observed BTEX concentration data can be normalized to 1,3,5-TMB, 1,2,4-TMB, and/or 1,2,3-TMB or another tracer with similar physiochemical properties. The TMB compounds can serve as good tracers

because they can be recalcitrant under anaerobic conditions, and they have sorptive properties similar to the BTEX compounds (Cozzarelli *et al.*, 1990 and 1994). Thus, the TMB is assumed to respond similarly to the processes of advection, dispersion, and sorption without experiencing a reduction in concentration due to biodegradation.

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

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

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

A log-linear plot of the corrected contaminant concentrations versus the travel time from the origin can be used to determine whether the data set can be described using a first-order exponential equation (i.e. r^2 is greater than approximately 0.9). When this occurs, the exponential slope can be used as the anaerobic rate constant.

An average anaerobic rate constant for BTEX decay at FPTA3 was determined from November 1994 BTEX and TMB data. Table 5.1 presents the data for a first-order rate constant calculation for BTEX using 1,3,5-TMB as a conservative tracer. The TMB-corrected total BTEX concentration represents the theoretical BTEX concentration at a point if biodegradation were the only process affecting BTEX concentrations. The graph that accompanies the table illustrates that an anaerobic rate constant of 0.0003 day^{-1} is predicted. TMB should serve as a conservative tracer because retardation coefficients for 1,3,5-TMB are from 1.4 to 7 times higher than those of benzene, toluene, ethylbenzene, or xylene. Therefore, the anaerobic rate constant is expected to be higher than calculated from this technique.

5.3.5.2 Method of Buscheck and Alcantar

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

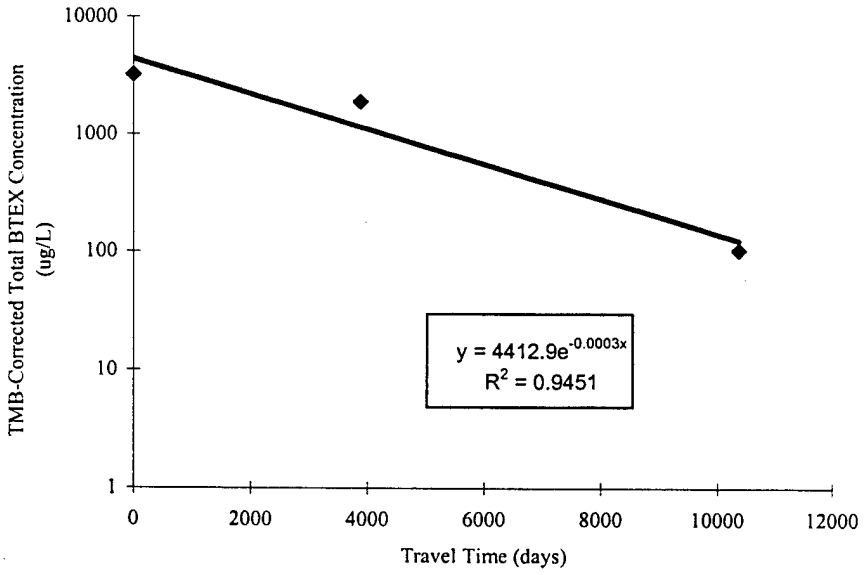
$$\lambda = \frac{v_c}{4\alpha_x}\left(\left[1 + 2\alpha_x\left(\frac{k}{v_x}\right)\right]^2 - 1\right)$$

TABLE 5.1
FIRST-ORDER RATE CONSTANT CALCULATION
USING TMB AS A CONSERVATIVE TRACER
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Point	Distance Downgradient (m)	Travel Time Between Upgradient and Downgradient Point (days)	Measured Total BTEX Concentration (µg/L)	1,3,5-TMB Concentration (µg/L)	TMB-Corrected Total BTEX Concentration (µg/L)
MP-2M	0	0	3233	57.9	3233
MP-4S	21	3879	1141	34.7	1904
MW6A	57	10363	5.2	1.8	103

v_x = 0.0055 m/day

PLOT OF TMB-CORRECTED TOTAL BTEX CONCENTRATION VERSUS TIME



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

The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Table 5.2 presents the data for a first-order rate constant calculation for BTEX using November 1994 data at FPTA3 and the method proposed by Buscheck and Alcantar (1992). An exponential fit to the data estimates a log-linear slope of 0.0875 m^{-1}. This value translates to a decay constant of 0.0006 day^{-1}

5.3.5.3 Selection of Anaerobic Decay Rate Constant

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), report first-order anaerobic biodegradation rates of 0.05 to 1.3 $week^{-1}$ (0.007 to 0.185 day^{-1}); Buscheck *et al.* (1993) reports 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 0.0006 day^{-1} was used in the Bioplume II model for this site. This value was selected because it is the higher value predicted by the two calculations; however, it is much less than the values reported in the literature and is therefore, probably 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 constant-head values, groundwater recharge/injection rates, and transmissivity 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 altering hydraulic parameters and transport parameters in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.3 lists input parameters used for the modeling effort. Model input and output are included in Appendix D.

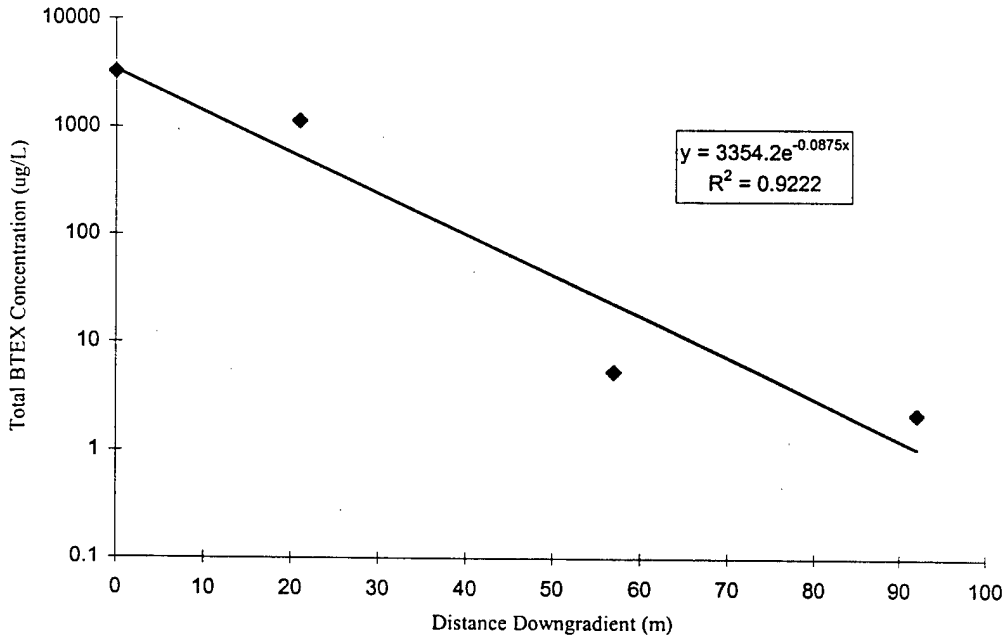
5.4.1 Analytical Models

Prior to developing and calibrating the Bioplume II numerical model, one-dimensional analytical models were used to evaluate values for estimated hydraulic parameters and decay coefficients. Analytical models provide exact, closed-form solutions to the

TABLE 5.2
FIRST-ORDER RATE CONSTANT CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Point	Distance Downgradient	Total BTEX (µg/L) Nov-94
A	0	3233
B	21	1141
C	57	5.4
D	92	2.2

PLOT OF TOTAL BTEX CONCENTRATION VERSUS DISTANCE



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

where $v_c = 0.0038$
$\alpha_x = 10$
$k/v_x = 0.0875$

therefore $\lambda = 0.0006$

TABLE 5.3
BIOPLUME II MODEL INPUT PARAMETERS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

		Model Runs			
Parameter	Description	Calibrated Model Setup	Decay-0 (No source decay)	Decay-4 (4% source decay per year)	Decay-50 (50% source decay per year)
NTIM	Maximum number of time steps in a pumping period	35	100	35	35
NPMP	Number of Pumping Periods	1	1	14	9
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*)(NPTPND) + 250	5355	5355	5355	5355
NPNT	Time step interval for printing data	1	1	5	1
NITP	Number of iteration parameters	7	7	7	7
NUMOBS	Number of observation points	0	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP [b]	200	200	200	200
NREC	Number of pumping or injection wells	27	27	27	27
NPTPND	Initial number of particles per node	9	9	9	9
NCODES	Number of node identification codes	2	2	2	2
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	0	0	0	0
NPDELC	Option to print computed changes in concentration	0	0	0	0
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)	35	500	35	35
TOL	Convergence criteria in ADIP	0.001	0.001	0.001	0.001
POROS	Effective porosity	0.20	0.20	0.20	0.20
BETA	Characteristic length (long. dispersivity; feet)	32.8	32.8	32.8	32.8
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)	35	35	35	35
YDEL	Width of finite difference cell in the y direction (feet)	40	40	40	40
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.05	0.05	0.05	0.05
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
DK	Distribution coefficient	0.055	0.055	0.055	0.055
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.65	1.65	1.65	1.65
THALF	Half-life of the solute	-	-	-	-
DEC1	Anaerobic decay coefficient (day^{-1})	0.0006	0.0006	0.0006	0.0006
DEC2	Reaeration coefficient (day^{-1})	0	0	0	0
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.14	3.14	3.14	3.14

* 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).

advection/dispersion equation, provided that several simplifying assumptions can be made. The two models used with FPTA3 data provided first-order solute decay solutions for a semi-infinite system with a constant contaminant source of constant concentration (modified from Bear, 1972, and van Genuchten and Alves, 1982 by Wexler, 1992,) and for a semi-infinite system with a point source of diminishing concentration (van Genuchten and Alves, 1982). Both models assume a homogeneous, isotropic aquifer; a uniform, constant-velocity flow field in the x-direction only; a constant longitudinal hydrodynamic dispersion; a source that fully penetrates the aquifer; biodegradation can be approximated by first-order decay; and sorption can be approximated by a linear model.

The constant-source model was initially used to simulate contaminant travel distances after 35 years (training activities at FPTA3 reportedly began in 1960) using estimated hydraulic parameters. A worst-case scenario was evaluated using a constant BTEX source of 35 mg/L (approximately the equilibrium between dissolved BTEX in water and JP-4) and no solute decay. At the end of 35 years, the model predicted a BTEX concentration of 2 µg/L at approximately 560 feet from the source; the observed BTEX concentration was 2.2 µg/L approximately 305 feet from the source. Using the same hydraulic parameters, solute decay rates of 0.0002 day^{-1} (conservative TMB-tracer method of calculation) and 0.0006 day^{-1} [Buscheck and Alcantar (1995) method of calculation] were added to the model. BTEX concentrations of 2 µg/L were predicted at approximately 490 and 360 feet from the main burn pit for the 0.0002 day^{-1} and the 0.0006 day^{-1} contaminant decay rates, respectively. The anaerobic decay constant of 0.0006 day^{-1} was retained for subsequent modeling because simulated downgradient results using this decay constant more closely approximated observed groundwater concentrations.

The decaying-source model was used to refine the estimates of the downgradient contaminant travel distance and to more closely approximate BTEX concentrations observed at the source. The model was run with the same hydraulic parameters as the constant-source model, a solute decay rate of 0.0006 day^{-1}, and source decay rates of 1, 2, and 5 percent. Models with each of the three source decay rates predicted BTEX concentrations of 2 µg/L at a distance of approximately 330 to 345 feet from the main burn pit. Calculated BTEX concentrations at the source were 3,500 µg/L at a source decay of 5 percent per year, 9,500 µg/L at 2 percent per year, and 13,000 µg/L at 1 percent per year. The highest observed BTEX concentration was 3,230 µg/L, in the sample collected at MP-2M. This sample was retrieved from the main source area at a depth of approximately 10 feet below the water table. The BTEX concentration is expected to be higher near the surface of the water table; therefore, a source decay rate of 2 to 5 percent per year would best represent site conditions using the decaying-source analytical model.

A summary of calculated BTEX concentrations at 50 and 100 meters (approximately 165 and 330 feet) for each of these models is provided in Table 5.4. Model outputs, including graphs of concentration versus time and distance are provided in Appendix C.

TABLE 5.4
SUMMARY OF ANALYTICAL MODEL INPUT AND RESULTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Input Parameter	Symbol	Unit	Selected Models					
Original Source Concentration	C_s	mg/L	35	35	35	35	35	35
Solute Decay Rate	λ	day^{-1}	0	0.0002	0.0006	0.0006	0.0006	0.0006
Source Decay Rate	α	%/year	0	0	0	1	2	5
Retardation Coefficient	R		1.456	1.456	1.456	1.456	1.456	1.456
Hydraulic Conductivity	K	m/day	1.84	1.84	1.84	1.84	1.84	1.84
Hydraulic Gradient	I		0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Effective Porosity	n_e		0.2	0.2	0.2	0.2	0.2	0.2
Groundwater Velocity (pore-water)	v_x	m/day	0.00552	0.00552	0.00552	0.00552	0.00552	0.00552
Longitudinal Dispersivity	α_x	m	10	10	10	10	10	10
Concentrations at 35 years:								
at 0 meters		mg/L	35	35	35	13.2	9.5	3.5
at 50 meters		mg/L	21	4.6	0.5	0.3	0.2	0.1
at 100 meters		mg/L	2	0.3	0.006	0.003	0.0027	0.0019
Concentrations at 100 meters:								
at 50 years		mg/L	9.0	0.59	0.0067	0.0029	0.0024	0.0013
at 75 years		mg/L	21.3	0.75	0.0068	0.0023	0.0015	0.0004
at 100 years		mg/L	28.8	0.77	0.0068	0.0018	0.0009	0.0001

5.4.2 Water Table Calibration

In order to calibrate the shallow water table at FPTA3, the water table was assumed to be influenced by several sources of continuous recharge and discharge:

- Recharge at areas of standing surface water
  - main burn pit
  - discharge pond
  - depressed area at the intersection of dirt roads, south of the main burn pit
  - drainage ditch on the west side of Harlan-Lewis Road
- Recharge and discharge at constant-head cells
  - along the unnamed tributary to the Base Lake
  - at the upgradient and downgradient model boundaries.

To be conservative, recharge of the aquifer through rainfall (which would add water, thereby increasing dilution of the plume) was only included at the locations where standing water accumulates. This is a reasonable assumption because the top 3 to 5 feet of soil consists of a low-permeability silty clay or clayey silt over most of the model domain. Substantial recharge is only likely to occur at locations where water stands long enough for the surface water to percolate to the water table.

Initial water levels at the constant-head cells, recharge rates at cells representing areas of standing water, and transmissivity values were varied to calibrate the water table surface. The model was calibrated under steady-state conditions. As described in Section 5.3.1, initial water levels at constant head cells were selected to simulate observed groundwater elevations, gradients, and flow directions.

Recharge was added to the system through the use of the recharge array and injection wells. Originally, recharge was added to the groundwater flow calibration model exclusively through the recharge array. This method yields an identical groundwater flow model; however, it resulted in numerical instabilities when BTEX and oxygen were injected into the model system. The system of using the recharge array in conjunction with injection wells permitted both the groundwater flow model and BTEX distribution models to be calibrated. The recharge and injection well array is presented in Appendix C.

A base recharge rate of 12 inches per year was used to calibrate the water table. This rate is equivalent to approximately 40 percent of the average annual rainfall at Offutt AFB. This rate was considered acceptable because the collection areas for each of the sources is much larger than the recharge areas. Surface water was injected at a rate of 12 inches per year at the discharge pond. It is known that water is not present in the main burn pit year round; therefore, 10 of the cells had 9-inch-per-year recharge rates, 2 cells had 6-inch-per-year recharge rates, and the remaining 3 cells had 3 inch-per-year-

recharge rates. For the same reason, a recharge rate of 6 inches per year was used for the depression south of the main burn pit and north of the dirt road intersection. A cell recharge rate of 3 inches per year was used for the drainage ditch because the ditch occupies only about one-quarter of the area of each cell through which it passes.

Transmissivity is the capacity of an aquifer to transmit water (Heath, 1980). Numerically, transmissivity is the product of hydraulic conductivity and aquifer thickness. An accurate estimate of transmissivity 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. Based on the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in transmissivity. Lower values of transmissivity result in a slower-moving plume that degrades more slowly because fewer electron receptors are available for biodegradation. Higher values of transmissivity result in a faster-moving plume that degrades faster because more electron acceptors are available for biodegradation.

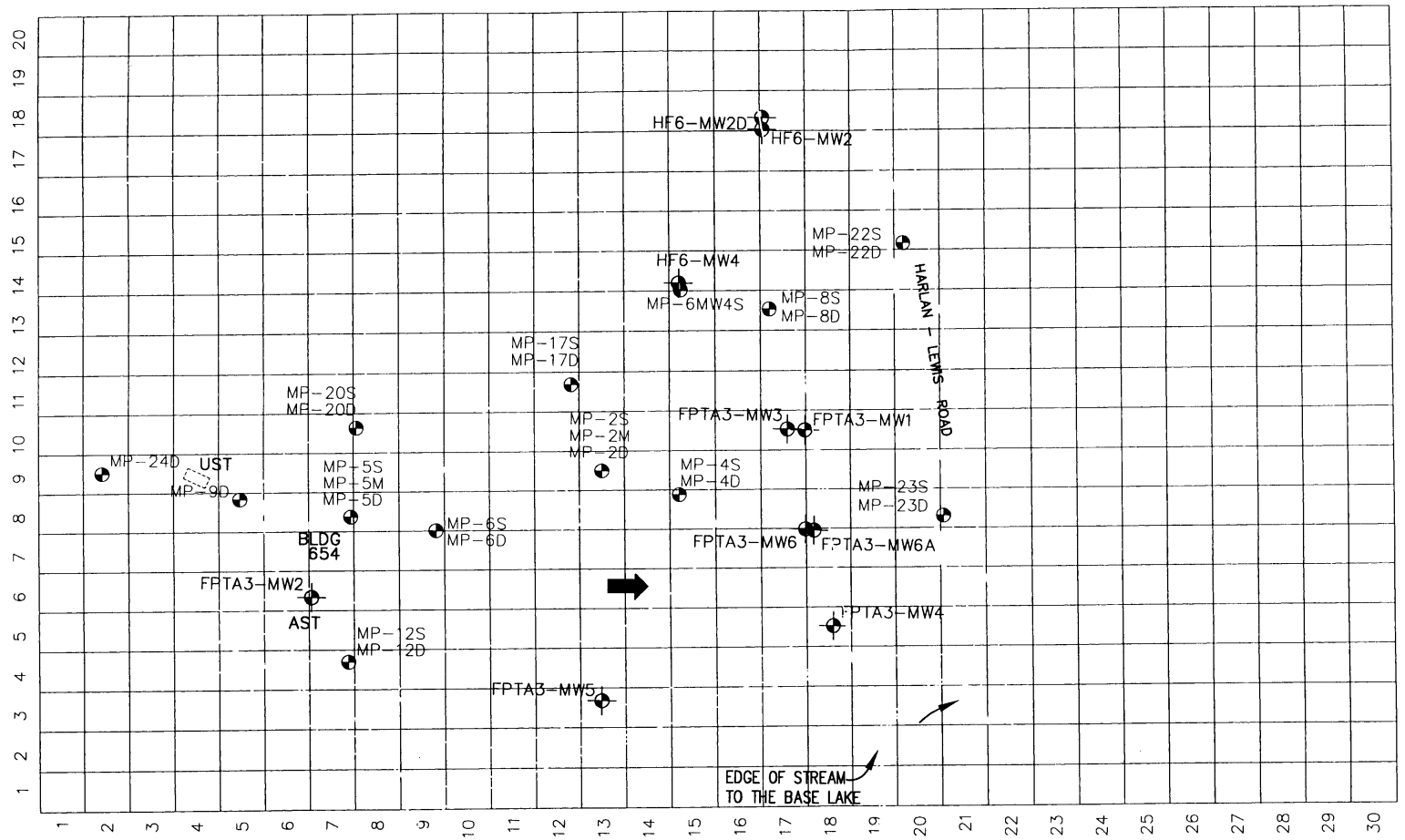
An initial uniform estimate of transmissivity was derived from site data. As described in Section 3.3.2.2, the hydraulic conductivity at FPTA3 was estimated from slug tests performed during site investigations. The average hydraulic conductivity for FPTA3 is 6.04 ft/day. On the basis of the geologic log of monitoring well FPTA3-MW1, the shallow aquifer is believed to extend from approximately 10 feet bgs to at least 90 feet bgs. However, an effective aquifer thickness of 30 feet was used for modeling at FPTA3. A thickness of 30 feet was selected for two reasons. First, 30 feet is the estimated depth to which BTEX contamination from FPTA3 is believed to be present in the aquifer. Second, a slight downward vertical gradient has been measured in the shallow portion of the aquifer (approximately the upper 25 feet), but not for the entire penetrated thickness of the aquifer (approximately 80 feet).

During the calibration process, transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to the site well locations matched the observed water levels as closely as possible. Figure 5.2 shows the calibrated water table. Calibrated model transmissivities ranged from 1.05×10^{-3} square feet per second (ft^2/sec) to 4.2×10^{-3} ft^2/sec.

Observed water level elevation data from 19 monitoring well and monitoring point locations were compared to simulated heads to evaluate how close the model reproduced observed conditions. The locations included MP-2M, MP-4D, MP-5M, MP-6D, MP-8D, MP-9D, MP-12D, MP-17D, MP-20D, MP-22D, MP-23D, MP-24D, FPTA3-MW2, FPTA3-MW3, FPTA3-MW4, FPTA3-MW5, FPTA3-MW6A, HF6-MW2, and HF6-MW4.

The root mean squared (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:

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



LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.1

MODEL GRID

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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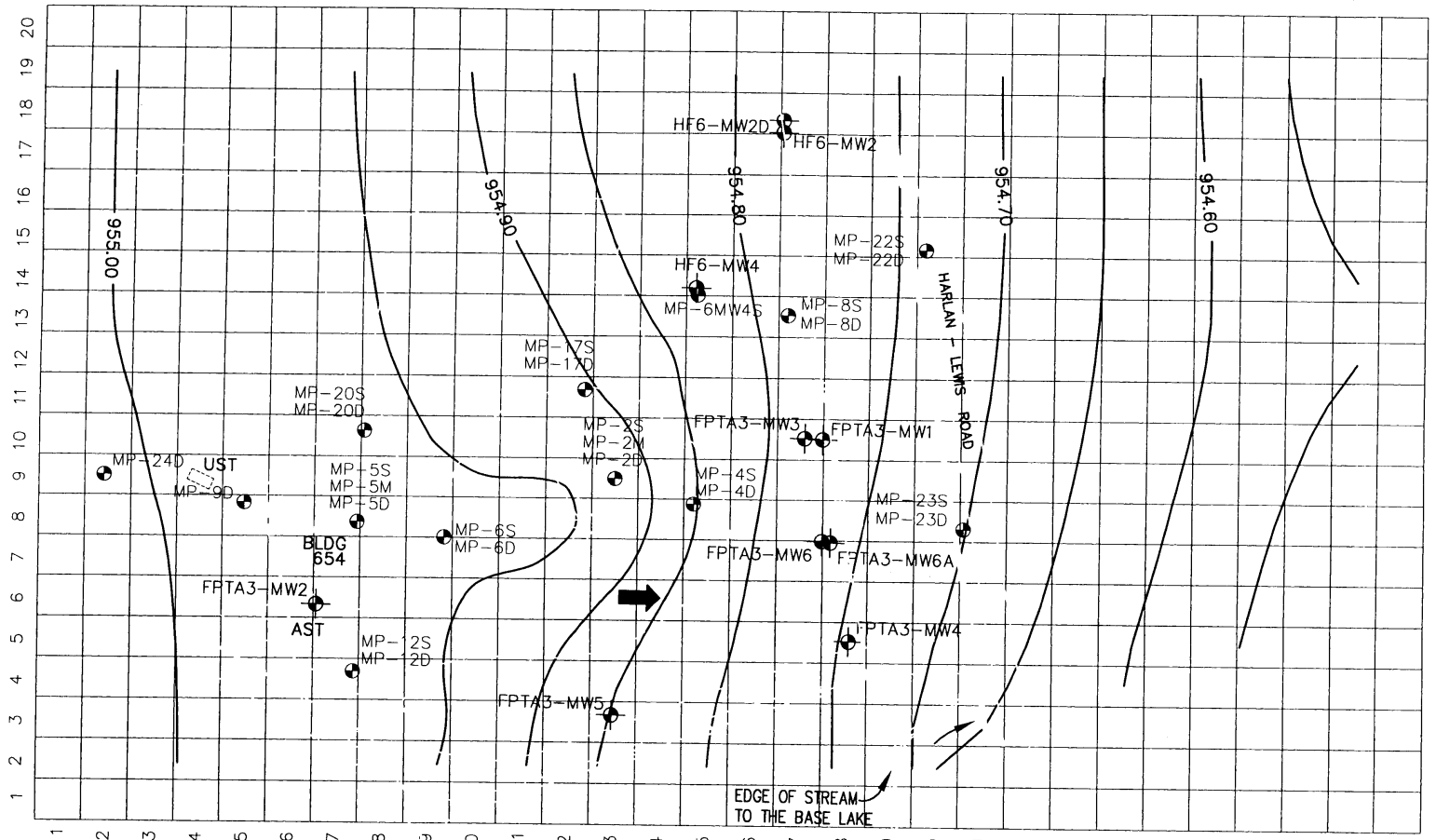

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
954.90 LINE OF EQUAL SIMULATED GROUNDWATER ELEVATION
CONTOUR INTERVAL = 0.05 FEET

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.2

CALIBRATED WATER TABLE MAP

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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

h_m = measured head value

h_s = simulated head value.

The RMS error between observed and calibrated values at the 19 comparison points was 0.046 foot, which corresponds to a calibration error of 9.2 percent (water levels dropped about 0.5 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A scatter plot of measured heads vs. simulated heads is also useful for judging model calibration. Deviation of the plotted points from a straight line should be randomly distributed (Anderson and Woessner, 1992), as is the case for the scatter plot presented in Appendix C.

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. The hydraulic mass balance for the calibrated model numerically accounted for 98.9 percent of the water flux into and out of the system (i.e., a 1.1-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. The less-than-ideal 1.1-percent error in the hydraulic mass balance is believed to arise from the intersection of flow paths with no-flow boundary cells and the resultant loss of water. The presence of a small flow component perpendicular to the no-flow boundary cells is the result of groundwater mounding at the sources of recharge. This particular hydraulic configuration does not significantly affect the model, as the BTEX plume does not reach the no-flow boundary cells.

5.4.3 BTEX Plume Calibration

Calibration of the fate and transport portion of a Bioplume II model generally requires that the contaminant distribution be known for two different times. Groundwater investigation results were available for 1988, 1989, 1990, and 1992; however, the sampled wells were too distant from the source areas to define initial concentrations across the entire site. Therefore, the groundwater was assumed to have no BTEX concentration at the time fire protection training exercises reportedly were initiated at the site in 1960. The BTEX concentrations measured in November 1994 were used as the second data set.

Using the calibrated steady-state hydraulic parameters, model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified such that model predictions approximated the distribution of dissolved total BTEX observed in November 1994. Plume calibration simulations were made with a 35-year time constraint. In other words, computed BTEX plume concentrations and configurations were compared to November 1994 BTEX data after 35 years of simulation time incorporating injection, transport, and degradation of contaminants in groundwater. It was assumed that during the calibration simulation, injected BTEX concentrations would not decrease. This is a conservative assumption because after 1974, the use of fuels and solvents decreased by 90 percent or more. Furthermore, no fuels have been used at the site since 1990. This assumption does not have a significant effect on the

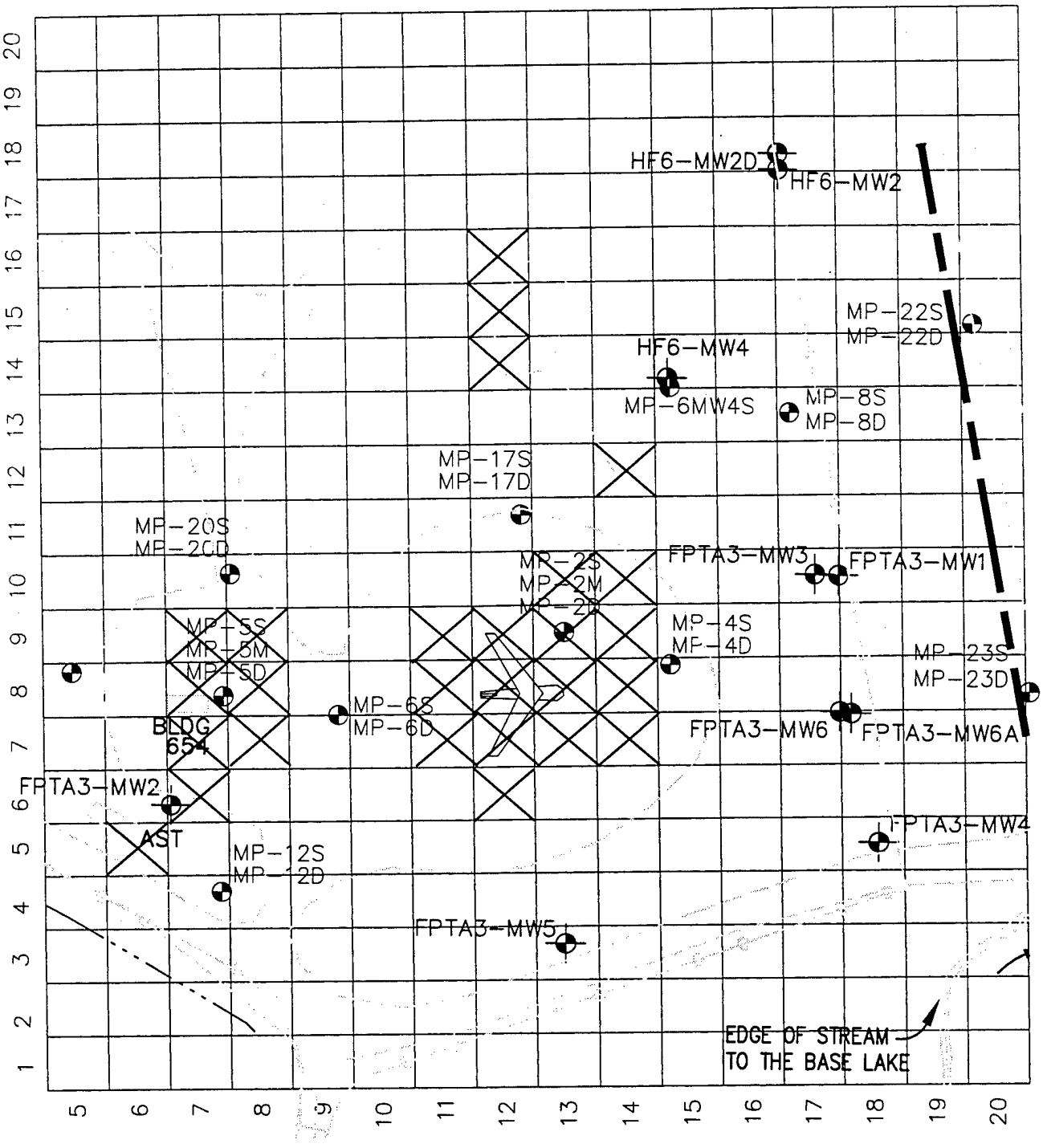
downgradient extent of the dissolved plume because this dimension is primarily controlled by the length of injection time and the anaerobic decay rate.

Initially, it may appear that the assumption of a non-decaying source contradicts the findings of the analytical modeling where a source decay of 2 to 5 percent per year produced the best simulation of observed results. The difference in a source decay rate arises because the analytical model uses an original source concentration nearly equivalent to the BTEX partitioning equilibrium between fresh JP-4 and water while the Bioplume II numerical model uses multiple injected BTEX sources at between 5 and 50 percent of the BTEX partitioning equilibrium between fresh JP-4. The way in which the sources were modeled are not so much a contradiction or difference, but rather a reflection on the degree of additional sophistication provided by the Bioplume II numerical model. The analytical models provide for a single source and one set of model variables, whereas, Bioplume II allows the use of multiple sources of varying strengths and the flexibility of changing both source and model variables with time. In order to simulate past, present, and future conditions using the analytical model, a single set of simplifying model variables were used; however, the flexibility of the Bioplume II model allowed variables to be altered throughout the model simulation to account for changing site conditions or projected changes in site conditions. The most important change at FPTA3 within the past 35 years was the cessation of fire training activities in 1990. The elimination of a continuing source could be incorporated into the Bioplume II models, but not into the analytical models.

Because residual LNAPL is present in the vicinity of the water table at the site, it was necessary to include simulated injection wells to model partitioning of BTEX compounds from the residual phase into the groundwater. The location of the injection wells is shown on Figure 5.3. Locations of injection wells were based on the known location of the residual LNAPL and the extent of soil contamination pictured on Figure 4.1. It was also assumed that contamination in discharge pond sediments is a source of groundwater contamination.

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 groundwater recharge injection rates of 3.3×10^{-5} and 4.4×10^{-5} cubic feet per second (ft^3/s) (9 and 12 cell-area-inches per year) were used to inject contaminants in cells representing the main burn pit and remaining discharge pond. The volume of water in these recharge rates was included in the calibration of the groundwater flow model. Injection rates of 1.12×10^{-7} ft^3/s and 9.33×10^{-9} ft^3/s were used for cells encompassing the former discharge pond and the Building 654 area, respectively. The volume of water injected at these low rates did not affect the flow calibration and water balance.

Total BTEX and DO injection concentrations were determined by varying the injection concentration for the various wells until the modeled total BTEX plume approximated the total BTEX plume observed in November 1994. Injected BTEX concentrations were based on the 35-mg/L equilibrium concentration of BTEX resulting from the exposure of JP-4 to water. The estimate was based on the work of Bruce *et al.* (1991). DO also was injected at each of the injection locations. In general, the higher the injected BTEX concentration, the lower the injected DO concentration because more DO



0 25 50 100 200

FEET

LEGEND

- DIRT ROADS
- PAVED ROADS
- FENCE
- DRAIN PIPE
- MONITORING WELL
- MONITORING POINT
- CELL WITH SIMULATED INJECTION WELL

FIGURE 5.3

LOCATION OF SIMULATED INJECTION WELLS FOR CALIBRATION AND PREDICTION

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in the percolating groundwater would be consumed by microorganisms present in soil with the highest fuel concentrations. By varying the injection well contaminant and oxygen concentrations, the distribution of injection wells, background oxygen concentrations, initial oxygen concentrations, dispersivity, and the anaerobic decay coefficient, the BTEX plume was calibrated to approximate the observed plume in terms of plume extent and BTEX concentrations in the source areas. The calibrated plume configuration is shown on Figure 5.4. BTEX and DO injection rates are provided in Appendix C.

The calibrated model plume (Figure 5.4) is very similar, but not identical, to the observed BTEX plume (Figure 4.2). The simulated and observed 1,000-µg/L isopleths are similar in shape. Furthermore, the simulated BTEX concentrations in the main burn pit and Building 654 source areas are similar to the measured concentrations in groundwater samples from monitoring points MP-2M and MP-4D (Main Burn Pit) and MP-5M (East of Building 654). In addition, the total area of the simulated BTEX plume (represented by the 1-µg/L isopleth) is comparable to the plume observed in 1994. In fact, groundwater samples collected at five peripheral locations (FPTA3-MW2, HF6-MW4, MP-8S, MP-20S, and MP-23S) had low BTEX concentrations very similar to simulated concentrations in the same area.

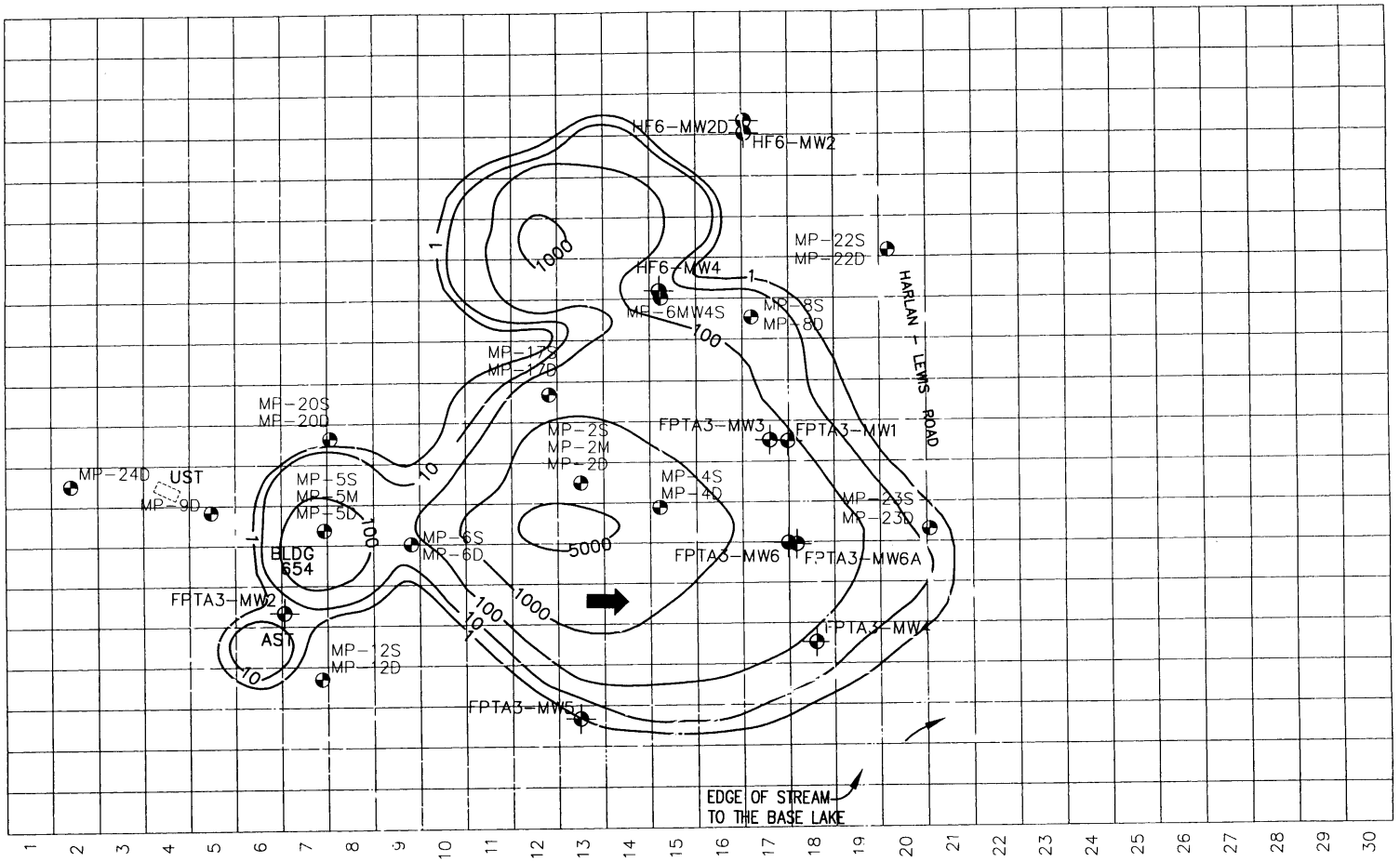
In general, the simulated plume is both larger and contains more mass than estimated from BTEX concentrations in groundwater samples. For example, the area of the computed 100-µg/L isopleth is noticeably larger than that suggested by the observed concentrations. Furthermore, three locations where no BTEX were detected in the groundwater are within the area of the simulated plume. The simulated distribution also represents a greater total mass of BTEX because the model assumes that contamination extends throughout the total depth of the aquifer. In reality, the plume is only present in a portion of the total aquifer thickness, and concentrations appear to diminish with depth. Because of this, and because the calibrated model BTEX concentrations are similar to the observed concentrations, the predictions made by this model should be conservative.

5.4.3.1 Discussion of Parameters Varied During Plume Calibration

As noted previously, the transport parameters varied during plume calibration were dispersivity, retardation, and the anaerobic decay coefficient. These parameters were 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. Wherever possible, the plume distribution was simulated using best initial estimates. If the initial estimate of a parameter proved inadequate, the parameter was varied within a reasonable range based on literature and measured values.

5.4.3.1.1 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 at 32.8 feet (10 meters) or approximately one-tenth of the distance from the main burn pit to the downgradient extent of the plume. During plume calibration, longitudinal dispersivity was varied;



LEGEND

DIRT ROADS

PAVED ROADS

FENCE

DRAIN PIPE

MONITORING WELL

MONITORING POINT

LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)

CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.4

CALIBRATED BTEX PLUME

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however, the initial value was used in the final model. The transverse dispersivity was initially estimated as one-tenth (0.1) of the longitudinal dispersivity values as recommended by Domenico and Schwartz (1990). However, because the plume was relatively narrow in relation to the width of the combined source areas, the final model input incorporated a ratio of 0.05.

5.4.3.1.2 Anaerobic Decay Coefficient

As discussed in Section 5.3.5, the anaerobic decay coefficient was originally estimated to be 0.0002 to 0.0006 day^{-1} using the TMB-tracer and Buscheck-Alcantar methods, respectively. Simulated plumes computed from analytical models that included an anaerobic decay constant of 0.0006 day^{-1} closely approximated observed data; therefore, an anaerobic decay constant of 0.0006 day^{-1} was selected for initial model calibration. This rate prevented the plume from migrating too far in the calibration run, and at the same time prevented contaminant concentrations in the center portion of the plume from becoming excessively high. Selection of a lower anaerobic decay constant as predicted by the conservative TMB-tracer method resulted in a plume that was much longer than observed. Higher anaerobic decay constants, similar to reported literature values, resulted in smaller plumes than observed.

5.4.3.1.3 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. On the basis of the average measured TOC concentration from five saturated-zone soil samples at two boreholes (0.07 percent), and assuming a bulk density of 1.65 grams/cubic centimeter, and published values of the soil sorption coefficient (K_{oc}) for the BTEX compounds (as listed in Wiedemeier *et al.*, 1994), the coefficients of retardation for the BTEX compounds were calculated. The results of these calculations are summarized in Table 5.5. Computed BTEX retardation coefficients ranged from 1.46 to 3.70. The lower the assumed coefficient of retardation, the farther the BTEX plume will migrate downgradient. To be conservative, the retardation coefficient calculated for benzene (1.46) was used as a constraint for model input.

During plume calibration, the coefficient of retardation was varied from 1.27 to 2.1. A retardation coefficient of 1.27 was computed using a low bulk density of 1.37 grams/cubic centimeter for fine sand (Walton, 1988) and lowest measured quantity of TOC (0.05 percent) in the five saturated samples. A retardation coefficient of 2.1 is the computed value for toluene using the original assumptions. The initial selection of 1.46 yielded the most satisfactory simulation of the BTEX distribution.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. On the basis of the work of Rifai *et al.* (1988), the Bioplume II model is typically most sensitive to changes in the coefficient of reaeration, 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. The sensitivity analysis for this model was conducted by varying transmissivity (hydraulic

TABLE 5.5
CALCULATION OF RETARDATION COEFFICIENTS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

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 (m/day) [b/]	Contaminant Velocity (m/day)
Benzene	79	0.0007	0.055	1.65	0.20	1.46	0.0055	0.00378
Toluene	190	0.0007	0.133	1.65	0.20	2.10	0.0055	0.00262
Ethylbenzene	468	0.0007	0.328	1.65	0.20	3.70	0.0055	0.00149
m-xylene	405	0.0007	0.284	1.65	0.20	3.34	0.0055	0.00165
o-xylene	422	0.0007	0.295	1.65	0.20	3.44	0.0055	0.00160
p-xylene	357	0.0007	0.250	1.65	0.20	3.06	0.0055	0.00180
Vinyl Chlorid	2.455	0.0007	0.002	1.65	0.20	1.01	0.0055	0.00542
trans-DCE	59	0.0007	0.041	1.65	0.20	1.34	0.0055	0.00410
TCE	95.1	0.0007	0.067	1.65	0.20	1.55	0.0055	0.00355

NOTES:

[a/] From technical protocol document (Wiedemeier *et al.*, 1994) and Groundwater Chemical Desk Reference (Mongomery and Welkom, 1990).

[b/] From site data (8.5-9' and 10.5-11' samples from borehole SS1).

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

[d/] Literature values.

conductivity), the coefficient of anaerobic decay, the coefficient of retardation, effective porosity, and dispersivity. Reaeration of the aquifer was not expected to contribute significantly to attenuation processes at the site; therefore, as a conservative assumption, a coefficient of reaeration was not used in the model. Any contribution resulting from reaeration is effectively included in the coefficient of anaerobic decay.

To perform the sensitivity analyses, individual runs of the plume calibration model were made with the same input as the calibrated model, except that one of the aforementioned parameters was varied. The models were run for a 35-year period, just as the original was, so that the independent effect of each variable could be assessed. 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 to 2.1 (toluene);

6) Coefficient of retardation decreased to 1.0 (no retardation);

7) Effective porosity decreased to 0.1;

8) Effective porosity increased to 0.3;

9) Longitudinal dispersivity increased by a factor of 2; and

10) Longitudinal dispersivity decreased by a factor of 2.

The results of the sensitivity analyses are shown graphically on Figures 5.5 through 5.9. These figures display the modeled BTEX concentrations versus distance along the centerline of the plume (in the eighth model column). This manner of displaying data is useful because BTEX concentrations are highest in the eighth model column and the plume migrates in a direction approximately parallel to the model grid. Furthermore, the figures allow easy visualization of the changes in BTEX concentration caused by varying model input parameters.

The effects of varying transmissivity are shown by Figure 5.5. Uniformly increasing the transmissivity by a factor of five increased the spreading of the plume such that the maximum simulated concentrations in the source cell area were only about 4,600 µg/L, compared to the calibrated maximum of 6,953 µg/L. In addition, the leading edge of the BTEX plume was approximately 400 feet farther downgradient than in the calibrated model. In contrast, decreasing the transmissivity by a factor of five slowed overall plume migration, which shortened the plume length approximately 100 feet. Because background conditions at the site are anaerobic, changes in the flux of water contacting

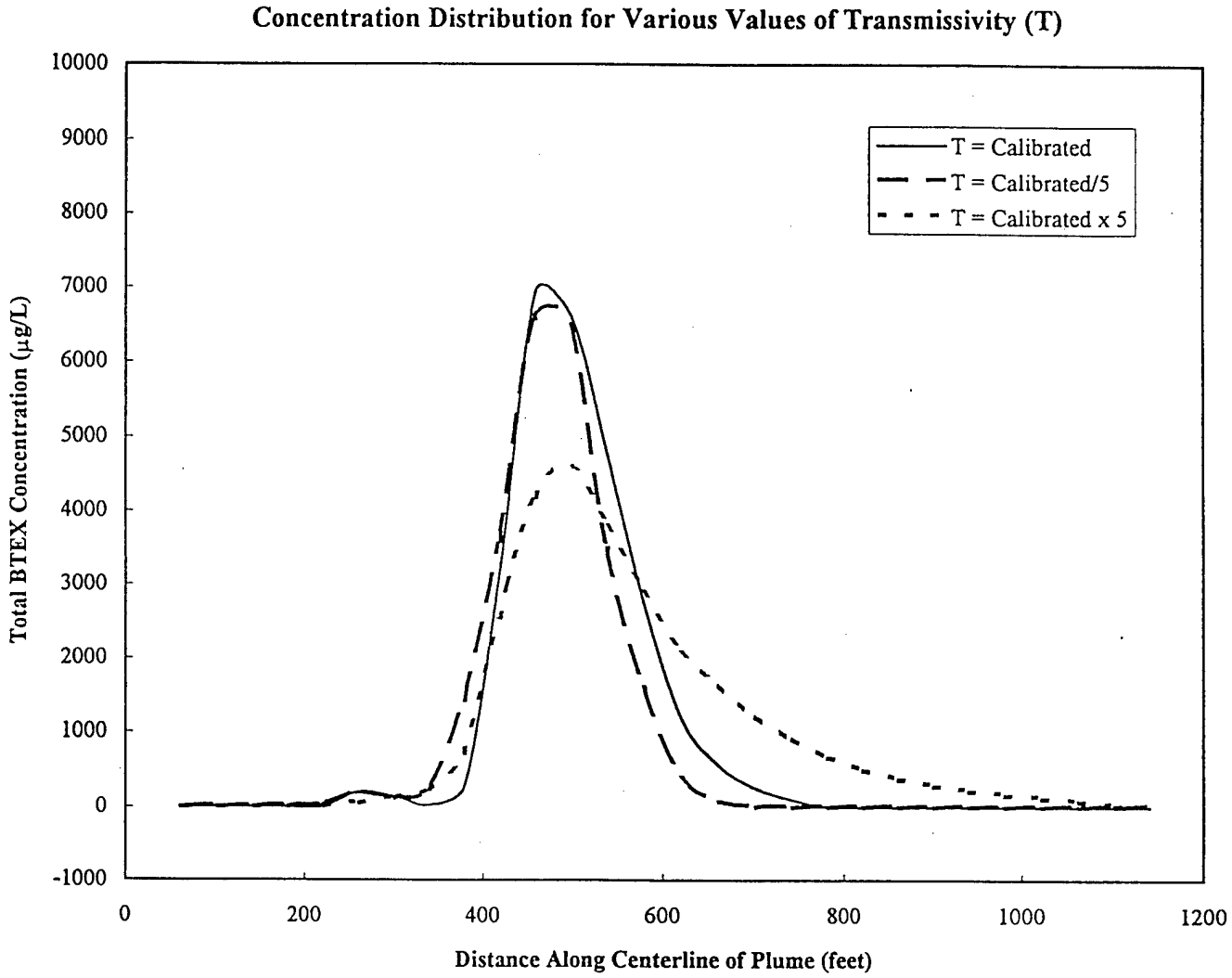

FIGURE 5.5

MODEL SENSITIVITY TO VARIATIONS IN TRANSMISSIVITY

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Intrinsic Remediation TS
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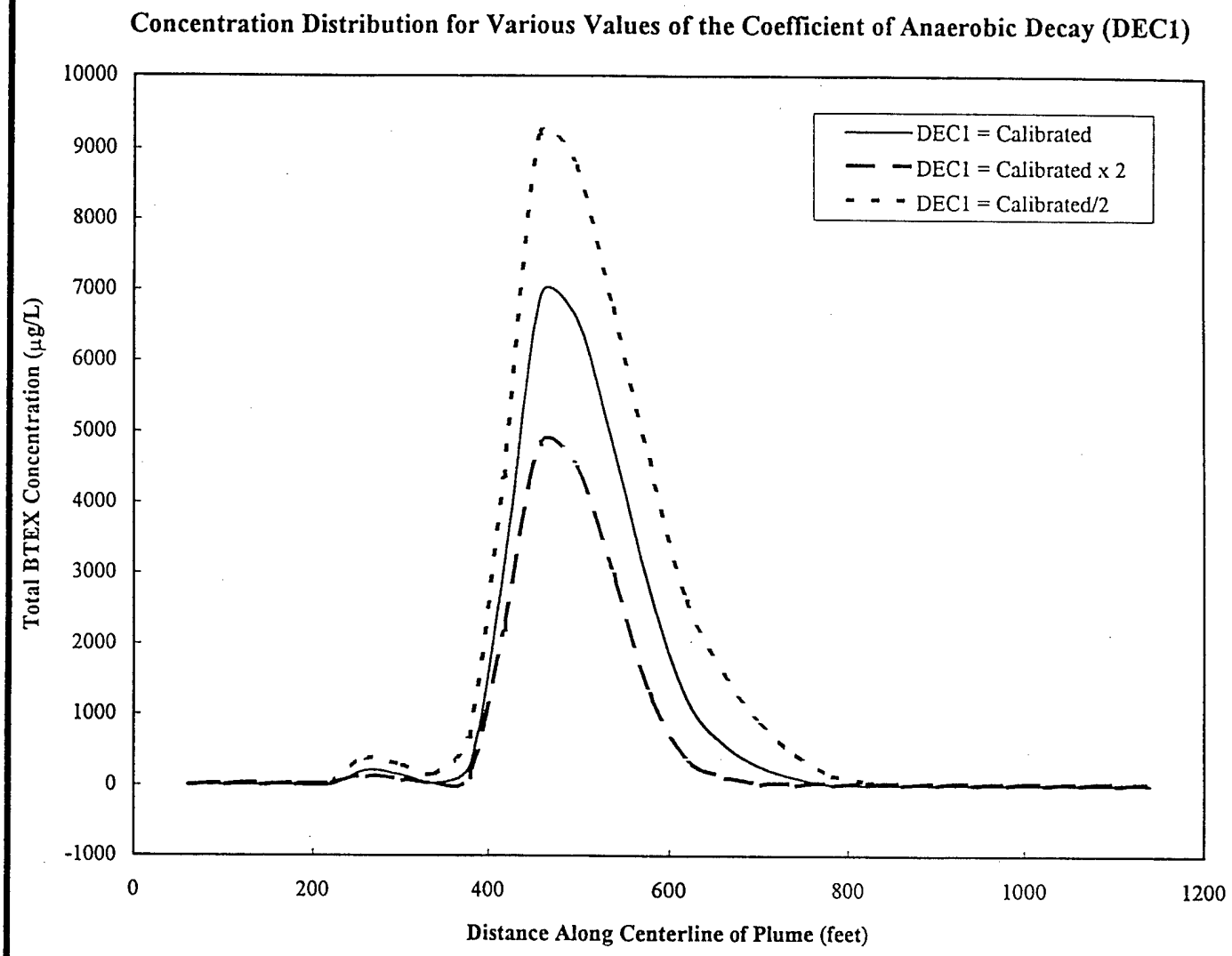

FIGURE 5.6

MODEL SENSITIVITY TO VARIATIONS IN THE ANAEROBIC DECAY COEFFICIENT

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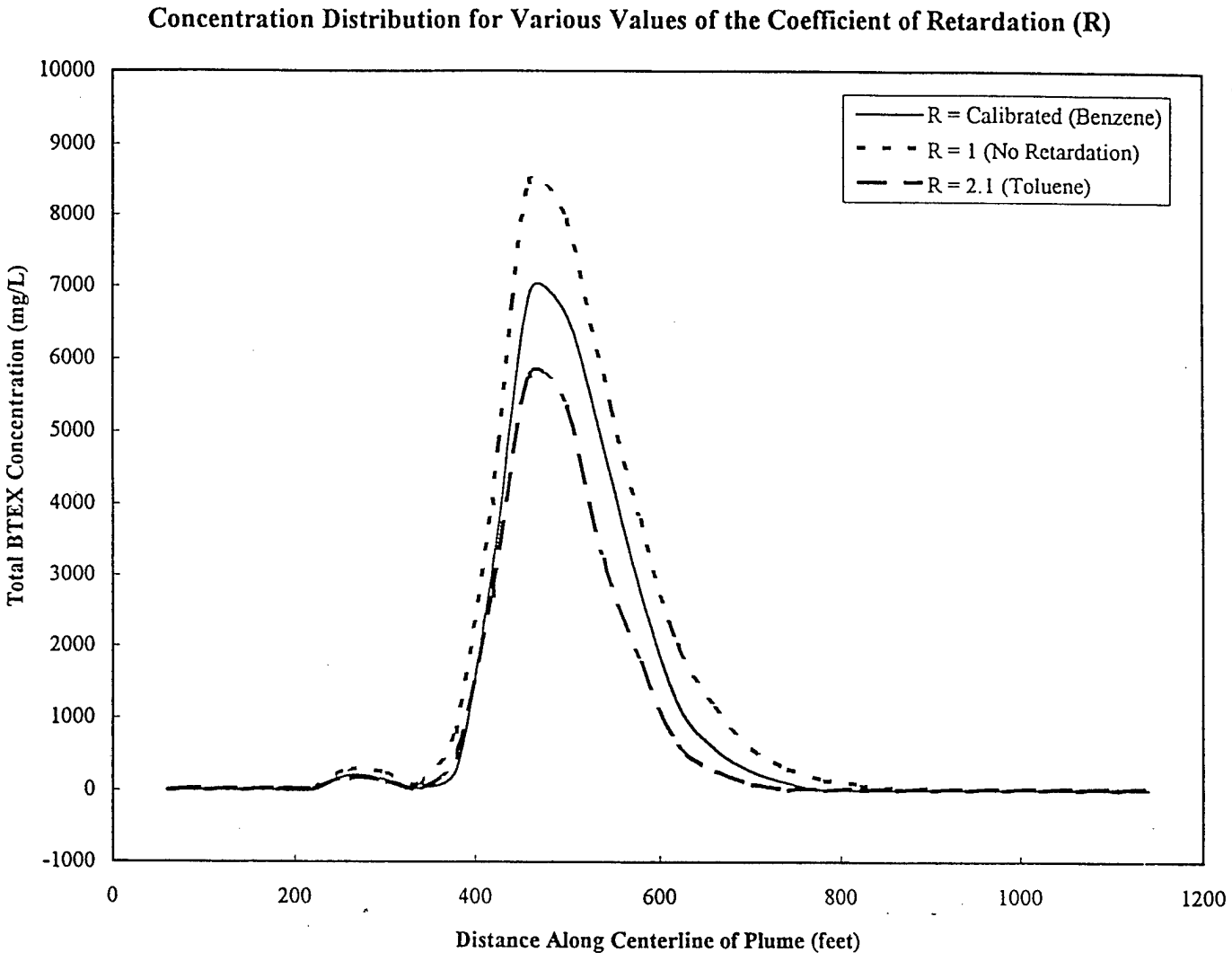

FIGURE 5.7

MODEL SENSITIVITY TO VARIATIONS IN THE COEFFICENT OF RETARDATION

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Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
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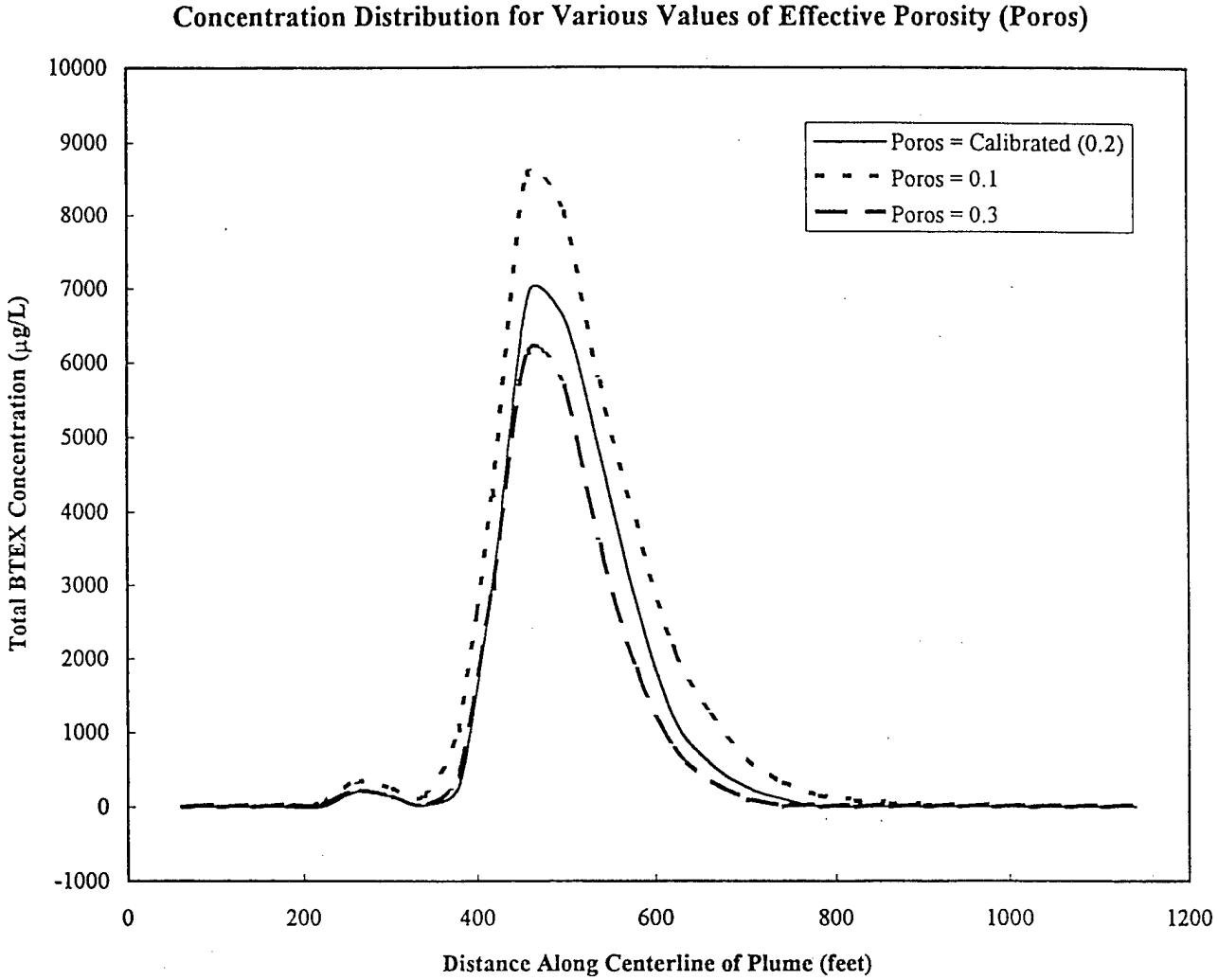

FIGURE 5.8

MODEL SENSITIVITY TO VARIATIONS IN THE EFFECTIVE POROSITY

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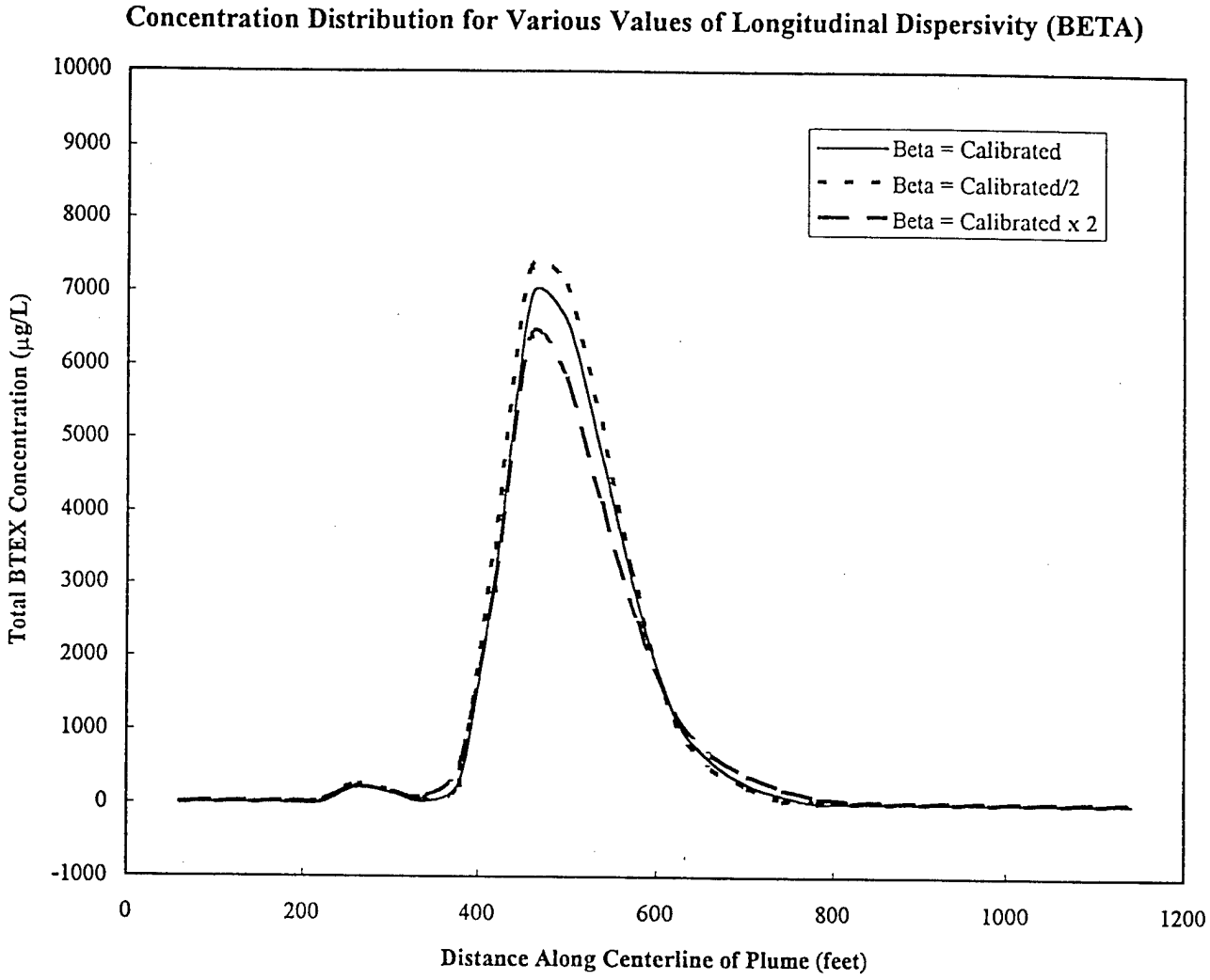

FIGURE 5.9

MODEL SENSITIVITY TO VARIATIONS IN THE LONGITUDINAL DISPERSIVITY

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Intrinsic Remediation TS
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the plume do not result in significant increases or decreases in total BTEX concentrations in the plume as a result of aerobic biodegradation.

Figure 5.6 shows the effects of varying the anaerobic decay coefficient. Increasing this parameter by a factor of two results in rapid degradation of dissolved BTEX. The overall plume length decreases by approximately 150 feet; the maximum BTEX concentration decreases by about 2,100 µg/L; and the mass of BTEX in the plume decreases by approximately 40 percent. This significant reduction in plume dimensions, contaminant concentrations, and contaminant mass is the result of the large increase in the decay rate resulting from the exponential relationship between the coefficient of decay and solute decay rate (see Section 5.3.5). Conversely, decreasing the anaerobic decay coefficient by a factor of two greatly decreases the rate of degradation. Maximum BTEX concentrations increase by over 2,200 µg/L; the plume length increases approximately 50 feet; and the mass of BTEX in the plume increases by approximately two-thirds. The sensitivity of the model to the anaerobic decay coefficient suggests that a reasonable value was used in the calibrated model.

The effects of varying the coefficient of retardation (R) are shown on Figure 5.7. Increasing R to 2.1 (computed retardation for toluene) from 1.46 (computed retardation for benzene) results in the maximum BTEX concentration decreasing by approximately 1,200 µg/L, and the downgradient extent of the plume decreasing by approximately 50 feet. On the other hand, decreasing R to 1.00 (no retardation) produces a plume that reaches approximately 100 feet further downgradient than the original model plume and that has a maximum BTEX concentration approximately 1,500 µg/L higher than the calibrated model. These results suggest that the R used for the calibrated simulation is acceptable, because the model is less sensitive to higher values of R, while a value of R that is too low will result in a simulated plume that travels beyond the limits of the observed plume.

The effects of varying the effective porosity are illustrated by Figure 5.8. Walton (1988) gives a range of 0.1 to 0.3 for the effective porosity of fine sand. A comparison of the models using the extreme values of effective porosity (0.1 and 0.3) shows a maximum BTEX concentration difference of only 2,400 µg/L at the source and a difference of only 150 feet in plume length. Therefore, the model is relatively insensitive to the range of reasonable values for effective porosity.

The effects of varying dispersivity are illustrated by Figure 5.9. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.05. Increasing the dispersivity by a factor of two resulted in slightly lower maximum BTEX concentrations spread out over a slightly larger area. Decreasing dispersivity by a factor of two produced a plume with slightly higher BTEX concentrations over a slightly smaller area. For all dispersivity sensitivity runs, the maximum BTEX concentrations were within 1,000 µg/L and the plume lengths were within 100 feet of each other. The model appears to be relatively insensitive to dispersivity within the range of reasonable values evaluated for this analysis.

The results of the sensitivity analysis suggest that the calibrated model used for this report is appropriate. The calibrated model is most sensitive to transmissivity and the anaerobic decay coefficient, although retardation and effective porosity both can affect

the plume dimensions and concentrations. Increasing the anaerobic decay coefficient and transmissivity greatly diminishes the predicted maximum BTEX concentrations, although only anaerobic decay coefficient results in a corresponding decrease in the mass of BTEX. Lowering the value of the anaerobic decay coefficient or increasing the transmissivity lengthens the plume beyond recent observations at the site. Decreases in the retardation and porosity both resulted in increases in maximum simulated BTEX concentrations and a lengthening of the plume. Increases in these parameters resulted in the opposite responses. The model appears relatively insensitive to dispersivity; however, adjustment to this parameter contributed toward producing an appropriate plume configuration.

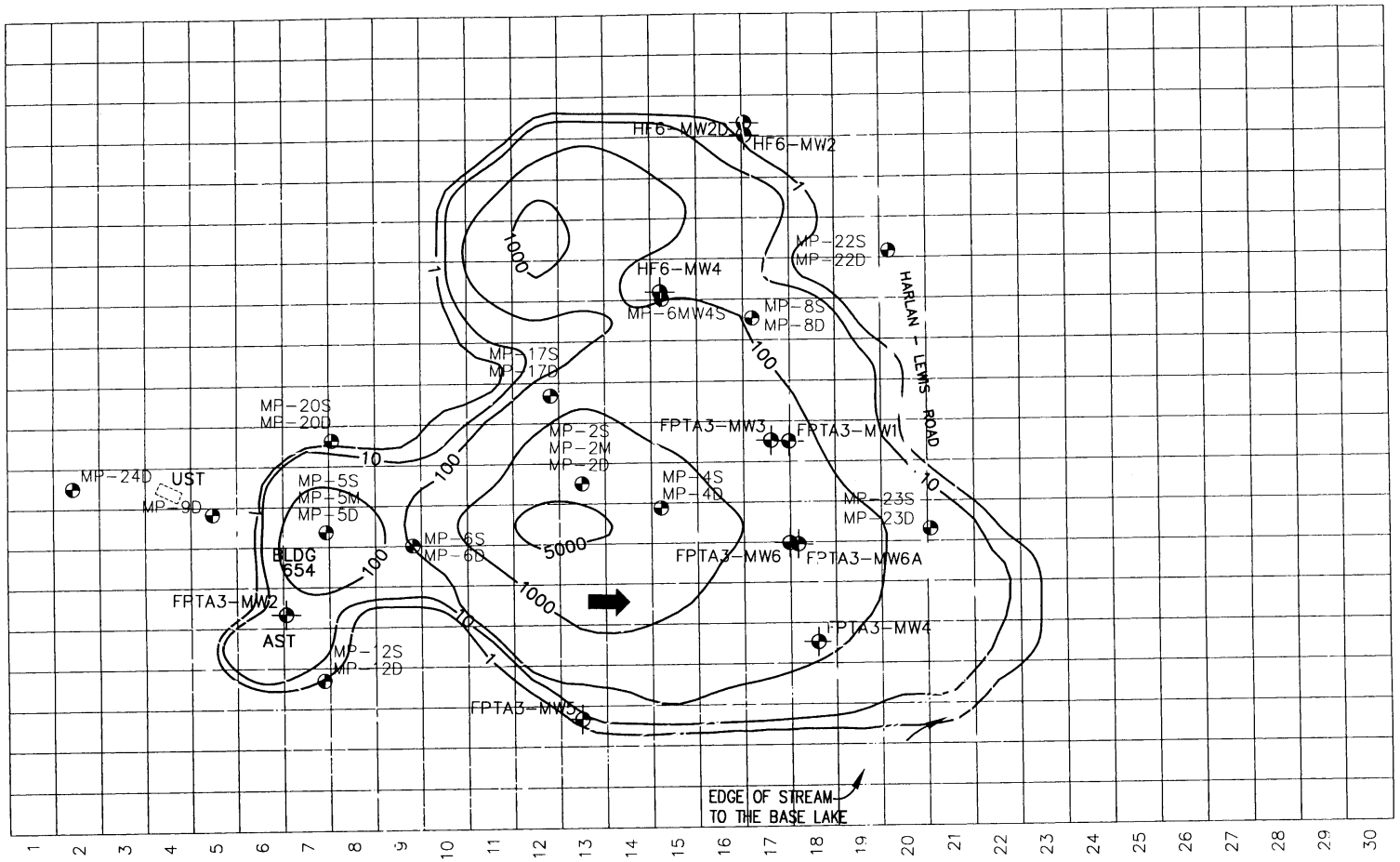
5.6 MODEL RESULTS

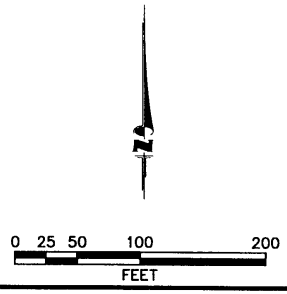
To predict fate and transport of dissolved BTEX compounds at FPTA3, three Bioplume II simulations (Decay-0, Decay-4, and Decay-50) were run under steady-state conditions. The first simulation represents a worst-case scenario based on the assumption that the conditions that produced the calibrated model remain constant, including the rates at which BTEX and DO are introduced to the aquifer through injection wells. The second simulation incorporates a 4-percent-per-year reduction in BTEX loading rates based on the assumption that the source strength decreases asymptotically due to weathering, dissolution, and biodegradation of the source. The final simulation assumes active source reduction and incorporates a 50-percent source reduction per year for 8 years. Complete input and output files are provided in Appendix D. Model results are described in the following sections.

5.6.1 Continuation of Calibrated Conditions (Model Decay-0)

Model Decay-0 was used to simulate the migration and biodegradation of the BTEX plume assuming that the conditions that produced the calibrated model continue, including continuing sources of dissolved BTEX compounds. The calibrated simulation was run to predict conditions up to 500 years beyond the initiation of fire protection training activities at FPTA3, or 465 years beyond 1995. This model assumes a source that does not change in magnitude or composition for the next 465 years. The model does not account for natural source reduction resulting from dissolution of BTEX into groundwater or biodegradation and weathering of the soil source. As a result, the results of this simulation provide a conservative prediction of plume migration.

Figure 5.10 shows the plume after 20 years of additional simulation time. The plume (as defined by the 1-µg/L isopleth) is approximately 80 feet longer than the plume observed in November 1994. After 50 years of additional simulation time (Figure 5.11), the leading edge of the plume reaches approximately 160 feet farther than observed in 1994. And after 100 years of additional simulation time (Figure 5.12), the leading edge of the plume reaches approximately 250 farther than observed in 1994. Beyond 100 years of simulation time the plume stabilizes, with a configuration similar to that predicted for 100 years beyond 1994. Modeled BTEX concentrations in the source area are predicted to remain relatively stable at approximately 7,000 µg/L. Simulated maximum concentrations actually vary between approximately 6,700 and 7,300 µg/L in the source area.





LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (μg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.10

PREDICTED BTEX PLUME AFTER 20 YEARS, MODEL DECAY-0

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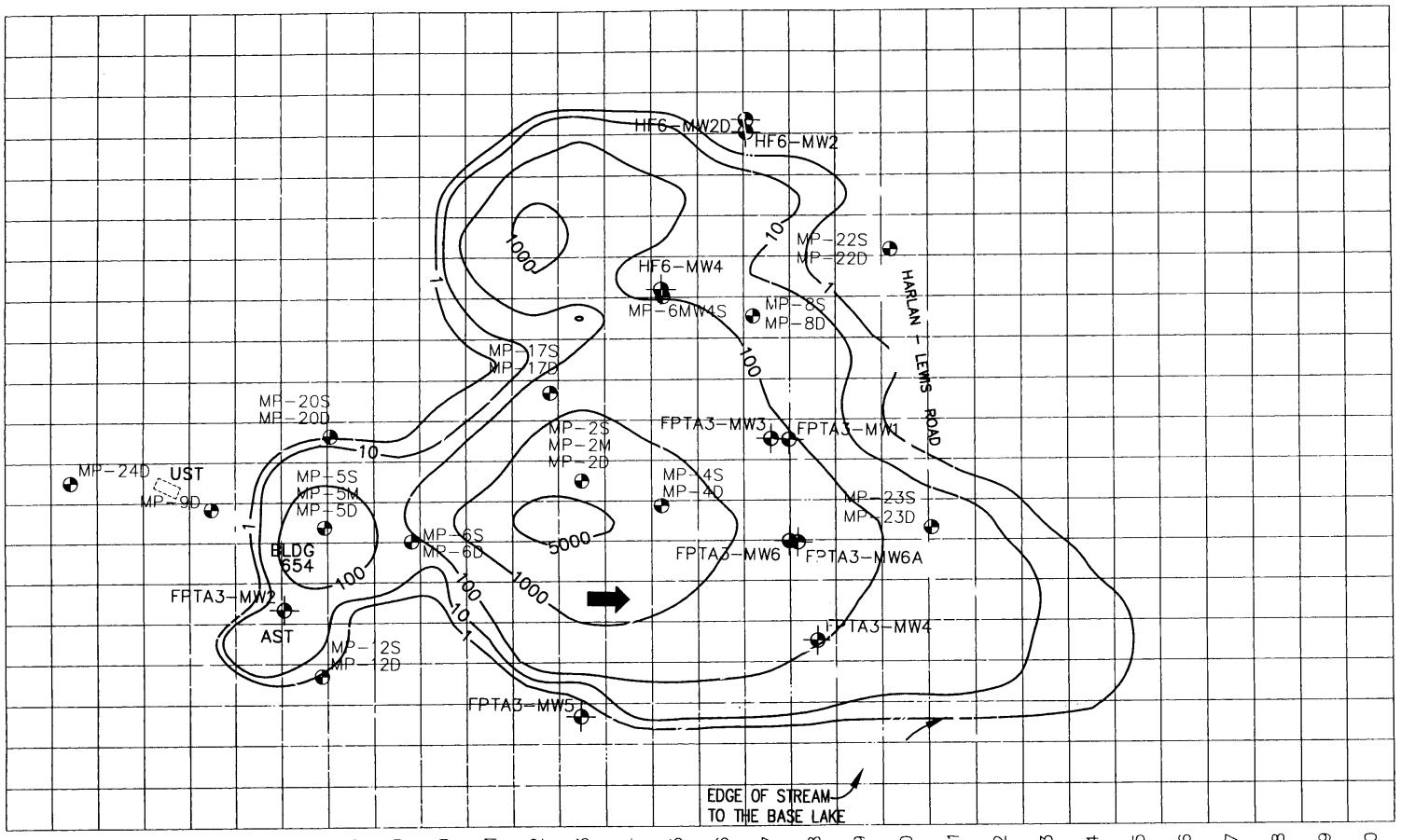

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.11

PREDICTED BTEX PLUME AFTER 50 YEARS, MODEL DECAY-0

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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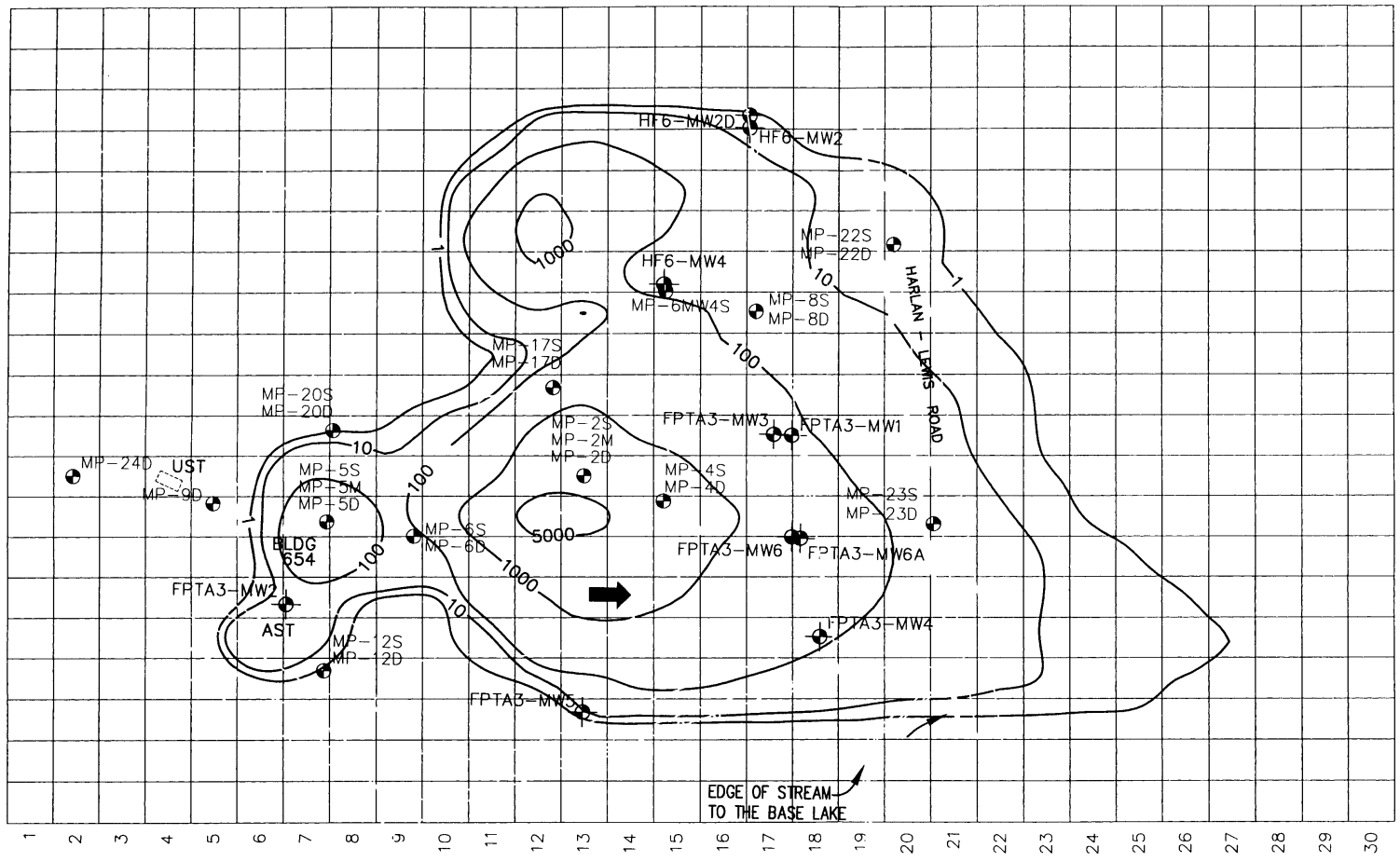

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.12

PREDICTED BTEX PLUME AFTER 100 YEARS, MODEL DECAY-0

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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Denver, Colorado

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These results suggest that the observed BTEX plume is approaching a stable configuration, and should stabilize in about 100 years. Stabilization of a plume reflects a configuration in which the downgradient portion of the plume is attenuated by dispersion, sorption, and biodegradation, but BTEX is replenished from the upgradient source at a rate sufficient to keep the plume front in a relatively stationary position. In actuality, as the residual hydrocarbons in the source area weather, degrade, and are dissolved, BTEX loading rates would decrease and the plume would eventually recede after reaching its maximum extent. This is simulated by model Decay-4.

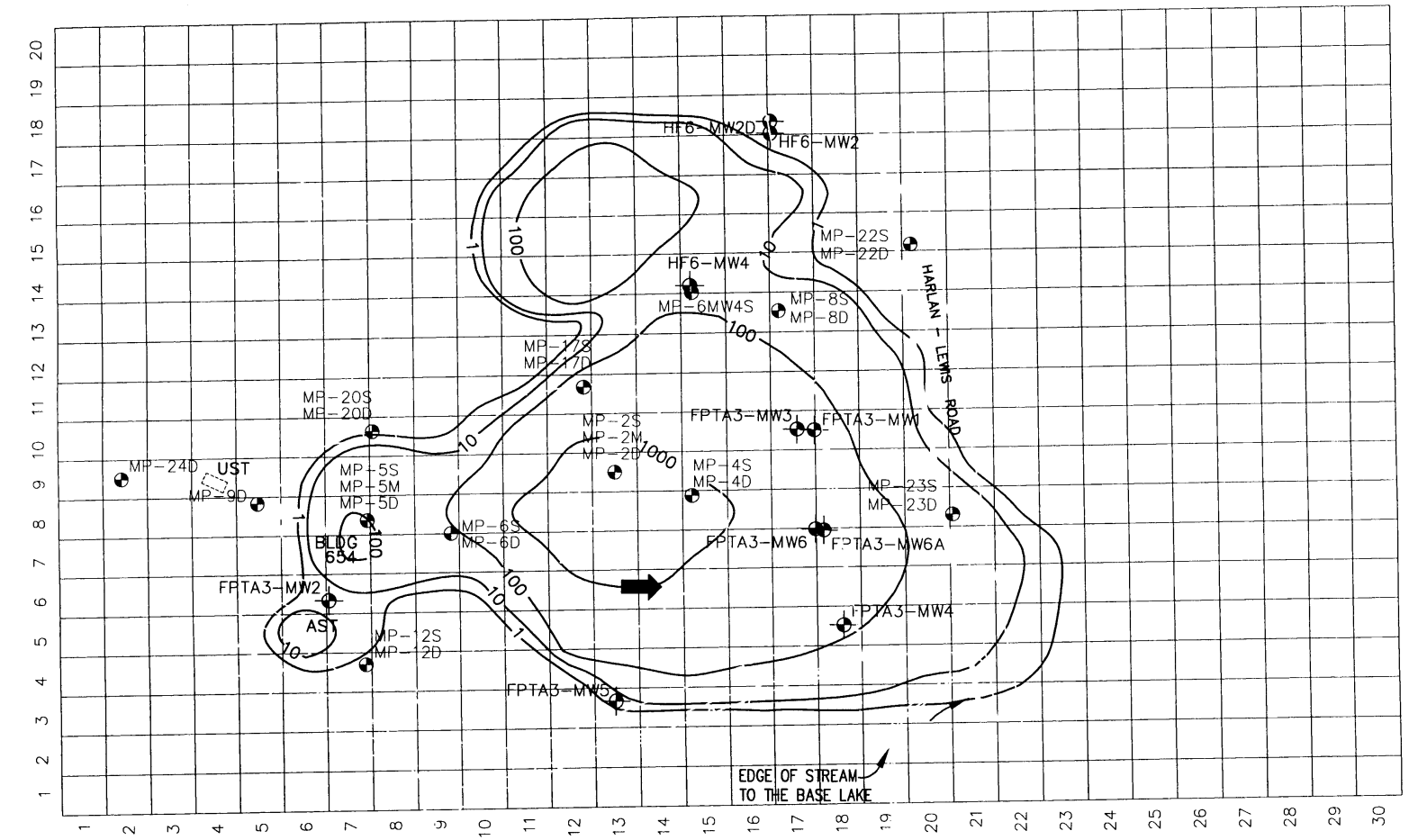
5.6.2 Natural Source Decay (Model Decay-4)

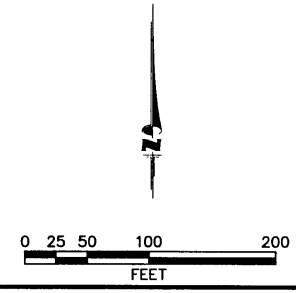
Model Decay-4 was developed to more realistically evaluate the future of the dissolved plume at FPTA3, given that fire protection training exercises at the site have ceased and fuel is no longer being added to the source. Unlike model Decay-0, which assumes that the BTEX source never changes, model Decay-4 assumes that natural processes acting on the source area result in a decrease in the amount of BTEX entering the groundwater as time progresses. Processes which would affect the size and composition of the source area, and hence, the concentration of BTEX released to the groundwater include:

- Reduction of the BTEX in the source soils through dissolution in groundwater;
- Natural biodegradation of BTEX in the source soils; and
- Weathering of the BTEX in the source areas.

In order to simulate the anticipated decrease in the source size and composition, model Decay-4 utilizes 14 pumping periods. The first pumping period is a copy of the calibrated model. Each of the following pumping periods has a duration of 5 years and assumes a BTEX injection rate 20 percent lower than the previous period. This represents a geometric source reduction rate of approximately 4 percent per year. The final pumping period is continued an additional 30 years to make predictions on the fate of the plume. A source reduction rate of 4 percent is within the 2 to 5 percent range of source reduction rates which provided the best calibration for the analytical models.

This model predicts that the plume will reach its maximum areal extent in approximately 20 years. Figure 5.13 shows the plume after 20 years of additional simulation time, or 20 years past 1995. The plume (as defined by the 1-µg/L isopleth) is approximately 80 feet longer than the plume observed in November 1994. Although the total areal extent of the plume begins to diminish after 20 years, the leading edge of the plume reaches its maximum distance from the source area after approximately 60 years (Figure 5.14). At 60 years the leading edge of the plume extends approximately 190 feet farther than observed in 1994. After 95 years of additional simulation time (Figure 5.15), the leading edge of the plume has receded approximately 25 feet from its furthest downgradient extent. Furthermore, after 95 years of additional simulation time, the predicted area of the plume occupies an area approximately 40 percent of the size of the area the plume currently occupies.





LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.13

PREDICTED BTEX PLUME AFTER 20 YEARS, MODEL DECAY-4

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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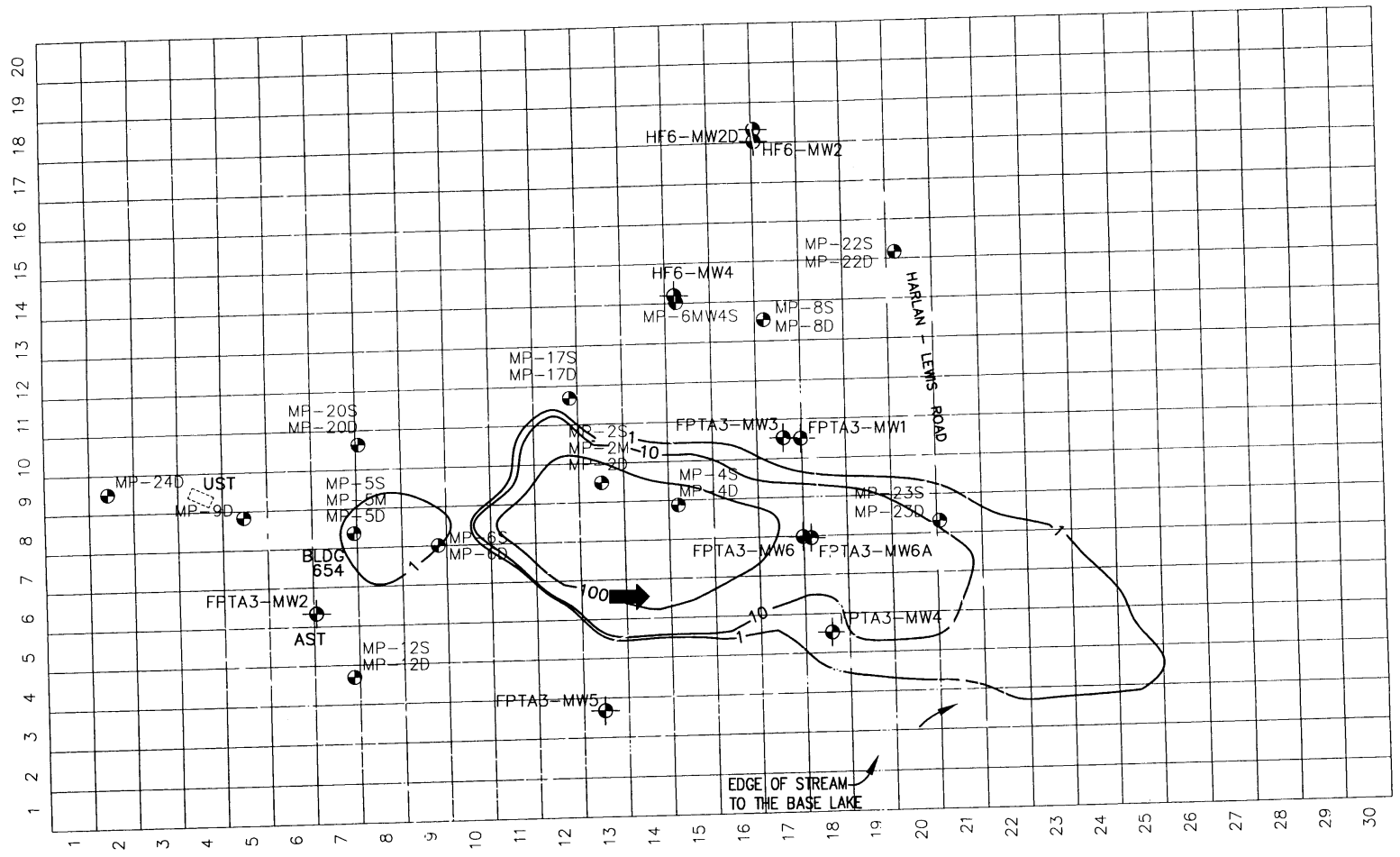

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.14

PREDICTED BTEX PLUME AFTER 60 YEARS, MODEL DECAY-4

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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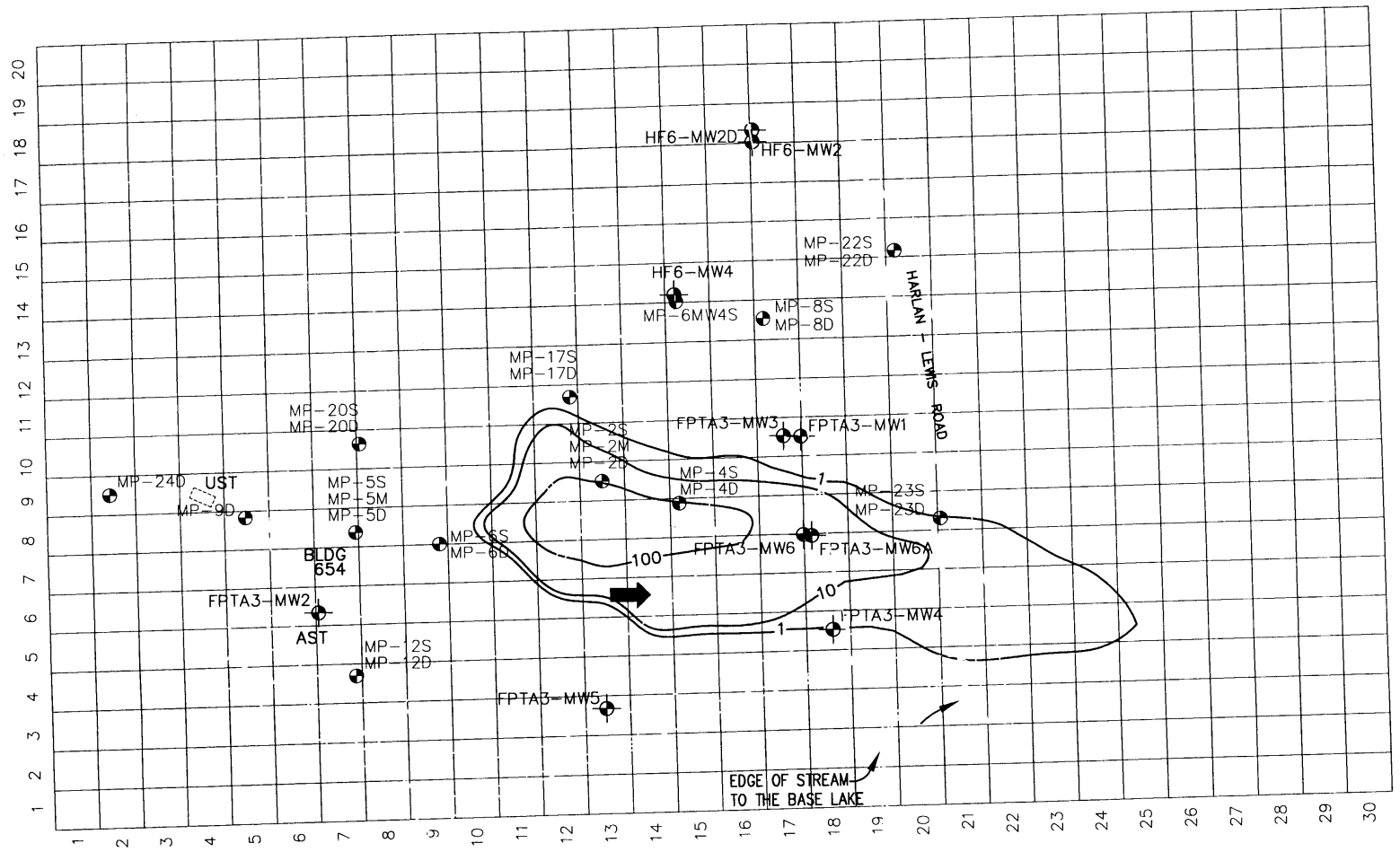

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.15

PREDICTED BTEX PLUME AFTER 95 YEARS, MODEL DECAY-4

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Because this model assumes a decreasing source, maximum BTEX concentrations continually decrease throughout the model simulation. The model predicts a maximum BTEX concentration of 6,950 µg/L for the current conditions. At 20, 60, and 95 years in the future, the model predicts maximum BTEX concentrations to drop to 3,180, 525 and 357 µg/L, respectively.

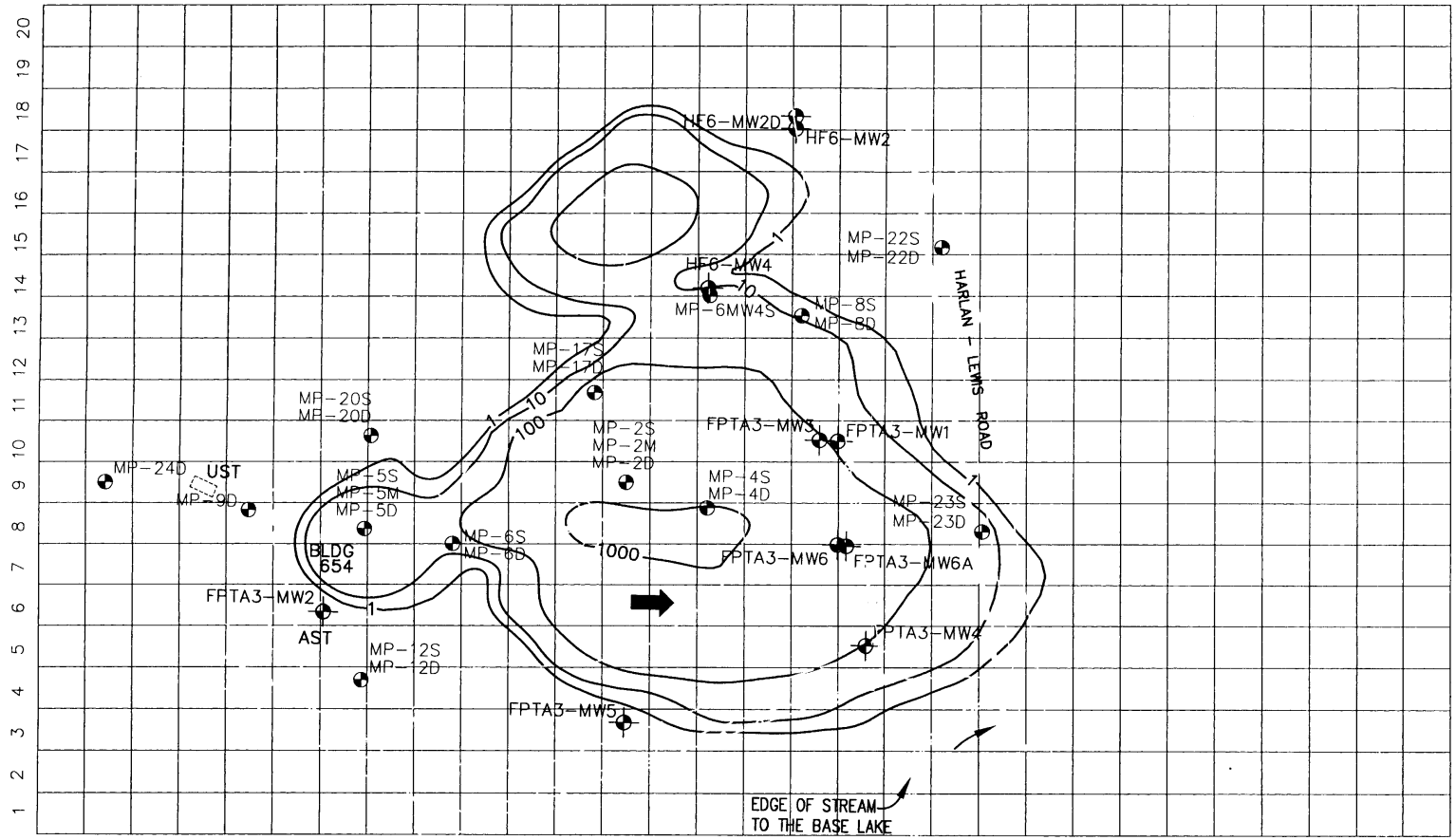
These results suggest that the observed BTEX plume will continue to expand areally for approximately 20 years before beginning to decrease in areal extent. Results also suggest that the leading edge of the plume will advance approximately 190 feet in the next 60 years before beginning to recede. This maximum downgradient extent is still approximately 200 feet from the western shore of the Base Lake. The model also predicts that maximum BTEX concentrations observed in the source areas have already peaked and are beginning to decline. It is this decline at the source areas that ultimately allows more complete attenuation of the plume through dispersion, sorption, and biodegradation.

5.6.3 Active Source Reduction (Model Decay-50)

To illustrate the impact of engineered source reduction activities upon dissolved BTEX migration, model Decay-50 incorporates decreasing BTEX loading rates, assuming that groundwater extraction, bioventing or a similar *in situ* method would be used to remediate the source areas. Groundwater extraction involves the removal and treatment of groundwater followed by either reinjection in the ground or release to surface water. Bioventing is an *in situ* process where low-flow air injection or extraction is used to enhance the biodegradation of organic contaminants in subsurface soils by supplying oxygen to indigenous microbes. Whether a bioventing system is extracting or injecting air, BTEX compounds are preferentially removed because of the benefits microbes derive from aerobic degradation. A bioventing or air sparging system might be counterproductive in the natural attenuation of chlorinated solvents, because of the introduction of oxygen will reduce concentrations of enzymes and cofactors resulting from anaerobic BTEX degradation. A groundwater extraction system would preferentially remove both BTEX and chlorinated solvent compounds.

Model Decay-50 was set up using 9 pumping periods to reflect source removal over a period of 8 years beyond the present. The first pumping period models the period from 1960 to 1995 and is an exact copy of the calibrated model. Each of the following pumping periods has a duration of 1 year and assumes a BTEX injection rate 50 percent lower than the previous year. The final pumping period is continued an additional 69 years to make predictions on the fate of the plume. This scenario reduces BTEX injection by 99.6 percent over the 8-year period. 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 maximum BTEX concentrations in the source areas followed by a much slower decrease in the areal extent of the plume. Figure 5.16 shows the computed plume configuration after the 8 years of source reduction have been completed. At this time, the simulated lateral extent of the plume (as defined by the 1-µg/L isopleth) is roughly equivalent in area to the currently observed plume; however, the leading edge of the plume is predicted to have advanced about 40 feet. Over the



0 25 50 100 200
FEET

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.16

PREDICTED BTEX PLUME AFTER 8 YEARS, MODEL DECAY-50

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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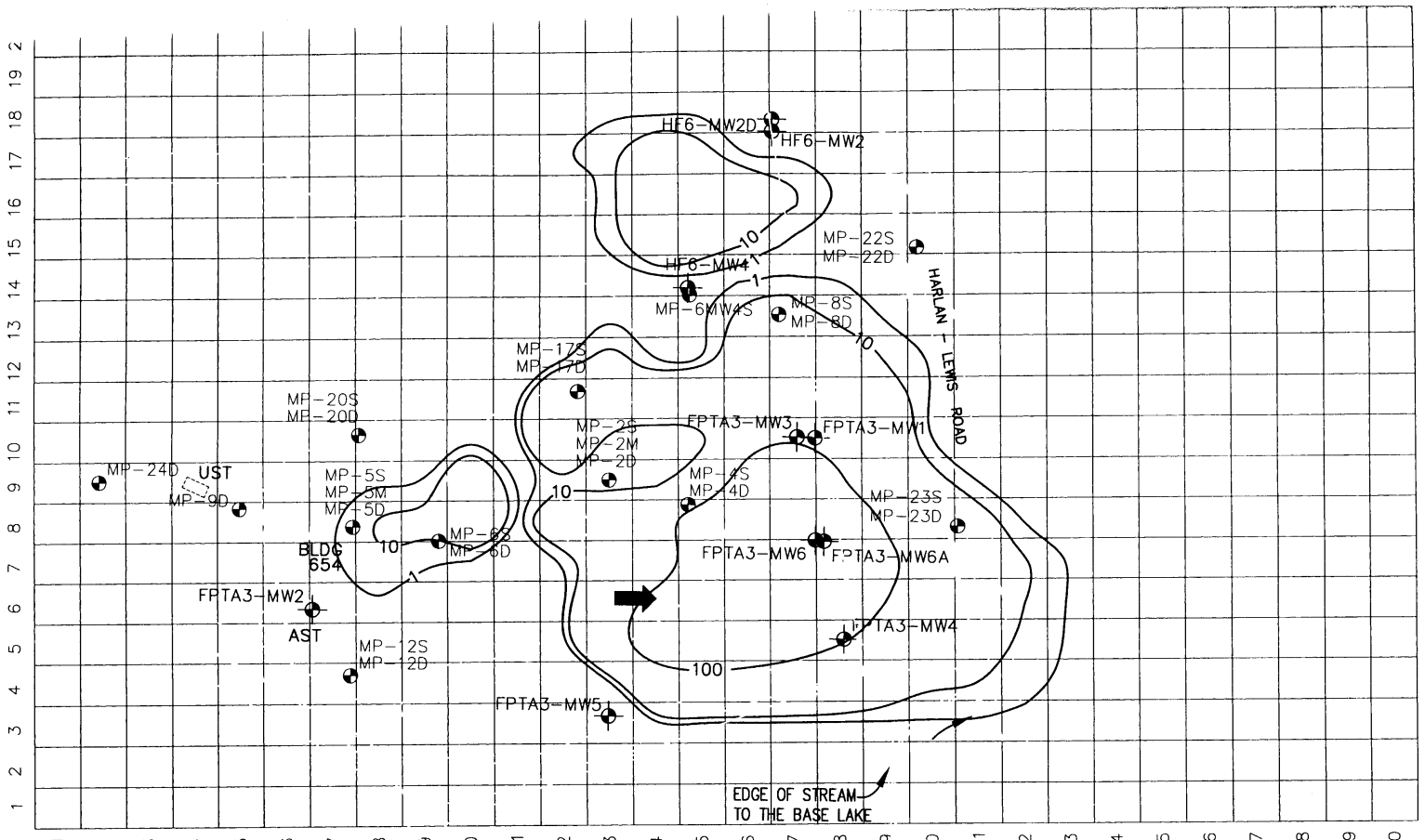
course of the active source reduction, the maximum simulated BTEX concentrations in the main burn pit are estimated to fall from 6,950 to 1,290 µg/L, an 81 percent decrease in concentration. Twenty years after the initiation of source reduction, the model predicts that the area of the BTEX plume will have decreased; however, the distance between the source and the leading edge of the plume will have increased by an additional 80 feet (Figure 5.17). At this time, the plume has detached from the source area and the maximum simulated BTEX concentration (240 µg/L) lies downgradient of the original source area. The leading edge of the plume is predicted to reach its maximum downgradient extent approximately 40 years after the initiation of active source remediation (Figure 5.18). The distance between the source and the leading edge of the plume is projected to be 115 feet beyond the current leading edge. At this time, the plume is rapidly shrinking and the maximum predicted BTEX concentration is only 6 µg/L. The model predicts that the plume will disappear entirely 45 years after the initiation of active source reduction.

For comparison of model Decay-50 assumptions to estimated groundwater extraction results, a batch flushing model for groundwater extraction was used. The batch flushing model uses saturated soil and groundwater BTEX concentrations from the main burn pit in conjunction with a 20-percent partitioning efficiency, a cubic meter cell, and a flushing rate of two times per year. The results of this model suggest that benzene concentrations could decrease approximately 95 percent per year. Using the same assumptions, ethylbenzene concentrations decrease approximately 24 percent per year. Toluene and total xylenes reductions are between these two extremes. After 8 years, the batch flushing model predicts a total BTEX reduction of 90, percent with 100 percent removal of benzene and toluene. This model, however, does not incorporate additional BTEX injection from unsaturated source area soils. The results of the batch flushing model are presented in Appendix C.

Model Decay-50 assumptions are conservative when compared to anticipated BTEX removal from bioventing. Results from three bioventing pilots tests at Offutt AFB have consistently resulted in BTEX removal rates in excess of 90 percent after 1 year of operation. Initially, site TPH degradation rates were estimated at 180 to 31,600 milligrams TPH per kilogram of soil per year (mg/kg/year). After one year of operation, TPH degradation rates of 7 to 5,100 mg/kg/year were observed. Results of an evaluation of bioventing systems at 57 sites (AFCEE, 1994) indicate that TPH degradation rates range from less than 300 to greater than 9,000 mg/kg/year, with rates at most sites exceeding 1,000 mg/kg/year. A closer look at BTEX removal rates at 16 of these sites shows that after 1 year of bioventing, average BTEX concentrations in soil were reduced by 91 percent (for benzene) to greater than 99 percent (for ethylbenzene and xylenes) (AFCEE, 1994). During the same 1-year period, soil TPH concentrations were reduced by an average of 70 percent, confirming that the BTEX compounds are preferentially removed.

5.7 MODELING CHLORINATED SOLVENT FATE AND TRANSPORT

As Bioplume II is not designed to model the cometabolism of chlorinated solvents, the one-dimensional decaying source analytical model [method of van Genuchten and Alves (1982) as described in Section 5.4.1] was used to predict the fate of chlorinated solvents dissolved in the groundwater. Modeling the chlorinated solvent plume was complicated



LEGEND

- DIRT ROADS
- PAVED ROADS
- FENCE
- DRAIN PIPE
- MONITORING WELL
- MONITORING POINT
- LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
- CONTOUR INTERVAL = VARIABLE
- APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.17

PREDICTED BTEX PLUME AFTER 20 YEARS, MODEL DECAY-50

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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Denver, Colorado

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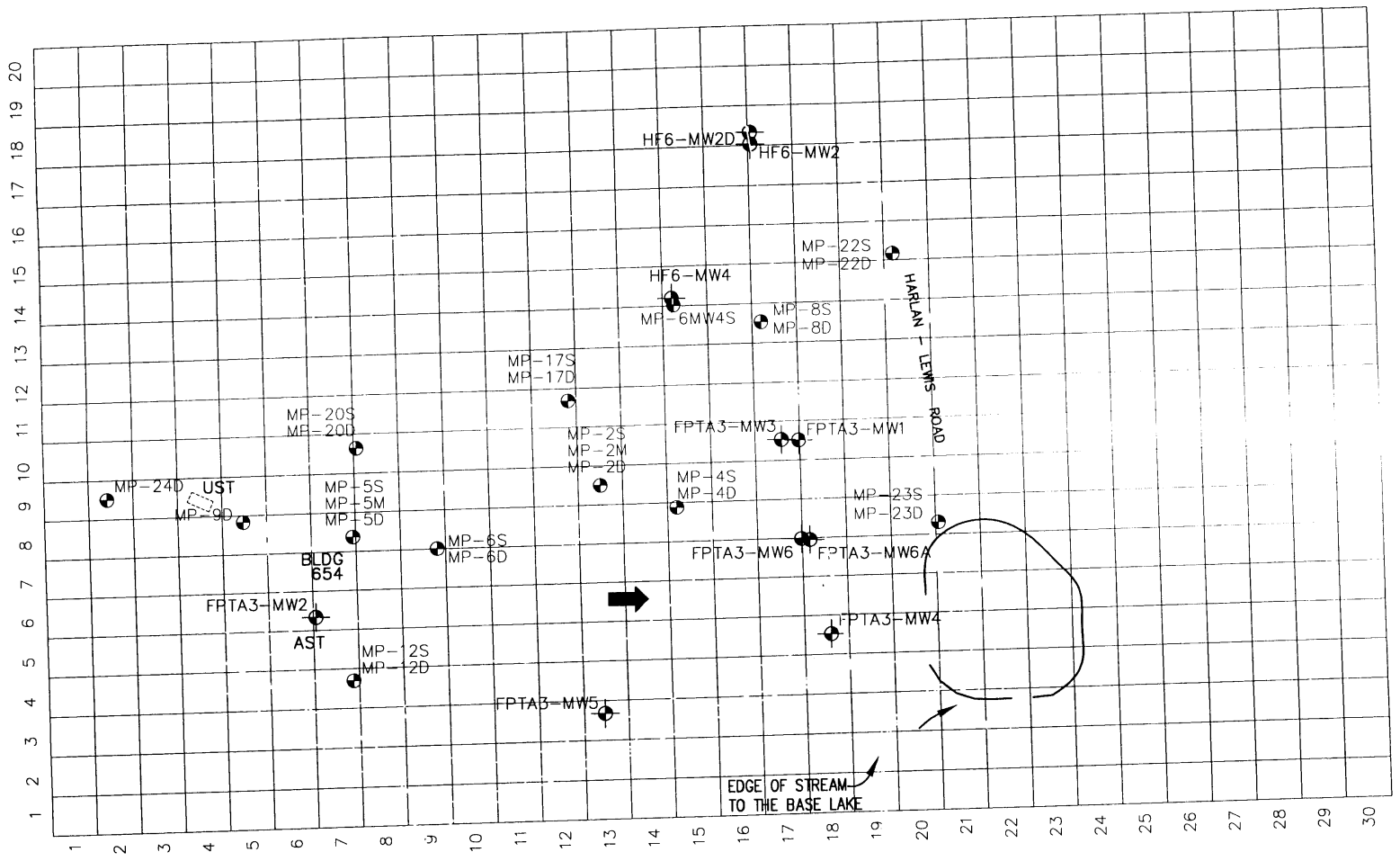

LEGEND

DIRT ROADS
PAVED ROADS
FENCE
DRAIN PIPE

MONITORING WELL
MONITORING POINT
LINE OF EQUAL SIMULATED BTEX CONCENTRATION (µg/L)
CONTOUR INTERVAL = VARIABLE

APPROXIMATE DIRECTION OF GROUNDWATER FLOW

FIGURE 5.18

PREDICTED BTEX PLUME AFTER 40 YEARS, MODEL DECAY-50

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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by the anaerobic decay sequence of chlorinated solvents and the presence of two source areas.

Chlorinated solvents, with the exception of vinyl chloride, degrade anaerobically to other chlorinated compounds known as daughter products. This means that chlorinated solvents can be created from the anaerobic degradation of other dissolved chlorinated solvents at any point along the plume. The only daughter product that will not be created downgradient of the source is the original source solvent, or in this case TCE. As the majority of TCE in groundwater at FPTA3 has been degraded to other chlorinated solvents, the TCE plume cannot be modeled. Furthermore, in order to determine the ultimate downgradient extent of the chlorinated solvent plume, vinyl chloride, the final chlorinated solvent in the anaerobic decay cycle, must be modeled.

The largest source of chlorinated solvents at FPTA3 is believed to be the Building 654 area; therefore, this area is considered the source in the analytical models. The problem with this assumption is that the main burn pit may be a second, albeit smaller source of chlorinated solvents; however, the model is capable of simulating only one source area. The influx of solvents at a second downgradient source exaggerates the length of the plume and changes the chlorinated solvent concentrations within the plume. Given this situation, a conservative solute decay rate must be selected in order to simulate both upgradient and downgradient chlorinated solvent concentrations using only one source.

Models were run both for total chlorinated solvents and for vinyl chloride, which makes up approximately 70 percent of the mass of all chlorinated solvents at the site. The same hydraulic parameters used in the calibrated analytical and numerical models for BTEX also were used for the total chlorinated solvent and vinyl chloride analytical models. The only remaining parameters included the concentration of the injected contaminant, the solute decay rate, the source decay rate, and the retardation coefficient.

Estimates for the solute decay rates were obtained by using the method of Buscheck and Alcantar (1995). Three rates were calculated for total chlorinated solvents and for vinyl chloride. Calculations are provided in Appendix C. The first rate was for the entire site, the second was for the portion of the site between Building 654 and the main burn pit, and the third was for the portion of the site between the main burn pit and the leading edge of the plume. For total chlorinated solvents, the estimated range for the solute decay rate was 0.00013 to 0.00082 $year^{-1}$. For vinyl chloride, the estimated range was 0.00016 to 0.0010 $year^{-1}$. In order to be conservative, solute decay rates at the low end of the range were used in the models. Because vinyl chloride is a subset of the total chlorinated solvents, it follows that neither the source nor solute decay rates for total chlorinated solvents can exceed the rates for vinyl chloride alone. Furthermore, the strength of the source for total chlorinated solvents must equal or exceed the strength of the vinyl chloride source. A retardation coefficient of 1.014 was computed from the soil sorption coefficient for vinyl chloride. For all intents and purposes, this is equivalent to no retardation and therefore results in a conservative model.

Using the ranges and assumptions listed in the following paragraphs, the upgradient and downgradient contaminant concentrations in the two models were best matched using very similar input parameters. The total chlorinated solvent model assumed a source decay rate of 1 percent per year, a solute decay rate of 0.00021 $year^{-1}$, and a source

concentration of 1,500 µg/L. The vinyl chloride model assumed the same source decay rate, the same source concentration, and a solute decay rate of 0.00024 $year^{-1}$. If either the source strength is increased or the source decay rate is decreased in the total chlorinated solvent model, contaminant concentrations at the source and leading edge of the plume are too high. The effect is magnified if both operations are performed. This situation arises because over 99.5 percent of the chlorinated solvent concentration at the source consists of vinyl chloride.

Because the two models are so similar, the results are nearly identical; therefore, only the results for the vinyl chloride model will be discussed. The model predicts that maximum vinyl chloride concentrations should be decreasing at present and should continue to decrease as a result of a decreasing source. The model also predicts that the leading edge of the plume (as defined by a concentration of 1 µg/L) will travel approximately 125 feet over the next 50 years. In the following 50 years, the model predicts that the leading edge of the plume will recede approximately 25 feet. At monitoring well FPTA3-MW6A (approximately 400 feet from the source at Building 654), the model predicts that the vinyl chloride concentration will peak at almost 14 µg/L in approximately 25 years. At a point 100 feet upgradient of the Base Lake, the model predicts that the vinyl chloride concentration will never exceed a concentration of 0.25 µg/L. Graphs of predicted vinyl chloride concentrations with time at MP-4S, FPTA3-MW6A, and a point 100 feet upgradient of the Base Lake are presented on Figure 5.19. Model results are provided in Appendix C.

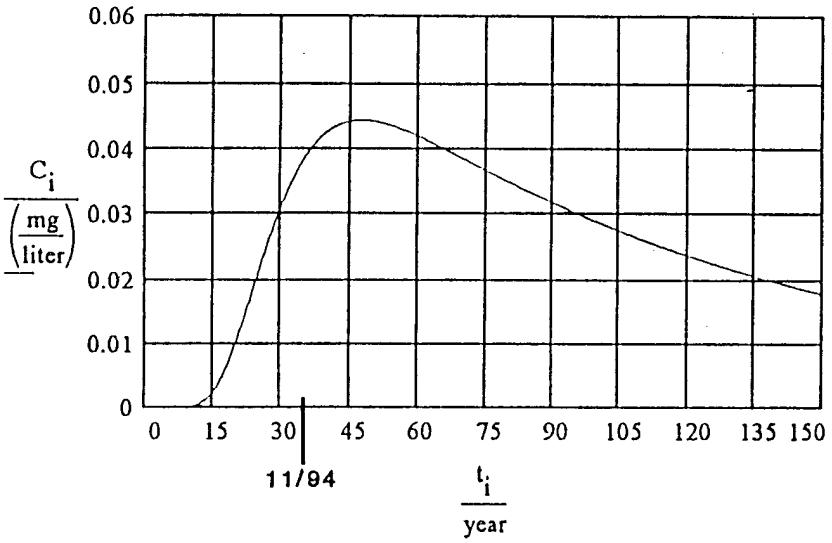
5.8 CONCLUSIONS AND DISCUSSION

The results of three Bioplume II model scenarios for FPTA3 at Offutt AFB suggest that the dissolved BTEX plume front is not likely to migrate more than 250 feet downgradient from its September 1994 position. The first scenario, model Decay-0, assumed that the conditions that produced the calibrated model would remain constant for the full duration of the simulation. The second scenario, model Decay-4, assumed that BTEX loading rates would be reduced via natural processes over time. The final scenario, model Decay-50 assumed that BTEX loading rates would be reduced via bioventing or some other remedial action.

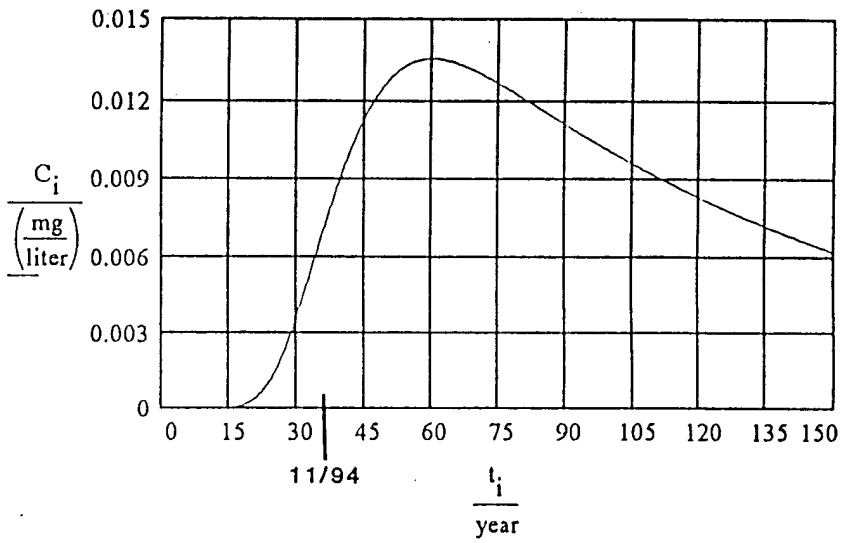
Model Decay-0 results suggest that within 100 years the BTEX plume will reach its maximum extent before stabilizing. The model predicts that the stabilized plume will encompass an area approximately 50 percent larger and will extend approximately 250 feet further downgradient than currently observed. Neither the increase in area or length brings the plume in contact with the Base Lake or groundwater pumping wells. This model is considered conservative because it assumes that BTEX injection at the source does not change with time.

The results of model Decay-4 simulate a plume that reaches its maximum areal extent in approximately 20 years, and its maximum downgradient extent in approximately 60 years. Both the maximum areal extent and maximum downgradient extent are less than predicted by model Decay-0; therefore, no impact on potential receptors is expected. Model Decay-4 is intended to represent anticipated site conditions; however, it still includes several conservative assumptions (see below).

Location MP-4 (approx. 90 meters from the source area)



Location FPTA-6A (approx. 125 meters from the source area)



Location 250 meters from the source area (approx. 30 meters from the Base Lake)

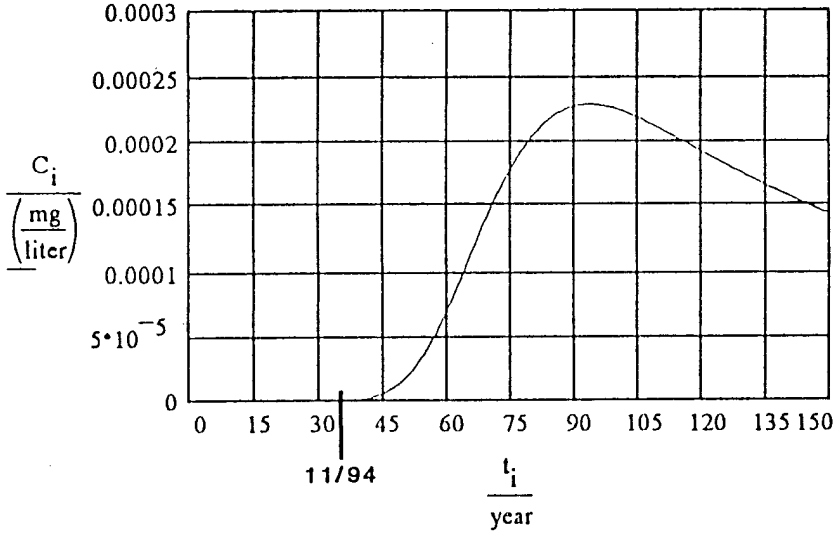


FIGURE 5.19

PREDICTED VINYL CHLORIDE CONCENTRATIONS OVER TIME

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

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Denver, Colorado

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The results of model Decay-50 simulate the fate of the BTEX plume should source reduction/removal be implemented at the site. The model predicts that the areal extent of the plume will shrink following the removal of the source; however, the leading edge of the plume will continue to advance for approximately 40 years following the initiation of source reduction. The model also predicts that the BTEX plume will be completely degraded after 45 years.

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

1) The stoichiometry used to determine the ratio between DO and total BTEX assumed that no microbial cell mass was produced during the reaction. As discussed in Section 4.3.2.1, this approach may be too conservative by a factor of three.

2) DO was only introduced with groundwater recharge at the source areas and at the upgradient model boundary; however, a small amount of groundwater recharge occurs across the entire site as a result of precipitation. In addition, sources of groundwater recharge such as the drainage ditch along Harlan-Lewis Road are also potential sources of oxygen recharge, but were not simulated as such.

3) The coefficient of retardation for benzene (1.46) was used for model simulations. Minimum coefficient of retardation values for toluene, ethylbenzene, and xylene range from 2.1 to 3.7. The use of the low coefficient of retardation tends to increase the distance traveled by the simulated BTEX plume, but may provide a more accurate estimate of benzene transport.

4) The anaerobic decay constant (0.0006 day^{-1}) is conservative compared to literature values of 0.001 to 0.185 day^{-1} (See Section 5.3.5.3). The use of a low anaerobic decay constant increases the length of travel of the contaminant plume as well as the time required for natural attenuation to completely reduce the contaminant concentrations.

5) The model assumes a uniform contaminant concentration over the entire aquifer thickness. As the Bioplume II model is calibrated to the highest detected BTEX concentrations, the models include much more contaminant mass than is expected to be present at the site.

The degradation and stabilization of the BTEX plumes observed in the three model simulations is feasible, given the observed BTEX concentrations, the conservative assumptions made in constructing the simulation, and the strong geochemical evidence of aerobic and anaerobic biodegradation. Models Decay-0 and Decay-50 represent two endpoints in a continuum of probable scenarios at this site. Model Decay-0 is a "worst-case" scenario in that it assumes BTEX dissolution into the aquifer will continue indefinitely at the same rates, while the rates should actually decrease due to partial source remediation, weathering and degradation of the residual soil contamination, and continuing dissolution of BTEX from the source area. Model Decay-0 predicts that the

leading edge of the BTEX plume will stabilize approximately 100 feet upgradient of the Base Lake; therefore, BTEX from FPTA3 is not expected ever to impact the Base Lake. Model Decay-50 is an optimistic prediction which assumes that active source remediation can rapidly reduce BTEX partitioning into the dissolved phase. It is likely that future site conditions will fall somewhere between those suggested by these two simulations.

The chlorinated solvent analytical model also predicts that the chlorinated solvents will have degraded before the plume reaches the Base Lake. The model includes two conservative assumptions:

1) A very low coefficient of retardation for vinyl chloride (1.014) was used for model simulations. Minimum coefficient of retardation values for DCE and TCE are approximately 1.34 and 1.55. The use of the low coefficient of retardation tends to increase the distance traveled by the simulated chlorinated solvent plume, but may provide a more accurate estimate of vinyl chloride transport.

2) The model assumes a single chlorinated solvent source located at Building 654 to simulate the source area and leading edge solvent concentrations. If in fact the main burn pit is contributing chlorinated solvents to the plume, then the solute decay rate is probably higher than the value used in the model. This would occur because a portion of the chlorinated solvent concentration at downgradient locations would have originated from a downgradient (and not accounted for) source, but the entire chlorinated solvent concentration at downgradient locations was modeled as part of the decay sequence of the Building 654 source. A higher solute decay rate causes the plume to degrade more rapidly and inhibits the advancement of the leading edge of the plume.

The fate and ultimate degradation of the chlorinated solvent plume as predicted from the one-dimensional decaying source model simulation is feasible given the observed chlorinated solvent concentrations, the conservative assumptions made in constructing the simulation, and the composition of the chlorinated solvent plume, which consists primarily of the anaerobic degradation products of the original source solvent (TCE).

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of two groundwater remedial alternatives for FPTA3 at Offutt AFB. The intent of this evaluation is to determine if intrinsic remediation is an appropriate and cost-effective remedial technology 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 evaluation 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 (OSWER Directive 9355.3-01). These criteria included (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 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 site-related contamination in shallow groundwater is qualitatively assessed by conservatively estimating if a potential exposure pathway involving groundwater could be completed, either now or in the future. 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 described. 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 (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 inflation factor of 5 percent was assumed in present worth calculations. Costing worksheets and calculations are included in Appendix E.

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 natural attenuation demonstration program; contaminant, groundwater, and soil properties; present and future land use; and potential 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 site.

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 FPTA3 study is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons 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 exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (soil, soil gas, etc.), technologies have been evaluated based primarily on 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 will also 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 meet these criteria include institutional controls, groundwater pump and treat, soil vapor extraction, and intrinsic remediation. Bioventing, soil excavation, slurry walls, sheet piling, carbon adsorption, *ex situ* biological or chemical treatment, and onsite/offsite disposal are not considered attractive technology candidates for this site.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at FPTA3 are the BTEX compounds. Other site contaminants considered in the remediation strategy include the chlorinated solvents TCE, DCE, and vinyl chloride. The source of this contamination is the fuels and solvents used during fire training activities. Residual contamination is concentrated in the capillary fringe and saturated soil in the vicinity of Building 654, the main burn pit, and the historic discharge pond. 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 over 300 compounds with different physiochemical characteristics. JP-4 is classified as an LNAPL with a liquid density of 0.75 gram per cubic centimeter (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). Toluene sorbs more readily to soil media relative to benzene, but still

is very mobile. The solubility of pure toluene in water at 20°C is approximately 515 mg/L at 20°C (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 but less strongly than toluene (Abdul *et al.*, 1987). 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, 1975; Pankow and Rosen, 1988). Of all of the BTEX compounds, xylenes sorb most strongly to soil, but still can leach from soil into the groundwater (Abdul *et al.*, 1987). 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 FPTA3 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 cometabolic processes (see Section 4). There are no known microorganisms that are capable of growth using halogenated aliphatic compounds (e.g., TCE, DCE, and vinyl chloride) as a primary carbon source (Chapelle, 1993). The microorganisms that can facilitate cometabolic degradation of the chlorinated solvents in the soil and groundwater use the BTEX compounds as the primary carbon substrate.

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 4,400 mg/L at 20°C. Microbial degradation of TCE by dehalogenation can yield the degradation products 1,1-dichloroethane (1,1-DCA), cis-1,2-DCE, trans-1,2-DCE, chloroethane, 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 significantly more mobile than both TCE and benzene (see Table 5.5). 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 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, soil vapor extraction, bioventing, biosparging, groundwater extraction, and air stripping technologies could all be effective options for collecting, destroying, and/or treating BTEX and chlorinated solvent contaminants at FPTA3. 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 technologies 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 exposure pathways. Each of these site-specific characteristics have influenced the selection 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 and groundwater gradient. Slug testing conducted in the vicinity of the site indicate a moderate conductivity within the fine sand unit present in the vicinity of the source area and dissolved plume. Estimated conductivity values ranged from 8.8×10^{-4} to 6.6×10^{-3} ft/min, characteristic of sand or silty sand. The hydraulic conductivity at this site directly influences the fate and transport of contaminants, but it has not contributed to a rapid increase in the extent of contamination. Plume expansion has been limited by the very shallow groundwater gradient of approximately 0.0006 ft/ft. The average site advective groundwater velocity was estimated at 0.018 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 very slowly. The low estimated groundwater velocity implies that a contaminant plume experiencing no retardation would travel only a little over 6 ft/year. Attenuation processes 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.

Site geology and hydrogeology also impact the types of practical engineered remedial technologies. The hydraulic conductivity can contribute to the effectiveness of remedial technologies, such as groundwater extraction and biosparging. For example, it should be less expensive and time-consuming to capture and treat the contaminant plume using a network of extraction wells in areas of high hydraulic conductivity. Contaminant recovery may also be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil. In addition, the effectiveness of biosparging may increase as hydraulic conductivity increases because of reduced entry pressures and an increased radius of influence.

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, electron acceptors, essential nutrients, 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 document 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 and cometabolism of the chlorinated solvents. Ferric iron, sulfate, and carbon dioxide (which is utilized during methanogenesis) represent sources of electron acceptor capacity for the biodegradation of BTEX compounds at the site. Further, because fuel hydrocarbon-degrading microorganisms have been known to thrive under a wide range of temperature and pH conditions (Freeze and Cherry, 1979), 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 through cometabolism rather than direct biodegradation. Microorganisms in the groundwater produce enzymes or cofactors during the degradation of BTEX. These enzymes and/or cofactors then participate in the degradation of the chlorinated solvents. There also appears to be a correlation between cometabolism reaction rates and reducing conditions; the more reducing the conditions, the faster dechlorination occurs (Bouwer and Wright, 1988).

Groundwater results presented in Section 4 strongly support the conclusion that both biodegradation of BTEX and the cometabolism of 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 cometabolism prefers highly reducing conditions, the reduction in the cometabolic rate of chlorinated solvents might far outweigh the benefits of a biosparging system. Bioventing is another technology that was not considered a viable option because only fuel hydrocarbons are removed from source soils. If concentrations of fuel hydrocarbons are significantly lowered in the groundwater without a comparable decrease in chlorinated solvent concentrations, insufficient enzymes and/or cofactors may be produced to sustain chlorinated solvent cometabolism.

6.2.3.3 Potential Exposure Pathways

A pathways analysis identifies the potential human and ecological receptors that could potentially 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 if the approach will be sufficient and adequate to minimize plume expansion so that potential exposure pathways involving shallow groundwater will not be completed.

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 FPTA3 source areas consist of the main burn pit, the Building 654 area, and the historic discharge pond. Approximately 2,000 feet upgradient (west) of the site lies the main Base runway. Between the site and the runway lie open fields and a landfill. The end of the runway is approximately 1,000 feet south of the site. Immediately north of the site is a hardfill disposal area; an ordnance facility lies north of the hardfill. Harlan-Lewis road is immediately east of the site. The Base Lake is approximately 400 feet east of Harlan-Lewis Road. A railroad track and a lake access road lie between Harlan-Lewis Road and the Base Lake. The road and railroad occupy a 300-foot-wide strip of land that is not part of the Base property. The groundwater plume originating from FPTA3 is migrating to the east, and has impacted groundwater as far east as Harlan-Lewis Road. Thus, the current land use within and downgradient from the contaminant plume is open, or used for transportation, disposal, or recreation.

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 and analytical model results, both BTEX and chlorinated solvent groundwater contamination will completely degrade prior to discharge into the Base Lake; therefore, recreational users of the lake are not potential receptors. Groundwater from the shallow aquifer is not currently used to meet any demands at Offutt AFB. On-Base water demands are met by municipal supply wells located 4 miles south of the Base. 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.

Assumptions about hypothetical future land uses must also be made to ensure that the remedial technology or alternative considered for shallow groundwater at the site is adequate and sufficient to provide long-term protection. No changes in land use are anticipated in the foreseeable future, so the current land use assumptions are appropriate for future scenarios. Thus, potential future receptors include only worker populations. The potential future exposure pathways involving workers are identical to those under current conditions provided shallow groundwater is not used to meet industrial water demands. In summary, the use of the intrinsic remediation technology at this site will require that the source area be maintained as industrial property and that restrictions on shallow groundwater use be enforced in areas downgradient from the site until natural attenuation reduces contaminants to levels that pose no risk. Should LTM demonstrate that the contamination migrates further than predicted by the groundwater models, it may be necessary to evaluate potential risks to recreational users of the Base Lake. If source removal technologies such as soil vapor extraction, bioventing, biosparging, or groundwater pump and treat are implemented, they will have some impact on the short- and long-term land use options and will require some level of institutional control and worker protection during remediation.

6.2.3.4 Remediation Goals for Shallow Groundwater

Model results suggest that BTEX compounds are not likely to move more that 250 feet downgradient from the observed plume front. Therefore, an area approximately 300 feet beyond the plume boundary observed in November 1994, has been identified as the POC for groundwater remedial activities because this appears to be beyond the maximum extent of future contaminant migration. This is a suitable location for monitoring and for demonstrating compliance with protective groundwater quality standards, such as promulgated groundwater maximum contaminant levels (MCLs). The location is also approximately 100 feet upgradient from the Base Lake. Given an estimated advective groundwater velocity of approximately 6.7 ft/yr, the travel time from the POC to the Base Lake is approximately 15 years.

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 FPTA3 is limiting plume expansion to prevent exposure of downgradient receptors to concentrations of BTEX or chlorinated solvents in groundwater at levels that exceed regulatory standards. 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 attainment of State of Nebraska groundwater standards and federal MCLs listed in Table 6.1 for each of the BTEX and detected chlorinated solvent compounds. Although it is unlikely that groundwater would be ingested by humans, this level of long-term protection is appropriate.

TABLE 6.1
POINT-OF-COMPLIANCE REMEDIATION GOALS
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Compound	Nebraska Groundwater Standard (µg/L)	Federal MCL (µg/L)
Benzene	5	5
Toluene	1,000	1,000
Ethylbenzene	700	700
Total Xylenes	10,000	10,000
TCE	5	5
1,1,1-TCA	200	200
cis-1,2-DCE	70	70
trans-1,2-DCE	100	100
Vinyl Chloride	2	2

In summary, available data suggest that there is no complete potential exposure pathway involving shallow groundwater under current conditions. Moreover, it is likely that no 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 250 feet downgradient of the 1994 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 Technology Screening

Several remedial technologies have been identified and screened for use in treating the shallow groundwater at the site. Table 6.2 identifies the initial remedial technologies 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.

The remedial technologies retained for development of remedial alternatives and comparative analysis include institutional controls, intrinsic remediation, LTM, groundwater extraction, and soil vapor extraction. Bioventing and biosparging, though implementable, were not retained for further consideration because each alters the site geochemistry in such a way that cometabolism of chlorinated solvents might decrease. The decreased degradation of chlorinated solvents could potentially outweigh the benefits of the technology.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into two remedial alternatives for FPTA3. 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 and Institutional Controls with Long-Term 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 existing evidence of intrinsic remediation described in Section 4, these processes are occurring at FPTA3 and will continue to reduce contaminant mass in the plume area.

Results of model Decay-0 suggest that the dissolved BTEX plume should reach its maximum lateral extent within 100 years. After that time, the Bioplume II model predicts that intrinsic remediation within the BTEX plume and along the plume margins will prevent further plume expansion, assuming BTEX loading in the source area remains constant. This model predicts that the BTEX plume could extend approximately 250 feet further downgradient than observed in November 1994. A more realistic model, Decay-4

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability	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 wells.	Yes
		Point-of-Compliance Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The majority of the plume area is currently within the base boundary and land use and groundwater use are under base jurisdiction. The leading edge of the plume extends beneath a county road under county jurisdiction.	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	No
		Point-of-Use Treatment	No shallow groundwater is extracted from the plume area for any use.	No
	Public Education	Meetings/ Newsletters	Base public relations and environmental management offices have many information avenues to workers and residents.	Yes
Containment of Plume	Hydraulic Controls	Passive Drain Collection	No likely receptors downgradient of site. Groundwater gradients are very low. Hydraulic conductivity of site soils favors pumping.	No
		Minimum Pumping/Gradient Control	No likely receptors downgradient of site. The rate of plume advance is very low as a result of low site groundwater gradients.	No
	Physical Controls	Slurry Walls/Grout Curtains	Limited effectiveness. Contaminant migration is limited by very low advective groundwater velocities.	No
		Sheet Piling	Limited effectiveness. Contaminant migration is limited by very low advective groundwater velocities.	No
	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Degration of BTEX and chlorinated solvents can be stimulated by allowing groundwater to flow through a nutrient-rich barrier. Contaminant migration is limited by very low advective groundwater velocities. New, unproven technology.	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability	Retain
In Situ Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and/or nutrients are injected downgradient of plume to limit plume migration by enhancing biodegradation and reducing BTEX concentrations as the plume moves downgradient from the source area. Could negatively effect cometabolism of chlorinated solvents by altering site geochemistry.	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 FPTA3 indicates that this is a major, ongoing remediation process.	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and into vadose zone. Could negatively effect cometabolism of chlorinated solvents by altering site geochemistry.	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 rapidly reduce source area contaminant concentrations, thereby significantly reducing the length of time required for natural attenuation processes to complete the groundwater restoration.	Yes
		Downgradient Horizontal Drains	See Passive Drain Collection.	No
	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	No
	Chemical/Physical	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX and chlorinated solvents at higher flow rates. Potential permitting for air emissions.	Yes
		Activated Carbon	Cost prohibitive for more concentrated BTEX. Creates a carbon disposal problem. Ineffective for removal of vinyl chloride.	No
		UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors.	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability	Retain
Aboveground Treatment	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)		Viable option when an IWWTP is readily available and capable of handling BTEX, chlorinated solvent, and hydraulic loading.	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable.	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable.	No
	Treated Groundwater Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance.	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting.	No
	Discharge to Surface Waters	Storm Drains	Viable option. Generally requires NPDES or other discharge permit.	Yes
Source Removal/Soil Remediation	Excavation/ Treatment	Biological Landfarming	Excavation may be feasible at this site. Soil remediation may be unnecessary for groundwater remediation.	No
		Thermal Desorption	Excavation may be feasible at this site. Soil remediation may be unnecessary for groundwater remediation.	No
	In Situ	Bioventing	Air injection to stimulate biodegradation of fuel residuals. Ineffective on chlorinated solvents. May reduce cometabolism of chlorinated solvents by altering groundwater geochemistry through a reduction in BTEX concentrations.	No
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites. Soil remediation may be unnecessary for groundwater remediation. Effective for both BTEX and chlorinated solvents.	Yes

predicts that the areal extent of the dissolved BTEX plume will reach a maximum in approximately 20 years and the downgradient maximum will be reached in approximately 60 years. After 60 years, the model Decay-4 predicts that the BTEX plume will extend 190 feet further downgradient than observed in 1994. This model assumes that BTEX loading in the source area decreases at a geometric rate of 4 percent per year. An analytical model for chlorinated solvents predicts that the vinyl chloride concentration of 2 µg/L will never travel more than a few feet to the east of Harlan-Lewis Road. Furthermore, the vinyl chloride concentration should never exceed 0.25 µg/L at a location 100 feet upgradient from the shore of the Base Lake.

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 of 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. Model scenarios Decay-0 and Decay-50 (a geometric decay of the injection source of 50 percent per year) delineate the maximum and minimum estimated plume migration distances. Future plume migration and degradation will most likely result in conditions that fall between these limits. To be conservative, the results of model Decay-4 should be considered in making decisions regarding groundwater monitoring and potential land use restrictions.

As a minimum, groundwater monitoring within the plume area would be conducted once every 2 years as part of this remedial technology to evaluate the progress of natural attenuation processes. Based on the potential BTEX plume migration suggested by model Decay-4, it is unlikely that benzene concentrations exceeding the federal MCL or state groundwater criterion of 5 µg/L would be present more that 190 feet downgradient of the 1994 plume front. This would be true even if it were assumed that model contaminant concentrations are all benzene rather than total BTEX. Results of model Decay-50 suggest that with source reduction, the BTEX plume would reach no more than 115 feet beyond the 1994 plume front.

Because there are no apparent downgradient receptors, and the contaminant plume is currently delineated by existing wells, long-term monitoring at the existing monitoring network should be performed to determine the effectiveness of intrinsic remediation at the site. A long-term monitoring plan is recommended in Section 7. Detection of benzene or other compounds in excess of regulatory guidelines at the furthest downgradient LTM wells may require additional evaluation and modeling to assess BTEX and/or chlorinated solvent migration, or to determine if additional corrective action is necessary.

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 other 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 - Groundwater Extraction, Intrinsic Remediation, Institutional Controls with Long-Term Groundwater Monitoring, and Optional Soil Vapor Extraction Test

This alternative is identical to Alternative 1 except that groundwater extraction would be used to reduce the concentration of organic contaminants in groundwater. This would be accomplished through extraction of source area groundwater at low pumping rates. The removal of contaminated groundwater (and hence contaminants) from the system would reduce the predicted future extent of the contaminant plume and the predicted length of time required for intrinsic remediation to complete groundwater remediation. As the groundwater gradient is nearly flat near FPTA3, groundwater extraction could result in additional flow into the source area from upgradient as well as downgradient areas. This effect would increase source area flushing while serving to capture and/or retard movement of contamination downgradient of the site. It is estimated that two wells each pumped at a rate of 11.5 gpm would be required to capture the contamination in the source area. Proposed well locations are presented on Figure 6.1. Monitoring wells are estimated to be 40 feet deep, 4-inches in diameter, and screened across the shallow aquifer. Assuming contaminant concentrations in groundwater reach 20 percent of the partitioning equilibrium with surrounding saturated soils, groundwater extraction would reduce groundwater contaminant concentrations below regulatory criteria in approximately 2 years. If a partitioning efficiency of 10 percent is assumed, the time increases to approximately 6 years. These time estimate do not account for contaminant influx from vadose zone soils; therefore, operation of the groundwater extraction system has been estimated for cost purposes at 8 years. Calculations used to arrive at this configuration of extraction wells and the length of time of groundwater extraction are presented in Appendix C.

The extracted groundwater may require treatment prior to release to drainages adjacent to the site. Air stripping is the recommended method of treatment, as activated carbon is ineffective at the removal of vinyl chloride. Treated groundwater could be released into the drainage east of the site, or released into the main burn area for reinfiltration and flushing of vadose zone soils, or a combination of these alternatives.

Reduction of the soil source should also be considered concurrently with reduction of the groundwater source. The maximum total BTEX concentration in soil was 351 mg/kg, with approximately 3 mg/kg attributed to benzene; however, total BTEX concentrations did not exceed 14 mg/kg in other source area soil samples. Chlorinated solvent concentrations were not detected in any of the 16 soil samples collected in 1994. Past investigations have detected concentrations as high as 387 mg/kg total BTEX and 5.2 mg/kg TCE (ES, 1990a and 1990b). As the historic results are several years old, and the samples were collected during a time when fire training activities were still regularly conducted at the site, it is uncertain whether the results are representative of current conditions. A single-well soil vapor extraction test could be performed in the vicinity of Building 654 and/or the main burn pit to assess the effectiveness of BTEX and chlorinated solvent removal. If test results suggest that a sizable quantity of chlorinated solvents can be eliminated through soil vapor extraction prior to dissolution and

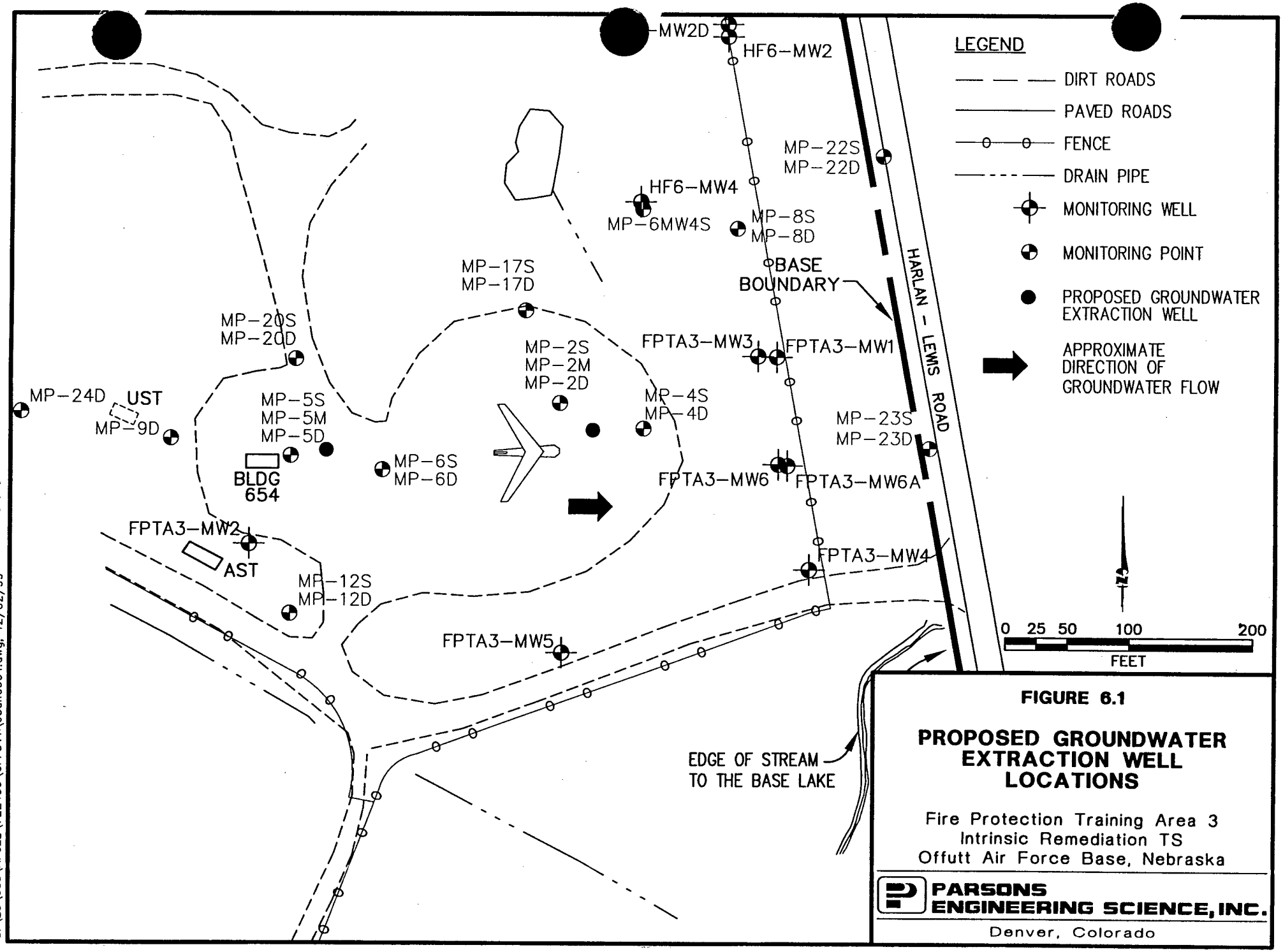

FIGURE 6.1

PROPOSED GROUNDWATER EXTRACTION WELL LOCATIONS

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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cometabolism in groundwater, then implementation of a full-scale soil vapor extraction system should be considered.

Neither biosparging or bioventing were considered in groundwater and soil source reduction because both could preferentially eliminate BTEX compounds. By disrupting the balance of BTEX to chlorinated solvents, the rate of cometabolism of chlorinated solvents could decrease. Such a decrease would adversely effect the restoration of site groundwater.

As indicated in Section 5.6.2, it has been estimated that a groundwater extraction system could reduce the source area groundwater contamination by approximately 50 percent per year. Simulation Decay-50 assumed such a decrease. In this case, the predicted BTEX plume reaches its maximum extent (approximately 115 feet downgradient from the observed plume front) within 40 years. After reaching that extent, model Decay-50 suggests that the combination of source reduction and natural attenuation results in the disappearance of the plume within the next 5 years.

As with Alternative 1, institutional controls and LTM would be required. LTM wells would be the same locations indicated in the previous section. Groundwater monitoring would also follow the same schedule.

6.4 EVALUATION OF ALTERNATIVES

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

6.4.1 Alternative 1 - Intrinsic Remediation and Institutional Controls with Long-Term Monitoring

6.4.1.1 Effectiveness

Section 5 of this document presents the results of the Bioplume II modeling completed to support the intrinsic remediation alternative at FPTA3. Three models (Decay-0, Decay-4, and Decay-50) were used to illustrate the range of potential future BTEX concentration distributions at the site. Decay-0 predicted BTEX migration and degradation based on conditions that produced the calibrated model. Decay-4 assumed a geometric decrease in source concentration of 4 percent per year. Model Decay-50 incorporated the effects of BTEX loading rates resulting from a source reduction by groundwater extraction. Analytical models for chlorinated solvent distributions were also discussed in Section 5.

Model results predicted that natural attenuation mechanisms will significantly limit contaminant migration and reduce contaminant mass and toxicity. Benzene and vinyl chloride concentrations should not exceed state and federal criteria at downgradient wells. The Bioplume II model is based upon numerous conservative assumptions. Groundwater monitoring will ensure the protectiveness of this alternative. While this alternative would not cease to be protective if the benzene or chlorinated solvent plumes were intercepted

by the furthest downgradient 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 will be required to ensure that shallow groundwater will not be pumped or removed for potable use within a radius of approximately 500 feet from 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 POC wells.

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 will 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 FPTA3 using field data and the Bioplume II model demonstrated that the BTEX plume migration will be limited and the extent eventually reduced.

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 100 years under Alternative 1. Furthermore, it is assumed that sampling will be performed every other year for 20 years and every fifth year thereafter. Two additional groundwater sampling rounds at 105 and 110 years will be required to demonstrate that intrinsic remediation has uniformly reduced 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 LTM and POC wells and groundwater monitoring are standard procedures. Long-term management efforts will be required to ensure proper sampling procedures are followed. 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 likely that over the next 110 years that this site may change ownership several times. Perpetual deed restrictions would be required to limit land and groundwater uses. Regulators and the public will have to be informed of the benefits and limitations of the intrinsic remediation option. Educational programs are not difficult to implement, and 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. Costing worksheets and calculations are included in Appendix E. Capital costs are limited to the construction of eight new stainless steel wells. Included in the $191,000 total present worth cost estimate for Alternative 1 are the costs of maintaining institutional controls and long-term groundwater monitoring for a total of 30 years.

TABLE 6.3
ALTERNATIVE 1 - COST ESTIMATE
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Capital Costs	Cost
Design/Construct 6 Monitoring Wells	$16,800
Operation, Maintenance and Monitoring Costs (per Sampling Event)	**Cost per Event**
Conduct Groundwater Sampling at 13 wells (per event) (every second year for first 20 years, every fifth year for next 10 years)	$9,500
Maintain Institutional Controls/Public Education (30 years)	$5,000
Project Management and Reporting (30 years)	$8,300
Present Worth of Alternative 1 [a/]	**$191,000**

[a/] Based on an annual inflation factor of 5 percent.

6.4.2 Alternative 2 - Groundwater Extraction, Intrinsic Remediation and Institutional Controls with Long-Term Groundwater Monitoring

6.4.2.1 Effectiveness

The effectiveness of the intrinsic remediation, institutional controls, and LTM components of this alternative have been described under Alternative 1. Groundwater extraction and treatment is an established technology for reducing source contamination and controlling plume migration. The goal of groundwater extraction would be to target the removal of BTEX and chlorinated solvents from the source area so that intrinsic remediation of contaminants beyond the source area could proceed without the introduction of additional contaminant concentrations. The model Decay-50 suggests that reduction of the source would expedite the decrease in the size of the BTEX plume.

Extracted groundwater would likely require treatment prior to discharge. Air stripping is an effective technology for the removal of volatile constituents from water. Activated carbon treatment was not considered a viable option, because activated carbon is not effective at retaining vinyl chloride. It is likely that air emissions controls would not be required for the air stripper offgas due to dilute levels. A surface water discharge or reinjection permit would likely be required for the treated groundwater.

A pilot-scale SVE system would be used to remove fuel hydrocarbons from the vadose zone. SVE would reduce soil gas contaminant levels, and would gradually decrease the amount of residual LNAPL in the source area by volatilization. A pilot-scale test using a single extraction well would indicate whether suitable extraction rates can be achieved at FPTA3.

Alternative 2 should provide reliable, continuous protection with little risk from temporary system failures. This alternative also complies with the program goals because intrinsic remediation remains the predominant remediation method for the site. However, this remedial alternative will result in the generation of drill cuttings, groundwater, and other wastes requiring treatment and/or disposal.

It is assumed for cost comparison purposes that dissolved benzene and/or vinyl chloride concentrations will exceed state and federal criteria throughout the plume for approximately 30 years under Alternative 2. Furthermore, it is assumed that sampling will be performed every other year at eight new wells for 20 years and every fifth year thereafter. Two additional groundwater sampling rounds at 35 and 40 years will be required to demonstrate that intrinsic remediation has uniformly reduced all BTEX and chlorinated solvent concentrations to levels below regulatory criteria. Costs for installation of the groundwater extraction system are based on the conceptual design discussed in Section 6.3.2.

6.4.2.2 Implementability

Installing and operating a groundwater extraction system to reduce source area dissolved BTEX and chlorinated solvent concentrations in groundwater at FPTA3 will present additional implementability concerns. Installation involves standard drilling practices for wells, downhole pump installation, limited shallow excavation for piping connections and electrical conduit, and construction of an air stripper. Groundwater extraction pumps and air stripping equipment is readily available, and the technology used to construct the system is proven and reliable. Implementation of the optional soil vapor extraction test system would require standard drilling and limited shallow excavation for piping, manifold connections, and electrical conduit. Vapor extraction pumps are readily available. The technical and administrative implementability concerns associated with the intrinsic remediation and LTM component of this remedial alternative are similar to those discussed in Alternative 1. Installation and operation of a groundwater extraction system (and the optional soil vapor extraction system) would require an increased commitment of man-hours and other resources to maintain and monitor the system.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. Costing worksheets and calculations are included in Appendix E. The total present worth cost of Alternative 2 is $396,000. The cost of Alternative 2 is increased from the costs of Alternative 1 by the addition of groundwater extraction and treatment. It is assumed that the groundwater extraction system will operate for 8 years after installation. If the cost for the optional soil vapor extraction test is included, the total present worth cost of Alternative 2 is $420,000. LTM would continue for 30 years to ensure that intrinsic remediation is reducing BTEX and chlorinated solvent concentrations below regulatory criteria throughout the plume and to verify that contamination does not reach the downgradient monitoring wells.

TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Capital Costs	Cost
Design/Construct 6 Monitoring Wells	$16,800
Design/Construct Groundwater Extraction System, Including 2 Extraction Wells, Submersible Pumps, Piping, and Air Stripper Treatment System	$69,200
Design/Construct/Operate/ Pilot-Scale Soil Vapor Extraction System (including end of test report) (Optional)	$25,400
Operation, Maintenance and Monitoring Costs	**Cost per annum or event**
Operate and Maintain Groundwater Extraction System (8 years, annual cost)	$17,600
Groundwater Extraction Annual Report (annual cost)	$3,830
Conduct Groundwater Sampling at 13 wells (cost per event) (every second year for first 20 years, every fifth year for next 10 years)	$9,500
Maintain Institutional Controls/Public Education (cost per event) (30 years)	$5,000
LTM Project Management and Reporting (cost per event) (30 years)	$8,300
Present Worth of Alternative 2 [a]	**$396,000**
Present Worth of Alternative 2 (with optional SVE pilot test)[a]	**$420,000**

[a] Based on an annual inflation factor of 5 percent.

6.5 RECOMMENDED REMEDIAL APPROACH

Two remedial alternatives have been evaluated for remediation of the shallow groundwater at FPTA3. Components of the alternatives evaluated include groundwater extraction, soil vapor extraction, intrinsic remediation with LTM, and institutional controls. Table 6.5 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria. On the basis of this evaluation, Parsons ES

TABLE 6.5
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUNDWATER REMEDIATION
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			
- Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Contaminant mass, volume, and toxicity will be significantly reduced and plume migration should be halted. MCLs for BTEX and chlorinated solvents not likely to be exceeded at POC wells.	Readily implementable. Long-term management, groundwater use controls and monitoring required for an estimated 100 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.	$191,000
Alternative 2			
- Groundwater Extraction - Soil Vapor Extraction Pilot Test - Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of a groundwater extraction system. An optional soil vapor extraction pilot test is included to address residual LNAPL in soil. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternative 1. Less likely that MCLs will be exceeded at POC.	Readily implementable. Installation of groundwater extraction system (and optional soil vapor extraction pilot test system) should present no problems. Groundwater extraction estimated to continue for 8 years. Long-term management, groundwater controls, and monitoring required for an estimated 40 years. If MCLs are exceeded at POC, additional remedial work may be required.	$420,000

recommends Alternative 1 as achieving the best combination of risk reduction and cost effectiveness.

Both alternatives make maximum use of intrinsic remediation mechanisms to reduce plume migration and toxicity. Alternative 2 would provide additional protection against further plume migration, but would still rely on intrinsic remediation mechanisms to reduce plume toxicity downgradient of the groundwater extraction system. Implementation of Alternative 2 would decrease the time frame for remediation, but would require a greater capital expenditure.

Both of the remedial alternatives are implementable, and both alternatives effectively reduce potential hydrocarbon migration and toxicity. Both 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, neither alternative completes the groundwater restoration in a short time frame. Implementation of either alternative will require land use and groundwater use controls to be enforced for at least 40 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 two remedial alternatives was cost. It is the opinion of Parsons ES that the additional cost of Alternative 2 over Alternative 1 is not justified by the minimal additional protection it provides. Therefore, Alternative 1 is recommended.

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for FPTA3 at Offutt AFB (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, and evaluate the need for additional remediation. This plan was developed using groundwater monitoring data collected between November 1994 and June 1998 (Appendix G).

The LTM plan consists of identifying the locations of LTM wells and developing a groundwater sampling and analysis strategy to demonstrate attainment with site-specific remediation goals and to verify the predictions of the Bioplume II model developed for FPTA3. 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.

The LTM plan for FPTA3 presented in this section describes a monitoring scheme for the next 30 years for planning and budgeting purposes. It should be noted that this plan was devised on the basis of currently available data; the LTM program should be reassessed and revised as appropriate as new data are obtained. If LTM results indicate that the dissolved contaminant plume is stable or receding, then the frequency of LTM could conceivably be reduced, or LTM could be discontinued altogether and the site placed in an inactive (but managed) status as long as institutional controls on land and groundwater use are maintained. If land use changes (e.g., if a regularly occupied building is constructed at the site or if significant excavation in the contaminated area is performed), then further sampling should be performed at that time to assess groundwater quality and risks posed to potential receptors. Conversely, if the data collected at any time during the LTM period indicate the need for additional remedial activities or for installation of additional LTM wells (e.g., further downgradient), then the LTM program should be adjusted accordingly.

7.2 MONITORING NETWORK

Groundwater elevation data collected in November 1994, June 1996, and June 1998 (Appendix G) suggests a variable groundwater flow direction in the shallow aquifer. An

easterly groundwater flow direction was inferred for November 1994, and a northerly groundwater flow direction was inferred for June 1996 and June 1998. The distribution of dissolved contaminants in groundwater suggests that the easterly flow direction is dominant; however, the LTM plan presented in this section is structured to detect both easterly and northerly migration.

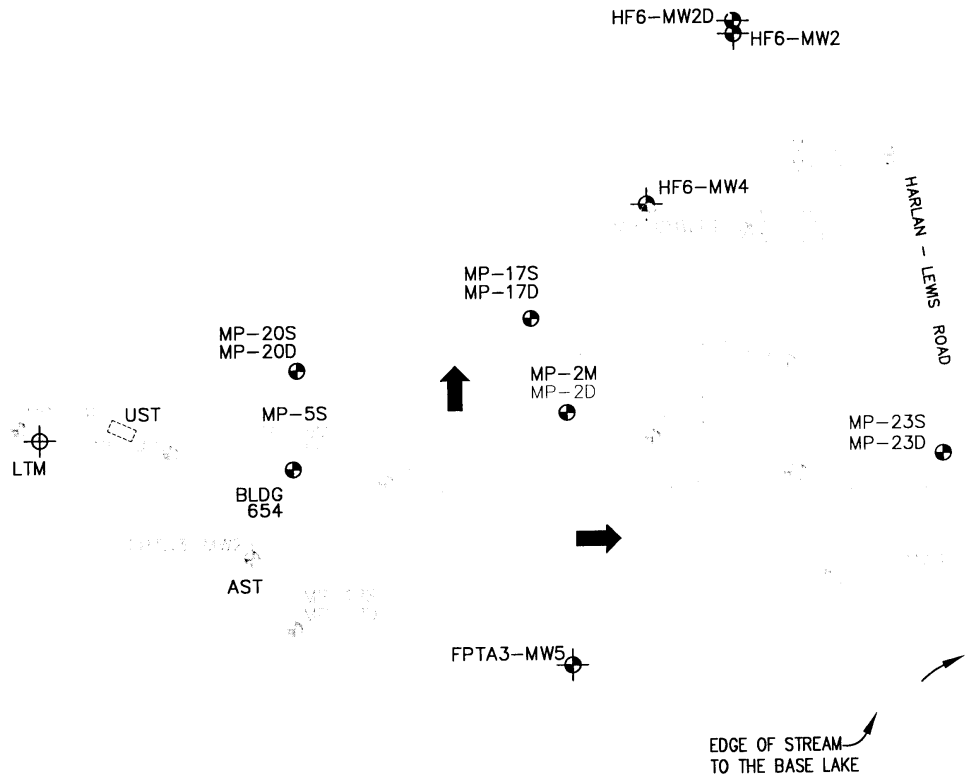
The locations of recommended LTM wells are shown on Figure 7.1. Sampling of two upgradient to cross-gradient wells is recommended to monitor for changes in background groundwater quality that can provide an indication of changing conditions that could affect natural attenuation. These wells include FPTA3-MW5 and a proposed new well to be installed near MP-24D. The new LTM well should be constructed of PVC and have a 10-foot screen, with approximately 8 feet below the average water table. Sampling of two monitoring points within the core of the existing contaminant plume is recommended to monitor changes in maximum contaminant concentrations over time. These points include MP-5S and MP-2M.

Sampling of nine wells/points near the northern and eastern perimeter of the dissolved plume is recommended to facilitate evaluation of plume dynamics (i.e., is the plume advancing, steady-state, or receding?). These wells/points include MP20S/20D, MP17S/17D, HF6-MW4, HF6-MW2/MW2D, and MP23S/23D. Sampling of wells/points screened at the top of the aquifer and in deeper zones will ensure that any downgradient plume migration that occurs will be detected. Wells HF6-MW2D and HF6-MW2 should only be sampled once to confirm the absence of contamination at these locations. If significant contamination is not detected in these wells, then additional sampling is not recommended.

The usable lifespan of the existing monitoring wells/points included in the LTM plan may be less than the desired duration of LTM. Therefore, if a sampling station becomes unusable or yield poor-quality data due to clogging, silt build up, etc., it should be replaced with a new 2-inch-diameter, PVC monitoring well. The optimal screened interval for each new well should be determined based on all available LTM data. For costing purposes, it is assumed that a total of five new wells, in addition to the new upgradient well described above, are installed by calendar year 2009.

7.3 SAMPLING FREQUENCY

To ensure that sufficient contaminant removal is occurring at FPTA3 to meet site-specific remediation goals, the long-term groundwater monitoring plan must include a sampling and analysis plan. As the rate of groundwater flow is very low at FPTA3, it is recommended that groundwater samples be collected and analyzed every second year for 20 years to verify that natural processes are effectively reducing contaminant mass and mobility. For cost purposes, groundwater sampling was assumed to occur every fifth year from years 20 to 30. 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 remediation concentration goals for BTEX and chlorinated solvents that are protective of human health and the environment.



LEGEND

- MONITORING WELL
- MONITORING POINT
- RECOMMENDED ADDITIONAL LONG–TERM MONITORING WELL
- DIRT ROADS
- PAVED ROADS
- FENCE
- DRAIN PIPE
- APPROXIMATE DIRECTION OF GROUNDWATER FLOW

N

0 25 50 100 200
FEET

FIGURE 7.1

LOCATIONS OF LONG-TERM MONITORING WELLS

Fire Protection Training Area 3
Intrinsic Remediation TS
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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7.4 ANALYTICAL PROTOCOL

All LTM wells should 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 Table 7.1. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating the LTM program.

TABLE 7.1
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AFB, NEBRASKA

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 or Hach 25140-25	Filter if turbid	May indicate an anaerobic degradation process due to the depletion of oxygen, nitrate, and manganese	Each sampling event	Collect 100 mL of water in a glass container; for Method A3500-FeD, acidify with hydrochloric acid per method	Field
Temperature	E170.1, direct-reading meter	Measure at well-head	Purging adequacy; metabolism rates for microorganisms depend on temperature	Each sampling event	Measure at well-head using a flow-through cell	Field
Dissolved Oxygen	Dissolved oxygen meter	Measure at well-head; refer to Method A4500 for a comparable laboratory procedure	Purging adequacy; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling event	Measure at well-head using a flow-through cell	Field
pH	E150.1/SW9040, direct-reading meter	Measure at well-head	Purging adequacy; aerobic and anaerobic processes are pH-sensitive	Each sampling event	Measure at well-head using a flow-through cell	Field
Conductivity	E120.1/SW9050, direct-reading meter	Measure at well-head	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Each sampling event	Collect 100–250 mL of water in a glass or plastic container or measure at wellhead using flow-through cell	Field
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	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach method)

TABLE 7.1 (Concluded)
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AFB, NEBRASKA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Oxidation-Reduction Potential (ORP)	A2580 B, direct-reading meter	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	Each sampling event	Measure at well-head using a flow-through cell	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 National Risk Management Research Laboratory	The presence of methane indicates the presence of sufficiently reducing conditons for reductive dehalogenation to occur	Each sampling event	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
Volatile Organics	GS/MS method SW8260B	Handbook method	Measured for regulatory compliance	Each sampling event	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	Fixed-base

[a/] Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation / Feasibility Study (RI/FS)."

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of intrinsic remediation (natural attenuation) for remediation of fuel-hydrocarbon-contaminated groundwater in the vicinity of FPTA3 at Offutt AFB, Nebraska. 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 fuel hydrocarbon compounds dissolved in groundwater. To collect the data necessary for the intrinsic remediation demonstration, Parsons ES researchers collected soil and groundwater samples from the site. Physical and chemical data collected under this program were supplemented (where necessary) with data collected during previous site characterization events.

Comparison of BTEX, chlorinated solvent, electron acceptor, and biodegradation byproduct isopleth maps for FPTA3 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 the anaerobic processes of 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, the ratio of source chlorinated solvents to their anaerobic decay products suggests that chlorinated solvents in the groundwater are being degraded through reductive dechlorination and/or cometabolism.

Site-specific geologic, hydrologic, and laboratory analytical data 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. Extensive 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 sediments 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 worst-case scenarios given the other modeling assumptions regarding source removal.

For one simulation (model Decay-0), 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 250 feet beyond the November 1994 plume front before BTEX migration halts and the plume stabilizes as a result of natural attenuation. Model Decay-4 assumed that source of groundwater contamination declined at a geometric

rate of 4 percent per year. Under this scenario, the plume would migrate approximately 190 feet beyond the November 1994 plume front. This model also shows a gradual shrinking of plume dimensions and contaminant concentrations. Model Decay-50 assumed a contaminant source reduction through groundwater extraction and/or source area reduction. The model used a geometric rate of decay of 50 percent per year for 8 years. Results of this model suggest that the plume will migrate approximately 115 feet beyond the November 1994 plume front before natural attenuation mechanisms effectively halt migration and shrink the plume. Model Decay-50 predicts that the BTEX plume will completely attenuate in 45 years.

An analytical model was used to simulate the fate and transport of chlorinated solvents dissolved in the groundwater. The model predicted that over the next 50 years the chlorinated solvent plume will migrate approximately 125 feet beyond the November 1994 plume front. After 50 years, the model predicts that the chlorinated solvent plume will begin to recede.

The results of this study suggest that natural attenuation of BTEX and chlorinated solvent compounds is occurring at FPTA3 to the extent that the dissolved concentrations of these compounds in groundwater should be reduced to levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected (i.e., the potential contaminant migration pathway will not be complete for any of the potential receptors described in Section 6.2). Actual dissolved BTEX degradation rates observed during LTM at the site will probably be less than predicted by model Decay-50 and greater than predicted by model Decay-0. Results of model Decay-4 were selected as most representative of expected conditions. This will result in a shorter plume migration distance than predicted by model Decay-0. Given the rates of BTEX and chlorinated solvent plume migration and degradation predicted by the models, and that there are no identifiable downgradient receptors within the plume extent predicted by model Decay-0, Parsons ES is recommending natural attenuation, institutional controls, and LTM as the remedial option for BTEX-impacted groundwater at the site. 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. Because anaerobic conditions at the site are effectively limiting the migration of chlorinated solvents, remedial actions that induce aerobic conditions (e.g., air sparging) are not recommended.

To ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, it is recommended that groundwater be sampled biennially (every other year) for 20 years to monitor the long-term migration and degradation of the dissolved BTEX and chlorinated solvent plumes. Biennial sampling should be sufficiently protective given the very low groundwater migration rate. The need for additional sampling and the appropriate sampling interval should be re-evaluated after 20 years, at a minimum. In addition to analyses used to verify the effectiveness of intrinsic remediation, the groundwater samples should be analyzed for BTEX and chlorinated solvents by United States Environmental Protection Agency (USEPA) Method SW8260B.

SECTION 9

REFERENCES

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Woodward-Clyde Consultants (W-C), 1992c, *Installation Restoration Program Remedial Investigations*. Prepared for Offutt Air Force Base, Nebraska. USAF Contract No. F25600-90-C0063.

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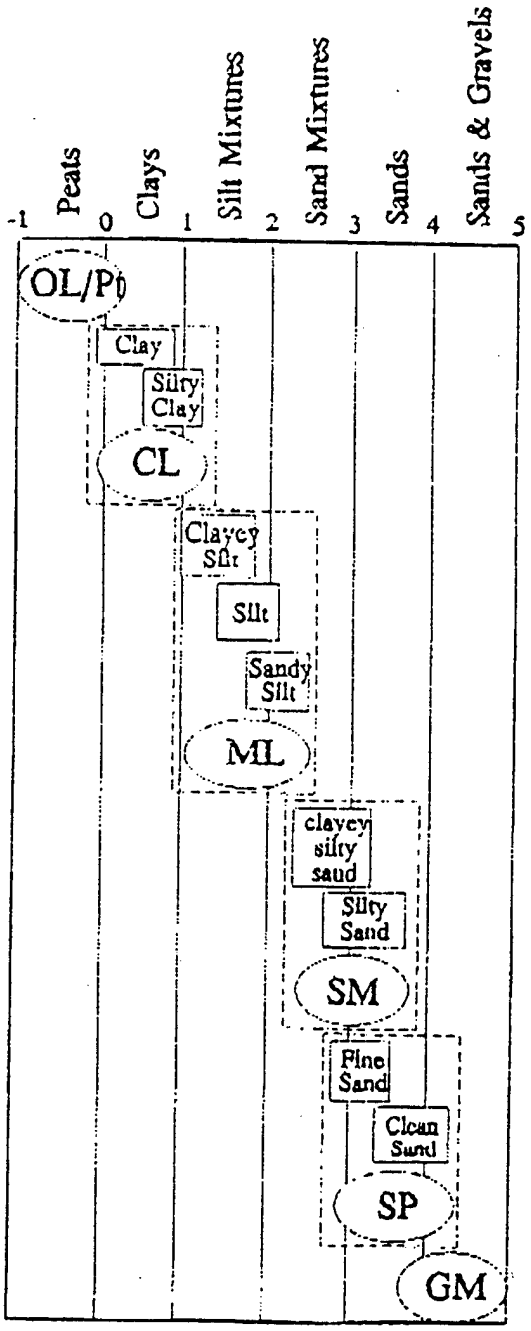
APPENDIX A

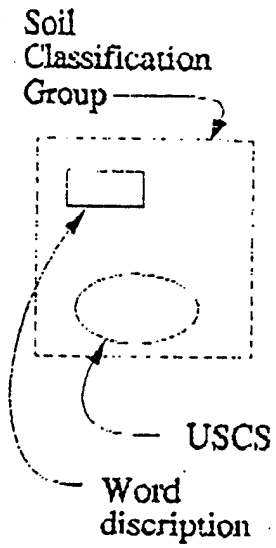
CONE PENETROMETER LOGS, BOREHOLE LOGS, MONITORING POINT INSTALLATION RECORDS, SURVEY RESULTS, AND SLUG TEST RESULTS

CPT based SOIL CLASSIFICATION



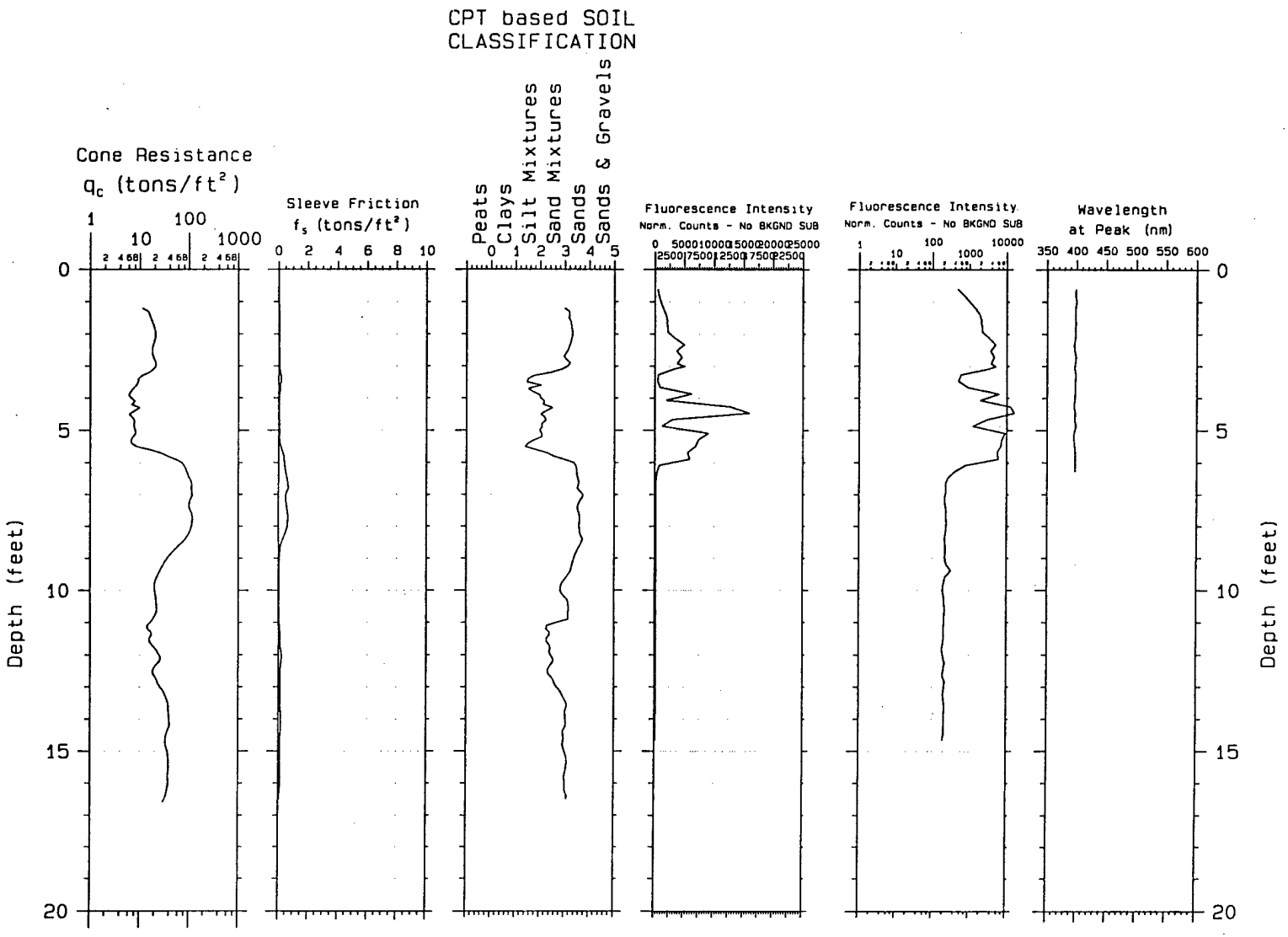
CPT soil classification number (SCN)

Key;



Equivalent Unified Soil Classification System (USCS) and word classification description zones on the Olsen CPT soil classification chart (Olsen, 1988)

Comparison between the Unified Soil Classification System (USCS) from soil samples and the CPT Soil Characterization Number (SCN)



CPT-2

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

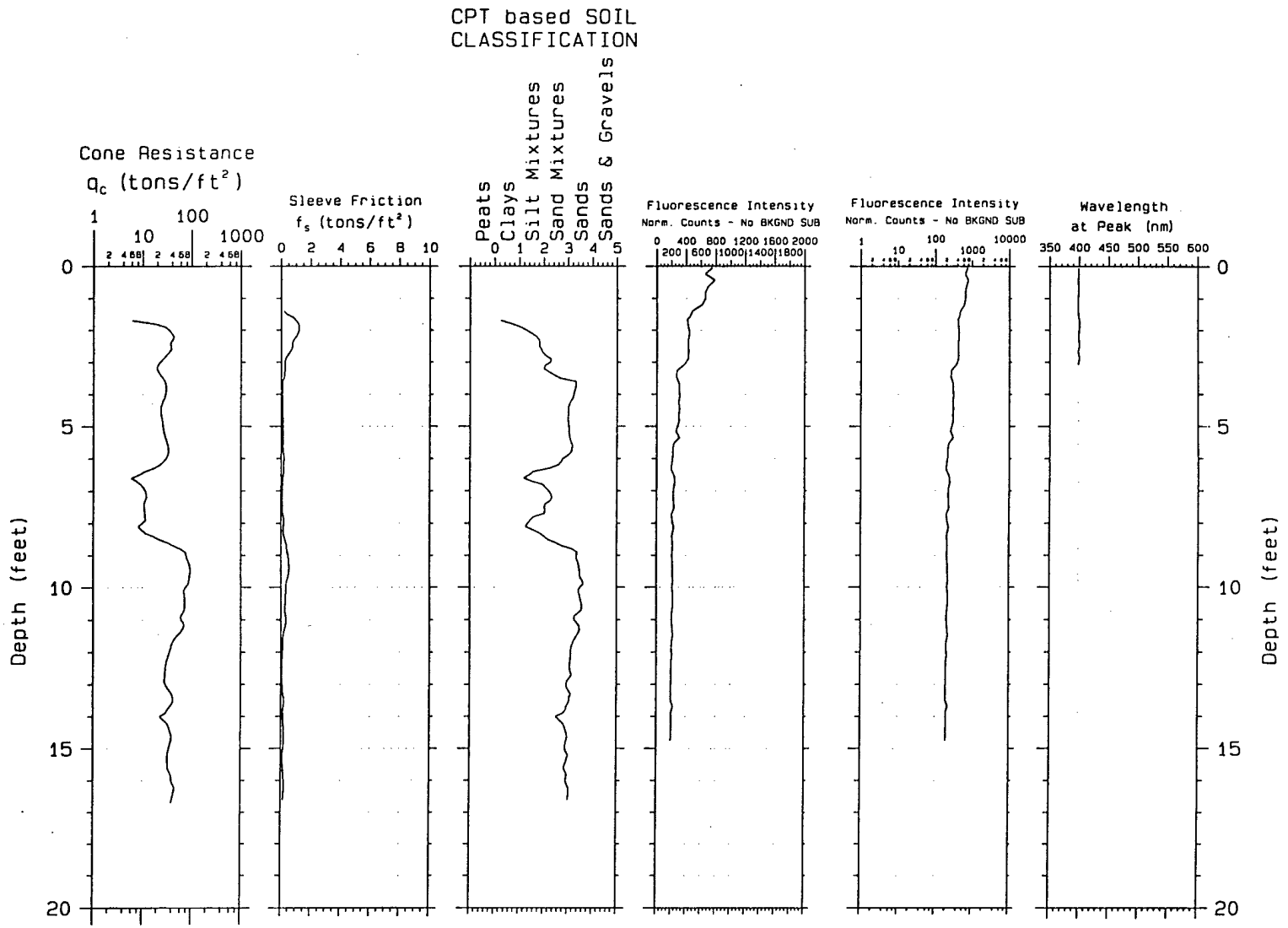
Site Characterization and Analysis Penetrometer System

Project; Offutt AFB

Probe Depth; 16.86

CPT; 40NEF02

Probing date; 09-27-1994



CPT-4

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

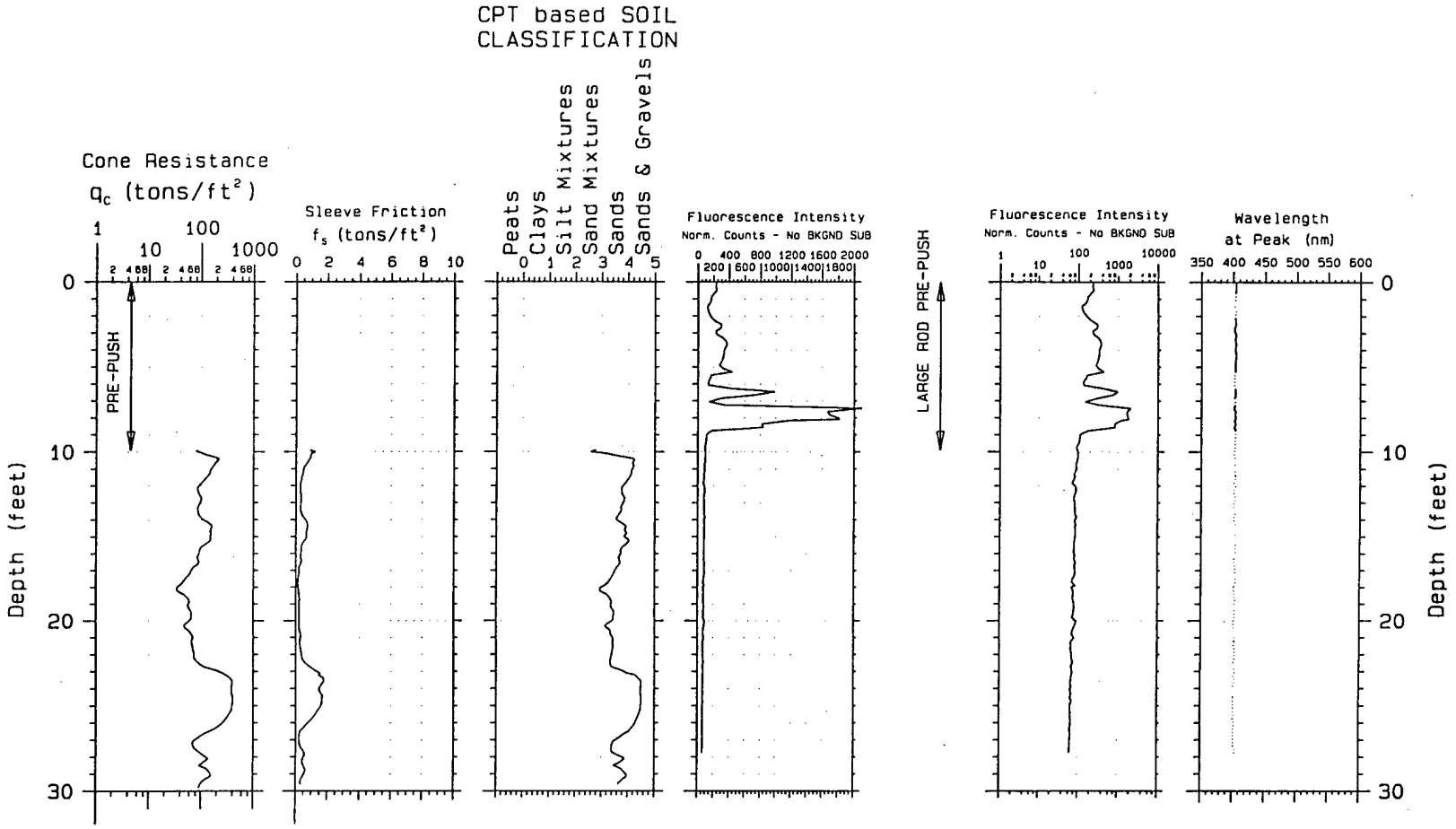
Site Characterization and Analysis Penetrometer System

Project; Offutt AFB

Probe Depth; 16.90

Probing date; 09-27-1994

CPT; 45NEFF4



CPT-5

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 29.91

Laser Induced fluorescence of POL via fiber optics

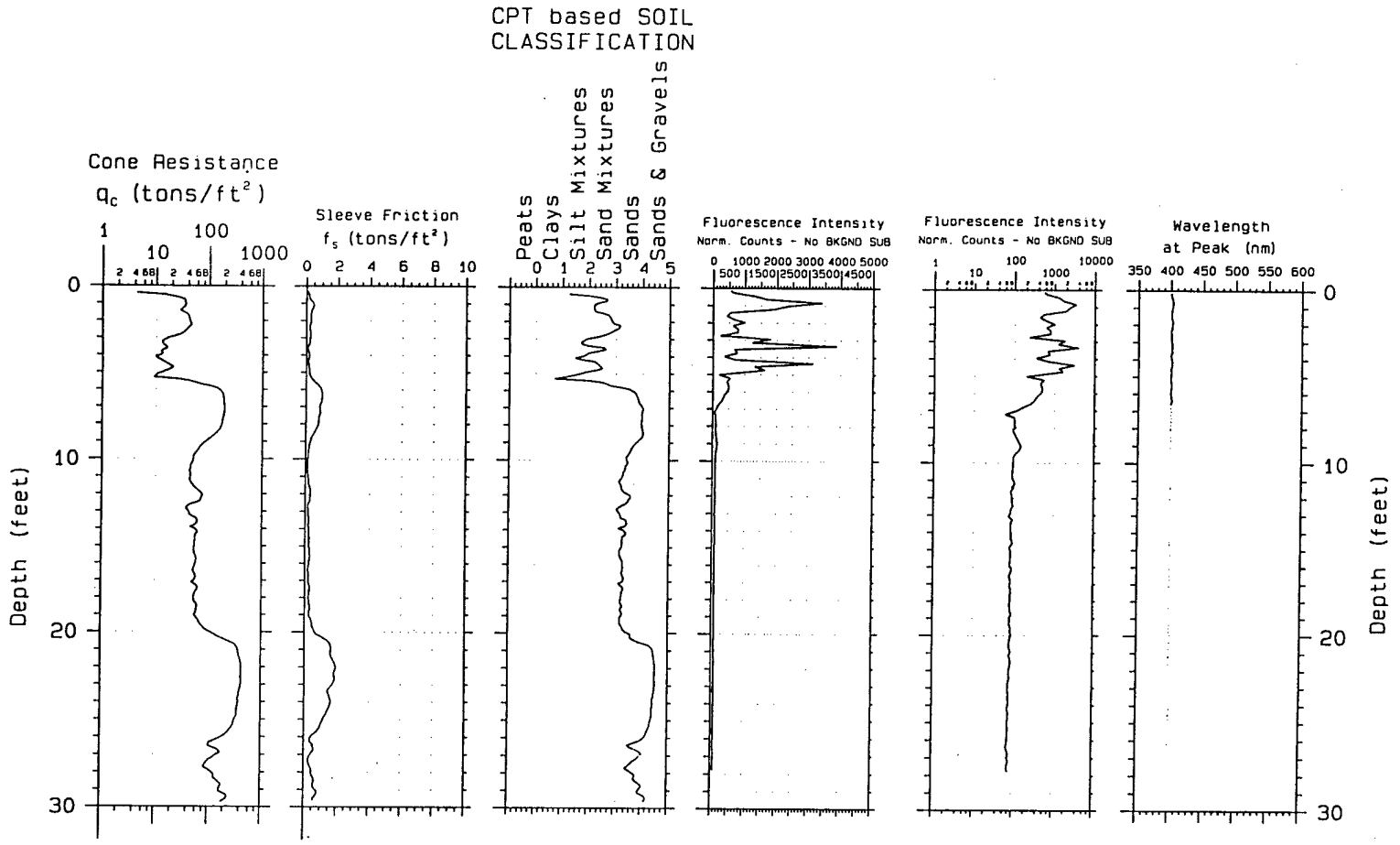
U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 52NEFF5

Probing date; 11-15-1994



CPT-7

Laser induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

Project; Offutt Airforce Base Fire Training Area

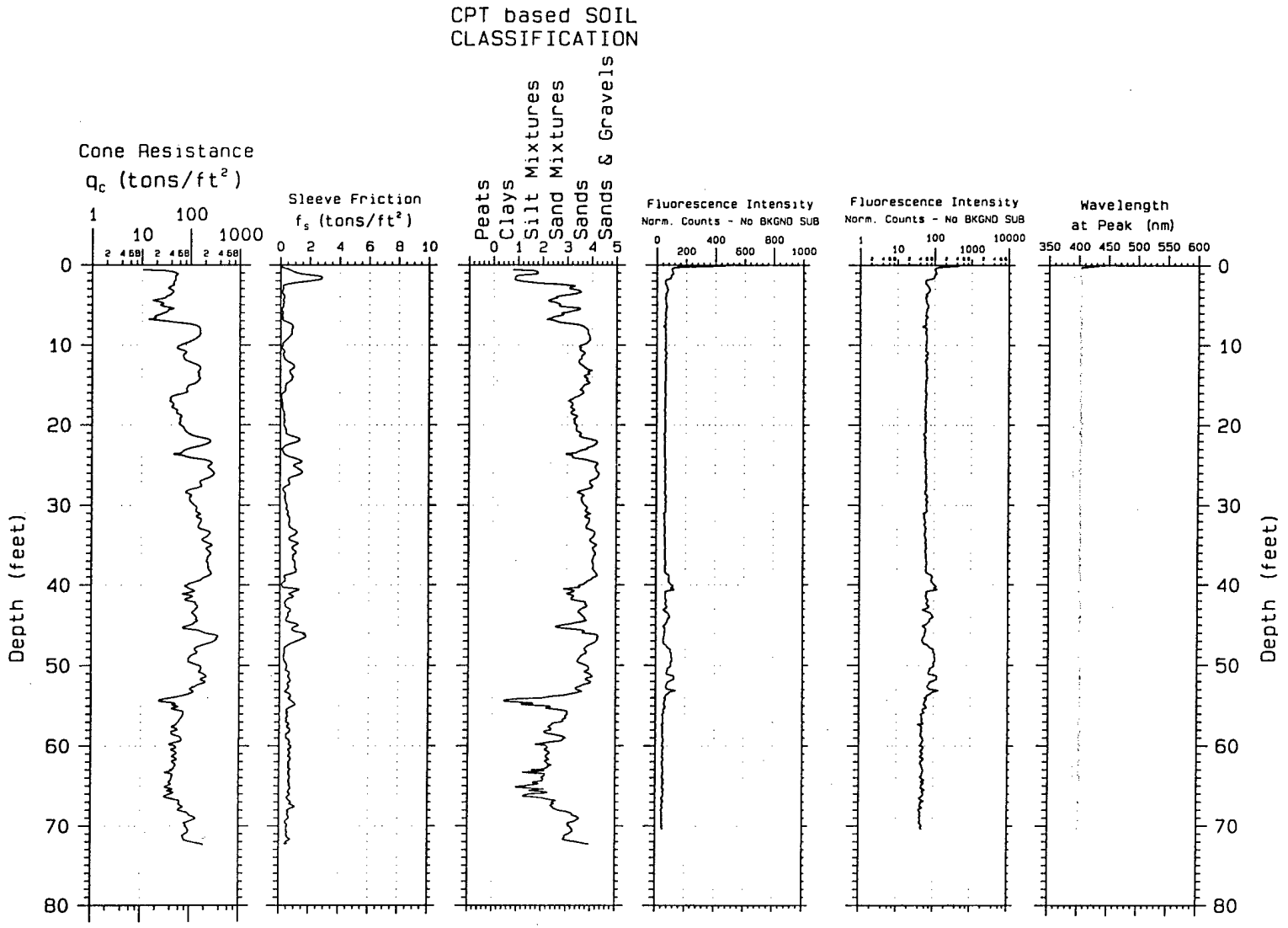
Probe Depth; 29.90

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 62NEFF7

Probing date; 11-15-1994



CPT-9

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 72.58

Laser Induced fluorescence of POL via fiber optics

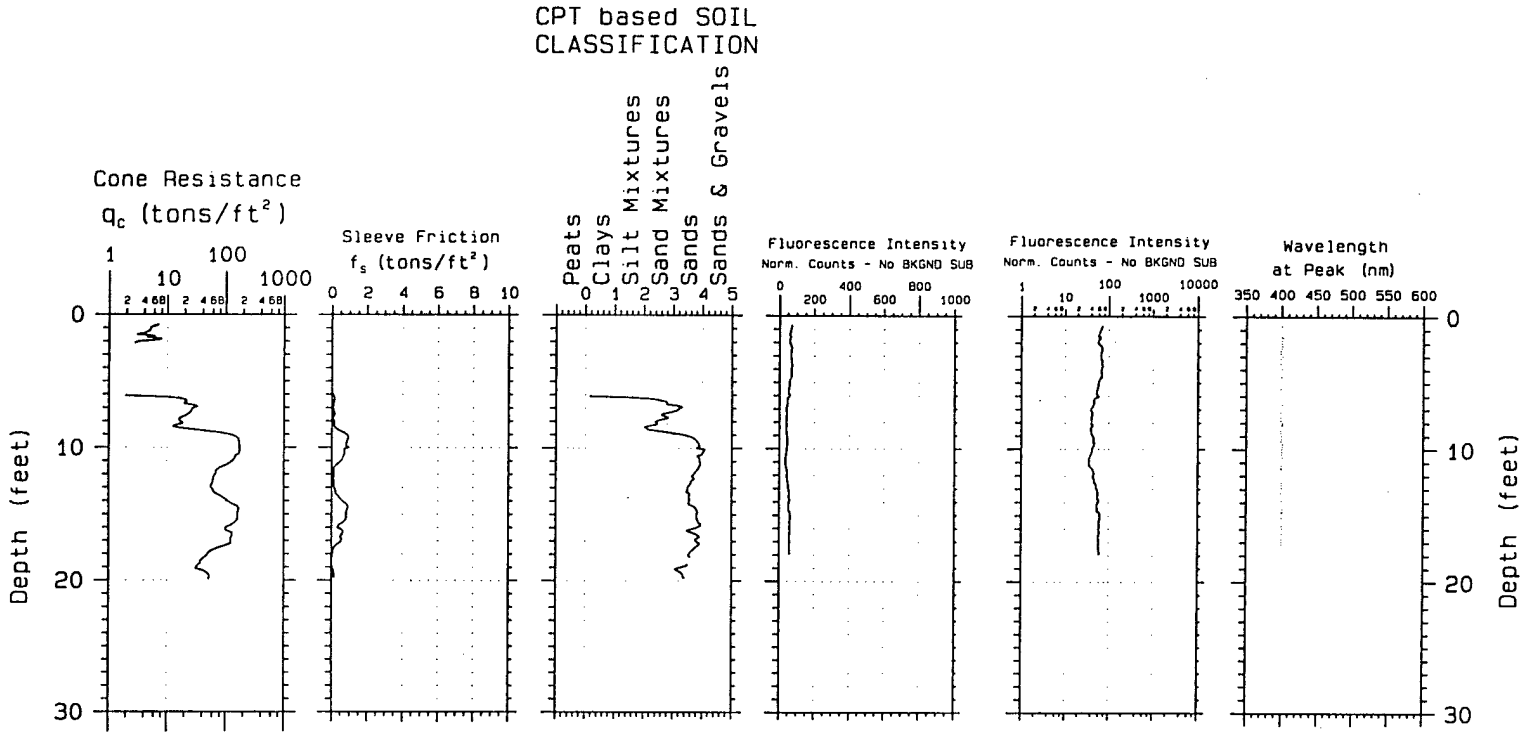
U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Probing date; 11-16-1994

CPT; 71NEFF9



CPT-11

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 20.08

Laser induced fluorescence of POL via fiber optics

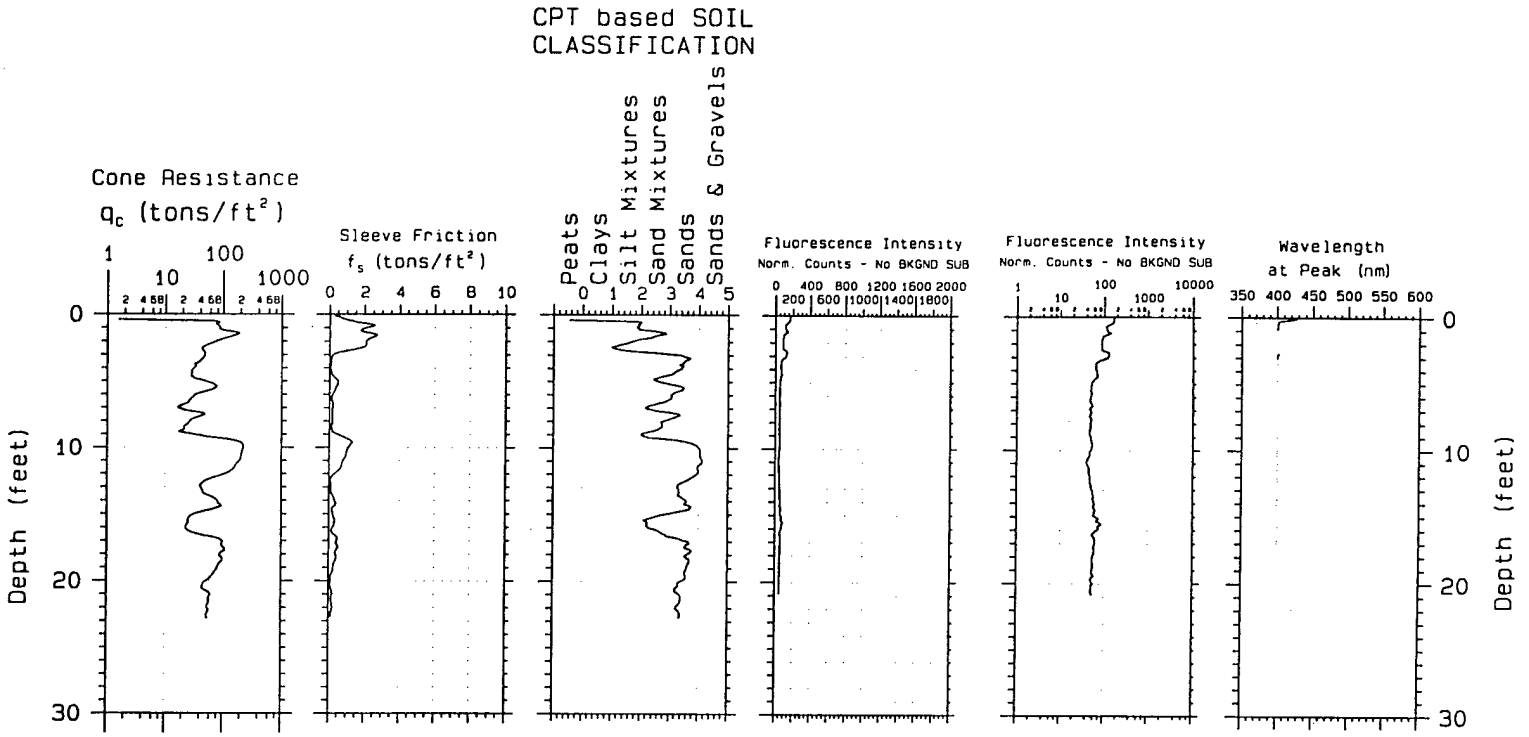
U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 74NEFF11

Probing date; 11-16-1994



CPT-13

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 22.98

Probing date; 11-16-1994

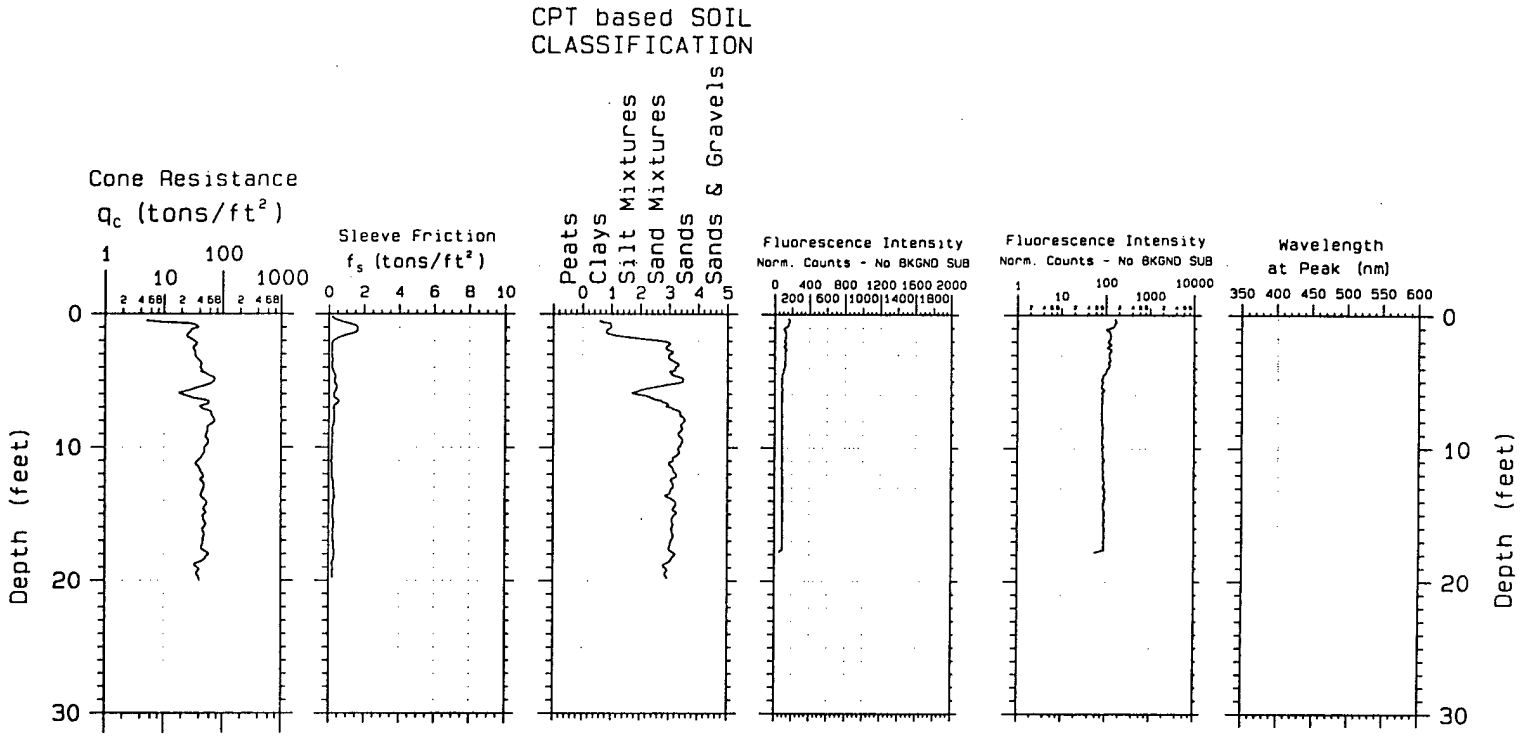
Laser Induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 78NEFF13



CPT-15

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 20.02

Laser induced fluorescence of POL via fiber optics

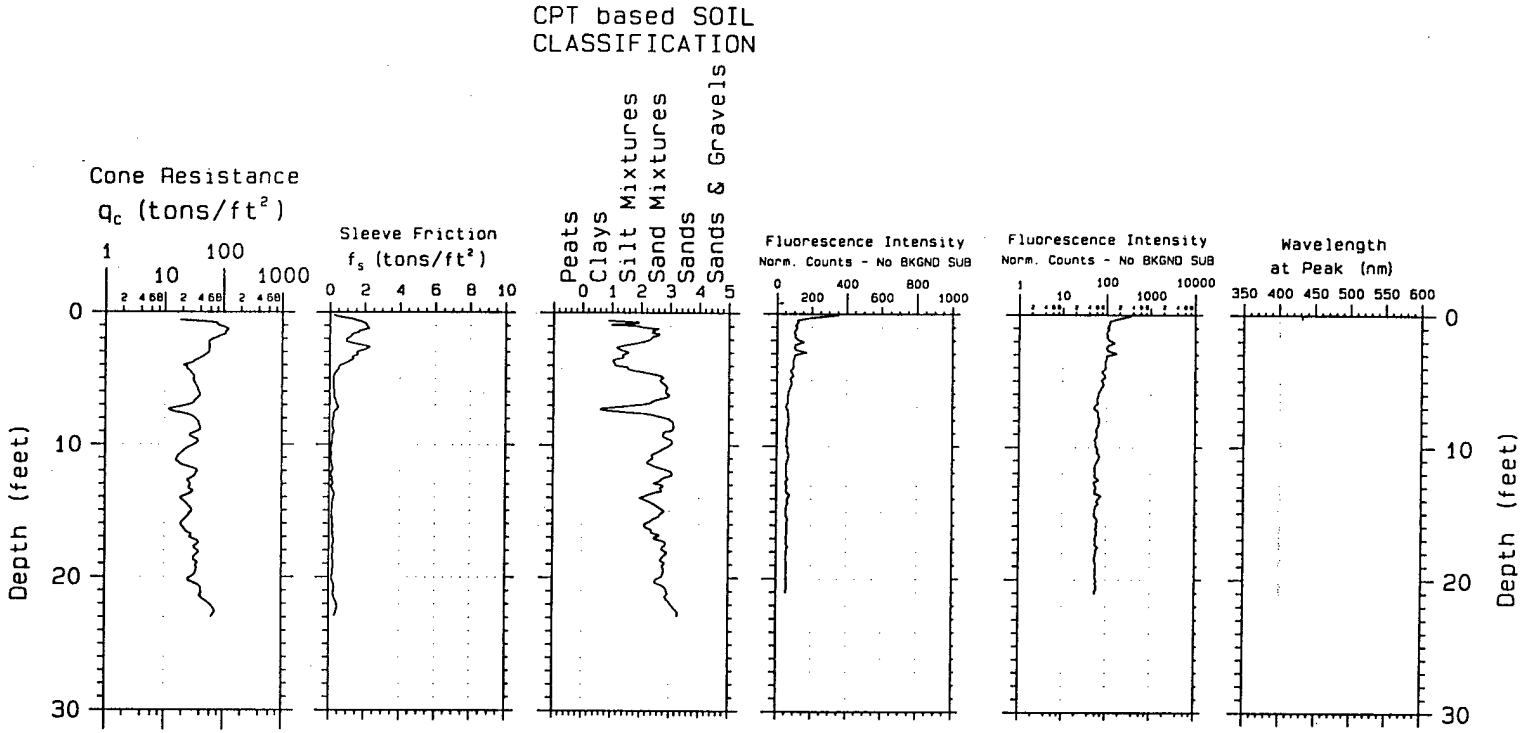
U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

CPT; 80NEFF15

Probing date; 11-17-1994



CPT-17

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 23.23

Laser Induced fluorescence of POL via fiber optics

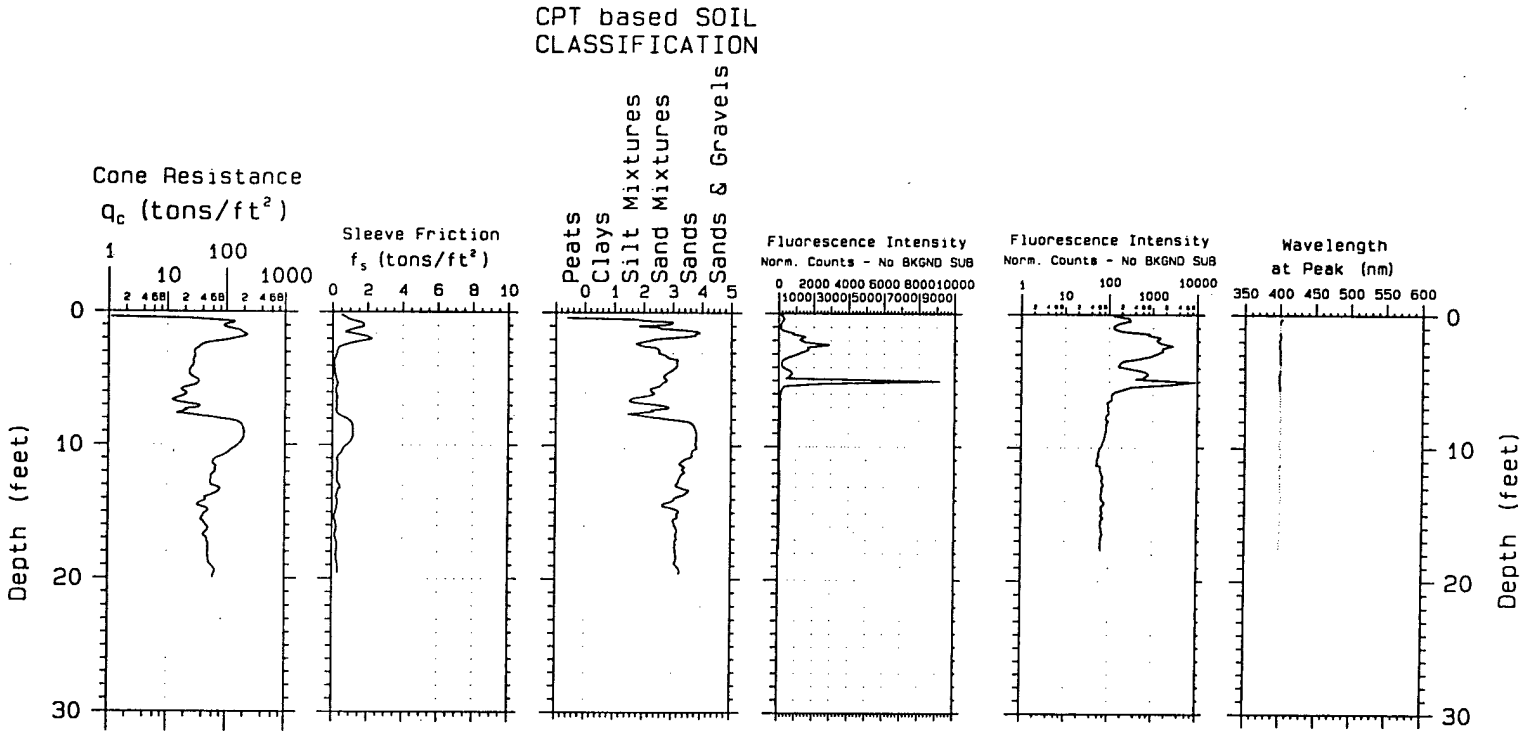
U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Probing date; 11-17-1994

CPT; 82NEFF17



CPT-19

Laser Induced fluorescence of POL via fiber optics

U.S.Army Engineer District Kansas City Geotechnical Branch

Project; Offutt Airforce Base Fire Training Area

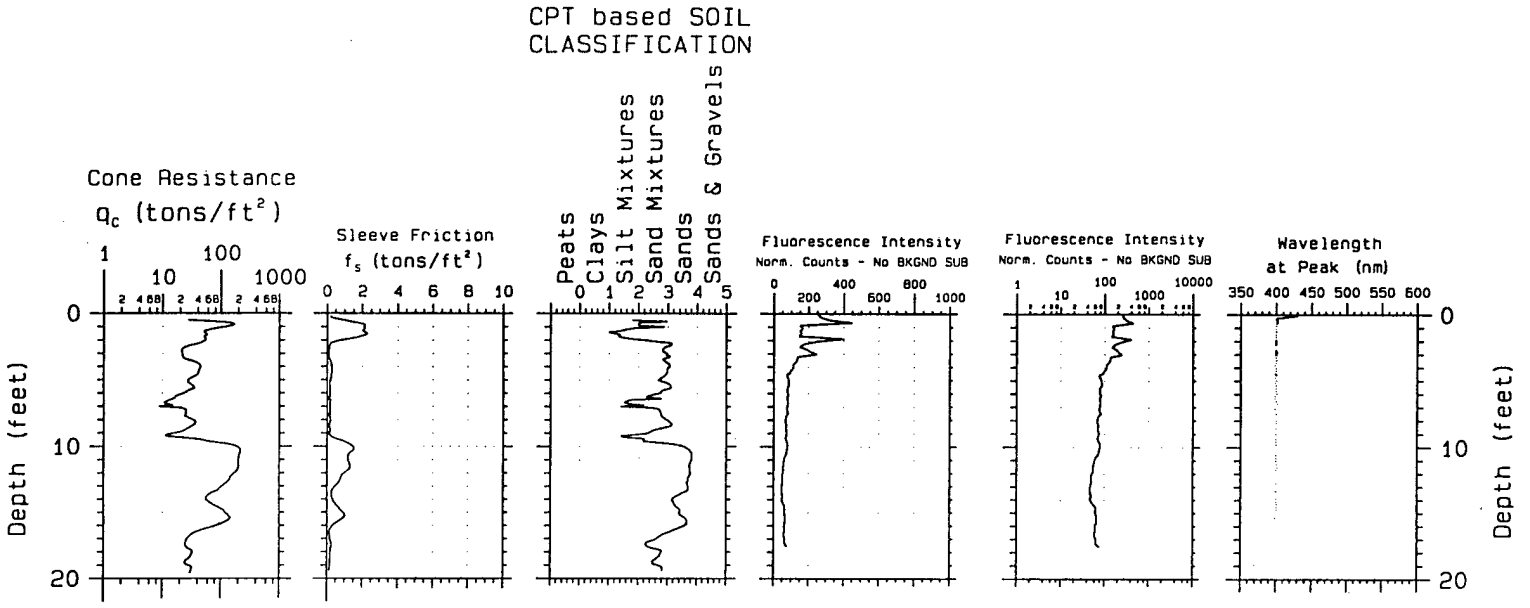
Probe Depth; 20.00

SCAPS

Site Characterization and Analysis Penetrometer System

Probing date; 11-17-1994

CPT; 86NEFF19



CPT-21

Laser Induced fluorescence of POL via fiber optics

Project; Offutt Airforce Base Fire Training Area

Probe Depth; 19.76

U.S.Army Engineer District Kansas City Geotechnical Branch

SCAPS

Site Characterization and Analysis Penetrometer System

Probing date; 11-17-1994

CPT; 90NEFF21

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FP743 · HP4-2M

JOB NUMBER 722450.24 — INSTALLATION DATE 11/15/94 — LOCATION FIRE TRAINING 3

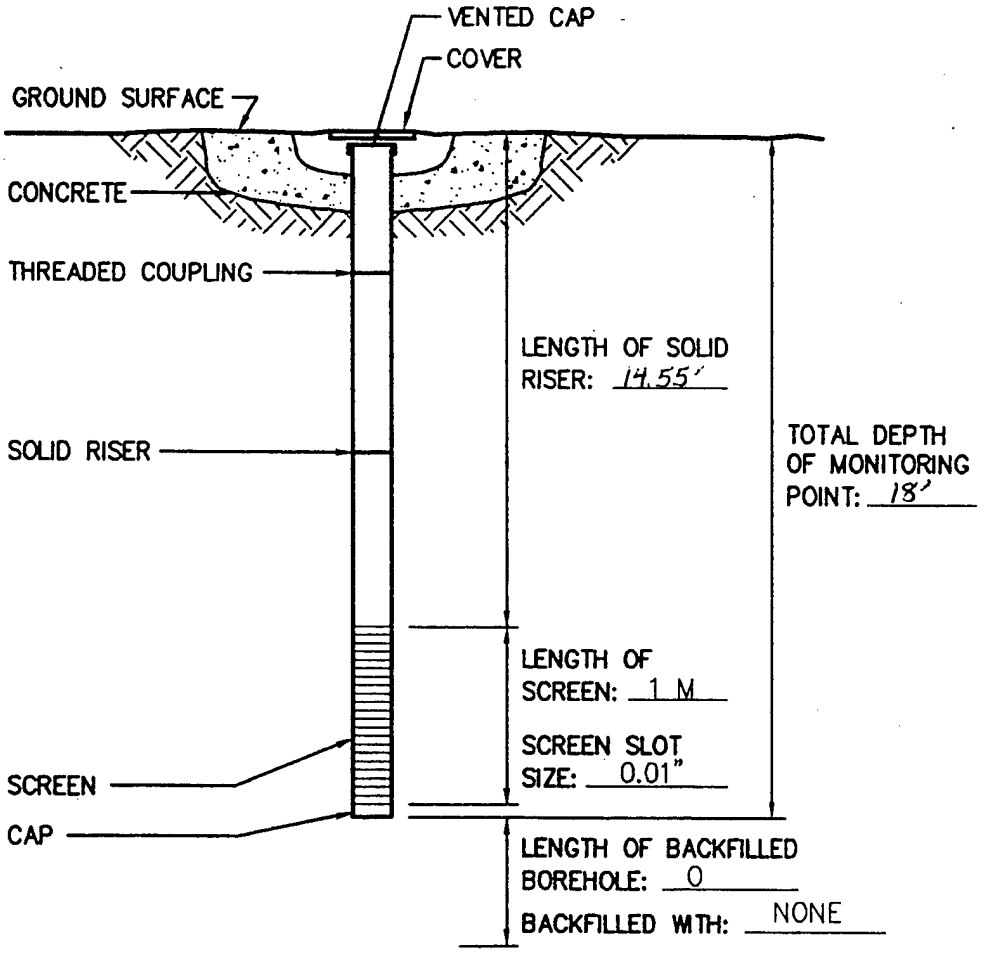
DATUM ELEVATION 961.91 — GROUND SURFACE ELEVATION 962.0

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-45

JOB NUMBER 722450.24 — INSTALLATION DATE 11/15/94 — LOCATION FIRE TRAINING 3

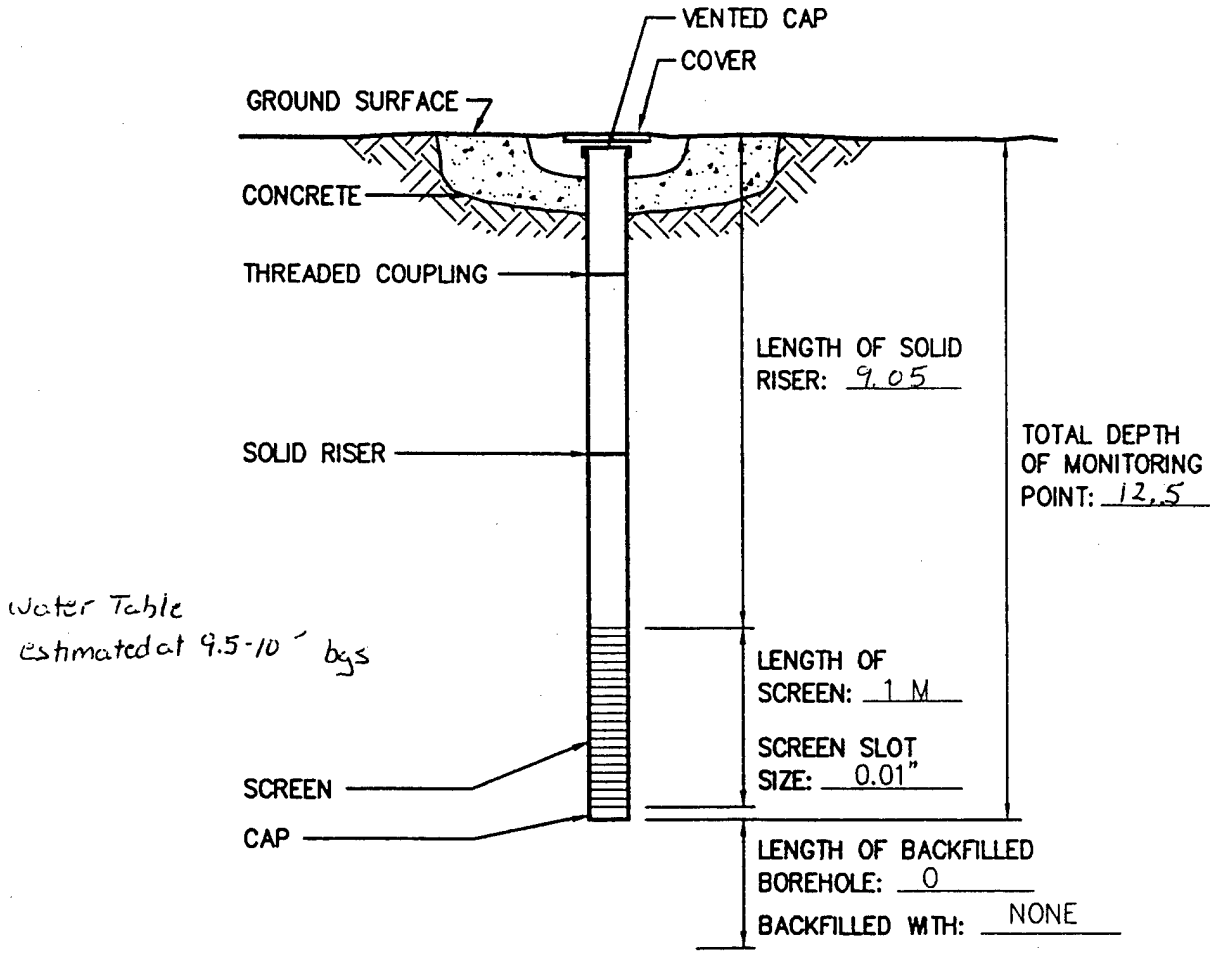
DATUM ELEVATION 964.81 — GROUND SURFACE ELEVATION ~~963.2~~ DTM 964.9

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

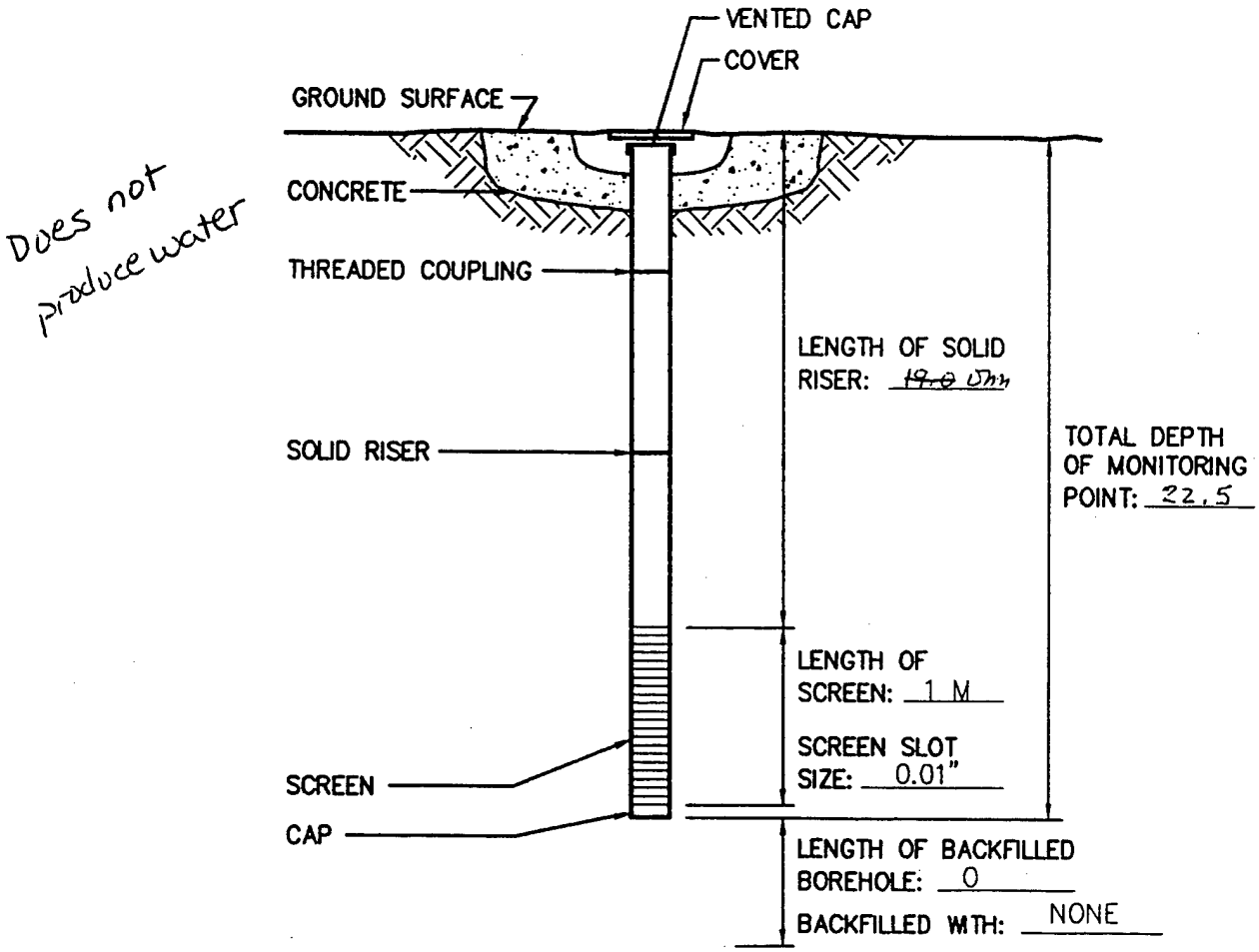
Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB
MONITORING POINT NUMBER MP-FPTA3-4DD/DM
JOB NUMBER 722450.24
INSTALLATION DATE 11/15/94
LOCATION FIRE TRAINING 3
DATUM ELEVATION 964.85
GROUND SURFACE ELEVATION 964.9
DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING
SCREEN DIAMETER & MATERIAL 1.5 ~~0.5~~ DM INCH OD PVC
SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 1.5 ~~0.5~~ DM INCH OD PVC
BOREHOLE DIAMETER 1.4 INCHES
CONE PENETROMETER CONTRACTOR USACE
ES REPRESENTATIVE DM/KC/JB



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MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-5M

JOB NUMBER 722450.24 — INSTALLATION DATE 11/15/94 — LOCATION FIRE TRAINING 3

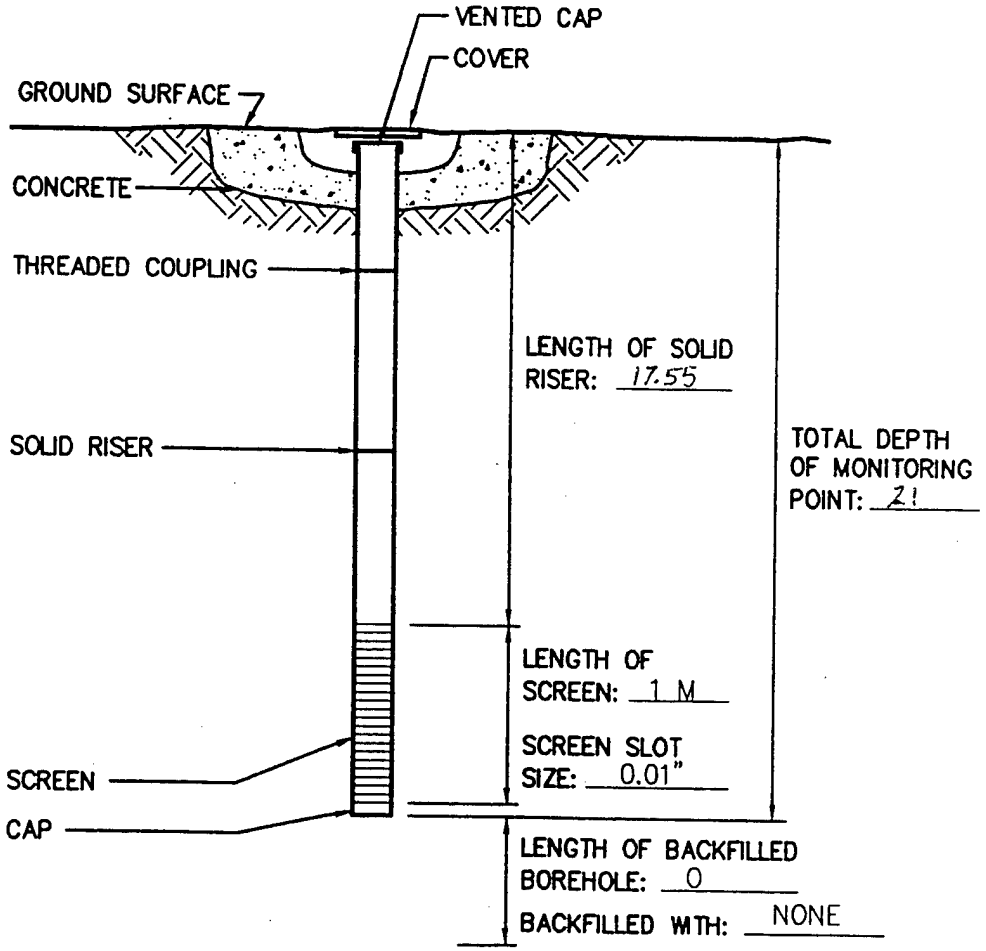
DATUM ELEVATION 964.27 — GROUND SURFACE ELEVATION 964.6

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



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MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-6S

JOB NUMBER 722450.24 — INSTALLATION DATE 11/15/94 — LOCATION FIRE TRAINING 3

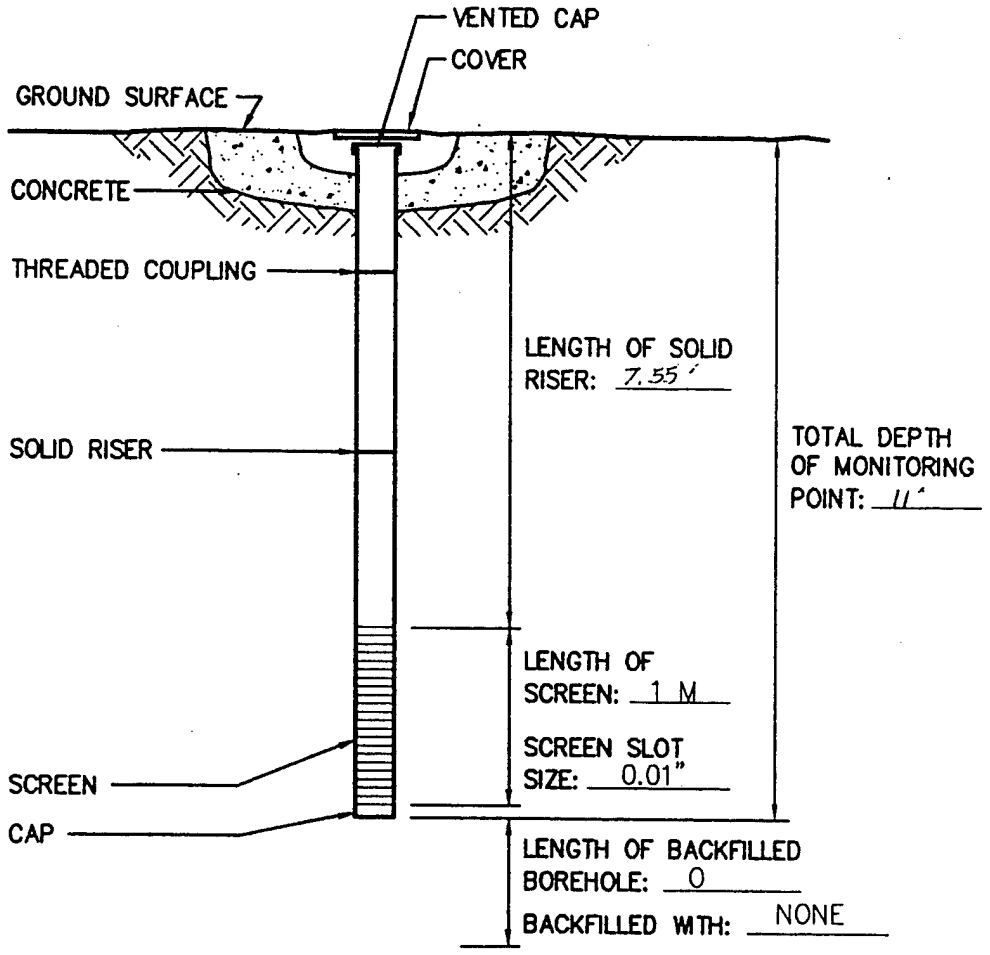
DATUM ELEVATION 964.32 — GROUND SURFACE ELEVATION 964.7

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

CONE PENETROMETER LOG

BORING NO.: SS2 | CONTRACTOR: USACE | DATE SPUD: 11/18/94
CLIENT: AFCEE | RIG TYPE: HAND | DATE CMPL.: 11/18/94
JOB NO.: 722450.24 | DRLG METHOD: CPT | ELEVATION:
LOCATION: OFFUTT AFB | BORING DIA.: 3.0 OD INCH | TEMP: 40 F
GEOLOGIST: JB/KC | DRLG FLUID: NONE | WEATHER: CLEAR
COMMENTS:

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			Grey, sandy CLAY. Strong chemical odor.	1	0-0.5						
			SW	Light brown, silty, very fine-grained SAND. Strong chemical odor present. Turning grey at 2.5 ft bgs. Black clay lens at 3.0 feet bgs. Strong odor.	2	1.0-1.5						
				SAA saturated with black viscous substance at 3.7 ft.	3	2.5-3.0	G					
			MH	Grey, sandy, clayey SILT.	4	3.5-4.0	R					
	5				5	5.0-5.5	A					
			SW	Clayey, silty SAND.	6	6.5-7.0	B					
				Saturated at 9 feet bgs.	7	8.5-9.0						
	10			Bottom of hole at 9.5 feet bgs.	8	9.0-9.5						
	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

GEOLOGIC BORING LOG

Fire Protection Training Area 3 (FPTA3)
Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

L:\45024\DRAWINGS\BORINGS\SS2, 05/02/95 at 08:40

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-EPTA3-6D/6M

JOB NUMBER 722450.24 — INSTALLATION DATE 11/15/94 — LOCATION FIRE TRAINING 3

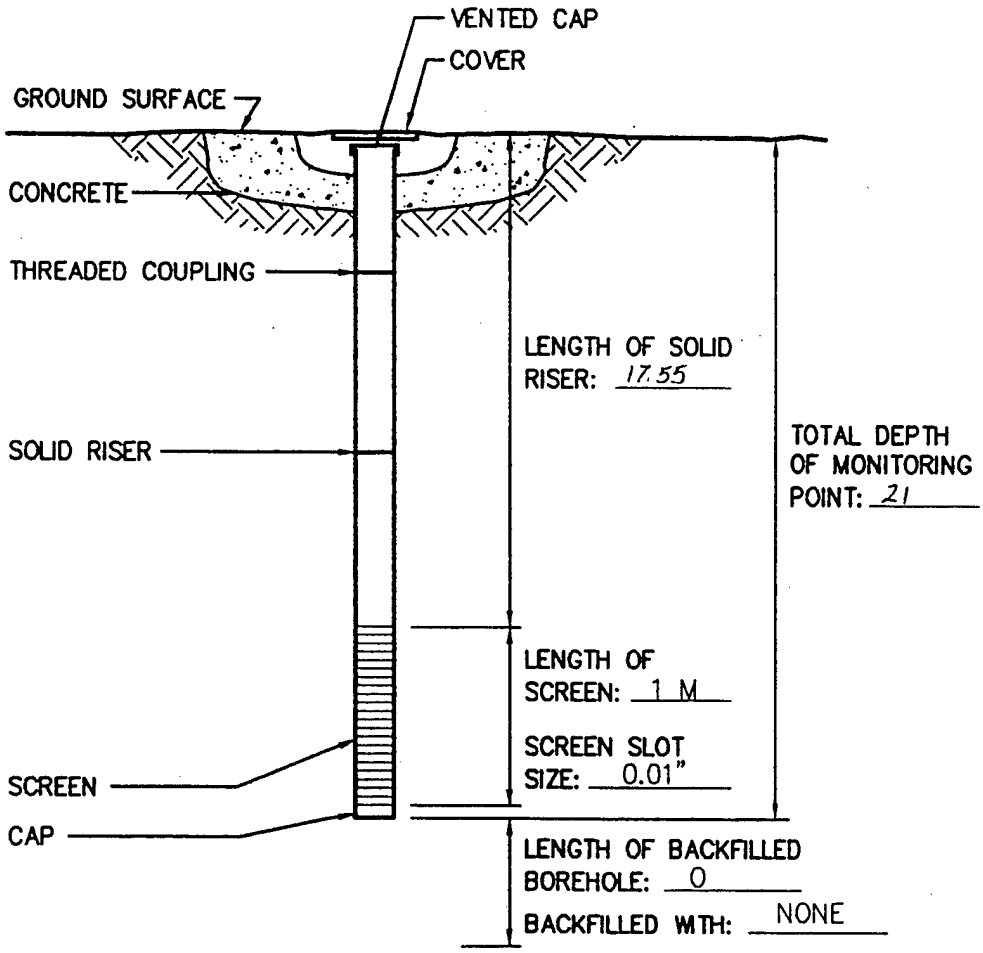
DATUM ELEVATION 964.35 — GROUND SURFACE ELEVATION 964.7

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-8D/D

JOB NUMBER 722450.24 — INSTALLATION DATE 11/16/94 — LOCATION FIRE TRAINING 3

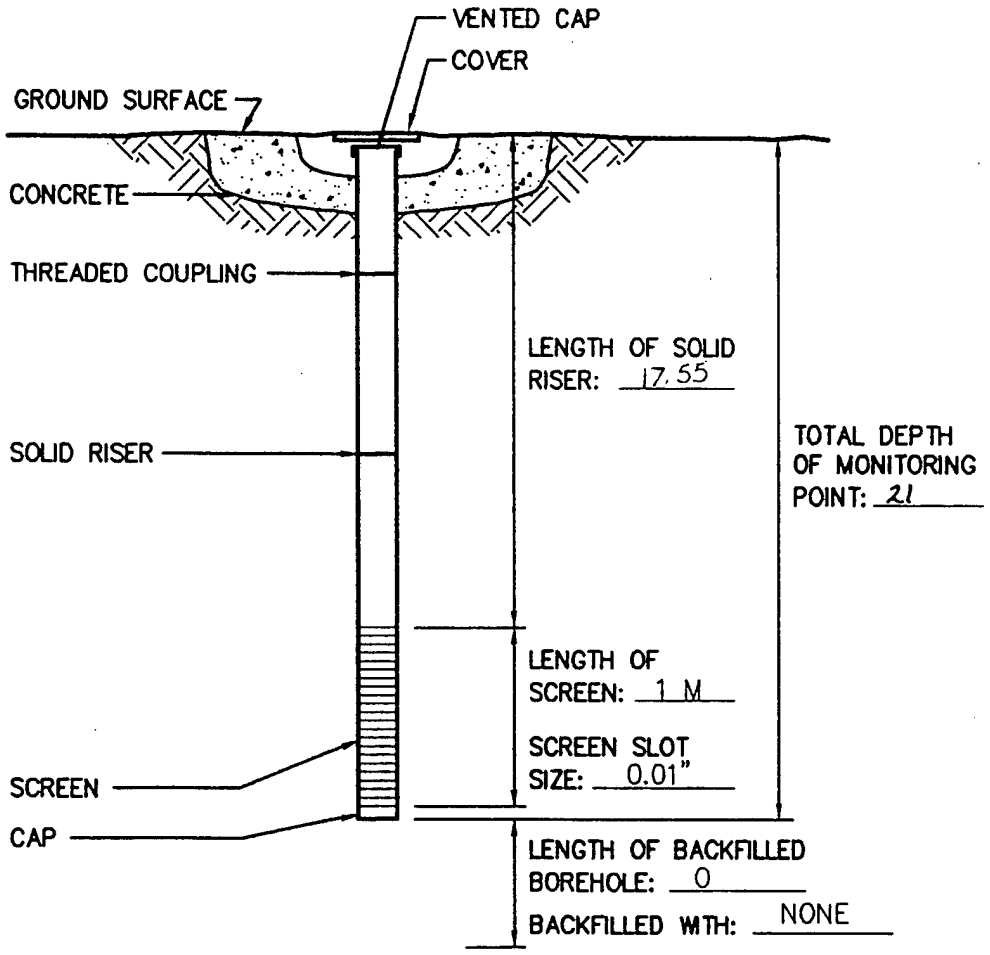
DATUM ELEVATION 963.32 — GROUND SURFACE ELEVATION 963.4

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-EPTA3-12S

JOB NUMBER 722450.24 — INSTALLATION DATE 11/16/94 — LOCATION FIRE TRAINING 3

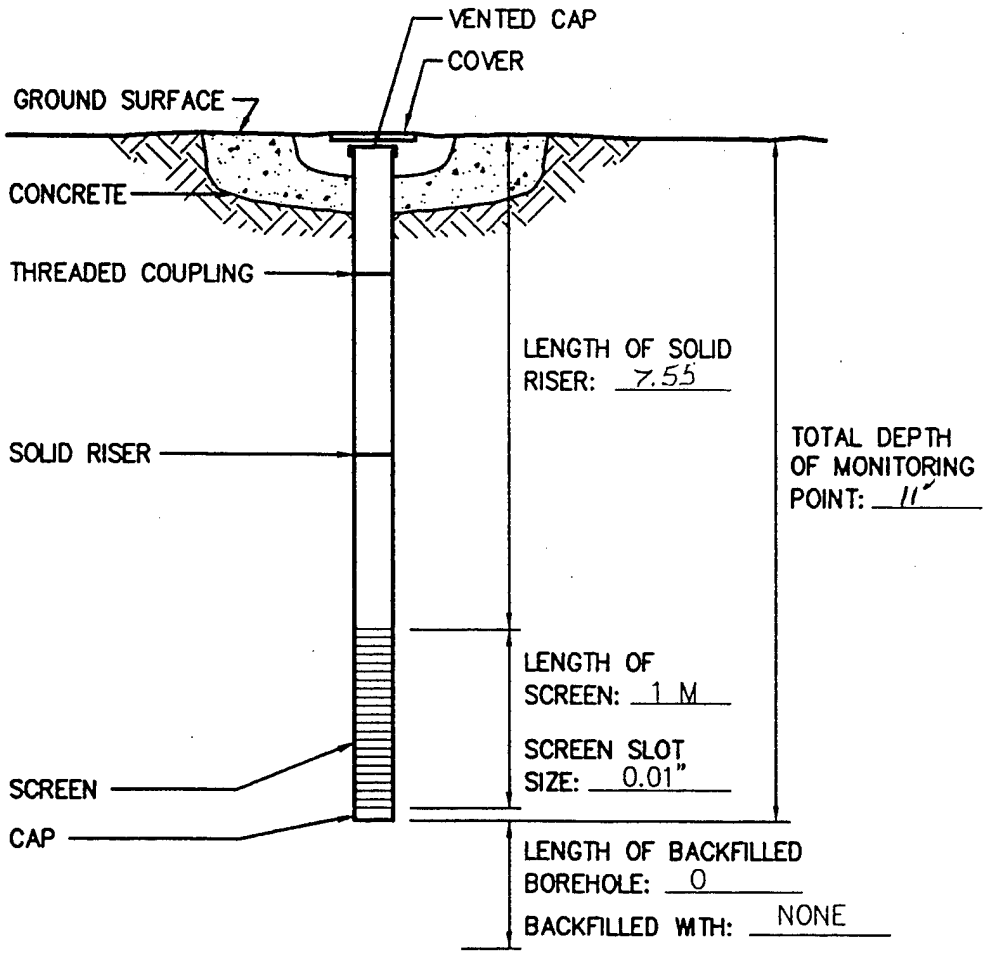
DATUM ELEVATION 963.11 — GROUND SURFACE ELEVATION 963.3

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-EPTA3-175

JOB NUMBER 722450.24 — INSTALLATION DATE 11/17/94 — LOCATION FIRE TRAINING 3

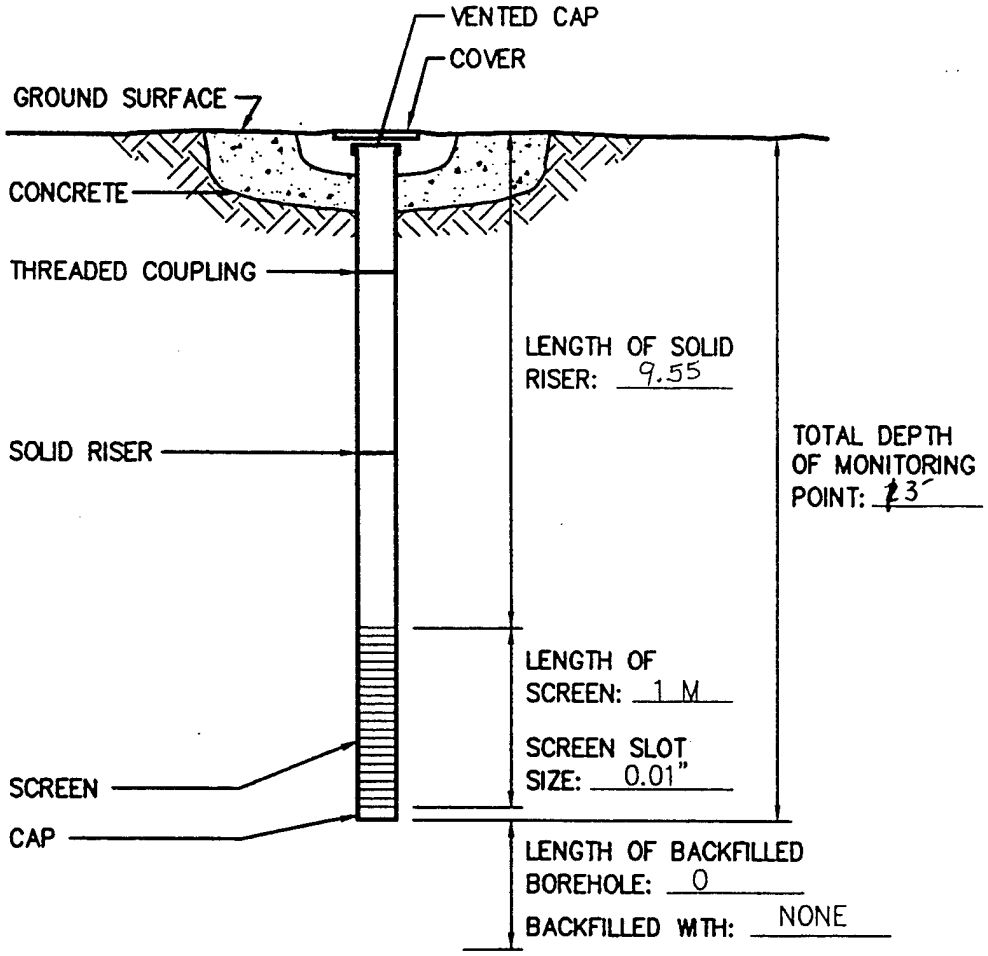
DATUM ELEVATION 964.88 — GROUND SURFACE ELEVATION 965.0

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-2DS

JOB NUMBER 722450.24 — INSTALLATION DATE 11/17/94 — LOCATION FIRE TRAINING 3

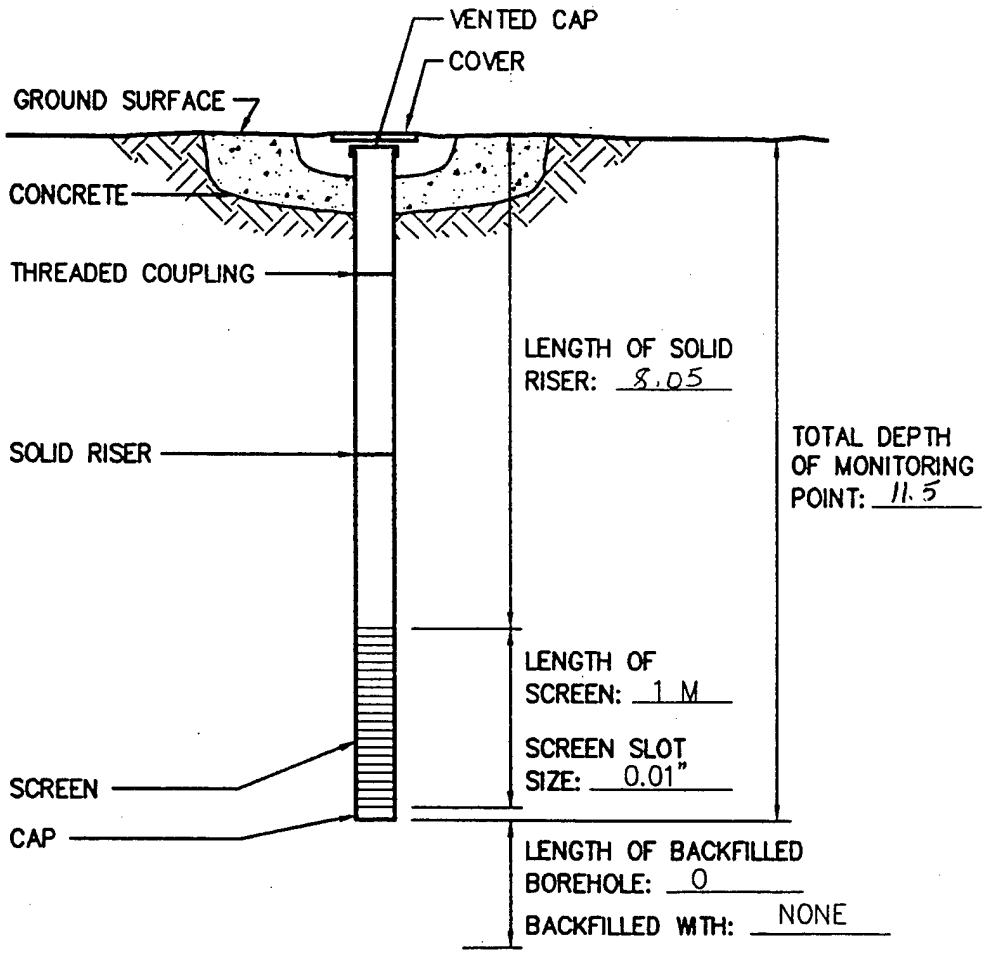
DATUM ELEVATION 963.42 — GROUND SURFACE ELEVATION 963.5

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-225

JOB NUMBER 722450.24 — INSTALLATION DATE 11/17/94 — LOCATION FIRE TRAINING 3

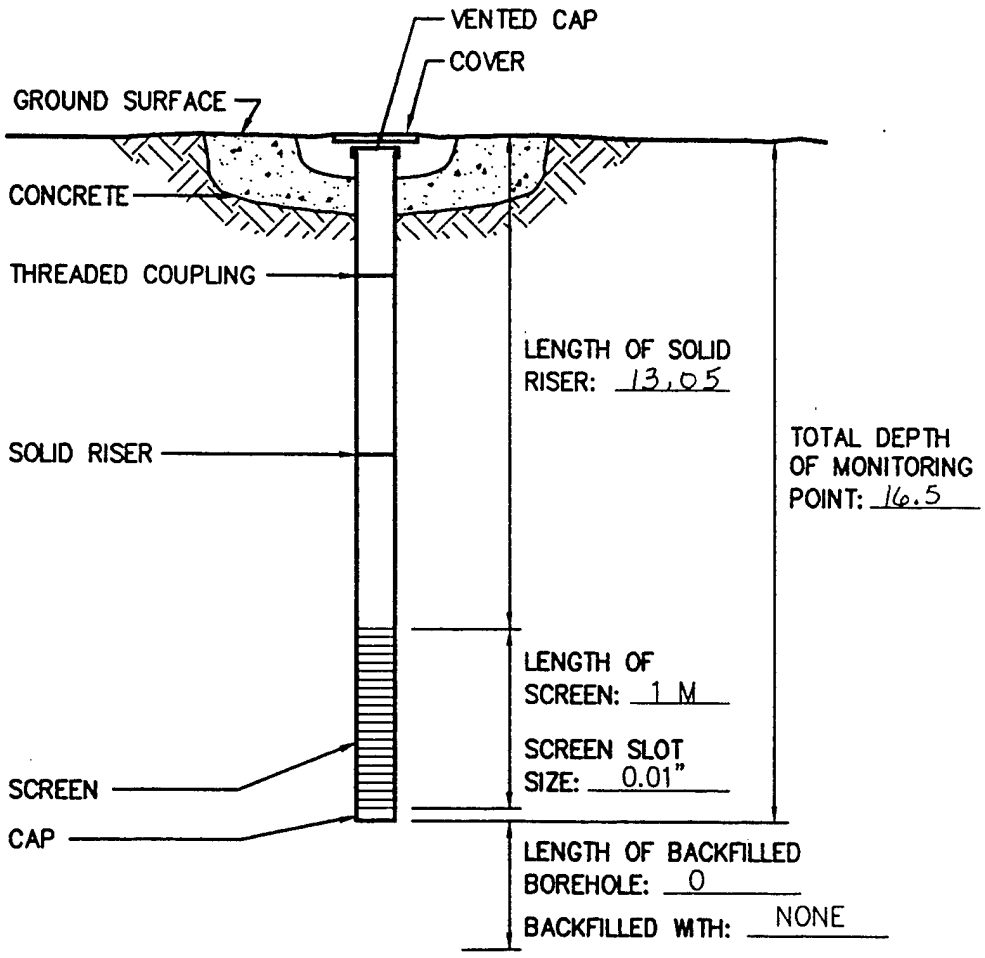
DATUM ELEVATION 967.01 — GROUND SURFACE ELEVATION 967.3

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-235

JOB NUMBER 722450.24 — INSTALLATION DATE 11/17/94 — LOCATION FIRE TRAINING 3

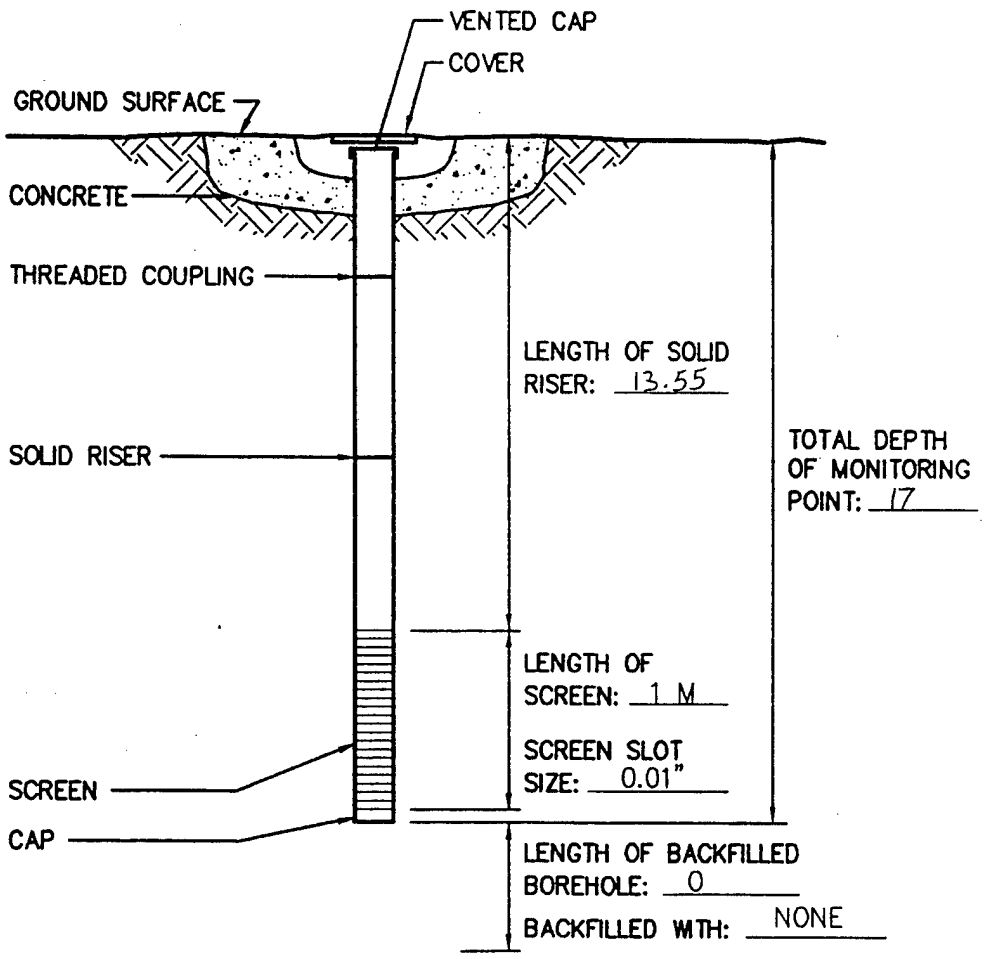
DATUM ELEVATION 967.72 — GROUND SURFACE ELEVATION 967.9

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT INSTALLATION RECORD

JOB NAME OFFUTT AFB — MONITORING POINT NUMBER MP-FPTA3-24D

JOB NUMBER 722450.24 — INSTALLATION DATE 11/18/94 — LOCATION FIRE TRAINING 3

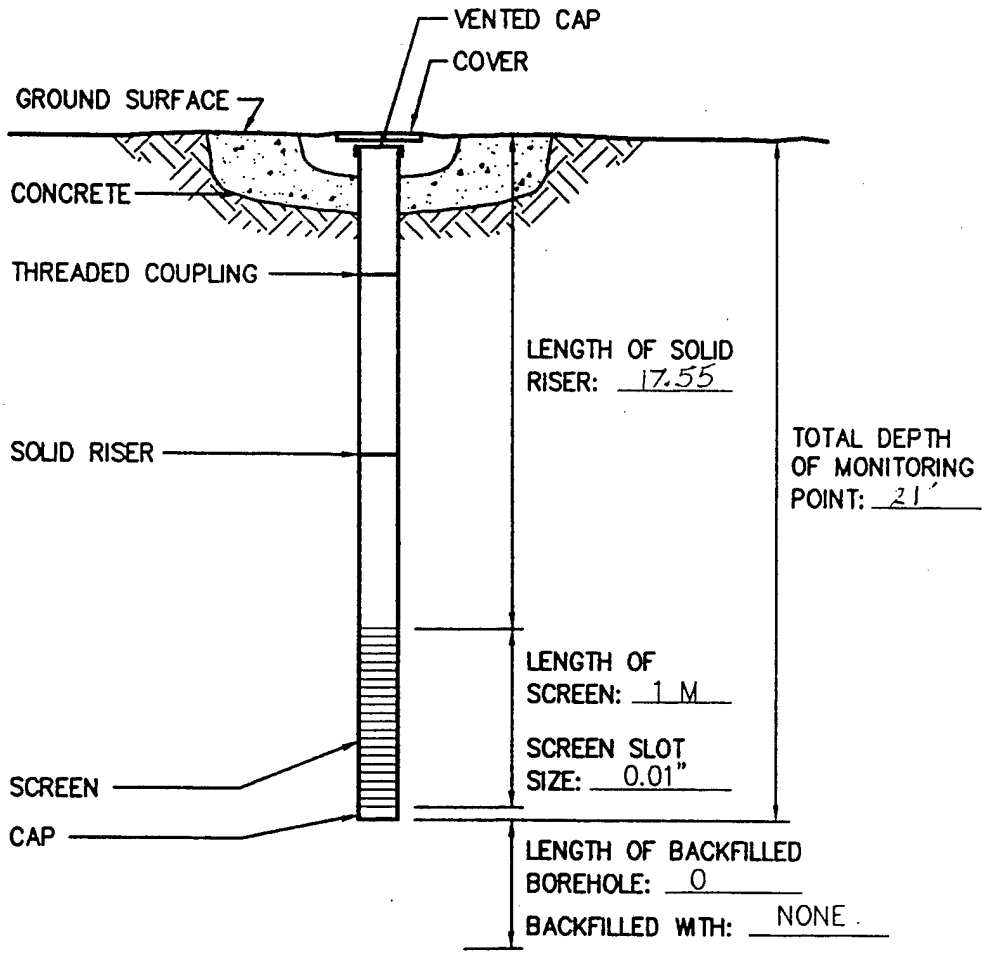
DATUM ELEVATION 962.34 — GROUND SURFACE ELEVATION 962.2

DATUM FOR WATER LEVEL MEASUREMENT TOP OF CASING

SCREEN DIAMETER & MATERIAL 0.5 INCH OD PVC — SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 0.5 INCH OD PVC — BOREHOLE DIAMETER 1.4 INCHES

CONE PENETROMETER CONTRACTOR USACE — ES REPRESENTATIVE DM/KC/JB



(NOT TO SCALE)

MONITORING POINT INSTALLATION RECORD

Intrinsic Remediation Demonstration
Offutt Air Force Base, NB

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

94DN0363, 08/08/94 at 15:22

MONITORING POINT LOCATIONS

FIRE PROTECTION

TRAINING AREA 3

OFFUTT AIR FORCE BASE, NEBRASKA

LEGEND

Top Metal Casing	TMC
Cover	CV
Top PVC	TPVC

Elevations are USGS DATUM

LOUIS SURVEYING
11926 Arbor Street
Suite 102
Omaha, Nebraska 68144

By Louis Whisonant
12/8/94

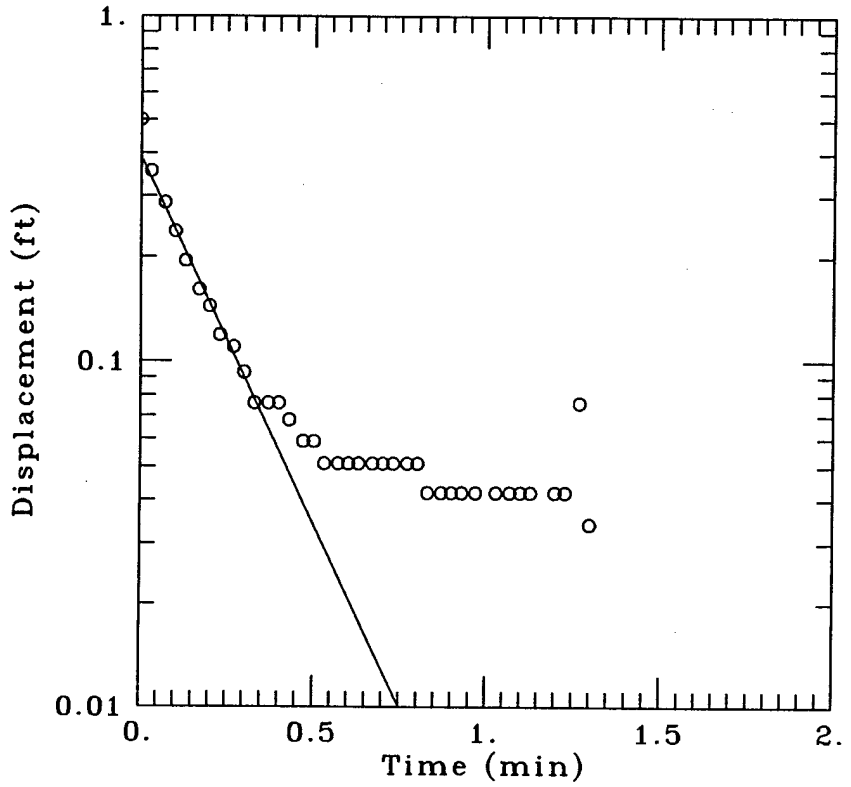
NEBRASKA REGISTERED LS-421 LAND SURVEYOR LOUIS WHISONANT

LOCATION NUMBER	ITEM	HORIZONTAL COORDINATES		GROUND SURFACE ELEVATION	MEASURING POINT ELEVATION
		North	East		
Location 1	Soil Borehole	6243.01	4853.33	961.9	
Location 2	Ground Shot	6317.82	4868.14	962.0	
	MP-FPTA3-2S	6317.27	4867.89	962.0	961.83 TPVC
	MP-FPTA3-2M	6318.60	4868.21	962.0	961.91 TPVC
	MP-FPTA3-2D	6319.85	4868.38	962.0	961.92 TPVC
	MP-FPTA3-2S	6317.35	4867.85		962.05 CV
	MP-FPTA3-2M	6318.65	4868.22		962.14 CV
	MP-FPTA3-2D	6319.79	4868.38		962.11 CV
Location 3	Soil Borehole	6397.48	4933.39	963.2	
Location 4	Soil Borehole	6313.82	4929.47	964.9	
	MP-FPTA3-4S	6296.95	4936.98	964.9	964.81 TPVC
	MP-FPTA3-4D	6300.32	4936.38	964.9	964.84 TPVC
	MP-FPTA3-4DD	6298.03	4936.89	964.9	964.85 TPVC
	MP-FPTA3-4S	6296.96	4936.95		965.14 CV
	MP-FPTA3-4D	6300.40	4936.44		965.11 CV
	MP-FPTA3-4DD	6298.04	4936.92		965.14 CV
Location 5	Ground Shot	6275.18	4647.25	964.6	
	MP-FPTA3-5S	6273.95	4646.55	964.6	964.37 TPVC
	MP-FPTA3-5M	6275.17	4646.32	964.6	964.27 TPVC
	MP-FPTA3-5D	6276.39	4646.12	964.6	964.28 TPVC
	MP-FPTA3-5S	6273.95	4646.62		964.68 CV
	MP-FPTA3-5M	6275.19	4646.30		964.64 CV
	MP-FPTA3-5D	6276.22	4646.15		964.65 CV
Location 6	Ground Shot	6264.42	4721.37	964.7	
	MP-FPTA3-6S	6263.78	4721.67	964.7	964.32 TPVC
	MP-FPTA3-6D	6265.30	4721.09	964.7	964.35 TPVC
	MP-FPTA3-6S	6263.72	4721.69		964.73 CV
	MP-FPTA3-6D	6265.10	4721.15		964.69 CV
Location 7	Soil Borehole	6278.20	4796.21	961.7	
Location 8	Ground Shot	6463.98	5013.20	963.4	
	MP-FPTA3-8S	6462.31	5013.77	963.4	963.33 TPVC
	MP-FPTA3-8D	6464.97	5012.41	963.4	963.32 TPVC
	MP-FPTA3-8S	6462.29	5013.78		963.58 CV
	MP-FPTA3-8D	6464.98	5012.45		963.62 CV

LOCATION NUMBER	ITEM	HORIZONTAL COORDINATES		GROUND SURFACE ELEVATION	MEASURING POINT ELEVATION
		North	East		
Location 22 (Cont.)	MP-FPTA3-22S	6521.34	5132.41		967.29 CV
	MP-FPTA3-22D	6522.61	5132.21		967.32 CV
Location 23	On Concrete	6282.60	5171.22	967.9	
	MP-FPTA3-23S	6282.12	5171.46	967.9	967.72 TPVC
	MP-FPTA3-23D	6283.22	5171.18	967.9	967.70 TPVC
	MP-FPTA3-23S	6282.09	5171.45		967.96 CV
	MP-FPTA3-23D	6283.12	5171.25		967.96 CV
Location 24	Ground Shot	6310.63	4424.06	962.2	
	MP-FPTA3-24D	6311.09	4424.94	962.2	962.34 TPVC
	MP-FPTA3-24D	6311.00	4424.88		962.55 CV
SS-MW6	Soil Borehole	6272.20	5047.57	963.7	
SS-2	Soil Borehole	6281.03	4890.49	962.0	
HF6-MW2	Monitoring Well	6618.65	5005.24	962.6	
		6619.98	5005.11		964.71 TMC
		6619.72	5005.24		964.47 TPVC
HF6-MW2D	Monitoring Well	6629.10	5005.41	962.7	
		6630.11	5004.83		965.38 TMC
		6629.98	5004.97		965.17 TPVC
HF6-MW4	Monitoring Well	6483.66	4934.51	963.4	
		6484.00	4933.38		966.06 TMC
		6484.04	4933.62		965.79 TPVC
	MP-FPTA3-6MW4S	6477.87	4934.49	963.4	
		6478.09	4935.32		963.60 CV
		6478.13	4935.30		963.34 TPVC
FPTA3-MW1	Monitoring Well	6356.81	5046.16	963.6	
		6356.88	5046.70		966.15 TMC
		6356.80	5046.85		965.42 TPVC
FPTA3-MW2	Monitoring Well	6204.25	4612.35	964.1	
		6203.50	4612.04		965.96 TMC
		6203.26	4612.45		964.66 TPVC
FPTA3-MW3	Monitoring Well	6357.39	5030.28	963.6	
		6357.37	5030.97		965.52 TMC
		6357.42	5031.28		964.02 TPVC

Parsons Engineering Science	Client: AFCEE
Project No.: 722450.24	Location: Offutt AFB, Nebraska

FPTA3-MW6 (Rising Head Test-1)



DATA SET:
m:\45024\slugtest\fpta03\fpta6r1.aqt
01/06/95

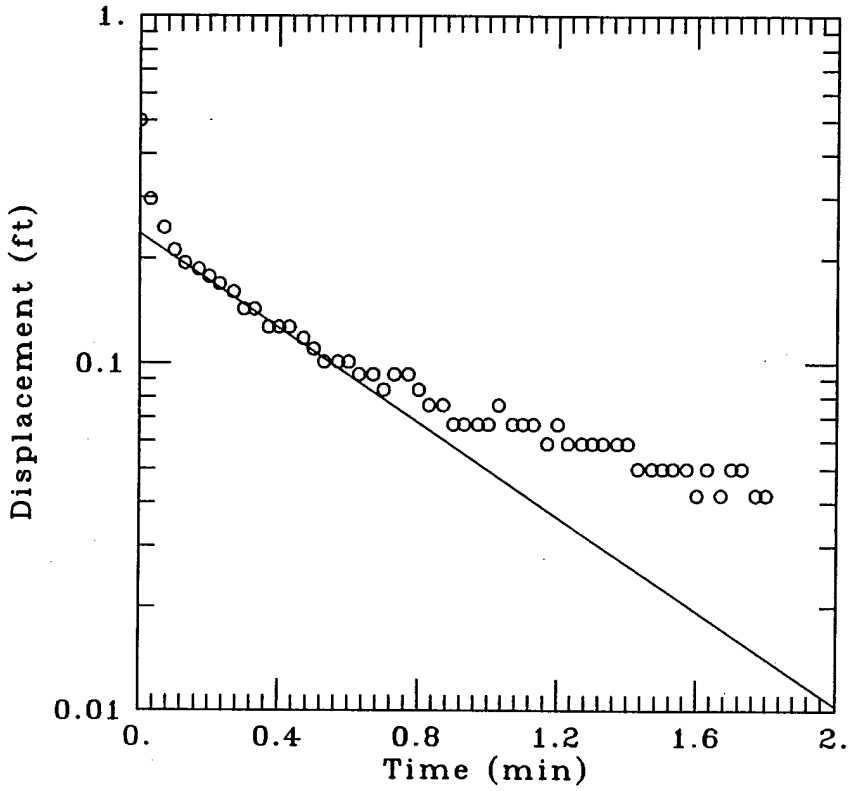
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
11/19/94

ESTIMATED PARAMETERS:
K = 0.003564 ft/min
y0 = 0.3908 ft

TEST DATA:
H0 = 0.5 ft
rc = 0.0833 ft
rw = 0.3 ft
L = 15. ft
b = 19.4 ft
H = 19.4 ft

Parsons Engineering Science	Client: **AFCEE**
Project No.: **722450.24**	Location: **Offutt AFB, Nebraska**

HF6-MW4 (Rising Head Test-1)



DATA SET:
m:\45024\slugtest\fpta03\hf64r1.aqt
01/06/95

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
11/19/94

ESTIMATED PARAMETERS:
K = 0.0009341 ft/min
y0 = 0.2366 ft

TEST DATA:
H0 = 0.5 ft
rc = 0.0833 ft
rw = 0.3 ft
L = 15. ft
b = 8. ft
H = 8. ft

APPENDIX B

LABORATORY ANALYTICAL DATA

Offutt AFB Analytical Data Package Check-Off List

Water - alkalinity - yes
- Ammonia - yes
- Chloride - yes
- Conductivity - yes
- Dissolved gases - yes
- Ferrous iron - yes
- Free Carbon Dioxide - yes
- Free Product - yes
- Metals - yes
- Nitrate + Nitrite - yes
- Fuel Carbon - yes
- Inorganic Carbon - yes
- pH - yes
- Phenols - yes
- BTEXXXBTM - yes
- ReDox - yes
- Sol Mn - yes
- Sulfate - yes
- Sulfides - yes
- Temperature - yes
- TOC - yes
- VOA - yes
- Volatile Fatty acids - No
- Dissolved Oxygen - yes

Soils - DHA - yes
- Moisture - yes
- TOC - Yes
- BTEXXXBTM - yes - 22
- TPH - yes

analyses for ~~Free product and~~ Volatile Fatty acids delayed because of work load backlog in mass spectrometry lab.

RECEIVED
JAN 03 1995

Don Campbell 12/29/94

Offutt AFB
Core Sample Analyses

Sample	Moisture mg/gram	TPH mg Oil/Kg soil	DHA ug Formazan/g. soil
SS1 0-6"	302	< 50	52
SS1 2.5-3'	36	< 50	0.5
SS1 4.5-5'	252	< 50	0.5
SS1 6.5-7'	353	50	0.2
SS1 8.5-9'	251	< 50	0.8
SS1 10.5-11'	319	< 50	0.5
SS2 0-6"	257	7200	65
SS2 1-1.5'	78	20600	16
SS2 2.5-3'	105	700	16
SS2 3.5-4'	311	23400	130
SS2 4.5-5'	323	450	300
SS2 6.5-7'	228	< 50	N.D.
SS2 8.5-9'	258	150	235
SS2 9.0-9.5'	238	82	230

Offutt AFB - Novem - 1994

Field site measurements

	Sample	Date	Water table TOC	Redox mv	pH units	Cond.	Total Alk. mg/l as CaCO3	Free CO2 mg/L	Ferrous Iron (+2) mg/L	Sulfide mg/L	Phenols mg/l	Soluble Mn mg/l	Dissolved oxygen mg/l	Water Temperature °C
	MW 349-5	11-14-94		230	7.4	1064	164	128	2.05	—	—	—	5.8	16.3
	MW 349-4			234	7.4	681	154	52		—	—	—	5.5	17.3
	MW 349-3			260	7.5	612	150	62		—	—	—	0.7	19.2
	MW 349-12			264	7.5	702	276	160		—	—	—	8.4	14.4
	MW 349-10			266	7.3	835	324	240		—	—	—	7.4	14.9
	MW349-9			260	7.2	608	205	126		—	—	—	0.7	14
	MW349-11	11-15-94		231	7.4	670	325	109		—	—	—	8	11.2
	MW349-7			215	7.4	930	387	220		—	—	—	2.4	12.7
	MW 349-11			214	7.5	929	394	180		—	—	—	NA	NA
	MW 349-8			166	7.4	954	336	160		—	0.2	0.4	0.7	15.
	MW 349-6			—	7.2	1015	500	252		—	—	—	NA	NA
	MW 349-1			—	7.2	1072	492	420		—	—	—	NA	NA
	MW349-2			-	7.2	1563	550	482		—	0.1	0.4	1.4	14.4
	MW 349-13			195	7.3	564	319	216		—	0.2	<.1	8.4	15.9
	MW349-14			194	7.4	667	338	180		—	—	—	8.4	14.7
	MW349-16			194	7.4	660	348	216	↓	—	—	—	#14 dup	
	FPT-3-MW6	11-16-94		-50	7.1	1154	600	300	0.4	—	0.3	0.4	0.1	12
	FPT-3 MW6A			-100	7.2	1271	675	440	8.7	—	0.3	0.4	0.1	11.3
	HF-6-MW4			-90	7.0	1862	678	600	24	—	—	—	0.1	12.9
	HF6-MW14			-91	7.0	1856	670	630	34.3	—	0.8	0.4	NA	NA
	HF6-MW2A			-60	6.8	1488	460	440	8.3	<.1	0.3	0.3	0.1	13.1
	HF6-MW2B			-100	7.2	1058	500	230	3.9	<.1	<.1	<.1	0.3	13.5
	HF6-MW12D			-105	7.2	1054	520	240	4.1	<.1	<.1	<.1	0	12.8
	FPTA3-MW2			-145	7.0	1174	760	522	23.3	<.1	0.2	<.1	0.1	13.8
	FPTA3-MW4			-86	6.8	1443	794	652	20.0	<.1	0.3	0.2	0.1	13.8
	FPTA3-MW1			-120	6.9	1053	502	282	7.5	—	0.2	<.1	0.2	13.5
	FPTA3-MW5			+30	7.1	849	428	132	2.05	—	<.1	<.1	0.2	13.3
	FPTA-MW4			+90	7.3	820	446	160	2.05	—	0.3	0.2	3.3	13.8
MP	MP-FPTA3-8D	11-17-94		-130	7.2	871	518	304	8.7	<.1	0.4	0.6	0.3	12.3
MP	FPTA3-4D			-120	7.2	1303	712	540	22.5	<.1	0.1	0.1	0.6	13.7
MP	FPTA3-2D			-140	7.2	1211	632	474	18.1	<.1	0.3	0.2	0.3	14.3
MP	FPTA3-2M			-165	7.3	1239	640	424	26.3	<.1	0.4	<.1	0.1	14.3
MP	FPTA3-6D			-110	7.1	1792	654	580	18.4	—	0.3	0.5	0.2	13.8
MP	FPTA3-5D			-160	7.2	926	480	450	16.3	—	0.3	0.4	0.2	12.6
MP	FPTA3-5M			-170	7.3	1466	520	460	17.5	<.1	0.2	<.1	0.1	13.5
MP	FPTA3-9M	11-18-94		-98	7.2	1019	514	182	7.5	—	0.2	0.2	0	12.1 → 9D
MP	FPTA3-12D			-60	7.2	1116	570	260	17	—	<.1	<.1	0.1	11.7
MP	FPTA3-17D			-111	6.9	1365	670	560	24.7	<.1	0.2	<.1	0.1	12.8
MP	FPTA3-20D			-120	6.9	1390	746	780	27.0	—	<.1	<.1	0.2	12.8
MP	FPTA3-DUP			—	7.0	1361	614	—	25.8	—	0.2	<.1	#17 dup	
MP	FPTA3-21D			-80	7.0	903	470	266	2.12	—	—	0.1	0.2	12.5
MP	FPTA3-L2S			-32	7.0	944	464	212	1.2	—	—	<.1	0.3	12.4
MP	FPTA3-25D			-129	7.1	964	492	342	6.3	<.1	—	0.1	0.2	13.2
MP	6-MW1			-113	7.1	1074	498	340	9.1	<.1	—	0.1	0	12.3
FP	TA-UST1			+82	7.3	693	142	100	2.05	.1	<.1	0.1	0.1	11.8
MP	FPTA3-24	11-11-94		-70	7.2	820	412	104	4.3	—	<.1	0.1	0	11.6

09/25/00 12:45 FAX AFCEE 012

SF-1-98 Dr. Kampbell | Offutt AFB Core Extracts and Floating Product | GC/MSD

Sample	Benzene	TCE	PCE	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,3-TMB	1,3,5-TMB
Core Extracts (mg/kg)											
SS-10-6"	ND	ND	ND	ND	ND	BLQ	ND	ND	BLQ	BLQ	BLQ
SS-12.5-3'	ND	ND	ND	ND	ND	BLQ	ND	ND	BLQ	BLQ	BLQ
SS-14.5-5'	ND	ND	ND	ND	ND	BLQ	ND	ND	BLQ	ND	BLQ
SS-16.5-7'	ND	BLQ	BLQ	ND	ND	BLQ	ND	ND	BLQ	BLQ	BLQ
SS-18.5-9'	ND	BLQ	BLQ	ND	ND	BLQ	ND	ND	BLQ	BLQ	BLQ
SS-110.5-11'	ND	ND	ND	ND	ND	BLQ	ND	ND	BLQ	BLQ	BLQ
SS-20-6"	ND	ND	ND	ND	ND	ND	ND	ND	BLQ	BLQ	BLQ
SS-21-1.5'	1.38E-01	ND	ND	4.12E-02	2.41E+00	5.76E+00	5.43E+00	ND	2.02E+01	3.51E+01	5.08E+00
SS-22.5-3'	ND	ND	ND	BLQ	9.44E-02	2.27E-01	2.23E-01	ND	9.33E-01	1.58E+00	2.89E-01
SS-23.5-4'	7.48E-02	ND	ND	3.21E-02	8.00E-01	6.96E-01	6.14E-01	5.02E-01	1.45E+00	3.42E+00	1.08E+00
SS-24.5-5'	2.06E-02	ND	ND	ND	9.69E-02	6.21E-02	6.01E-02	5.39E-02	1.33E-01	3.52E-01	1.49E-01
SS-26.5-7'	5.52E-02	ND	ND	ND	1.07E-01	6.04E-02	5.77E-02	2.70E-02	1.41E-01	3.28E-01	1.21E-01
SS-28.5-9'	1.25E-01	ND	ND	BLQ	1.86E-01	8.74E-02	6.60E-02	3.59E-02	1.31E-01	3.26E-01	1.28E-01
SS-29-9.5'	1.30E-01	ND	ND	1.53E-02	3.05E-01	1.99E-01	1.41E-01	9.96E-02	4.89E-01	1.06E+00	4.09E-01
Floating Product											
MW349-1 (ug/ml)	8.28E+03	ND	ND	4.11E+04	1.03E+04	8.98E+03	2.17E+04	1.14E+04	4.42E+03	1.41E+04	3.32E+03
MW349-1 (ug/g)	1.12E+04	ND	ND	5.57E+04	1.40E+04	1.22E+04	2.94E+04	1.54E+04	6.00E+03	1.92E+04	4.50E+03
MW349-7 (ug/ml)	5.62E+03	ND	ND	2.86E+04	9.26E+03	8.92E+03	2.14E+04	1.16E+04	4.99E+03	1.70E+04	4.26E+03
MW349-7 (ug/g)	7.62E+03	ND	ND	3.89E+04	1.26E+04	1.21E+04	2.90E+04	1.57E+04	6.77E+03	2.31E+04	5.79E+03
QC Summary (ug/ml)											
0.5	5.10E-01	5.05E-01	4.84E-01	5.02E-01	5.03E-01	4.70E-01	5.22E-01	5.00E-01	5.08E-01	5.06E-01	5.08E-01
5	5.37E+00	5.32E+00	5.36E+00	5.18E+00	5.17E+00	5.15E+00	5.19E+00	5.20E+00	5.25E+00	5.22E+00	5.24E+00
5	5.38E+00	5.16E+00	5.07E+00	5.17E+00	5.12E+00	5.10E+00	5.43E+00	5.11E+00	5.06E+00	5.09E+00	5.09E+00
5	4.62E+00	4.84E+00	4.93E+00	4.83E+00	4.88E+00	4.90E+00	5.17E+00	4.88E+00	4.94E+00	4.91E+00	4.91E+00
50	5.48E+01	5.35E+01	5.29E+01	5.46E+01	5.39E+01	5.32E+01	5.44E+01	5.43E+01	5.43E+01	5.43E+01	5.42E+01
50	4.68E+01	4.64E+01	4.74E+01	4.79E+01	4.86E+01	4.74E+01	4.85E+01	4.87E+01	4.90E+01	4.89E+01	4.88E+01
Method Blank	ND	ND	ND	ND	ND	BLQ	ND	ND	ND	BLQ	BLQ
QC 1 1 ug/ml	1.04E+00	N/A	N/A	9.81E-01	9.27E-01	9.42E-01	9.71E-01	9.72E-01	9.74E-01	9.75E-01	9.84E-01
QC 2 5 ug/ml	5.45E+00	5.46E+00	5.21E+00	5.19E+00	5.15E+00	5.00E+00	4.99E+00	5.17E+00	5.19E+00	5.15E+00	5.17E+00

Analyst: D.A.Kovacs

BLQ<0.05ug/ml (Napthalenes<0.1 ug/ml)

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09/25/00 12:45 FAX AFCEE 013

09/25/00 12:46 FAX AFCEE 014

Sample	Naphthalene	2-Methylnaphthalene	1-Methylnaphthalene
Core Extracts (mg/kg)			
SS-1 0-6"	BLQ	BLQ	BLQ
SS-1 2.5-3'	BLQ	BLQ	BLQ
SS-1 4.5-5'	BLQ	BLQ	BLQ
SS-1 6.5-7'	BLQ	BLQ	BLQ
SS-1 8.5-9'	BLQ	BLQ	BLQ
SS-1 10.5-11'	BLQ	BLQ	BLQ
SS-2 0-6"	ND	ND	ND
SS-2 1-1.5'	1.05E+01	2.33E+01	2.14E+01
SS-2 2.5-3'	5.73E-01	1.31E+00	1.14E+00
SS-2 3.5-4'	4.83E-01	1.01E+00	8.23E-01
SS-2 4.5-5'	8.14E-02	7.83E-02	6.40E-02
SS-2 6.5-7'	8.55E-02	1.31E-01	1.08E-01
SS-2 8.5-9'	7.95E-02	1.17E-01	9.65E-02
SS-2 9-9.5'	2.07E-01	4.23E-01	3.88E-01
Floating Product			
MW349-1 (ug/ml)	1.85E+03	1.60E+03	8.94E+02
MW349-1 (ug/g)	2.52E+03	2.17E+03	1.21E+03
MW349-7 (ug/ml)	2.17E+03	1.42E+03	7.49E+02
MW349-7 (ug/g)	2.95E+03	1.92E+03	1.02E+03
QC Summary (ug/ml)			
0.5	4.70E-01	4.70E-01	4.78E-01
5	5.32E+00	5.25E+00	5.31E+00
5	5.24E+00	5.34E+00	5.45E+00
5	4.76E+00	4.61E+00	4.55E+00
50	5.06E+01	5.08E+01	5.24E+01
50	4.60E+01	4.50E+01	4.58E+01
Method Blank	BLQ	BLQ	BLQ
QC 1 1 ug/ml	9.81E-01	9.81E-01	9.81E-01
QC 2 5 ug/ml	5.38E+00	N/A	5.23E+00

Table 1. Quantitation Report for S.R. # SF-1-98 from Offutt AFB.

Concentration = ppb

Compound	MP-FPTA3 2D	MP-FPTA3 2M	MP-FPTA3 4D	MP-FPTA3 4S	MP-FPTA3 5D	MP-FPTA3 5M	MP-FPTA3 5M Field Dup	MP-FPTA3 6D	MP-FPTA3 8D	MP-FPTA3 8S
VINYL CHLORIDE	---	2.6	---	40.7	---	817	766	51.9	---	---
1,1-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	---	---	---	2.4	---	1.6	1.5	1.7	---	---
C-1,2-DICHLOROETHENE	---	---	---	273	2.2	---	---	93.3	---	---
CHLOROFORM	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
CARBON TETRACHLORIDE	---	---	---	---	---	---	---	---	---	---
BENZENE	28.3	630	---	170	---	56.7	55.0	2.9	3.4	---
1,2-DICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
TRICHLOROETHENE	---	---	---	8.6	---	---	---	---	---	---
TOLUENE	2.8	4.0	1.0	186	1.5	29.8	28.4	5.5	2.4	31.3
TETRACHLOROETHENE	---	---	---	---	---	---	---	---	---	---
CHLOROBENZENE	---	---	---	---	---	---	---	---	---	---
ETHYLBENZENE	---	990	---	106	---	21.7	19.7	---	---	---
m+p-XYLENE	---	1710	---	338	---	45.1	42.6	---	---	---
o-XYLENE	---	15.9	---	173	---	46.7	41.1	---	---	---

Compound	MP-FPTA3 9D	MP-FPTA3 12D	MP-FPTA3 17D	MP-FPTA3 17D Lab Dup	MP-FPTA3 20D	MP-FPTA3 20S	MP-FPTA3 20S Field Dup	MP-FPTA3 22D	MP-FPTA3 22S	MP-FPTA3 23D
VINYL CHLORIDE	---	---	6.7	6.7	---	---	---	---	---	---
1,1-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
CHLOROFORM	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	---	---	---	---	---	3.1	3.3	---	---	---
CARBON TETRACHLORIDE	---	---	---	---	---	---	---	---	---	---
BENZENE	---	---	---	---	---	---	---	---	---	---
1,2-DICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
TRICHLOROETHENE	---	---	---	---	---	6.7	7.6	---	---	---
TOLUENE	---	---	---	---	---	2.5	2.6	---	---	---
TETRACHLOROETHENE	---	---	---	---	---	---	---	---	---	---
CHLOROBENZENE	---	---	---	---	---	---	---	---	---	---
ETHYLBENZENE	---	---	---	---	---	---	---	---	---	---
m+p-XYLENE	---	---	---	---	---	---	---	---	---	---
o-XYLENE	---	---	---	---	---	---	---	---	---	---

Dup = Duplicate --- = Below Calibration Limit(1.0 ppb)

09/25/00 12:46 FAX AFCEE 015

Table 2. Quantitation Report for S.R. # SF-1-98 from Offutt AFB.

Concentration = ppb

Compound	MP-FPTA3 23S	MP-FPTA3 24	MP-FPTA3 27D	FPTA3 MW1	FPTA3 MW1 Field Dup	FPTA3 MW2	FPTA3 MW3	FPTA3 MW3 Lab Dup	FPTA3 MW4	FPTA3 MW5
VINYL CHLORIDE	---	---	6.4	---	---	---	2.6	2.6	---	---
1,1-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
CHLOROFORM	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
CARBON TETRACHLORIDE	---	---	---	---	---	---	---	---	---	---
BENZENE	---	---	---	5.9	5.9	3.8	---	---	---	---
1,2-DICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
TRICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
TOLUENE	2.4	---	---	18.9	19.0	---	---	---	---	---
TETRACHLOROETHENE	---	---	---	---	---	---	---	---	---	---
CHLOROBENZENE	---	---	---	---	---	---	---	---	---	---
ETHYLBENZENE	---	---	---	2.7	2.8	2.3	---	---	---	---
m+p-XYLENE	---	---	---	7.2	7.3	1.3	---	---	1.3	---
o-XYLENE	---	---	---	2.3	2.4	---	---	---	---	---

Compound	FPTA3 MW6	FPTA3 MW6 Lab Dup	FPTA3 MW6A	HF6 MW1	HF6 MW2	HF6 MW2D	HF6 MW4	HF6 MW12D	HF6 MW14	FPTA3 UST1
VINYL CHLORIDE	---	---	6.2	---	---	---	---	---	---	---
1,1-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
T-1,2-DICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
C-1,2-DICHLOROETHENE	---	---	2.7	---	---	---	---	---	---	---
CHLOROFORM	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
CARBON TETRACHLORIDE	---	---	---	---	---	---	---	---	---	---
BENZENE	---	---	4.6	---	---	19.4	3.9	13.2	3.9	---
1,2-DICHLOROETHANE	---	---	---	---	---	---	---	---	---	---
TRICHLOROETHENE	---	---	---	---	---	---	---	---	---	---
TOLUENE	---	---	---	---	---	44.1	---	31.2	---	---
TETRACHLOROETHENE	---	---	---	---	---	---	---	---	---	---
CHLOROBENZENE	---	---	---	---	---	---	---	---	---	---
ETHYLBENZENE	---	---	---	---	---	5.3	---	4.1	---	---
m+p-XYLENE	---	---	---	---	1.0	13.5	---	10.6	---	---
o-XYLENE	---	---	---	---	---	4.9	---	3.7	---	---

Dup = Duplicate --- = Below C ation Limit(1.0 ppb)

09/25/00 12:46 FAX AFCEE 016

Table 3. Quantitation Report for S.R. # SF-1-98 from Offutt AFB.

Concentration = ppb

Compound	MP-6 MW4S	MP-6 MW4S Lab Dup	MP-6 MW4S Field Dup	QC1207C 20 ppb	QC1207D 200 ppb	QC1207E 20 ppb	QC1207F 200 ppb	QC1207G 20 ppb	QC1207H 200 ppb	QC1207I 20 ppb
VINYL CHLORIDE	---	---	---	19.8	199	18.7	214	20.5	216	19.3
1,1-DICHLOROETHENE	---	---	---	20.6	188	19.9	203	20.7	194	19.3
T-1,2-DICHLOROETHENE	---	---	---	22.8	200	20.1	203	21.5	203	20.6
C-1,2-DICHLOROETHENE	---	---	---	22.1	185	19.0	197	20.2	189	19.0
CHLOROFORM	---	---	---	---	---	---	---	---	---	---
1,1,1-TRICHLOROETHANE	---	---	---	23.1	196	23.1	205	24.4	205	22.5
CARBON TETRACHLORIDE	---	---	---	23.0	204	21.3	217	23.0	218	22.0
BENZENE	1.0	1.0	1.2	22.5	196	20.6	198	21.5	199	20.6
1,2-DICHLOROETHANE	---	---	---	21.3	190	18.9	185	18.6	193	19.0
TRICHLOROETHENE	---	---	---	23.9	208	21.2	210	22.8	224	22.1
TOLUENE	35.5	36.9	34.0	22.0	198	19.7	202	20.7	201	19.6
TETRACHLOROETHENE	---	---	---	22.6	183	21.3	202	22.9	195	20.5
CHLOROBENZENE	---	---	---	22.4	191	19.7	192	20.8	188	19.9
ETHYLBENZENE	---	---	---	21.7	205	20.3	218	21.6	212	19.9
m+p-XYLENE	---	---	---	41.8 *	405 **	40.0 *	406 **	42.3 *	396 **	39.4 *
o-XYLENE	---	---	---	22.2	204	19.6	208	21.4	208	20.3

Compound	QC1207J 200 ppb	BL1207A	BL1207B
VINYL CHLORIDE	200	---	---
1,1-DICHLOROETHENE	180	---	---
T-1,2-DICHLOROETHENE	205	---	---
C-1,2-DICHLOROETHENE	194	---	---
CHLOROFORM	---	---	---
1,1,1-TRICHLOROETHANE	191	---	---
CARBON TETRACHLORIDE	206	---	---
BENZENE	206	---	---
1,2-DICHLOROETHANE	223	---	---
TRICHLOROETHENE	211	---	---
TOLUENE	203	---	---
TETRACHLOROETHENE	187	---	---
CHLOROBENZENE	202	---	---
ETHYLBENZENE	203	---	---
m+p-XYLENE	402 **	---	---
o-XYLENE	208	---	---

Dup = Duplicate --- = Below Calibration Limit * = 40 ppb ** = 400 ppb QC = Quality Control Std. BL = Blank

09/25/00 12:46 FAX AFCEE 017

OFFUTT AFB

ANALYZED 11/18/94 SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MW349-1	0.002	BLQ
MW349-2	0.007	BLQ
MW349-3	BLQ	ND
MW349-4	BLQ	ND
MW349-5	BLQ	ND
MW349-6	BLQ	ND
MW349-6 FIELD DUP	BLQ	BLQ
MW349-7	0.001	BLQ
MW349-8	0.003	BLQ
MW349-9	BLQ	ND

ANALYZED 11/21/94 SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MW349-10	BLQ	ND
MW349-11	BLQ	ND
MW349-12	BLQ	ND
MW349-13	0.001	BLQ
MW349-14	BLQ	ND
MW349-17	0.001	BLQ
MW349-18	BLQ	ND

ANALYZED 11/23/94 SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
HF6-MW2	0.010	ND
HF6-MW2D	0.008	ND
HF6-MW4	7.910	ND
HF6-MW12D	0.017	ND
" LAB DUP	0.016	ND

ANALYZED 11/28/94 SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
HF6-MW14	8.089	ND
" FIELD DUP	7.662	ND
FPTA3-MW2	0.170	ND
MP-FPTA3-2D	8.411	0.003
FPTA3-MW3	4.315	0.003
FPTA3-MW4	0.007	ND
FPTA3-MW5	0.010	ND
FPTA3-MW6	0.978	BLQ
FPTA3-MW6A	2.290	BLQ
" LAB DUP	2.072	BLQ

OFFUTT AFB

ANALYZED 11/28/94 SAMPLE	METHANE	ETHYLENE
MP-FPTA3-6D	2.264	0.017
MP-FPTA3-2M	17.578	BLQ
MP-FPTA3-4D	2.932	ND
MP-FPTA3-5D	0.013	ND
MP-FPTA3-5M	22.452	0.895
MP-FPTA3-8D	0.384	ND
MP-FPTA3-9D	0.008	ND

ANALYZED 11/29/94 SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
HF6-MW1	0.004	ND
FPTA3-MW1	0.008	ND
MP-FPTA3-8S	0.037	ND
MP-FPTA3-12D	0.001	ND
MP-FPTA3-17D	1.332	0.003
MP-FPTA3-20D	0.096	ND
MP-FPTA3-20S	0.008	ND
MP-FPTA3-22D	1.181	BLQ
MP-FPTA3-22S	0.050	ND
" FIELD DUP	0.050	ND
MP-FPTA3-23D	0.014	ND
MP-FPTA3-23S	0.005	ND
MP-FPTA3-24	0.106	ND
MP-FPTA3-27D	1.324	0.004
FPTA3-UST1	0.008	ND
" LAB DUP	0.007	ND

STANDARDS	METHANE	ETHYLENE
10 PPM CH4	10.24	ND
100 PPM CH4	99.97	ND
990 PPM CH4	993.69	ND
1 % CH4	1.01	ND
10 % CH4	10.00	ND
10 PPM C2H4	ND	10.20
100 PPM C2H4	ND	99.98
1000 PPM C2H4	ND	1019.81
1 % C2H4	ND	1.00

LOWER LIMITS OF QUANTITATION

METHANE	ETHYLENE
0.001	0.003

OFFUTT AFB

UNITS FOR THE SAMPLES ARE mg/L.
UNITS FOR THE STANDARDS CORRESPOND
TO THE UNITS IN THE SAMPLE COLUMN.

ND DENOTES NONE DETECTED.
BLQ DENOTES BELOW LIMIT OF QUANTITATION.

GROUNDWATER SAMPLES FROM OAFB FOR TOC & TIC (SR# SF-1-98)

SAMPLES	TOTAL CARBON MG/L	TOTAL ORGANIC CARBON MG/L	TOTAL INORGANIC CARBON MG/L (TC-TOC)
HF6-MW1	119.2	5.6	113.6
HF6-MW2	144.0	7.2	136.8
HF6-MW2D	124.4	4.0	120.4
HF6-MW4	188.0	41.6	146.4
HF6-MW12D	118.8	3.6	115.2
HF6-MW14 REP1	197.2	55.2	142.0
HF6-MW14 REP2	197.2	57.6	139.6
MW349-1	168.0	72.8	95.2
MW349-2	156.0	48.0	108.0
MW349-3	36.0	1.6	34.4
MW349-3 DUP	36.0	1.6	34.4
MW349-4	34.8	2.0	32.8
MW349-4 DUP	35.2	2.0	33.2
MW349-5	40.8	3.6	37.2
MW349-6 REP1	130.4	105.6	24.8
MW349-6 REP2	130.4	89.6	40.8
MW349-7	161.6	94.8	66.8
MW349-8	94.4	20.8	73.6
MW349-9	46.0	1.2	44.8
MW349-10	75.6	1.2	74.4
MW349-11	83.2	1.6	81.6
MW349-12	66.4	1.2	65.2
MW349-12 DUP	66.4	1.2	65.2
MW349-13	66.8	1.2	65.6
MW349-14	82.0	1.2	80.8
MW349-14 DUP	82.0	1.2	80.8
MW349-17	143.2	84.0	59.2
MW349-18	82.4	1.6	80.8
FPTA3-MW1	126.0	3.2	122.8
FPTA3-MW2	215.6	59.2	156.4
FPTA3-MW3	144.4	10.8	133.6
FPTA3-MW4	98.4	1.6	96.8
FPTA3-MW5	107.6	2.4	105.2
FPTA3-MW6	183.6	30.4	153.2
FPTA3-MW6 DUP	183.6	30.4	153.2
FPTA3-MW6A	228.0	60.4	167.6
MPFPTA3-2D	263.6	76.8	186.8
MPFPTA3-2D DUP	262.4	76.8	185.6
MPFPTA3-2M	312.0	167.2	144.8
MPFPTA3-4D	226.4	55.6	170.8
MPFPTA3-5D	123.6	8.8	114.8
MPFPTA3-5M	163.2	26.8	136.4
MPFPTA3-6D	171.6	31.6	140.0
MPFPTA3-8D	181.6	71.6	110.0
MPFPTA3-9D	117.6	5.2	112.4
MPFPTA3-12D	153.6	12.0	141.6

TRUE VALUE: WPO32-II = 9.60 MG/L OC

GROUNDWATER SAMPLES FROM OAFB FOR TOC & TIC (SR# SF-1-98)

SAMPLES	TOTAL CARBON MG/L	TOTAL ORGANIC CARBON MG/L	TOTAL INORGANIC CARBON MG/L (TC-TOC)
MPFPTA3-12D DUP	153.6	11.2	142.4
MPFPTA3-17D	176.0	13.6	162.4
MPFPTA3-20D	180.8	17.2	163.6
MPFPTA3-20D DUP	183.6	17.2	166.4
MPFPTA3-20S	******	19.6	*****
MPFPTA3-22D	178.4	43.2	135.2
MPFPTA3-22S REP1	131.2	10.0	121.2
MPFPTA3-22S REP2	131.2	10.8	120.4
MPFPTA3-23D	137.6	8.0	129.6
MPFPTA3-23S	95.2	2.4	92.8
MPFPTA3-24	110.8	2.8	108.0
MPFPTA3-27D	158.0	7.6	150.4
MPFPTA3-27D DUP	158.0	7.2	150.8
FPTA3-UST1	50.0	11.6	38.4
WPO32-II		9.8	
		10.0	
		10.1	
		10.0	
		10.0	
		10.1	
		10.2	
		10.2	
		10.0	
		10.3	

TRUE VALUE: WPO32-II = 9.60 MG/L OC

SR SF-1-92 Dr. Kampbell

Offutt AFB Cores Methylene Chloride Extracts

Units = mg/kg

SAMPLE	Benzene	TCE	PCE	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
OAFB-1	BLQ	ND	2.37E-02	BLQ	ND	BLQ	BLQ	BLQ	ND	ND	ND
OAFB-2	3.99E-01	BLQ	7.72E-02	ND	1.27E+00	2.63E+00	2.81E+00	1.31E+00	3.28E+00	6.63E+00	4.38E-01
OAFB-3	BLQ	BLQ	5.60E-02	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND
OAFB-4	BLQ	ND	BLQ	BLQ	ND	BLQ	BLQ	BLQ	ND	ND	ND
OAFB-5	8.13E+00	BLQ	2.26E-02	4.14E+01	6.70E+00	2.40E+01	5.22E+01	3.59E+01	1.79E+01	4.61E+01	1.34E+01
OAFB-6	4.28E+01	BLQ	2.40E-02	1.05E+02	2.44E+01	1.93E+01	4.24E+01	2.43E+01	7.23E+00	2.18E+01	5.13E+00
OAFB-7	BLQ	BLQ	2.85E-02	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
OAFB-8	ND	ND	2.93E-02	BLQ	ND	BLQ	BLQ	ND	ND	BLQ	ND
OAFB-9(1)	2.84E+00	ND	BLQ	4.18E-02	1.27E+02	6.18E+01	1.36E+02	3.54E+00	1.45E+02	3.85E+02	2.07E+02
OAFB-9 DUP.	3.04E+00	BLQ	BLQ	6.19E-02	1.34E+02	6.60E+01	1.44E+02	3.98E+00	1.57E+02	4.17E+02	2.26E+02
OAFB-10	BLQ	BLQ	BLQ	3.39E-02	5.49E-02	4.91E-02	1.07E-01	3.81E-02	7.11E-02	2.26E-01	1.23E-01
QC SUMMARY (ug/ml)											
0.5	5.01E-01	5.11E-01	5.00E-01	5.05E-01	5.02E-01	5.07E-01	4.99E-01	5.08E-01	4.97E-01	5.19E-01	5.01E-01
5	4.78E+00	4.79E+00	4.73E+00	4.79E+00	4.82E+00	4.81E+00	4.79E+00	4.82E+00	4.92E+00	4.75E+00	4.81E+00
50	5.21E+01	5.17E+01	5.17E+01	5.16E+01	5.18E+01	5.16E+01	5.13E+01	5.16E+01	5.20E+01	5.08E+01	5.13E+01
50	4.79E+01	4.83E+01	4.83E+01	4.84E+01	4.82E+01	4.84E+01	4.87E+01	4.84E+01	4.80E+01	4.92E+01	4.87E+01
50	5.25E+01	5.20E+01	5.23E+01	5.19E+01	5.13E+01	5.11E+01	5.10E+01	5.05E+01	5.03E+01	4.98E+01	4.97E+01
1.6 QC	1.56E+00	1.44E+00	1.45E+00	1.61E+00	1.67E+00	1.68E+00	1.64E+00	1.66E+00	1.68E+00	1.74E+00	1.67E+00
100 QC	1.04E+02	1.05E+02	1.04E+02	1.04E+02	1.05E+02	1.04E+02	1.01E+02	1.05E+02	1.06E+02	1.01E+02	1.03E+02
50 Aromatics QC	5.42E+01	N/A	N/A	5.33E+01	5.38E+01	5.34E+01	5.36E+01	5.38E+01	5.38E+01	5.36E+01	5.33E+01
MeCl2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Method Blank	BLQ	ND	ND	BLQ	ND	ND	ND	ND	ND	ND	ND

Analyst: David A. Kovacs

BLQ<0.05 ug/ml

Printed: 10/26/94 1 of 1

09/25/00 12:48 FAX AFCEE 023

DP-P&T/GC-FID:PID Analyses for Dr. Kampbell

Units=ng/mL Analyst:L.Black

SAMPLE NAME	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
QC, OBSERVED, PPB	4.68E+01	4.61E+01	4.69E+01	4.51E+01	4.52E+01	4.60E+01	4.44E+01	4.60E+01	4.34E+01	N/A
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	N/A
HF6-MW4	3.70E+00	ND	BLQ	BLQ	ND	BLQ	2.16E+00	2.36E+00	2.22E+00	6.13E+01
HF6-MW4 Duplicate	3.28E+00	ND	BLQ	ND	BLQ	ND	1.84E+00	BLQ	BLQ	7.02E+01
HF6-MW12D	1.10E+01	2.77E+01	3.01E+00	2.38E+00	5.50E+00	3.09E+00	ND	1.67E+00	ND	1.05E+02
HF6-MW14	3.30E+00	ND	ND	ND	ND	ND	2.70E+00	2.08E+00	BLQ	7.41E+01
MW-349-1	3.40E+04	3.57E+04	3.58E+03	2.79E+03	6.85E+03	4.64E+03	7.39E+02	2.93E+03	9.16E+02	9.03E+04
MW-349-2	3.80E+04	3.68E+04	2.74E+03	2.17E+03	5.16E+03	3.56E+03	3.59E+02	1.55E+03	5.03E+02	8.64E+04
MW349-3	ND	BLQ	ND	ND	1.39E+00	ND	ND	ND	ND	8.67E+00
MW349-4	6.13E+00	1.14E+01	1.16E+00	1.33E+00	3.20E+00	2.08E+00	BLQ	2.79E+00	1.59E+00	4.94E+01
MW349-5	2.71E+00	5.44E+00	BLQ	1.09E+00	3.29E+00	2.38E+00	1.66E+00	3.21E+00	2.27E+00	3.06E+01
MW-349-6	4.24E+04	4.22E+04	4.05E+03	2.84E+03	6.78E+03	4.43E+03	5.17E+02	2.20E+03	6.87E+02	1.06E+05
MW-349-7	6.89E+04	1.26E+05	2.55E+04	2.29E+04	5.64E+04	3.45E+04	6.92E+03	2.63E+04	8.10E+03	4.75E+05
MW-349-8	1.40E+04	2.82E+04	2.93E+03	2.09E+03	5.32E+03	3.55E+03	3.32E+02	1.45E+03	4.65E+02	6.11E+04
500 PPB	4.91E+02	4.79E+02	4.79E+02	4.79E+02	5.15E+02	4.78E+02	4.71E+02	4.69E+02	4.75E+02	N/A
MW349-9	3.22E+00	5.41E+00	1.57E+00	1.54E+00	2.65E+00	1.77E+00	1.87E+00	2.86E+00	2.22E+00	6.56E+02
MW349-10	1.27E+00	2.46E+00	BLQ	BLQ	1.87E+00	1.30E+00	BLQ	1.99E+00	ND	2.39E+01
MW349-11	9.12E-01	2.08E+00	BLQ	BLQ	2.04E+00	1.49E+00	1.43E+00	2.22E+00	1.75E+00	2.13E+01
MW349-12	BLQ	1.38E+00	ND	ND	1.39E+00	ND	ND	ND	ND	2.12E+01
MW349-13	4.58E+02	6.71E+02	4.17E+01	2.78E+01	5.52E+01	3.67E+01	2.81E+00	9.32E+00	2.81E+00	1.73E+03
MW349-14	2.64E+02	4.65E+02	2.89E+01	2.00E+01	4.66E+01	2.33E+01	2.10E+00	5.84E+00	1.80E+00	1.22E+03
MW349-17	4.46E+04	8.48E+04	1.32E+04	1.19E+04	2.88E+04	1.75E+04	3.02E+03	1.33E+04	4.03E+03	2.73E+05
MW349-18	2.35E+02	4.19E+02	3.35E+01	2.48E+01	5.69E+01	3.00E+01	3.24E+00	1.01E+01	2.65E+00	1.15E+03
MP-FPTA3-4S	2.34E+02	2.06E+02	1.17E+02	9.52E+01	2.93E+02	1.96E+02	3.47E+01	1.37E+02	8.09E+01	1.63E+03
MP-FPTA3-8S	1.53E+00	4.37E+01	BLQ	ND	1.40E+00	ND	ND	ND	ND	5.81E+01
MP-FPTA3-20S	BLQ	3.20E+00	ND	ND	BLQ	ND	ND	ND	ND	1.01E+01
MP-6MW4S	1.72E+00	4.00E+01	BLQ	ND	ND	ND	ND	ND	ND	3.86E+01
GC LAB BLANK, PPB	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	N/A
100 PPB	9.34E+01	9.46E+01	9.47E+01	9.24E+01	8.70E+01	9.32E+01	9.32E+01	9.22E+01	9.09E+01	N/A
QC, OBSERVED, PPB	5.08E+01	5.03E+01	5.06E+01	4.97E+01	4.75E+01	4.99E+01	4.85E+01	5.07E+01	4.78E+01	N/A
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

09/25/00 12:48 FAX AFCEE 024

09/25/00 12:49 FAX AFCEE

SAMPLE NAME	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
100 PPB	1.00E+02	1.00E+02	9.92E+01	9.92E+01	9.40E+01	1.00E+02	9.90E+01	9.94E+01	9.88E+01	N/A
QC, OBSERVED, PPB	5.09E+01	5.01E+01	5.08E+01	4.93E+01	4.93E+01	5.04E+01	4.95E+01	5.09E+01	4.85E+01	N/A
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	N/A
MP-FPTA3-2D	5.50E+01	1.31E+01	4.83E+00	4.37E+00	4.51E+00	3.13E+00	5.52E+00	4.01E+00	3.36E+00	2.50E+02
MP-FPTA3-2M	7.75E+02	4.05E+00	9.91E+02	4.41E+02	1.02E+03	2.18E+00	5.79E+01	ND	BLQ	3.30E+03
MP-FPTA3-4D	1.06E+00	BLQ	3.29E+00	2.06E+00	4.08E+00	ND	ND	ND	9.95E-01	4.07E+01
MP-FPTA3-5D	BLQ	1.11E+00	BLQ	BLQ	1.01E+00	ND	ND	ND	ND	4.11E+00
MP-FPTA3-5M	5.66E+01	2.93E+01	2.07E+01	1.53E+01	2.53E+01	4.19E+01	ND	ND	1.76E+00	1.72E+02
MP-FPTA3-5M Duplicate	5.42E+01	2.88E+01	1.93E+01	1.46E+01	2.31E+01	3.93E+01	ND	ND	1.73E+00	1.65E+02
MP-FPTA3-6D	2.77E+00	4.94E+00	BLQ	BLQ	BLQ	ND	ND	ND	ND	1.63E+01
MP-FPTA3-8D	2.89E+00	1.92E+00	ND	ND	ND	BLQ	ND	2.02E+00	3.59E+00	2.85E+02
MP-FPTA3-9D	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
MP-FPTA3-12D	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
500 PPB	4.86E+02	4.94E+02	4.81E+02	4.71E+02	4.29E+02	4.91E+02	4.98E+02	4.93E+02	4.86E+02	N/A
MP-FPTA3-17D	1.11E+00	1.20E+00	BLQ	9.25E-01	9.48E-01	ND	1.25E+00	1.62E+00	ND	7.48E+00
MP-FPTA3-20D	ND	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND	BLQ
MP-FPTA3-22D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-FPTA3-22S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-FPTA3-23D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-FPTA3-23S	ND	2.20E+00	ND	ND	ND	ND	ND	ND	ND	2.28E+00
MP-FPTA3-24	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-FPTA3-27D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-FPTA3-27D Duplicate	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
FPTA3-UST1	ND	ND	ND	ND	ND	ND	ND	ND	BLQ	BLQ
HF6-MW1	ND	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
1000 PPB	1.00E+03	1.02E+03	1.04E+03	1.03E+03	1.03E+03	1.02E+03	1.04E+03	1.03E+03	1.01E+03	N/A
FPTA3-MW-1	6.42E+00	1.96E+01	2.64E+00	2.21E+00	4.59E+00	2.43E+00	ND	1.82E+00	ND	6.13E+01
FPTA3-MW-2	3.48E+00	ND	2.60E+00	1.28E+00	9.22E-01	ND	9.13E+00	9.21E+00	5.30E+00	1.76E+02
FPTA3-MW-3	ND	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND	BLQ
FPTA3-MW-4	ND	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND	BLQ
FPTA3-MW-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW-5 Duplicate	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
FPTA3-MW-6	BLQ	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
FPTA3-MW-6A	5.42E+00	ND	ND	ND	BLQ	ND	1.77E+00	ND	ND	9.84E+01
HF6-MW2	ND	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND	BLQ
HF6-MW2D	1.98E+01	5.06E+01	5.26E+00	4.04E+00	9.72E+00	4.69E+00	ND	2.04E+00	ND	1.62E+02
100 PPB	9.67E+01	9.77E+01	9.88E+01	9.59E+01	9.76E+01	9.62E+01	9.65E+01	9.65E+01	9.43E+01	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

025

DON KAMPBELL'S SOIL SAMPLES FROM OFFUTT AFB FOR TOC (SR# SF-1-92)

SAMPLE	SOIL FILT %OC	SOLIDS %OC	TOTAL SOIL %TOC	MEAN %TOC
OAFB 1-1	0.130	0.145	0.158	0.160
OAFB 1-2	0.150	0.147	0.162	
OAFB 2-1	0.013	0.098	0.111	0.111
OAFB 2-2	0.016	0.095	0.111	
OAFB 3-1	0.008	0.075	0.083	0.081
OAFB 3-2	0.006	0.073	0.079	
OAFB 3-3	0.007	0.075	0.082	
OAFB 3-1 FIELD DUP	0.006	0.076	0.082	0.078
OAFB 3-2 FIELD DUP	0.004	0.071	0.075	
OAFB 3-3 FIELD DUP	0.004	0.072	0.076	
OAFB 4-1	0.006	0.054	0.060	0.059
OAFB 4-2	0.006	0.052	0.058	
OAFB 4-1 FIELD DUP	0.006	0.081	0.087	0.091
OAFB 4-2 FIELD DUP	0.011	0.080	0.091	
OAFB 4-3 FIELD DUP	0.006	0.089	0.095	
OAFB 5-1	0.032	0.262	0.294	0.296
OAFB 5-2	0.032	0.266	0.298	
OAFB 6-1	0.006	0.039	0.045	0.045
OAFB 6-2	0.006	0.039	0.045	
OAFB 6-1 FIELD DUP	0.007	0.046	0.053	0.052
OAFB 6-2 FIELD DUP	0.008	0.043	0.051	
OAFB 7-1	0.006	0.013	0.019	0.019
OAFB 7-2	0.006	0.012	0.018	
OAFB 7-1 FIELD DUP	0.004	0.014	0.018	0.017
OAFB 7-2 FIELD DUP	0.003	0.013	0.016	
OAFB 8-1	0.011	0.095	0.106	0.105
OAFB 8-2	0.010	0.095	0.105	
OAFB 8-1 FIELD DUP	0.013	0.111	0.124	0.122
OAFB 8-2 FIELD DUP	0.011	0.109	0.120	
OAFB 9-1	0.070	2.531	2.601	2.600
OAFB 9-2	0.060	2.539	2.599	

SAMPLE	SOIL FILT %OC	SOLIDS %OC	TOTAL SOIL %TOC	MEAN %TOC
OAFB 10-1	0.037	0.319	0.356	0.359
OAFB 10-2	0.033	0.329	0.362	
LECO		1.001		
		1.008		
		1.024		
		1.031		
WPO32-II				
	9.7 MG/L			
	9.6 MG/L			
	9.6 MG/L			
	9.9 MG/L			

TRUE VALUES: LECO = 1.00 +/- 0.04% C
WPO32-II = 9.60 MG/L OC

09/25/00 12:49 FAX AFCEE 026

Sample	mg/L $NO^-_2+NO^-_3$(N)	mg/L NH_3(N)	mg/L Cl^-	mg/L $SO_4^=$
MW349-1	.07	<.05	15.6	78.2
MW349-2	<.05	<.05	14.8	49.7
MW349-2 Dup	<.05	<.05	----	----
MW349-3	.58	<.05	47.8	68.5
MW349-4	1.78	<.05	64.4	85.4
MW349-4 Dup	----	----	64.7	85.8
MW349-5	1.37	<.05	170	77.4
MW349-6	<.05	<.05	31.7	28.7
MW349-7	<.05	<.05	33.0	51.0
MW349-8	<.05	<.05	67.3	74.4
MW349-9	15.4	<.05	28.9	11.9
MW349-9 Dup	----	----	29.0	12.0
MW349-10	14.3	<.05	10.0	61.7
MW349-10 Dup	14.2	<.05	----	----
MW349-11	3.10	<.05	2.11	8.31
MW349-12	8.15	<.05	28.6	14.1
MW349-13	1.28	<.05	1.81	1.14
MW349-14	1.66	<.05	10.7	1.75
MW349-17	<.05	<.05	33.8	52.0
MW349-18	1.60	<.05	11.1	1.83
HF6-MW2	<.05	<.05	20.4	175
HF6-MW2D	<.05	.46	4.85	48.5
HF6-MW2D Dup	----	----	4.88	48.3
HF6-MW4	<.05	<.05	25.2	391
HF6-MW12D	<.05	.41	5.59	49.4
HF6-MW14	<.05	<.05	25.3	387
FPTA3-MW1	<.05	.59	4.53	45.8
FPTA3-MW1 Dup	<.05	.53	----	----
FPTA3-MW2	<.05	<.05	3.60	17.8
FPTA3-MW2 Dup	----	----	3.70	17.9
FPTA3-MW3	<.05	.22	17.2	3.72
FPTA3-MW4	1.52	<.05	4.61	15.6
FPTA3-MW5	<.05	<.05	2.98	24.0
FPTA3-MW6	<.05	.45	22.8	17.6
FPTA3-MW6A	<.05	.66	19.5	5.75
FPTA3-MW6A Dup	<.05	.64	----	----
MP-FPTA3-2D	<.05	1.27	10.5	2.35
MP-FPTA3-2M	<.05	1.18	16.2	<.5
MP-FPTA3-4D	<.05	1.71	18.1	2.83
MP-FPTA3-5D	<.05	.93	5.57	46.0
MP-FPTA3-5M	<.05	1.38	129	23.2
MP-FPTA3-6D	<.05	.56	213	8.35
MP-FPTA3-6D Dup	<.05	.57	----	----
MP-FTPA3-8D	<.05	<.05	5.31	<.5
MP-FTPA3-9D	<.05	<.05	7.19	65.0
MP-FTPA3-12D	<.05	<.05	7.00	42.2
MP-FTPA3-12D Dup	----	----	6.94	42.6
MP-FTPA3-17D	<.05	.39	65.9	35.5
MP-FTPA3-20D	<.05	1.07	22.9	4.72
MP-FTPA3-20D Dup	<.05	.99	----	----
MP-FTPA3-22D	<.05	<.05	7.87	6.75

Sample	mg/L $NO_2^- + NO_3^-$ (N)	mg/L NH_3 (N)	mg/L Cl^-	mg/L $SO_4^=$
MP-FTPA3-22S	<.05	.31	13.0	41.3
MP-FTPA3-23D	<.05	.75	11.1	24.5
MP-FTPA3-23S	.20	<.05	15.9	27.9
MP-FTPA3-24	<.05	<.05	3.74	21.5
MP-FTPA3-27D	<.05	.45	165	36.1
MP-FTPA3-UST1	<.05	<.05	49.4	117
HF6-MW1	<.05	.68	4.27	67.5
HF6-MW1 Dup	<.05	.71	4.07	66.6
Blank	<.05	<.05	<.5	<.5
	<.05	<.05	<.5	<.5
WP032	2.68	2.26	107	74.4
	2.51	2.12	108	74.5
WP032 T.V.	2.81	2.30	106	75.0
Spike Recovery	101%	100%	99%	100%
	104%	100%	96%	97%

ELEMENTAL CONST. ENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7908		7909		7910		7911		
STATION	MP-FPTA3-2		MW-394-4		FPTA3-MW6A		MP-FPTA-3-		
TIME	12:31		12:33		12:35		12:36		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	66.4	6.5	57.4	5.6	19.4	1.9	33.1	3.2	0.6182
K	6.24	0.51	1.78	0.45	4.15	0.45	5.44	0.45	0.4051
Ca	167.	16.	71.9	7.2	185.	18.	169.	17.	0.0744
Mg	39.4	3.9	12.6	1.2	55.1	5.5	49.1	4.9	0.0269
Fe	24.6	2.4	<0.10	0.10	5.92	0.60	22.6	2.2	0.0951
Mn	0.825	0.084	<0.015	0.015	4.65	0.46	3.96	0.39	0.0138
Co	<0.0035	0.0035	<0.0035	0.0035	<0.0035	0.0035	0.0065	0.0035	0.0031
Mo	0.014	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	0.110	0.048	<0.048	0.048	<0.048	0.048	0.126	0.048	0.0440
As	0.103	0.021	<0.021	0.021	0.024	0.022	0.044	0.022	0.0195
Se	<0.017	0.017	<0.015	0.015	<0.015	0.015	<0.016	0.016	0.0140
Cd	0.0053	0.0023	<0.0023	0.0023	0.0024	0.0023	0.0053	0.0023	0.0021
Be	<0.0014	0.0014	<0.0007	0.0007	<0.0015	0.0015	<0.0014	0.0014	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0162	0.0091	0.0950	0.0091	0.0178	0.0092	0.0156	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0189	0.0090	<0.0088	0.0088	0.0095	0.0089	0.0166	0.0089	0.0079
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0138
Pb	<0.022	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	0.17	0.13	<0.13	0.13	0.23	0.13	0.17	0.13	0.1193
Sr	1.36	0.13	0.275	0.027	1.70	0.17	1.66	0.16	0.0007
V	<0.019	0.019	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.0179
Ba	0.570	0.057	0.172	0.017	0.436	0.043	0.983	0.098	0.0047
B	0.099	0.019	0.229	0.026	0.086	0.019	0.093	0.019	0.0174
Ti	<0.0019	0.0019	<0.0019	0.0019	<0.0019	0.0019	0.0140	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:50 FAX AFCEE 029

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7912		7913		7914		7915		
STATION	MW-349-8		FPTA 3-MW6		MP-FPTA 3-		MP-FPTA 3-		
TIME	12:38		12:40		12:42		12:44		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	24.6	2.4	15.1	1.4	14.0	1.3	14.5	1.4	0.6182
K	<0.45	0.45	4.58	0.45	4.16	0.45	4.61	0.45	0.4051
Ca	152.	15.	170.	17.	124.	12.	160.	16.	0.0744
Mg	21.3	2.1	47.0	4.7	32.0	3.2	31.3	3.1	0.0269
Fe	0.56	0.10	4.26	0.43	4.10	0.41	4.87	0.49	0.0951
Mn	4.61	0.46	3.01	0.30	1.26	0.12	1.39	0.14	0.0138
Co	0.0111	0.0035	0.0061	0.0035	0.0060	0.0035	0.0039	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	<0.048	0.048	0.064	0.048	<0.048	0.048	<0.048	0.048	0.0440
As	<0.022	0.022	0.026	0.021	0.046	0.021	0.055	0.021	0.0195
Se	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Cd	0.0028	0.0023	0.0024	0.0023	<0.0023	0.0023	0.0074	0.0023	0.0021
Be	<0.0013	0.0013	<0.0014	0.0014	<0.0011	0.0011	<0.0013	0.0013	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0304	0.0091	0.0239	0.0091	0.0101	0.0091	0.0202	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0140	0.0089	<0.0089	0.0089	<0.0089	0.0089	0.0174	0.0089	0.0079
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0138
Pb	0.026	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	<0.13	0.13	<0.13	0.13	<0.13	0.13	0.21	0.13	0.1193
Sr	0.364	0.036	1.47	0.14	1.00	0.10	1.24	0.12	0.0007
V	<0.019	0.019	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.0179
Ba	0.524	0.052	0.342	0.034	0.178	0.018	0.219	0.022	0.0047
B	0.072	0.019	0.075	0.019	0.063	0.019	0.057	0.019	0.0174
Ti	0.0036	0.0019	0.0063	0.0019	<0.0019	0.0019	0.0056	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:50 FAX AFCEE 030

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7916		7917		7918		7919		
STATION	MW-349-6		MP-FPTA3-5		FPTA 3-MW5		MP-FPTA3-4		
TIME	12:45		12:47		12:58		13:00		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	23.9	2.3	11.7	1.1	9.90	0.94	21.3	2.0	0.6182
K	<0.45	0.45	3.47	0.45	2.54	0.45	6.71	0.55	0.4051
Ca	169.	16.	132.	13.	157.	15.	181.	18.	0.0744
Mg	29.4	2.9	38.6	3.8	24.7	2.4	55.4	5.5	0.0269
Fe	<0.10	0.10	19.3	1.9	<0.10	0.10	24.3	2.4	0.0951
Mn	0.711	0.073	2.68	0.27	0.044	0.015	1.83	0.18	0.0138
Co	<0.0035	0.0035	0.0063	0.0035	<0.0035	0.0035	0.0061	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	<0.048	0.048	<0.048	0.048	<0.048	0.048	<0.048	0.048	0.0440
As	<0.021	0.021	0.030	0.021	<0.021	0.021	0.083	0.021	0.0195
Se	<0.015	0.015	<0.016	0.016	<0.015	0.015	<0.016	0.016	0.0140
Cd	<0.0023	0.0023	<0.0023	0.0023	0.0029	0.0023	0.0038	0.0023	0.0021
Be	<0.0014	0.0014	<0.0011	0.0011	<0.0013	0.0013	<0.0015	0.0015	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0339	0.0091	<0.0091	0.0091	<0.0091	0.0091	0.0134	0.0092	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	<0.0089	0.0089	<0.0089	0.0089	<0.0089	0.0089	0.0090	0.0090	0.0079
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0138
Pb	0.117	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	<0.13	0.13	<0.13	0.13	<0.13	0.13	0.23	0.13	0.1193
Sr	0.624	0.062	1.24	0.12	1.10	0.11	2.04	0.20	0.0007
V	<0.019	0.019	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.0179
Ba	0.491	0.049	0.343	0.034	0.249	0.025	0.582	0.058	0.0047
B	0.108	0.019	0.065	0.019	0.153	0.019	0.227	0.028	0.0174
Ti	<0.0019	0.0019	<0.0019	0.0019	<0.0019	0.0019	0.0030	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:50 FAX AFCEE 032

ELEMENTAL CONS. ENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7920		7921		7922		7923		
STATION	MW-349-13		MP-FPTA3-6		FPTA3-MW3		MW-349-18		
TIME	13:02		13:04		13:06		13:08		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	45.3	4.4	23.9	2.3	22.1	2.1	14.3	1.3	0.6182
K	<0.45	0.45	6.34	0.50	4.42	0.45	<0.45	0.45	0.4051
Ca	69.5	6.9	243.	24.	172.	17.	115.	11.	0.0744
Mg	15.4	1.5	65.7	6.5	41.0	4.1	14.7	1.4	0.0269
Fe	<0.10	0.10	19.2	1.9	26.9	2.7	<0.10	0.10	0.0951
Mn	<0.015	0.015	4.09	0.41	1.55	0.15	<0.015	0.015	0.0138
Co	0.0037	0.0035	<0.0035	0.0035	<0.0035	0.0035	<0.0035	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	<0.048	0.048	0.071	0.048	<0.048	0.048	0.049	0.048	0.0440
As	<0.021	0.021	0.065	0.022	0.155	0.021	<0.021	0.021	0.0195
Se	<0.015	0.015	<0.016	0.016	<0.017	0.017	<0.015	0.015	0.0140
Cd	<0.0023	0.0023	0.0046	0.0023	0.0049	0.0023	<0.0023	0.0023	0.0021
Be	<0.0007	0.0007	<0.0020	0.0020	<0.0014	0.0014	<0.0010	0.0010	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0097	0.0091	0.0385	0.0092	0.0115	0.0092	0.0123	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	<0.0088	0.0088	0.0195	0.0091	0.0113	0.0090	0.0123	0.0088	0.0079
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0138
Pb	<0.022	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	<0.13	0.13	0.24	0.13	<0.13	0.13	<0.13	0.13	0.1193
Sr	0.141	0.014	2.04	0.20	1.45	0.14	0.327	0.032	0.0007
V	<0.019	0.019	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.0179
Ba	0.200	0.020	0.424	0.042	0.441	0.044	0.245	0.024	0.0047
B	0.046	0.019	0.069	0.019	0.157	0.020	0.101	0.019	0.0174
Ti	<0.0018	0.0018	0.0079	0.0020	0.0078	0.0019	0.0069	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:50 FAX AFCEE 031

ELEMENTAL CONST. ENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7924		7925		7926		7927		
STATION	MP-FPTA3-5		MP-FPTA3-8		MP-FPTA3-1		MW 349-5		
TIME	13:10		13:11		13:13		13:15		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	138.	13.	12.9	1.2	7.27	0.68	68.6	6.8	0.6182
K	5.35	0.45	1.27	0.45	4.00	0.45	1.84	0.45	0.4051
Ca	123.	12.	131.	13.	197.	19.	122.	12.	0.0744
Mg	51.2	5.1	37.9	3.8	35.0	3.5	19.8	1.9	0.0269
Fe	19.4	1.9	6.51	0.65	1.55	0.16	<0.10	0.10	0.0951
Mn	0.233	0.025	3.78	0.38	1.43	0.14	<0.015	0.015	0.0138
Co	0.0063	0.0035	<0.0035	0.0035	0.0070	0.0035	0.0046	0.0035	0.0031
Mo	0.035	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	<0.048	0.048	<0.048	0.048	0.065	0.048	<0.048	0.048	0.0440
As	0.275	0.027	0.023	0.022	0.032	0.021	<0.021	0.021	0.0195
Se	<0.016	0.016	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0140
Cd	0.0061	0.0023	0.0042	0.0023	0.0040	0.0023	0.0025	0.0023	0.0021
Be	<0.0011	0.0011	<0.0011	0.0011	<0.0016	0.0016	<0.0010	0.0010	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.130	0.012	0.0124	0.0091	0.0208	0.0092	0.0095	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	<0.0089	0.0089	<0.0089	0.0089	0.0253	0.0090	<0.0089	0.0089	0.0079
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0138
Pb	<0.022	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	<0.13	0.13	<0.13	0.13	0.16	0.13	<0.13	0.13	0.1193
Sr	1.67	0.16	1.23	0.12	1.58	0.15	0.438	0.044	0.0007
V	<0.019	0.019	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.0179
Ba	0.360	0.036	0.332	0.033	0.208	0.021	0.197	0.020	0.0047
B	0.132	0.019	0.072	0.019	0.046	0.019	0.132	0.019	0.0174
Ti	<0.0019	0.0019	<0.0019	0.0019	0.0031	0.0019	<0.0019	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:51 FAX AFCEE 033

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3416 WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7932		7933		7934		7935		
STATION	MW-349-12		FPTA 3-MW1		FPTA 3-MW4		HF6-MW1 1		
TIME	16:24		16:26		16:28		16:30		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	12.8	1.2	29.9	2.9	8.26	0.78	36.9	3.6	0.6182
K	<0.45	0.45	5.20	0.45	2.89	0.45	4.90	0.45	0.4051
Ca	92.6	9.2	148.	14.	140.	14.	143.	14.	0.0744
Mg	16.8	1.6	45.0	4.5	23.9	2.3	45.1	4.5	0.0269
Fe	<0.10	0.10	7.29	0.73	<0.10	0.10	9.56	0.96	0.0951
Mn	<0.015	0.015	0.376	0.040	<0.015	0.015	2.76	0.27	0.0138
Co	<0.0035	0.0035	0.0047	0.0035	0.0049	0.0035	<0.0035	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	0.059	0.048	<0.048	0.048	0.089	0.048	<0.048	0.048	0.0440
As	0.038	0.021	0.036	0.021	0.051	0.021	0.047	0.021	0.0195
Se	0.039	0.015	0.023	0.015	0.066	0.015	0.021	0.015	0.0140
Cd	<0.0023	0.0023	0.0026	0.0023	0.0039	0.0023	0.0025	0.0023	0.0021
Be	<0.0008	0.0008	<0.0012	0.0012	<0.0012	0.0012	<0.0012	0.0012	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0126	0.0091	0.0185	0.0091	0.0183	0.0091	0.0188	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0216	0.0088	0.0251	0.0089	0.0362	0.0089	0.0241	0.0089	0.0079
Tl	<0.015	0.015	0.015	0.015	0.031	0.015	0.022	0.015	0.0138
Pb	<0.022	0.022	<0.022	0.022	0.024	0.022	<0.022	0.022	0.0206
Li	<0.13	0.13	0.19	0.13	0.34	0.13	0.13	0.13	0.1193
Sr	0.348	0.035	1.28	0.12	0.950	0.095	1.32	0.13	0.0007
V	0.027	0.019	0.022	0.019	0.038	0.019	<0.019	0.019	0.0179
Ba	0.292	0.029	0.394	0.039	0.252	0.025	0.305	0.030	0.0047
B	0.136	0.019	0.134	0.019	0.093	0.019	0.144	0.019	0.0174
Ti	<0.0019	0.0019	0.0029	0.0019	0.0100	0.0019	0.0035	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7928	7929	7930	7931
STATION	FPTA3-MW2	HF6-MW4 1	HF6-MW14	FPAT3-VSTI
TIME	16:17	16:19	16:20	16:22
DATE	01-DEC-94	01-DEC-94	01-DEC-94	01-DEC-94
PR DIL	1.1100	1.1100	1.1100	1.1100
DIL	1.0000	1.0000	1.0000	1.0000

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	23.8	2.3	28.0	2.7	28.5	2.8	89.6	8.9	0.6182
K	3.72	0.45	4.71	0.45	4.43	0.45	10.8	1.0	0.4051
Ca	236.	23.	309.	30.	312.	31.	42.0	4.2	0.0744
Mg	48.2	4.8	67.1	6.7	67.4	6.7	14.4	1.4	0.0269
Fe	22.9	2.3	26.4	2.6	26.8	2.6	<0.10	0.10	0.0951
Mn	2.95	0.29	4.44	0.44	4.47	0.44	0.352	0.038	0.0138
Co	0.0075	0.0035	0.0167	0.0035	0.0220	0.0035	<0.0035	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	0.012	0.012	<0.012	0.012	0.0108
Al	0.082	0.048	0.147	0.048	0.083	0.048	<0.048	0.048	0.0440
As	0.075	0.022	0.111	0.022	0.098	0.022	0.021	0.021	0.0195
Se	<0.016	0.016	0.026	0.017	<0.017	0.017	0.020	0.015	0.0140
Cd	0.0178	0.0023	0.0077	0.0024	0.0060	0.0024	<0.0023	0.0023	0.0021
Be	<0.0019	0.0019	<0.0025	0.0025	<0.0025	0.0025	<0.0005	0.0005	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0254	0.0092	0.0467	0.0093	0.0440	0.0093	0.0093	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0368	0.0091	0.0534	0.0093	0.0445	0.0093	0.0132	0.0088	0.0079
Tl	0.026	0.015	0.037	0.015	0.026	0.015	<0.015	0.015	0.0138
Pb	<0.022	0.022	<0.023	0.023	<0.023	0.023	<0.022	0.022	0.0206
Li	0.25	0.13	0.34	0.13	0.41	0.13	<0.13	0.13	0.1193
Sr	2.06	0.20	2.01	0.20	2.02	0.20	0.279	0.028	0.0007
V	0.034	0.019	0.044	0.019	0.039	0.019	<0.019	0.019	0.0179
Ba	0.940	0.094	0.155	0.015	0.149	0.015	0.0399	0.0052	0.0047
B	0.135	0.019	0.090	0.019	0.056	0.019	0.121	0.019	0.0174
Ti	0.0035	0.0020	0.0081	0.0021	0.0045	0.0021	<0.0018	0.0018	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:51 FAX AFCEE 034

ELEMENTAL CONST. ..NTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7932		7933		7934		7935		
STATION	MW-349-12		FPTA 3-MW1		FPTA 3-MW4		HF6-MW1 1		
TIME	16:24		16:26		16:28		16:30		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	12.8	1.2	29.9	2.9	8.26	0.78	36.9	3.6	0.6182
K	<0.45	0.45	5.20	0.45	2.89	0.45	4.90	0.45	0.4051
Ca	92.6	9.2	148.	14.	140.	14.	143.	14.	0.0744
Mg	16.8	1.6	45.0	4.5	23.9	2.3	45.1	4.5	0.0269
Fe	<0.10	0.10	7.29	0.73	<0.10	0.10	9.56	0.96	0.0951
Mn	<0.015	0.015	0.376	0.040	<0.015	0.015	2.76	0.27	0.0138
Co	<0.0035	0.0035	0.0047	0.0035	0.0049	0.0035	<0.0035	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	0.059	0.048	<0.048	0.048	0.089	0.048	<0.048	0.048	0.0440
As	0.038	0.021	0.036	0.021	0.051	0.021	0.047	0.021	0.0195
Se	0.039	0.015	0.023	0.015	0.066	0.015	0.021	0.015	0.0140
Cd	<0.0023	0.0023	0.0026	0.0023	0.0039	0.0023	0.0025	0.0023	0.0021
Be	<0.0008	0.0008	<0.0012	0.0012	<0.0012	0.0012	<0.0012	0.0012	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0126	0.0091	0.0185	0.0091	0.0183	0.0091	0.0188	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0216	0.0089	0.0251	0.0089	0.0362	0.0089	0.0241	0.0089	0.0079
Tl	<0.015	0.015	0.015	0.015	0.031	0.015	0.022	0.015	0.0138
Pb	<0.022	0.022	<0.022	0.022	0.024	0.022	<0.022	0.022	0.0206
Li	<0.13	0.13	0.19	0.13	0.34	0.13	0.13	0.13	0.1193
Sr	0.348	0.035	1.28	0.12	0.950	0.095	1.32	0.13	0.0007
V	0.027	0.019	0.022	0.019	0.038	0.019	<0.019	0.019	0.0179
Ba	0.292	0.029	0.394	0.039	0.252	0.025	0.305	0.030	0.0047
B	0.136	0.019	0.134	0.019	0.093	0.019	0.144	0.019	0.0174
Ti	<0.0019	0.0019	0.0029	0.0019	0.0100	0.0019	0.0035	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:51 FAX AFCEE 035

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7936		7937		7938		7939		
STATION	MW-349-12		MW-349-14		MW-349-17		MW-349-3		
TIME	16:32		16:34		16:40		16:41		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	17.2	1.6	14.8	1.4	24.4	2.4	84.3	8.3	0.6182
K	4.31	0.45	0.60	0.45	<0.45	0.45	2.32	0.44	0.4051
Ca	114.	11.	113.	11.	153.	15.	42.2	4.2	0.0744
Mg	30.6	3.0	14.6	1.4	21.4	2.1	6.65	0.66	0.0269
Fe	<0.10	0.10	<0.10	0.10	0.10	0.10	<0.10	0.10	0.0951
Mn	<0.015	0.015	<0.015	0.015	3.51	0.35	<0.015	0.015	0.0138
Co	0.0087	0.0035	0.0057	0.0035	0.0047	0.0035	<0.0035	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	0.014	0.012	<0.012	0.012	0.0108
Al	0.068	0.048	0.134	0.048	0.071	0.048	0.321	0.048	0.0440
As	0.039	0.021	0.055	0.021	0.035	0.021	0.052	0.021	0.0195
Se	0.029	0.015	0.043	0.015	0.035	0.015	0.062	0.015	0.0140
Cd	0.0032	0.0023	<0.0023	0.0023	0.0029	0.0023	<0.0023	0.0023	0.0021
Be	<0.0010	0.0010	<0.0010	0.0010	<0.0013	0.0013	<0.0005	0.0005	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0171	0.0091	0.0184	0.0091	0.0357	0.0091	0.0152	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0284	0.0088	0.0350	0.0088	0.0285	0.0089	0.0364	0.0088	0.0079
Tl	0.025	0.015	0.032	0.015	0.019	0.015	0.033	0.015	0.0138
Pb	<0.022	0.022	0.035	0.022	0.103	0.022	0.051	0.022	0.0206
Li	0.19	0.13	0.15	0.13	0.20	0.13	<0.13	0.13	0.1193
Sr	0.464	0.046	0.319	0.032	0.354	0.035	0.157	0.015	0.0007
V	0.031	0.019	0.055	0.019	0.029	0.019	0.067	0.019	0.0179
Ba	0.237	0.023	0.248	0.025	0.477	0.047	0.162	0.016	0.0047
B	0.133	0.019	0.102	0.019	0.067	0.019	0.153	0.019	0.0174
Ti	0.0103	0.0019	0.0076	0.0019	0.0041	0.0019	0.0090	0.0018	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:52 FAX AFCEE 036

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7940		7941		7942		7943		
STATION	MW-349-7		MW-349-11		MF6-MW2D		MW-349-12		
TIME	16:43		16:45		16:47		16:48		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	24.2	2.3	18.7	1.8	32.1	3.1	24.4	2.4	0.6182
K	1.24	0.45	3.26	0.45	5.12	0.45	<0.45	0.45	0.4051
Ca	149.	14.	98.7	9.8	146.	14.	107.	10.	0.0744
Mg	20.8	2.0	22.1	2.2	43.6	4.3	13.2	1.3	0.0269
Fe	<0.10	0.10	<0.10	0.10	3.12	0.31	<0.10	0.10	0.0951
Mn	3.40	0.34	<0.015	0.015	0.315	0.034	<0.015	0.015	0.0138
Co	0.0058	0.0035	0.0046	0.0035	0.0042	0.0035	<0.0035	0.0035	0.0031
Mo	0.014	0.012	<0.012	0.012	<0.012	0.012	<0.012	0.012	0.0108
Al	0.101	0.048	0.063	0.048	0.068	0.048	0.168	0.048	0.0440
As	0.043	0.021	0.029	0.021	0.041	0.021	0.034	0.021	0.0195
Se	0.029	0.015	0.031	0.015	0.032	0.015	0.042	0.015	0.0140
Cd	0.0031	0.0023	<0.0023	0.0023	0.0032	0.0023	<0.0023	0.0023	0.0021
Be	<0.0012	0.0012	<0.0009	0.0009	<0.0012	0.0012	<0.0009	0.0009	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0341	0.0091	0.0146	0.0091	0.0199	0.0091	0.0142	0.0091	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0304	0.0089	0.0221	0.0088	0.0269	0.0089	0.0275	0.0088	0.0079
Tl	0.026	0.015	0.027	0.015	0.016	0.015	<0.015	0.015	0.0138
Pb	0.090	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	0.25	0.13	<0.13	0.13	<0.13	0.13	<0.13	0.13	0.1193
Sr	0.342	0.034	0.397	0.039	1.19	0.11	0.274	0.027	0.0007
V	0.034	0.019	0.028	0.019	0.023	0.019	0.039	0.019	0.0179
Ba	0.459	0.046	0.288	0.029	0.170	0.017	0.256	0.026	0.0047
B	0.070	0.019	0.133	0.019	0.137	0.019	0.062	0.019	0.0174
Ti	0.0084	0.0019	0.0058	0.0019	0.0059	0.0019	0.0048	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:52 FAX AFCEE 037

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	7944		7945		7946		7947		
STATION	HF6-MW2 1		MP FPTA3-1		MP-FPTA3-2		MP-FPTA3-2		
TIME	16:50		16:52		16:54		16:56		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
PR DIL	1.1100		1.1100		1.1100		1.1100		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	37.1	3.6	16.6	1.6	23.0	2.2	17.4	1.7	0.6182
K	5.75	0.45	6.54	0.53	6.94	0.57	6.56	0.53	0.4051
Ca	239.	23.	183.	18.	194.	19.	190.	19.	0.0744
Mg	48.8	4.8	48.4	4.8	50.1	5.0	50.0	5.0	0.0269
Fe	7.60	0.76	11.6	1.1	17.2	1.7	14.6	1.4	0.0951
Mn	2.31	0.23	0.603	0.062	0.532	0.055	0.634	0.065	0.0138
Co	0.0129	0.0035	0.0047	0.0035	0.0109	0.0035	0.0058	0.0035	0.0031
Mo	<0.012	0.012	<0.012	0.012	0.012	0.012	<0.012	0.012	0.0108
Al	<0.048	0.048	0.094	0.048	0.079	0.048	0.109	0.048	0.0440
As	0.065	0.021	0.078	0.021	0.130	0.021	0.084	0.021	0.0195
Se	0.036	0.015	0.034	0.015	0.018	0.016	0.041	0.016	0.0140
Cd	0.0058	0.0023	0.0028	0.0023	0.0054	0.0023	0.0042	0.0023	0.0021
Be	<0.0019	0.0019	<0.0015	0.0015	<0.0016	0.0016	<0.0016	0.0016	0.0003
Cu	<0.42	0.42	<0.42	0.42	<0.42	0.42	<0.42	0.42	0.3862
Cr	<0.010	0.010	<0.010	0.010	<0.010	0.010	<0.010	0.010	0.0095
Ni	0.0300	0.0092	0.0383	0.0092	0.0234	0.0092	0.0402	0.0092	0.0082
Zn	<0.43	0.43	<0.43	0.43	<0.43	0.43	<0.43	0.43	0.3916
Ag	0.0322	0.0090	0.0357	0.0089	0.0329	0.0090	0.0330	0.0090	0.0079
Tl	0.017	0.015	0.018	0.015	0.024	0.015	0.023	0.015	0.0138
Pb	<0.022	0.022	<0.022	0.022	<0.022	0.022	<0.022	0.022	0.0206
Li	0.27	0.13	0.31	0.13	0.29	0.13	0.24	0.13	0.1193
Sr	1.69	0.17	1.58	0.15	1.86	0.18	1.63	0.16	0.0007
V	0.021	0.019	0.035	0.019	0.030	0.019	0.034	0.019	0.0179
Ba	0.202	0.020	0.178	0.018	0.594	0.059	0.189	0.019	0.0047
B	0.100	0.019	0.161	0.021	0.136	0.019	0.181	0.023	0.0174
Ti	0.0079	0.0020	0.0125	0.0019	0.0055	0.0019	0.0087	0.0019	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:52 FAX AFCEE 038

ELEMENTAL CONST..ENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	STD1X10		STD1X10		STD1X10		STD1X10		
STATION	----------		----------		----------		----------		
TIME	11:57		12:03		12:05		12:27		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
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	0.96	0.61	2.57	0.61	2.79	0.61	<0.61	0.61	0.6182
K	1.22	0.40	2.07	0.40	2.29	0.40	<0.40	0.40	0.4051
Ca	<0.074	0.074	<0.074	0.074	<0.074	0.074	<0.074	0.074	0.0744
Mg	<0.026	0.026	0.059	0.026	0.067	0.026	<0.026	0.026	0.0269
Fe	<0.095	0.095	<0.095	0.095	<0.095	0.095	<0.095	0.095	0.0951
Mn	<0.013	0.013	<0.013	0.013	<0.013	0.013	<0.013	0.013	0.0138
Co	<0.0031	0.0031	0.0046	0.0031	0.0038	0.0031	<0.0031	0.0031	0.0031
Mo	0.487	0.048	0.497	0.049	0.990	0.099	0.985	0.098	0.0108
Al	<0.044	0.044	<0.044	0.044	0.049	0.044	<0.044	0.044	0.0440
As	<0.019	0.019	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.0195
Se	0.515	0.051	0.513	0.051	1.04	0.10	1.01	0.10	0.0140
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0021
Be	0.508	0.050	0.499	0.049	0.998	0.099	1.00	0.10	0.0003
Cu	<0.38	0.38	<0.38	0.38	0.84	0.38	0.85	0.38	0.3862
Cr	0.150	0.014	0.149	0.014	0.317	0.030	0.311	0.029	0.0095
Ni	0.517	0.051	0.509	0.051	1.01	0.10	1.02	0.10	0.0082
Zn	<0.39	0.39	<0.39	0.39	<0.39	0.39	<0.39	0.39	0.3916
Ag	0.148	0.014	0.150	0.014	0.297	0.029	0.284	0.028	0.0079
Tl	0.486	0.047	0.492	0.048	0.990	0.097	0.979	0.097	0.0138
Pb	0.472	0.048	0.471	0.048	1.00	0.10	0.970	0.098	0.0206
Li	0.20	0.11	0.28	0.11	0.37	0.11	<0.11	0.11	0.1193
Sr	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	0.0007
V	<0.017	0.017	<0.017	0.017	0.024	0.017	<0.017	0.017	0.0179
Ba	<0.0047	0.0047	<0.0047	0.0047	<0.0047	0.0047	<0.0047	0.0047	0.0047
B	<0.017	0.017	<0.017	0.017	<0.017	0.017	<0.017	0.017	0.0174
Ti	0.0046	0.0017	0.0051	0.0017	0.0089	0.0017	0.0035	0.0017	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:52 FAX AFCEE 039

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	STD1X10		STD1X10		STD1X10		ZSTD5		
STATION									
TIME	16:35		17:00		17:26		13:51		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
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	1.19	0.61	<0.61	0.61	7.96	0.75	<0.87	0.87	0.6182
K	1.64	0.40	0.68	0.40	6.08	0.54	<0.58	0.58	0.4051
Ca	<0.074	0.074	<0.074	0.074	<0.074	0.074	<0.074	0.074	0.0744
Mg	<0.026	0.026	<0.026	0.026	0.289	0.031	<0.22	0.22	0.0269
Fe	<0.095	0.095	<0.095	0.095	<0.095	0.095	97.3	9.7	0.0951
Mn	<0.013	0.013	<0.013	0.013	<0.013	0.013	96.9	9.7	0.0138
Co	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	0.0031
Mo	0.977	0.097	0.994	0.099	0.995	0.099	0.014	0.010	0.0108
Al	0.103	0.044	0.058	0.044	0.062	0.044	97.6	9.7	0.0440
As	0.036	0.019	0.024	0.019	0.036	0.019	<0.16	0.16	0.0195
Se	1.05	0.10	1.05	0.10	1.09	0.10	<0.044	0.044	0.0140
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0021
Be	1.00	0.10	1.02	0.10	1.02	0.10	0.0122	0.0008	0.0003
Cu	0.85	0.38	0.87	0.38	0.83	0.38	<0.38	0.38	0.3862
Cr	0.314	0.030	0.320	0.030	0.320	0.030	<0.0095	0.0095	0.0095
Ni	1.01	0.10	1.02	0.10	1.04	0.10	<0.0082	0.0082	0.0082
Zn	<0.39	0.39	<0.39	0.39	<0.39	0.39	<0.39	0.39	0.3916
Ag	0.305	0.030	0.303	0.030	0.300	0.029	<0.0087	0.0087	0.0079
Tl	1.02	0.10	1.03	0.10	1.05	0.10	<0.019	0.019	0.0138
Pb	0.99	0.10	0.98	0.10	1.02	0.10	<0.11	0.11	0.0206
Li	<0.11	0.11	<0.11	0.11	0.75	0.11	<0.11	0.11	0.1193
Sr	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	0.0007
V	0.043	0.017	0.028	0.017	0.036	0.017	<0.018	0.018	0.0179
Ba	<0.0047	0.0047	<0.0047	0.0047	<0.0047	0.0047	0.0215	0.0050	0.0047
B	<0.017	0.017	<0.017	0.017	<0.017	0.017	<0.017	0.017	0.0174
Ti	0.0116	0.0017	0.0089	0.0017	0.0342	0.0031	<0.0026	0.0026	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	STD1X10		STD1X10		STD1X10		STD1X10		
STATION	---		---		---		---		
TIME	12:50		13:17		13:45		16:05		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
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	<0.61	0.61	<0.61	0.61	<0.85	0.85	1.79	0.61	0.6182
K	<0.40	0.40	<0.40	0.40	<0.53	0.53	1.82	0.40	0.4051
Ca	<0.074	0.074	<0.074	0.074	<0.074	0.074	<0.074	0.074	0.0744
Mg	<0.026	0.026	<0.026	0.026	<0.031	0.031	0.045	0.026	0.0269
Fe	<0.095	0.095	<0.095	0.095	<0.095	0.095	<0.095	0.095	0.0951
Mn	<0.013	0.013	<0.013	0.013	<0.013	0.013	<0.013	0.013	0.0138
Co	0.0046	0.0031	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	0.0031
Mo	1.00	0.10	0.976	0.097	0.956	0.095	0.99	0.10	0.0108
Al	<0.044	0.044	<0.044	0.044	<0.044	0.044	0.107	0.044	0.0440
As	<0.019	0.019	<0.019	0.019	<0.019	0.019	0.042	0.019	0.0195
Se	1.02	0.10	1.00	0.10	0.984	0.098	1.06	0.10	0.0140
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0021
Be	1.01	0.10	0.993	0.099	0.972	0.097	1.02	0.10	0.0003
Cu	0.87	0.38	0.84	0.38	0.86	0.38	0.85	0.38	0.3862
Cr	0.315	0.030	0.308	0.029	0.302	0.028	0.321	0.030	0.0095
Ni	1.04	0.10	1.02	0.10	1.00	0.10	1.03	0.10	0.0082
Zn	<0.39	0.39	<0.39	0.39	<0.39	0.39	<0.39	0.39	0.3916
Ag	0.296	0.029	0.283	0.028	0.283	0.028	0.309	0.030	0.0079
Tl	0.996	0.098	0.982	0.097	0.933	0.093	1.03	0.10	0.0138
Pb	1.00	0.10	0.968	0.098	0.926	0.094	1.02	0.10	0.0206
Li	<0.11	0.11	<0.11	0.11	<0.11	0.11	0.23	0.11	0.1193
Sr	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	0.0007
V	<0.017	0.017	<0.017	0.017	<0.017	0.017	0.045	0.017	0.0179
Ba	<0.0047	0.0047	<0.0047	0.0047	<0.0047	0.0047	<0.0047	0.0047	0.0047
B	<0.017	0.017	<0.017	0.017	<0.017	0.017	<0.017	0.017	0.0174
Ti	0.0026	0.0017	0.0064	0.0017	<0.0022	0.0022	0.0100	0.0017	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:53 FAX AFCEE 040

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	STD1X10		STD1X10		STD1X10		ZSTD5		
STATION									
TIME	16:35		17:00		17:26		13:51		
DATE	01-DEC-94		01-DEC-94		01-DEC-94		01-DEC-94		
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	1.19	0.61	<0.61	0.61	7.96	0.75	<0.87	0.87	0.6182
K	1.64	0.40	0.68	0.40	6.08	0.54	<0.58	0.58	0.4051
Ca	<0.074	0.074	<0.074	0.074	<0.074	0.074	<0.074	0.074	0.0744
Mg	<0.026	0.026	<0.026	0.026	0.289	0.031	<0.22	0.22	0.0269
Fe	<0.095	0.095	<0.095	0.095	<0.095	0.095	97.3	9.7	0.0951
Mn	<0.013	0.013	<0.013	0.013	<0.013	0.013	96.9	9.7	0.0138
Co	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	<0.0031	0.0031	0.0031
Mo	0.977	0.097	0.994	0.099	0.995	0.099	0.014	0.010	0.0108
Al	0.103	0.044	0.058	0.044	0.062	0.044	97.6	9.7	0.0440
As	0.036	0.019	0.024	0.019	0.036	0.019	<0.16	0.16	0.0195
Se	1.05	0.10	1.05	0.10	1.09	0.10	<0.044	0.044	0.0140
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0021
Be	1.00	0.10	1.02	0.10	1.02	0.10	0.0122	0.0008	0.0003
Cu	0.85	0.38	0.87	0.38	0.83	0.38	<0.38	0.38	0.3862
Cr	0.314	0.030	0.320	0.030	0.320	0.030	<0.0095	0.0095	0.0095
Ni	1.01	0.10	1.02	0.10	1.04	0.10	<0.0082	0.0082	0.0082
Zn	<0.39	0.39	<0.39	0.39	<0.39	0.39	<0.39	0.39	0.3916
Ag	0.305	0.030	0.303	0.030	0.300	0.029	<0.0087	0.0087	0.0079
Tl	1.02	0.10	1.03	0.10	1.05	0.10	<0.019	0.019	0.0138
Pb	0.99	0.10	0.98	0.10	1.02	0.10	<0.11	0.11	0.0206
Li	<0.11	0.11	<0.11	0.11	0.75	0.11	<0.11	0.11	0.1193
Sr	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	<0.0007	0.0007	0.0007
V	0.043	0.017	0.028	0.017	0.036	0.017	<0.018	0.018	0.0179
Ba	<0.0047	0.0047	<0.0047	0.0047	<0.0047	0.0047	0.0215	0.0050	0.0047
B	<0.017	0.017	<0.017	0.017	<0.017	0.017	<0.017	0.017	0.0174
Ti	0.0116	0.0017	0.0089	0.0017	0.0342	0.0031	<0.0026	0.0026	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:53 FAX AFCEE 041

ELEMENTAL CONSTITUENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

CONCENTRATION IN: MG/L

TAG NO.	ZSTD5
STATION	----------
TIME	17:31
DATE	01-DEC-94
ER DIL	1.0000
DIL	1.0000

ELEMENT	VALUE	STDV +/-	LOD
Na-1	4.91	0.61	0.6182
K	2.61	0.41	0.4051
Ca	<0.074	0.074	0.0744
Mg	<0.28	0.28	0.0269
Fe	103.	10.	0.0951
Mn	103.	10.	0.0138
Co	<0.0031	0.0031	0.0031
Mo	0.031	0.010	0.0108
Al	102.	10.	0.0440
As	0.32	0.19	0.0195
Se	<0.044	0.044	0.0140
Cd	<0.0021	0.0021	0.0021
Be	0.0129	0.0009	0.0003
Cu	<0.38	0.38	0.3862
Cr	<0.0095	0.0095	0.0095
Ni	<0.0082	0.0082	0.0082
Zn	<0.39	0.39	0.3916
Ag	0.0166	0.0088	0.0079
Tl	<0.023	0.023	0.0138
Pb	<0.11	0.11	0.0206
Li	0.39	0.11	0.1193
Sr	<0.0007	0.0007	0.0007
V	0.036	0.018	0.0179
Ba	0.0239	0.0051	0.0047
B	<0.017	0.017	0.0174
Ti	0.0177	0.0026	0.0017

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

09/25/00 12:53 FAX AFCEE 042

ELEMENTAL CONST..ENTS ANALYSIS BY ICAP
THIS REPORT ([CLARK.ICAP]LIST.LST;3410) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1974

PROJECT: WILSON/COOK AQ SAMPLES

TA5

THIS REPORT WAS GENERATED WITH THE FOLLOWING INFORMATION:

ERROR LEVEL PERCENTAGE : 10%

STATISTICAL SENSITIVITES WITH A 2.0 SIGMA INTERVAL WERE USED

CONCENTRATION IN: MG/L

THE CONSTANT FILES USED:

[CLARK.ICAP]TYPE1.AMAX;1
[CLARK.ICAP]TYPE1.XQCA;1
[CLARK.ICAP]TYPE1.XQCB;1
[CLARK.ICAP]TYPE1.XQCC;1
[CLARK.ICAP]TYPE1.STD1;1
[CLARK.ICAP]TYPE1.STD2;1
[CLARK.ICAP]TYPE1.STD3;1
[CLARK.ICAP]TYPE1.STD4;1
[CLARK.ICAP]TYPE1.STD5;1
[CLARK.ICAP]TYPE1.XSS1;1
[CLARK.ICAP]TYPE1.XSS2;1
[CLARK.ICAP]TYPE1.FIXX;1
[CLARK.ICAP]TYPE1.LCN;55
LCN TIME: 12:42:02 LCN DATE: 17-OCT-94 FILTER FACTOR: 0.000002

THE DATA FILES USED:

[CLARK.ICAP]IC0001.DAT;2880
[CLARK.ICAP]TAG.DAT;2998
[CLARK.ICAP]OUTPUT.DAT;1974
[CLARK.ICAP]OUTPUT.LST;1891
[CLARK.ICAP]ARCH.DAT;15

09/25/00 12:53 FAX AFCEE 043

MANTECH

Ref: 94-JH36/vg

December 29, 1994

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:

Attached are TOC results for a set of 14 soil samples submitted to ManTech Environmental December 22, 1994 under Service Request #SF-1-98 Mod. 1. TOC determinations were begun December 22, 1994 and completed December 29, 1994 using RSKSOP-102 and RSKSOP-120.

A Leco standard soil and a known AQC sample were analyzed with your samples for quality control. If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

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

OFFUTT AFB SOILS FOR TOC (SR# SF-1-98 MOD 1)

SAMPLES	%OC SOIL FILTRATES	%OC SOLIDS	%TOC TOTAL	%TOC MEAN
SS#1 0-6' 1	0.089	2.241	2.330	2.347
SS#1 0-6' 2	0.093	2.270	2.363	
SS#2 0-6' 1	0.065	1.290	1.355	1.354
SS#2 0-6' 2	0.069	1.284	1.353	
SS#2 1-1.5' 1	0.019	0.444	0.463	0.444
SS#2 1-1.5' 2	0.018	0.406	0.424	
SS#1 2.5-3' 1	0.011	0.184	0.195	0.198
SS#1 2.5-3' 2	0.010	0.191	0.201	
SS#2 2.5-3' 1	0.014	0.150	0.164	0.165
SS#2 2.5-3' 2	0.015	0.150	0.165	
SS#2 3.5-4' 1	0.030	0.819	0.849	0.854
SS#2 3.5-4' 2	0.030	0.829	0.859	
SS#1 4.5-5' 1	0.014	0.343	0.357	0.333
SS#1 4.5-5' 2	0.013	0.296	0.309	
SS#2 4.5-5' 1	0.022	0.536	0.558	0.543
SS#2 4.5-5' 2	0.023	0.504	0.527	
SS#1 6.5-7' 1	0.014	0.281	0.295	0.308
SS#1 6.5-7' 2	0.014	0.306	0.320	
SS#2 6.5-7' 1	0.008	0.043	0.051	0.051
SS#2 6.5-7' 2	0.007	0.043	0.050	
SS#1 8.5-9' 1	0.005	0.060	0.065	0.068
SS#1 8.5-9' 2	0.004	0.067	0.071	
SS#2 8.5-9' 1	0.010	0.108	0.118	0.109
SS#2 8.5-9' 2	0.010	0.086	0.096	
SS#2 8.5-9' 3	0.012	0.100	0.112	
SS#2 9-9.5' 1	0.008	0.052	0.060	0.059
SS#2 9-9.5' 2	0.007	0.050	0.057	
SS#1 10.5-11' 1	0.004	0.067	0.075	0.072
SS#1 10.5-11' 2	0.006	0.062	0.068	

SAMPLES	%OC SOIL FILTRATES	%OC SOLIDS	%TOC TOTAL	%TOC MEAN
LECO		0.991		
		0.993		
		0.990		
		1.007		
WPO32-II	9.7 MG/L			
	9.9 MG/L			
	9.9 MG/L			
	9.9 MG/L			
	9.9 MG/L			
	10.1 MG/L			

TRUE VALUES: LECO = 1.00 +/- 0.044 C
WPO32-II = 9.60 MG/L OC

09/25/00 12:54 FAX AFCEE 045
TOTAL P.03

APPENDIX C

MODEL INPUT PARAMETERS AND RELATED CALCULATIONS

TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION ONE DIMENSIONAL FLOW, TYPE ONE BOUNDARY CONDITION (CONSTANT 35 mg/l SOURCE WITH NO DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy $K := 2.13 \cdot 10^{-3} \cdot \frac{cm}{sec}$ $K = 6.038 \cdot \frac{ft}{day}$

Hydraulic gradient $I := 0.0006 \cdot \frac{ft}{ft}$

Effective porosity $n_e := 0.2$

Longitudinal dispersivity $\alpha_x := 10 \cdot m$

Initial Contaminant Concentration $C_o := 35 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Contaminant Decay Rate $\lambda := 0.000 \cdot \frac{1}{day}$

Soil sorption coefficient (EPA, 1990) $K_{oc} := 79 \cdot \frac{mL}{gm}$

Particle mass density (Freeze and Cherry, 1979) $\rho_s := 2.65 \cdot \frac{gm}{cm^3}$

Bulk density (Freeze and Cherry, 1979) $\rho_b := 1.65 \cdot \frac{gm}{cm^3}$

Organic carbon content $f_{oc} := 0.0007$

Retardation coefficient $R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water) $v_x := \frac{K \cdot I}{n_e}$ $v_x = 0.006 \cdot \frac{m}{day}$

Contaminant velocity $v_c := \frac{v_x}{R}$ $v_c = 0.012 \cdot \frac{ft}{day}$

Longitudinal dispersion coefficient $D_x := \alpha_x \cdot v_x$ $D_x = 0.594 \cdot \frac{ft^2}{day}$

20 Years after start of Fire Training Activities (approx. 1980)

Initial Plume Distribution Calculation

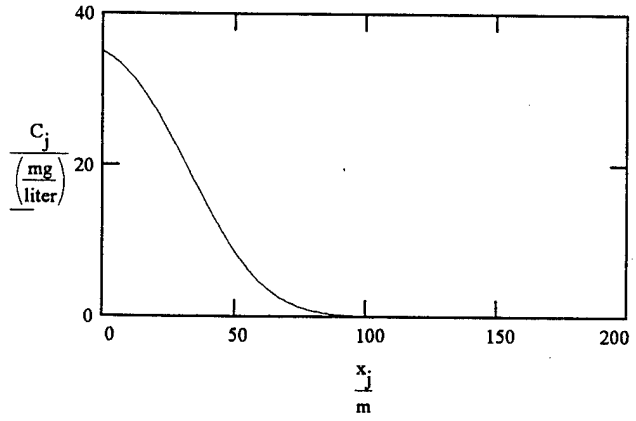
$j := 0..200$ $\quad t := 7300 \cdot day$

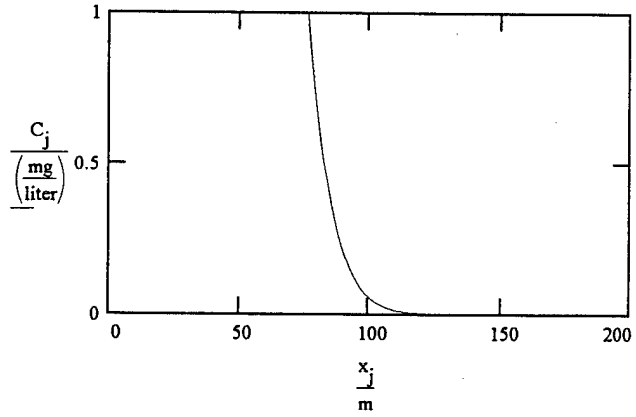
$\Delta x := 1 \cdot m$

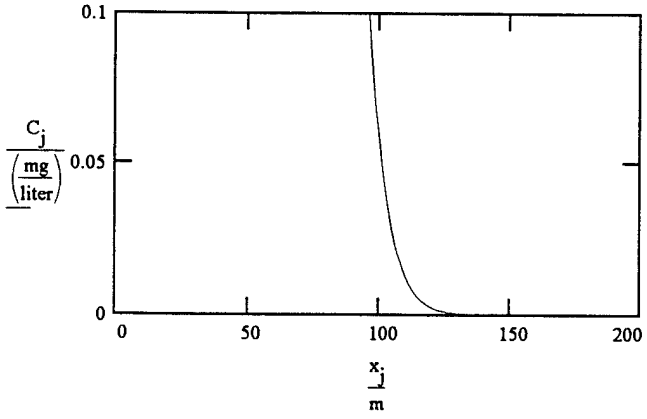
$x_j := \Delta x \cdot j$

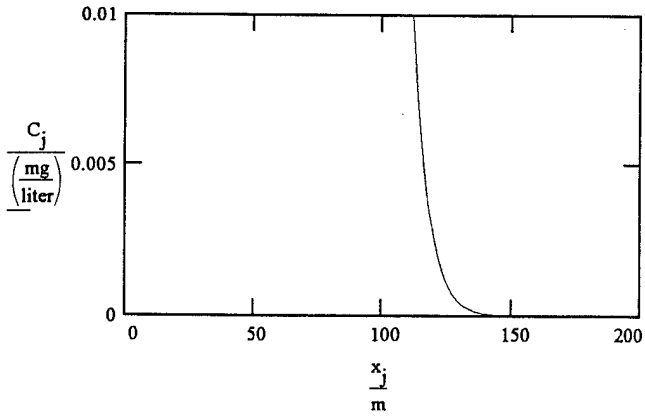
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right]$$









20 Years from Present (approx. 2015)

Initial Plume Distribution Calculation

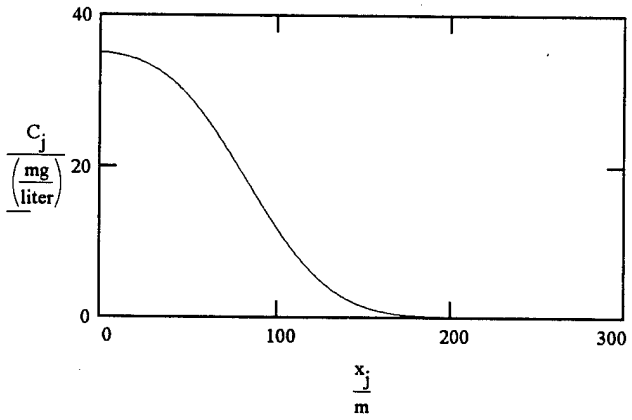
$j := 0..300$ $\quad t := 20075 \cdot day$

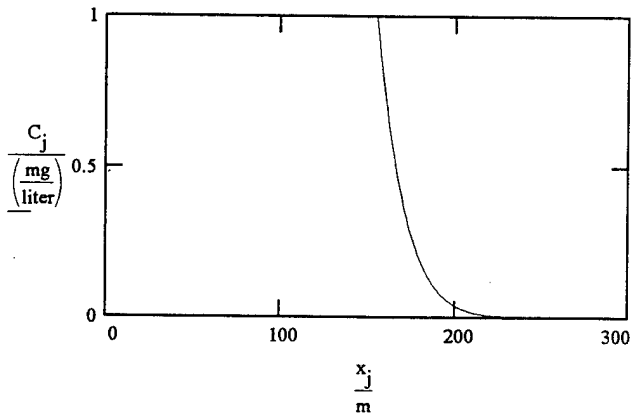
$\Delta x := 1 \cdot m$

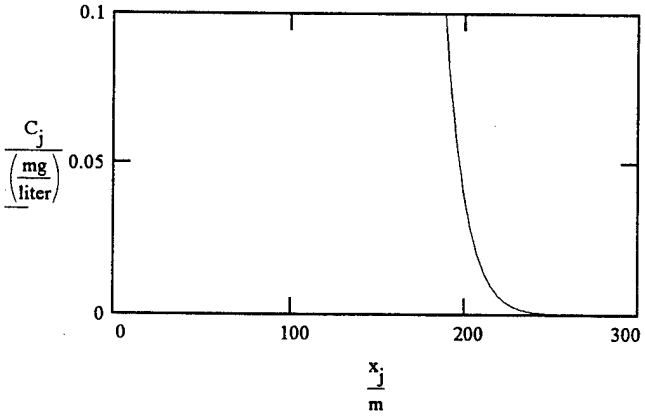
$x_j := \Delta x \cdot j$

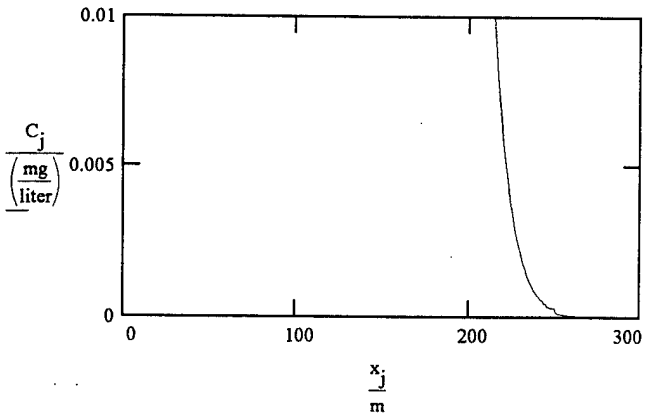
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









100 Years from Present (approx. 2095)

Initial Plume Distribution Calculation

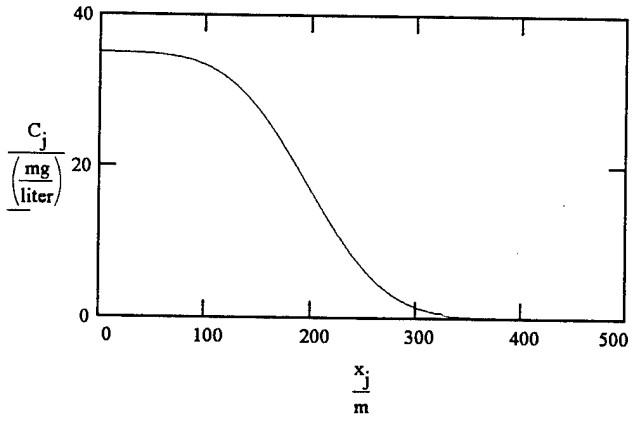
$j := 0..500$ $t := 49275 \cdot day$

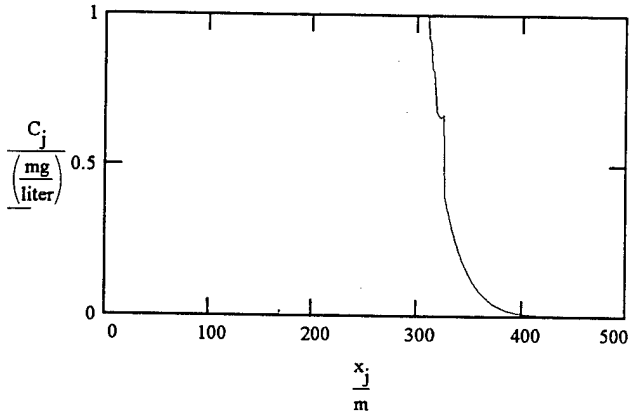
$\Delta x := 1 \cdot m$

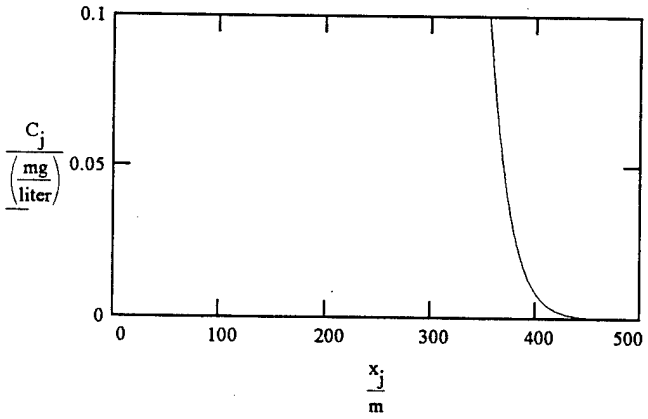
$x_j := \Delta x \cdot j$

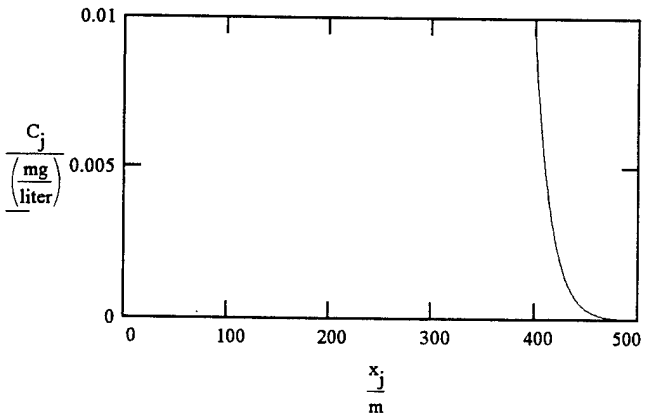
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION ONE DIMENSIONAL FLOW, TYPE ONE BOUNDARY CONDITION (CONSTANT 35 mg/l SOURCE WITH A 0.0002 day-1 DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy $K := 2.13 \cdot 10^{-3} \cdot \frac{cm}{sec}$ $K = 6.038 \cdot \frac{ft}{day}$

Hydraulic gradient $I := 0.0006 \cdot \frac{ft}{ft}$

Effective porosity $n_e := 0.2$

Longitudinal dispersivity $\alpha_x := 10 \cdot m$

Initial Contaminant Concentration $C_o := 35 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Contaminant Decay Rate $\lambda := 0.0002 \cdot \frac{1}{day}$

Soil sorption coefficient (EPA, 1990) $K_{oc} := 79 \cdot \frac{mL}{gm}$

Particle mass density (Freeze and Cherry, 1979) $\rho_s := 2.65 \cdot \frac{gm}{cm^3}$

Bulk density (Freeze and Cherry, 1979) $\rho_b := 1.65 \cdot \frac{gm}{cm^3}$

Organic carbon content $f_{oc} := 0.0007$

Retardation coefficient $R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water) $v_x := \frac{K \cdot I}{n_e}$ $v_x = 0.006 \cdot \frac{m}{day}$

Contaminant velocity $v_c := \frac{v_x}{R}$ $v_c = 0.012 \cdot \frac{ft}{day}$

Longitudinal dispersion coefficient $D_x := \alpha_x \cdot v_x$ $D_x = 0.594 \cdot \frac{ft^2}{day}$

20 Years after start of Fire Training Activities (approx. 1980)

Initial Plume Distribution Calculation

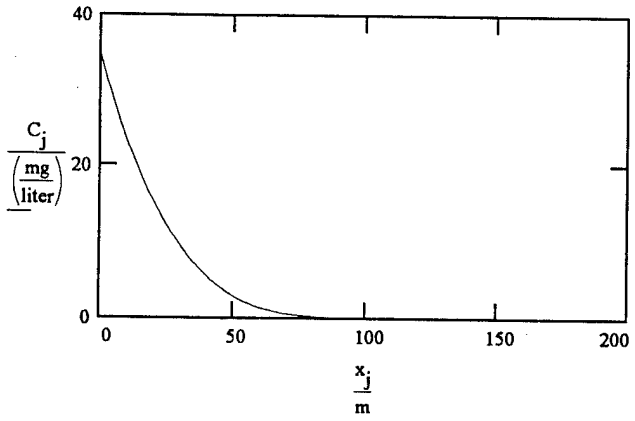
$j := 0..200$ $\quad t := 7300 \cdot day$

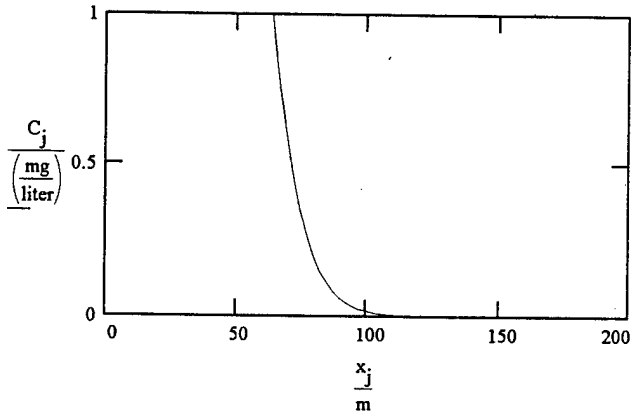
$\Delta x := 1 \cdot m$

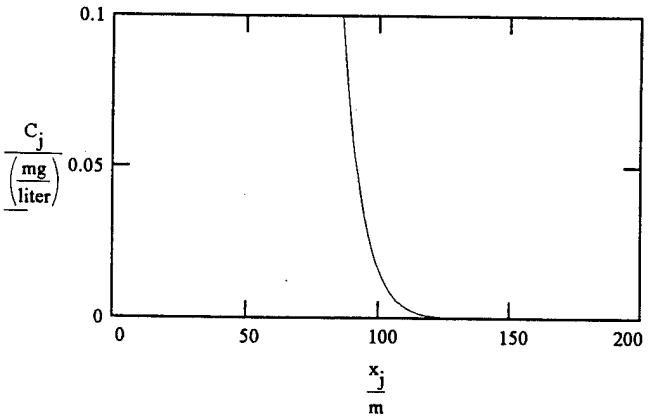
$x_j := \Delta x \cdot j$

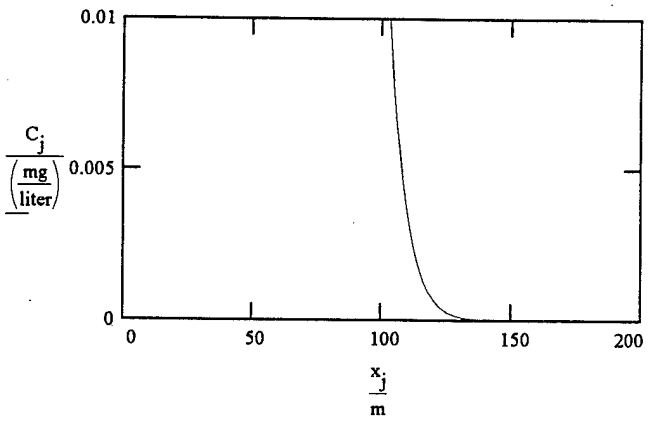
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









20 Years from Present (approx. 2015)

Initial Plume Distribution Calculation

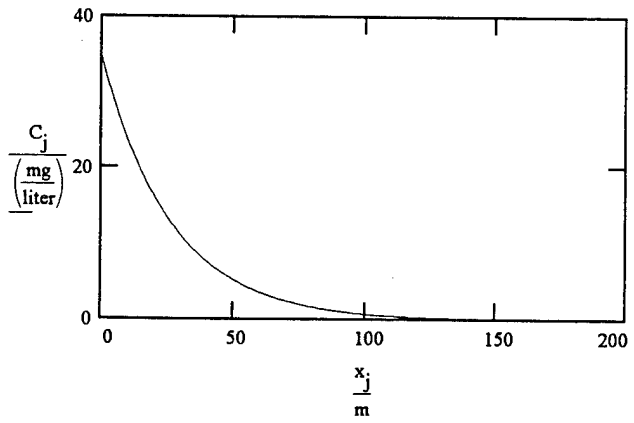
$j := 0..200$ $\quad t := 20075 \cdot day$

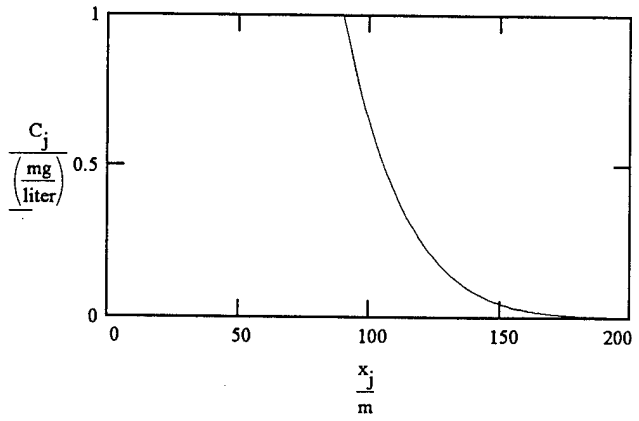
$\Delta x := 1 \cdot m$

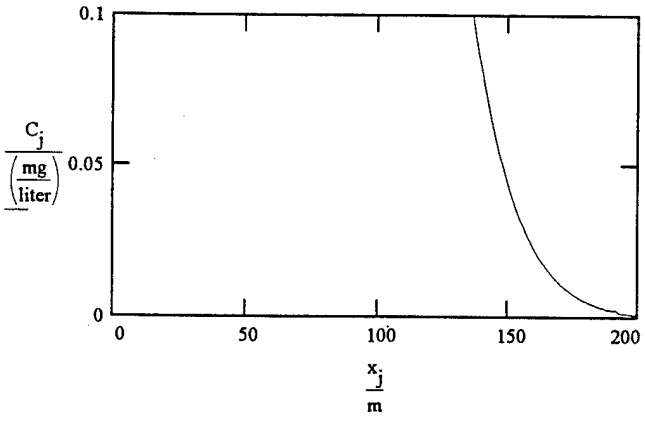
$x_j := \Delta x \cdot j$

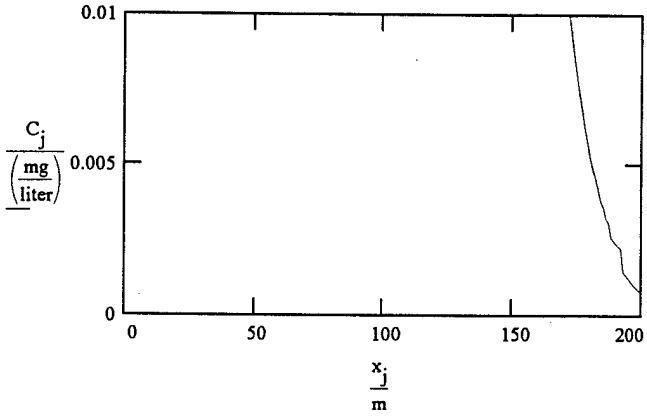
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









100 Years from Present (approx. 2095)

Initial Plume Distribution Calculation

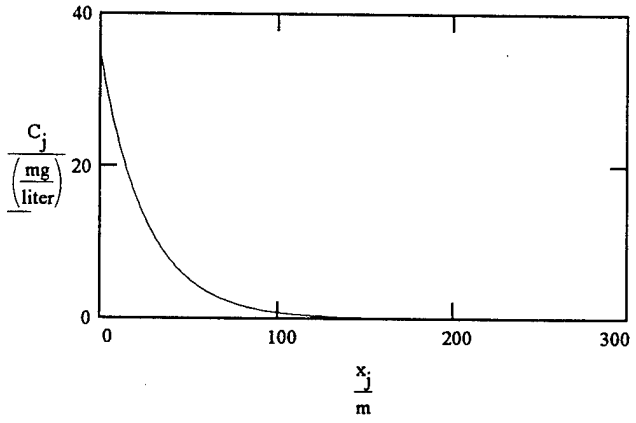
$j := 0..300$ $\quad t := 49275 \cdot day$

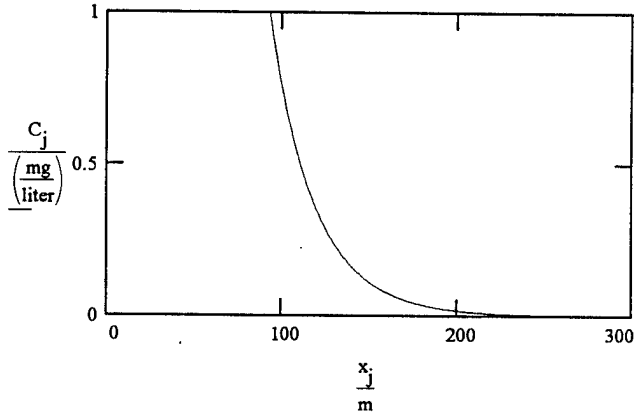
$\Delta x := 1 \cdot m$

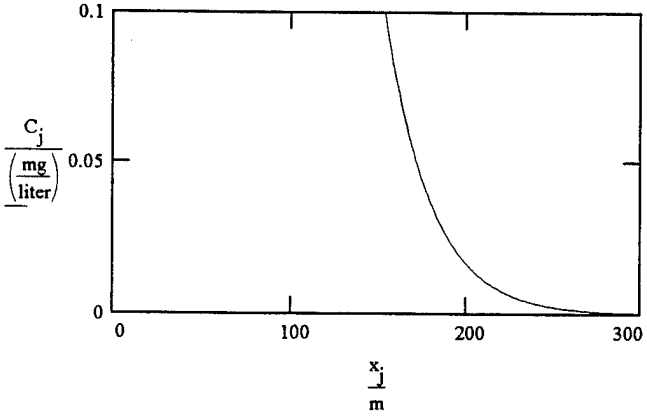
$x_j := \Delta x \cdot j$

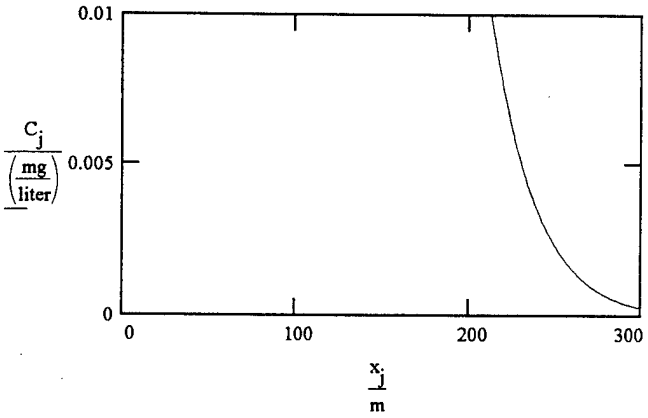
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right]$$









TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION ONE DIMENSIONAL FLOW, TYPE ONE BOUNDARY CONDITION (CONSTANT 35 mg/l SOURCE WITH A 0.0006 day-1 DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 2.13 \cdot 10^{-3} \cdot \frac{cm}{sec}$	$K = 6.038 \cdot \frac{ft}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$	
Effective porosity	$n_e := 0.2$	
Longitudinal dispersivity	$\alpha_x := 10 \cdot m$	
Initial Contaminant Concentration	$C_o := 35 \cdot \frac{mg}{liter}$	

Retardation Coefficient Calculation

Contaminant Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$	
Particle mass density (Freeze and Cherry, 1979)	$\rho_s := 2.65 \cdot \frac{gm}{cm^3}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.0007$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.012 \cdot \frac{ft}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

20 Years after start of Fire Training Activities (approx. 1980)

Initial Plume Distribution Calculation

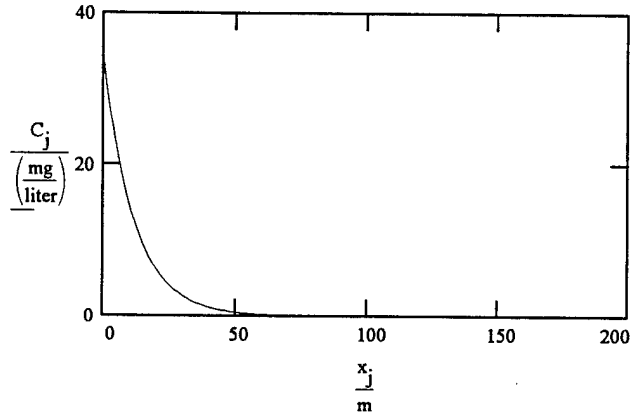
$j := 0..200$ $t := 7300 \cdot day$

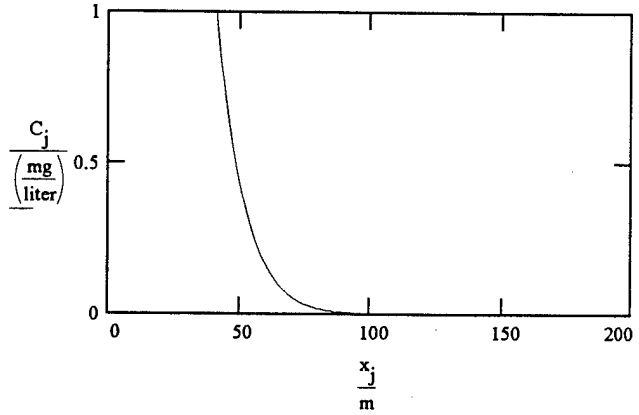
$\Delta x := 1 \cdot m$

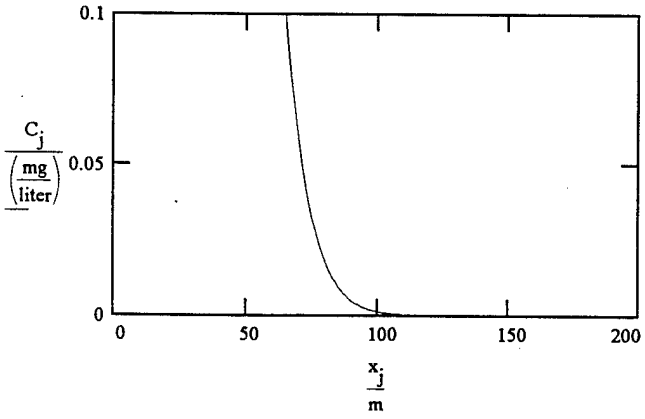
$x_j := \Delta x \cdot j$

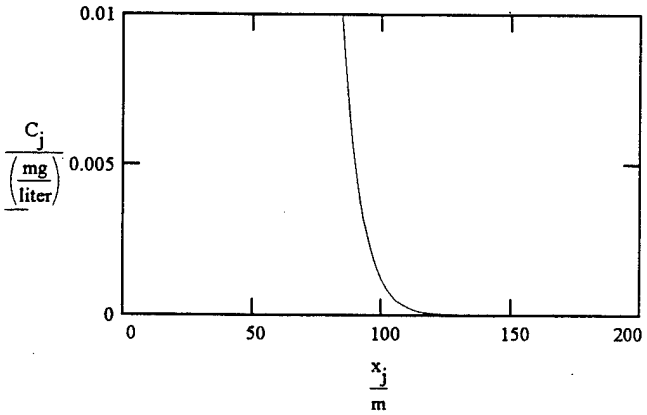
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









20 Years from Present (approx. 2015)

Initial Plume Distribution Calculation

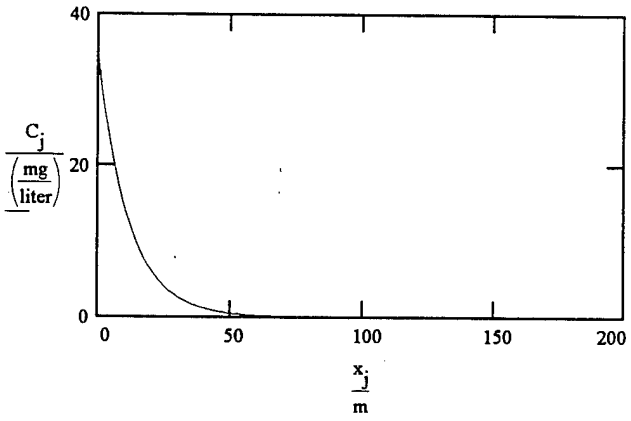
$j := 0..200$ $t := 20075 \cdot day$

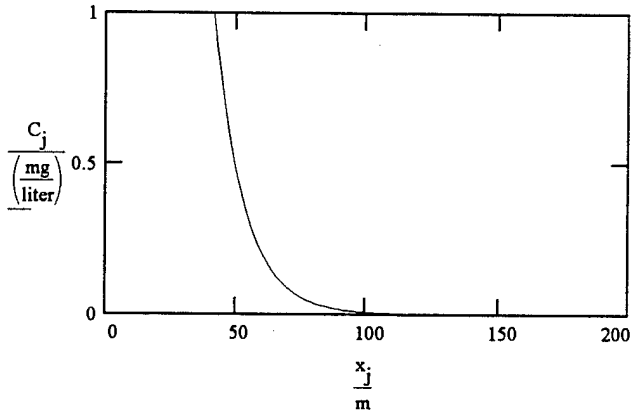
$\Delta x := 1 \cdot m$

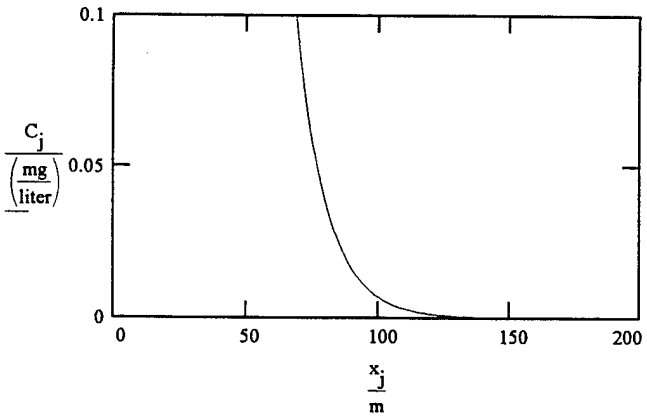
$x_j := \Delta x \cdot j$

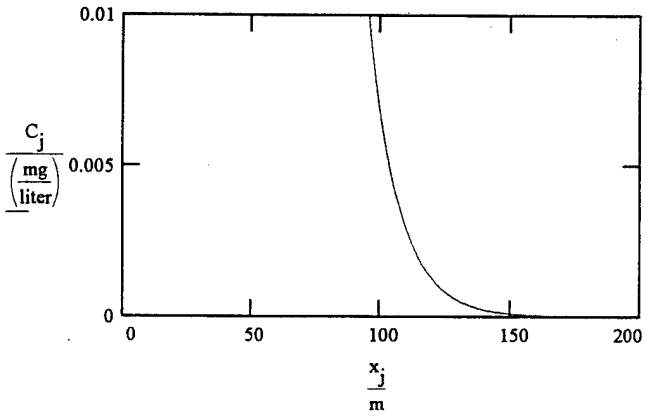
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









100 Years from Present (approx. 2095)

Initial Plume Distribution Calculation

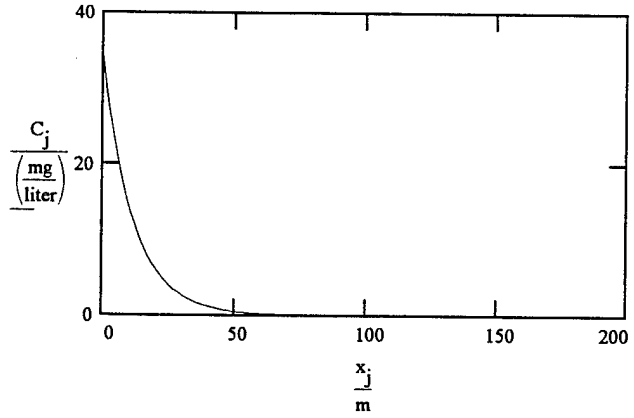
$j := 0..200$ $\quad t := 49275 \cdot day$

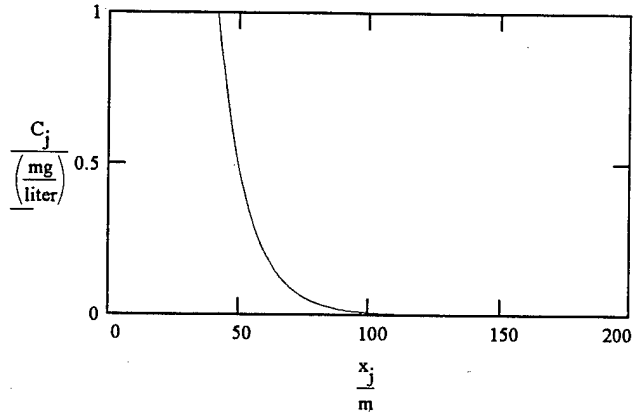
$\Delta x := 1 \cdot m$

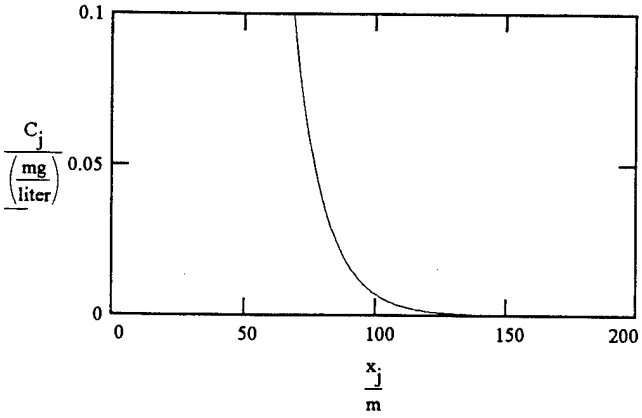
$x_j := \Delta x \cdot j$

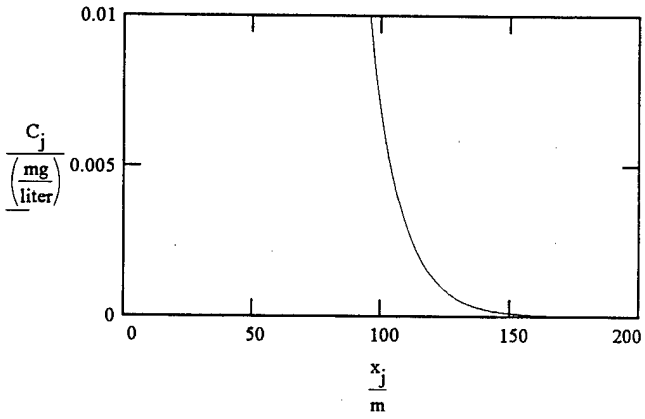
For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_j := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j - t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] + \exp\left[\frac{x_j}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x_j + t \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t}} \right] \right] \right]$$









TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION ONE DIMENSIONAL FLOW, TYPE ONE BOUNDARY CONDITION (CONSTANT 35 mg/l SOURCE WITH NO ANAEROBIC DECAY, CONSTANT LOCATION, VARIABLE TIME)

Hydrogeologic Data

Hydraulic conductivtiy $K := 2.13 \cdot 10^{-3} \cdot \frac{cm}{sec}$ $K = 6.038 \cdot \frac{ft}{day}$

Hydraulic gradient $I := 0.0006 \cdot \frac{ft}{ft}$

Effective porosity $n_e := 0.2$

Total porosity $n := 0.35$

Longitudinal dispersivity (EPRI, 1985) $\alpha_x := 10 \cdot m$

Initial Contaminant Concentration $C_o := 35 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Contaminant Decay Rate $\lambda := 0.000 \cdot \frac{1}{day}$

Soil sorption coefficient (EPA, 1990) $K_{oc} := 79 \cdot \frac{mL}{gm}$

Particle mass density (Freeze and Cherry, 1979) $\rho_s := 2.65 \cdot \frac{gm}{cm^3}$

Bulk density (Freeze and Cherry, 1979) $\rho_b := 1.65 \cdot \frac{gm}{cm^3}$

Organic carbon content $f_{oc} := 0.0007$

Retardation coefficient $R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water) $v_x := \frac{K \cdot I}{n_e}$ $v_x = 0.006 \cdot \frac{m}{day}$

Contaminant velocity $v_c := \frac{v_x}{R}$ $v_c = 0.012 \cdot \frac{ft}{day}$

Longitudinal dispersion coefficient $D_x := \alpha_x \cdot v_x$ $D_x = 0.594 \cdot \frac{ft^2}{day}$

50 Meters from the Source Area

Initial Plume Distribution Calculation

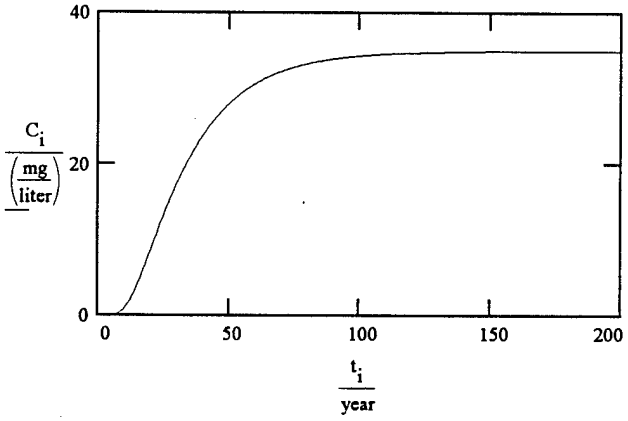
$i := 1..365$ $\quad x := 50 \cdot m$

$\Delta t := 200 \cdot day$ $\quad year := 365 \cdot day$

$t_i := \Delta t \cdot i$

For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_i := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x - t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] + \exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x + t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] \right]$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION ONE DIMENSIONAL FLOW, TYPE ONE BOUNDARY CONDITION (CONSTANT 35 mg/l SOURCE WITH A 0.0002 day-1 ANAEROBIC DECAY, CONSTANT LOCATION, VARIABLE TIME)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 2.13 \cdot 10^{-3} \cdot \frac{cm}{sec}$	$K = 6.038 \cdot \frac{ft}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$	
Effective porosity	$n_e := 0.2$	
Total porosity	$n := 0.35$	
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 10 \cdot m$	
Initial Contaminant Concentration	$C_o := 35 \cdot \frac{mg}{liter}$	

Retardation Coefficient Calculation

Contaminant Decay Rate	$\lambda := 0.0002 \cdot \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$	
Particle mass density (Freeze and Cherry, 1979)	$\rho_s := 2.65 \cdot \frac{gm}{cm^3}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.0007$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.012 \cdot \frac{ft}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

50 Meters from the Source Area

Initial Plume Distribution Calculation

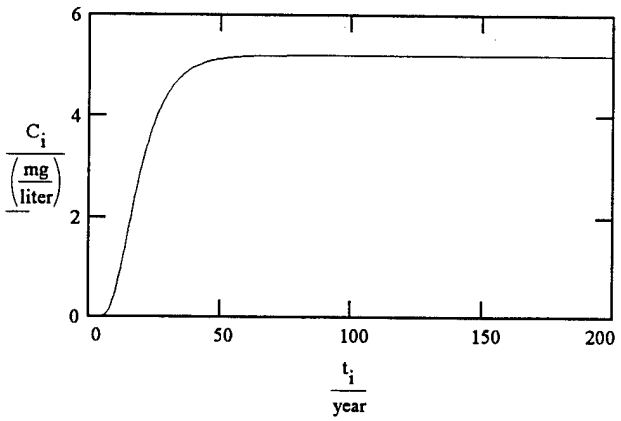
$i := 1 .. 365$ $\quad x := 50 \cdot m$

$\Delta t := 200 \cdot day$ $\quad year := 365 \cdot day$

$t_i := \Delta t \cdot i$

For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_i := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x - t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] + \exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x + t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] \right]$$



250 Meters from the Source Area

Initial Plume Distribution Calculation

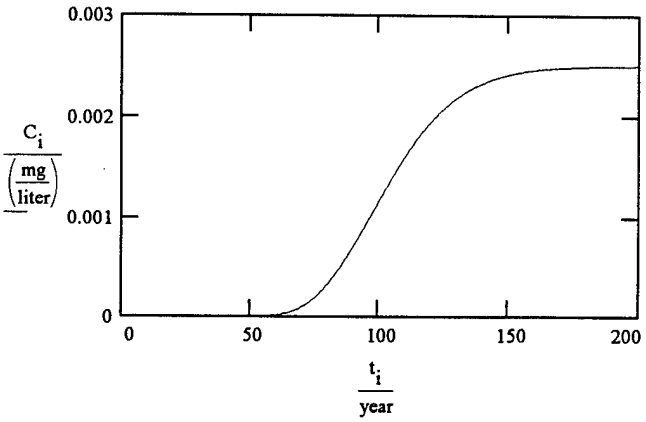
$i := 1..365$ $\quad x := 250 \cdot m$

$\Delta t := 200 \cdot day$ $\quad year := 365 \cdot day$

$t_i := \Delta t \cdot i$

For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_i := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x - t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] + \exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x + t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] \right]$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION ONE DIMENSIONAL FLOW, TYPE ONE BOUNDARY CONDITION (CONSTANT 35 mg/l SOURCE WITH A 0.0006 day-1 ANAEROBIC DECAY, CONSTANT LOCATION, VARIABLE TIME)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 2.13 \cdot 10^{-3} \cdot \frac{cm}{sec}$	$K = 6.038 \cdot \frac{ft}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$	
Effective porosity	$n_e := 0.2$	
Total porosity	$n := 0.35$	
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 10 \cdot m$	
Initial Contaminant Concentration	$C_o := 35 \cdot \frac{mg}{liter}$	

Retardation Coefficient Calculation

Contaminant Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$	
Particle mass density (Freeze and Cherry, 1979)	$\rho_s := 2.65 \cdot \frac{gm}{cm^3}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.0007$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.012 \cdot \frac{ft}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

50 Meters from the Source Area

Initial Plume Distribution Calculation

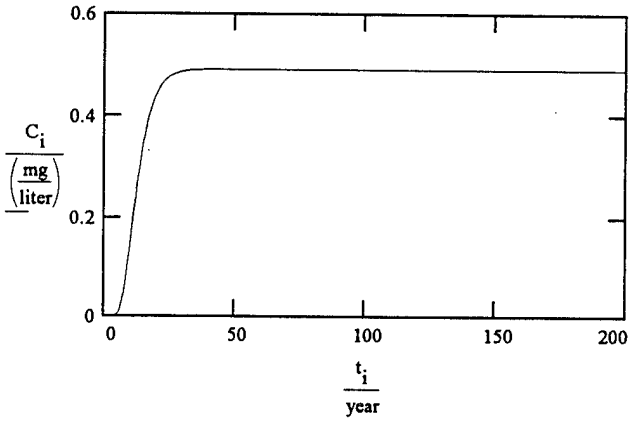
$i := 1..365$ $\quad x := 50 \cdot m$

$\Delta t := 200 \cdot day$ $\quad year := 365 \cdot day$

$t_i := \Delta t \cdot i$

For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_i := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x - t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] + \exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x + t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] \right]$$



250 Meters from the Source Area

nitial Plume Distribution Calculation

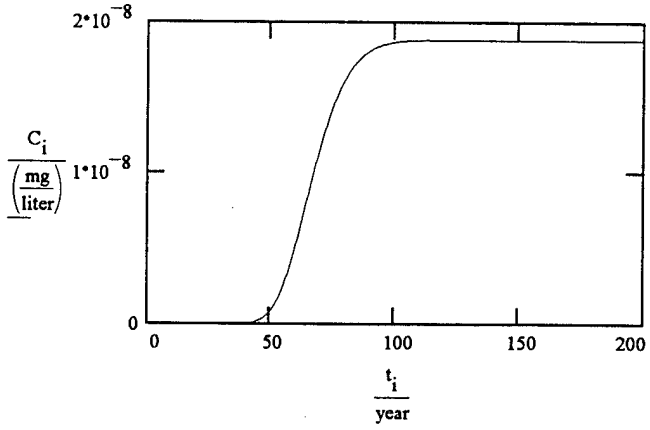
$i := 1..365$ $\quad x := 250 \cdot m$

$\Delta t := 200 \cdot day$ $\quad year := 365 \cdot day$

$t_i := \Delta t \cdot i$

For Retarded Flow with Biodegradation (Wexler, 1992, p. 18)

$$C_i := \frac{C_o}{2} \cdot \left[\exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} - \sqrt{\left[\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R} \right]} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x - t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] + \exp\left[\frac{x}{2 \cdot \frac{D_x}{R}} \cdot \left[\frac{v_x}{R} + \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}} \right] \right] \cdot \left[1 - \operatorname{erf}\left[\frac{x + t_i \cdot \sqrt{\left(\frac{v_x}{R} \right)^2 + 4 \cdot \lambda \cdot \frac{D_x}{R}}}{2 \cdot \sqrt{\frac{D_x}{R} \cdot t_i}} \right] \right] \right]$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (35 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.0006 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 1.84 \cdot \frac{m}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 10 \cdot m$
Concentration of Injected Contaminant	$C_s := 35 \cdot \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$
Source Decay Rate	$\alpha := 0.000027 \cdot \frac{1}{day}$
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$
Organic carbon content	$f_{oc} := 0.0007$
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.004 \cdot \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

20 Years after start of Fire Training Activities (approx. 1980)

Initial Plume Distribution Calculation

$j := 0..200$ $\quad t := 7300 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

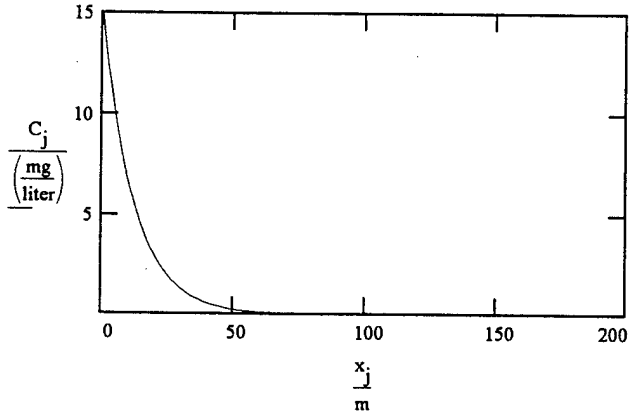
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

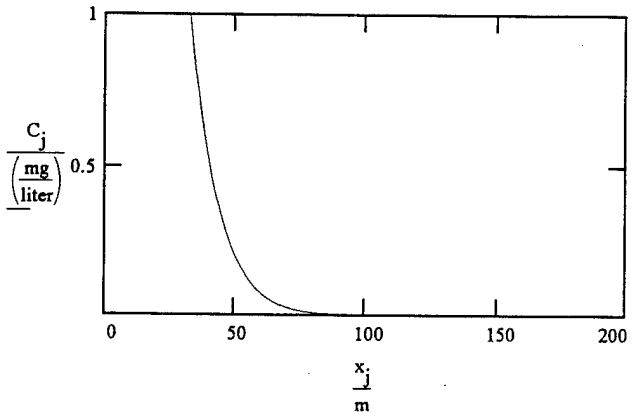
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

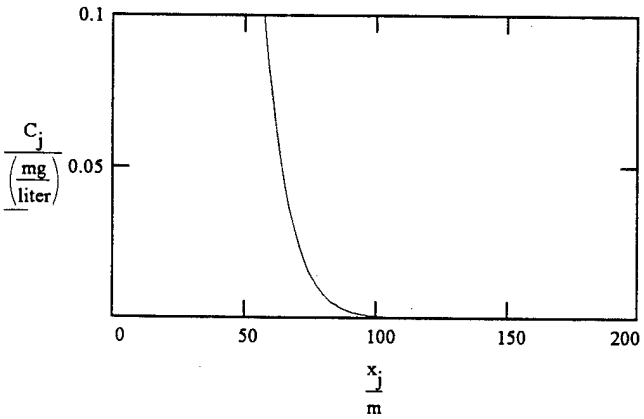
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots \right.$$

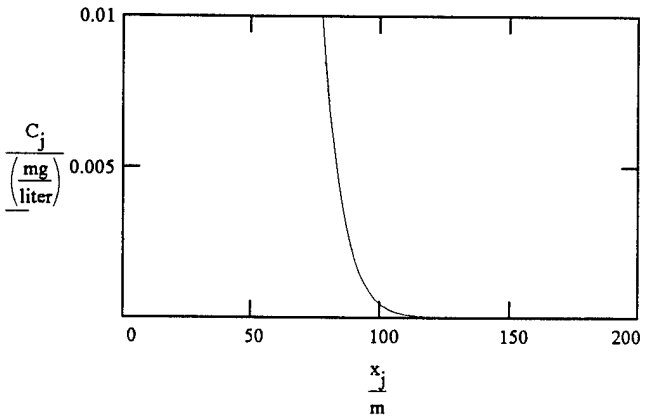
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









20 Years from Present (approx. 2015)

Initial Plume Distribution Calculation

$j := 0..200$ $\quad t := 20075 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

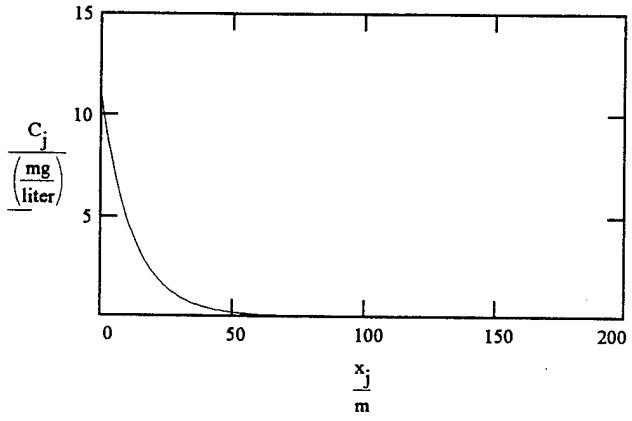
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

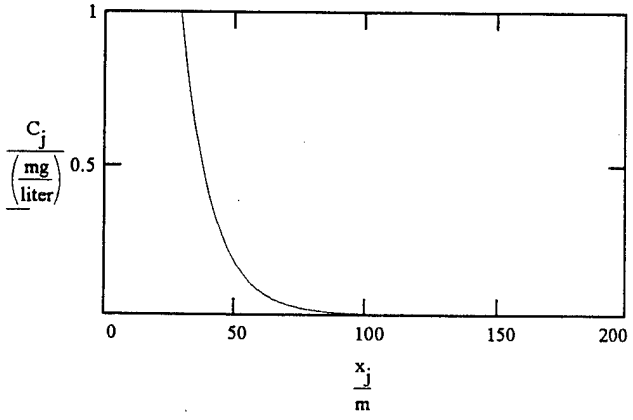
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

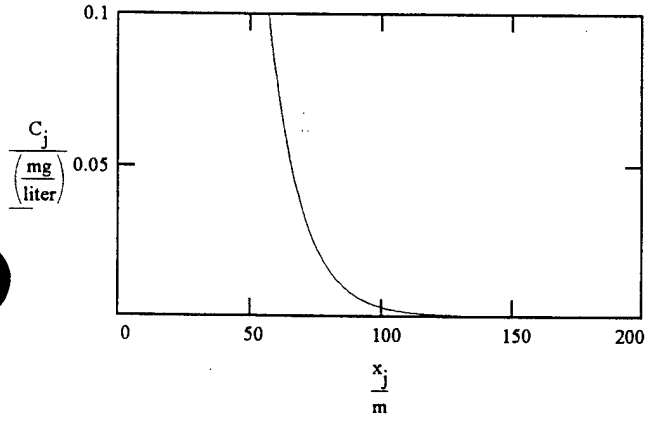
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots \right.$$

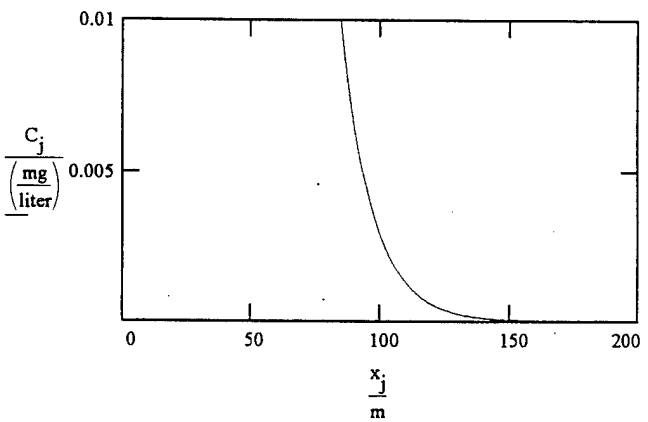
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (35 mg/l SOURCE DECAYING AT 2 %/year WITH A 0.0006 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 1.84 \cdot \frac{m}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 10 \cdot m$
Concentration of Injected Contaminant	$C_s := 35 \cdot \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$
Source Decay Rate	$\alpha := 0.000055 \cdot \frac{1}{day}$
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$
Organic carbon content	$f_{oc} := 0.0007$
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.004 \cdot \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

20 Years after start of Fire Training Activities (approx. 1980)

Initial Plume Distribution Calculation

$j := 0..200$ $\quad t := 7300 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

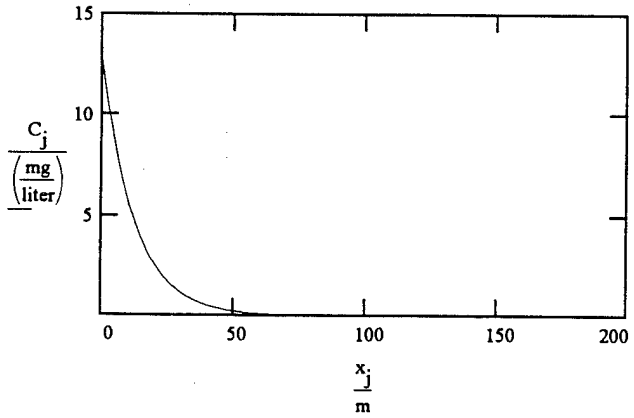
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

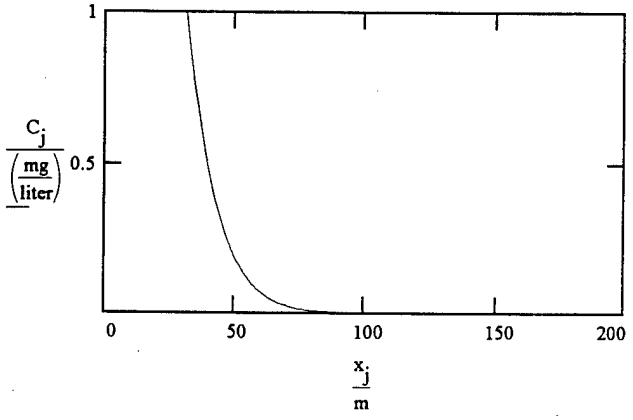
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

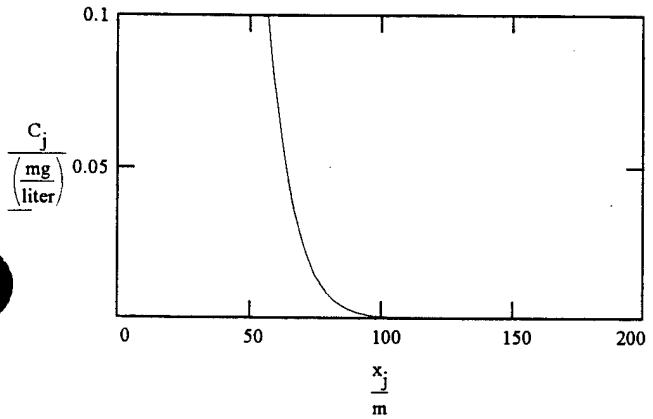
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots \right.$$

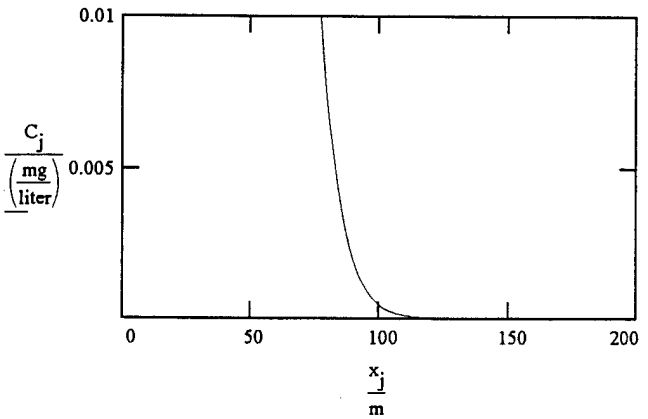
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









20 Years from Present (approx. 2015)

Initial Plume Distribution Calculation

$j := 0 .. 200$ $\quad t := 20075 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

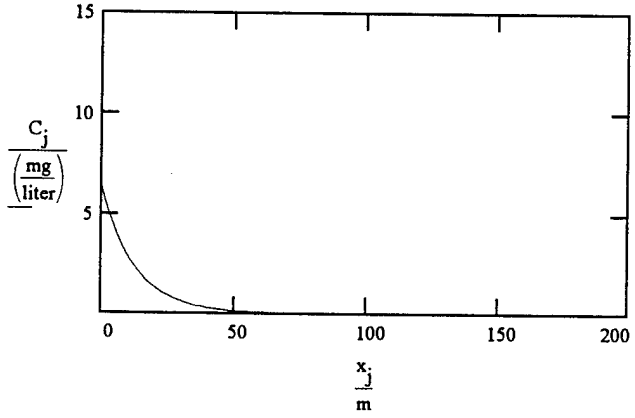
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

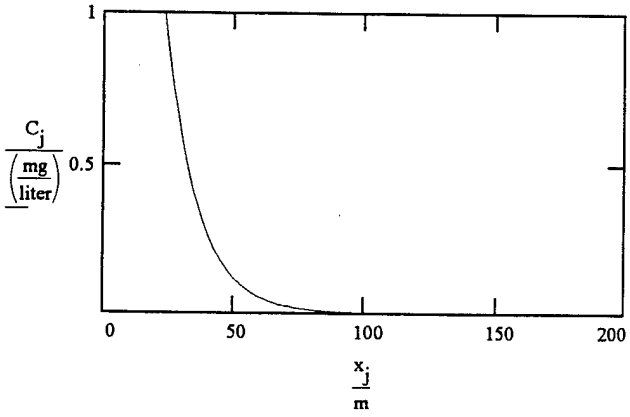
$$C_j := C_0 \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \dots$$

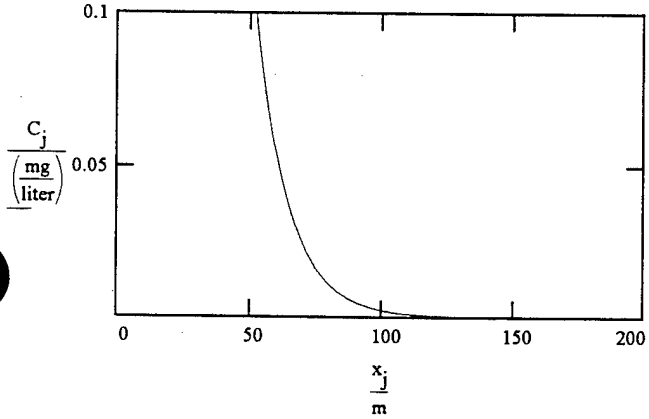
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots \right.$$

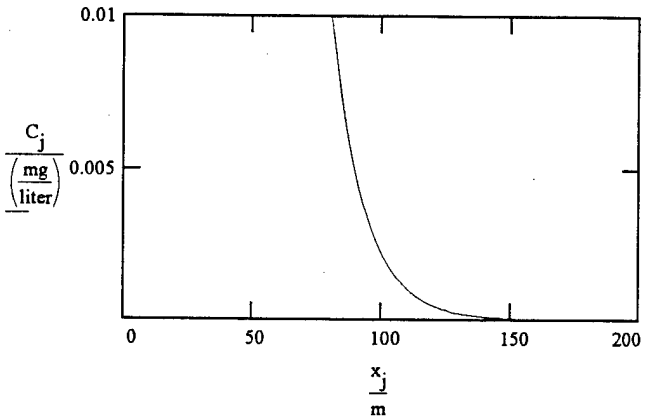
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \dots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









100 Years from Present (approx. 2095)

Initial Plume Distribution Calculation

$j := 0..200$ $\quad t := 49275 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

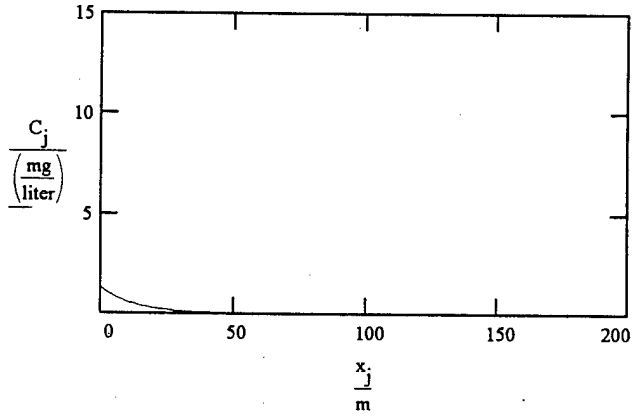
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

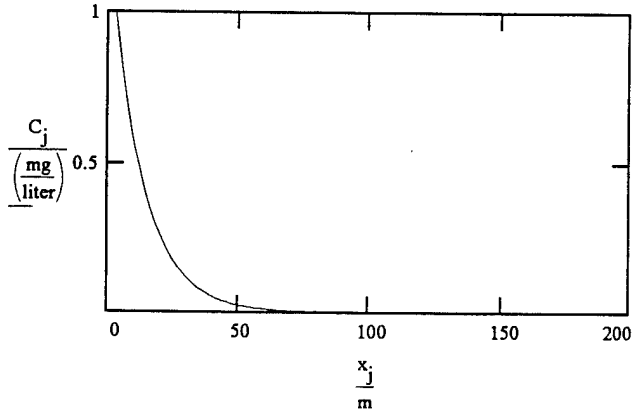
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \ldots$$

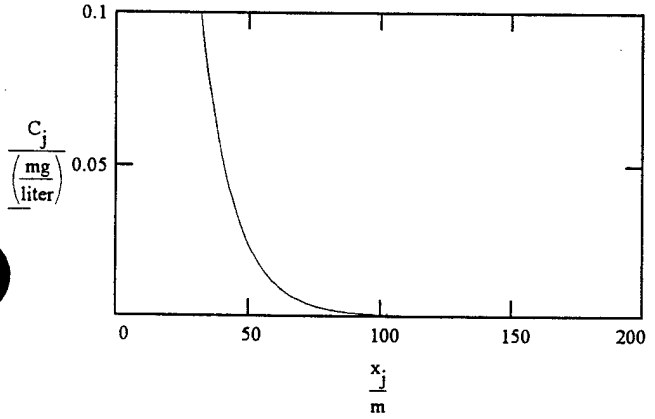
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots \right.$$

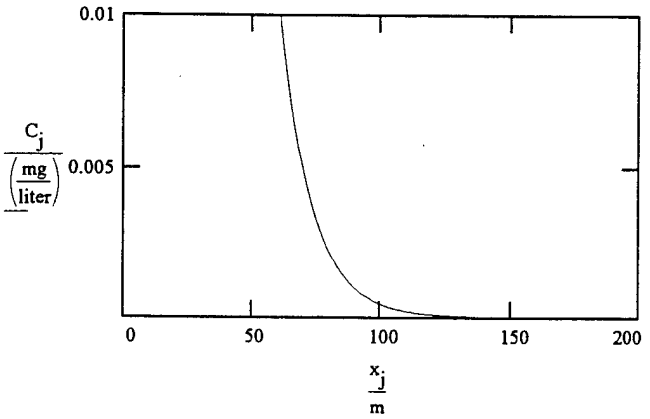
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (35 mg/l SOURCE DECAYING AT 5 %/year WITH A 0.0006 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 1.84 \cdot \frac{m}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity	$\alpha_x := 10 \cdot m$
Concentration of Injected Contaminant	$C_s := 35 \cdot \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$
Source Decay Rate	$\alpha := 0.000137 \cdot \frac{1}{day}$
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$
Organic carbon content	$f_{oc} := 0.0007$
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.004 \cdot \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

20 Years after start of Fire Training Activities (approx. 1980)

Initial Plume Distribution Calculation

$j := 0..200$ $\quad t := 7300 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

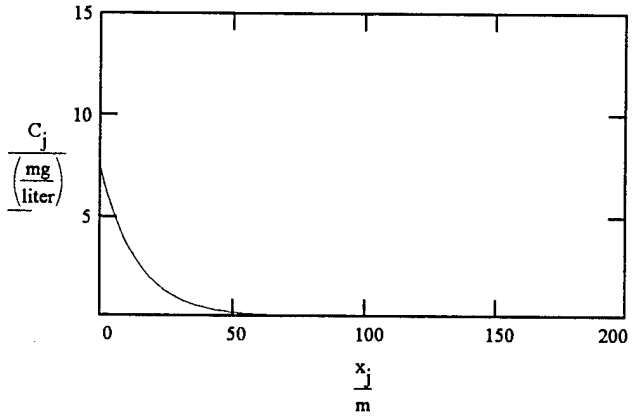
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

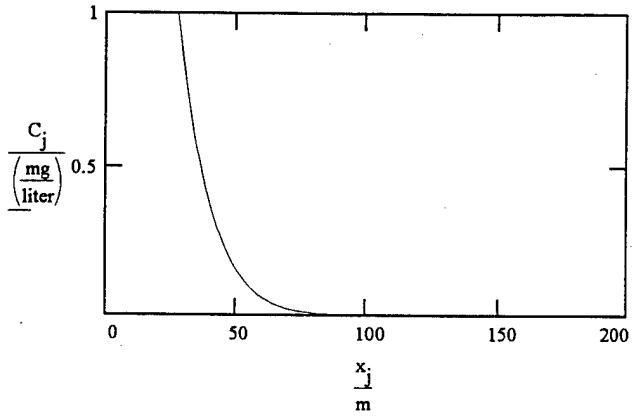
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \ldots$$

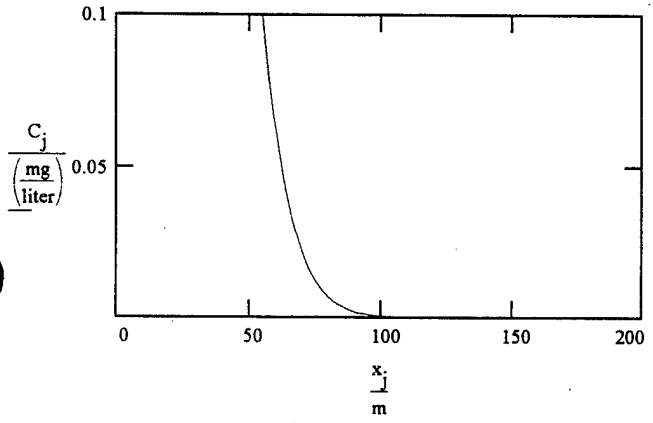
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots \right.$$

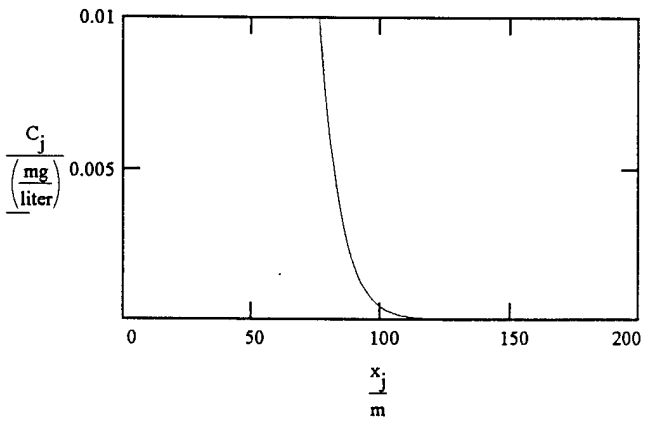
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









20 Year from Present (approx. 2015)

Initial Plume Distribution Calculation

$j := 0..200$ $\quad t := 20075 \cdot day$

$\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$

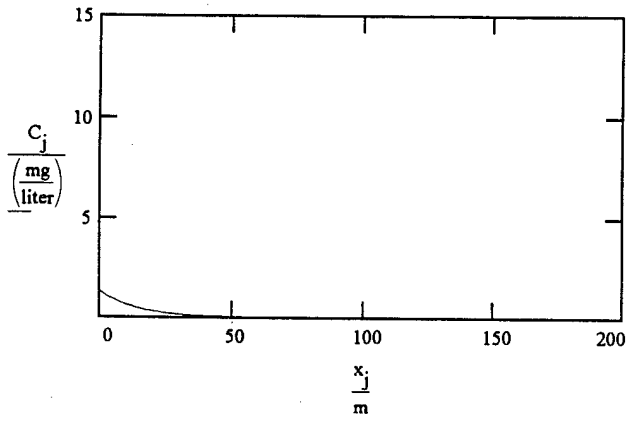
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

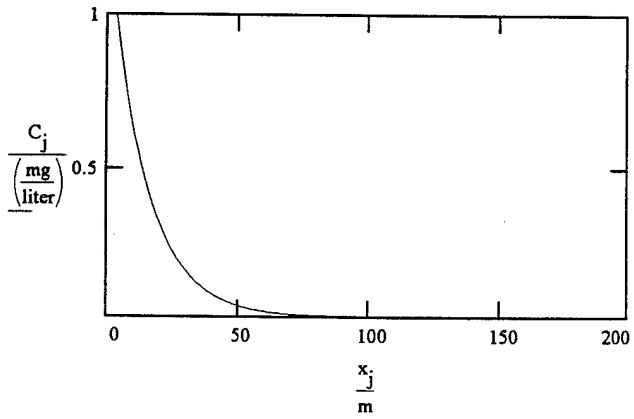
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \ldots$$

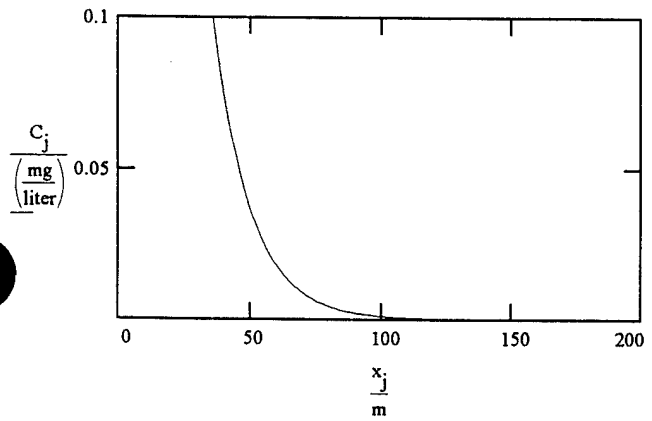
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots \right.$$

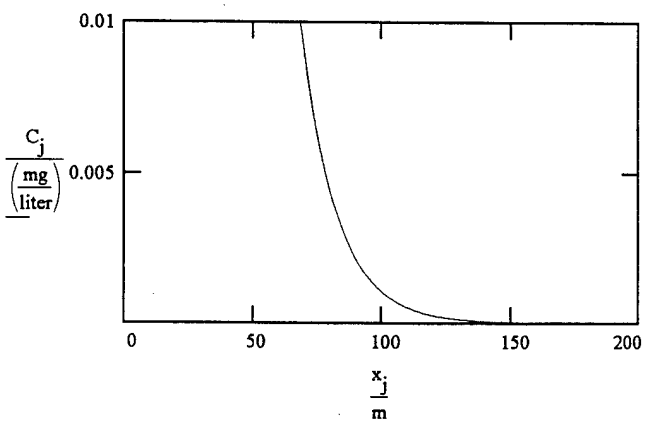
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$









TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMEMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (35 mg/l SOURCE DECAYING AT 1 %/year WITH A 0.006 day-1 ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 1.84 \cdot \frac{m}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 10 \cdot m$
Concentration of Injected Contaminant	$C_s := 35 \cdot \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.000027 \cdot \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.0007$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.004 \cdot \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

50 Meters from the Source Area

Initial Plume Distribution Calculation

$year := 365 \cdot day \quad i := 1 .. 365 \quad x := 50 \cdot m$

$\Delta t := 100 \cdot day$

$t_i := \Delta t \cdot i$

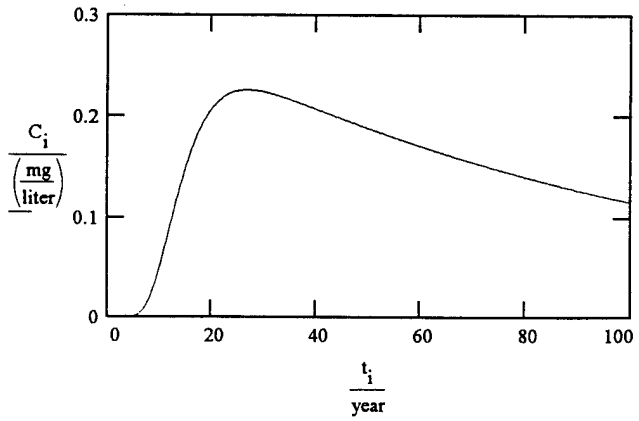
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}}\right)\right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R}\right) \cdot \exp\left[-\frac{\left(R \cdot x - v_x \cdot t_i\right)^2}{4 \cdot D_x \cdot R \cdot t_i}\right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R}\right) \cdot \exp\left(\frac{v_x \cdot x}{D_x}\right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}}\right)\right)\right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}\right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}\right] \cdot x}{2 \cdot D_x}\right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}\right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}}\right]\right] \ldots\right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}\right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}\right] \cdot x}{2 \cdot D_x}\right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}}\right]\right] \ldots$$

$$\left.+ \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)}\right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i\right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}}\right)\right)\right]$$



250 Meters from the Source Area

Initial Plume Distribution Calculation

$year := 365 \cdot day \quad i := 1 .. 365 \quad x := 250 \cdot m$

$\Delta t := 100 \cdot day$

$t_i := \Delta t \cdot i$

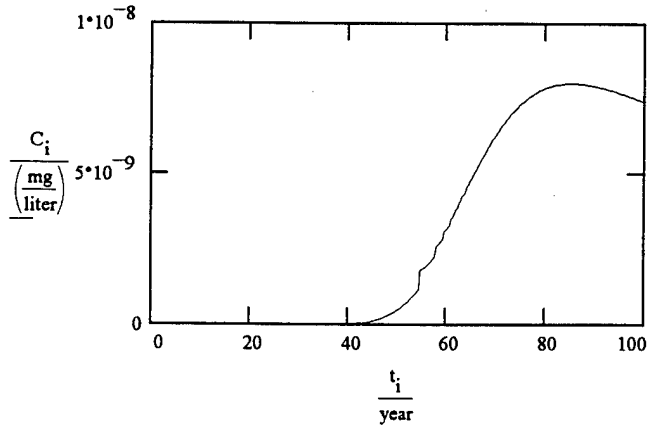
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{\left(R \cdot x - v_x \cdot t_i \right)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMEMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (35 mg/l SOURCE DECAYING AT 2 %/year WITH A 0.006 day-1 ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 1.84 \cdot \frac{m}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 10 \cdot m$
Concentration of Injected Contaminant	$C_s := 35 \cdot \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.000055 \cdot \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.0007$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.004 \cdot \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

50 Meters from the Source Area

Initial Plume Distribution Calculation

$year := 365 \cdot day \quad i := 1 .. 365 \quad x := 50 \cdot m$

$\Delta t := 100 \cdot day$

$t_i := \Delta t \cdot i$

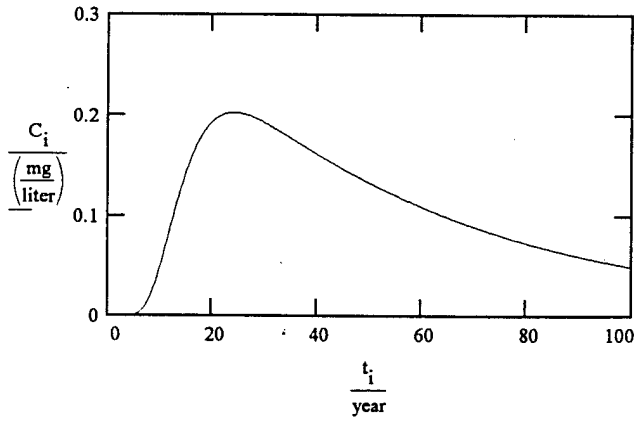
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_0 \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{\left(R \cdot x - v_x \cdot t_i \right)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



250 Meters from the Source Area

Initial Plume Distribution Calculation

year := 365·day i := 1 .. 365 x := 250·m

Δt := 100·day

$t_i := \Delta t \cdot i$

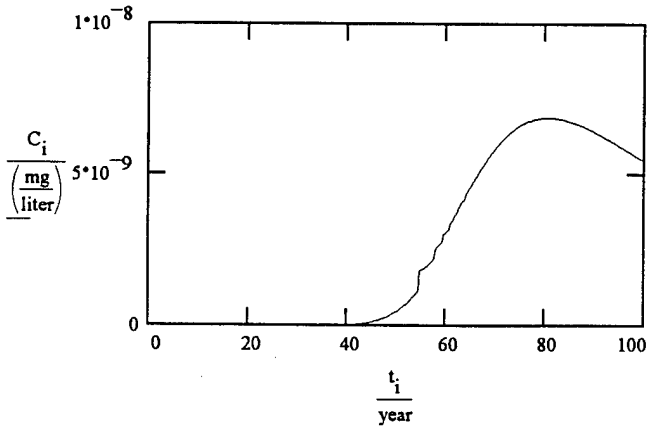
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{\left(R \cdot x - v_x \cdot t_i \right)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMEMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (35 mg/l SOURCE DECAYING AT 5 %/year WITH A 0.006 day-1 ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy	$K := 1.84 \cdot \frac{m}{day}$
Hydraulic gradient	$I := 0.0006 \cdot \frac{ft}{ft}$
Effective porosity	$n_e := 0.2$
Total porosity	$n := 0.35$
Longitudinal dispersivity (EPRI, 1985)	$\alpha_x := 10 \cdot m$
Concentration of Injected Contaminant	$C_s := 35 \cdot \frac{mg}{liter}$
Initial Dissolved Contaminant Concentration	$C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate	$\lambda := 0.0006 \cdot \frac{1}{day}$	
Source Decay Rate	$\alpha := 0.000137 \cdot \frac{1}{day}$	
Soil sorption coefficient (EPA, 1990)	$K_{oc} := 79 \cdot \frac{mL}{gm}$	
Bulk density (Freeze and Cherry, 1979)	$\rho_b := 1.65 \cdot \frac{gm}{cm^3}$	
Organic carbon content	$f_{oc} := 0.0007$	
Retardation coefficient	$R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$	$R = 1.456$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water)	$v_x := \frac{K \cdot I}{n_e}$	$v_x = 0.006 \cdot \frac{m}{day}$
Contaminant velocity	$v_c := \frac{v_x}{R}$	$v_c = 0.004 \cdot \frac{m}{day}$
Longitudinal dispersion coefficient	$D_x := \alpha_x \cdot v_x$	$D_x = 0.594 \cdot \frac{ft^2}{day}$

50 Meters from the Source Area

Initial Plume Distribution Calculation

year := 365·day i := 1 .. 365 x := 50·m

Δt := 100·day

$t_i := \Delta t \cdot i$

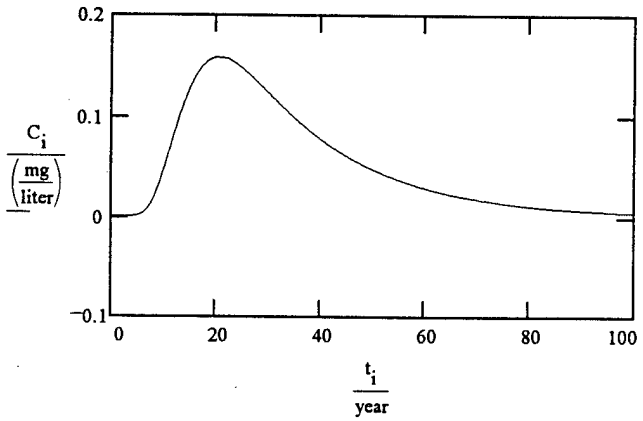
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{\left(R \cdot x - v_x \cdot t_i \right)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



ES ENGINEERING-SCIENCE, INC.

Client _____ Job No. 722450.24030 Sheet 1 of 1

Subject MODEL GRID WITH BOUNDARY CONDITIONS By DM 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	955.01	955.01	955.01	955.01	955.01	955.01	955.01	955.005	955.005	955.005	955.00	955.00	955.00	955.00	955.00	955.00	955.00	955.00	X
3	X																			X
4	X																			X
5	X																			X
6	X																			X
7	X																			X
8	X																			X
9	X																			X
10	X																			X
11	X																			X
12	X																			X
13	X																			X
14	X																			X
15	X																			X
16	X																			X
17	X																			X
18	X																			X
19	X																			X
20	X	954.68	954.68																	X
21	X	X	954.66	954.66																X
22	X	X	X	954.64																X
23	X	X	X	954.62																X
24	X	X	X	954.60																X
25	X	X	X	954.58	954.58															X
26	X	X	X	X	954.56															X
27	X	X	X	X	954.54															X
28	X	X	X	X	954.52															X
29	X	X	X	X	954.50	954.50	954.50	954.51	954.52	954.53	954.54	954.55	954.56	954.55	954.57	954.53	954.52	954.51	954.50	X
30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X = No-Flow Cell

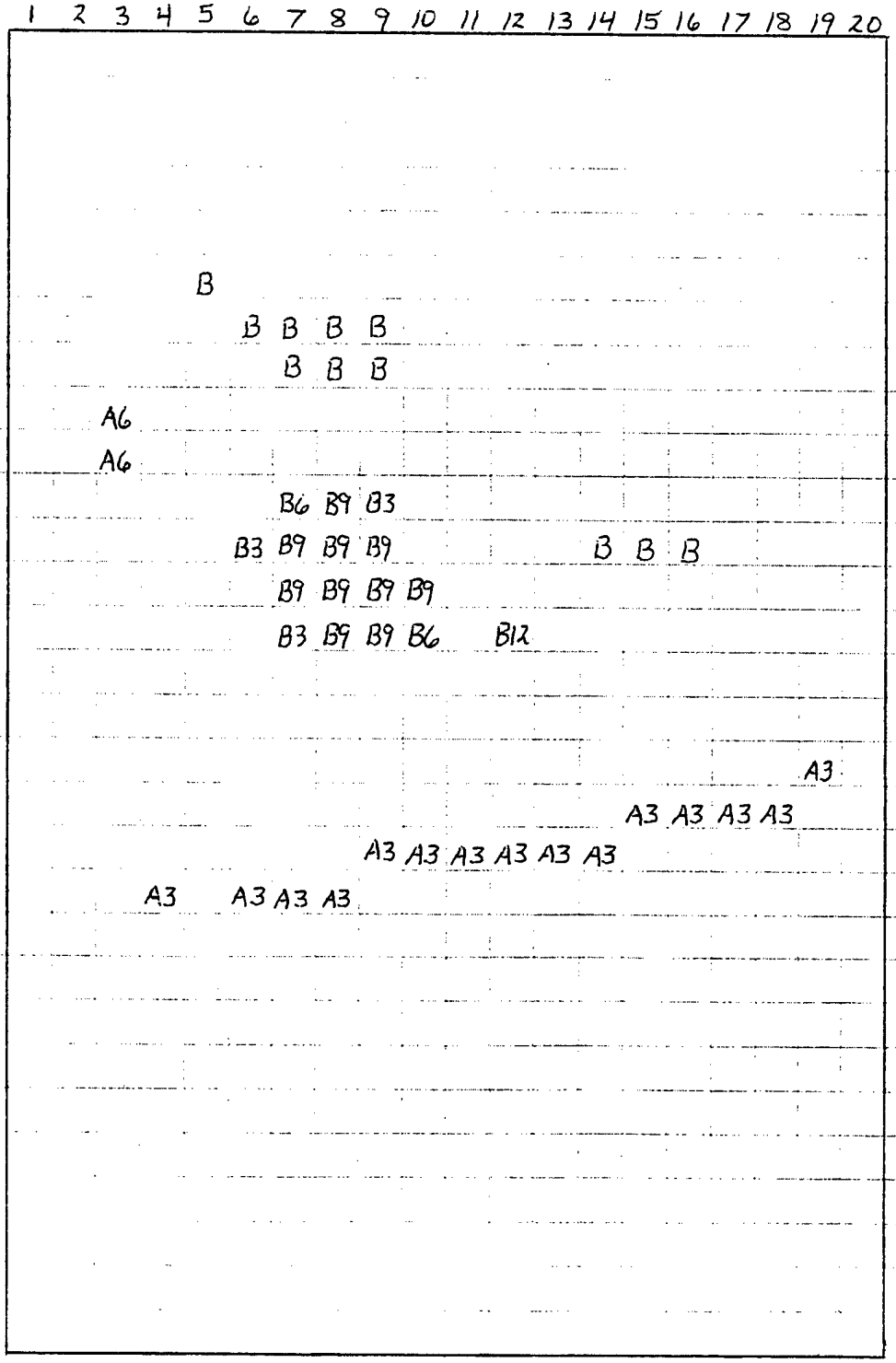
955.01 = Constant Head Cell, with assigned head value

ES ENGINEERING-SCIENCE, INC.

Client _____ Job No. 722450.24030 Sheet 1 of 1

Subject GROUNDWATER RECHARGE By DM Date _____

_____ Checked _____ Rev. _____



A = Recharge Array Injection Cell

B = Injection Well Recharge Cell

3 = 3" per year (1.1×10^{-5} ft/s)

6 = 6" per year (2.2×10^{-5} ft/s)

9 = 9" per year (3.3×10^{-5} ft/s)

12 = 12" per year (4.4×10^{-5} ft/s)

All other injection wells introduced water at rates of less than 0.03" per year; therefore, they had no effect on the groundwater flow.

RMS Error Calculations for Calibrated Flow Model
FPTA-3 Offutt AFB

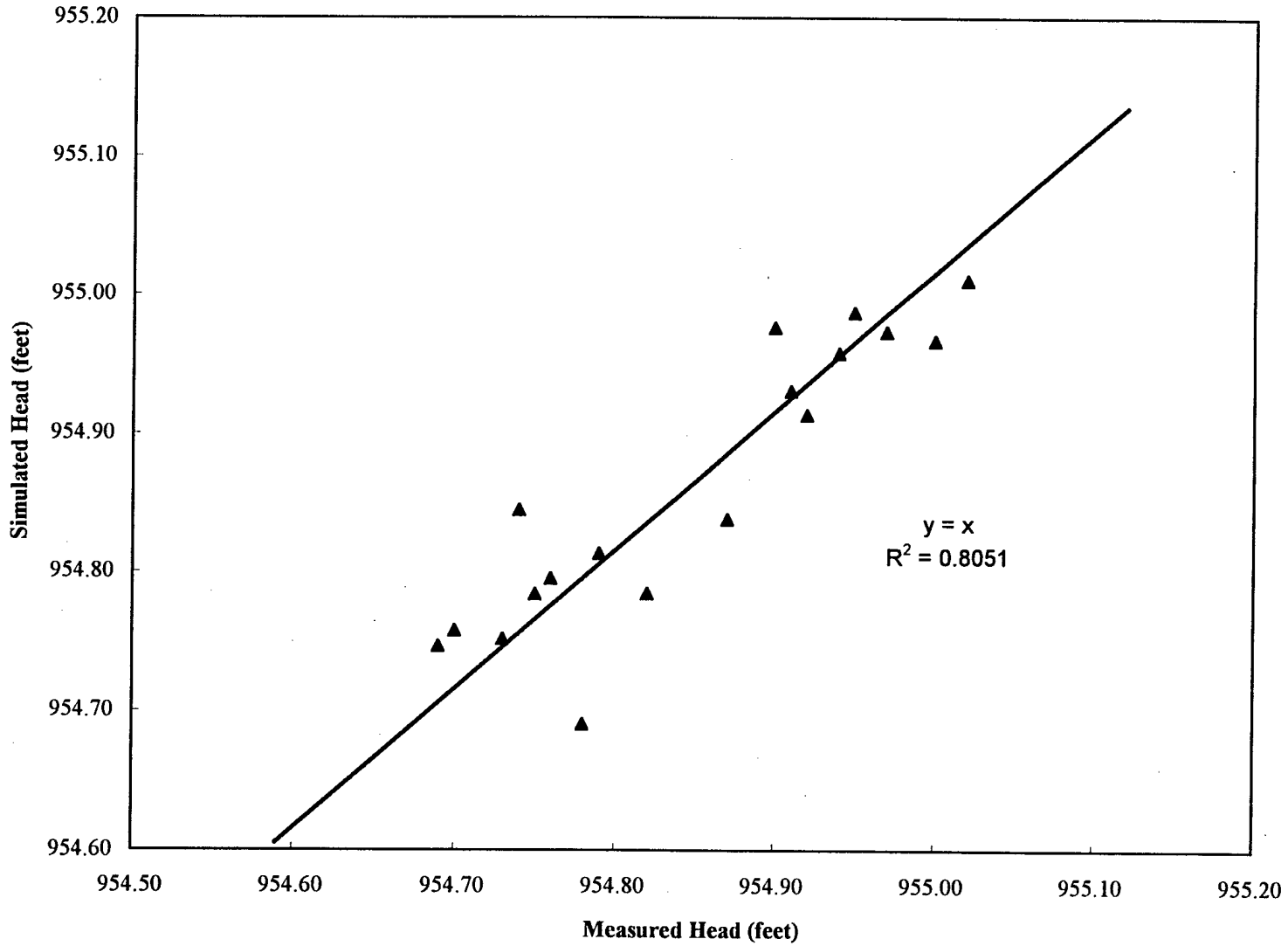
Well/CPT	Cell Location x,y	Measured Head Hm	Simulated Head Hs	Hm - Hs	(Hm - Hs)2
MP-2M	9,13	954.91	954.93	-0.0201	0.0004
MP-4D	9,15	954.87	954.84	0.0324	0.0010
MP-5M	8,7	954.97	954.97	-0.0025	0.0000
MP-6D	7,9	954.94	954.96	-0.0175	0.0003
MP-8D	13,17	954.82	954.78	0.0359	0.0013
MP-9D	8,5	954.95	954.99	-0.0366	0.0013
MP-12D	4,8	955.00	954.97	0.0336	0.0011
MP-17D	11,12	954.92	954.91	0.0069	0.0000
MP-20D	10,8	954.94	954.96	-0.0176	0.0003
MP-22D	15,19	954.73	954.75	-0.0212	0.0004
MP-23D	8,21	954.78	954.69	0.0900	0.0081
MP-24D	8,2	955.02	955.01	0.0100	0.0001
FPTA3-MW2	6,7	954.90	954.98	-0.0758	0.0057
FPTA3-MW3	10,17	954.75	954.78	-0.0339	0.0011
FPTA3-MW4	5,18	954.69	954.75	-0.0559	0.0031
FPTA3-MW5	3,13	954.74	954.84	-0.1044	0.0109
FPTA3-MW6A	8,18	954.70	954.76	-0.0575	0.0033
HF6-MW2	18,16	954.76	954.80	-0.0350	0.0012
HF6-MW4	14,15	954.79	954.81	-0.0229	0.0005

Sum of Squares of Remainders	0.041
Average of Squares of Remainders	0.0021
RMS	0.0462
RMS as a percentage of the head drop over the model domain (Head Drop is about 0.5 feet)	9.23

BTEX AND OXYGEN INJECTION RATES
FOR BIOPLUME II MODEL
FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

- Main Burn Pit, center 2 cells: BTEX at 0.5 saturation concentration (17.5 mg/L) and DO at 0.4 mg/L at an infiltration rate of 9 inches of water over the area of the cell per year.
- Main Burn Pit, 6 cells: BTEX at 0.25 saturation concentration (8.75 mg/L) and DO at 0.4 mg/L at an infiltration rate of 9 inches of water over the area of the cell per year.
- Main Burn Pit, 2 cells: BTEX at 0.125 saturation concentration (4.375 mg/L) and DO at 0.8 mg/L at an infiltration rate of 9 inches of water over the area of the cell per year.
- Main Burn Pit, 2 perimeter cells: BTEX at 0.05 saturation concentration (1.75 mg/L) and DO at 1.6 and 2.0 mg/L at an infiltration rate of 6 inches of water over the area of the cell per year.
- Main Burn Pit, 3 perimeter cells: No BTEX and 2.0 mg/L DO at an infiltration rate of 3 inches of water over the area of the cell per year.
- Remaining Discharge Pond, 1 cell: BTEX at 0.05 saturation concentration (1.75 mg/L) and DO at 0.4 mg/L at an infiltration rate of 12 inches of water over the area of the cell per year.
- Former Discharge Pond, center cell: BTEX at 0.01 saturation concentration (3.5 mg/L) and DO at 0.4 mg/L at an infiltration rate of 12 inches of water over the area of the cell per year. (This high rate of infiltration has ceased; however, it would have been legitimate up until the time that the discharge pond was filled.)
- Former Discharge Pond, 2 outside cells: BTEX at 0.05 saturation concentration (1.75 mg/L) and DO at 0.4 mg/L at an infiltration rate of 12 inches of water over the area of the cell per year. (See above.)

Simulated Head vs. Measured Head, Calibrated Groundwater Model for FPTA3



Knowns:

a) linear GW velocity ≈ 0.0055 m/day

b) porosity ≈ 0.35

c) soil bulk density ≈ 1.65 g/cm³

d) C_{os} (benzene) = ~~130 ug/kg~~ ≈ 130 ug/kg
C_{os} (toluene) = BLQ
C_{os} (ethylbenzene) = ~~186 ug/kg~~ ≈ 305 ug/kg
C_{os} (xylenes) = 440 ug/kg

e) C_{ow} (benzene) = 775 ug/L
C_{ow} (toluene) = 4.1 ug/L
C_{ow} (ethylbenzene) = 991 ug/L
C_{ow} (xylenes) = 1463.2 ug/L

f) Based on an average site f_{oc} = 0.0015 and literature values of K_{oc} from Wiedemeier, et al, 1994

K_{d_b} = 0.055 L/kg
K_{d_t} = 0.133 L/kg
K_{d_e} = 0.328 L/kg
K_{d_x} ≈ 0.28 L/kg

Assumptions:

a) 20% of equilibrium will be reached with each flush. This value was not selected as 100% because of limited contact time and because some contaminant mass will not be in contact w/ flowing pore water with each flush. Choosing a value less than 100% is also more conservative.

b) simulated mass = 1 m³ mass of soil ≈ 1650 kg/m³
mass of water ≈ 350 kg/m³

c) New volume of H_2O will pass through soil mass approximately twice per year.

$\frac{i}{V} = \frac{1}{0.0055\ m/day} = 182\ day \approx \frac{1}{2}\ year$

PUMP-AND-TREAT CONTAMINANT REMOVAL EFFICIENCIES

FIRE PROTECTION TRAINING AREA 3
INTRINSIC REMEDIATION TS
OFFUTT AIR FORCE BASE, NEBRASKA

Years	1m3 Pore Volume	Benzene Soil Concen.	Water Concen.	Toluene Soil Concen.	Water Concen.	Ethylbenzene Soil Concen.	Water Concen.	Total Xylenes Soil Concen.	Water Concen.
0	0	213.1	775.0	2.7	4.1	1625.2	991.0	2048.5	1463.2
0.5	1	48.8	177.5	1.8	2.8	1415.1	862.9	1738.3	1241.6
1	2	11.2	40.7	1.2	1.9	1232.2	751.4	1475.1	1053.6
1.5	3	2.6	9.3	0.9	1.3	1072.9	654.2	1251.7	894.1
2	4	0.6	2.1	0.6	0.9	934.2	569.7	1062.1	758.7
2.5	5	0.1	0.5	0.4	0.6	813.5	496.0	901.3	643.8
3	6	0.0	0.1	0.3	0.4	708.3	431.9	764.8	546.3
3.5	7	0.0	0.0	0.2	0.3	616.7	376.1	649.0	463.6
4	8	0.0	0.0	0.1	0.2	537.0	327.5	550.7	393.4
4.5	9	0.0	0.0	0.1	0.1	467.6	285.1	467.3	333.8
5	10	0.0	0.0	0.1	0.1	407.2	248.3	396.6	283.3
5.5	11	0.0	0.0	0.0	0.1	354.5	216.2	336.5	240.4
6	12	0.0	0.0	0.0	0.0	308.7	188.2	285.6	204.0
6.5	13	0.0	0.0	0.0	0.0	268.8	163.9	242.3	173.1
7	14	0.0	0.0	0.0	0.0	234.0	142.7	205.6	146.9
7.5	15	0.0	0.0	0.0	0.0	203.8	124.3	174.5	124.6
8	16	0.0	0.0	0.0	0.0	177.4	108.2	148.1	105.8
10	20	0.0	0.0	0.0	0.0	102.0	62.2	76.8	54.8
15	30	0.0	0.0	0.0	0.0	25.6	15.6	14.9	10.6
20	40	0.0	0.0	0.0	0.0	6.4	3.9	2.9	2.1
25	50	0.0	0.0	0.0	0.0	1.6	1.0	0.6	0.4
30	60	0.0	0.0	0.0	0.0	0.4	0.2	0.1	0.1
35	70	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
40	80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Shaded boxes show when predicted concentrations no longer exceeding first the most stringent generic Type C and then Type B criteria.

TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.5 mg/l VINYL CHLORIDE SOURCE DECAYING AT 1 %/year WITH A 0.00024 day-1 ANAEROBIC DECAY, CONSTANT TIME, VARIABLE LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy $K := 1.84 \cdot \frac{m}{day}$

Hydraulic gradient $I := 0.0006 \cdot \frac{ft}{ft}$

Effective porosity $n_e := 0.2$

Total porosity $n := 0.35$

Longitudinal dispersivity $\alpha_x := 10 \cdot m$

Concentration of Injected Contaminant $C_s := 1.5 \cdot \frac{mg}{liter}$

Initial Dissolved Contaminant Concentration $C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate $\lambda := 0.00024 \cdot \frac{1}{day}$

Source Decay Rate $\alpha := 0.000027 \cdot \frac{1}{day}$

Soil sorption coefficient (EPA, 1990) $K_{oc} := 2.455 \cdot \frac{mL}{gm}$

Bulk density (Freeze and Cherry, 1979) $\rho_b := 1.65 \cdot \frac{gm}{cm^3}$

Organic carbon content $f_{oc} := 0.0007$

Retardation coefficient $R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.014$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water) $v_x := \frac{K \cdot I}{n_e}$ $v_x = 0.006 \cdot \frac{m}{day}$

Contaminant velocity $v_c := \frac{v_x}{R}$ $v_c = 0.005 \cdot \frac{m}{day}$

Longitudinal dispersion coefficient $D_x := \alpha_x \cdot v_x$ $D_x = 0.594 \cdot \frac{ft^2}{day}$

Present Day -- 1995 (approx. 35 Years after start of Fire Training Activities)

Initial Plume Distribution Calculation

$j := 0..300$ $\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$ $t := 12775 \cdot day$

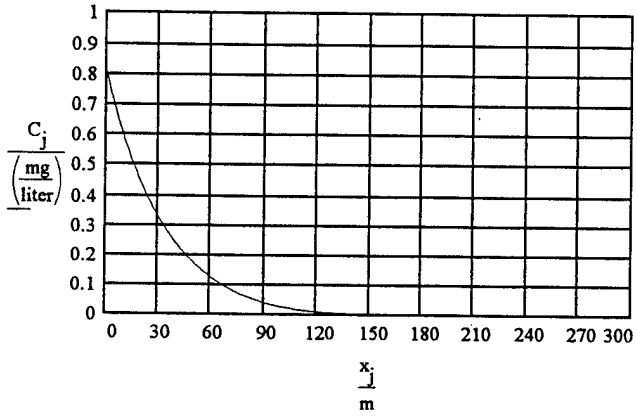
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

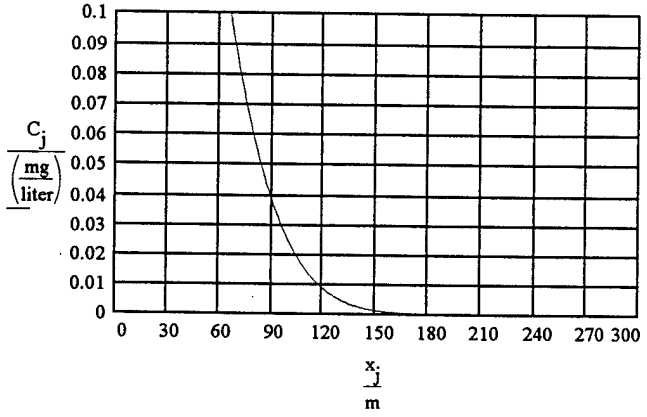
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \ldots$$

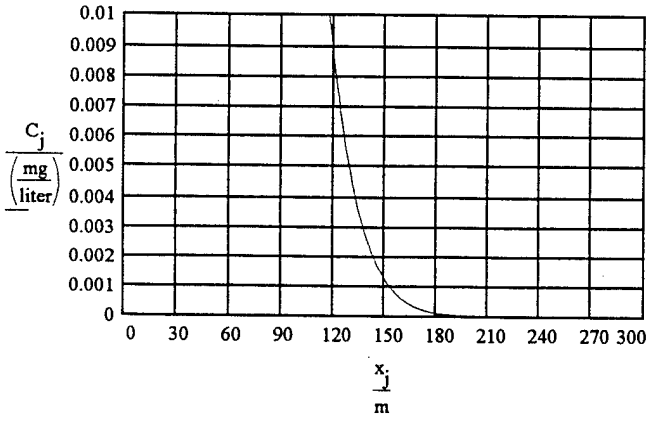
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$







50 Years from Present (approx. 2045)

Initial Plume Distribution Calculation

$j := 0..300$ $\Delta x := 1 \cdot m$

$x_j := \Delta x \cdot j$ $t := 31025 \cdot day$

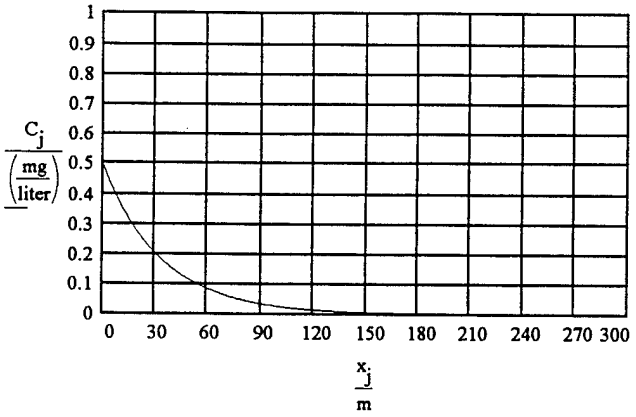
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

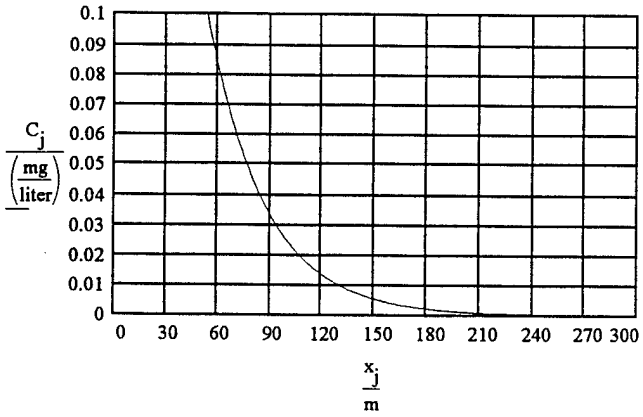
$$C_j := C_o \cdot \exp(-\lambda \cdot t) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j - v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) - \left(\frac{v_x^2 \cdot t}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{(R \cdot x_j - v_x \cdot t)^2}{4 \cdot D_x \cdot R \cdot t} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x_j}{D_x} + \frac{v_x^2 \cdot t}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x_j}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right] \ldots$$

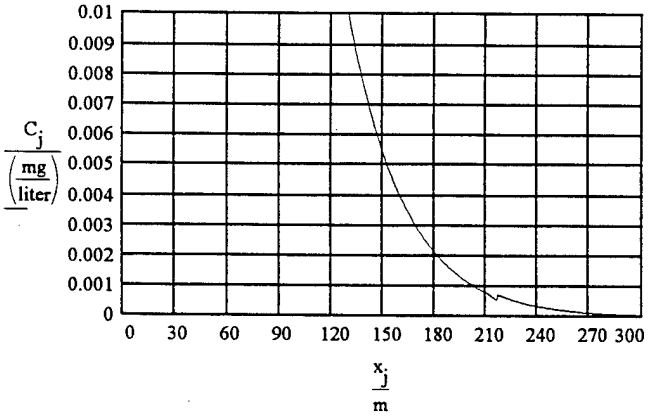
$$+ C_s \cdot \exp(-\alpha \cdot t) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j - t \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x_j}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x_j + t \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x_j}{D_x} - (\lambda - \alpha) \cdot t \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x_j + v_x \cdot t}{2 \cdot \sqrt{D_x \cdot R \cdot t}} \right) \right) \right]$$







TRANSIENT SOLUTION TO THE ADVECTIVE-DISPERSIVE EQUATION FOR ONE-DIMEMENSIONAL FLOW, TYPE THREE BOUNDARY CONDITION (1.5 mg/l VINYL CHLORIDE SOURCE DECAYING AT 1 %/year WITH A 0.00024 day-1 ANAEROBIC DECAY, VARIABLE TIME, CONSTANT LOCATION)

Hydrogeologic Data

Hydraulic conductivtiy $K := 1.84 \cdot \frac{m}{day}$

Hydraulic gradient $I := 0.0006 \cdot \frac{ft}{ft}$

Effective porosity $n_e := 0.2$

Total porosity $n := 0.35$

Longitudinal dispersivity (EPRI, 1985) $\alpha_x := 10 \cdot m$

Concentration of Injected Contaminant $C_s := 1.5 \cdot \frac{mg}{liter}$

Initial Dissolved Contaminant Concentration $C_o := 0 \cdot \frac{mg}{liter}$

Retardation Coefficient Calculation

Solute Decay Rate $\lambda := 0.00024 \cdot \frac{1}{day}$

Source Decay Rate $\alpha := 0.000027 \cdot \frac{1}{day}$

Soil sorption coefficient (EPA, 1990) $K_{oc} := 2.455 \cdot \frac{mL}{gm}$

Bulk density (Freeze and Cherry, 1979) $\rho_b := 1.65 \cdot \frac{gm}{cm^3}$

Organic carbon content $f_{oc} := 0.0007$

Retardation coefficient $R := 1 + \frac{\rho_b \cdot K_{oc} \cdot f_{oc}}{n_e}$ $R = 1.014$

Groundwater Hydraulics Calculations

Groundwater velocity (pore-water) $v_x := \frac{K \cdot I}{n_e}$ $v_x = 0.006 \cdot \frac{m}{day}$

Contaminant velocity $v_c := \frac{v_x}{R}$ $v_c = 0.005 \cdot \frac{m}{day}$

Longitudinal dispersion coefficient $D_x := \alpha_x \cdot v_x$ $D_x = 0.594 \cdot \frac{ft^2}{day}$

Location MP-4 (approx. 90 meters from the source area)

itial Plume Distribution Calculation

year := 365·day i := 1 .. 365 x := 90·m

Δt := 150·day

$t_i := \Delta t \cdot i$

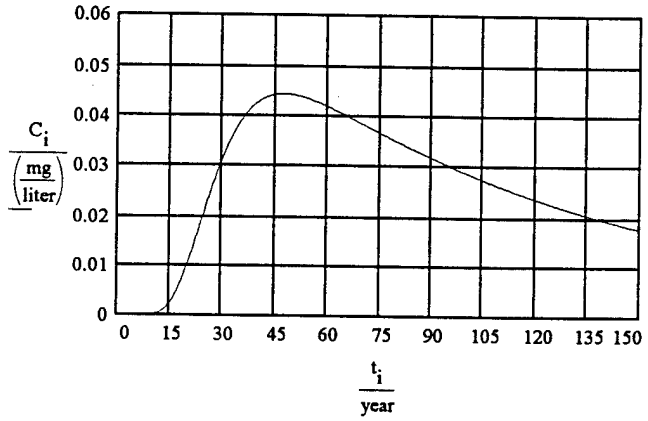
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{\left(R \cdot x - v_x \cdot t_i \right)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots \right.$$

$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\frac{\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



Location 250 meters from the source area (approx. 30 meters from the Base Lake)

Initial Plume Distribution Calculation

$year := 365 \cdot day \qquad i := 1..365 \qquad x := 250 \cdot m$

$\Delta t := 150 \cdot day$

$t_i := \Delta t \cdot i$

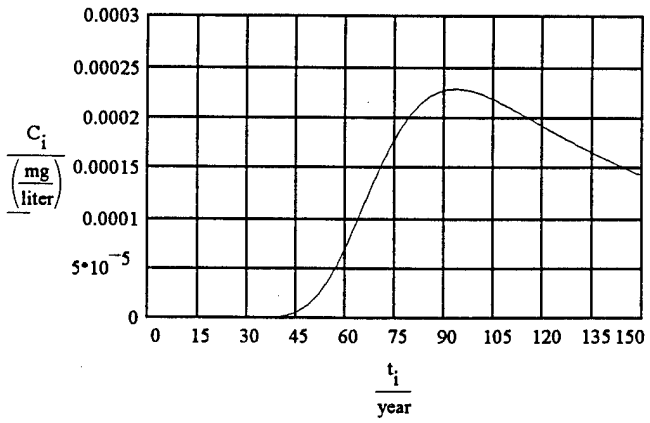
For Retarded Flow with Biodegradation and a Decaying Source (van Genuchten and Alves, 1982)

$$C_i := C_o \cdot \exp\left(-\lambda \cdot t_i\right) \cdot \left[1 - \frac{1}{2} \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x - v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) - \left(\frac{v_x^2 \cdot t_i}{\pi \cdot D_x \cdot R} \right) \cdot \exp\left[- \frac{\left(R \cdot x - v_x \cdot t_i \right)^2}{4 \cdot D_x \cdot R \cdot t_i} \right] + \frac{1}{2} \cdot \left(1 + \frac{v_x \cdot x}{D_x} + \frac{v_x^2 \cdot t_i}{D_x \cdot R} \right) \cdot \exp\left(\frac{v_x \cdot x}{D_x} \right) \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right] \ldots$$

$$+ C_s \cdot \exp\left(-\alpha \cdot t_i\right) \cdot \left[\left[\frac{v_x}{v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\left[v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \frac{x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x - t_i \cdot \left[v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right]}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots \right.$$

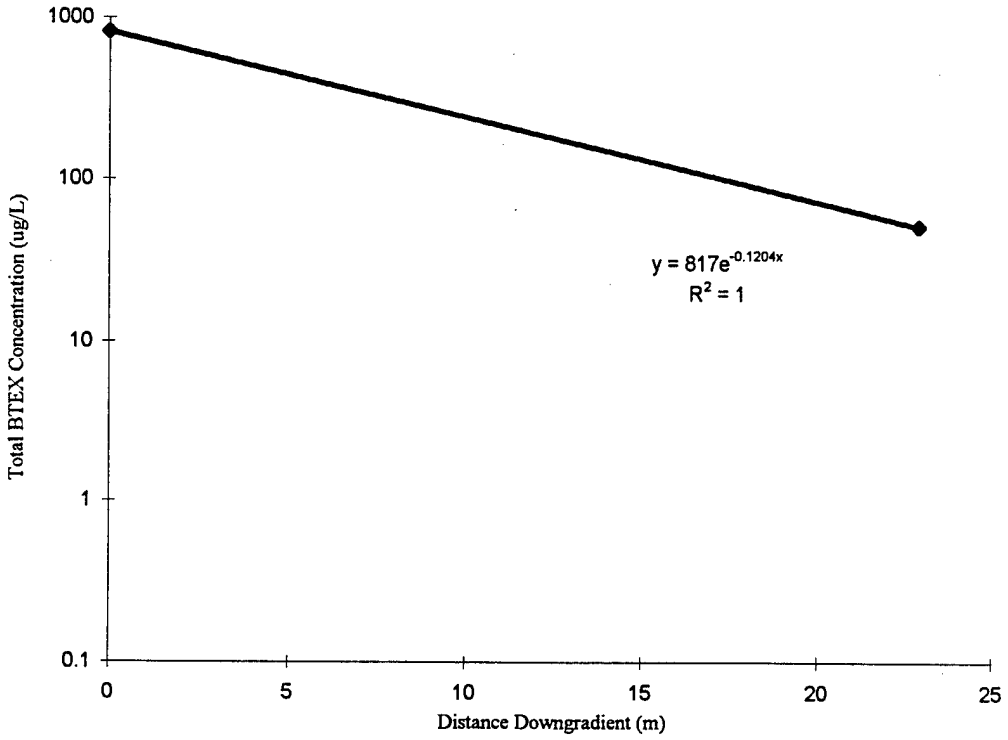
$$+ \left[\frac{v_x}{v_x - v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}} \right] \cdot \exp\left[\left[v_x + v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)} \right] \cdot \frac{x}{2 \cdot D_x} \right] \cdot \left[1 - \operatorname{erf}\left[\frac{R \cdot x + t_i \cdot v_x \cdot \sqrt{1 + \frac{4 \cdot D_x \cdot R}{v_x^2} \cdot (\lambda - \alpha)}}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right] \right] \ldots$$

$$\left. + \left[\frac{v_x^2}{2 \cdot D_x \cdot R \cdot (\lambda - \alpha)} \right] \cdot \exp\left[\frac{v_x \cdot x}{D_x} - (\lambda - \alpha) \cdot t_i \right] \cdot \left(1 - \operatorname{erf}\left(\frac{R \cdot x + v_x \cdot t_i}{2 \cdot \sqrt{D_x \cdot R \cdot t_i}} \right) \right) \right]$$



Data for First Order Rate Constant Calculation

Point	Distance Downgradient	Vinyl Chloride (µg/L)
		Nov-94
A	0	817
B	22.9	51.9



v_c = 0.0038

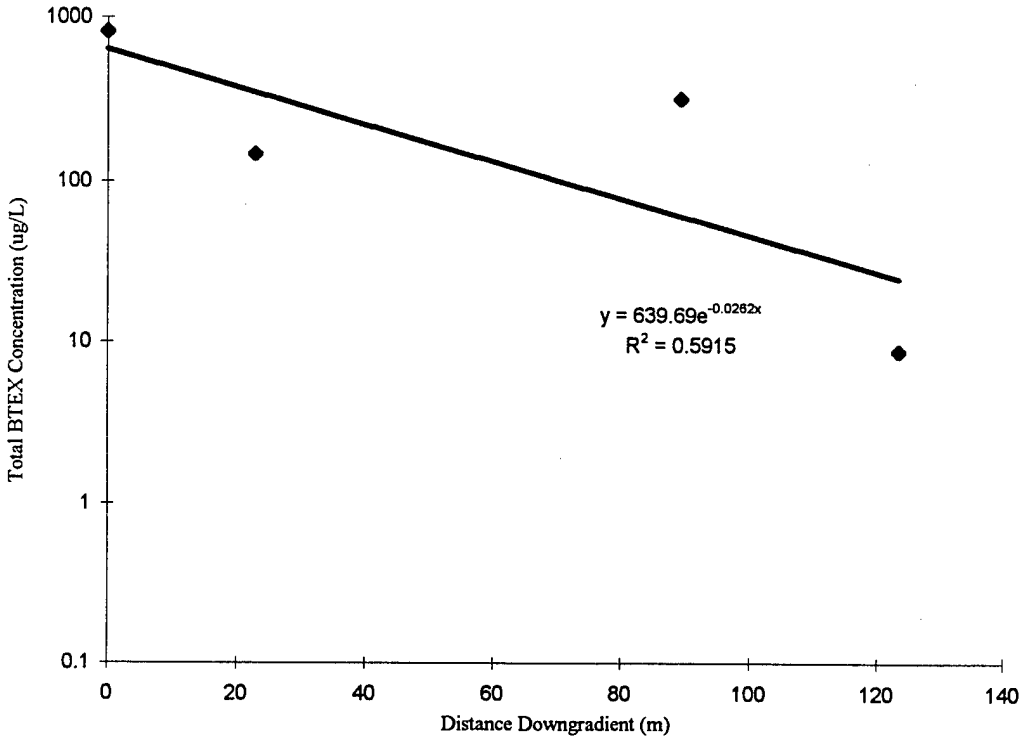
α_x = 10

k/v = 0.1204

λ = 1.01E-03

Data for First Order Rate Constant Calculation

Point	Distance Downgradient	Total Clorinated Solvent (µg/L)
		Nov-94
A	0	821
B	22.9	147
C	89.3	325
D	123.4	8.9



$v_c = 0.0038$

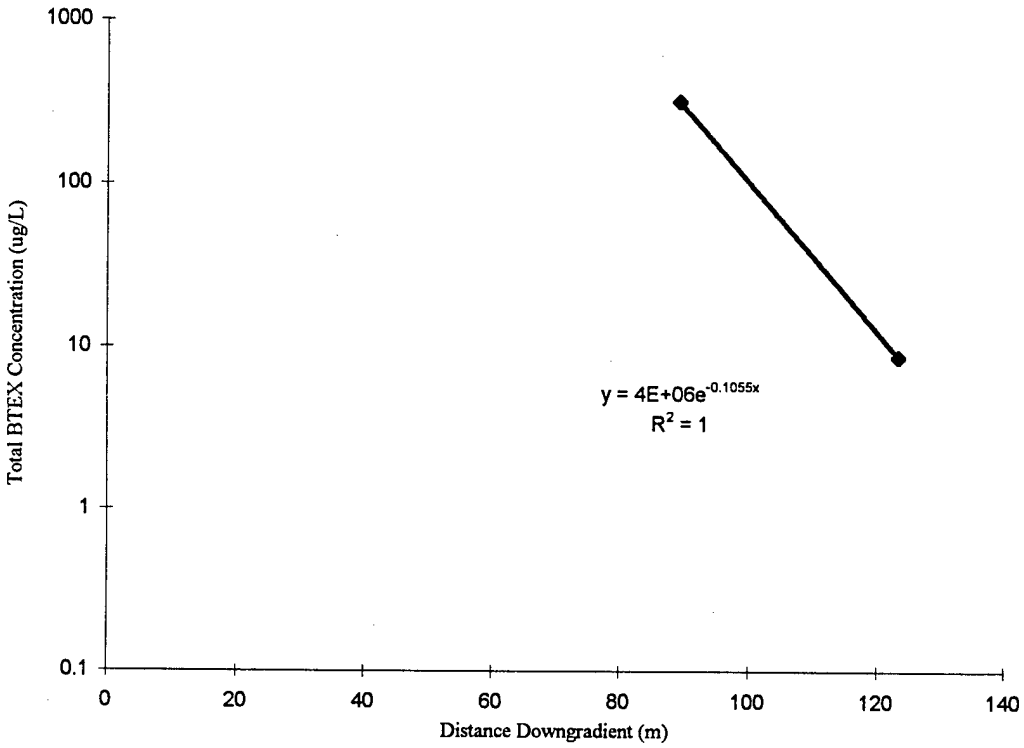
$\alpha_x = 10$

$k/v = 0.0262$

$\lambda = 1.26E\text{-}04$

Data for First Order Rate Constant Calculation

Point	Distance Downgradient	Total Chlorinated Solvent (µg/L)
		Nov-94
C	89.3	325
D	123.4	8.9



$v_c = 0.0038$

$\alpha_x = 10$

$k/v = 0.1055$

$\lambda = 8.24E\text{-}04$

APPENDIX D

MODEL INPUT AND OUTPUT FILES

APPENDIX E

REMEDIAL ALTERNATIVE DESIGN AND COST CALCULATIONS

Present Worth Analysis

Annual Adjustment Factor = 5%

Alternative 1: Intrinsic Remediation with Institutional Controls and Long-Term Groundwater Monitoring	years	Present Worth ($)	Year: 1	2	8	9	20	21	30
Maintain Institutional Controls	30	$38,431	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500
Long-term Monitoring									
Install New Wells	1	$15,965	$16,763	$0	$0	$0	$0	$0	$0
Groundwater Sampling	30	$73,096	$4,755	$4,755	$4,755	$4,755	$4,755	$4,755	$4,755
Reporting/Project Mgmt	30	$63,750	$4,147	$4,147	$4,147	$4,147	$4,147	$4,147	$4,147
Subtotal Present Worth ($)		$191,241							

Total Present Worth Cost ($): $191,241

Present Worth Analysis Annual Adjustment Factor = 5%

Alternative 2: Intrinsic Remediation and Groundwater Extraction with Institutional Controls and Long-Term Groundwater Monitoring	years	Present Worth ($)	Year: 1	2	8	9	20	21	30
Groundwater Extraction									
GW Extraction System Installation	1	$65,919	$69,215	$0	$0	$0	$0	$0	$0
System Maintenance	8	$113,822	$17,611	$17,611	$17,611	$0	$0	$0	$0
Annual Report	8	$24,728	$3,826	$3,826	$3,826	$0	$0	$0	$0
Subtotal Present Worth ($)		$204,469							
Maintain Institutional Controls	30	$38,431	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500
Long-term Monitoring									
Install New Wells	1	$15,965	$16,763	$0	$0	$0	$0	$0	$0
Groundwater Sampling	30	$73,096	$4,755	$4,755	$4,755	$4,755	$4,755	$4,755	$4,755
Reporting/Project Mgmt	30	$63,750	$4,147	$4,147	$4,147	$4,147	$4,147	$4,147	$4,147
Subtotal Present Worth ($)		$191,241							
Vapor Extraction Pilot Test (Optional)									
Develop Work Plan	1	$3,663	$3,846	$0	$0	$0	$0	$0	$0
Install Test Wells, Conduct Tests	1	$15,253	$16,016	$0	$0	$0	$0	$0	$0
Reporting Costs	1	$5,318	$5,584	$0	$0	$0	$0	$0	$0
		$24,234							

Total Present Worth Cost ($): $395,711
Total Present Worth Cost with Option ($): $419,945

Alternatives 1 and 2: Long-Term Monitoring and Institutional Controls

tandard Rate Schedule

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Install New LTM 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	32	$1,280	20	$800
Staff Level 16/(65)	$57	60	$3,420	32	$1,824	32	$1,824
Project Level 12/(70)	$65	4	$260	4	$260	30	$1,950
Senior Level 10/(80)	$85	1	$85	0	$0	2	$170
Principal 02/(85)	$97	0	$0	0	$0	0	$0
Total Labor (hrs | $)		74	$4,153	68	$3,364	144	$7,054
ODCs							
Phone			$20		$0		$40
Photocopy			$10		$0		$100
Mail			$50		$300		$50
Computer			$100		$0		$400
CAD			$0		$0		$450
WP			$0		$0		$200
Travel			$500		$1,000		$0
Per Diem			$400		$696		$0
pt. & Supplies			$200		$100		$0
Total ODCs			$1,280		$2,096		$1,240
Outside Services							
LTM/POC Well Installation Costs [a/]			$11,000		$0		$0
Laboratory Fees [b/]		Soils	$330	13 LTM	$4,050		$0
Other: Maintain Institutional Controls			$0	and 2qa/qc,	$0		$5,000
Total Outside Services			$11,330		$4,050		$5,000

Proposal Estimate	Task 1	Task 2	Task 3
Labor	$4,153	$3,364	$7,054
ODC's	$1,280	$2,096	$1,240
Outside Services	$11,330	$4,050	$5,000
Total by Task	$16,763	$9,510	$13,294

Total Labor	$14,571
Total ODCs	$4,616
Total Outside Services	$20,380
Total Project	$39,567

k 1: Install New LTM Wells

sk 2: Sampling per Event

Task 3: Reporting and PM per Sampling Event

[a/] 6 Wells, 180ft @ $45/ft, $2000mob, $1400 soil handling

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

Alternative 2: Groundwater Extraction

Standard Rate Schedule

Billing Category / Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Design & Install Recovey System ($)	Task 2 (hrs)	System Monitoring/ Maintenance (6x per yr)($)	Task 3 (hrs)	End of Report ($)
Word Processor 88/(15)	$30	50	$1,500	0	$0	8	$240
CADD Operator 58/(25)	$47	60	$2,820	0	$0	8	$376
Technician 42/(50)	$40	60	$2,400	180	$7,200	0	$0
Staff Level 16/(65)	$57	140	$7,980	40	$2,280	40	$2,280
Project Level 12/(70)	$65	80	$5,200	20	$1,300	8	$520
Senior Level 10/(80)	$85	8	$680	0	$0	2	$170
Principal 02/(85)	$97	2	$194	0	$0	0	$0
Total Labor (hrs|$)		400	$20,774	240	$10,780	66	$3,586
CDCs							
Phone			$200		$60		$10
Photocopy			$100		$0		$50
Mail			$100		$120		$40
Computer			$200		$0		$40
CAD			$240		$0		$60
WP			$100		$0		$40
Travel			$0		$3,522		$0
Eqpt. & Supplies			$0		$500		$0
Total ODCs			$940		$4,202		$240
Outside Services							
Well Installation			$7,400		$0		$0
Recovery System Installation			$23,501		$0		$0
Equipment Costs			$16,000		$0		$0
Product Hauling/Disposal			$0		$0		$0
Electrical Costs			$0		$229		$0
Laboratory Fees			$600		$2,400		$0
Other			$0		$0		$0
Total Outside Services			$47,501		$2,629		$0

Estimate	Task 1	Task 2	Task 3
Labor	$20,774	$10,780	$3,586
ODC's	$940	$4,202	$240
Outside Services	$47,501	$2,629	$0
Total by Task	$69,215	$17,611	$3,826
Total Labor	$35,140		
Total ODCs	$5,382		
Total Outside Services	$50,130		
Total Project	$90,652		

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

Alternative 2 (Optional): Vapor Extraction System Design and Installation

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			$200		$0		$200
CAD			$150		$0		$180
WP			$200		$0		$200
Travel			$0		$1,870		$0
Eqpt. & Supplies			$0		$500		$0
Total ODCs			$715		$2,500		$770
Outside Services							
Well Installation			$0		$1,050		$0
Electrical Costs			$0		$0		$0
Natural Gas Costs			$0		$0		$0
Laboratory Fees			$0		$1,100		$0
Equipment Costs			$0		$800		$0
Construction Costs			$0		$2,626		$0
Total Outside Services			$0		$5,576		$0

Proposal Estimate	Task 1	Task 2	
Labor	$3,131	$7,940	$4,814
ODC's	$715	$2,500	$770
Outside Services	$0	$5,576	$0
Total by Task	$3,846	$16,016	$5,584

Total Labor	$15,885
Total ODCs	$3,985
Total Outside Services	$5,576
Total Project	$25,446

Task 1: Work Plan Development
Task 2: Vapor Extraction/Bioventing/Air Sparging Pilot Study
Task 3: Report Preparation

Offutt AFB Backup Calculations

Alternatives 1 and 2: Long-term Monitoring

Misc calculations

Number of LTM wells:		
Number of wells:	6	
Depth each:	30	ft

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 11,000	
Mobilization	ea	1	$ 2,000	$ 2,000		
Well Installation	ln ft	180	$ 45	$ 8,100		
Soil Disposal	drum	9	$ 100	$ 900		

Offutt AFB Backup Calculations

Alternative 2: Groundwater Extraction System

Misc calculations

Number of groundwater extraction wells:		
Number of wells:	2	
Depth each:	40	ft
Trench Volume/Area		
Width:	12	in
Depth:	2	ft
Length:	800	ft
Volume:	1,600	cf
	59	cy
Surface Area:	800	sf
	89	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 7,400	
Mobilization	ea	1	$ 1,000	$ 1,000		
Well Installation	ln ft	80	$ 70	$ 5,600		
Soil Disposal	drum	8	$ 100	$ 800		
Equipment Costs					$ 16,000	
Pumps	ea	2	$ 1,500	$ 3,000		
Air Stripper	ea	1	$ 10,000	$ 10,000		
Pump Electronics	ea	2	$ 1,500	$ 3,000		Means 132 151 5540
System Installation					$ 23,501	
Mob/Demob	ea	1	$ 1,000	$ 1,000		
Trenching	cy	59	$ 5.05	$ 298		Means 022 254 0050
Pipe laying	ln ft	960	$ 13.05	$ 12,528		Means 151 701 0550/026 686 2800
Backfill	cy	59	$ 17.20	$ 1,015		Means 022 204 0600
Compaction	cy	59	$ 5.10	$ 301		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Reseeding	sy	178	$ 1.91	$ 340		Means 029 304 0310
Piping	lf	100	$ 9.30	$ 930		Means 151 551 1880
Mechanical	man hr	20	$ 38.83	$ 777		Means Q-1 crew
Electrical	ls	1	$ 5,000	$ 5,000		
Slab	cy	2	$ 97.00	$ 194		Means 033 130 4700
Building	ea	-	$ 4,925	$ -		Means 131 221 0010
Contingency	%	5%	$ 22,382	$ 1,119		
Product Hauling /Disposal	load	-	$ -	$ -		Assumed to be free-of-charge

Offutt AFB Backup Calculations

Alternative 2: Vapor Extraction

Misc calculations

Wells/Monitoring Points		
Number of Wells:	1	
Number of MPs:	-	
Depth:	10	ft
Trench Volume/Area		
Width:	12	in
Depth:	1	ft
Length:	40	ft
Volume:	40	cf
	1	cy
Surface Area:	40	sf
	4	sy

Cost calculations

Description	Unit	Qty.	Unit Price	Subtotal	Total	Source (If applicable)
Well Installation					$ 1,050	
Mobilization	ea	1	$ 500	$ 500		
Well Installation	ln ft	10	$ 45	$ 450		
MP Installation	ln ft	-	$ 25	$ -		
Soil Disposal	drum	1	$ 100	$ 100		
Equipment Costs					$ 800	
Blowers	ea	1	$ 800	$ 800		
System Installation					$ 2,626	
Mob/Demob	ea	-	$ 1,000	$ -		
Trenching	cy	59	$ 5.05	$ 298		Means 022 254 0050
Pipe laying	ln ft	48	$ 13.05	$ 626		Means 151 701 0550/026 686 2800
Backfill	cy	-	$ 17.20	$ -		Means 022 204 0600
Compaction	cy	-	$ 5.10	$ -		Means 022 204 0600
Pavement Base	sy	-	$ 5.25	$ -		Means 022 308 0100
Concrete repair	cy	-	$ 97.00	$ -		Means 033 130 4700
Reseeding	sy	8	$ 1.91	$ 15		Means 029 304 0310
Piping	lf	20	$ 9.30	$ 186		Means 151 551 1880
Mechanical	man hr	-	$ 38.83	$ -		Means Q-1 crew
Electrical	ls	1	$ 1,000	$ 1,000		
Slab	cy	-	$ 97.00	$ -		Means 033 130 4700
Blower House	ea	1	$ 500	$ 500		Means 131 221 0010

ES ENGINEERING-SCIENCE, INC.

Client AFCEE | Job No. 722450.24050 | Sheet 1 of 1

Subject Groundwater Extraction System Design — Basic - Equations (from PRG, 1990) | By D. Hautaux | Date 4/25/95

Checked | Rev.

1) Radius of Influence (R_o):

$$R_o = 575\,\Delta s\sqrt{HK}$$

where:
ΔS = drawdown in meters
H = initial sat. thickness in meters
K = hydraulic conductivity in m/s
575 is conversion factor (units of $\frac{1}{\sqrt{m^2/s}}$)

Application: Unconfined Aquifers

Reference: Maximov, V.M. (ed.) 1967. Handbook For Hydrogeologists, Vol. 1. Translated from Russian for the US Dept. of Interior, Bureau of Reclamation, and the National Science Foundation by the Indian Scientific Documentation Centre, New Delhi, 1975.

2) Pumping Rate (Q)

$$Q = \frac{K(H^2 - h_w^2)}{458 \ln R_o/r_w}$$

where:
K = hydraulic conductivity in gpd/ft^2
H = initial sat. thickness in feet
h_w = sat. thickness at well during pumping (ft)
R_o = radius of influence in ft.
r_w = well casing radius in ft.

Application: Radial Flow, unconfined aquifer

Reference: (Powers, 1981)

Note: Equation assumes 100% well efficiency

ES ENGINEERING-SCIENCE, INC.

Client AFCEE | Job No. 722450.24050 | Sheet 1 of 1

Subject Groundwater Extraction System Design at FPTA3, Offutt AFB | By D. Moutoux | Date 4/25/95

Checked M. Vesscey | Rev.

K from slug tests + previous reports $\cong$ 1.84 m/day or 0.0000213 m/s

H is the estimated depth of contamination $\cong$ 9m

Δs (assume a drawdown of 2/3 sat. thickness per D. Downey $\cong \frac{2}{3}(9) = 6m$

$$R_0 = 575 \Delta S \sqrt{HK} = 575(6)\sqrt{(9)(0.0000213)} = 47.8\ m\ (157\ ft)$$

$\therefore$ For for FPTA3 2 wells should be sufficient... near Building 654 and at nose of mock plane fuselage.

h_w assuming a 67% well efficiency (Driscoll, 1986 p 217)

$= H - H(.67) = 9 - 6 = 3\ m\ (10\ ft)$

$$Q = \frac{K(H^2 - h_w^2)}{458 \ln R_0/r_w} = \frac{(45\ gpd/ft^2)((30\ ft)^2 - (10\ ft)^2)}{458 \ln (157/0.1667)} = 11.5\ gpm$$

APPENDIX F

RESPONSES TO COMMENTS

PARSONS

Parsons Engineering Science, Inc. • A Unit of Parsons Infrastructure & Technology Group Inc.
1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax: (303) 831-8208 • www.parsons.com

28 September 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Responses to Comments on the Draft Treatability Study in Support of Intrinsic Remediation for Fire Protection Training Area 3, Offutt Air Force Base, Nebraska (Contract F41624-92-D-8036-0006)

Dear Mr. Hansen:

This letter provides responses to comments received on the Draft Intrinsic Remediation Treatability Study (TS) for Fire Protection Training Area 3 (FPTA-3), Offutt Air Force Base (AFB), Nebraska. The draft TS was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and the 55 CES/CEVR, Offutt AFB, Nebraska.

The intent of the TS was to determine the role of natural attenuation in remediating fuel hydrocarbon contamination in groundwater at Fire Protection Training Area 3 (FPTA-3). The draft TS was submitted to AFCEE in May 1995. Comments on the draft TS were received from AFCEE as reviewed by Chung Yen (date unknown). Responses to these comments were prepared by Parsons ES and are attached to this letter.

If you have any questions or comments regarding this responses please do not hesitate to contact me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry

Bruce M. Henry, P.G.
Project Manager

Enclosures

S:\ES\REMED\BIOPLUME\OFFUTT\FPTA3\FTA3-RESP.DOC

Responses to AFCEE Comments on the Draft Treatability Study in Support of Intrinsic Remediation for Fire Protection Training Area 3, Offutt Air Force Base, Nebraska

Comment 1) The figures and text pages should be stamped "Draft".

Parsons ES Response: *The draft Treatability Study (TS) will be submitted in "Final" format. Therefore, it will not be necessary to stamp the figures and text.*

Comment 2) Page 2-6, Paragraph 3: The rationale for selection of monitoring wells FPTA3-MW6 and HF6-MW4 for conducting rising head slug tests are not provided.

Parsons ES Response: *Monitoring wells FPTA3-MW6 and HF6-MW4 were selected for rising head slug tests based upon a lack of free product and a determination from borehole logs that the screened intervals for these wells were representative of the shallow aquifer. The text will be changed to reflect this rationale.*

Comment 3) Fig 4.2, Total BTEX Isopleth Map for Groundwater, and 4.3, Vertical Profile of Total BTEX Isopleths for Groundwater: BTEX isopleth from prior data on a separate or same figure will be helpful to show bioattenuating activities in the past before this study. Historical benzene isopleth superimposed on current benzene isopleth can also show some bioactivities.

Parsons ES Response: *Parsons ES has completed an addendum to the TS that shows historical trends of BTEX and benzene over time. This addendum will be referenced and attached as an appendix to the final TS.*

Comment 4) Sec 5.3.5, Anaerobic Degradation Rates: It appears that the text does not provide adequate justification for using first order degradation assumption. Need to cite any supportable literature recommendations.

Parsons ES Response: *The following will be added to Section 5.3.5:*

"Although a first-order rate assumption may provide a reasonable approximation of how BTEX compounds are degrading in groundwater systems, these reactions may be more appropriately approximated by a second-order rate expression. Unfortunately, currently available fate and transport models (i.e., BIOLPLUME II) are incapable of using second-order rates."

Comment 7) Sec 6, Alternative 2:

a. The depth, size, and screening interval of the two groundwater extraction wells are not specified.

b. The text need to specify whether the POC well are cost out as monitoring wells.

c. Table 6.4: The discussion and line item for vapor treatment system is missing. Is it included in the $69,200 for "Design/Construct Groundwater Extraction System...., and Air Stripper Treatment System"?

Parsons ES Response:

a. *The text will be amended to indicate the extraction wells were costed to be 40 feet deep, 4-inches in diameter, and screened across the shallow aquifer.*

b. *See the above response to Comment 6a.*

c. *A discussion of the optional soil vapor extraction (SVE) system will be added to Section 6.4.2.1. The line item for the optional SVE system is listed in Table 6.4 below the line item for "Design/Construct Groundwater Extraction System..."*

Comment 8) Sec 6, Page 6-19, 1st Paragraph: How was the eight years of operation of the groundwater extraction conservatively determined? It would be useful to construct a estimation method to conservatively determine the time of groundwater extraction.

Parsons ES Response: *As indicated in Section 6.3.2, the eight year operation period was estimated based upon a pumping rate of 11.5 gallons per minute (gpm) per extraction well, and a partitioning equilibrium between groundwater and surrounding saturated soils of 10 percent or less. Calculations for the configuration of the extraction wells and the length of time of groundwater extraction are included in Appendix C.*

APPENDIX G

FINAL INTRINSIC REMEDIATION TREATABILITY STUDY ADDENDUM

FINAL
INTRINSIC REMEDIATION TREATABILITY STUDY ADDENDUM

for

FIRE PROTECTION TRAINING AREA 3
OFFUTT AIR FORCE BASE
OMAHA, NEBRASKA

September 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

55 CES/CEVR
OFFUTT AIR FORCE BASE
OMAHA, NEBRASKA

Prepared by:

Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

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ATTACHMENT A - ANALYTICAL DATA

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LIST OF ACRONYMS AND ABBREVIATIONS

1,1-DCE	1,1-dichloroethene
µg/L	micrograms per liter
ACC	Air Combat Command
AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence, Technology Transfer Division
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAHs	chlorinated aliphatic hydrocarbons
cis-1,2-DCE	*cis*-1,2-dichloroethene
CO_2	carbon dioxide
DO	dissolved oxygen
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron
FPTA3	Fire Protection Training Area No. 3
ft/day	feet per day
ft/ft	foot/foot
ft amsl	feet above mean sea level
ft/yr	feet per year
H_2S	hydrogen sulfide
LTM	long-term monitoring
mg/L	milligrams per liter
Mn^{2+}	manganese II (reduced form)
Mn^{3+}	manganese III
MTBE	methyl tertiary-butyl ether
mV	millivolts
N	nitrogen
NRMRL	National Risk Management Research Laboratory
ORP	oxidation-reduction potential
Parsons ES	Parsons Engineering Science, Inc.
STRATCOM	Strategic Command
TCE	trichloroethene
TMBs	trimethylbenzenes
TOC	total organic carbon
trans-1,2-DCE	*trans*-1,2-dichloroethene
TS	treatability study
USEPA	US Environmental Protection Agency
VC	vinyl chloride
W-C	Woodward-Clyde Consultants

1.0 INTRODUCTION

This report was prepared for the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT) by Parsons Engineering Science, Inc. (Parsons ES) as an addendum to the Draft Treatability Study (TS) in Support of Intrinsic Remediation for Fire Protection Training Area 3 (FPTA3), Offutt Air Force Base (AFB), Nebraska (Parsons ES, 1995). The initial TS sampling event was conducted in November 1994 to evaluate the use of natural attenuation with long-term monitoring (LTM) for remediation of aromatic and chlorinated aliphatic hydrocarbons (CAHs) dissolved in groundwater at the site. This addendum summarizes results of the second and third sampling events completed as part of the natural attenuation evaluation. Groundwater samples were collected from previously installed monitoring wells in June 1996 and June 1998 by researchers from the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL), Subsurface Protection and Remediation Division.

1.1 Scope and Objectives

The primary objective of this addendum is to evaluate changes in concentrations of the dissolved fuel hydrocarbons benzene, toluene, ethylbenzene, and xylenes (BTEX); BTEX plume extent; and natural attenuation mechanisms acting on BTEX between November 1994 and June 1998. A secondary objective is to evaluate changes in concentrations of chlorinated solvents including dissolved trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), *trans*-1,2-dichloroethene (*trans*-1,2-DCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride (VC). Although the focus of the TS was on natural attenuation of the BTEX compounds, changes in chlorinated solvent plume extent and natural attenuation mechanisms acting on chlorinated solvents also are discussed herein. Results, calculations, and predictions presented in the TS are used as the basis for comparison. Analytical data for the June 1996 and June 1998 sampling events are included in Attachment A. Additional site information, including the site investigation history and geology, is provided in the TS report (Parsons ES, 1995).

1.2 Site Background

Offutt AFB occupies approximately 2,750 acres in eastern Sarpy County, Nebraska. Since 1992, the Base has served as the Strategic Command (STRATCOM) Headquarters and is an Air Combat Command (ACC) base. The Base presently employs approximately 11,000 military and civilian personnel [Woodward-Clyde Consultants (W-C), 1992].

FPTA3 is located west of Harlan-Lewis Road in the southeastern corner of the Base. Fire protection training exercises were conducted at the site from 1960 until the spring of 1990. From 1960 to 1974, exercises were conducted at a frequency of approximately once per week and up to 2,000 gallons of waste fuels and solvents were used per training day. After 1974, exercises were conducted with approximately 300 gallons of jet fuel (JP-4) at a frequency of approximately twice per calendar quarter (Engineering-Science, Inc. [ES], 1990a).

The central training area at FPTA3 is a bermed burn pit surrounding a mock aircraft fuselage (Figure 1). The berm is topped by a gravel track, which circumscribes a circular area approximately 200 feet in diameter and stands roughly three feet higher than the pit interior. The flat interior area of the pit is approximately 100 feet in diameter and is referred to as the main burn pit. Soils in the main burn pit are visibly contaminated and support very little vegetation. Disturbance of these surficial soils releases a strong hydrocarbon odor. A drain pipe on the north side of the main burn pit was used to discharge contaminated water from the main burn pit into a former discharge pond north of the pit.

Building 654, located west of the main burn pit, is a cinder block shell that appears to also have been used for training exercises. Historic aerial photographs are reported to indicate a fire training area where Building 654 currently stands (ES, 1990a). A semi-circular gravel path north, south, and west of Building 654 may define the extent of this former fire training area.

Another burn pit is located between Building 654 and the historic discharge pond (Figure 1). This secondary burn pit is surrounded by a one-foot-high berm and is approximately 45 feet in diameter. The berm is breached on the eastern side. A structure constructed of a barrel split lengthwise and mounted on legs (resembling a barbecue grill) stands at the center of the secondary burn pit.

The results of previous investigations demonstrate that soil and groundwater associated with, and downgradient from, FPTA3 are contaminated with JP-4 related compounds and chlorinated solvents. Fuel mixtures not burned during fire training exercises seeped into the ground and contaminated the soil and groundwater underlying the source areas. At some locations, the soil is reportedly saturated with fuel. However, free-phase hydrocarbons have not been detected in any of the site groundwater monitoring wells.

The 1994/1995 TS indicated that biodegradation of both BTEX and chlorinated solvent compounds was occurring at the site. Biodegradation of fuel hydrocarbons was occurring at the site primarily via the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis. In addition, the ratio of chlorinated solvent parent compounds to anaerobic biodegradation daughter products suggested that chlorinated solvents in the groundwater were being degraded through cometabolism.

The results of the TS further suggested that dissolved BTEX and chlorinated solvent contamination present in groundwater poses no significant risk to human health or the environment in its present, or predicted future, concentration and distribution. The TS recommended that natural attenuation with LTM be implemented as the appropriate remedial action to address dissolved BTEX and chlorinated solvent contamination in groundwater. Natural attenuation is currently the only process acting to reduce contaminant mass at the site.

2.0 MONITORING RESULTS

Groundwater samples were collected at FPTA3 on two occasions (June 1996 and June 1998) following the initial TS sampling event (November 1994). During the June

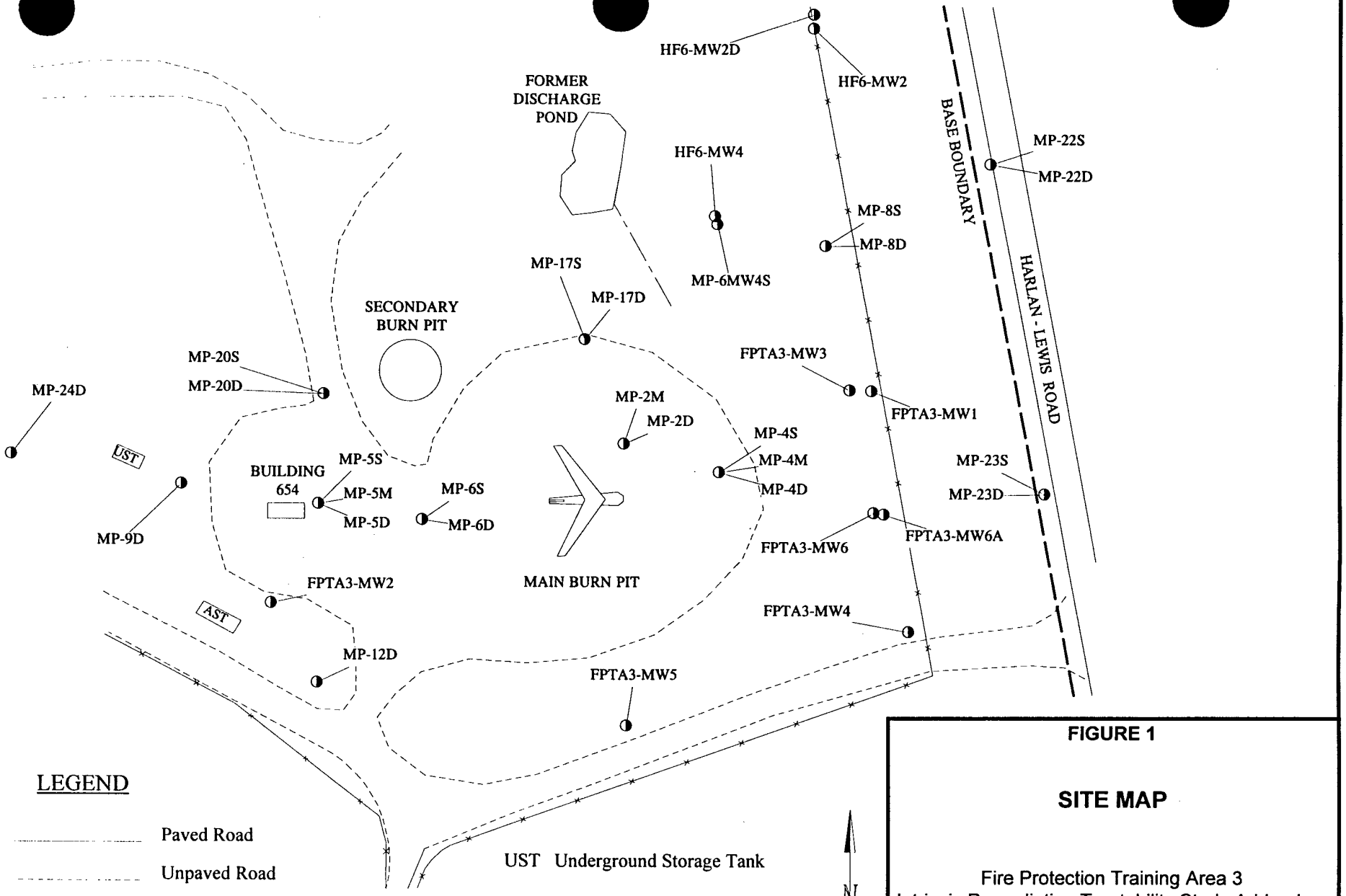


FIGURE 1

SITE MAP

Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

FILE NAME: ES\...\Offutt\FPTA3\tunkstemp\MapInfoFiles\sitemap2.wor DATE: 07/02/99

1996 sampling event, groundwater samples were collected from 23 monitoring wells (ten shallow, eight intermediate, and five deep monitoring wells). During the June 1998 sampling event, groundwater samples were collected from nine monitoring wells (three shallow, five intermediate, and one deep monitoring well(s)). All samples were collected by USEPA NRMRL personnel and were analyzed at the USEPA NRMRL in Ada, Oklahoma.

Samples were analyzed for BTEX, trimethylbenzenes (TMBs), methyl tert-butyl ether (MTBE), CAHs, methane, ethane, ethene, ammonia, nitrate+nitrite as nitrogen (N), chloride, sulfate, and total organic carbon (TOC). Analytical methods for June 1998 are summarized in Table 1. Where sufficient groundwater sample volume was available, samples were analyzed in the field for temperature, pH, conductivity, dissolved oxygen (DO), oxidation/reduction potential (ORP), ferrous iron, manganese, alkalinity, carbon dioxide (CO_2), and hydrogen sulfide (H_2S). Groundwater elevations also were measured prior to sample collection during both of the groundwater sampling events.

Since 1988, groundwater monitoring wells/points have been installed at the site on several occasions. Multiple depth zones were investigated in order to evaluate the vertical distribution of contamination in the subsurface. Monitoring well/point completion details are summarized in Table 2. The wells have been grouped according to screen midpoint elevations. Three general intervals of screen midpoint elevations have been arbitrarily selected for analysis purposes: shallow - 950 to 956 feet above mean sea level (ft amsl); intermediate - 943 to 946 ft amsl; and deep - 880 to 936 ft amsl.

2.1 Geology and Hydrogeology

Subsurface geology at FPTA3 consists of Pleistocene and Recent glacial sand, silt and clay deposits overlying interbedded limestone and shale deposits of Pennsylvanian age. The unconsolidated glacial deposits are at least 90 feet thick beneath the site, and the depth to bedrock has not been determined (Parsons ES, 1995). Unconfined groundwater flow occurs within the unconsolidated glacial deposits, and depth to water ranges from approximately 6 to 12 feet below ground surface (bgs).

Groundwater elevations for November 1994, June 1996, and June 1998 are shown on Table 3 and Figure 2. Groundwater elevation contours are based on data collected from wells screened primarily in the intermediate depth interval; data for this interval were used for contouring in the 1995 TS report. During November 1994, the predominant groundwater flow direction was east-northeast at an average horizontal gradient of approximately 0.0004 foot per foot (ft/ft). A hydraulic gradient of 0.0006 ft/ft was estimated as representative of the average annual hydraulic gradient at the site based on previous monitoring events (ES, 1995).

Both June 1996 and June 1998 groundwater elevations were significantly higher than those measured in November 1994, and the inferred groundwater flow direction shifted towards the north-northwest. Average hydraulic gradients were 0.0008 ft/ft in June 1996, and 0.0017 ft/ft in June 1998. The apparent change in groundwater flow direction from November 1994 to June 1998 may be a result of temporal changes in

TABLE 1
SUMMARY OF GROUNDWATER ANALYTICAL METHODS
JUNE 1998
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Analyte	Method	Field (F) or Fixed-Base Laboratory (L)
Oxidation\Reduction Potential	Direct Reading Meter	F
Dissolved Oxygen	Direct Reading Meter	F
Conductivity	Direct Reading Meter	F
Temperature	Direct Reading Meter	F
pH	Direct Reading Meter	F
Ferrous Iron (Fe^{2+})	Colorimetric, Hach Method 8146 or equivalent	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01 or equivalent	F
Manganese	Colorimetric, HACH Method 8034, or equivalent	F
Hydrogen Sulfide	Colorimetric, Hach Method 8131 or equivalent	F
Alkalinity (Carbonate [CO_3^{2-}] and Bicarbonate [HCO_3^-])	Titrimetric, Hach Method 8221 or equivalent	F
Nitrate + Nitrite	Waters Capillary Electrophoresis Method N-601	L
Ammonia	Lachat FIA Method 10-107-06-1	L
Conductivity	EPA Method 120.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane and Ethene	RSKSOP-175[a/] and RSKSOP-194	L
Total Organic Carbon	RSKSOP-102	L
BTEX, TMBs, and MTBE[b/]	RSKSOP-122	L
Chlorinated Volatile Organics	RSKSOP-148	L

[a/] RSKSOP = Robert S. Kerr Laboratory (now known as NRMRL) standard operating procedure.

[b/] BTEX = benzene, toluene, ethylbenzene, and xylenes; TMB = trimethylbenzenes; MTBE = methyl tertiary-butyl ether.

TABLE 2
MONITORING WELL/POINT COMPLETION SUMMARY
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Well ID	Well Installation Date	Ground Elevation (ft amsl)[a/]	Total Depth (ft bgs)[b/]	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Top (ft amsl)	Screen Bottom (ft amsl)	Screen Midpoint (ft amsl)	Screen Length (feet)
Shallow Wells (screen midpoint approximately 950 ft amsl to 956 ft amsl)									
FPTA3-MW2	9/6/1988	964.30	22.30	4.70	19.70	959.60	944.60	952.10	15.00
FPTA3-MW3	9/6/1988	963.90	22.00	4.00	19.50	959.90	944.40	952.15	15.50
FPTA3-MW4	9/6/1988	964.45	22.00	7.00	22.00	957.45	942.45	949.95	15.00
FPTA3-MW5	9/25/1988	964.33	23.50	5.50	20.50	958.83	943.83	951.33	15.00
HF6-MW2	9/8/1988	962.96	22.30	4.80	19.80	958.16	943.16	950.66	15.00
HF6-MW4	8/1/1991	963.68	20.00	5.00	19.00	958.68	944.68	951.68	14.00
MP-2S	11/15/1994	962.00	8.00	4.55	7.08	957.45	954.92	956.19	2.53
MP-4S	11/15/1994	964.90	12.50	9.05	11.58	955.85	953.32	954.59	2.53
MP-5S	11/15/1994	964.60	11.00	7.55	10.08	957.05	954.52	955.79	2.53
MP-6S	11/15/1994	964.70	11.00	7.55	10.08	957.15	954.62	955.89	2.53
MP-8S	11/16/1994	963.40	11.00	7.55	10.08	955.85	953.32	954.59	2.53
MP-12S	11/16/1994	963.30	11.00	7.55	10.08	955.75	953.22	954.49	2.53
MP-17S	11/17/1994	965.00	13.00	9.55	12.08	955.45	952.92	954.19	2.53
MP-20S	11/17/1994	963.50	11.50	8.05	10.58	955.45	952.92	954.19	2.53
MP-22S	11/17/1994	967.30	16.50	13.05	15.58	954.25	951.72	952.99	2.53
MP-23S	11/17/1994	967.90	17.00	13.55	16.08	954.35	951.82	953.09	2.53
MP-6MW4S	11/17/1994	963.40	10.90	7.45	9.98	955.95	953.42	954.69	2.53
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl)									
MP-2M	11/15/1994	962.00	18.00	14.55	17.08	947.45	944.92	946.19	2.53
MP-4M	NA [c/]	NA	NA	NA	NA	NA	NA	NA	NA
MP-4D	11/16/1994	964.90	22.50	19.05	21.58	945.85	943.32	944.59	2.53
MP-5M	11/15/1994	964.60	21.19	17.55	20.08	947.05	944.52	945.79	2.53
MP-6D	11/15/1994	964.70	21.00	17.55	20.08	947.15	944.62	945.89	2.53
MP-8D	11/16/1994	963.40	21.00	17.55	20.08	945.85	943.32	944.59	2.53
MP-9D	11/16/1994	962.90	21.00	17.55	20.08	945.35	942.82	944.09	2.53
MP-12D	11/16/1994	963.30	21.00	17.55	20.08	945.75	943.22	944.49	2.53
MP-17D	11/17/1994	965.00	22.90	19.45	21.98	945.55	943.02	944.29	2.53
MP-20D	11/17/1994	963.50	21.50	18.05	20.58	945.45	942.92	944.19	2.53
MP-22D	11/17/1994	967.30	26.50	23.05	25.58	944.25	941.72	942.99	2.53

TABLE 2 (concluded)
MONITORING WELL/POINT COMPLETION SUMMARY
Fire Protection Training Area 3

Intrinsic Remediation Treatability Study Addendum

Offutt Air Force Base, Nebraska

Well ID	Well Installation Date	Ground Elevation (ft amsl)[a/]	Total Depth (ft bgs)[b/]	Screen Top (ft bgs)	Screen Bottom (ft bgs)	Screen Top (ft amsl)	Screen Bottom (ft amsl)	Screen Midpoint (ft amsl)	Screen Length (feet)
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl) (continued)									
MP-23D	11/17/1994	967.90	27.00	23.55	26.08	944.35	941.82	943.09	2.53
MP-24D	11/17/1994	962.20	21.00	17.55	20.08	944.65	942.12	943.39	2.53
Deep Wells (screen midpoint approximately 880 ft amsl to 936 ft amsl)									
FPTA3-MW1	9/1/1988	963.90	89.00	79.50	89.00	884.40	874.90	879.65	9.50
FPTA3-MW6	NA	963.87	30.50	NA	NA	NA	NA	935.00	NA
FPTA3-MW6A	11/17/1989	963.83	37.00	20.00	35.00	943.83	928.83	936.33	15.00
HF6-MW2D	NA	NA	NA	NA	NA	NA	NA	NA	NA
MP-2D	11/15/1994	962.00	28.00	24.55	27.08	937.45	934.92	936.19	2.53
MP-5D	11/15/1994	964.60	31.00	27.55	30.08	937.05	934.52	935.79	2.53

[a/] ft amsl = feet above mean sea level.

[b/] ft bgs = feet below ground surface.

[c/] NA = data not available.

TABLE 3
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Location	Measurement Date	Datum Elevation (ft amsl) [a/]	Depth to Water (ft btoc) [b/]	Groundwater Elevation (ft msl)
Shallow Wells (screen midpoint approximately 950 ft amsl to 956 ft amsl)				
FPTA3-MW2	Aug-91	964.98	11.22	953.76
	Oct-91	964.98	11.79	953.19
	Dec-91	964.98	7.68	957.30
	Mar-92	964.98	11.14	953.84
	Apr-92	964.98	10.89	954.09
	May-92	964.98	9.85	955.13
	Aug-92	964.98	10.09	954.89
	Nov-94	964.66	9.76	954.90
	Jun-96	964.66	5.44	959.22
FPTA3-MW3	Aug-91	964.37	10.86	953.51
	Oct-91	964.37	11.48	952.89
	Dec-91	964.37	11.44	952.93
	Mar-92	964.37	11.17	953.20
	Apr-92	964.37	10.88	953.49
	May-92	964.37	9.75	954.62
	Aug-92	964.37	9.75	954.62
	Nov-94	964.02	9.27	954.75
	Jun-96	964.02	NM[c/]	NM
FPTA3-MW4	Aug-91	966.17	12.65	953.52
	Oct-91	966.17	13.29	952.88
	Dec-91	966.17	13.29	952.88
	Mar-92	966.17	13.04	953.13
	Apr-92	966.17	12.74	953.43
	May-92	966.17	11.65	954.52
	Aug-92	966.17	11.60	954.57
	Nov-94	965.81	11.12	954.69
FPTA3-MW5	Aug-91	966.43	12.79	953.64
	Oct-91	966.43	13.39	953.04
	Dec-91	966.43	13.37	953.06
	Mar-92	966.43	13.02	953.41
	Apr-92	966.43	12.72	953.71
	May-92	966.43	11.63	954.80
	Aug-92	966.43	11.72	954.71
	Nov-94	966.06	11.32	954.74
HF6-MW2	Aug-91	964.82	11.28	953.54
	Oct-91	964.82	11.89	952.93
	Dec-91	964.82	11.88	952.94
	Mar-92	964.82	11.57	953.25
	Apr-92	964.82	11.27	953.55
	May-92	964.82	10.24	954.58
	Aug-92	964.82	10.17	954.65
	Nov-94	964.47	9.71	954.76
	Jun-96	964.47	5.83	958.64

TABLE 3 (continued)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Location	Measurement Date	Datum Elevation (ft amsl) [a/]	Depth to Water (ft btoc) [b/]	Groundwater Elevation (ft amsl)
Shallow Wells (screen midpoint approximately 950 ft amsl to 956 ft amsl) (continued)				
HF6-MW4	Aug-91	966.14	12.54	953.60
	Oct-91	966.14	13.13	953.01
	Dec-91	966.14	13.11	953.03
	Mar-92	966.14	12.80	953.34
	Apr-92	966.14	12.51	953.63
	May-92	966.14	11.43	954.71
	Aug-92	966.14	11.44	954.70
	Nov-94	965.79	11.00	954.79
	Jun-96	965.79	6.50	959.29
MP-2S	Nov-94	961.83	6.91	954.92
MP-4S	Nov-94	964.81	9.87	954.94
	Jun-96	964.81	5.65	959.16
	Jun-98	964.81	6.00	958.81
MP-5S	Nov-94	964.37	9.35	955.02
	Jun-96	964.37	5.25	959.12
	Jun-98	964.37	5.50	958.87
MP-6S	Nov-94	964.32	9.41	954.91
	Jun-96	964.32	5.38	958.94
	Jun-98	964.32	5.50	958.82
MP-8S	Nov-94	963.33	8.43	954.90
	Jun-96	963.33	4.12	959.21
MP-12S	Nov-94	963.11	8.11	955.00
MP-17S	Nov-94	964.88	9.95	954.93
	Jun-96	964.88	5.77	959.11
MP-20S	Nov-94	963.42	8.44	954.98
MP-22S	Nov-94	967.01	12.26	954.75
MP-23S	Nov-94	967.72	12.92	954.80
	Jun-96	967.72	8.54	959.18
MP-6MW4S	Nov-94	963.34	8.51	954.83
	Jun-96	963.34	4.02	959.32
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl)				
MP-2M	Nov-94	961.91	7.00	954.91
	Jun-96	961.91	3.31	958.60
MP-4M	Jun-98	NA [d/]	6.30	NA
MP-4D	Nov-94	964.84	9.97	954.87
	Jun-96	964.84	5.64	959.20
	Jun-98	964.84	5.90	958.94
MP-5M	Nov-94	964.27	9.30	954.97
	Jun-96	964.27	5.11	959.16
	Jun-98	964.27	5.50	958.77
MP-6D	Nov-94	964.35	9.41	954.94
	Jun-96	964.35	5.23	959.12
	Jun-98	964.35	5.50	958.85

TABLE 3 (concluded)
SUMMARY OF GROUNDWATER LEVEL MEASUREMENTS
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Location	Measurement Date	Datum Elevation (ft amsl) [a/]	Depth to Water (ft btoc) [b/]	Groundwater Elevation (ft amsl)
MP-8D	Nov-94	963.32	8.50	954.82
	Jun-96	963.32	4.16	959.16
	Jun-98	963.32	4.70	958.62
MP-9D	Nov-94	962.81	7.86	954.95
	Jun-96	962.81	3.66	959.15
MP-12D	Nov-94	963.16	8.16	955.00
MP-17D	Nov-94	964.82	9.90	954.92
	Jun-96	964.82	5.69	959.13
MP-20D	Nov-94	963.35	8.41	954.94
MP-22D	Nov-94	967.05	12.32	954.73
MP-23D	Nov-94	967.70	12.92	954.78
	Jun-96	967.70	8.47	959.23
MP-24D	Nov-94	962.34	7.32	955.02
Deep Wells (screen midpoint approximately 880 ft amsl to 936 ft amsl)				
FPTA3-MW1	Aug-91	965.77	12.25	953.52
	Oct-91	965.77	12.89	952.88
	Dec-91	965.77	12.88	952.89
	Mar-92	965.77	12.61	953.16
	Apr-92	965.77	12.31	953.46
	May-92	965.77	11.23	954.54
	Aug-92	965.77	11.16	954.61
	Nov-94	965.42	10.70	954.72
	Jun-96	965.42	NM	NM
FPTA3-MW6	Aug-91	966.01	12.49	953.52
	Oct-91	966.01	13.10	952.91
	Dec-91	966.01	13.10	952.91
	Mar-92	966.01	12.84	953.17
	Apr-92	966.01	12.55	953.46
	May-92	966.01	11.40	954.61
	Aug-92	966.01	11.42	954.59
	Nov-94	965.65	10.97	954.68
FPTA3-MW6A	Aug-91	966.01	12.5	953.51
	Oct-91	966.01	13.12	952.89
	Dec-91	966.01	13.11	952.90
	Mar-92	966.01	13.87	952.14
	Apr-92	966.01	12.56	953.45
	May-92	966.01	11.45	954.56
	Aug-92	966.01	11.43	954.58
	Nov-94	965.65	10.95	954.70
	Jun-96	965.65	6.42	959.23
	Jun-98	965.65	6.90	958.75
HF6-MW2D	Nov-94	965.17	10.40	954.77
MP-2D	Nov-94	961.92	7.09	954.83
	Jun-96	961.92	3.31	958.61
MP-5D	Nov-94	964.28	9.41	954.87
	Jun-96	964.28	5.11	959.17

[a/] ft amsl = feet above mean sea level.

[b/] ft btoc = feet below top of casing.

[c/] NM = Not Measured.

[d/] NA = Not Available.

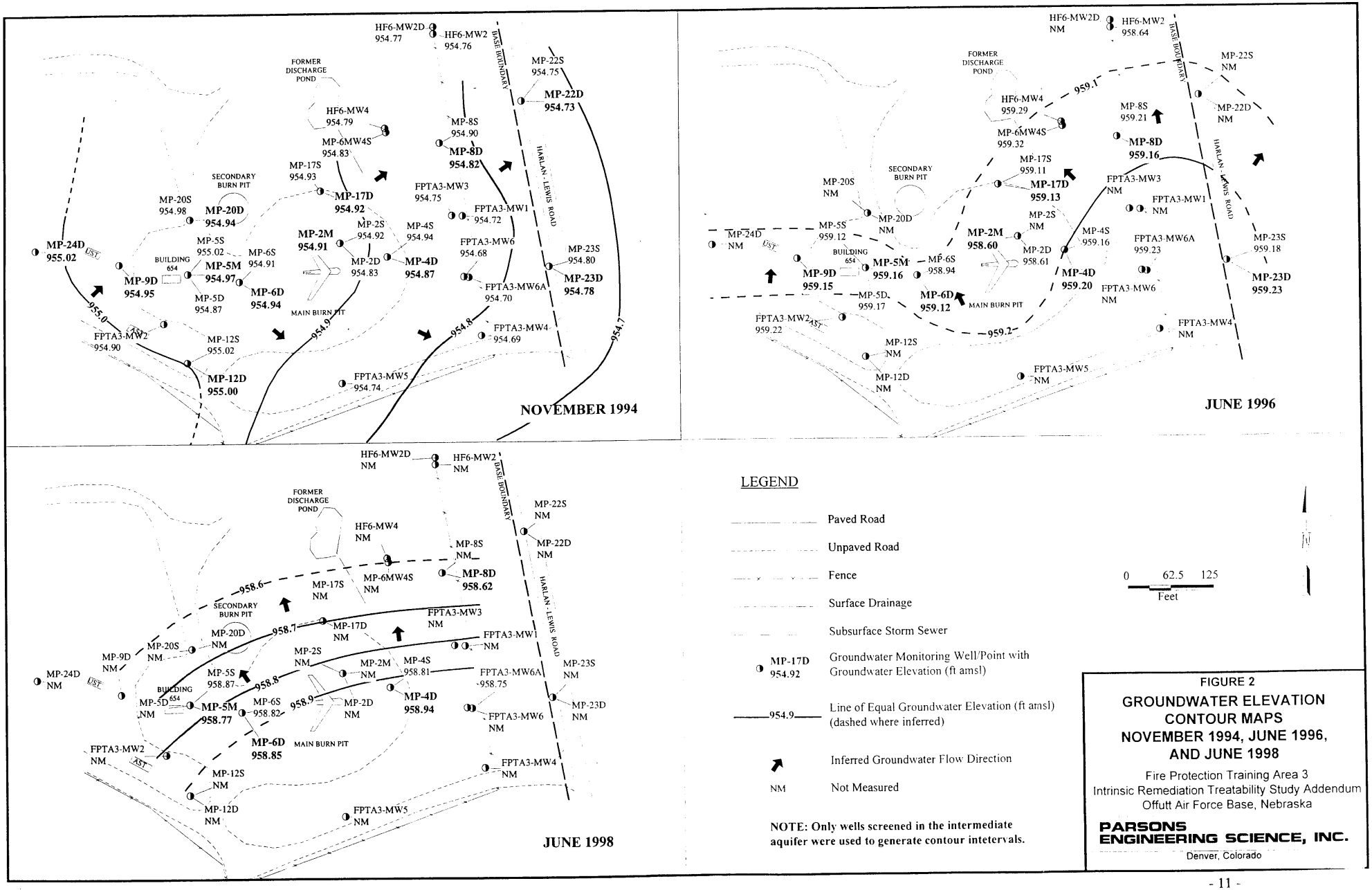


FIGURE 2

GROUNDWATER ELEVATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

FILL :: 022\ES\REMEDIBIOPLUME\OFFUTT\FPTA3\TUNK\STEMPMAPINFOFILES\G+WELEV.WOR 7/02/99

groundwater elevations due to varying precipitation and recharge rates, or the relative paucity of groundwater elevation data for June 1996 and June 1998 (data from only eight and four monitoring points available, respectively).

Contouring of November 1994 groundwater elevation data obtained from wells screened in the shallow depth interval also indicates an easterly to southeasterly flow direction, similar to that indicated by the intermediate zone data. Contouring of shallow zone data collected in June 1996 indicates an overall southerly groundwater flow direction (opposite from that indicated by the intermediate zone data), and contouring of shallow zone data from June 1998 indicates an easterly flow direction similar to November 1994. In summary, the groundwater elevation data do not reveal a consistent flow direction beneath the site. Rather, the data suggest that flow directions are temporally and spatially variable, and are potentially influenced by variations in precipitation rates. In all cases, the horizontal hydraulic gradient is relatively flat, resulting in very low groundwater flow velocities.

Figure 3 presents groundwater elevation data over time for selected FPTA3 monitoring wells. A significant rise in the water table, in the range of four to six feet, has occurred beneath the site since 1991-1992. The groundwater elevation increases are larger than would be expected from seasonal fluctuations based on quarterly data from 1991 to 1992. A regional increase in the groundwater elevation may be the result of increased annual precipitation or anthropogenic activities.

The hydraulic conductivity measured at the site averaged 6.1 feet per day (ft/day) (Parsons ES, 1995). Using this average hydraulic conductivity, a gradient of 0.0006 ft/ft, and assuming an effective porosity for fine sand of 0.2, an advective groundwater flow velocity of 0.018 ft/day (6.7 feet per year [ft/yr]) was calculated for November 1994 (Parsons ES, 1995). Average advective groundwater velocities at the site were calculated to be approximately 0.024 ft/day (8.9 ft/yr) during June 1996, and 0.052 ft/day (18.9 ft/yr) during June 1998. The increased groundwater velocity in June 1998 is a result of the increase in the hydraulic gradient measured at the site during this sampling event.

2.2 Dissolved BTEX Contamination

Groundwater analytical results for fuel hydrocarbons are provided in Table 4. BTEX compounds were detected in groundwater samples collected from 10 of the 23 monitoring wells/points sampled in June 1996 and from 5 of the 9 monitoring wells/points sampled in June 1998. The estimated areal distributions of dissolved BTEX for November 1994, June 1996, and June 1998 are presented on Figure 4. Dissolved BTEX concentrations for select wells/points (MP-4S, MP-4D, MP-5S, MP-5M, MP-6D, MP-8D, FPTA3-MW6A) are plotted against time on Figure 5. Where nested wells are present and BTEX was detected in more than one well, isopleths are drawn based on the maximum detected BTEX concentration.

The BTEX plume appears to have originated from two source areas, one at Building 654 and one at the main burn pit. Groundwater samples collected at 22 monitoring wells/points were analyzed for BTEX during at least two of the three sampling events (November 1994, June 1996, and June 1998) conducted at the site. BTEX

FIGURE 3
GROUNDWATER ELEVATIONS IN SELECTED WELLS
AUGUST 1991 TO JUNE 1998
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

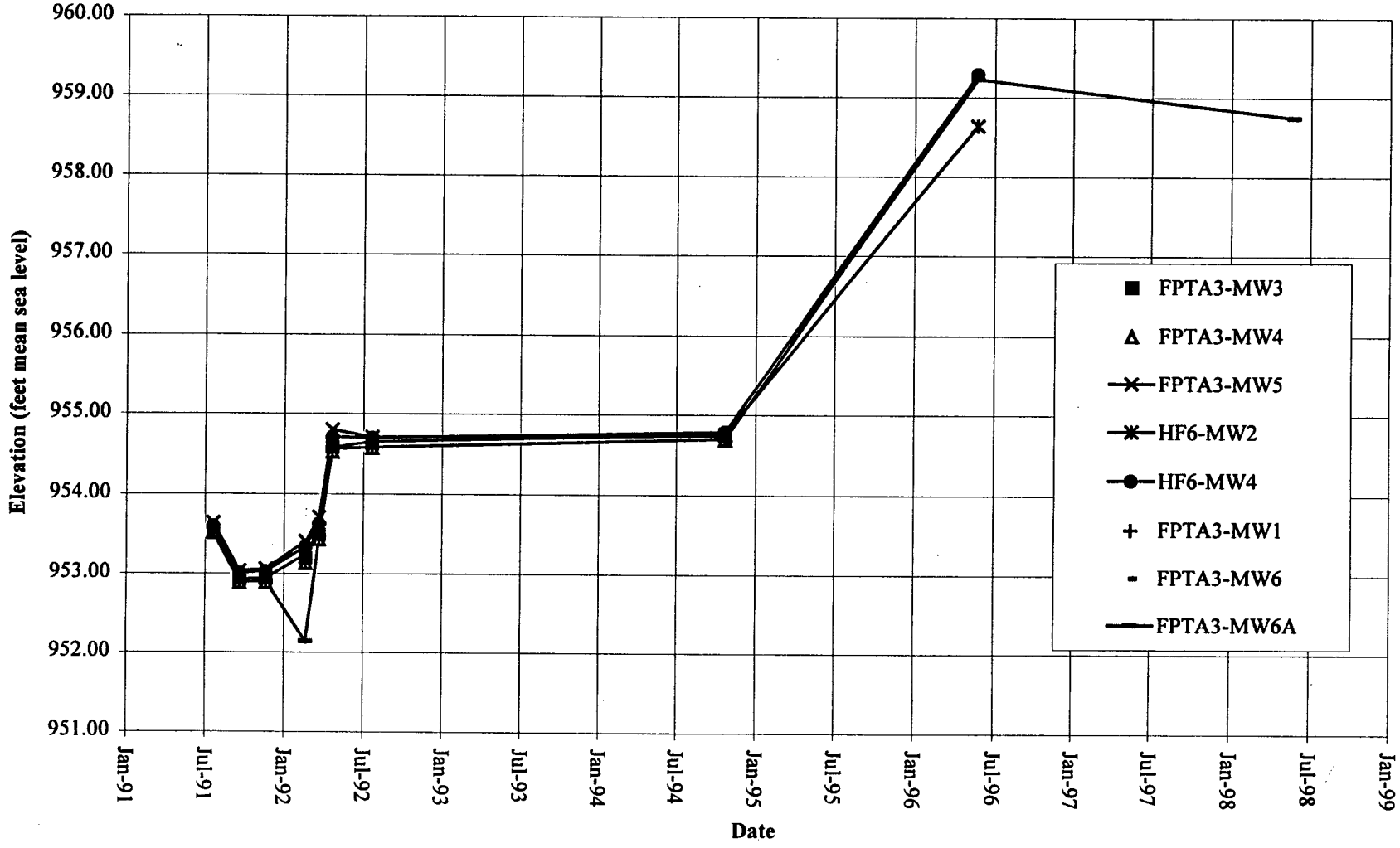


TABLE 4
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Benzene (µg/L) [a]	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
Shallow Wells (screen midpoint approximately 950 ft amsl [b] to 956 ft amsl)												
FPTA3-MW2	Nov-94	3.5	ND [c]	2.6	1.3	0.9	ND	2.2	8.3	9.1	9.2	5.3
	Jun-96	< 1	< 1	54.0	15.3	< 1	9.6	24.9	78.9	22.5	64.2	25.6
FPTA3-MW3	Nov-94	ND	ND	<1 [d]	<1	<1	ND	BLQ [d]	<1	ND	ND	ND
	Jun-96	< 1	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0
FPTA3-MW4	Nov-94	ND	ND	<1	<1	<1	ND	BLQ	<1	ND	ND	ND
FPTA3-MW5	Nov-94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nov-94 [e]	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND
HF6-MW2	Nov-94	ND	ND	<1	<1	<1	ND	BLQ	<1	ND	ND	ND
HF6-MW4	Nov-94	3.7	ND	<1	<1	ND	<1	BLQ	3.7	2.2	2.4	2.2
	Nov-94 [e]	3.3	ND	<1	ND	<1	ND	<1	3.3	1.8	<1	<1
	Nov-94 [e]	3.3	ND	ND	ND	ND	ND	ND	3.3	2.7	2.1	<1
	Jun-96	9.6	< 1	64.8	23.6	30.4	37	91	165	38.1	165	101
MP-4S	Nov-94	234	206	117	95.2	293	196	584	1140	34.7	137	80.9
	Jun-96	294	147	184	142	357	271	770	1400	50	148	103
	Jun-98	339	260	189	125	339	263	727	1510	40.0	118	65.2
MP-5S	Jun-96	105	23	61.3	21.2	18.1	28.3	67.6	257	31.9	98.8	73.2
	Jul-98	36.0	2.7	14.2	3.2	1.3	5.9	10.4	63.3	19.7	54.9	31.0
MP-6S	Jun-96	< 1	ND	ND	ND	ND	ND	ND	< 1	ND	ND	ND
	Jul-98	BLQ	BLQ	ND	ND	ND	ND	ND	BLQ	ND	ND	ND

TABLE 4 (continued)
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Benzene (µg/L) [a/]	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
Shallow Wells (screen midpoint approximately 950 ft amsl to 956 ft amsl) (continued)												
MP-8S	Nov-94	1.5	43.7	<1	ND	1.4	ND	1.4	46.6	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-17S	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-20S	Nov-94	<1	3.2	ND	ND	<1	ND	<1	3.2	ND	ND	ND
MP-22S	Nov-94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-23S	Nov-94	ND	2.2	ND	ND	ND	ND	ND	2.2	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-6MW4S	Nov-94	1.7	40.0	<1	ND	ND	ND	ND	41.7	ND	ND	ND
	Jun-96	< 1	ND	ND	ND	ND	ND	ND	< 1	ND	ND	ND
Intermediate Wells (screen midpoint approx. 943 ft amsl to 946 ft amsl)												
MP-2M	Nov-94	775	4.1	991	441	1020	2.2	1460	3230	57.9	ND	<1
	Jul-96	622	< 1	952	471	1090	9.5	1570	3150	32.4	146	215
MP-4M	Jun-98	BLQ	2.4	BLQ	BLQ	BLQ	BLQ	BLQ	2.4	ND	BLQ	ND
MP-4D	Nov-94	1.1	<1	3.3	2.1	4.1	ND	6.1	10.5	ND	ND	1.0
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Jun-98	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	<1	ND	BLQ	BLQ
MP-5M	Nov-94	56.6	29.3	20.7	15.3	25.3	41.9	82.5	189	ND	ND	1.8
	Nov-94 [e/]	54.2	28.8	19.3	14.6	23.1	39.8	77.5	180	ND	ND	1.7
	Jun-96	49.3	18.4	9.8	7.1	4.0	30.7	41.8	119	< 1	ND	< 1
	Jun-98	25.2	12.8	4.7	5.7	3.8	22.2	31.7	74.4	BLQ	BLQ	BLQ

TABLE 4 (continued)
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Benzene (µg/L) [a/]	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl) (continued)												
MP-6D	Nov-94	2.8	4.9	<1	<1	<1	<1	BLQ	7.7	ND	ND	ND
	Jun-96	2.9	ND	ND	ND	ND	ND	ND	2.9	ND	ND	ND
	Jun-98	BLQ	BLQ	ND	BLQ	ND	ND	BLQ	BLQ	ND	ND	ND
MP-8D	Nov-94	2.9	1.9	ND	ND	ND	<1	ND	4.8	ND	2.0	3.6
	Jun-96	11.9	ND	53.1	25	2.4	2.8	30.2	95.2	3.5	78.1	131
	Jun-98	1.2	BLQ	BLQ	ND	ND	1.1	1.1	2.3	12.0	18.6	ND
MP-9D	Nov-94	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-12D	Nov-94	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND
MP-17D	Nov-94	1.1	1.2	<1	0.9	0.9	ND	1.9	4.2	1.3	1.6	466
	Nov-94 [c/]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nov-94 [c/]	<1	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND
	Jun-96	ND	< 1	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-20D	Nov-94	ND	ND	<1	<1	<1	ND	BLQ	<1	ND	ND	ND
MP-22D	Nov-94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-23D	Nov-94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-24D	Nov-94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 4 (concluded)
FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUNDWATER
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Benzene (µg/L) [a]	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
Deep Wells (screen midpoint approx. 880 ft amsl to 936 ft amsl)												
FPTA3-MW1	Nov-94	6.4	19.8	2.6	2.2	4.7	2.4	9.3	38.2	ND	1.8	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW6	Nov-94	<1	ND	ND	ND	<1	ND	<1	<1	ND	ND	ND
FPTA3-MW6A	Nov-94	5.4	ND	ND	ND	<1	ND	<1	5.4	1.8	ND	ND
	Jun-96	3.0	ND	< 1	ND	ND	ND	ND	3.0	ND	< 1	< 1
	Jun-98	BLQ	BLQ	ND	ND	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
HF6-MW2D	Nov-94	19.8	50.8	5.3	4.0	9.7	4.7	18.5	94.3	ND	2.0	ND
	Nov-94 [e]	11.0	27.7	3.0	2.4	5.5	3.1	11.0	52.7	ND	1.7	ND
	Jun-96	< 1	ND	ND	ND	ND	ND	ND	< 1	ND	ND	ND
	Jun-96 [e]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-2D	Nov-94	55.0	13.1	4.8	4.4	4.5	3.1	12.0	84.9	5.5	4.0	3.4
	Jul-96	161	< 1	2.5	1.7	1.1	4.6	7.4	171	< 1	1.2	0.9
MP-5D	Nov-94	<1	1.1	<1	<1	1.0	ND	1.0	2.1	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] µg/L = micrograms per liter.

[b] ft amsl = feet above mean sea level.

[c] ND = not detected.

[d] BLQ = below the limit of quantitation; <1 = below specified limit of quantitation.

[e] duplicate sample.

concentrations at 13 of these locations (4 shallow, 5 intermediate, and 4 deep wells/points) decreased over time. Conversely, concentrations at 4 locations (3 shallow and 1 deep) increased over time, and concentrations at 4 locations (2 shallow and 2 intermediate) remained below detection over time. BTEX concentrations in one intermediate well increased from 1994 to 1996 and then decreased from 1996 to 1998. The available data indicate that dissolved BTEX contamination at the site primarily resides in the shallow and intermediate depth intervals (uppermost 15 to 20 feet of the saturated zone).

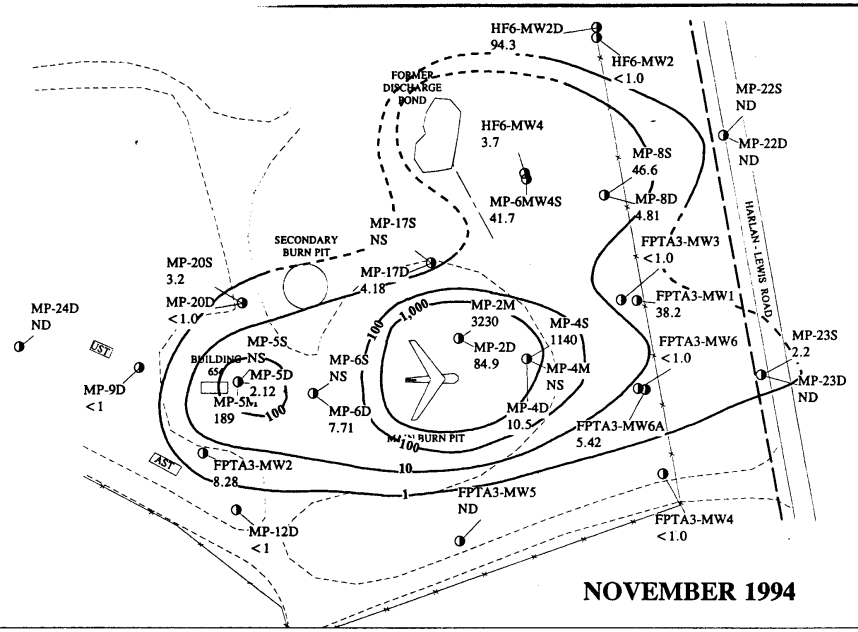
With only one exception (MP-2D), the increase in BTEX concentrations occurred in wells/points screened in the shallow portion of the aquifer (FPTA3-MW2, HF6-MW4, and MP-4S). The increased BTEX concentrations in shallow wells are likely due to the water table rising into residual soil contamination with resulting dissolution of additional hydrocarbon mass. In June 1998, the highest dissolved BTEX concentration detected at the site was in the sample collected from monitoring well MP-4S, which is located in the main burn pit (Figure 4). The dissolved BTEX concentration at well MP-4S has consistently increased from 1,140 micrograms per liter (µg/L) in November 1994 to 1,400 µg/L in June 1996 to 1,510 µg/L in June 1998 (Figure 5 and Table 4). Since monitoring well MP-4S is located within the main burn pit source area, the observed increases in dissolved BTEX concentrations in groundwater at this location indicate that residual fuel hydrocarbons still exist in source area soils.

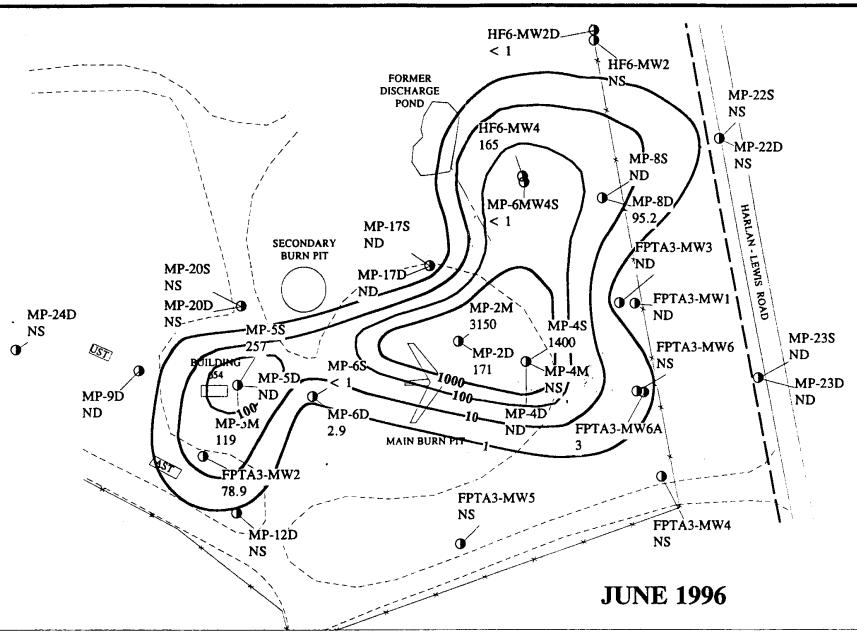
With two exceptions (FPTA3-MW2 and HF6-MW4), most of the observed decreases in dissolved BTEX concentrations in groundwater at the site occurred near the outer perimeter of the plume. For example, dissolved BTEX concentrations measured at deep monitoring well FPTA3-MW6A decreased from 5.42 µg/L in November 1994, to 3.0 µg/L in June 1996, to below detection in June 1998 (Figure 5 and Table 4). In addition, the measured BTEX concentration at FPTA3-MW1 decreased from 38 µg/L in 1994 to below the detection limit in 1996. These data suggest that the plume extent is receding to the east and northeast of the main burn pit source area (Figure 4). Potential causes for this recession include natural attenuation and changing groundwater flow directions.

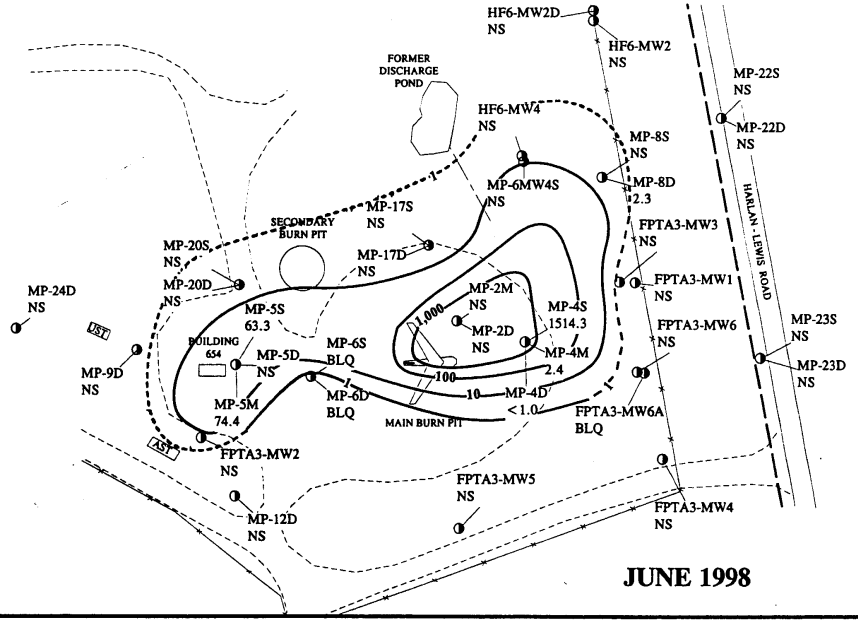
Results of the June 1996 and June 1998 sampling events indicate BTEX concentrations in groundwater underlying Building 654 have decreased in the past 3.5 years (Figure 5 and Table 4). BTEX concentrations in groundwater collected from monitoring well MP-5M, located immediately east of Building 654, have consistently decreased from 189 µg/L in November 1994, to 119 µg/L in June 1996, to 74.4 µg/L in June 1998. This observation suggests that the BTEX source at Building 654 is steadily decreasing due to the effects of weathering.

A stable or attenuating plume provides strong evidence in support of BTEX biodegradation, particularly along the plume perimeter. However, data to the north and northwest are insufficient to determine the current extent of the BTEX plume in these directions as a result of changes in hydraulic gradient and direction of groundwater flow (Section 2.1).

Site-specific geologic, hydrologic, and laboratory analytical data collected in November 1994 were used in the Bioplume II numerical groundwater model to simulate







LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- MP-6D 7.71 — Groundwater Monitoring Well/Point with Dissolved BTEX Concentration (µg/L)
- 100 — Line of Equal Dissolved BTEX Concentration (µg/L)
- BLQ — Below Limit of Quantitation
- ND — Not Detected
- NS — Not Sampled
- < 1 — Measured Concentration Less Than Specified Practical Quantitation Limit

0 62.5 125
Feet

N

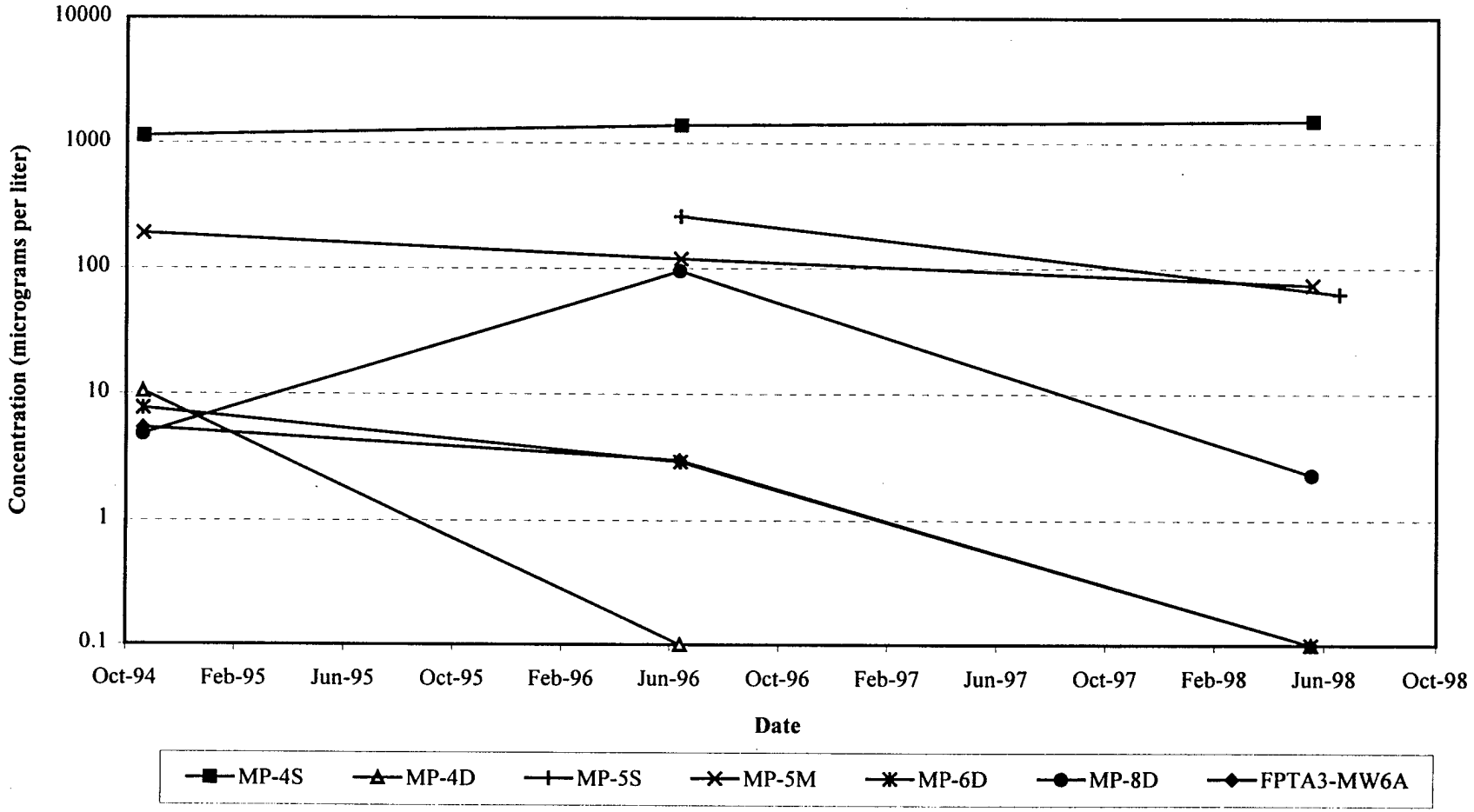
FIGURE 4
DISSOLVED BTEX CONCENTRATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

F ME: 022\ES\REMEDBIOPLUME\OFFUTT\FPTA3\TUNKSTEMP\MAPINFOFIL... ...\TEX_ALL.WOR 6/24/99

FIGURE 5
DISSOLVED BTEX CONCENTRATIONS FOR SELECTED WELLS
NOVEMBER 1994 TO JUNE 1998
Fire Protection Training Area 3
Intrinsic Remediation Treatablility Study Addendum
Offutt Air Force Base, Nebraska



the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the dissolved BTEX plume (Parsons ES, 1995). 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 sediments similar to those found at the site. Conservative aquifer parameters were used to construct the Bioplume II model for the 1995 RNA TS.

For one simulation (model Decay-0), it was assumed that conditions that produced the calibrated model would persist for the duration of the simulation. This simulation suggested that the plume would migrate a maximum of 250 feet beyond the November 1994 plume front before BTEX migration halted and the plume stabilized as a result of natural attenuation. Another simulation (model Decay-4) assumed that the source of groundwater contamination would decline at a geometric rate of 4 percent per year. Under this scenario, the model simulated that the BTEX plume would migrate a maximum of approximately 190 feet beyond the November 1994 plume front. This model simulation also showed a gradual shrinking of plume dimensions and contaminant concentrations.

June 1998 data indicate that the BTEX plume is no longer expanding to the east and northeast (the downgradient direction as measured in 1994), suggesting that the maximum BTEX migration distance in this direction has been achieved. Model simulations were conducted using what were believed to be conservative estimates of site conditions; therefore, it is possible that the BTEX plume will be remediated by natural attenuation more quickly than model predictions have indicated. The conservative nature of the model is supported by the apparent lack of plume expansion to the east, contrary to model predictions. However, changes in BTEX plume extent also may be a result of changes in hydraulic gradient and direction of groundwater flow (Section 2.1). Therefore, continued long-term monitoring is necessary to ensure that natural attenuation limits plume migration toward the north (MP-17S and MP-17D) and northwest (MP-20S and MP-20D).

2.3 Chlorinated Aliphatic Hydrocarbons

Groundwater samples were analyzed for CAHs (chlorinated solvents) during all three sampling events. Analytical results for CAHs in groundwater at the site are summarized in Table 5. Detectable concentrations of CAHs were reported for groundwater samples collected from 11 of the 23 monitoring wells/points sampled in June 1996 and from 5 of the 9 monitoring wells/points sampled in June 1998. A detailed analysis of CAH biodegradation was not included in the TS scope. However, a discussion of CAH biodegradation is presented in this addendum in Section 2.5.

Concentrations of TCE ranging up to 51.7 µg/L were detected during the November 1994, June 1996, and June 1998 sampling events. The areal distribution of dissolved TCE at FPTA-3 is presented in Figure 6. Detected concentrations of TCE were limited to groundwater beneath the Building 654 and Main Burn Pit source areas. The maximum TCE concentration (51.7 µg/L) was detected at monitoring point MP-5S in June 1996. Monitoring point MP-5S was not sampled in November 1994; the TCE concentration at MP-5S decreased to 27.0 µg/L in June 1998. Monitoring results from June 1998 further indicate that TCE in groundwater is restricted to the area near

TABLE 5
SUMMARY OF CHLORINATED VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER

Fire Protection Training Area 3

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Offutt Air Force Base, Nebraska

Sample Location	Date	PCE (µg/L) [a]	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	*trans*-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA (µg/L)	Total Chlorinated Volatile Organics (µg/L)
Shallow Wells (screen midpoint approximately 950 ft amsl [b] to 956 ft amsl)								
FPTA3-MW2	Nov-94	ND [c]	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW3	Nov-94	ND	ND	ND	ND	2.6	ND	2.6
	Jun-96	ND	ND	< 1	ND	8.2	ND	8.2
FPTA3-MW4	Nov-94	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW5	Nov-94	ND	ND	ND	ND	ND	ND	ND
HF6-MW2	Nov-94	ND	ND	ND	ND	ND	ND	ND
HF6-MW4	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Nov-94 [d]	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-4S	Nov-94	ND	8.6	273	2.4	40.7	ND	325
	Jun-96	ND	< 1.0 [c]	417	4.5	78.3	ND	500
	Jun-98	ND	ND	442	3.6	138	ND	584
MP-5S	Jun-96	<1.0	51.7	4,880	12.0	48	21.5	5,010
	Jun-98	<1.0	27.0	1,720	4.8	19.8	23.4	1,800
MP-6S	Jun-96	ND	< 1	132	2.1	3.4	ND	138
	Jun-98	ND	< 1.0	85.3	1.6	2.1	ND	89.0
MP-8S	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-17S	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-20S	Nov-94	ND	6.7	ND	ND	ND	3.1	9.8
	Nov-94 [d]	ND	7.6	ND	ND	ND	3.3	10.9
MP-22S	Nov-94	ND	ND	ND	ND	ND	ND	ND
MP-23S	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-6MW4S	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl)								
MP-2M	Nov-94	ND	ND	ND	ND	2.6	ND	2.6
	Jul-96	ND	ND	< 1	ND	1.9	ND	1.9

TABLE 5 (Continued)
SUMMARY OF CHLORINATED VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER

Fire Protection Training Area 3

Intrinsic Remediation Treatability Study Addendum

Offutt Air Force Base, Nebraska

Sample Location	Date	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	*trans*-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA (µg/L)	Total Chlorinated Volatile Organics (µg/L)
Intermediate Wells (screen midpoint approx. 943 ft amsl to 946 ft amsl) (Continued)								
MP-4M	Jun-98	ND	ND	< 1.0	ND	ND	ND	< 1.0
MP-4D	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	<1.0	ND	ND	ND	<1.0
	Jun-98	ND	< 1.0	< 1.0	ND	ND	ND	<2.0
MP-5M	Nov-94	ND	ND	ND	1.6	817	ND	819
	Nov-94 [d/]	ND	ND	ND	1.5	766	ND	768
	Jun-96	ND	ND	1.1	8.9	1,050	ND	1,060
	Jun-98	ND	1.6	9.9	34.6	2,520	ND	2,570
MP-6D	Nov-94	ND	ND	93.3	1.7	51.9	ND	147
	Jun-96	ND	ND	83.5	1.8	34.6	ND	120
	Jun-98	ND	ND	21.4	ND	16.2	ND	37.6
MP-8D	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
	Jun-98	ND	ND	ND	ND	ND	ND	ND
MP-9D	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-12D	Nov-94	ND	ND	ND	ND	ND	ND	ND
MP-17D	Nov-94	ND	ND	ND	ND	6.7	ND	6.7
	Nov-94 [d/]	ND	ND	ND	ND	6.4	ND	6.4
	Jun-96	ND	ND	ND	ND	15.5	ND	15.5
MP-20D	Nov-94	ND	ND	ND	ND	ND	ND	ND
MP-22D	Nov-94	ND	ND	ND	ND	ND	ND	ND
MP-23D	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-24D	Nov-94	ND	ND	ND	ND	ND	ND	ND
Deep Wells (screen midpoint approx. 880 ft amsl to 936 ft amsl)								
FPTA3-MW1	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Nov-94 [d/]	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW6	Nov-94	ND	ND	ND	ND	ND	ND	ND

TABLE 5 (Concluded)
SUMMARY OF CHLORINATED VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER

Fire Protection Training Area 3

Intrinsic Remediation Treatability Study Addendum

Offutt Air Force Base, Nebraska

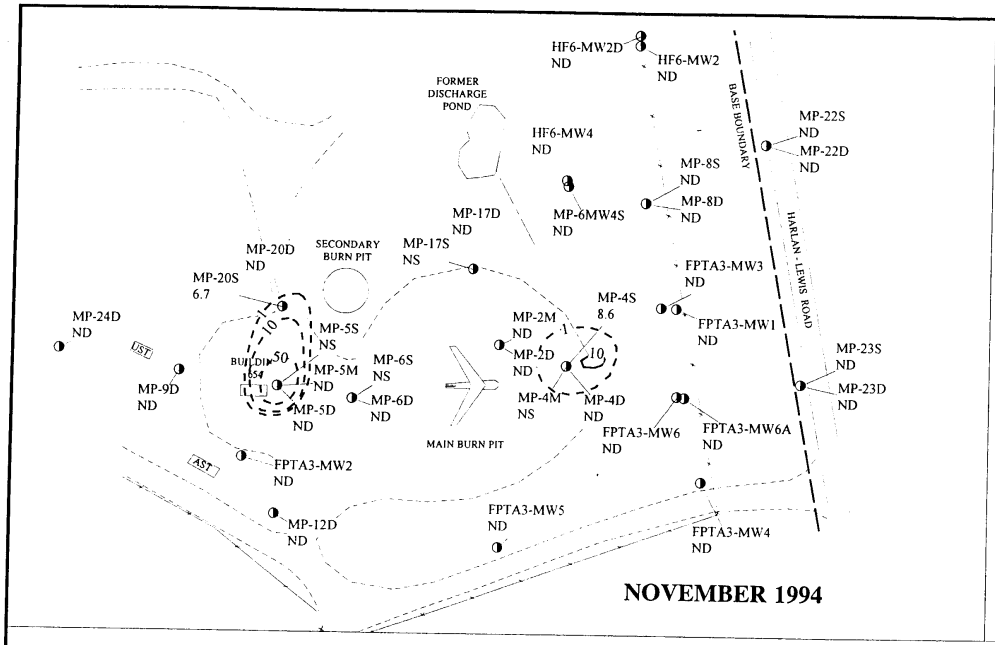
Sample Location	Date	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	*trans*-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA (µg/L)	Total Chlorinated Volatile Organics (µg/L)
Deep Wells (screen midpoint approximately 880 ft amsl to 936 ft amsl) (Continued)								
FPTA3-MW6A	Nov-94	ND	ND	2.7	ND	6.2	ND	8.9
	Jun-96	ND	ND	1.6	ND	1.6	ND	3.2
	Jun-98	ND	ND	< 1.0	ND	ND	ND	< 1.0
HF6-MW2D	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Nov-94 [d/]	ND	ND	ND	ND	ND	ND	ND
	Jun-96	ND	ND	ND	ND	ND	ND	ND
MP-2D	Nov-94	ND	ND	ND	ND	ND	ND	ND
	Jul-96	ND	ND	2.9	ND	6.2	ND	9.1
MP-5D	Nov-94	ND	ND	3.2	ND	ND	ND	2.2
	Jun-96	ND	ND	1.1	ND	ND	ND	1.1

[a/] µg/L = micrograms per liter

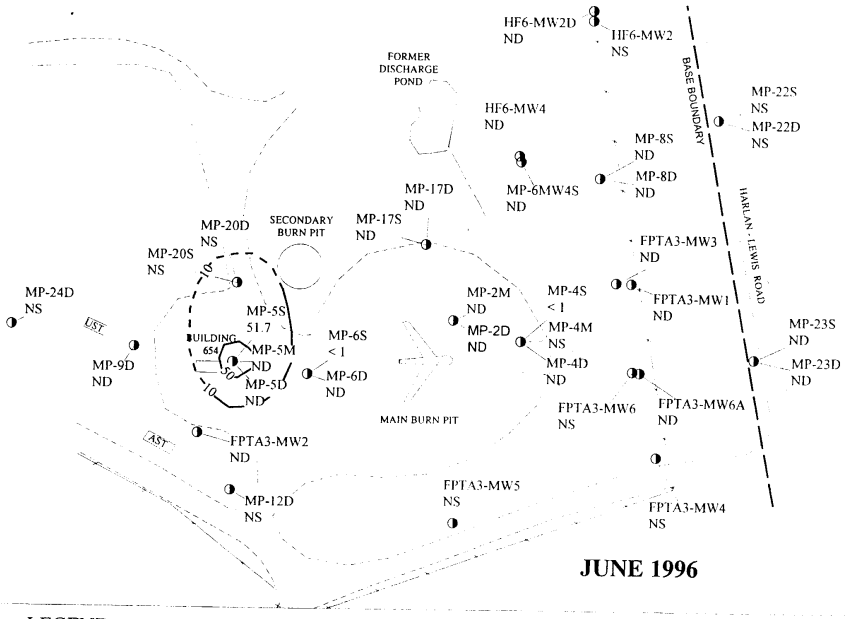
[b/] ft amsl = feet above mean sea level.

[c/] ND = not detected; <1 = concentration below the specified practical quantitation limit.

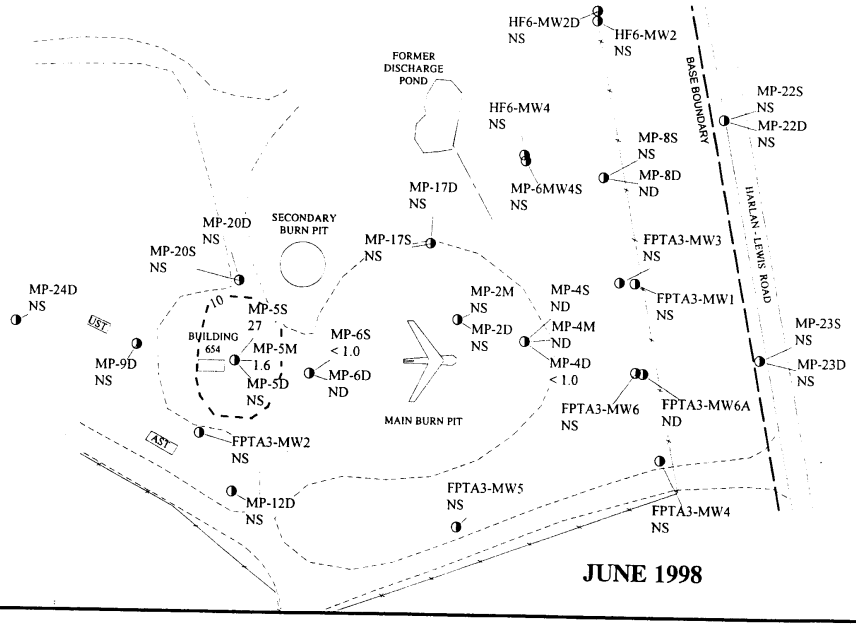
[d/] duplicate sample.



NOVEMBER 1994



JUNE 1996



JUNE 1998

LEGEND

	Paved Road
	Unpaved Road
	Fence
	Surface Drainage
	Subsurface Storm Sewer
MP-4S 8.6	Groundwater Monitoring Well/Point with TCE Concentration (µg/L)
10	Line of Equal TCE Concentration (µg/L) (dashed where inferred)
ND	Not Detected
NS	Not Sampled
< 1	Measured Concentration Less Than Specified Practical Quantitation Limit
UST	Underground Storage Tank
AST	Above Ground Storage Tank

0 62.5 125
Feet

N

FIGURE 6
TCE CONCENTRATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Building 654 (Figure 6). TCE degradation products *cis*-1,2-DCE and VC also were detected in groundwater beneath the two source areas (Figures 7 and 8). The elevated concentrations of these reductive dehalogenation daughter products indicates that biodegradation of TCE in groundwater at the site is occurring.

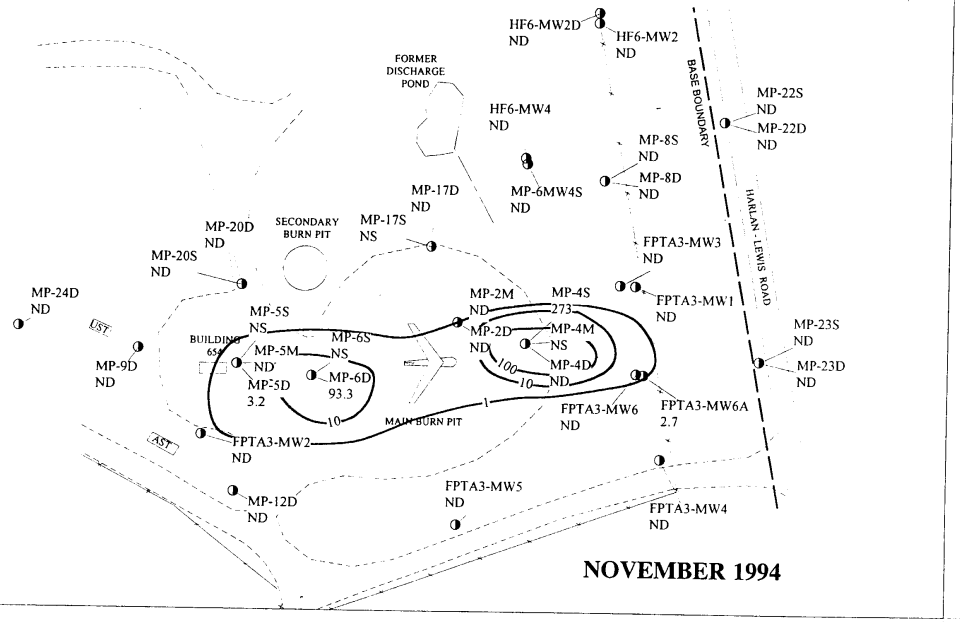
Concentrations of *cis*-1,2-DCE ranging up to 4,880 µg/L were detected during the November 1994, June 1996, and June 1998 sampling events (Figure 7). While concentrations of *cis*-1,2-DCE are higher than TCE, the distribution is similar in that detected concentrations of *cis*-1,2-DCE are limited to the Building 654 and Main Burn Pit source areas. To evaluate temporal trends in *cis*-1,2-DCE concentrations, selected concentrations are plotted against time in Figure 9. *cis*-1,2-DCE concentrations increased through time at monitoring locations MP-4S and MP-5M, but decreased at other sampling locations. Both MP-4S and MP-5M are centrally located beneath the main burn pit (MP-4S) and Building 654 (MP-5M) source areas, indicating the continued presence of residual CAHs adsorbed to soil particles in these areas.

Similar to TCE and *cis*-1,2-DCE, VC is generally limited to the area near and slightly downgradient from the two primary source areas (Figure 8), at concentrations up to 2,520 µg/L (Table 5). Concentrations of VC have increased at monitoring points MP-5M and MP-4S, centrally located beneath the main burn pit (MP-4S) and Building 654 (MP-5M) source areas (Figure 10). VC concentrations decreased at monitoring points MP-5S and MP-6D, and remained relatively constant at MP-6S.

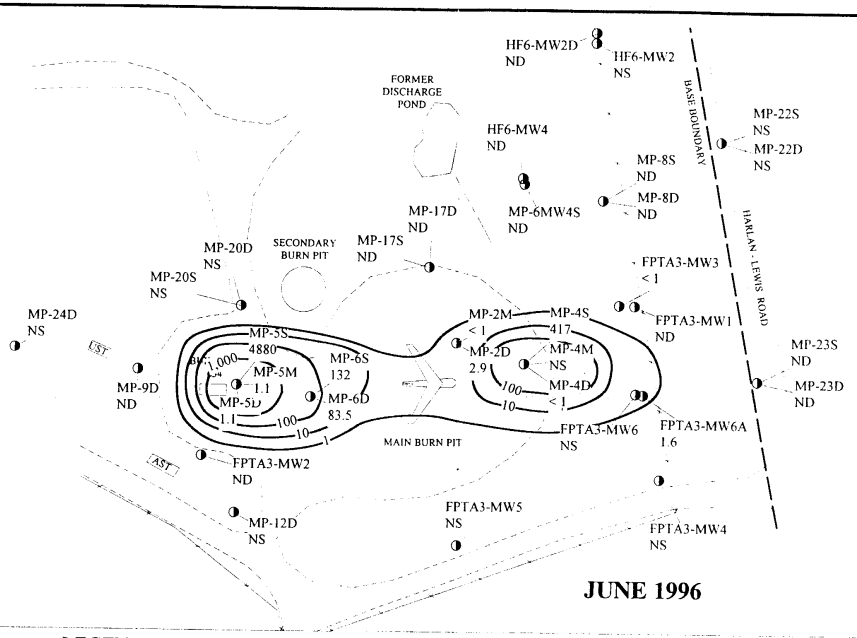
Data for TCE, *cis*-1,2-DCE, and VC suggest that these CAHs are limited in extent to the vicinity of the two primary source areas. The highest TCE and *cis*-1,2-DCE concentrations detected in the Building 654 area were detected in shallow groundwater from MP-5S. Conversely, the highest VC concentrations occurred at a slightly greater depth in MP-5M. This distribution of parent and daughter products suggests that TCE and DCE are being degraded and VC is being produced as groundwater migrates deeper in the shallow aquifer. At the main burn pit (monitoring point cluster MP-4S/4M/4D), TCE, *cis*-1,2-DCE, and VC appear to be present primarily in the shallow zone near the water table. Furthermore, a decrease in TCE concentrations over time is associated with an increase in, or accumulation of, *cis*-1,2-DCE and VC at monitoring points MP-4S and MP-5M. This suggest continued degradation of TCE to *cis*-1,2-DCE, and of *cis*-1,2-DCE to VC.

2.4 Inorganic Chemistry and Geochemical Indicators of BTEX Biodegradation

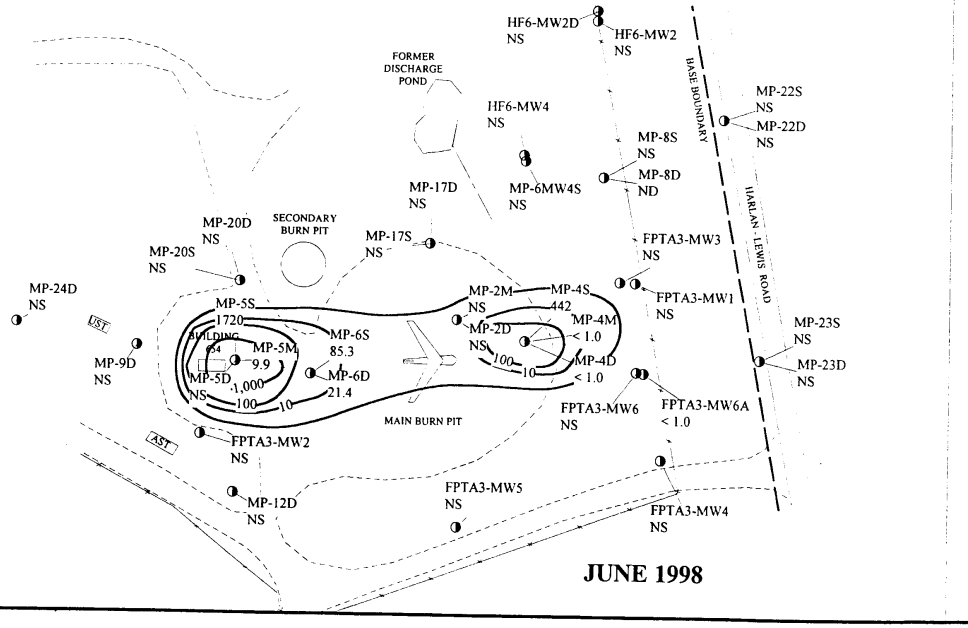
Micro-organisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous oxidation/reduction reactions involving the transfer of electrons from electron donors to available electron acceptors (Parsons ES, 1995). This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at FPTA3 are 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 oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide. Microorganisms preferentially utilize these electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is



NOVEMBER 1994



JUNE 1996



JUNE 1998

LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- PMW1 / 100 — Groundwater Monitoring Well/Point with cis-1,2-DCE Concentration (µg/L)
- 100 — Line of Equal cis-1,2-DCE Concentration (µg/L)
- ND — Not Detected
- NS — Not Sampled
- < 1 — Measured Concentration Less Than Specified Practical Quantitation Limit
- UST — Underground Storage Tank
- AST — Above Ground Storage Tank

0 62.5 125
Feet

FIGURE 7
cis-1,2-DCE CONCENTRATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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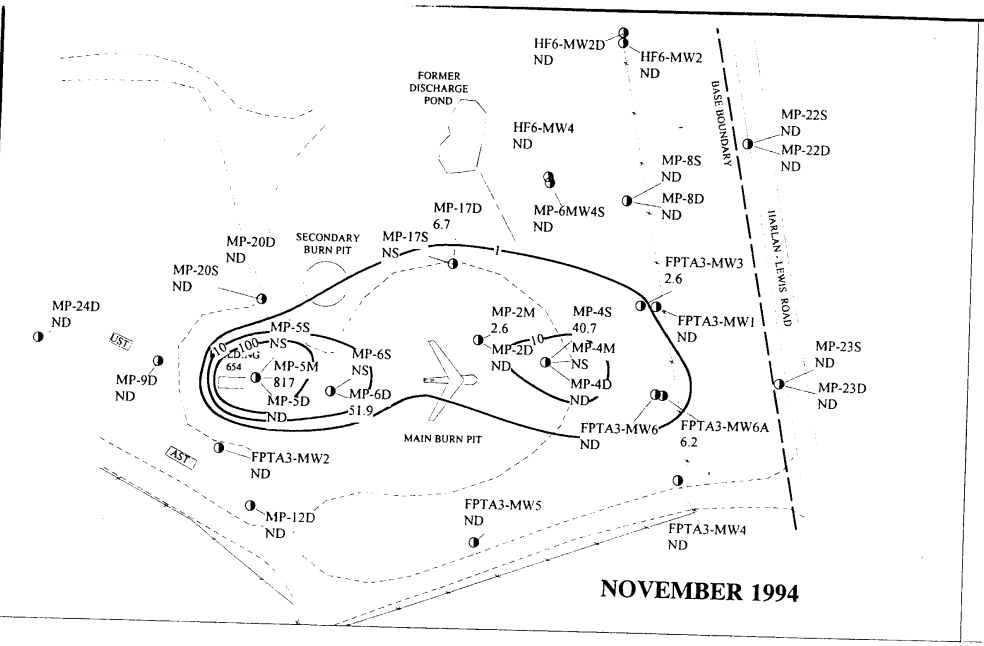

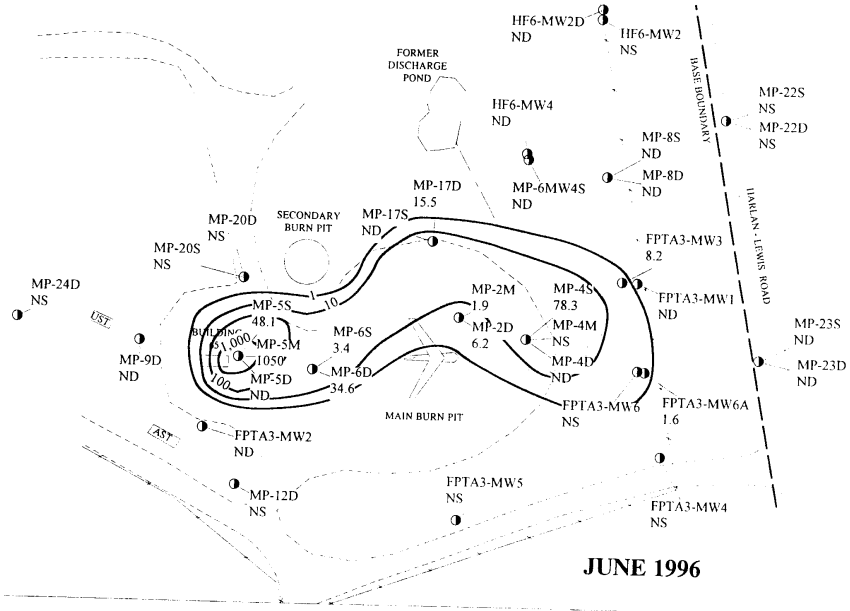

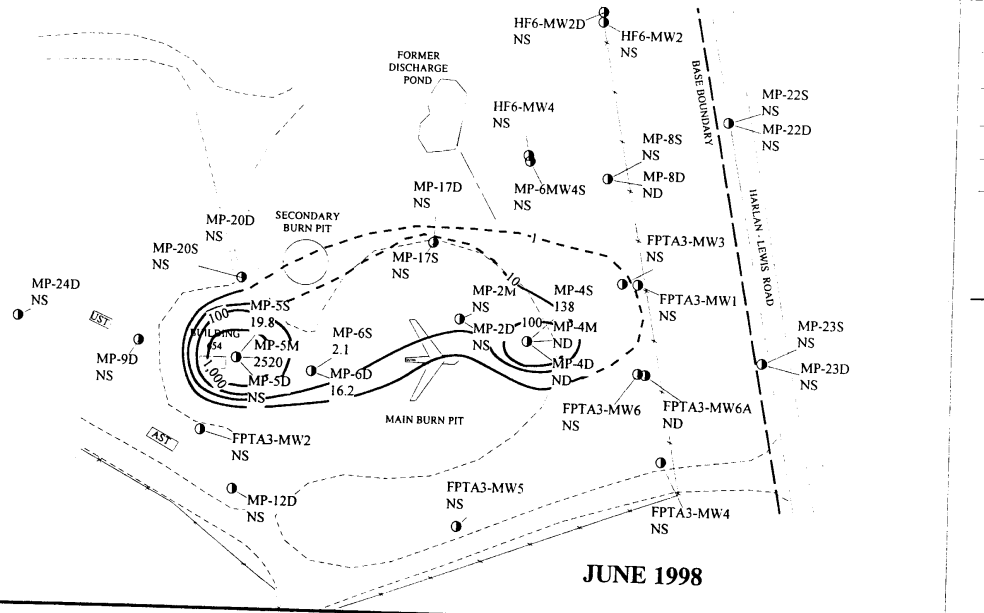

LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- PMW1 100 — Groundwater Monitoring Well/Point with VC Concentration (µg/L)
- 100 — Line of Equal VC Concentration (µg/L) (dashed where inferred)
- ND — Not Detected
- NS — Not Sampled
- < 1 — Measured Concentration Less Than Specified Practical Quantitation Limit
- UST — Underground Storage Tank
- AST — Above Ground Storage Tank

0 62.5 125
Feet

N

FIGURE 8
VC CONCENTRATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

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Denver, Colorado

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FIGURE 9
***cis*-1,2-DCE CONCENTRATIONS FOR SELECTED WELLS**
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

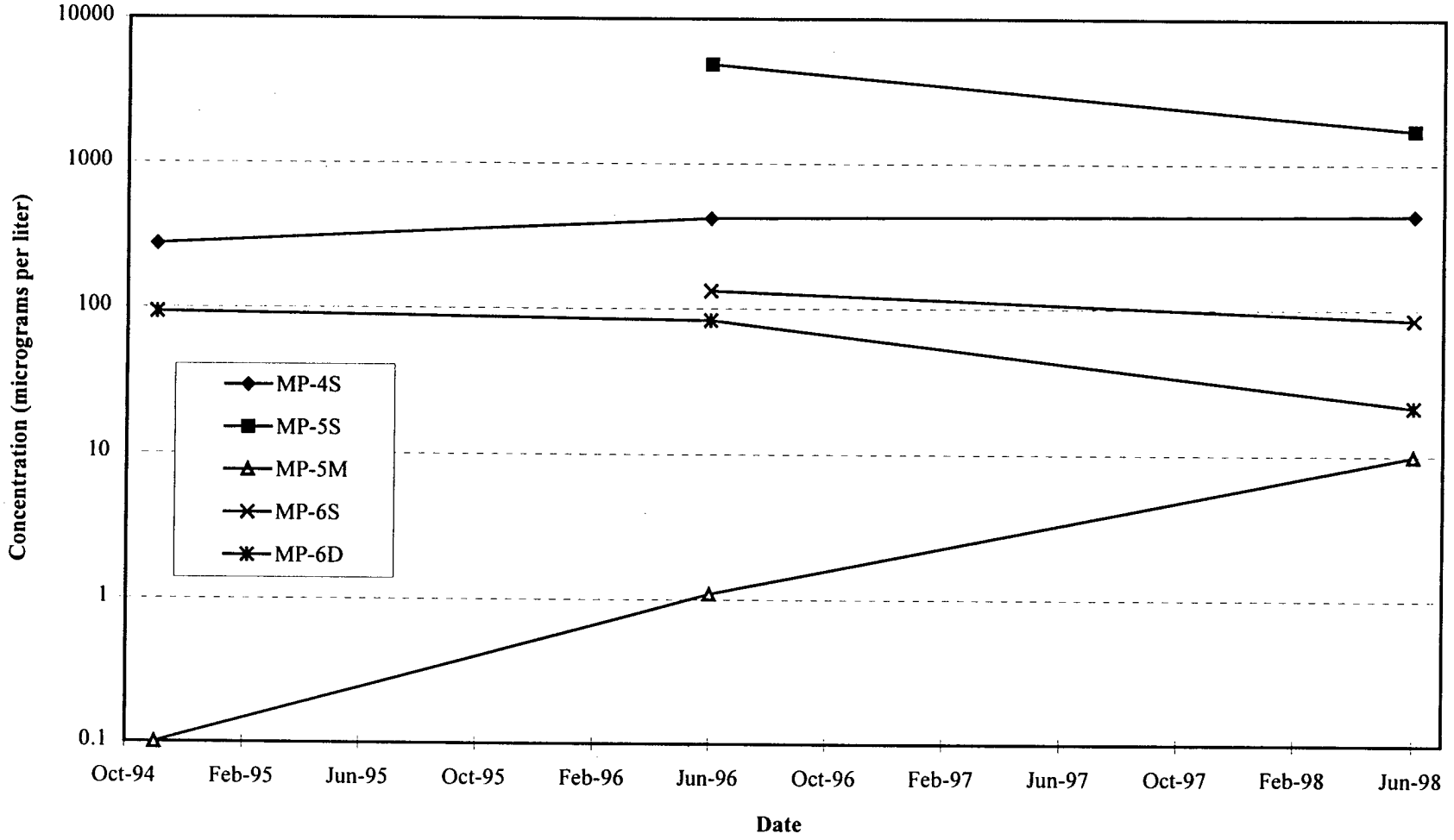

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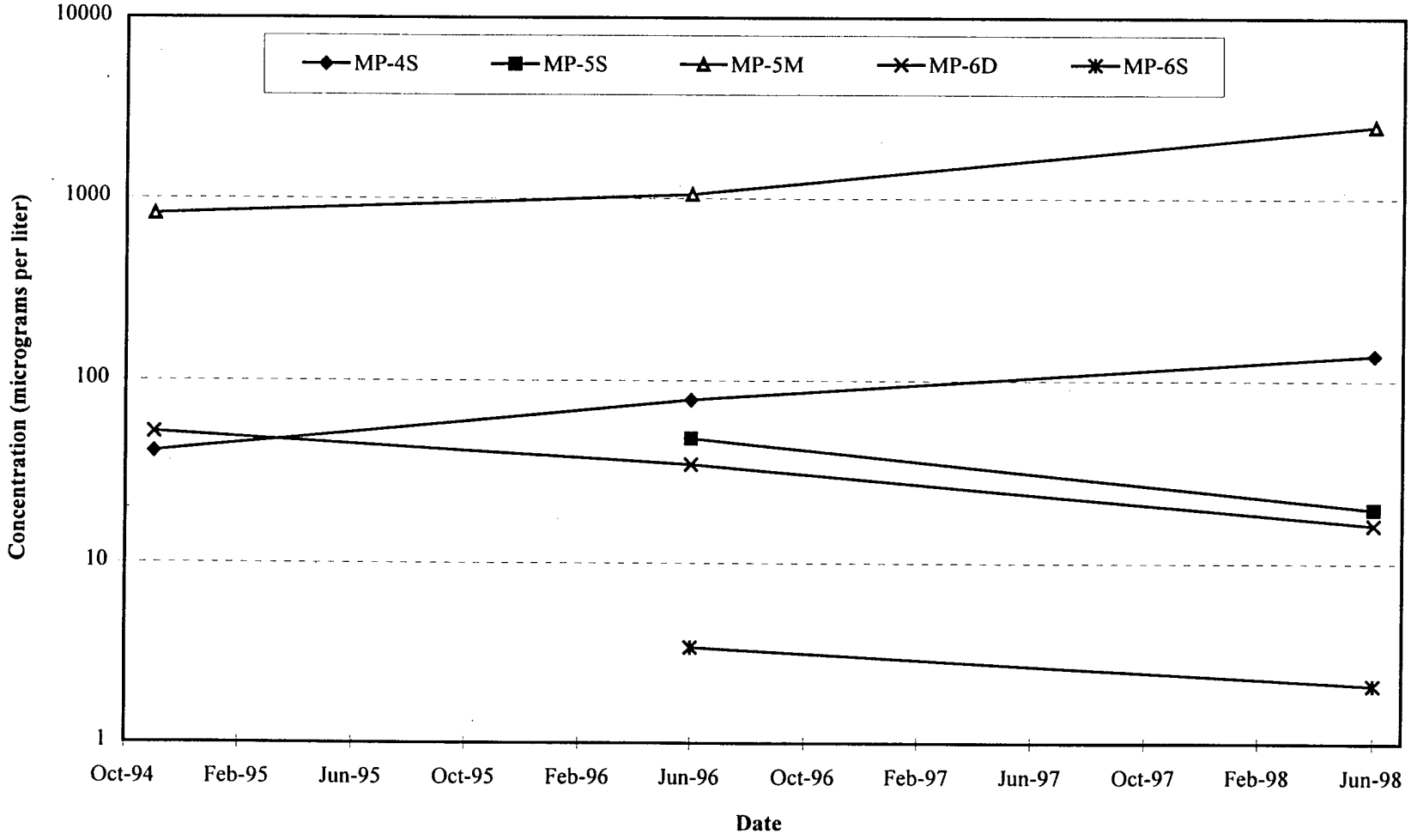
FIGURE 10
VINYL CHLORIDE CONCENTRATIONS FOR SELECTED WELLS
Fire Protection Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska



consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, and finally carbon dioxide. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, the reduction of nitrate and manganese, the solubilization of iron, the reduction of sulfate, and the production of methane (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990).

Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the affected area. Concentrations of compounds used as electron acceptors (e.g., DO, nitrate, and sulfate) are depleted, and byproducts of electron acceptor reduction (e.g., ferrous iron and methane) are enhanced. By measuring these changes, it is possible to evaluate the occurrence of natural attenuation at a site. Results of electron acceptor and metabolic byproduct analyses for groundwater at FPTA3 are presented in Table 6. The following subsections discuss the geochemical data and evaluate BTEX biodegradation processes.

2.4.1 Oxidation-Reduction Potential

Oxidation-Reduction Potential (ORP) is a measure of the relative tendency of a solution to accept or transfer electrons. The dominant electron acceptor being reduced by microorganisms during BTEX oxidation is related to the groundwater ORP.

ORP was measured at all 23 wells sampled in June 1996, and at six of the nine wells sampled in June 1998 (Table 6). ORP measurements in June 1996 ranged from -170 to 109 millivolts (mV), and ORP measurements in June 1998 ranged from -209 mV to -48 mV. Figure 11 shows how the site ORP relates to the sequence of microbially mediated oxidation-reduction processes. The measured range of ORPs indicates that dissolved BTEX contaminants at the site may be subjected to a variety of biodegradation processes, including aerobic respiration, denitrification, manganese reduction, and iron reduction. However, many authors have noted that field ORP potential data alone cannot be used to reliably predict the electron acceptors that may be operating at a site, because the platinum electrode probes are not sensitive to some ORP couples (e.g., sulfate/sulfide) (Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994).

In order to evaluate the variation in ORP over time, ORP values measured in site groundwater in November 1994, June 1996, and June 1998 are plotted on Figure 12. In November 1994, the lowest observed ORP measurements at the site were detected in the source areas at Building 654 (at MP-5M) and in the main burn pit (at MP-2M). This trend has been consistent over time, with low ORP values typically occurring near the source areas. Comparison of Figures 4, 6, 7, and 8 indicates that areas with elevated concentrations of dissolved BTEX, TCE, *cis*-1,2-DCE, and VC also are characterized by lower ORP values.

ORP was measured in 16 of the same monitoring wells during both the November 1994 and June 1996 sampling events. With only one exception (HF6-MW4), ORP increased at all of these wells between November 1994 and June 1996. High rainfall amounts in June 1996 may have caused the shallow groundwater system to become more oxidizing. Ponded water was present at the main burn pit during this sampling

TABLE 6
GROUNDWATER GEOCHEMICAL DATA
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Redox Potential (mV) [a]	Dissolved Oxygen (mg/L) [b]	Nitrate+ Nitrite (mg/L)	Ammonia (mg/L)	Manganese (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	pH (su) [c]	Temp. (°C) [d]	Conductivity (µS/cm) [e]
Shallow Wells (screen midpoint approximately 950 ft amsl [f] to 956 ft amsl)														
FPTA3-MW2	Nov-94	-86	0.1	<0.05 [g]	<0.05	0.2	20	17.8	0.17	784	652	6.8	13.8	1,440
	Nov-94 [h]	NA [i]	NA	NA	NA	NA	NA	17.9	NA	NA	NA	NA	NA	NA
	Jun-96	-79	1.2	0.1	0.22	<0.3	6.9	21.1	0.018	461	NA	6.7	14.7	877
FPTA3-MW3	Nov-94	-145	0.1	<0.05	0.22	<0.1	23.3	3.72	4.32	760	522	7.0	13.8	1,170
	Jun-96	-107	0.5	0.1	1.00	NA	10.1	< 0.1	6.83	568	NA	6.9	13.3	1,070
FPTA3-MW4	Nov-94	90	3.3	1.52	<0.05	0.2	<0.5	15.6	0.007	446	160	7.3	13.8	820
FPTA3-MW5	Nov-94	30	0.2	<0.05	<0.05	<0.1	<0.5	24	0.01	428	132	7.1	13.3	849
HF6-MW2	Nov-94	-60	0.1	<0.05	<0.05	0.3	8.3	175	0.01	460	440	6.8	13.1	1,490
HF6-MW4	Nov-94	-90	0.1	<0.05	<0.05	NA	24	391	7.91	678	600	7.0	12.9	1,860
	Nov-94 [f]	-91	NA	<0.05	<0.05	0.4	24.3	387	8.09	670	630	7.0	NA	1,860
	Jun-96	-117	0.7	<0.05	0.63	NA	9.3	101	6.02	584	NA	7.0	16.5	1,240
MP-4S	Jun-96	-93	1.8	<0.05	1.32	NA	10.3	2.1	19.4	585	NA	7.0	16.1	1,140
MP-5S	Jun-96	-75	0.7	0.07	47.5	NA	20	552	0.29	832	NA	6.8	15.8	2,660
MP-5S	Jun-98	NA	NA	<0.10	60.7	NA	NA	513	NA	NA	NA	NA	NA	NA
MP-6S	Jun-96	48	3.4	1.34	<0.05	NA	<0.05	35.6	0.326	537	NA	6.7	18.6	1,490
	Jun-98	NA	NA	5.59	<0.10	0.3	3	59.9	0.305	640	100	7.0	NA	NA
MP-8S	Nov-94	NA	NA	NA	NA	NA	NA	NA	0.037	NA	NA	NA	NA	NA
	Jun-96	109	1.5	<0.05	<0.05	NA	<0.05	22.6	0.029	562	NA	6.7	12.4	1,070
MP-17S	Jun-96	-27	1.5	1.16	0.19	<0.3	<0.05	32.8	0.06	900	NA	6.9	14.8	2,320
MP-20S	Nov-94	NA	NA	NA	NA	NA	NA	NA	0.008	NA	NA	NA	NA	NA

TABLE 6 (Continued)
GROUNDWATER GEOCHEMICAL DATA
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Redox Potential (mV) [a/]	Dissolved Oxygen (mg/L) [b/]	Nitrate+ Nitrite (mg/L)	Ammonia (mg/L)	Manganese (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	pH (su)	Temp. (°C) [c/]	Conductivity (µS/cm) [d/]
Shallow Wells (screen midpoint approximately 950 ft amsl to 956 ft amsl) (continued)														
MP-22S	Nov-94	-37	0.3	<0.05	0.31	<0.1	1.2	41.3	0.05	464	212	7.0	12.4	944
MP-23S	Nov-94	NA	NA	0.2	<0.05	NA	NA	27.9	0.005	NA	NA	NA	NA	NA
	6/25/1996	15	0.9	<0.05	<0.05	NA	<0.05	27.4	0.006	448	NA	6.8	16.8	926
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl)														
MP-2M	Nov-94	-165	0.1	<0.05	1.18	<0.1	26.3	<0.5	17.6	640	424	7.3	14.3	1,230
	Jun-96	-104	0.4	<0.05	1.67	NA	NA	8	18.7	NA	NA	7.3	14.4	NA
MP-4M	Jun-98	-66	1.5	NA	NA	NA	NA	NA	NA	NA	NA	7.6	14	752
MP-4D	Nov-94	-120	0.6	<0.05	1.71	0.1	22.5	2.83	2.93	712	540	7.2	13.7	1,300
	Jun-96	-112	0.7	<0.05	2.44	NA	7.4	2.97	1.85	684	NA	7.0	16.2	1,250
	Jun-98	-48	1.8	<0.10	0.46	0.6	2	20.3	0.509	580	110	6.7	14.1	482
MP-5M	Nov-94	-170	0.1	<0.05	1.38	<0.1	17.5	23.2	22.5	520	460	7.3	13.5	1,470
	Jun-96	-142	0.5	0.05	2.18	NA	15.2	45.4	25.4	528	NA	7.0	15.7	1,470
	Jun-98	-209	0.1	<0.10	1.74	< 0.1	50	105	24.9	500	140	NA	12.4	1,550
MP-6D	Nov-94	-130	0.2	<0.05	0.56	0.5	18.4	8.35	2.26	654	580	7.1	13.8	1,790
	Nov-94 [f/]	NA	NA	<0.05	0.57	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jun-96	-105	0.8	<0.05	1.4	NA	19.8	1.47	3.92	605	NA	7.0	14.9	1,960
	Jun-98	-142	0.1	<0.10	1.01	2	40	<0.10	6.31	600	150	7.5	12.1	1,850

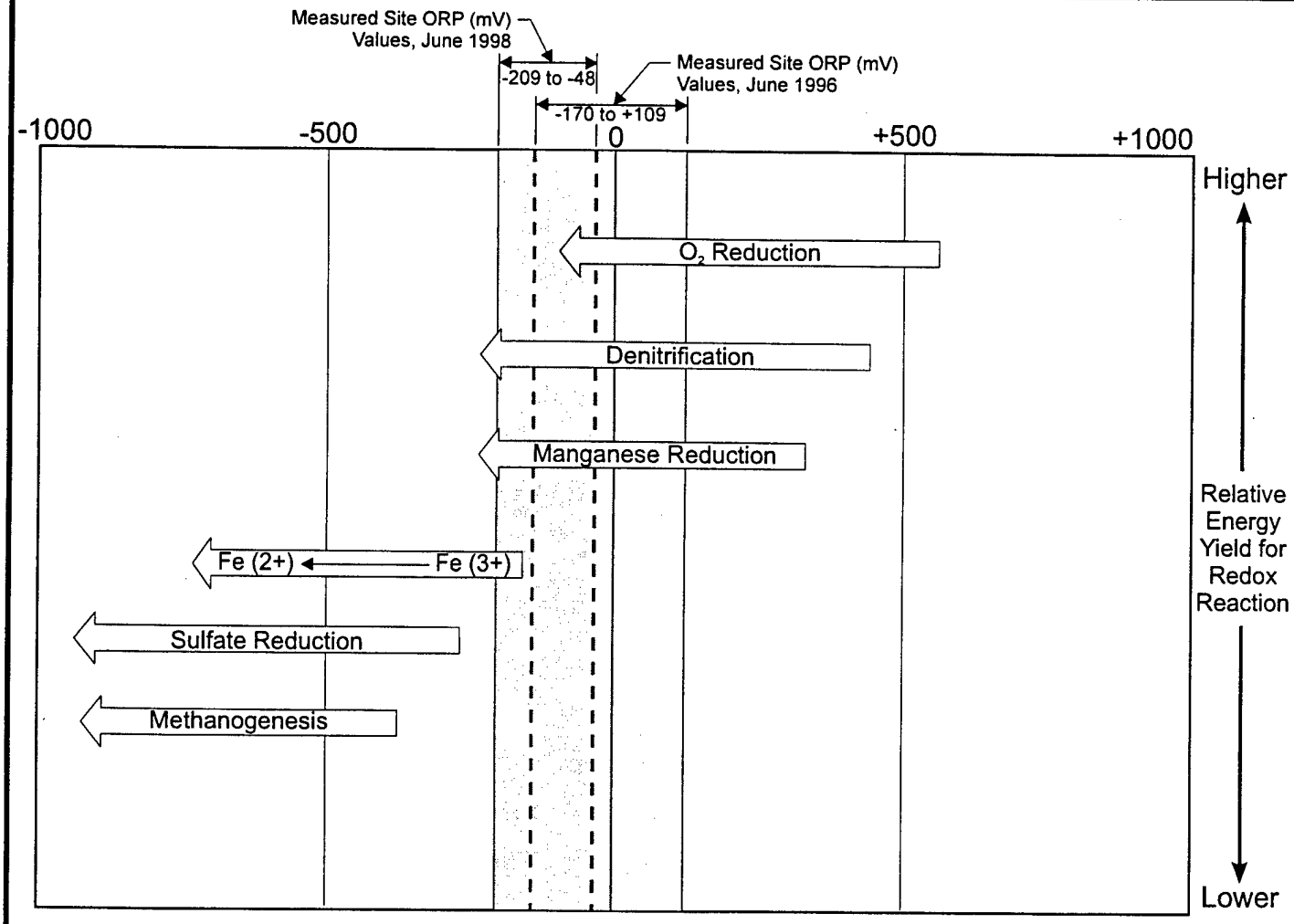
TABLE 6 (Continued)
GROUNDWATER GEOCHEMICAL DATA
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Redox Potential (mV) [a/]	Dissolved Oxygen (mg/L) [b/]	Nitrate+ Nitrite (mg/L)	Ammonia (mg/L)	Manganese (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	pH (su)	Temp. (°C) [c/]	Conductivity (µS/cm) [d/]
Intermediate Wells (screen midpoint approximately 943 ft amsl to 946 ft amsl) (continued)														
MP-8D	Nov-94	-130	0.3	<0.05	<0.05	0.6	8.7	<0.5	0.384	518	304	7.2	12.3	871
	Jun-96	-118	0.2	<0.05	0.49	3.5	6.4	0.45	0.807	485	NA	7.3	12.5	890
	Jun-98	-147	0.0	<0.10	0.57	2	12	7.44	0.206	620	120	7.2	11.7	1,090
MP-9D	Nov-94	-98	0.0	<0.05	<0.05	0.2	7.5	65	0.008	514	182	7.2	12.1	1,020
	Jun-96	-89	1.2	<0.05	0.45	1	4.5	31.4	0.006	391	NA	7.2	13.8	783
MP-12D	Nov-94	-60	0.1	<0.05	<0.05	<0.1	1.7	42.2	0.001	570	260	7.2	11.7	1,120
	Nov-94 [f/]	NA	NA	NA	NA	NA	NA	42.6	NA	NA	NA	NA	NA	NA
MP-17D	Nov-94	-111	0.1	<0.05	0.39	<0.1	24.7	35.5	1.33	630	560	6.9	12.8	1,370
	Nov-94 [f/]	NA	NA	<0.05	0.45	<0.1	25.8	36.1	1.32	614	NA	7.0	NA	1,360
	Jun-96	-23	0.7	<0.05	1.34	<0.3	22.5	32.7	2.22	602	NA	7.2	14.8	1,280
MP-20D	Nov-94	-120	0.2	<0.05	1.07	<0.1	27	4.72	0.096	766	780	6.9	12.8	1,390
	Nov-94 [f/]	NA	NA	<0.05	0.99	NA	NA	NA	NA	NA	NA	NA	NA	NA
MP-22D	Nov-94	-80	0.2	<0.05	<0.05	0.1	2.2	6.75	1.18	470	266	7.0	12.5	903
MP-23D	Nov-94	-127	0.2	<0.05	0.75	0.1	6.3	24.5	0.014	492	342	7.1	13.2	964
	Jun-96	-112	0.8	<0.05	1.34	NA	8.8	23.7	0.015	485	NA	7.0	16.3	922
MP-24D	Nov-94	-70	0.0	<0.05	<0.05	0.1	4.3	21.5	0.106	412	104	7.2	11.6	820

TABLE 6 (Concluded)
GROUNDWATER GEOCHEMICAL DATA
Fire Protection Training Area 3
Intrinsic Remediation Treatability Study Addendum
Offutt Air Force Base, Nebraska

Sample Location	Sample Date	Redox Potential (mV) [a/]	Dissolved Oxygen (mg/L) [b/]	Nitrate+ Nitrite (mg/L)	Ammonia (mg/L)	Manganese (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Methane (mg/L)	Alkalinity (mg/L)	Carbon Dioxide (mg/L)	pH (su)	Temp. (°C) [c/]	Conductivity (µS/cm) [d/]
Deep Wells (screen midpoint approximately 880 ft amsl to 936 ft amsl)														
FPTA3-MW1	Nov-94	-120	0.2	<0.05	0.59	<0.1	7.5	45.8	NA	502	282	6.9	13.5	1,053
	Nov-94 [f/]	NA	NA	<0.05	0.53	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jun-96	-78	0.1	0.11	1.00	NA	5.3	47.9	0.008	501	NA	7.1	15.1	1,008
FPTA3-MW6	Nov-94	-50	0.1	<0.05	0.45	0.4	9.4	17.6	0.978	600	300	7.1	12	1,154
FPTA3-MW6A	Nov-94	-100	0.1	<0.05	0.66	0.4	8.7	5.75	2.29	675	440	7.2	11.3	1,271
	Nov-94 [f/]	NA	NA	<0.05	0.64	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Jun-96	-82	0.2	<0.05	1.39	NA	6.6	6.77	1.16	670	NA	7.3	13.4	1,227
	Jun-98	-128	0.1	<0.1	0.92	2	9	21.3	0.478	540	110	7.3	13.2	979
HF6-MW2D	Nov-94	-100	0.3	<0.05	0.46	<0.1	3.9	48.5	0.008	500	230	7.2	13.5	1,058
	Nov-94 [f/]	NA	NA	NA	NA	NA	NA	48.3	NA	NA	NA	NA	NA	NA
	Nov-94 [f/]	-105	0	<0.05	0.41	<0.1	4.1	49.4	0.017	520	240	7.2	12.8	1,054
	Jun-96	-60	0.4	< 0.05	1.02	NA	3.4	43.2	0.015	499	NA	6.7	15.3	1,000
MP-2D	Nov-94	-140	0.3	<0.05	1.27	0.2	18.1	2.35	8.411	632	476	7.2	14.3	1,211
	Jun-96	-117	0.9	<0.05	1.96	NA	NA	14	6.91	NA	NA	7.2	14.8	NA
MP-5D	Nov-94	-160	0.2	<0.05	0.93	0.4	16.3	46	0.013	480	450	7.2	12.6	926
	Jun-96	-146	0.4	<0.05	1.66	NA	9.1	61.9	0.012	507	NA	6.9	15.6	1,015

[a/] mV = millivolts.
[b/] mg/L = milligrams per liter.
[c/] su = standard pH units.
[d/] °C = degrees Centigrade.
[e/] µS/cm = microsiemens per centimeter.
[f/] ft amsl = feet above mean sea level.
[g/] <0.05 = not detected at concentration above specified practical quantitation limit.
[h/] duplicate sample.
[i/] NA = not analyzed.



Notes

ORP = Oxidation Reduction Potential

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.

2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the pE of the system.

3. Redox sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 11

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

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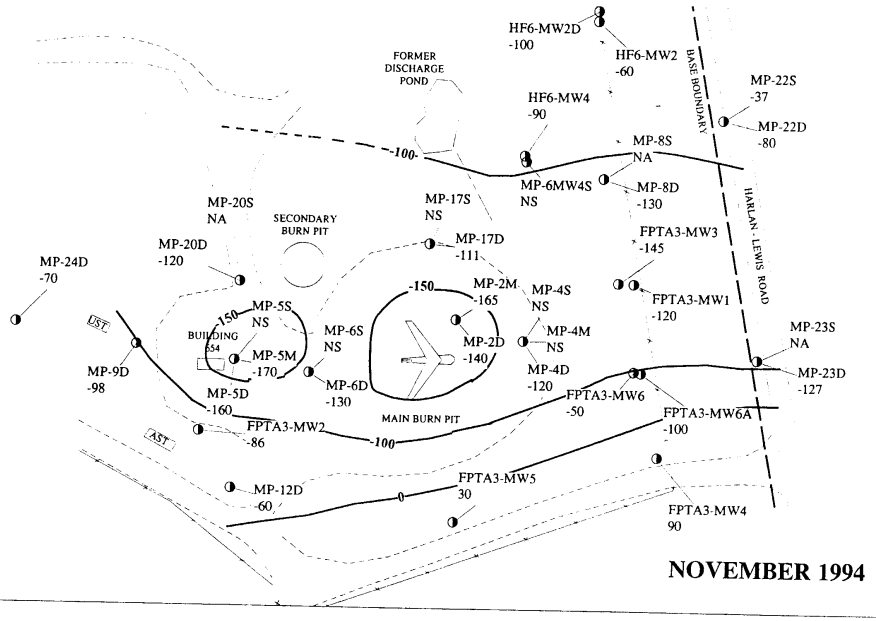
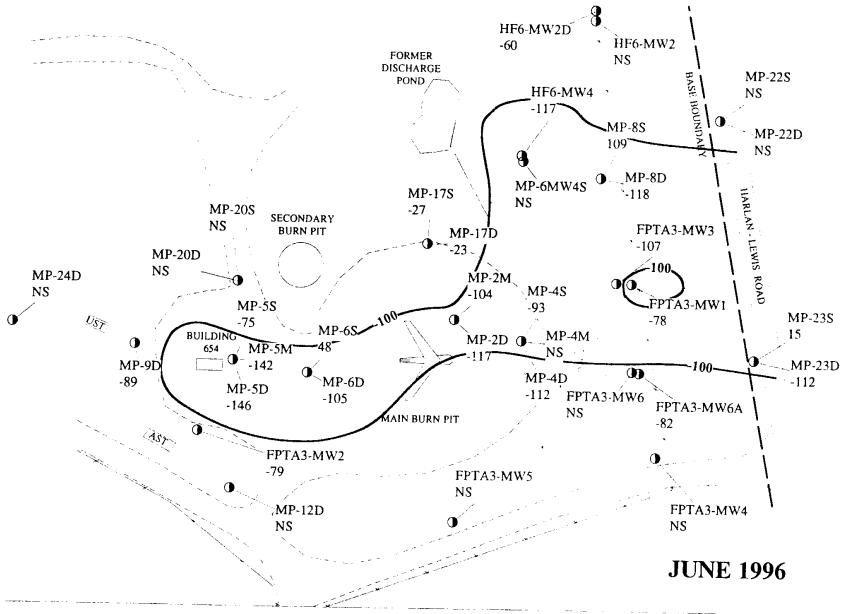
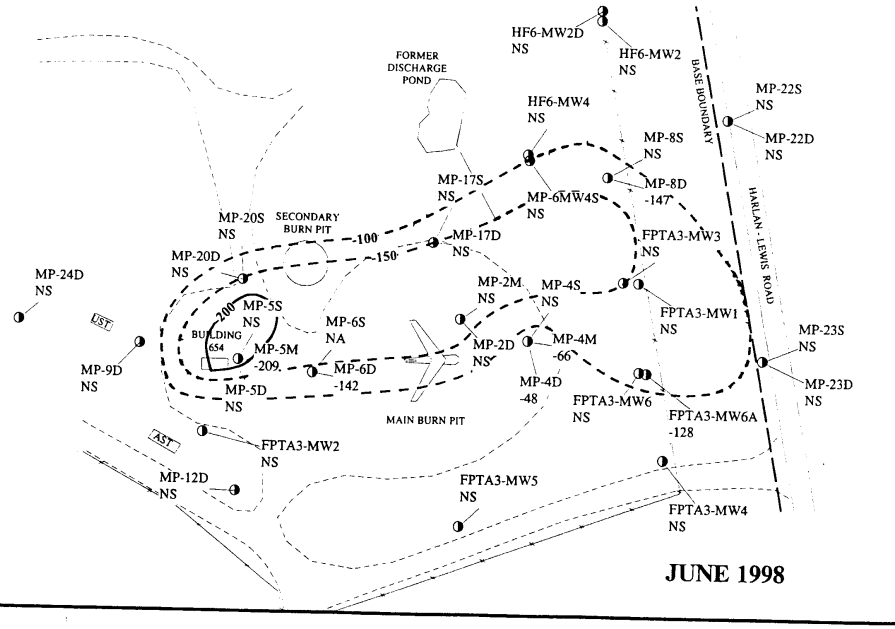


NOVEMBER 1994



JUNE 1996



JUNE 1998

LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- MP-2D -140 — Groundwater Monitoring Well/Point with Oxidation-Reduction Potential (millivolts)
- 100 — Oxidation-Reduction Potential Contour (mV) (Dashed where inferred)
- NA — Not Analyzed
- NS — Not Sampled
- UST — Underground Storage Tank
- AST — Above Ground Storage Tank

0 62.5 125
Feet

FIGURE 12
OXIDATION-REDUCTION POTENTIAL NOVEMBER 1994, JUNE 1996, AND JUNE 1998

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event. ORP was measured in five monitoring wells during both the June 1996 and June 1998 sampling events. During this time interval, ORP decreased in all but one of the wells (MP-4D) in which it was measured.

2.4.2 Dissolved Oxygen

DO concentrations in groundwater are used to evaluate whether aerobic respiration of BTEX is occurring. Generally, DO concentrations in excess of 1 milligram per liter (mg/L) indicate sufficient DO to support aerobic respiration (Wiedemeier *et al*, 1995). DO measured in groundwater samples collected during the November 1994 sampling event were generally less than 1 mg/L, indicating anaerobic groundwater conditions across the site. Similarly, DO concentrations were less than 1 mg/L in groundwater from 15 of the 21 wells sampled in June 1996, and in four of the six wells sampled in June 1998 (Table 6). The overall DO deficiency in both background groundwater and in groundwater within the plume has remained consistent since the 1994 sampling event. Typically, measured DO concentrations greater than 1 mg/L occurred in groundwater samples from wells located within the plume (i.e., MP-4D). The elevated DO concentrations may have been caused by measurement error associated with purging and sampling. In addition, five of the eight DO concentrations that exceeded 1 mg/L were measured in June 1996, possibly reflecting the effects of high rainfall amounts and infiltration. The lack of dissolved oxygen in groundwater at FPTA3 indicates aerobic respiration may not be a significant process contributing to BTEX attenuation.

2.4.3 Nitrate

After DO has been depleted in a microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation of organic carbon via denitrification. Nitrate concentrations below background in areas with high organic carbon and low DO concentrations are indicative of denitrification. Concentrations of nitrate in both background and site groundwater (Table 6) are generally less than 0.05 mg/L. The lack of nitrate in groundwater at FPTA3 indicates denitrification is not contributing significantly to BTEX attenuation.

2.4.4 Manganese

Dissolved manganese II (Mn^{+2}) is the reduced form of manganese and is a byproduct of manganese III (Mn^{+3}) reduction via BTEX biodegradation. Increases in dissolved manganese II concentrations can therefore indicate that manganese reduction is occurring as a result of BTEX biodegradation. Manganese II concentrations measured at all locations in November 1994, June 1996, and June 1998 are summarized in Table 6.

Concentrations of manganese II have not been elevated in plume core wells sampled for this constituent. For example, manganese II concentrations detected at MP-2M and MP-5M have been less than 0.1 mg/L. Higher manganese II concentrations have been detected in wells near the perimeter of the plume (MP-8D, 0.6-3.5 mg/L; FPTA3-MW6A, 0.4-2 mg/L; MP-6D, 0.5-2 mg/L), beneath the plume core (MP-4D, 0.6 mg/L), and upgradient from the plume (MP-9D, 1 mg/L). However, these wells have

generally had relatively low to non-detectable BTEX concentrations. Therefore, the manganese data suggest that the significance of manganese reduction as a BTEX biodegradation process at this site is spatially variable, and that the total mass of BTEX degraded via this process is not substantial.

2.4.5 Ferrous Iron

Dissolved ferrous iron (Fe^{+2}) is the reduced form of iron and is a byproduct of ferric iron (Fe^{+3}) reduction via BTEX biodegradation. Increases in dissolved ferrous iron concentrations can therefore indicate iron reduction is occurring as a result of biodegradation. Ferrous iron concentrations measured at all locations in November 1994, June 1996, and June 1998 are summarized in Table 6, and the distributions of ferrous iron in groundwater in November 1994 and June 1998 are shown on Figure 13. Comparison of Figures 4 and 13 indicates that areas with elevated concentrations of dissolved BTEX are characterized by increased concentrations of ferrous iron (MP-5M and MP-2M). The distribution of elevated concentrations of dissolved ferrous iron strongly suggests that the reduction of ferric to ferrous iron is occurring during biodegradation of BTEX.

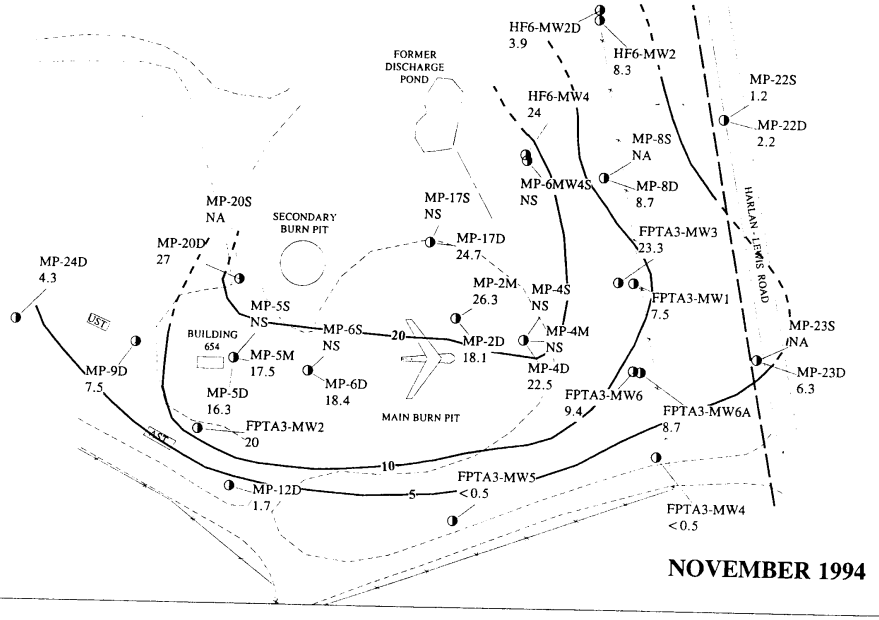
Ferrous iron was measured in the same 14 monitoring wells/points during at least two of the three sampling events. Concentrations of ferrous iron increased in groundwater samples from six of these wells (FPTA3-MW6A, MP-5M, MP-8D, MP-23D, MP-6D, and MP-6S) between 1994 and 1998, and decreased between 1994 and 1998 in eight of the wells (FPTA3-MW1, FPTA3-MW2, FPTA3-MW3, HF6-MW2D, HF6-MW4, MP-17D, MP-4D, and MP-9D).

Ferrous iron concentrations for select wells are plotted against time on Figure 14. The most significant increase in ferrous iron concentrations occurred in groundwater collected from monitoring wells MP-5M and MP-6D, which are both located downgradient of Building 654 within the BTEX plume. Ferrous iron concentrations in samples from these wells increased from 17.5 mg/L and 18.4 mg/L in November 1994 to 50 mg/L and 40 mg/L in June 1998, respectively. These data indicate that the contribution to BTEX degradation by iron reduction continues at the site.

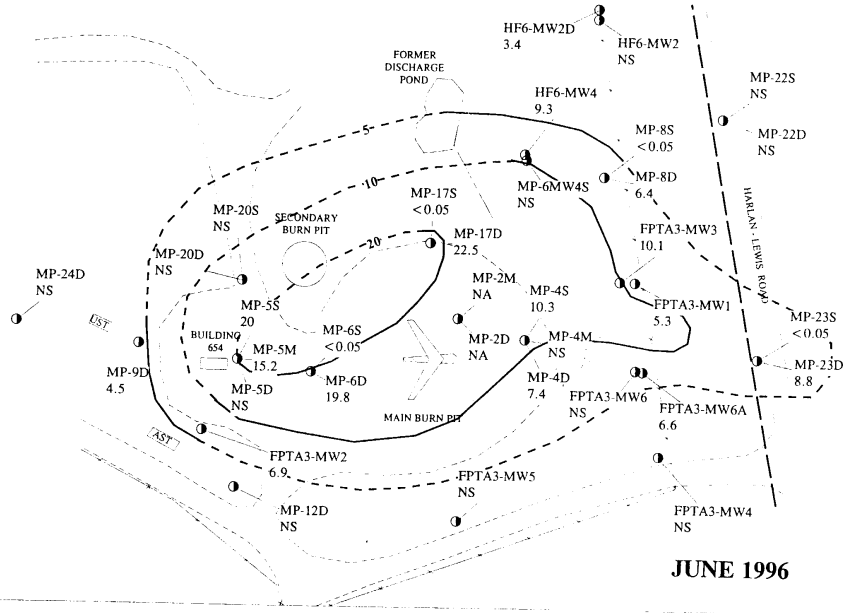
2.4.6 Sulfate

Sulfate may also be used as an electron acceptor during microbial degradation of natural or anthropogenic organic carbon under anaerobic conditions (Grbic-Galic, 1990). This ORP reaction is commonly called sulfate reduction, which results in a decrease in groundwater sulfate concentrations. Sulfate concentrations measured at all locations in November 1994, June 1996, and June 1998 are summarized in Table 6, and the distributions of sulfate in groundwater for these events are shown on Figure 15.

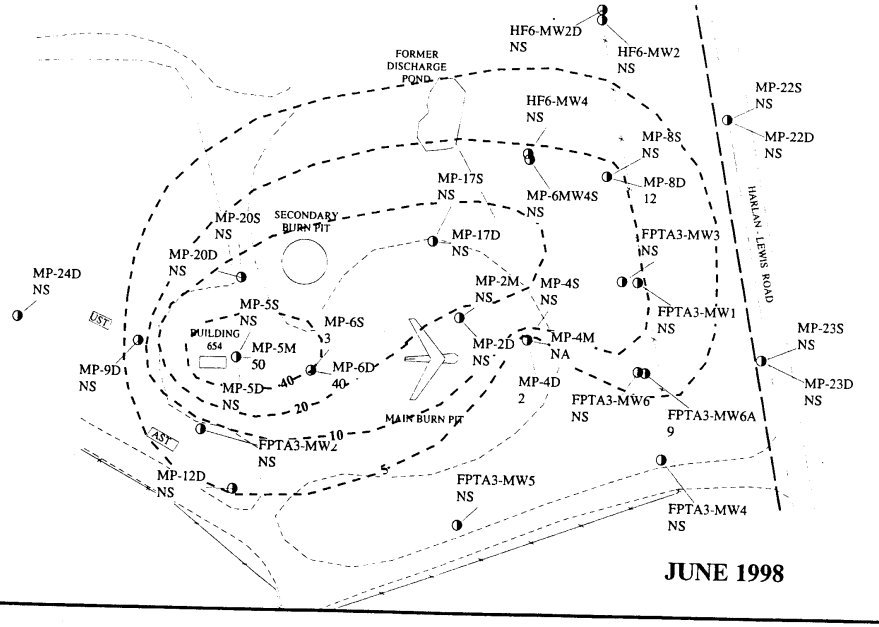
Comparison of sulfate isopleth maps to the BTEX plumes (Figure 4) show that, with the exception of monitoring point MP-5S at Building 654, areas of depleted sulfate concentrations coincide with elevated BTEX concentrations. Low sulfate concentrations were detected beneath the main burn pit area (MP-2M and MP-4S), and



NOVEMBER 1994



JUNE 1996



JUNE 1998

LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- MP-2D 18.1 — Groundwater Monitoring Well/Point with Ferrous Iron Concentration (mg/L)
- 20 — Line of Equal Ferrous Iron Concentration (mg/L) (Dashed where inferred)
- NA — Not Analyzed
- ND — Not Detected
- NS — Not Sampled
- < 1 — Measured Concentration Less Than Specified Practical Quantitation Limit

0 62.5 125
Feet

N

FIGURE 13

FERROUS IRON CONCENTRATION CONTOUR MAP NOVEMBER 1994, JUNE 1996, AND JUNE 1998

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FIGURE 14
FERROUS IRON CONCENTRATIONS IN GROUNDWATER OVER TIME
Fire Protection Training Area 3
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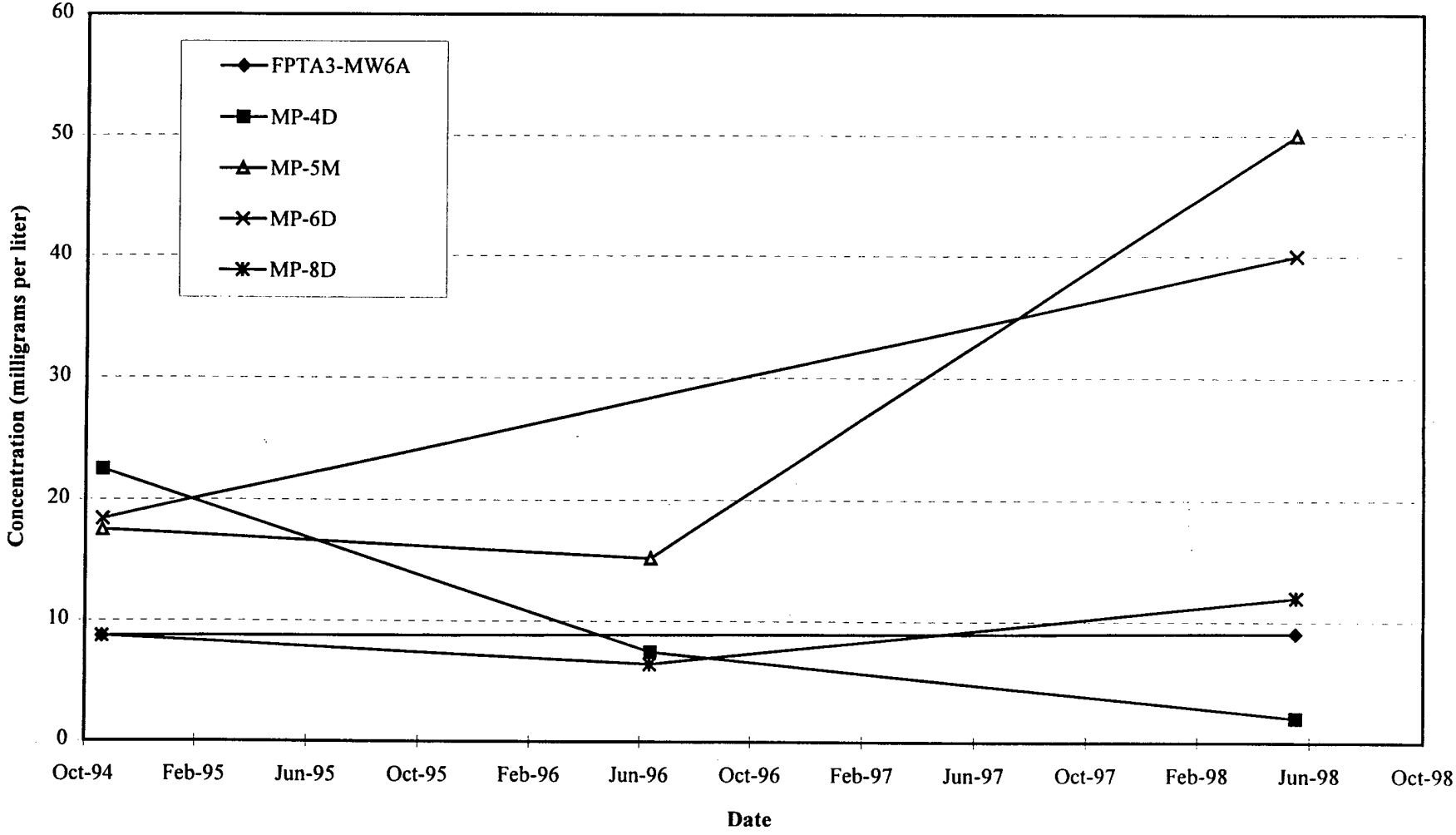
Offutt Air Force Base, Nebraska



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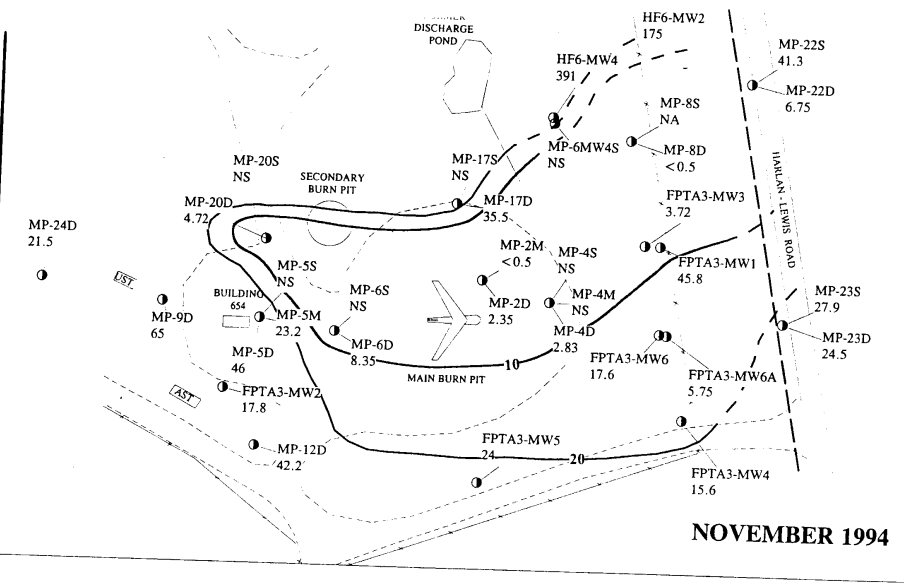
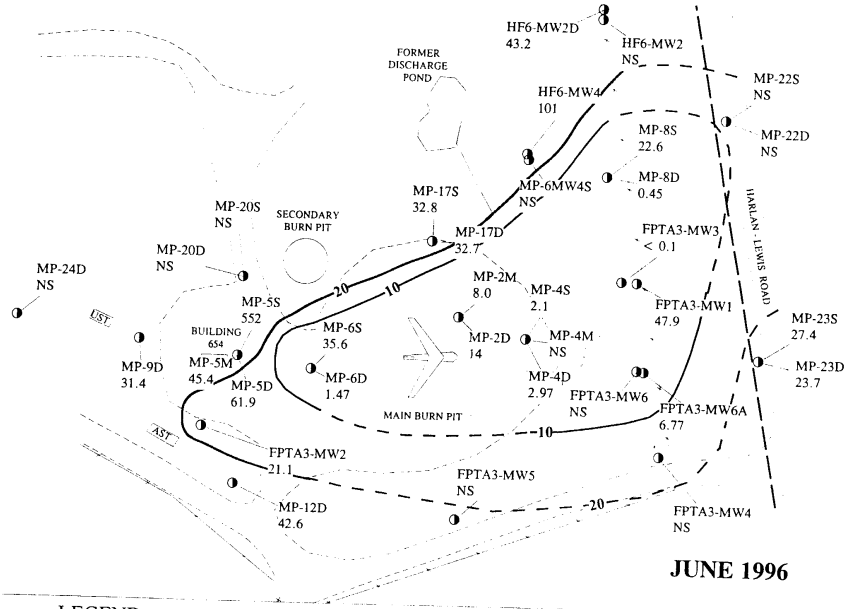
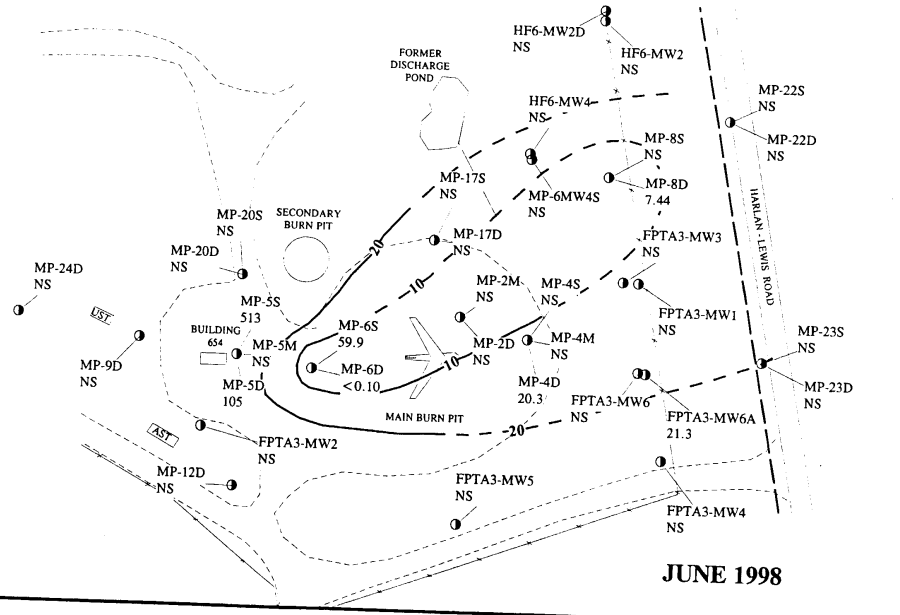


NOVEMBER 1994



JUNE 1996



JUNE 1998

LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- MP-2D 18.1 — Groundwater Monitoring Well/Point with Sulfate Concentration (mg/L)
- 20 — Line of Equal Sulfate Concentration (mg/L) (Dashed where inferred)
- ND — Not Detected
- NS — Not Sampled
- < 1 — Measured Concentration Less Than Specified Practical Quantitation Limit

NOTE: Lowest sulfate concentration at each well cluster was used for the determination of isopleths.

N

0 62.5 125
Feet

FIGURE 15

SULFATE CONCENTRATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

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to the east of the main burn pit (FPTA3-MW3). Sulfate concentrations have remained relatively low beneath, and to the east of the main burn pit. Sulfate concentrations are higher at Building 654.

These relationships are a strong indication that anaerobic biodegradation of BTEX has occurred in groundwater beneath the main burn pit through the microbially mediated process of sulfate reduction. Furthermore, the continuing trend of diminished sulfate concentrations indicates that this process is continuing at the site. However, sulfate reduction does not appear to be a significant degradation process in groundwater beneath Building 654, despite the presence of reducing conditions (ORP of -209 mV in June 1998).

2.4.7 Methanogenesis

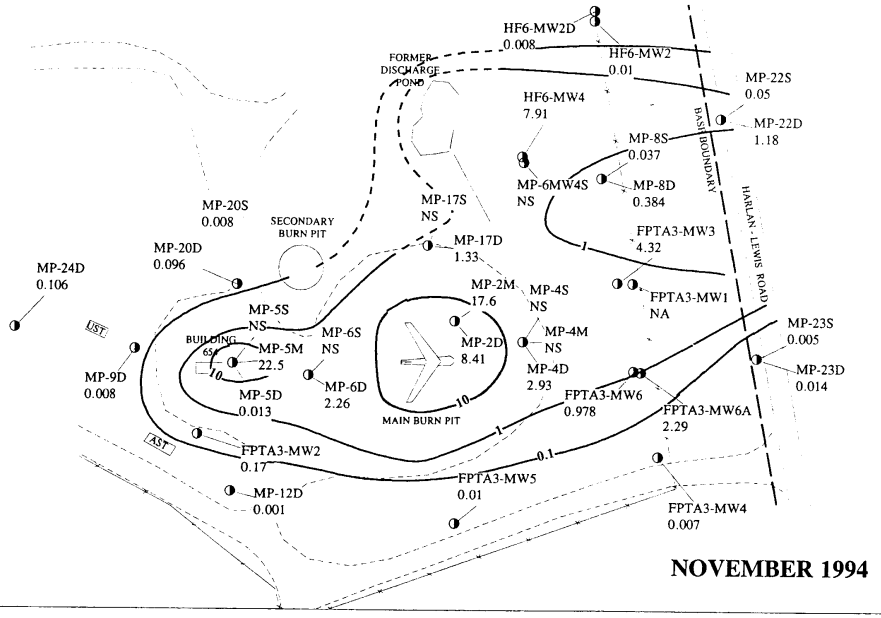
The presence of methane in BTEX-contaminated groundwater indicates that anaerobic biodegradation of BTEX is occurring via the microbially mediated process of methanogenesis (carbon dioxide reduction). Methane concentrations measured at all locations in November 1994, June 1996, and June 1998 are summarized in Table 6, and the distributions of groundwater methane for November 1994, June 1996 and June 1998 are shown on Figure 16. Comparison of Figure 4 with Figure 16 indicates that areas with elevated concentrations of dissolved BTEX are characterized by elevated concentrations of methane. The coincident methane and BTEX plumes indicate that biodegradation of BTEX is occurring via methanogenesis.

Methane was measured in the same 17 monitoring wells/points during at least two of the three sampling events. Concentrations of methane appear to have remained relatively stable between 1994 and 1998, with concentrations increasing slightly at eight wells/points (FPTA3-MW3, HF6-MW2D, MP-17D, MP-23D, MP-23S, MP-2M, MP-5M, and MP-6D), and decreasing slightly at nine wells/points (FPTA3-MW2, FPTA3-MW6A, HF6-MW4, MP-2D, MP-4D, MP-6S, MP-8S, MP-8D, and MP-9D). The source areas (Building 654 and the Main Burn Pit), where the highest BTEX concentrations are present, continue to exhibit the highest methane concentrations.

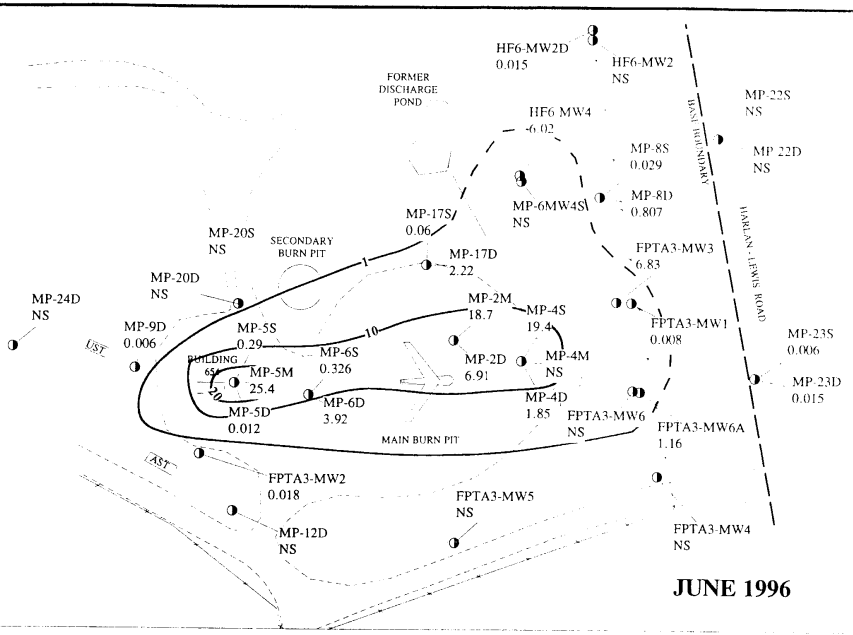
2.4.8 Alkalinity

Total alkalinity (as calcium carbonate) is a measure of the ability of water to buffer changes in pH. Biodegradation of BTEX produces carbon dioxide which, when mixed with water in the proper conditions, produces carbonic acid. In aquifers that have carbonate minerals as part of the matrix, carbonic acid dissolves these minerals, increasing the alkalinity of the groundwater. Therefore, an increase in alkalinity can be observed in areas of active biodegradation of BTEX. Alkalinity was measured at all sampled locations in November 1994, June 1996, and June 1998, and results are summarized in Table 6.

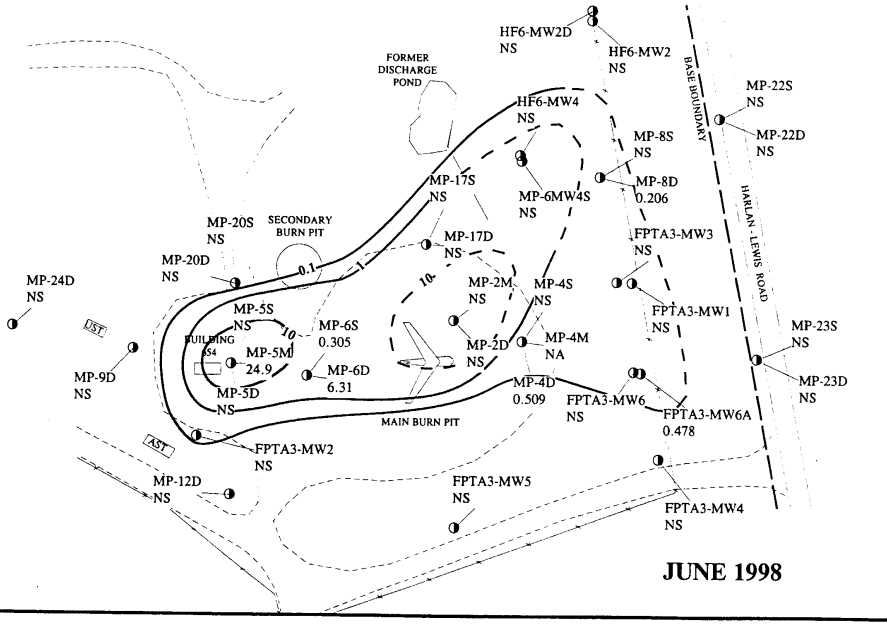
Alkalinity was measured in the same 14 monitoring wells/points during at least two of the three sampling events. With only two exceptions (MP-6S and MP-8D), alkalinity decreased in all of these groundwater samples between 1994 and 1998. The highest alkalinity values measured at the site during June 1996 were from groundwater samples collected at monitoring points MP-17S (900 mg/L) and MP-5S (832 mg/L).



NOVEMBER 1994



JUNE 1996



JUNE 1998

LEGEND

- Paved Road
- Unpaved Road
- Fence
- Surface Drainage
- Subsurface Storm Sewer
- MP-12D 0.001 — Groundwater Monitoring Well/Point with Methane Concentration (mg/L)
- 10 — Methane Concentration Contour (mg/L) (dashed where inferred)
- NA — Not Analyzed
- ND — Not Detected
- UST — Underground Storage Tank
- AST — Above Ground Storage Tank

0 62.5 125
Feet

N

FIGURE 16

METHANE CONCENTRATION CONTOUR MAPS NOVEMBER 1994, JUNE 1996, AND JUNE 1998

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MP-5S is located within the BTEX plume, and MP-17S is located at the perimeter of the June 1996 plume. The highest alkalinity value measured at the site during June 1998 was at monitoring point MP-6S (640 mg/L), which is located downgradient from the Building 654 source area at the southern edge of the June 1998 BTEX plume. The data indicate that the alkalinity is sufficient to continue buffering the groundwater pH against the effects of biologically mediated BTEX oxidation reactions.

2.5 Biodegradation of CAHs

CAHs 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 and 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; McCarty and Semprini, 1994; Vogel, 1994). Biodegradation of CAHs is similar in principle to biodegradation of BTEX as described in the March 1995 TS for Site FPTA3; 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 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 microbial process. A fourth degradation mechanism that may occur is abiotic degradation, including hydrolysis and dehydrohalogenation reactions. However, attributing degradation of CAHs to abiotic processes is usually difficult, particularly at the field scale (Butler and Barker, 1996).

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.

2.5.1 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 of chlorinated ethenes occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene as shown in Figure 17. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

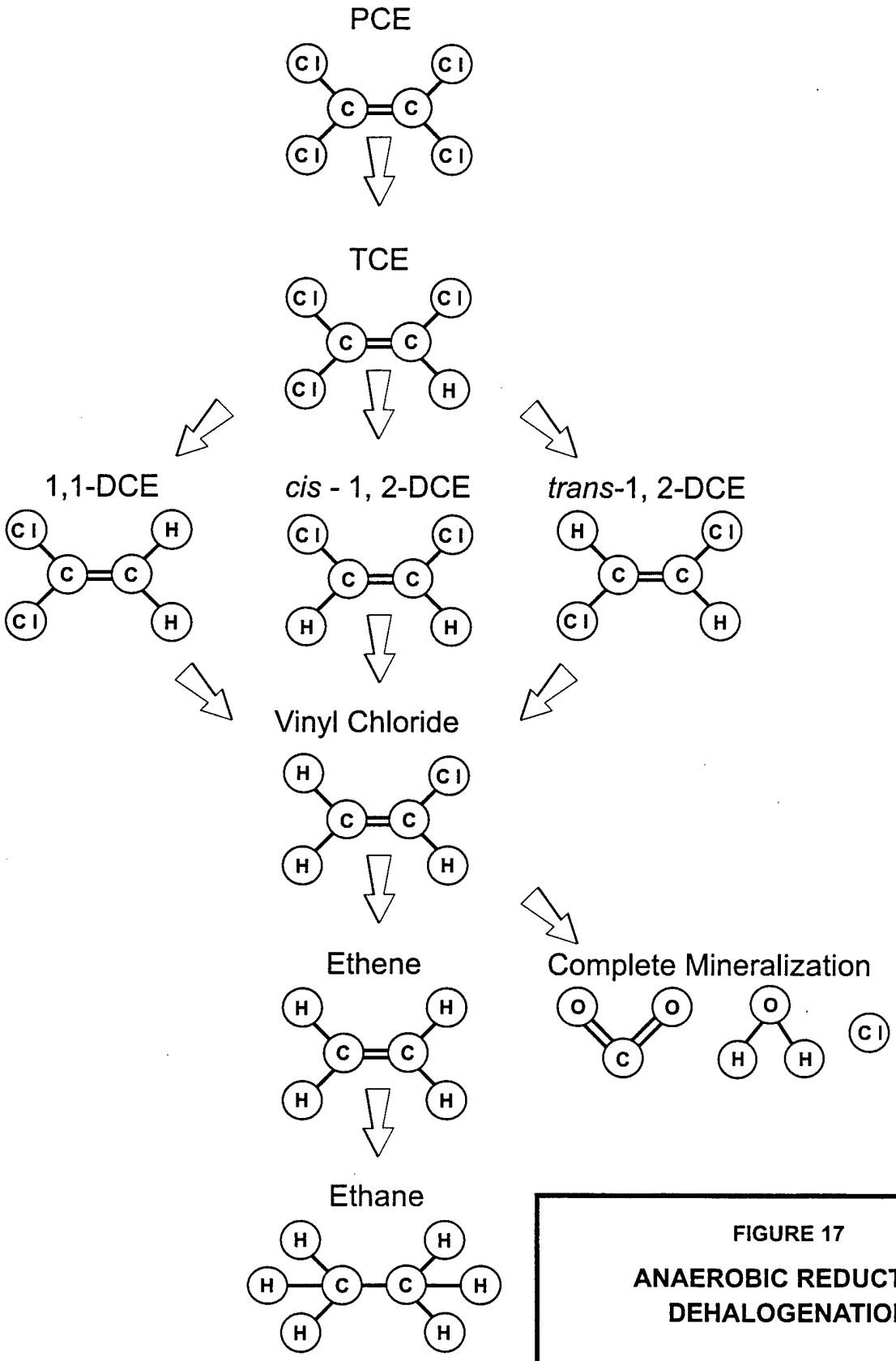

FIGURE 17

ANAEROBIC REDUCTIVE DEHALOGENATION

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Reductive dehalogenation affects each of the chlorinated ethenes differently. The rate of reductive dehalogenation has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC 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 ORP 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 ferric iron reduction (Vogel *et al.*, 1987), while the transformation of DCE to VC, or the transformation from VC to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; DeBruin *et al.*, 1992).

Because CAHs 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. At FPTA3, the occurrence of ferric iron reduction, sulfate reduction, and methanogenesis, and the corresponding low ORPs in the core of the commingled BTEX plume as measured in November 1994, June 1996, and June 1998 support the possibility that reductive dehalogenation has occurred at the site.

This supposition is confirmed by the presence of relatively large concentrations of TCE daughter products. In fact, *cis*-1,2-DCE (a daughter product of the reductive dehalogenation of TCE) and VC (a daughter product of the reductive dehalogenation of *cis*-1,2-DCE) are present more frequently and at higher concentrations than any other CAHs at the site. An elevated concentration of ethene was detected at monitoring point MP-5M (2.2 mg/L), indicating that degradation of VC is occurring at this location.

2.5.2 Electron Donor Reactions

Under aerobic conditions some CAHs can be utilized as the primary substrate (i.e., electron donor) in biologically mediated ORP 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 less oxidized CAHs can be utilized as electron donors in biologically mediated ORP reactions.

Aerobic degradation pathways for chlorinated ethenes are illustrated in Figure 18. Davis and Carpenter (1990) and McCarty and Semprini (1994) describe the aerobic oxidation of VC in groundwater. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is

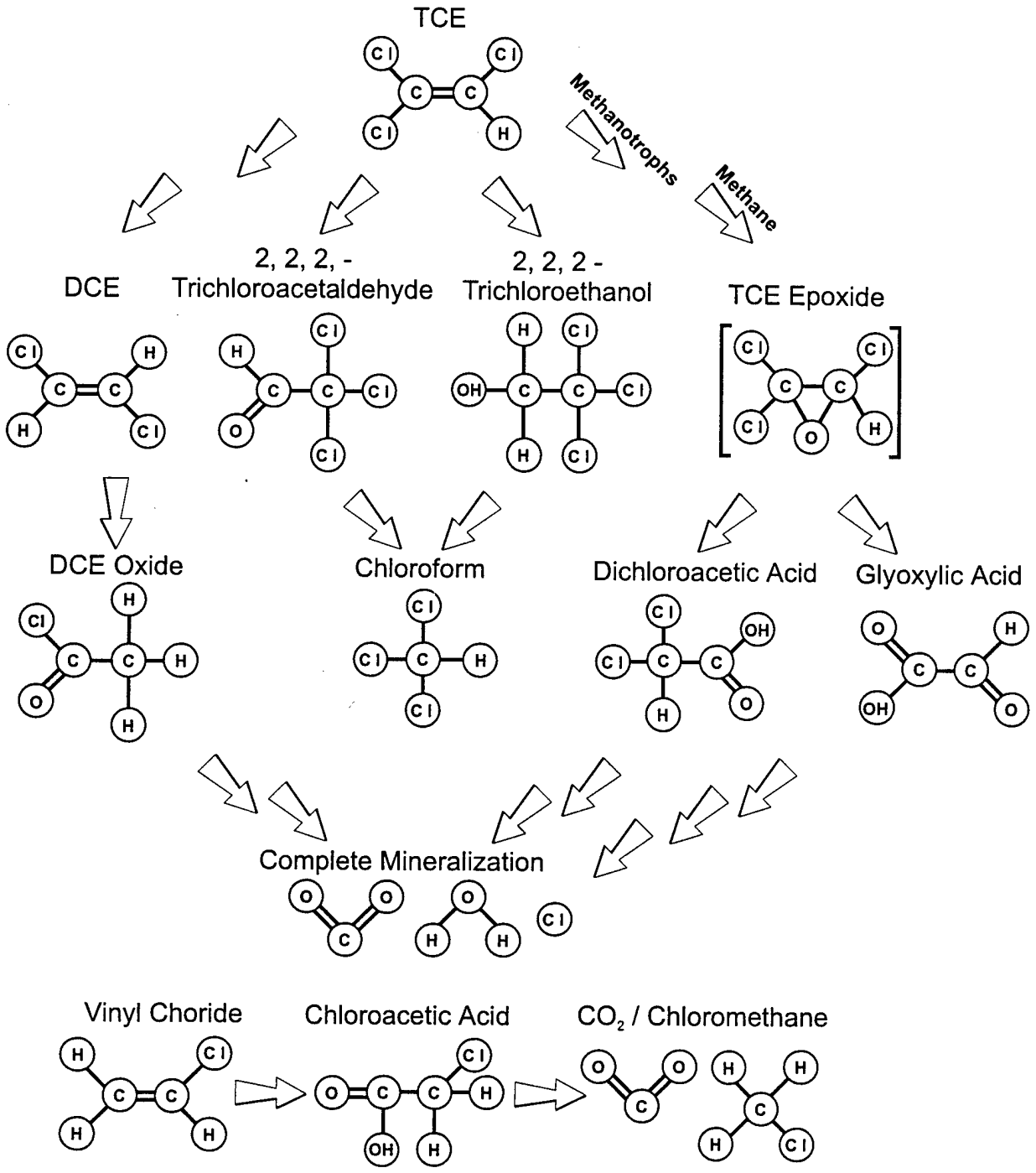

FIGURE 18

AEROBIC DEGRADATION PATHWAYS

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sufficient bioavailable iron (III). Klier *et al.* (1996) write that naturally occurring microorganisms in soil and groundwater are capable of biodegrading DCE by using this compound as a primary substrate (i.e. an electron donor). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic oxidation of VC and DCE or reduction of VC under iron-reducing conditions may be characterized by contaminant mass loss, a decreasing molar ratio of DCE and/or VC to other CAH compounds, and the presence of elevated carbon dioxide concentrations.

2.5.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated ORP 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. The TS report (Parsons ES, 1995) attributes the degradation of CAHs to cometabolism. However, there is no site-specific evidence to either support or disallow that dissolved TCE, *cis*-1,2-DCE, and VC concentrations are being reduced through cometabolic processes. However, there is strong evidence supporting the interpretation that CAHs at FPTA3 are degrading primarily through anaerobic reductive dehalogenation.

2.5.4 Summary of CAH Biodegradation at FPTA-3

Similar to the BTEX data, the CAH data indicate that there are residual sources of CAHS near Building 654 and in the Main Burn Pit. The areal extents of *cis*-1,2-DCE and VC at FPTA3 are similar to or less than the extent of the dissolved BTEX plume. Biodegradation of CAHs at FPTA3 occurs primarily by reductive dehalogenation in the reducing environment of the BTEX plume. The relative scarcity of TCE, combined with the abundance of *cis*-1,2-DCE and VC and the presence of ethene support this interpretation. VC, which degrades more slowly than DCE or TCE in anaerobic environments, appears to be accumulating.

Given an advective groundwater velocity of approximately 18.9 ft/yr and an estimated retardation coefficient for TCE of 1.55 (Parsons ES, 1995), the TCE plume could potentially have migrated approximately 460 feet in the 38 years between 1960, when fire training exercises began, and June 1998. Similarly, given an estimated retardation coefficient for VC of 1.01 (Parsons ES, 1995), the VC plume potentially could have migrated approximately 710 feet over the same time interval. The actual

reduced plume migration distances provide strong evidence supporting the occurrence of CAH biodegradation along the plume flowpath.

The available data suggest that the CAH plume has stabilized and is not migrating further downgradient. As with the Bioplume II model constructed for the BTEX plume, the analytical model used to predict the fate and transport of CAHs (Parsons ES, 1995) was based on conservative assumptions. This model predicted that the VC plume would migrate 125 feet beyond the November 1994 plume toe. It is possible the CAH plume has already reached its maximum downgradient migration distance. However, continued accumulation of VC could result in further migration of this compound. Therefore, continued long-term monitoring is necessary to ensure that natural attenuation continues to effectively limit plume migration.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Comparison of BTEX, electron acceptor, and biodegradation byproduct isopleth maps for FPTA3 provides strong qualitative evidence of the continued biodegradation of BTEX. Geochemical data indicate that fuel hydrocarbon biodegradation continues to occur at the site primarily via the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis.

Although natural attenuation appears to have stabilized the BTEX plume, the continued presence of residual fuel contamination in source area soils, combined with rising water levels, have caused dissolved BTEX concentrations beneath the main burn pit to persist and increase in some areas. Available data suggest that the easterly extent of the BTEX plume may be receding. However, this may be due at least in part to temporal changes in groundwater flow directions. Considering the low hydraulic gradient at the site, it is unlikely that the BTEX plume will migrate a significant distance in any direction from its current position. As BTEX concentrations in the source area decrease due to the continued effects of weathering, the plume is expected to recede back towards the source area. As a result of the low groundwater flow velocity at the site, the electron acceptor supply in the plume core is replenished slowly. This may limit the rate at which dissolved BTEX is degraded, and support the persistence of the BTEX plume.

The chlorinated solvent plume exhibits conditions of anaerobic reductive dehalogenation, where the primary source of biologically available organic carbon is anthropogenic fuel hydrocarbons (BTEX). Typical of these conditions is a decrease in concentrations of TCE, an increase in *cis*-1,2-DCE, and the accumulation of VC. These characteristics are observed at the FPTA-3 site. Most of the TCE has been effectively degraded to *cis*-1,2-DCE by reductive dehalogenation. With time, *cis*-1,2-DCE has been reduced to VC. Within the source area, VC is accumulating because the anaerobic degradation rate of VC is slow relative to TCE and *cis*-1,2-DCE. The presence of ethene at MP-5M suggests that VC also is degrading, at least within the highly reducing core of the BTEX plume.

Observed BTEX and CAH plume behavior have not exceeded the conservative predictions made using the numerical and analytical models developed in the TS report (Parsons ES, 1995). Given the rates of BTEX and CAH plume migration and

degradation predicted by the models, and considering that there are no impacted receptors at or downgradient from the site, natural attenuation, institutional controls, and continued LTM are recommended as the remedial option for BTEX- and CAH-impacted groundwater at the site. However, if shortening of the remedial time-frame becomes desirable, engineered source reduction (soil remediation) should be considered.

To ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, it is recommended that groundwater be sampled biennially (every other year) and analyzed for the parameters listed in Table 7.1 of the TS report. Biennial sampling should be sufficiently protective given the very low groundwater migration rate. Due to the apparent shift in groundwater flow direction, monitoring points MP-24D, MP-17S, MP-17D, MP-20S, MP-20D, and HF6-MW4 in particular should be added to the LTM plan. Because anaerobic conditions at the site are effectively limiting the migration of CAHs, remedial actions that induce aerobic conditions (e.g., air sparging) are not recommended.

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ATTACHMENT A

ANALYTICAL DATA

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 96\LB50

July 15, 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:

Please find attached the analytical results for Service Request SF-2-209 requesting the analysis of Offutt 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 the 74 groundwater samples, most in duplicate, in capped, 40 mL VOA autosampler vials July 1-5, 1996, and they were analyzed July 8-11, 1996. The samples were acquired and processed using the Millennium data system. A 5 place (1-1000 ppb) external standard curve was used to quantitate sample concentration 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

[redacted]ed 7/15/96 SF-2-209

DP-PT/GC-FID:P[redacted] AFB Analyses for Dr. Don Kampbell

Units [redacted] Analyst: 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	9.9	10.7	10.9	11.5	10.8	10.5	11.0	11.7	10.5	N/A
QC, OBSERVED, PPB	51.7	51.5	57.8	53.7	51.2	52.3	53.5	54.1	51.2	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
GC LAB BLANK, PPB	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	N/A
Trip Blank Offutt AFB	ND	1.2	ND	BLQ	1.0	BLQ	ND	ND	ND	3.9
MP-1S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-2	ND	1.0	ND	ND	ND	ND	ND	ND	ND	1.0
MP-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-4S	294	147	184	142	357	271	50	148	103	1920
MP-4D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-5S	105	23.0	61.3	21.2	18.1	28.3	31.9	98.8	73.2	820
MP-5D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-5M	49.3	18.4	9.8	7.1	4.0	30.7	BLQ	ND	BLQ	115
MP-6D	2.9	ND	ND	ND	ND	ND	ND	ND	ND	35.2
MP-6S	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
1 PPB	1.1	1.0	1.1	1.0	1.0	1.0	1.0	0.9	1.0	N/A
FPTA Rinseate	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
MP-8S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-8D	11.9	ND	53.1	25.0	2.4	2.8	3.5	78.1	131	1490
MP-9D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-17D	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
MP-17S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-23D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-23S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-1 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW12S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FPTA3-MW1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
100 PPB	107	107	107	107	99	104	107	105	103	N/A
FPTA3-MW2	BLQ	BLQ	54.0	15.3	BLQ	9.6	22.5	64.2	25.6	408
FPTA-MW3	BLQ	ND	ND	ND	ND	ND	ND	ND	1.0	16.6
FPTA3-MW6A	3.0	ND	BLQ	ND	ND	ND	ND	BLQ	BLQ	161
SW2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SW-2 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10 PPB	8.9	9.4	9.7	9.5	9.1	9.3	9.7	9.6	9.1	N/A
SW3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SW4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SW5	ND	1.1	ND	ND	ND	ND	ND	ND	ND	0.9
SW6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SW7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SW8 7/1/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	45.5	45.6	51.7	46.6	43.5	46.4	48.5	47.6	46.1	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
HF6-MW2D	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
HF6-MW-2D Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW2S	0.9	BLQ	ND	ND	ND	ND	ND	ND	ND	7.7

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

Printed 7/15/96 SF-2-209

DP-PT/GC-FID:PID Offut AFB Analyses for Dr. Don Kampbell

Units = ng/mL Analyst: 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
MW 8D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 8I	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 8I Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 8S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 9I	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 9S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 10S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 11S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HF6-MW4	9.6	BLQ	64.8	23.6	30.4	37.0	38.1	165	101	914
HF6-MW4S	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
1 PPB	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	N/A
B301-MW 1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
B301-MW 1 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
B301-MW 6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
B301-MW 13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-17I	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
MW 349-1	32000	39700	4200	2940	6880	4490	524	2060	592	94200
MW 349-2	44400	42600	3780	2850	6600	4390	518	2100	622	98000
MW 349-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 349-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 349-5	BLQ	ND	ND	ND	BLQ	ND	BLQ	ND	ND	BLQ
MW 349-6	46300	44300	4410	2870	6740	4540	419	1880	565	108400
MW 349-7	27300	34000	2960	2690	6490	4350	448	2050	637	79200
MW 349-8	9560	24000	3970	2620	6220	4180	499	2150	684	55100
MW 349-9	ND	ND	ND	ND	1.2	1.0	1.1	1.1	1.1	349
MW 349-10	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
MW 349-11	BLQ	ND	ND	ND	1.6	1.3	1.4	1.5	1.4	17.4
10 PPB	9.0	9.7	10.3	10.2	9.8	9.7	10.6	10.3	9.7	N/A
MW 349-12	ND	ND	ND	ND	BLQ	BLQ	BLQ	0.9	BLQ	19.4
MW 349-13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 349-14	ND	ND	ND	ND	1.0	BLQ	1.0	1.0	1.1	9.7
MW 2D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 7S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 7I	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 7D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 7D Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW 16	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
MW 15	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
MW 18	ND	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
QC, OBSERVED, PPB	47.4	47.5	53.9	48.6	45.6	48.3	50.3	49.4	48.1	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
Boiler Rinseate	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
MW 14I	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
SW-8 7/5/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SW-8 7/5/96 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MP-2M	622	BLQ	952	471	1092	9.5	32.4	146	215	3670
MP-2D	161	BLQ	2.5	1.7	1.1	4.6	BLQ	1.2	0.9	294
100 PP	96.7	98.9	102	101	93.9	98.8	107	104	101	N/A

ND = Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

MANTECH

Ref: 96JAD43

August 13, 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-2-209, headspace GC/MS analysis of 60 Offutt water samples for chlorinated volatile organics was completed. The samples were received on July 1 & 5, 1996 and analyzed on August 7-9, 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

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley JS
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.[redacted]# SF-2-209 from Offutt.

Concentration = ppb

Compound	Trip Blank	FTA RINSEATE	MP1S	MP2S	MP3	MP4	MP4D	MP4S	MP5D	MP5M
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	78.3	ND	1050
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	---	---	ND	4.5	ND	8.9
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	---	ND	561
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	3.4	21.0	---	417	1.1	1.1
CHLOROFORM	ND	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
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	1.8	ND	32.1	1.0	ND	---	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Compound	MP-5S	MP-5S Lab Dup	MP-5S Field Dup 1/5 Dil	MP-6D	MP-6S	MP-8D	MP-8D Field Dup	MP-8S	MP-9D	MP-17D
VINYL CHLORIDE	48.1	46.7	44.0	34.6	3.4	ND	ND	ND	ND	15.5
1,1-DICHLOROETHENE	5.3	5.3	5.0	ND	---	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	12.0	12.0	13.0	1.8	2.1	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	993	1030	941	12.9	22.8	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	*****	*****	4880	83.5	132	ND	ND	ND	ND	ND
CHLOROFORM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	21.5	22.0	13.0	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	261	240	301	6.8	117	ND	ND	ND	ND	ND
TRICHLOROETHENE	51.7	51.3	56.0	ND	---	ND	---	ND	ND	ND
TETRACHLOROETHENE	---	---	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Compound	MP-17S	MP-23D	MP-23S	TW-1	TW-1 Field Dup	HF6-MW-2D	HF6-MW-2D Lab Dup	HF6-MW-4	mp HF6-MW-4S	MW-8D
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	---	---	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	9.4	10.3	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	48.3	49.8	ND	ND	ND	ND	ND
CHLOROFORM	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	1.6
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	438	444	ND	ND	ND	ND	1.6
TETRACHLOROETHENE	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-2-209 from Offutt.

Concentration = ppb

Compound	MW-8I	MW-8S	MW-9I	MW-9S	MW-9S Field Dup	MW-10S	MW-11S	MW12S	MW-12S Lab Dup	FTPA3 -MW1
VINYL CHLORIDE	ND	ND	ND	1.0	1.1	ND	ND	1.3	1.3	ND
1,1-DICHLOROETHENE	6.7	ND	ND	1.4	1.5	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	2.1	2.3	ND	7.9	1.9	2.0	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	---	2.7	21.2	21.7	---	69.4	6.6	7.0	ND
CHLOROFORM	---	---	ND	---	---	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	10.0	1.1	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	201	9.0	---	372	383	51.4	15.2	4.9	5.2	ND
TETRACHLOROETHENE	---	ND	ND	---	---	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	FPTA3 -MW2	FPTA3 -MW3	FPTA -MW6A	SW2	SW3	SW4	SW5	SW6	SW7	SW7 Lab Dup
VINYL CHLORIDE	ND	8.2	1.6	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	---	ND	ND
T-1,2-DICHLOROETHENE	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	---	1.6	ND	---	ND	ND	3.7	ND	ND
CHLOROFORM	ND	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	ND	ND	---	ND	---	---	74.9	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	SW8 1/5 Dil	SW8 Field Dup	B301-MW1	B301-MW6	B301-MW13	MW-17I	SW-8	MP2M	MP2D	MP2D Lab Dup
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	1.9	6.2	6.1
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
C-1,2-DICHLOROETHENE	ND	ND	9.5	ND	ND	ND	---	---	2.9	2.9
CHLOROFORM	ND	ND	1.6	---	---	---	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	9.7	2.3	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	8.0	7.1	1.4	ND	9.2	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	[redacted]	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	[redacted]	ND	ND	ND	ND	ND	ND

Table 3. Quantitation Report for S.R. # SF-2-209 from Offutt.

Concentration = ppb

Compound	MW-2S	MW-2D	MW-7S	MW-7I	MW-7I Field Dup 1/5 Dil	MW-7D	MW-16	MW15	MW-18	BAILER RINSEATE
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	1.8	---	ND	ND	ND	28.6	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	4.8	5.0	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	1.0	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	1230	1250	ND	ND	ND	4.0	ND
CHLOROFORM	---	ND	3.8	2.9	---	ND	2.4	34.6	8.0	---
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	---	ND	ND	ND	ND	1.6	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	56.6	*****	17,500	---	---	2.2	3610	ND
TETRACHLOROETHENE	ND	ND	1.5	---	ND	ND	ND	ND	1.9	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	MW14I	MW14I Lab Dup	QC0807A 20 ppb	QC0807B 200 ppb	QC0807C 20 ppb	QC0807D 200 ppb	QC0807E 20 ppb	QC0807F 200 ppb	QC0807G 20 ppb	QC0807H 200 ppb
VINYL CHLORIDE	ND	ND	22.2	206	21.7	197	20.8	204	21.9	214
1,1-DICHLOROETHENE	ND	ND	23.8	224	22.0	222	22.1	228	22.7	229
T-1,2-DICHLOROETHENE	ND	ND	23.3	224	23.1	222	22.1	219	22.4	219
1,1-DICHLOROETHANE	ND	ND	22.5	201	22.7	197	22.9	191	22.6	194
C-1,2-DICHLOROETHENE	11.5	10.5	21.2	223	23.2	222	22.4	216	21.9	215
CHLOROFORM	4.0	4.0	21.2	215	23.0	217	22.2	205	21.8	210
1,1,1-TRICHLOROETHANE	ND	ND	22.6	207	20.6	205	20.3	212	21.8	217
CARBON TETRACHLORIDE	2.9	2.7	22.4	198	19.7	193	19.8	203	21.4	205
1,2-DICHLOROETHANE	ND	ND	21.7	223	23.2	216	21.0	204	21.6	203
TRICHLOROETHENE	2940	3020	19.8	184	18.4	187	19.1	189	19.1	188
TETRACHLOROETHENE	1.5	1.5	22.0	201	19.4	198	19.4	199	20.4	199
CHLOROBENZENE	ND	ND	21.2	213	21.3	208	21.5	204	21.8	208

	QC0807I 20 ppb	QC0807J 200 ppb	QC0807K 20 ppb	QC0807L 200 ppb	QC0809A 20 ppb	BL0807A
VINYL CHLORIDE	22.2	200	20.4	208	20.3	ND
1,1-DICHLOROETHENE	23.0	222	22.6	237	21.7	ND
T-1,2-DICHLOROETHENE	22.5	218	22.4	222	22.5	ND
1,1-DICHLOROETHANE	22.9	194	22.1	196	22.2	ND
C-1,2-DICHLOROETHENE	22.9	209	21.2	216	22.3	ND
CHLOROFORM	22.5	204	20.5	204	21.6	ND
1,1,1-TRICHLOROETHANE	21.9	210	21.8	215	20.3	ND
CARBON TETRACHLORIDE	21.2	202	21.1	209	19.3	ND
1,2-DICHLOROETHANE	22.4	201	20.5	204	22.6	ND
TRICHLOROETHENE	18.9	183	18.1	188	17.9	ND
TETRACHLOROETHENE	20.2	193	19.7	197	19.5	ND
CHLOROBENZENE	20.8	202	20.4	200	20.1	ND

ND = None Detected --- = Below Calibration Limit (1.0 ppb) QC = Quality Control Std. BL = Blank Dil = Dilution ***** = Above Calibration Limit (4000 ppb)

MANTECH

Ref: 96-JH67/vg

July 25, 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 1, 2, and 5, 1996 from Offutt AFB under Service Request #SF-2-209. 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 JB
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

SR# SF-2-209
OFFUTT AFB

ANALYSIS PERFORMED 7-2-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
B301-MW1	BLQ	ND
B301-MW6	BLQ	ND
B301-MW13	BLQ	ND
MW349-7	BLQ	BLQ
TW1	BLQ	ND
" LAB DUP	BLQ	ND
TW1 FIELD DUP	BLQ	ND

ANALYSIS PERFORMED 7-3-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MP-1S	BLQ	ND
MP-2S	0.001	ND
MP-3	12.29	ND
MP-4	0.004	ND
" FIELD UP	0.005	ND
MP-4D	1.85	BLQ
MP-4S	19.40	0.005
MP-17D	2.22	0.007
MP-17S	0.060	ND
" LAB DUP	0.053	ND
MW-2D	0.029	ND
MW-2S	BLQ	ND
MW-7D	BLQ	ND
MW-7I	0.001	ND
MW-7S	BLQ	ND
MW-8D	0.002	BLQ
" FIELD DUP	0.001	BLQ

ANALYSIS PERFORMED 7-8-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MW-8I	BLQ	ND
MW-8S	BLQ	ND
MW-9I	0.130	ND
MW-9S	0.003	ND
" FIELD DUP	0.003	ND
MW-10S	BLQ	ND
MW-11S	0.002	ND
MW-12S	0.084	ND
MW-17S	BLQ	ND
MW-~~18~~15 LM 3/10/97	0.001	ND
" LAB DUP	BLQ	ND
MW-14I	0.184	BLQ
MW-16	BLQ	ND
MW-18	BLQ	ND
MW349-1	0.001	BLQ
MW349-2	0.008	BLQ
" FIELD DUP	0.007	BLQ
MW349-3	BLQ	ND
MW349-4	BLQ	ND
MW349-5	BLQ	ND
MW349-6	BLQ	ND
MW349-8	0.002	BLQ
" LAB DUP	0.002	BLQ

ANALYSIS PERFORMED 7-11-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
✓MP-2D	6.91	0.006
✓MP-2M	18.74	BLQ
MW 349-9	0.001	ND
MW 349-10	0.001	ND
" FIELD DUP	BLQ	ND
MW 349-11	BLQ	ND
MW 349-12	BLQ	ND
MW 349-13	BLQ	ND
MW 349-14	BLQ	ND
✓HF6-MW2D	0.015	ND
" LAB DUP	0.012	ND
✓HF6-MW4	6.02	BLQ
✓MP HF6-MW4S	0.220	BLQ
✓FTPA-MW1	0.008	ND
✓FPTA-MW2	0.018	ND
✓FPTA-MW3	6.83	0.012
" FIELD DUP	7.11	0.011

ANALYSIS PERFORMED 7-12-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
FPTA3-MW6A	1.16	BLQ
MP-5D	0.012	ND
MP-5M	25.35	0.766
" LAB DUP	24.33	0.741
MP-5S	0.290	0.005
MP-6D	3.92	0.011
" FIELD DUP	4.29	0.011

ANALYSIS PERFORMED 7-15-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
MP-6S	0.326	BLQ
MP-8D	0.807	ND
" FIELD DUP	0.892	ND
MP-8S	0.029	ND
MP-9D	0.006	ND
MP-23D	0.015	ND
MP-23S	0.006	ND
" LAB DUP	0.005	ND
10 PPM CH4	9.97	NA
100 PPM CH4	100.12	NA
1000 PPM CH4	999.81	NA
1% CH4	1.00	NA
10% CH4	9.20	NA
20% CH4	20.35	NA
10 PPM C2H4	NA	10.24
100 PPM C2H4	NA	99.98
1000 PPM C2H4	NA	999.83
1% C2H4	NA	1.00

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-SH71/vg

July 16, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 63 Offutt liquids submitted July 3, 1996 under Service Request #SF-2-209. Sample analysis was begun July 3, 1996 and completed July 15, 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 JS
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

SAMPLE	MG/L TOC
MW349-13	2.54
MW349-14	1.31
MW349-14 DUP	1.26
✓FTPA3-MW1	5.04
✓FTPA3-MW2	2.67
✓FTPA3-MW3	11.9
FTPA3-MW3 DUP	12.0
✓ HFG ~~FTPA3-M26IA~~ MW6A	67.2
✓ HFG ~~FTPA3~~-MW2D	5.50
FTPA3-MW2D DUP	5.11
✓ HFG ~~FTPA~~-MW4	52.6
FTPA-MW4 DUP	53.0
✓ MP6-MW4S	34.3
✓MP-23-~~8~~D	2.03
✓MP-23-S	3.76
✓MP-6S	11.0
✓MP-8D	62.9
✓MP-8S	25.2
✓MP-9D	5.57
TW1	3.72
TW1 DUP	3.99
WPO35-II STD	39.7

WPO35-II STD t.v.=40.1

OFFUTT AIR FORCE BASE
FIELD DATA

Sample	Date	Redox mv	pH Units	Cond	Total Alkalinity mg/l $CaCo_3$	Ferrous Iron mg/l	Hydrogen Sulf[illegible] mg
MW-9-S	6-27-96	290	6.8	648	274	<.05	
MW-9-I	6-27-96	-98	6.9	1169	487	9.2	<.1
MW-17-I	6-27-96	154	7.1	649	317	<.05	
MW-8-S	6-27-96	177	6.9	962	413	<.05	
MW-8-I	6-27-96	181	7.2	634	310	<.05	
MW-8-D	6-27-96	60	7.2	675	375	.48	
MW-10-S	6-27-96	171	6.8	743	287	<.05	
MW-12-S	6-27-96	181	7.0	743	363	<.05	
MP-3	6-28-96	-40	6.9	742	398	4.4	<.1
MW-11-S	6-28-96	-70	6.9	702	321	5.3	<.1
MP-4	6-28-96	50	6.9	609	308	1.0	
TW-1	6-28-96	145	6.9	730	305	<.05	
MP-1-S	6-28-96	158	6.8	810	339	<.05	
MP-2-S	6-28-96	163	7.2	664	320	<.05	
B-301-MW-3	6-28-96	185	7.2	631	341	<.05	
B-301-MW-1	6-28-96	191	7.0	707	359	<.05	
B-301-MW-6	6-29-96	242	7.3	883	197	<.05	
MW-2-S	6-29-96	86	7.3	630	337	<.05	
MW-2-D	6-29-96	90	7.3	674	346	1.0	
MW-7-S	6-29-96	220	7.2	1034	488	<.05	
MW-7-I	6-29-96	193	8.2	771	243	<.05	
MW-7-D	6-29-96	243	7.3	640	358	<.05	
MW-14-I	6-29-96	300	7.4	850	346	<.05	
MW-1-S	7-1-96	302	8.2	446	129	<.05	
MW-16	7-1-96	311	8.0	639	194	<.05	
MW-18	7-1-96	312	8.1	668	207	<.05	

OFFUTT AIR FORCE BASE
FIELD DATA

Sample	Date	Redox mv	pH units	Cond	Total Alkalinity mg/l $CaCo_3$	Ferrous Iron mg/l	Hydrogen Sulfide mg/l
HF6-MW4	6-25-96	-133	7.0	1239	584	9.3	<.1
MP6-M4S	6-25-96	53	6.8	1690	752	<.05	-
MP349-8	6-26-96	255	7.5	749	337	<.05	-
MP6S	6-26-96	220	6.8	1490	537	<.05	-
MP6D	6-26-96	-80	7.0	1961	605	19.8	<.1
HF6 MW2D	6-26-96	-65	7.1	1000	499	3.4	<.1
MW349-1	6-26-96	66	6.8	164	80	<.05	-
MW349-2	6-26-96	118	7.0	1370	536	<.05	-
MP5M	6-26-96	-135	7.2	1473	528	15.2	<.1
MP5D	6-26-96	-120	7.2	1015	507	9.1	<.1
MP5S	6-26-96	-60	7.1	2660	832	20.0	-
MW349-6	6-26-96	65	7.4	1177	427	<.05	-
[illegible]4S	6-26-96	-78	6.9	1136	585	10.3	<.1
MP4D	6-26-96	-113	7.0	1253	684	7.4	<.1
MW349-7	6-26-96	109	7.6	815	378	<.05	-
MP17S	6-26-96	120	6.7	2320	900	<.05	-
MP17D	6-26-96	119	6.9	1281	602	22.5	-

OFFUTT AIR FORCE BASE FIELD DATA							
Sample	Date	Redox mv	pH Units	Cond	Total Alkalinity mg/l$CaCo_3$	Ferrous Iron mg/l	Hydrogen Sulfi[redacted] mg/[redacted]
MW-349-3	6-24-96	240	7.3	731	165	<.05	-
MW-349-4	6-24-96	244	7.5	658	167	<.05	-
MW-349-5	6-24-96	240	7.4	1037	163	<.05	-
MW-349-10	6-24-96	250	7.3	774	308	<.05	-
MP-9D	6-25-96	-95	7.2	783	391	4.5	<.1
FPTA3-MW2	6-25-96	-80	6.9	877	461	6.9	-
MW-349-9	6-25-96	130	7.0	458	177	<.05	-
MW-349-11	6-25-96	136	7.4	668	311	<.05	-
FPTA3-MW-1	6-25-96	-70	7.1	1008	501	5.3	<.1
FPTA3-MW3	6-25-96	-100	7.0	1065	568	10.1	<.1
FPTA3-MW6A	6-25-96	-124	7.1	1227	670	6.6	<.1
MW-349-12	6-25-96	25	7.4	620	281	<.05	-
MP-23S	6-25-96	165	6.9	926	448	<.05	-
MP-23D	6-25-96	-122	7.0	922	485	8.8	<.1
MW-349-14	6-25-96	96	7.9	651	343	<.05	-
MP-8S	6-25-96	157	7.1	1070	562	<.05	-
MP-8D	6-25-96	-140	7.2	890	485	6.4	-
MW-349-13	6-25-96	70	7.5	560	326	<.05	-

MANTECH TECHNOLOGY

Ref: 96-DF46

July 17, 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-2-209, GC/MS analysis for phenols and aliphatic/aromatic acids was done on four water samples from Offutt AFB. These samples were labeled: MP-4, MP-5S, MP-17D, and B301-MW7I. The samples were received on July 1 - 2, 1996. Derivatization of the samples was done by Amy Zhao on July 2 and 9, 1996. The extract was analyzed by GC/MS on July 10 - 11, 1996. RSKERL SOP 177 was used for the extraction, derivatization and GC/MS analysis of the samples.

During the methylene chloride extraction, severe emulsions occurred in two of the samples. We allowed some of the methylene chloride to settle and used 200 μl of the extract for derivatization. The remaining extract and emulsion was then dried by adding 35 g of anhydrous sodium sulfate. The methylene chloride layer was sampled again and was also derivatized.

Table I provides the concentrations of the phenols and aliphatic/aromatic acids found in water samples from the Offutt AFB. Included are concentrations for the methylene chloride extracts sampled below the emulsion and after the emulsion was dried. For sample MP-5S significant increases in phenols were found in the Na_2SO_4 dried emulsion/extract. Derivative and extraction blanks, a 50 ppb extraction recovery and a 100 ppb check standard are also included in the table.

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

Sincerely,

Dennis D. Fine

Dennis D. Fine

xc: J. Seeley
G. Smith
R. Cosby
J. Wilson
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 Offutt AFB (Service Request SF-2-209)

		Concentration ppb						
		MP-4	MP-4	MP-5S	MP-5S	MP-17D	B301-MW7I	Std. Blank
1	PROPANOIC ACID - PFB	***	8	10	12	N.F.	N.F.	***
2	2-METHYLPROPANOIC ACID - PFB	***	***	17	14	***	***	***
	TRIMETHYL ACETIC ACID - PFB	***	***	***	5	***	***	***
	BUTYRIC ACID - PFB	***	N.F.	14	129	***	***	***
5	2-METHYLBUTYRIC ACID - PFB	***	***	19	16	***	***	N.F.
6	3-METHYLBUTYRIC ACID - PFB	***	***	96	76	***	N.F.	***
7	3,3-DIMETHYLBUTYRIC ACID - PFB	N.F.	N.F.	68	55	N.F.	N.F.	N.F.
8	PENTANOIC ACID - PFB	***	***	10	9	***	***	***
9	2,3-DIMETHYLBUTYRIC ACID - PFB	N.F.	N.F.	8	7	N.F.	N.F.	N.F.
10	2-ETHYLBUTYRIC ACID - PFB	N.F.	N.F.	N.F.	***	N.F.	N.F.	N.F.
11	2-METHYLPENTANOIC ACID - PFB	N.F.	N.F.	***	***	N.F.	N.F.	N.F.
12	3-METHYLPENTANOIC ACID - PFB	N.F.	N.F.	5	5	N.F.	N.F.	N.F.
13	4-METHYLPENTANOIC ACID - PFB	N.F.	N.F.	***	***	N.F.	N.F.	N.F.
14	HEXANOIC ACID - PFB	14	17	23	21	***	45	***
15	2-METHYLHEXANOIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
16	PHENOL - PFB	N.F.	7	N.F.	7	N.F.	N.F.	***
17	CYCLOPENTANECARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	***	N.F.	N.F.	N.F.
18	5-METHYLHEXANOIC ACID - PFB	***	***	***	***	***	N.F.	N.F.
19	o-CRESOL - PFB	N.F.	N.F.	***	30	N.F.	N.F.	N.F.
20	2-ETHYLHEXANOIC ACID - PFB	N.F.	***	N.F.	71	12	***	***
21	HEPTANOIC ACID - PFB	9	14	20	21	***	18	N.F.
22	m-CRESOL - PFB	N.F.	N.F.	***	101	N.F.	N.F.	N.F.
23	p-CRESOL - PFB	N.F.	N.F.	N.F.	22	N.F.	N.F.	N.F.
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
25	o-ETHYLPHENOL - PFB	N.F.	N.F.	***	43	N.F.	N.F.	N.F.
26	CYCLOPENTANEACETIC ACID - PFB	N.F.	N.F.	***	***	N.F.	N.F.	N.F.
27	2,6-DIMETHYLPHENOL - PFB	N.F.	N.F.	***	N.F.	N.F.	N.F.	N.F.
28	2,5-DIMETHYLPHENOL - PFB	N.F.	N.F.	5	283	N.F.	N.F.	N.F.
29	CYCLOHEXANECARBOXYLIC ACID - PFB	N.F.	***	***	***	N.F.	N.F.	***
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
	2,4-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	28	N.F.	N.F.	N.F.
	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL - PFB	N.F.	N.F.	5	235	N.F.	N.F.	N.F.
33	OCTANOIC ACID - PFB	N.F.	32	18	22	***	39	N.F.
34	2,3-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	70	N.F.	N.F.	N.F.
35	p-ETHYLPHENOL - PFB	N.F.	N.F.	N.F.	11	N.F.	N.F.	N.F.
36	BENZOIC ACID - PFB	***	7	5	10	***	32	18
37	3,4-DIMETHYLPHENOL - PFB	N.F.	N.F.	N.F.	5	N.F.	N.F.	N.F.
38	m-METHYLBENZOIC ACID - PFB	N.F.	N.F.	74	67	N.F.	N.F.	***
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID - PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
40	CYCLOHEXANEACETIC ACID - PFB	N.F.	N.F.	***	***	N.F.	N.F.	N.F.
41	2-PHENYLPROPANOIC ACID - PFB	N.F.	N.F.	***	***	N.F.	N.F.	***
42	o-METHYLBENZOIC ACID - PFB	N.F.	N.F.	29	24	N.F.	N.F.	***
43	PHENYLACETIC ACID - PFB	N.F.	N.F.	11	10	N.F.	N.F.	***
44	m-TOLYLACETIC ACID - PFB	N.F.	N.F.	74	73	N.F.	N.F.	N.F.
45	o-TOLYLACETIC ACID - PFB	N.F.	N.F.	122	111	N.F.	N.F.	***
46	2,6-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	***	***	N.F.	N.F.	***
47	p-TOLYLACETIC ACID - PFB	N.F.	N.F.	67	64	N.F.	N.F.	N.F.
48	p-METHYLBENZOIC ACID - PFB	N.F.	***	16	13	***	N.F.	N.F.
49	3-PHENYLPROPANOIC ACID - PFB	N.F.	N.F.	***	N.F.	N.F.	N.F.	N.F.
50	2,5-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	10	12	N.F.	N.F.	N.F.
51	DECANOIC ACID - PFB	N.F.	6	8	N.F.	N.F.	***	***
52	2,4-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	17	16	N.F.	N.F.	***
53	3,5-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	8	7	N.F.	N.F.	N.F.
54	2,3-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	13	13	N.F.	N.F.	N.F.
55	4-ETHYLBENZOIC ACID - PFB	N.F.	N.F.	10	11	N.F.	N.F.	N.F.
56	2,4,6-TRIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	51	50	N.F.	N.F.	N.F.
57	3,4-DIMETHYLBENZOIC ACID - PFB	N.F.	N.F.	15	15	N.F.	N.F.	N.F.
	2,4,5-TRIMETHYLBENZOIC ACID - PFB	***	N.F.	9	12	N.F.	N.F.	N.F.

*** indicates concentration of extract was below lowest calibration standard (5 ppb).
N.F. indicates not found.

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids from Water Samples from Offutt AFB (Service Request SF-2-209)

		Concentration ppb		
		Extraction Blank	50 ppb Extraction Recovery	100 ppb Check Standard
1	PROPANOIC ACID – PFB	***	***	117
2	2-METHYLPROPANOIC ACID – PFB	***	15	114
3	TRIMETHYL ACETIC ACID – PFB	***	40	112
4	BUTYRIC ACID – PFB	***	14	108
5	2-METHYLBUTYRIC ACID – PFB	***	38	108
6	3-METHYLBUTYRIC ACID – PFB	***	34	104
7	3,3-DIMETHYLBUTYRIC ACID – PFB	N.F.	51	103
8	PENTANOIC ACID – PFB	***	37	103
9	2,3-DIMETHYLBUTYRIC ACID – PFB	N.F.	51	103
10	2-ETHYLBUTYRIC ACID – PFB	N.F.	48	105
11	2-METHYLPENTANOIC ACID – PFB	N.F.	50	104
12	3-METHYLPENTANOIC ACID – PFB	N.F.	51	101
13	4-METHYLPENTANOIC ACID – PFB	N.F.	51	96
14	HEXANOIC ACID – PFB	***	53	96
15	2-METHYLHEXANOIC ACID – PFB	N.F.	52	95
16	PHENOL – PFB	***	30	83
17	CYCLOPENTANECARBOXYLIC ACID – PFB	N.F.	46	123
18	5-METHYLHEXANOIC ACID – PFB	***	63	103
19	o-CRESOL – PFB	N.F.	39	81
20	2-ETHYLHEXANOIC ACID – PFB	***	48	94
21	HEPTANOIC ACID – PFB	***	54	92
22	m-CRESOL – PFB	N.F.	36	75
23	p-CRESOL – PFB	N.F.	41	77
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID – PFB	***	40	103
25	o-ETHYLPHENOL – PFB	N.F.	41	79
26	CYCLOPENTANEACETIC ACID – PFB	N.F.	50	93
27	2,6-DIMETHYLPHENOL – PFB	N.F.	40	75
28	2,5-DIMETHYLPHENOL – PFB	N.F.	42	71
29	CYCLOHEXANECARBOXYLIC ACID – PFB	N.F.	50	97
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID – PFB	N.F.	50	99
31	2,4-DIMETHYLPHENOL – PFB	N.F.	40	78
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL – PFB	N.F.	39	74
33	OCTANOIC ACID – PFB	***	55	86
34	2,3-DIMETHYLPHENOL – PFB	N.F.	44	77
35	p-ETHYLPHENOL – PFB	N.F.	41	67
36	BENZOIC ACID – PFB	6	55	92
37	3,4-DIMETHYLPHENOL – PFB	N.F.	42	72
38	m-METHYLBENZOIC ACID – PFB	N.F.	49	90
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID – PFB	N.F.	52	96
40	CYCLOHEXANEACETIC ACID – PFB	N.F.	51	95
41	2-PHENYLPROPANOIC ACID – PFB	N.F.	56	92
42	o-METHYLBENZOIC ACID – PFB	N.F.	55	95
43	PHENYLACETIC ACID – PFB	N.F.	58	88
44	m-TOLYLACETIC ACID – PFB	N.F.	54	87
45	o-TOLYLACETIC ACID – PFB	N.F.	71	96
46	2,6-DIMETHYLBENZOIC ACID – PFB	N.F.	48	78
47	p-TOLYLACETIC ACID – PFB	N.F.	49	77
48	p-METHYLBENZOIC ACID – PFB	N.F.	58	90
49	3-PHENYLPROPANOIC ACID – PFB	N.F.	53	87
50	2,5-DIMETHYLBENZOIC ACID – PFB	N.F.	53	77
51	DECANOIC ACID – PFB	***	55	79
52	2,4-DIMETHYLBENZOIC ACID – PFB	N.F.	54	81
53	3,5-DIMETHYLBENZOIC ACID – PFB	N.F.	59	87
54	2,3-DIMETHYLBENZOIC ACID – PFB	N.F.	59	83
55	4-ETHYLBENZOIC ACID – PFB	N.F.	62	81
56	2,4,6-TRIMETHYLBENZOIC ACID – PFB	N.F.	61	84
57	3,4-DIMETHYLBENZOIC ACID – PFB	N.F.	56	80
58	2,4,5-TRIMETHYLBENZOIC ACID – PFB	N.F.	56	79

*** indicates concentration of extract was below lowest calibration standard (5 ppb).
N.F. indicates not found.

MANTECH

Ref: 96-JRD31/vg

July 8, 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 18 samples submitted to MERSC as part of Service Request #SF-2-209. The samples were analyzed for phenols and manganese using chemetrics field test kits. Quality assurance measures performed on this set of samples included duplicates and blanks.

If you have any questions concerning these results, please feel free to contact me.

Sincerely,

Justin Daniel

Justin Daniel

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

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 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)
TW1	34.8	39.1	1.09	.14
MP1S	39.7	41.9	2.22	<.05
✓MP2S	9.30	25.9	6.92	<.05
MP3	15.3	4.61	<.05	2.96
MP4	19.8	29.9	<.05	<.05
✓MP4D	16.5	2.97	<.05	2.44
MP4D Dup	16.6	2.97	----	----
✓MP4S	12.7	2.10	<.05	1.32
B301-MW1	8.42	28.6	4.46	<.05
✓MP-17D	59.9	32.7	<.05	1.34
✓MP-17S	60.3	32.8	1.16	.19
MW-2D	5.11	13.3	.10	<.05
MW-2D Dup	5.08	13.3	----	----
MW-2S	8.98	4.45	1.51	<.05
MW-7D	1.68	9.47	1.63	<.05
MW-7I	47.6	55.4	12.2	<.05
MW-7S	20.7	39.8	6.68	<.05
MW-8D	2.80	16.8	.27	<.05
MW-8I	4.70	23.5	2.01	<.05
MW-8S	13.8	76.7	8.80	<.05
MW-8S Dup	----	----	8.86	<.05
MW-9I	76.2	45.6	.17	6.11
MW-9S	13.5	30.1	1.06	<.05
MW-9S Dup	13.4	29.8	----	----
MW-10S	43.0	38.3	3.20	<.05
MW-11S	20.6	45.6	<.05	.13
MW-12S	13.4	32.0	<.05	<.05
B301-MW-6	65.7	81.7	23.2	<.05
B301-MW-13	7.22	6.46	1.91	<.05
B301-MW-13 Dup	7.23	6.52	1.91	<.05
MW-17I	10.6	18.0	5.14	<.05
MW349-7	24.2	42.4	<.05	<.05
MW349-3	85.4	85.4	1.59	<.05
MW349-4	53.9	75.5	1.64	<.05
MW349-5	168	70.0	2.21	<.05
MW359-10	6.55	68.7	7.67	<.05
✓MP-9D	3.56	31.4	<.05	.45
✓FPTA-3-MW-2	1.10	21.1	.10	.22
FPTA-3-MW-2 Dup	1.06	20.9	.12	.26
MW-349-9	18.0	13.8	4.85	<.05
MW-349-11	4.75	15.2	4.87	<.05

MANTECH

Ref: 96-TH41/vg
96-MW74/vg
July 12, 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 63 Offutt AFB samples submitted to MERSC as part of Service Request #SF-2-209. The samples were received July 7 and 8, 1996 and analyzed immediately. The methods used for analysis were EPA Methods 353.1 for NO_2 and NO_3, 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,

Tim Hensley

Mark White

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

Sample	mg/l Cl^-	mg/l SO_4^{-2}	mg/l $NO^-_2+NO^-_3$ (N)	mg/l NH_3 (N)
✓FTPA-3-MW-1	5.14	47.9	.11	1.00
✓FPTA-3-MW-3	27.0	<.1	.10	1.00
✓FPTA-3-MW-6A	7.56	6.77	<.05	1.39
FPTA-3-MW-6A Dup	7.81	6.73	<.05	1.38
MW-349-12	25.5	10.3	7.33	<.05
✓MP-23-S	26.0	27.4	<.05	<.05
✓MP-23-D	9.51	23.7	<.05	1.34
MW-349-14	14.5	5.76	1.68	<.05
MW18	28.3	70.1	7.11	<.05
MW15	21.4	61.5	1.84	<.05
MW16	45.5	57.0	6.14	<.05
B301-MW14I	21.6	39.6	6.91	<.05
B301-MW14I Dup	----	----	6.91	<.05
MW349-13	4.00	5.03	1.54	<.05
✓MP-8S	9.40	22.6	<.05	<.05
✓MP-8D	6.88	.45	<.05	.49
✓~~HFG-4~~ HFC-MW4	9.79	101	<.05	.63
✓~~MPG-4S~~ MP-6 MW4S	22.7	215	<.05	<.05
MW-349-8	23.5	44.1	<.05	<.05
✓MP-6S	157	35.6	1.34	<.05
MP-6S Dup	157	35.4	1.35	<.05
✓~~HFG-MW2D~~ HFG-MW2D	8.06	43.2	<.05	1.02
✓MP-6D	289	1.47	<.05	1.40
MW-349-2	100	69.4	<.05	<.05
✓MP-5M	146	45.4	.05	2.18
✓MP-5D	7.67	61.9	<.05	1.66
MP-5D Dup	7.68	61.4	----	----
✓MP-5S	115	552	.07	47.5
MW-349-1	5.05	4.13	.09	.59
MW-349-6	38.5	81.0	<.05	<.05
✓MP-2D	6.10	14.0	<.05	1.96
MP-2D Dup	5.86	14.0	<.05	1.95
✓MP-2M	6.10	8.00	<.05	1.67
Blank	<.1	<.1	<.05	<.05
AQC	56.0	50.0	.35	1.58
	56.3	52.4	.39	1.44
	55.0	51.0	.38	1.49
AQC T.V.	55.9	52.0	.39	1.40
Spike Rec.	99%	97%	96%	100%
	97%	104%	100%	99%
	----	----	99%	99%

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 96-NV132/vg

July 11, 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 (4515.LST) for nine samples (Offutt AFB) submitted to MERSC as part of Service Request #62 under EPA Contract #68-C3-0322. The samples were received on July 3 and analyzed July 3 and 11, 1996. The samples did not receive any further treatment and they were analyzed using the ICAP system. GF-AAS was used for lead determination and results are in report PB60711.Lis;1. SOP for the ICP, GF-AAS 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. 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 CONSTI[redacted] ANALYSIS BY: ICAP (DATA.DAT)

THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;[redacted] WAS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3064

PROJECT: AQ FILTERED FIELD SAMPLES OFFUTT AFB
KAMPBELL
SR62

CONCENTRATION IN: MG/L

TAG NO.	14456		14457		14458		14459		
STATION	MW349-11		MP-9D		MW 349-8		MP 17D		
TIME	10:02		09:39		09:43		09:46		
DATE	03-JUL-96		03-JUL-96		03-JUL-96		03-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	18.7	2.0	13.0	1.3	20.2	2.0	14.6	1.4	0.1136
K	2.8	1.0	7.1	1.0	<1.0	1.0	5.3	1.0	1.0326
Ca	102.	10.	129.	12.	129.	12.	189.	18.	0.0545
Mg	23.3	2.3	25.1	2.5	18.0	1.8	49.0	4.9	0.0572
Fe	<0.0037	0.0037	4.54	0.45	<0.0038	0.0038	26.4	2.6	0.0036
Mn	<0.0008	0.0008	1.15	0.11	3.82	0.38	0.623	0.063	0.0004
Co	<0.0029	0.0029	<0.0029	0.0029	<0.0029	0.0029	0.0042	0.0030	0.0029
Mo	<0.061	0.061	<0.061	0.061	<0.061	0.061	<0.061	0.061	0.0616
Al	<0.057	0.057	<0.057	0.057	<0.057	0.057	<0.057	0.057	0.0570
As	<0.020	0.020	<0.020	0.020	<0.020	0.020	0.038	0.020	0.0200
Se	<0.018	0.018	<0.019	0.019	<0.018	0.018	<0.028	0.028	0.0187
Cd	<0.0025	0.0025	<0.0025	0.0025	<0.0025	0.0025	<0.0025	0.0025	0.0025
Be	<0.0013	0.0013	<0.0014	0.0014	<0.0014	0.0014	<0.0018	0.0018	0.0010
Cu	<0.018	0.018	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0182
Cr	0.0082	0.0013	0.0027	0.0013	<0.0013	0.0013	0.0034	0.0013	0.0013
Ni	0.0004	0.0032	<0.0032	0.0032	0.0142	0.0032	0.0159	0.0032	0.0032
Zn	0.0017	0.0004	<0.0004	0.0004	<0.0004	0.0004	<0.0007	0.0007	0.0004
Ag	<0.0068	0.0068	<0.0068	0.0068	<0.0068	0.0068	<0.0068	0.0068	0.0068
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0150
Pb	<0.013	0.013	<0.013	0.013	0.050	0.013	<0.013	0.013	0.0135
Sr	0.424	0.042	1.02	0.10	0.308	0.030	1.67	0.16	0.0005
V	<0.013	0.013	<0.013	0.013	<0.013	0.013	<0.013	0.013	0.0138
Ba	0.296	0.029	0.188	0.018	0.452	0.045	0.228	0.022	0.0016
B	0.132	0.011	0.0719	0.0058	0.0723	0.0057	0.194	0.016	0.0057
Ti	<0.0030	0.0030	<0.0030	0.0030	<0.0030	0.0030	<0.0030	0.0030	0.0029

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY: ICAP (DATA.DAT)

THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;4515) WAS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3064

PROJECT: AQ FILTERED FIELD SAMPLES OFFUTT AFB
KAMPBELL
SR62

CONCENTRATION IN: MG/L

TAG NO.	14460		14461		14462		14463		
STATION	MP3		MWI9		MW349-14		FPTA3-MW6A		
TIME	09:49		09:52		09:55		09:57		
DATE	03-JUL-96		03-JUL-96		03-JUL-96		03-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	23.1	2.3	29.9	2.9	12.9	1.2	24.0	2.4	0.1136
K	2.7	1.0	3.7	1.0	<1.0	1.0	4.2	1.0	1.0326
Ca	97.5	9.7	155.	15.	117.	11.	188.	18.	0.0545
Mg	28.9	2.9	37.1	3.7	15.4	1.5	54.8	5.5	0.0572
Fe	4.39	0.44	10.8	1.0	<0.0036	0.0036	8.39	0.84	0.0036
Mn	2.99	0.30	2.39	0.24	<0.0006	0.0006	4.72	0.47	0.0004
Co	<0.0029	0.0029	<0.0029	0.0029	<0.0029	0.0029	<0.0030	0.0030	0.0029
Mo	<0.061	0.061	<0.061	0.061	<0.061	0.061	<0.061	0.061	0.0616
Al	<0.057	0.057	<0.057	0.057	<0.057	0.057	<0.057	0.057	0.0570
As	0.030	0.020	<0.020	0.020	<0.020	0.020	<0.020	0.020	0.0200
Se	<0.019	0.019	<0.020	0.020	<0.018	0.018	<0.019	0.019	0.0187
Cd	0.0026	0.0025	<0.0025	0.0025	<0.0025	0.0025	<0.0025	0.0025	0.0025
Be	<0.0012	0.0012	<0.0016	0.0016	<0.0013	0.0013	<0.0018	0.0018	0.0010
Cu	<0.018	0.018	<0.018	0.018	<0.018	0.018	<0.018	0.018	0.0182
Cr	0.0019	0.0013	0.0022	0.0013	0.0043	0.0013	0.0024	0.0013	0.0013
Ni	<0.0032	0.0032	<0.0032	0.0032	0.0079	0.0032	0.0032	0.0032	0.0032
Zn	0.0103	0.0013	0.0007	0.0005	0.0091	0.0011	<0.0005	0.0005	0.0004
Ag	<0.0068	0.0068	<0.0068	0.0068	<0.0068	0.0068	<0.0068	0.0068	0.0068
Tl	<0.015	0.015	<0.015	0.015	<0.015	0.015	<0.015	0.015	0.0150
Pb	<0.013	0.013	<0.013	0.013	<0.013	0.013	<0.013	0.013	0.0135
Sr	0.370	0.037	0.626	0.062	0.346	0.034	1.74	0.17	0.0005
V	<0.013	0.013	<0.013	0.013	<0.013	0.013	<0.013	0.013	0.0138
Ba	0.401	0.040	0.831	0.083	0.245	0.024	0.463	0.046	0.0016
B	0.1007	0.0083	0.0801	0.0058	0.1040	0.0088	0.139	0.011	0.0057
Ti	<0.0030	0.0030	<0.0030	0.0030	<0.0030	0.0030	<0.0030	0.0030	0.0029

↑

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTIT[illegible] ANALYSIS BY: ICAP (DATA.DAT)
THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;45 [illegible]WAS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;38

PROJECT: AQ FILTERED FIELD SAMPLES OFFUTT AFB
KAMPBELL
SR62

CONCENTRATION IN: MG/L

		ZSTD5		IECCHK2		
TAG NO.	14464					
STATION	B301-MW1					
TIME	10:00	10:19		10:22		
DATE	03-JUL-96	03-JUL-96		03-JUL-96		
PR DIL	1.0000	1.0000		1.0000		
DIL	1.0000	1.0000		1.0000		

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	9.49	0.95	<0.11	0.11	<0.11	0.11	0.1136
K	2.9	1.0	<1.0	1.0	<1.0	1.0	1.0326
Ca	85.2	8.5	<0.054	0.054	303.	30.	0.0545
Mg	46.0	4.6	<0.26	0.26	257.	25.	0.0572
Fe	<0.0039	0.0039	103.	10.	<0.010	0.010	0.0036
Mn	<0.0012	0.0012	104.	10.	<0.0067	0.0067	0.0004
Co	<0.0029	0.0029	<0.0029	0.0029	<0.014	0.014	0.0029
Mo	<0.061	0.061	<0.061	0.061	<0.061	0.061	0.0616
Al	<0.057	0.057	103.	10.	<0.15	0.15	0.0570
As	<0.020	0.020	<0.20	0.20	<0.033	0.033	0.0200
Se	<0.018	0.018	<0.11	0.11	<0.019	0.019	0.0187
Cd	<0.0025	0.0025	<0.0025	0.0025	<0.0025	0.0025	0.0025
Be	<0.0012	0.0012	0.0030	0.0010	<0.0064	0.0064	0.0010
Cu	<0.018	0.018	<0.018	0.018	<0.022	0.022	0.0182
Cr	0.0310	0.0029	<0.0015	0.0015	0.0053	0.0014	0.0013
Ni	<0.0032	0.0032	<0.0032	0.0032	<0.0032	0.0032	0.0032
Zn	<0.0005	0.0005	<0.0015	0.0015	<0.0031	0.0031	0.0004
Ag	<0.0068	0.0068	<0.0071	0.0071	<0.034	0.034	0.0068
Tl	<0.015	0.015	<0.042	0.042	<1.3	1.3	0.0150
Pb	<0.013	0.013	<0.062	0.062	<0.014	0.014	0.0135
Sr	0.276	0.027	<0.0005	0.0005	0.0017	0.0006	0.0005
V	<0.013	0.013	<0.014	0.014	18.6	1.8	0.0138
Ba	0.312	0.031	<0.0016	0.0016	0.0115	0.0021	0.0016
B	0.0423	0.0057	<0.0090	0.0090	<0.0075	0.0075	0.0057
Ti	<0.0030	0.0030	<0.0029	0.0029	51.1	5.1	0.0029

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

ELEMENTAL CONSTITUENTS ANALYSIS BY: ICAP (DATA.DAT)

THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;4515) WAS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3064

PROJECT: AQ FILTERED FIELD SAMPLES OFFUTT AFB 10-JUL-96 13:20:41
KAMPBELL
SR62

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$DISK:[CLARK.ICAP]DATA.DAT;276	(INSTRUMENT RAW DATA)
USER$DISK:[CLARK.ICAP]IC0001.DAT;3900	(INSTRUMENT CALC. DATA)
USER$DISK:[CLARK.ICAP]TAG.DAT;4815	(ORIGINAL TAG FILE)
USER$DISK:[CLARK.ICAP]TAG.DAT;4816	(TAG FILE FOR CALC.)
USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3064	
USER$DISK:[CLARK.ICAP]OUTPUT.LST;2980	
USER$DISK:[CLARK.ICAP]ARCH.DAT;16	
USER$DISK:[CLARK.ICAP]LIST.LST;4515	
USER$DISK:[CLARK.ICAP]TRAILER.LST;670	

ELEMENTAL CONSTITUI ANALYSIS BY AA MEASUREMENTS

THIS REPORT ([.REPORT]PB60711.LIS;1) WAS GENERATED FROM DATASET [.DATA]PB60711.DAT;2

PROJECT: AQ FILTERED SAMPLES. OFFUTT AFB

METHOD: GF-AAS FOR LEAD DETERMINATION

CONCENTRATION UNITS: MG/L

TAG NUMBER	SAD #	STATION IDENT	MACHINE READING	PRIMARY DILUTION	REGULAR DILUTION	FINAL CONCENTRATION
14456	14456	MW349-11	0.000	1.000	1.000	0.000
14457	14457	MP-9D	0.000	1.000	1.000	0.000
14458	14458	MW 349-8	0.057	1.000	1.000	0.057
14459	14459	MP 17D	0.001	1.000	1.000	0.001
14460	14460	MP3	0.001	1.000	1.000	0.001
14461	14461	MWI9	0.000	1.000	1.000	0.000
14462	14462	MW349-14	0.000	1.000	1.000	0.000
14463	14463	FPTA3-MW6A	0.000	1.000	1.000	0.000
14464	14464	B301-MW1	0.000	1.000	1.000	0.000
BLANK1	%%%%%	**********	0.000	1.000	1.000	0.000
BLANK2	%%%%%	**********	0.000	1.000	1.000	0.000
STD2PPB	%%%%%	**********	0.003	1.000	1.000	0.003
STD5PPB	%%%%%	**********	0.005	1.000	1.000	0.005
STD5PPB	%%%%%	**********	0.004	1.000	1.000	0.004
STD10PPB	%%%%%	**********	0.010	1.000	1.000	0.010
STD10PPB	%%%%%	**********	0.011	1.000	1.000	0.011
STD20PPB	%%%%%	**********	0.024	1.000	1.000	0.024
STD20PPB	%%%%%	**********	0.018	1.000	1.000	0.018
STD50PPB	%%%%%	**********	0.047	1.000	1.000	0.047
STD50PPB	%%%%%	**********	0.052	1.000	1.000	0.052

MANTECH

Ref: 96-SH77/vg

July 25, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 24 Offutt AFB soils submitted July 8, 1996 under Service Request #SF-2-209. Sample analysis was begun July 9, 1996 and completed July 25, 1996 using RSKSOP-102 and RSKSOP-120.

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 SV FW
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 OFFUTT SOILS SF-2-209

SAMPLE (Revised Well #)	SOIL FILTRATE % O.C.	SOLIDS % O.C.	TOTAL SOIL % TOC	MEAN %TOC	STD DEV
MW 18,1-1 mw16	<.00004	.011	.011	.009	
1-2	<.00004	.006	.006		
MW 18I-60' mw16					
1-1	<.00004	.013	.013	.016	
1-2	<.00004	.018	.018		
MW 18I-66' mw16					
1-1	<.00004	.015	.015	.015	
1-2	.002	.012	.014		
MW 18I-54' mw16					
1-1	<.00004	.031	.031	.034	
1-2	<.00004	.036	.036		
MW 19I-44' mw15					
1-1	<.00004	.052	.052	.055.	
1-2	<.00004	.057	.057		
MW 19I-62' mw15					
1-1	<.00004	.016	.016	.024	.019
1-2	<.00004	.010	.010		
1-3	.020	.025	.045		
MW 19I-70' mw15					
1-1	<.00004	.003	.003	.002	
1-2	<.00004	.001	.001		
MW 17I-21'					
1-1	<.00004	.003	.003	.012	.019
1-2	<.00004	<.00004	<.00004		
1-3	.014	.020	.034		
MW 17I-40'					
1-1	<.00004	.067	.067	.066	
1-2	<.00004	.065	.065		
MW 17I-43'					
1-1	<.00004	.004	.004	.005	
1-2	<.00004	.005	.005		
MW 17I-48'					
1-1	<.00004	.011	.011	.009	
1-2	<.00004	.006	.006		
MP-3,10-14'					
1-1	.010	.194	.204	.197	
1-2	.002	.188	.190		

SAMPLE	SOIL	FILTRATE % O.C.	SOLIDS % O.C.	TOTAL SOIL % TOC	MEAN %TOC	STD DEV
Revised well #						
MP-3,20-22'						
	1-1	.007	.276	.283	.283	
	1-2	.008	.275	.283		
SD 1,	1-1	.063	1.76	1.82	1.87	
	1-2	.071	1.85	1.92		
SD 2,	1-1	.024	.578	.602	.607	
	1-2	.031	.580	.611		
SD 3,	1-1	.045	1.15	1.20	1.22	
	1-2	.049	1.18	1.23		
SD 4,	1-1	.038	.350	.388	.404	
	1-2	.057	.362	.419		
SD 5,	1-1	.042	.945	.987	1.04	
	1-2	.036	1.06	1.10		
MW 16I-58' MW14						
	1-1	.027	.039	.066	.070	
	1-2	.033	.041	.074		
MW 20I-38' MW18						
	1-1	.037	.015	.052	.036	.014
	1-2	.009	.015	.024		
	1-3	.014	.018	.032		
SD 6,	1-1	.173	6.85	7.02	7.29	
	1-2	.166	7.39	7.56		
B301-MP1-52,						
	1-1	.030	.200	.230	.227	
	1-2	.032	.192	.224		
MP2-51,	1-1	.009	.021	.030	.034	
	1-2	.016	.021	.037		
MP1-51,	1-1	.031	.324	.355	.342	
	1-2	.023	.306	.329		
LECO SOIL STD		.996				
WPO35-II STD			39.8			

Leco soil std t.v.=1.00+.04
WPO35-II std t.v.=40.1

MANTECH

Ref: 96-DK35/vg
July 24, 1996

John Hicks
Dissolved methane, ethan
To be mailed later
7/29/9
DK

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 Dr. Kampbell:

This report contains the results of my GC/MSD analysis of six methylene chloride core extracts (#SD1-6) and two "floating product" samples (#MW-349 and MW-349-8) from Offutt AFB for benzene, toluene, ethylbenzene, xylenes and trimethylbenzenes. In addition, a mass spectral library search and a TIC chromatogram is reported for each of the floating product samples. This work was performed under Service Request #SF-2-209.

The analytical method was a modification of RSKSOP-124. Cool (38°C), on-column injection (0.1 µl) was used with 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 X 0.53 mm uncoated capillary precolumn was used. Quantitation was based on calibration curves of target ions (SIM mode) for each compound chosen from those listed in EPA method 524.2 Revision 3.0. Calibration curve range was 0.05-250 ug/ml. Complete reports detailing the acquisition methods and calibration curves have been recorded. The samples were extracted July 2, 1996 and analyzed July 10, 1996.

If you require further information, please feel free to contact me.

Sincerely,

David A. Kovacs

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

Sample (mg/kg)	Benzene	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
Method Blank	ND	ND	ND	ND	ND	ND	ND	ND	ND
SD1	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
SD2	ND	ND	ND	ND	ND	ND	ND	ND	ND
SD3	ND	4.38E-01	BLQ	ND	ND	ND	ND	ND	ND
SD4	ND	ND	ND	ND	ND	ND	ND	ND	ND
SD5	ND	ND	ND	ND	ND	ND	ND	ND	ND
SD6	ND	ND	ND	ND	ND	ND	ND	ND	ND

Check Standards (ug/ml)	Benzene	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
250	2.71E+02	2.68E+02	2.67E+02	2.69E+02	2.70E+02	2.69E+02	2.69E+02	2.69E+02	2.69E+02
250	2.19E+02	2.24E+02	2.25E+02	2.23E+02	2.22E+02	2.24E+02	2.23E+02	2.23E+02	2.22E+02
50	4.49E+01	4.54E+01	4.60E+01	4.59E+01	4.59E+01	4.63E+01	4.61E+01	4.62E+01	4.61E+01
50	4.87E+01	4.87E+01	4.92E+01	4.90E+01	4.81E+01	4.85E+01	4.87E+01	4.84E+01	4.83E+01
5	5.42E+00	5.41E+00	5.41E+00	5.39E+00	5.45E+00	5.37E+00	5.41E+00	5.41E+00	5.41E+00
5	4.41E+00	4.43E+00	4.48E+00	4.50E+00	4.35E+00	4.52E+00	4.46E+00	4.46E+00	4.46E+00
0.5	4.52E-01	4.68E-01	4.63E-01	4.63E-01	4.49E-01	4.60E-01	4.59E-01	4.63E-01	4.58E-01
Methylene Chloride	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC #1 5ppm	5.08E+00	N/A	5.07E+00	4.88E+00	4.65E+00	4.85E+00	N/A	N/A	N/A
QC #2 250ppm	N/A	2.48E+02	N/A	2.75E+02	2.75E+02	2.71E+02	2.79E+02	N/A	N/A

Floating Product	Density (g/ml)	Benzene	Toluene	EB	p-X	m-X	o-X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Total
MW-349-1	0.724										
(ug/ml)		8.42E+03	3.64E+04	1.14E+04	9.36E+03	1.77E+04	1.07E+04	5.00E+03	1.31E+04	3.81E+03	1.16E+05
Mass Fraction		1.16E-02	5.02E-02	1.57E-02	1.29E-02	2.45E-02	1.48E-02	6.90E-03	1.81E-02	5.26E-03	1.60E-01
MW-349-8	0.742										
(ug/ml)		9.55E+02	1.23E+04	1.01E+04	8.03E+03	1.54E+04	9.15E+03	5.81E+03	1.48E+04	4.70E+03	8.12E+04
Mass Fraction		1.29E-03	1.66E-02	1.36E-02	1.08E-02	2.08E-02	1.23E-02	7.83E-03	1.99E-02	6.33E-03	1.09E-01

BLQ < 0.05 ug/ml

Analyst: David A. Kovacs

MANTECH

Ref: 96-BN11/vg

July 12, 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:

As requested in Service Request #SFTA-2-94, dissolved hydrogen analysis was completed on 22 monitoring wells at Offutt AFB. The dates for these analyses were June 25, 1996 - June 28, 1996. The concentrations for hydrogen are given in parts per million.

Sample	Concentration (ppm)
MP-9D	0.95
FPTA3-MW3	0.96
FPTA3-MW6A	0.59
MP-23S	0.65
MP-23S REP	0.71
MP-8S	0.32
MP-6D	23.98
MP-5M	18.43
MP-5D	49.94
MP-17S	2.11
MP-17D	22.00
MW-9S	0.97
MW-9S REP	0.97
MW-9I	1.39
MW-8S	11.98
MW-8I	0.69
MW-8D*	2047
MW-10S	0.51
MW-12S	0.33
MW-11S	0.77
MP-4*	128.5
MP-1S	26.23
MP-2S*	1419.86

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

* Denotes the samples could not be brought into the range of the calibration curve using dilutions of the samples. Well MW-8D was purged using the Grundfos pump, before being sampled for hydrogen.

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

Sincerely,

Bryan Newell

Bryan Newell

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

MANTECH

Ref: 98-MB2
July 7, 1998

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: Steve Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request SF-4-323 requesting the analysis of aqueous samples from Offutt AFB, NE to be analyzed for MTBE, BTEXXX and TMBs. The 17 samples were received in capped, 40 mL VOA vials on June 16, 1998. The samples were analyzed on July 6, 1998. All samples were acquired using the Millennium data system. A 6 point (1-1200 ppb) external calibration curve was used to determine the concentration for all compounds.

RSKSOP-122 "Analysis of Volatile Aromatic Hydrocarbons with Separation of Xylene Isomers by Purge & Trap Gas Chromatography" was used for these analyses. Auto-sampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Mark Blankenship

Mark Blankenship

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

Printed [redacted] SF-4-323 Analyses [redacted] Kampbell Units = ng/ml Analyst M. Blankenship

SAMPLE NAME	MTBE	BENZENE	TOLUENE	ETHYLBENZEN	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
QC, OBSERVED, 20 PPB	17.9	19.4	18.5	19.2	20.5	19.1	20.1	20.6	19.4	17.3
QC, TRUE VALUE, 20 PPB	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
MW-349-1	2.4	1976	14907	4784	2304	496.2	5500	1111	4237	1023
MW-349-5	83.3	195.9	3828	1035	2010	3940	2890	1133	3556	904.2
MW-349-7	2.0	1762	10346	2970	2459	4029	5143	802.4	3225	805.6
MW-349-8	1.7	1302	4167	4338	2259	3775	4327	609.1	2477	615.5
FTMP-4S	5.5	338.7	260.0	188.9	124.5	339.2	263.0	40.0	118.3	65.2
FTMP-8D	1.2	1.2	BLQ	BLQ	ND	ND	1.1	12.0	18.6	ND
1000 PPB STD	995.2	907.7	917.0	888.6	883.8	893.5	899.7	896.8	897.9	896.3
GC LAB BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-349-9	ND	6.0	35.0	9.4	12.9	31.1	17.5	10.8	35.0	10.2
MW-349-10	ND	1.8	7.1	1.4	1.3	3.0	1.1	BLQ	1.3	BLQ
MW-349-11	ND	1.0	3.7	BLQ	BLQ	1.5	BLQ	ND	BLQ	ND
MW-349-14	ND	BLQ	2.2	BLQ	BLQ	1.4	BLQ	ND	1.5	BLQ
FTMP-4M	2.5	BLQ	2.4	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
FTMP-4D	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	BLQ	BLQ
FTMP-5S	1.1	36.0	2.7	14.2	3.2	1.3	5.9	19.7	54.9	31.0
FTMP-5M	2.5	25.2	12.8	4.7	5.7	3.8	22.2	BLQ	BLQ	BLQ
FPTA-3-MW6A	ND	BLQ	BLQ	ND	ND	BLQ	BLQ	ND	ND	ND
FTMP-6D	19.2	BLQ	BLQ	ND	BLQ	ND	ND	ND	ND	ND
FTMP-6S	ND	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND
1000 PPB STD	891.3	940.0	933.3	936.7	928.8	953.0	921.4	989.9	970.4	935.6

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb

MANTECH

Ref: 98/JAD3

Contract # 68-c-98-138

July 8, 1998

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-4-323, headspace GC/MS analysis of 9 water samples for chlorinated volatile organics from Offutt AFB was completed. The samples were received on June 15, 1998 and analyzed on July 3-7, 1998. 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 15 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

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

Sincerely,

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley JS
J.T. Wilson JW

Table 1. Quantitation Report for S.R. # SF-4-323 from Offutt AFB.

Concentration = ppb

Compound	FTMP4M	FTMP4S	FTMP4D	FTMP4D Field Dup	FTMP4D Lab Dup	FTMP5S	FTMP5M	FPTA3 MW6A	FTMP-6D	FTMP6S
VINYL CHLORIDE	ND	138	ND	ND	ND	19.8	2520	ND	16.2	2.1
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	2.5	1.7	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	3.6	ND	ND	ND	4.8	34.6	ND	ND	1.6
1,1-DICHLOROETHANE	ND	---	ND	ND	ND	542	738	ND	3.8	15.1
C-1,2-DICHLOROETHENE	---	442	---	---	---	1720	9.9	---	21.4	85.3
CHLOROFORM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	23.4	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	66.5	ND	ND	9.0	87.2
TRICHLOROETHENE	ND	ND	---	---	---	27.0	1.6	ND	ND	---
TETRACHLOROETHENE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Compound	FTMP8D	QC0703A 20 ppb	QC0706A 200 ppb	QC0707A 20 ppb	BL0703A
VINYL CHLORIDE	ND	19.8	208	20.4	ND
1,1-DICHLOROETHENE	ND	22.9	235	23.8	ND
T-1,2-DICHLOROETHENE	ND	19.4	188	19.4	ND
1,1-DICHLOROETHANE	ND	21.5	211	21.4	ND
C-1,2-DICHLOROETHENE	ND	21.2	209	20.8	ND
CHLOROFORM	ND	20.9	196	20.7	ND
1,1,1-TRICHLOROETHANE	ND	21.3	227	22.1	ND
CARBON TETRACHLORIDE	ND	22.7	231	22.5	ND
1,2-DICHLOROETHANE	ND	22.1	196	20.4	ND
TRICHLOROETHENE	ND	20.6	200	20.6	ND
TETRACHLOROETHENE	ND	22.1	214	22.2	ND
CHLOROBENZENE	ND	22.4	203	21.0	ND
1,3-DICHLOROBENZENE	ND	22.1	198	21.6	ND
1,4-DICHLOROBENZENE	ND	22.8	202	22.9	ND
1,2-DICHLOROBENZENE	ND	22.3	201	21.8	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) QC = Quality Control Std Dup = Duplicate BL = Blank

MANTECH

Ref: 98-AZ1

June 18, 1998

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:

As requested in Service Request #SF-4-323, gas analysis was performed for methane, ethylene, and ethane on samples from Offutt AFB. The samples were received on June 15, 1998. The analyses were performed on June 16, 1998. These analyses were performed as per RSKSOP-194, and the calculations were done as per RSKSOP-175.

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

Sincerely,

Amy Zhao

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

SF-4-323 6/16/98

Sample	Methane	Ethylene	Ethane
100 ppm CH4	102.7	**	**
100 ppm C2H4	**	105.9	**
100 ppm C2H6	**	**	108.8
Helium Blank	**	**	**
Lab Blank	**	**	**
MW 349-1	0.002	**	0.003
MW 349-5	**	**	**
MW 349-7	**	**	0.002
MW 349-8	**	**	**
MW 349-9	**	**	**
MW 349-9 Lab Dup	**	**	**
MW 349-14	**	**	**
√FTMP -4D	0.509	**	**
√FTMP -5M	24.9	2.20	**
√ FTMP -5S	0.187	**	**
FTMP 5S Field Dup	0.153	0.003	**
10 ppm CH4	10.0	**	**
√ FPTA3-MW6A	0.478	**	**
√ FTPM-6D	6.31	0.003	**
√ FTPM-6S	0.305	**	**
√ FTMP-8D	0.206	**	0.002
Rep2	0.238	**	**
100 ppm CH4	95.1	**	**
100ppm C2H4	**	104.1	**
100 ppm C2H6	**	**	99.4
Lower Limit of Quantitation			
	0.001	0.003	0.002

Units for the samples are mg/L dissolved in water.
Units for the standards are parts per million.

** denotes None Detected.
* denotes Below Limit of Quantitation.

MANTECH

Ref: 98-SH48

June 18, 1998

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

Dear Don:

Attached are TOC results for 13 Offutt liquids submitted June 16, 1998 under Service Request #SF-4-323. Sample analysis was begun June 17, 1998 and completed June 17, 1998 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

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 OFFUTT LIQUIDS SF-4-323

SAMPLE	MG/L TOC
MW349-1	32.5
MW349-5	30.0
MW349-7	32.3
MW349-8	21.8
MW349-9	9.74
MW349-14	1.32
FT-MP-4D	18.2
FT-MP-5M	30.7
FT-MP-5S	176
FT-MP-6D	56.2
FT-MP-6S	4.98
FT-MP-8D	45.3
FPTA3-M26A	14.3
WS38	4.87

WS38 std. t.v.=4.92 +/-.05

MANTECH

MEMORANDUM
MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Science

In reply refer to: 99-42LP/lp
Contract # 68-C-98-138

To: Dr. Don Kampbell

Thru: D.D. Fine ~~DDF~~ mc

From: Lynda Pennington LKP

Subject: SR # SF-0-97

Ref:

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley JS

Date: May 3, 1999

After an exhaustive search for the Offutt AFB report letter from June, 1998, turned up nothing, Dr. Dennis Fine and I concluded that the data was overlooked and never reported. I found the original data in one of Mark White's notebooks and compiled the data myself. I apologize for the inconvenience this may have caused you.

Attached are inorganic results for Offutt AFB samples submitted to MERSC under Service Request # SF-4-323. The samples were received and analyzed June 15, 1998. The methods used for analysis were Waters capillary electrophoresis method N-601 for chloride, sulfate and nitrate, and Lachat FIA method 10-107-06-1 for ammonia.

Quality control measures performed along with your samples included analysis of blanks, duplicates, spikes, known WPO samples and check standards.

If you have any questions concerning this data, please feel free to contact me.

Rec'd 6-15-98
Analyzed 6-15-98
by Mark White

S.R. # SF-4-323
Don Kampbell
Offutt AFB

SAMPLE	NH_3 (N)	$NO_2^-+NO_3^-$ (N)	Cl^-	SO_4^{-2}
	mg/L	mg/L	mg/L	mg/L
FTMP-4D	0.46	<.10	2.70	20.3
FTMP-5M	1.74	<.10	121	105
FTMP-5S	60.7	<.10	53.2	513
FTMP-6D	1.01	<.10	346	<.10
FTMP-6S	(<.10) (<.10)	(5.62) (5.57)	(147) (147)	(60.9) (58.9)
FTMP-8D	0.57	<.10	9.22	7.44
MW-6A	0.92	<.10	8.17	21.3
Blank	<.10	<.10	<.10	<.10
AQC	9.92	0.64	36.2	44.0
AQC T.V.	10.00	0.62	34.8	44.0
Spike Recovery	98%	99%	100%	102%