

FINAL

**Source Reduction Effectiveness at
Fuel Contaminated Sites
Technical Summary Report**



Prepared For

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

February 2000

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Prepared by

**Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290**

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence/Technology Transfer Division
AMC	Air Mobility Command
ARB	Air Reserve Base
AST	aboveground storage tank
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
BX	Base Exchange
COC	chemical of concern
day ⁻¹	per day
DRO	diesel-range organics
ft/day	feet per day
ft/yr	feet per year
GRO	gasoline-range organics
LNAPL	light nonaqueous-phase liquid
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
MOGAS	motor vehicle gasoline
msl	mean sea level
MTBE	methyl <i>tert</i> -butyl ether
NGS	North Gas Station
PAH	polynuclear aromatic hydrocarbon
Parson ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
POL	petroleum, oils, and lubricants
ppmv	parts per million by volume
SGS	South Gas Station
SVE	soil vapor extraction
SWMU	solid waste management unit
TCE	trichloroethene
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TVH	total volatile hydrocarbons
UST	underground storage tank
VEP	vacuum-enhanced pumping
VOC	volatile organic compound

SECTION 1

INTRODUCTION

This source-reduction effectiveness study was performed by Parsons Engineering Science, Inc. (Parsons ES) under contract to the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT) through Air Mobility Command (AMC) contract number F11623-94-D0024, RL71.

1.1 PROJECT OBJECTIVES

The objectives of this study were to:

- Assess the degree to which various types of engineered source-reduction efforts at selected fuel-contaminated sites have resulted in decreasing concentrations of fuel constituents dissolved in groundwater; and
- Describe a methodology for evaluating the potential effectiveness of source-reduction actions at reducing the magnitude and extent of dissolved fuel constituents.

Volatile fuel constituents (e.g., benzene, toluene, ethylbenzene, and xylenes [BTEX]) dissolved in groundwater naturally attenuate under a broad range of environmental conditions (Parsons ES, 1999d). Attenuation mechanisms include biological and abiotic degradation of dissolved constituents and nondestructive processes such as dispersion, sorption, and volatilization. In addition, weathering of the contaminant source via biodegradation, volatilization, and leaching can result in reduced concentrations of dissolved constituents in the groundwater (Parsons ES, 1999b). Therefore, the effects of engineered source reduction may be difficult to distinguish from the effects of natural attenuation. An attempt is made in this study to distinguish between the effects of natural attenuation and engineered source reduction by qualitatively and quantitatively comparing temporal trends in contaminant concentrations both before and after initiation of engineered source reduction.

1.2 SITE-SELECTION CRITERIA

Sites for evaluation in this study were selected based on two primary criteria:

- Inclusion of a variety of source-reduction techniques for comparative purposes; and
- Availability of sufficient soil and groundwater quality data collected both prior to and after initiation of the source-reduction action to enable assessment of pre- and post-source-reduction temporal trends.

Identification of a sufficient number of sites that fulfilled the second objective was problematic, and this criterion was not always met.

1.3 TYPICAL CONCEPTUAL SITE MODEL

In selecting an appropriate source-reduction technique, it is important to identify the location of the greatest mass of subsurface contamination contributing to potential receptor risks. A valid conceptual site hydrogeological model that delineates the distribution of contaminants in the subsurface is essential for understanding how source-reduction techniques will impact groundwater contaminants. For example, at the site of a JP-4 jet fuel spill, benzene in groundwater may represent the chemical and receptor exposure pathway of greatest concern. Due to the relatively limited solubility of benzene in water (relative to its solubility in JP-4), the mass of dissolved benzene typically is quite small. It is not uncommon to find that less than 1 percent of the mass of benzene at a site is dissolved in groundwater, while more than 95 percent of the benzene mass often is retained in free product or fuel residuals trapped in soils near the source of the product release (AFCEE, 1998). It should be noted that the mass of BTEX present in free product or as fuel residuals can be substantially reduced over time through natural weathering. For example, the average first-order weathering rate for total BTEX at five JP-4 sites was estimated to be approximately 16 percent per year (Parsons ES, 1999b).

Fuel contamination may be present in the subsurface in several forms:

Occluded - in soils, light, nonaqueous-phase liquid (LNAPL) often exists at concentrations that are less than residual saturation. This fuel LNAPL is present as small droplets trapped between soil particles. Occluded LNAPL represents the majority of the contaminant mass at most sites.

Sorbed - this is contamination reversibly bound to the surface of soil particles, and may represent a more significant mass at many sites than dissolved contamination, but usually less mass than trapped product droplets.

Continuous free phase - this is the free-phase product, or recoverable (mobile) LNAPL, present at sufficiently high concentrations to form continuous layers that will flow into a monitoring well. Mobile LNAPL normally represents less than 10 percent of the LNAPL mass present at most sites, and rarely exceeds 33 percent.

Soil gas - the fraction of contamination in this phase depends upon the vapor pressure of the fuel and site-specific conditions. With a highly volatile fuel such as gasoline, 1 or 2 percent of the total hydrocarbon mass may reside in the soil gas.

Dissolved - this fraction of fuel contamination generally represents less than 1 percent of the total mass, and is dependent on the solubility of the fuel constituents, the age of the spill, and site hydrogeologic conditions.

Contamination can be present in the vadose zone and/or the saturated zone, depending on the depth at which the fuel release occurred. Generally, a major fraction of the LNAPL contaminant mass resides above the seasonal low water table. At most sites, the only

mechanism for transport downward to the water table is the leaching of dissolved hydrocarbons in infiltrating precipitation or irrigation waters. Leaching is minimized when soils are covered with impermeable materials and in low-precipitation regions. Two exceptions are 1) when the regional water table has been lower in the past than it is now, and 2) when fuels leak from sources that are installed below the seasonal low groundwater level.

The fuel hydrocarbon “smear zone” is defined as the layer between the permanent vadose and saturated zones. This is the zone within which the water table fluctuates seasonally, and where capillary forces maintain near-saturated conditions. The thickness of the smear zone is site-specific and is based on soil characteristics and seasonal water table fluctuations. At most sites, the water table fluctuates only a few feet. The thickness of the capillary fringe also will depend on site-specific conditions. In a coarse, sandy soil, the capillary fringe may be quite thin (e.g., a few inches thick); in a clay soil, the capillary fringe may extend several feet above the water table.

In summary, at a typical fuel release site, the contaminant mass will be distributed as occluded, sorbed, mobile free phase, vapor phase, and dissolved forms. The largest percentage of contaminant mass typically resides within the vadose zone, smear zone, and/or capillary fringe as residual (sorbed or occluded) LNAPL. Mobile LNAPL will typically contain no more than 10 to 30 percent of the contaminant mass. Therefore, the effectiveness of a source-reduction technology will be related to site-specific conditions (e.g., type of product released, lithology, depth to groundwater, magnitude of seasonal groundwater level fluctuations) and the effectiveness of the technology for removing mobile and residual LNAPL.

1.4 REPORT ORGANIZATION

This report contains five sections, including this introduction, and 2 appendices. A summary of source-reduction technologies included in this study is presented in Section 2. Data analysis procedures and temporal trends in soil and groundwater fuel hydrocarbon (primarily BTEX) concentrations at selected sites are assessed and interpreted in Section 3. Section 4 presents conclusions regarding the effectiveness of various source-reduction techniques at reducing fuel hydrocarbon concentrations dissolved in groundwater, and describes a methodology for evaluating the effectiveness of various source-reduction technologies. References cited are listed in Section 5. Appendix A contains maps depicting the layout of each site discussed in this report, and Appendix B contains supplemental soil quality data for Travis AFB and King Salmon Airport.

SECTION 2

SOURCE-REDUCTION TECHNOLOGY SUMMARY

Table 2.1 provides a listing of technologies with widespread application for treating environmental media contaminated with petroleum hydrocarbons. This table was first published in the *Handbook for Remediation of Petroleum-Contaminated Sites (A Risk-Based Strategy)* (AFCEE, 1998). Most of the source-reduction techniques discussed in this document are a subset of those listed in Table 2.1.

**TABLE 2.1
TECHNOLOGIES FOR REMEDIATION OF PETROLEUM-CONTAMINATED
SITES
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Treatment Technology	Soils- Vadose	Soils- Smear	Soils- Saturated	Ground- water	Soil gas
<i>In Situ</i>					
Natural Attenuation	1	1	1	1	1
Bioventing	2	2	6	6	3
Soil Vapor Extraction	3	3	6	6	2
In Situ Heating Methods	3	3	6	6	4
Air Sparging/Bioventing	3	3	4	4,5	4
Biological Enhancements	4	4	4	4	6
In-Well Aeration/Recirculation	8	4	4	4	6
Barrier/Treatment Walls	8	8	6	4	8
Pump and Treat	8	8	7	4, 5	8
Free Product Recovery					
Skimming	8	4	6	6	8
Groundwater Depression	8	4	6	5	8
Bioslurping	4	4	6	5	3
Excavation and <i>Ex Situ</i> Treatment/Disposal					
Biopile	3	3	3	6	3
Low-Temperature Thermal Desorption	3	3	3	6	6
Offsite Disposal	3	3	3	6	6

1. Technology of first choice, usually lowest cost and effective; a preferred remedy.
2. Technology of choice if natural attenuation cannot be applied; usually a preferred remedy.
3. Technology that may be selected if 1 or 2 cannot be applied; may be a preferred remedy.
4. Technology that will provide some treatment: effectiveness uncertain; not a preferred remedy.
5. Technology that may be effective for containment; not a preferred remedy.
6. Technology may provide limited treatment, but is not designed for this purpose, and its effectiveness is uncertain; not a preferred remedy.
7. No immediate impact is expected, long-term improvement may occur as a result of application; not a preferred remedy.
8. No impact anticipated; not a preferred remedy.

The sites selected for evaluation during this study and the source-reduction technique(s) used at each site are summarized in Table 2.2. The sites layouts are depicted

on maps presented in Appendix A. Each of the source-reduction technologies are briefly described in the following paragraphs.

TABLE 2.2
SUMMARY OF SOURCE-REDUCTION SITES AND TECHNOLOGIES
SOURCE-REDUCTION EFFECTIVENESS STUDY

Site	Location	Source-reduction Technology
Fort Rucker AFB SWMU 14 ^{a/}	Alabama	Bioventing
Maxwell AFB Site ST-001	Alabama	Bioventing
Westover ARB ^{b/} Site FT-03	Massachusetts	Bioventing
Patrick AFB Site ST-29	Florida	SVE ^{c/} /Bioventing
Charleston AFB Site ST-27	South Carolina	SVE/Bioventing
Eglin AFB Seventh Street Service Station	Florida	SVE/Bioventing
Carswell AFB Site ST14	Texas	Bioventing
Myrtle Beach AFB MOGAS Site	South Carolina	Biosparging
Langley AFB Site SS-04	Virginia	Vacuum-enhanced extraction
Tinker AFB Area A Service Station	Oklahoma	Vacuum-enhanced extraction
Travis AFB North and South Gas Stations	California	Excavation
King Salmon Airport Site FT-01	Alaska	Excavation

^{a/} AFB = Air Force Base; SWMU = solid waste management unit.

^{b/} ARB = Air Reserve Base.

^{c/} SVE = soil vapor extraction.

2.1 BIOVENTING

Bioventing is a proven technology that stimulates the natural *in situ* biodegradation of petroleum hydrocarbons in soil by providing oxygen to native soil microorganisms. In contrast to soil vapor extraction (SVE), bioventing utilizes low air-injection flow rates to provide only enough oxygen to sustain microbial activity. Oxygen is most commonly supplied through direct air injection into contaminated vadose-zone soils via vertical or horizontal vent wells. In addition to biodegradation of adsorbed fuel residuals, volatile organic compounds (VOCs) also are biodegraded as vapors move slowly through biologically active soils. Bioventing has been less successful in desert environments where low soil moisture may limit biodegradation, and in low-permeability soils where gas flow cannot be initiated. Bioventing will not effectively remediate the capillary fringe and saturated zone; however, air-injection bioventing may depress the water table somewhat, resulting in additional smear-zone treatment. To the extent that the water table fluctuates seasonally, the deeper portion of the smear zone also may be aerated during relatively dry periods when the water table is low.

2.2 SOIL VAPOR EXTRACTION

SVE is the process of extracting soil gas from the vadose zone to enhance the volatilization of contaminants and remove the vapor-phase contaminants for atmospheric discharge or aboveground treatment. SVE is a proven technology for treatment of volatile contaminants such as gasoline in the vadose zone. SVE airflow rates tend to be up to 10 to 20 times higher than those for bioventing. The effectiveness of SVE may be limited in low-permeability soils due to the higher required airflow rates. Similar to bioventing, SVE will not effectively remediate the capillary fringe and saturated zone. In addition, when air is extracted, the applied vacuum may cause the water table near the extraction wells to rise, resulting in less effective treatment of the smear zone at some sites. SVE is occasionally used prior to bioventing to remove explosive vapors from the subsurface prior to air injection.

2.3 AIR SPARGING/BIOSPARGING

Air sparging is the process of injecting air under pressure into an aquifer with the objective of forcing the air through the contaminated aquifer material and groundwater via as many small channels as possible. Treatment may occur either through volatilization or through aerobic biodegradation stimulated by the oxygen addition. One potential drawback is the tendency for injected air to form channels in the aquifer, resulting in very localized and non-uniform remediation of the contaminated zone. Homogeneous, sandy aquifers with shallow groundwater contamination may provide for more uniform treatment than those that are more stratigraphically heterogeneous.

2.4 VACUUM-ENHANCED EXTRACTION

Groundwater containment and/or free product extraction often is accomplished through the use of some form of pumping system. The capture zone of an extraction point can be increased by increasing the pumping rate. However, drawdown resulting from fluid withdrawal cannot exceed the total saturated thickness of a water table aquifer. The hydraulic gradient and the yield cannot be increased by increasing the pumping rate if drawdowns have reached their limiting value. The application of a vacuum to the extraction point provides a means to enhance these gradients, thereby increasing the capture zone, yield, and rate of water and free product recovery. In areas of small saturated thickness and/or low permeability, vacuum systems provide an alternative for cost-effective remediation when excavation may be the only other remedial option.

2.5 EXCAVATION

Excavation is normally the preferred remedy for small volumes (<500 cubic yards) of easily accessible, contaminated soil. Because excavation allows for visual observation and field screening of removed soils as well as *in situ* soils in the sidewalls and bottom of the excavated pit (assuming that groundwater is not present in the pit), the zone of significantly contaminated soil often can be removed rapidly and with a relatively high degree of confidence. However, excavation below the water table can be problematic, particularly in less-cohesive (e.g., sandy) soils, due to the potential for sloughing of the sidewalls into the pit. Use of physical shoring can be time-consuming and expensive.

SECTION 3

DATA ANALYSIS

Selected site-specific data, including historical soil and groundwater quality data, were compiled in tables. The purpose of compiling soil data was to assess the effectiveness of the engineered source-reduction system at remediating the contaminant source. In cases where multiple soil samples were collected at approximately the same location before, during, or after operation of the source-reduction system, analytical results for these samples were included in the site-specific tables to facilitate this assessment. In other cases, analytical results for soil samples collected within the same general area (i.e., the source area) over time were compiled, and the ranges and averages of the concentrations measured during different time periods were used for assessment purposes. In cases where soil data were not available, soil gas data (if available) were used to indicate the effectiveness of the source-reduction effort.

The purpose of compiling groundwater quality data was to facilitate comparison of groundwater quality trends both before and after startup of the source-reduction system. The groundwater data included in the site-specific summary tables are for selected wells located in the source area and downgradient from the source area along the approximate axis of the dissolved contaminant plume. Two simple statistical methods were used to assist in the trend evaluation. In cases where an analyte was not detected in soil or groundwater, the analyte concentration was assumed to equal one-half the reporting limit for purposes of graphing and statistical calculations. The statistical methods, and the site-specific environmental data and calculation results, are presented and discussed in the following subsections.

3.1 STATISTICAL ANALYSIS

3.1.1 Mann-Kendall Test

The Mann-Kendall (MK) nonparametric estimator for trends (Mann, 1945; Kendall, 1975; Gilbert, 1987) was used to assess whether contaminant concentrations measured prior to and after initiation of the source-reduction action were increasing or decreasing with time. This test is well-suited for environmental data because it requires only small sample sizes and does not assume any underlying distribution for the data. The output of the test is the S statistic. The null hypothesis of this test is that no trend exists in the data. Hypothesis testing to assess the presence of a trend can only be performed for data sets consisting of four or more data points. Because some of the data sets used for this study consisted of only three data points, hypothesis testing was not performed on the S statistic. However, positive and negative S statistics are indicators of increasing and decreasing concentration trends, respectively. Even though no statistical confidence is assigned to the conclusions of these tests, this is a quantitative method of determining if

the concentrations are increasing or decreasing with time, whereas a visual inspection of the time-series plot provides qualitative evidence of a trend.

3.1.2 Sen's Nonparametric Estimator of Slope

If a linear trend is present, the true slope (change per unit of time) of the time-series graph for a sampling station may be estimated using a simple, nonparametric procedure developed by Sen (1968) and described by Gilbert (1987). Unlike the true slope estimated by computing the least-squares estimate of the slope by linear regression methods, Sen's method is not greatly affected by gross data errors or outliers, and the slope can be computed when data are missing. Sen's estimator is closely related to the MK test, and the resulting slope can be used to assess temporal trends in pre- and post-remediation groundwater quality data. Similar to the S statistic discussed in Section 3.1.1, positive and negative slopes indicate increasing and decreasing trends, respectively. The magnitude of the slope is an indicator of the rate at which dissolved contaminant concentrations are changing (e.g., a slope of $-1,000$ indicates more rapid decreases than a slope of -500).

3.2 BIOVENTING SITES

3.2.1 Fort Rucker, Alabama (SWMU 14)

Fort Rucker is located in the southeastern corner of Alabama, adjacent to both Florida and Georgia.

3.2.1.1 Site Description

Solid Waste Management Unit (SWMU) 14, a petroleum, oils, and lubricants (POL) disposal pit, was used to dispose of contaminated helicopter fuel (JP-4), tanker truck washout fluids, and possibly motor oil during the period from 1978 to 1980. The unlined pit was about 80 feet in diameter and 7 feet deep. The pit was closed in 1981 by adding clay to absorb the waste POL material, and the top of the clay cover was mounded to promote surface runoff.

Soils at the site consist of approximately 12 to 15 feet of fill overlying unconsolidated deposits consisting primarily of sand with some silt and clay. Depth to groundwater ranges from approximately 36 to 40 feet below ground surface (bgs) in the immediate vicinity of the former pit. The average hydraulic conductivity of the shallow aquifer is estimated to be 4.4 feet per day (ft/day), and the average advective groundwater flow velocity beneath the site was calculated to be approximately 47 feet per year (ft/yr).

A pilot-scale bioventing system was installed in 1996. Based on the success of the pilot testing, the system was optimized, and then operated and monitored for approximately 2 years. It is believed that the system is still operational, but is not being maintained.

3.2.1.2 Soil and Soil Gas Quality

Soil and soil gas quality data for SWMU 14 are summarized in Table 3.1. Site characterization data indicate that the most highly contaminated soils remaining after 2

TABLE 3.1
ANALYTICAL DATA SUMMARY FOR SWMU 14
FORT RUCKER, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Soil Data

Location ID	Depth of Sample (ft bgs) ^{e/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	Total BTEX ^{a/b/} (mg/kg)	Naphthalene (mg/kg)	TPH ^{a/} (mg/kg)	DRO ^{a/} (mg/kg)	GRO ^{a/} (mg/kg)
VW1-10	10	May-96	0.37 J ^{e/}	< 0.62	1.5	8.5	10.7 J	NA ^{f/}	25,000	NA	NA
MPA-15	15	May-96	0.19 J	< 0.58	0.54 J	2.9	3.9 J	NA	5,600	NA	NA
MPB-15	15	May-96	0.2 J	< 0.8	0.6 J	2.2	3.4 J	NA	7,600	NA	NA
MPB-20	20	May-96	0.0013 J	< 0.0054	0.0019 J	0.0044 J	0.010 J	NA	1,900	NA	NA
MPD-15	15	May-96	< 0.0043	< 0.0043	< 0.0043	< 0.0043	< 0.009	NA	NA	NA	NA
CB1	40-42	Apr-99	2.7 U ^{g/}	2.7 U	2.7 U	2.7 U	5.40 U	1.41 U	NA	2.97 J1 ^{h/}	1.35 U
CB2	8-10	Apr-99	2.67 U	2.67 U	2.67 U	2.67 U	5.34 U	27.9 UJ ^{i/}	NA	5,410	30.7
CB3	8-11	Apr-99	2.7 U	2.7 U	2.7 U	2.7 U	5.40 U	28.6 UJ	NA	4,820	2.7 U
CB4	8-10	Apr-99	2.63 U	2.63 U	2.63 U	2.63 U	5.26 U	27.9 U	NA	5,130	44.1
CB5	15-17	Apr-99	2.5 U	2.5 U	2.5 U	2.5 U	5.00 U	7.5 UJ	NA	6.25 U	1.25 U
CB6	20-22	Apr-99	3.12 U	3.12 U	3.12 U	3.12 U	6.24 U	1.38 U	NA	7.81 U	1.56 U
CB7	10-12	Apr-99	2.63 U	2.63 U	2.63 U	2.63 U	5.26 U	27 UJ	NA	3,760	197

TABLE 3.1 (Continued)
ANALYTICAL DATA SUMMARY FOR SWMU 14
FORT RUCKER, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Soil Gas Data

Location ID	Depth of Sample (ft bgs)	Date Sampled	Benzene (ppmv) ^{j/}	Toluene (ppmv)	Ethyl-benzene (ppmv)	Xylenes (ppmv)	Total BTEX (ppmv)	TVH ^{a/} (ppmv)	Field Screening Data	
									Oxygen (%)	TVH (ppmv)
MPA	20	May-96	24	5.5	2	2.5	34.0	3,600	0.0	16,400
		Jul-97	< 0.002	0.006	0.002	0.009	0.018	22	9.0	84
		Sep-98	0.017	0.0074 J	0.0021	< 0.0021	0.028 J	2.2	8.8	400
MPA	40	May-96	19	15	2	2.5	19.5	8,000	0.0	14,400
		Jul-97	< 0.002	0.016	0.004	0.042	0.063	190	20.0	4
		Sep-98	< 0.0021	0.012	< 0.0021	< 0.0021	0.015	5.5	19.6	40
MPB	20	May-96	8.1	2.6	0.37	0.55	11.6	5,000	8.0	6,800
		Jul-97	0.68	0.85	0.26	1.0	2.79	1,000	0.0	480
		Sep-98	0.048	0.031	0.033	0.075	0.187	10	1.9	560
MPC	20	May-96	5.5	1.7	0.15	0.065	7.4	3,000	8.0	6,400
		Jul-97	0.026	0.076	0.068	0.33	0.500	170	0.0	88
		Sep-98	.04	.011	0.0028 J	0.0077 MJ ^{k/}	0.062	3.8	2.3	280
MPC	30	May-96	13	4.7	2.5	0.31	20.5	11,200	0.0	11,200
		Jul-97	< 0.002	0.003	< 0.002	0.003	0.008	24	17.0	24
		Sep-98	< 0.0021	0.0053 J	< 0.0021	< 0.0021	0.008	100	14.7	100
MPC	40	May-96	14	15 M ^{l/}	4.2	5.0	38.2	6,200	0.0	10,000
		Jul-97	< 0.007	0.009	0.003	0.034	0.050	240	19.5	16
		Sep-98	< 0.0022	0.017	< 0.0022	0.0059 J	0.025	11	18.3	20

TABLE 3.1 (Continued)
ANALYTICAL DATA SUMMARY FOR SWMU 14
FORT RUCKER, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{n/}	Date Sampled	Benzene (µg/L) ^{o/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	Total BTEX (µg/L)	Naphthalene (µg/L)	MTBE ^{m/} (µg/L)
14-G3 Source Area 35 - 45	35.86	Jul-91	110	< 5	< 5	140	255	NA	NA
		Jan-94	27	< 5	< 5	20	52.0	NA	NA
		Jul-97	< 1	< 1	< 1	< 2	< 5.0	NA	NA
		Dec-97	< 1	< 1	< 1	< 2	< 5.0	NA	NA
		May-98	9.90	< 0.33	< 0.37	1.49	11.7	NA	NA
		Aug-98	< 0.33	< 0.33	< 0.37	< 0.85	< 1.9	NA	NA
		Nov-98	< 0.33	< 0.33	< 0.37	< 0.85	< 1.9	NA	NA
		Feb-99	< 0.33	< 0.33	< 0.37	< 0.85	< 1.9	NA	NA
		Apr-99	1 U	1 U	1 U	1 U	2 U	NA	1 U
14-G4 Source Area 35 - 45	39.74	Jul-91	400	600	200	2,000	3,200	NA	NA
		Jan-94	70	200	200	1,000	1,470	NA	NA
		Jul-97	< 5	100	99	180	382	NA	NA
		Dec-97	< 2	5.1	150	910	1,070	NA	NA
		May-98	< 0.33	0.62	1.1	5.2	7.1	NA	NA
		Aug-98	1.4	290	180	1,110	1,580	NA	NA
		Nov-98	< 1.6	64	35	204	304	NA	NA
		Feb-99	< 8.2	16	140	810	970	NA	NA
		Apr-99	1 U	1 U	45	244	290 U	NA	14
14-G6 350 ft d/g ^{p/} from Source 18 - 28	18.57	Jan-94	64	< 5	< 5	32	101	NA	NA
		Jul-97	< 1	< 1	< 1	< 2	< 5.0	NA	NA
		Dec-97	< 1	< 1	< 1	< 2	< 5.0	NA	NA
		May-98	< 0.33	< 0.33	< 0.37	< 0.85	< 1.9	NA	NA
		Aug-98	6.1	< 0.33	2	11	19.2	NA	NA
		Nov-98	< 0.33	< 0.33	< 0.37	< 0.85	< 1.9	NA	NA
		Feb-99	< 0.33	< 0.33	< 0.37	< 0.85	< 1.9	NA	NA
Apr-99	1 U	1 U	1 U	1 U	2.0 U	NA	1 U		

TABLE 3.1 (Concluded)
ANALYTICAL DATA SUMMARY FOR SWMU 14
FORT RUCKER, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data (Continued)

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc)	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	Total BTEX (µg/L)	Naphthalene (µg/L)	MTBE (µg/L)
14-G9 575 ft d/g from Source 8 - 13	3.04	Jul-95	16.5	< 5	< 5	< 0.84	21.9	NA	NA
		Jul-97	74	< 2	< 2	10.7	86.7	NA	NA
		Dec-97	120	< 5	< 5	7.9	133	NA	NA
		May-98	160	< 0.33	< 0.37	0.85	161	NA	NA
		Aug-98	130	< 0.33	< 0.37	9.4	140	NA	NA
		Nov-98	94	< 1.6	< 1.8	< 4.3	97.9	NA	NA
		Feb-99	62	< 0.33	< 0.37	1.5	63.9	NA	NA
		Apr-99	51	1 U	1 U	1 U	52.5	NA	7

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes, TPH = total petroleum hydrocarbons, DRO = diesel-range organics, GRO = gasoline-range organics, TVH = total volatile hydrocarbons.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.
The data should be considered as a basis for decision-making and are usable for many purposes.

^{f/} NA = Not analyzed or not available.

^{g/} U = Compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{h/} J1 = The analyte is qualified as an estimated value solely because it is greater than the method detection limit (MDL) and less than the practical quantitation limit (PQL), indicating no laboratory quality issues.

^{i/} U = Compound analyzed for and is not present above the reported sample quantitation limit (SQL). J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.

^{j/} ppmv = parts per million by volume.

^{k/} M = Laboratory reported value may be biased due to apparent matrix interferences. J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.

^{l/} M = Laboratory reported value may be biased due to apparent matrix interferences.

^{m/} MTBE = methyl *tert*-butyl ether.

^{n/} ft btoc = feet below top of casing.

^{p/} µg/L = micrograms per liter.

^{q/} d/g = downgradient.

years of bioventing are between approximately 8 and 22 feet bgs beneath the former POL pit. Within this zone, soils exhibited localized staining, had mild to strong fuel odors, and were generally very moist to saturated. A comparison of analytical results for soil samples collected prior to and following approximately 2 years of bioventing system operation indicates an overall reduction in BTEX and total petroleum hydrocarbon (TPH) concentrations.

TPH concentrations in source area soils were reduced from an average of 10,000 milligrams per kilogram (mg/kg) prior to bioventing to an average of 2,770 mg/kg (diesel-plus gasoline-range hydrocarbons) following 2 years of bioventing (Figure 3.1). The majority of the remaining TPH consists of diesel-range organics (DRO), indicating that gasoline-range organics (GRO) were preferentially biodegraded by the bioventing system. With the exception of total xylenes, elevated detection limits resulting from sample dilution during analysis prevents comparison of pre- and post-remediation BTEX concentrations. However, for the sample pair VW1-10/CB3, total xylenes results indicate a reduction from 8.5 mg/kg to less than 2.7 mg/kg following 2 years of bioventing (Table 3.1).

Reductions in soil gas BTEX concentrations support the conclusion that the bioventing system has effectively reduced fuel hydrocarbon concentrations in site soil (Table 3.1). Average concentrations of total volatile hydrocarbons (TVH) in soil gas were reduced from 6,170 parts per million by volume (ppmv) prior to bioventing to 22 ppmv after 28 months of bioventing.

3.2.1.3 Groundwater Quality

Groundwater quality data collected in 1991 and 1994 at source area wells 14-G4 and 14-G3 indicate that dissolved BTEX concentrations were decreasing prior to installation of the bioventing system (Table 3.1 and Figure 3.1). These data, although very limited, suggest that natural weathering of the contaminant source was occurring prior to bioventing.

Groundwater quality data collected since the 1996 initiation of bioventing do not indicate clear trends. The fluctuations in dissolved BTEX concentrations, most evident for well 14-G4, suggest the continued presence of residual contamination that partitions into the groundwater at varying rates. This partitioning is probably most significant during wet periods when the water table is high (i.e., when groundwater contacts a greater thickness of the contaminated interval) and a greater volume of recharge water is percolating through the vadose zone. Dissolved BTEX concentrations at well 14-G9, located approximately 575 feet downgradient from the source area, generally increased from 1994 to 1998, indicating that the beneficial effects of natural source weathering and bioventing had not yet impacted this region of the plume. In contrast, the results from the last four sampling events (August 1998 through April 1999) indicate a decreasing trend (Figure 3.1). It is unlikely that these more recent data reflect the effects of the bioventing system so soon after system startup (2 years) given an average estimated groundwater velocity for this site of 47 ft/yr. Downgradient reductions are more likely the result of natural attenuation.

As shown in Table 3.2, the S statistics computed using the MK method (Section 3.1.1) and data collected after initiation of bioventing range from -3 to -9, indicating overall

FIGURE 3.1
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SMWU-14, FORT RUCKER, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

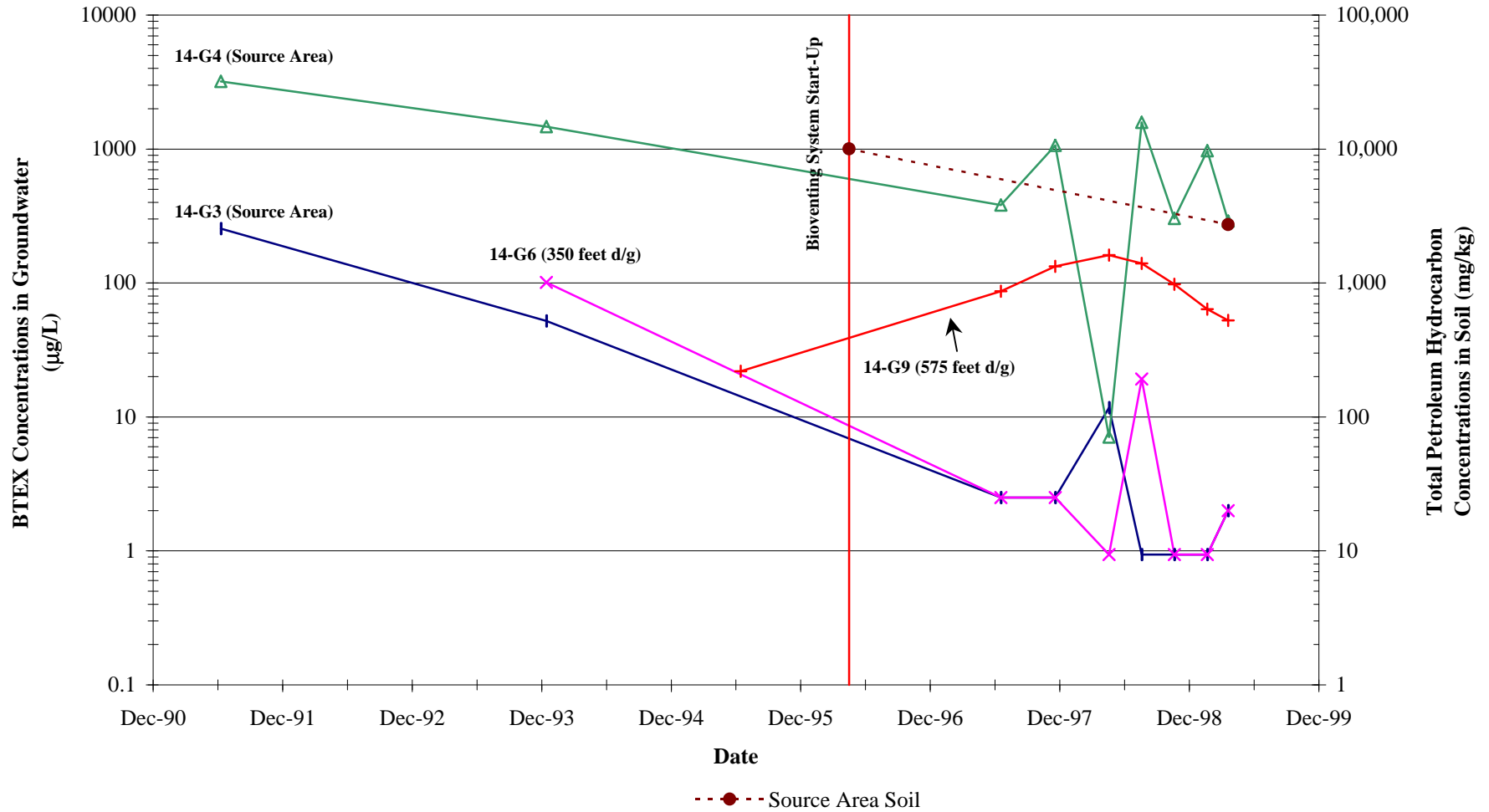


TABLE 3.2
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SWMU 14
FORT RUCKER, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{c/} (µg/L)
14-G4	Source	-- ^{f/}	-3	--	-15	1,470 (2.3 yr)	290 (2.9 yr)
14-G3	Source	--	-7	--	-0.1	52 (2.3 yr)	<4 (2.9 yr)
14-G6	350 feet d/g ^{g/}	--	-5	--	-0.1	101 (2.3 yr)	<4 (2.9 yr)
14-G9	575 feet d/g	--	-9	--	-16	21.9 (0.8 yr)	52.5 (2.9 yr)

^{a/} S Statistic computed using the Mann-Kendall method (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method (positive value indicates increasing trend, negative value indicates decreasing trend).

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = Insufficient data available.

^{g/} d/g = downgradient.

decreasing trends at each well. This observation is supported by the Sen's slopes, which range from -0.1 for wells 14-G3 and 14-G6 to -15 for well 14-G4. The minimal slopes computed for wells 14-G3 and 14-G6 are indicative of the fact that BTEX was not detected at these wells during the last few sampling events.

Well 14-G9 is the farthest downgradient sampling station that was monitored prior to April 1999. Therefore, the downgradient extent of the dissolved BTEX plume was not defined prior to this date. However, a swampy area with seeps and springs is located approximately 100 feet downgradient from 14-G9, and at least a portion of the BTEX plume may have discharged to this area in the past. The most recent sampling data suggest that the toe of the plume is currently located near this swampy area, and sampling results for 14-G9 suggest that the plume front may have started receding after May 1998.

3.2.1.4 Effectiveness Summary

Operation of the bioventing system appears to have caused substantial reductions in BTEX concentrations in vadose zone soils. The groundwater quality data for this site also indicate decreasing dissolved BTEX concentrations, but do not clearly indicate bioventing-related reductions. Bioventing would be expected to impact groundwater only within approximately 100 feet of the original source. Remediation of the vadose zone via bioventing has not yet impacted groundwater quality at downgradient wells 14-G6 and 14-G9. In addition, the available data do not indicate significant, bioventing-related changes in the areal extent of the dissolved BTEX plume. Available information suggests that the

very moist to saturated portions of the soil column described in Section 3.2.1.2 were not effectively remediated by the bioventing system.

3.2.2 Maxwell AFB, Alabama (Site ST-001)

Maxwell AFB is located in the south-central portion of Alabama.

3.2.2.1 Site Description

Site ST-001, also known as the old Base Motor Pool Service Station, was originally used for dispensing petroleum products for motorized vehicles beginning in the 1940s. Two underground storage tanks (USTs) located at the site were used to store diesel fuel and gasoline. The tanks and related piping were removed in March 1994. After the tanks were removed, the excavation was backfilled with clean soil and covered with gravel. There is no evidence of free product at the site.

Site ST-001 is underlain by alluvial deposits consisting of sand, gravel, silt, and clay layers. The grain sizes generally increase with depth, with approximately 8 to 10 feet of silty, sandy clay overlying sand and gravelly sand. In the vicinity of the former tank/piping excavation, much or all of the silty clay appears to have been removed and replaced with clean fill consisting of a mixture of clay, sand, and gravel. The water table is present beneath the site at depths of 20 to 23 feet bgs. The average hydraulic conductivity for the shallow aquifer was estimated to be 5.8 ft/day, and the average advective groundwater flow velocity was computed to be 31 ft/yr.

A pilot-scale bioventing system was operated and monitored from September 1995 to September 1996. The blower was then shut down to facilitate respiration testing. After a 36-day period, the blower was restarted and re-optimized. Based on the year-end respiration test and soil gas sampling results, significant remediation of vadose zone soils had occurred, and a recommendation was made to initiate site closure activities.

3.2.2.2 Soil Quality

Soil quality data collected from the same depth intervals in two closely-spaced boreholes during September 1995 and July 1997 indicate substantial reductions in soil BTEX concentrations as a result of bioventing (Table 3.3). Based on the analytical results for 16 confirmation soil samples collected in July 1997, the *Final Confirmation Sampling and Analysis Report for Site ST-001* (Parsons ES, 1999a) concluded that the potential source for groundwater contamination by partitioning of BTEX from soil to groundwater had essentially been eliminated via bioventing treatment of site soils. The relatively low concentrations of BTEX constituents detected in 1997 were located near the water table at depths of 22 to 24 feet bgs.

3.2.2.3 Groundwater Quality

Insufficient data were available to compute trend statistics for the pre-bioventing period using the statistical methods described in Section 3.1. However, groundwater quality data for source area well GMW-4 and downgradient well GMW-44, summarized in Table 3.3 and on Figure 3.2, suggest that natural attenuation processes were not significantly reducing maximum dissolved BTEX concentrations during the 4- to 5-year

TABLE 3.3
ANALYTICAL DATA SUMMARY FOR SITE ST-001
MAXWELL AFB, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Soil Data

Location ID	Depth of Sample (ft bgs) ^{c/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes (mg/kg)	BTEX (mg/kg)	Naphthalene (mg/kg)
VW / SB02	15-17	Sep-95	< 0.053	0.38	0.89	7.5	8.80	NA ^{e/}
	15-17	Jul-97	< 0.001	< 0.002	< 0.002	< 0.002	< 0.0070	NA
	20-22	Sep-95	< 0.055	< 0.055	1.00	5.90	6.96	NA
	20-22	Jul-97	< 0.001	< 0.002	< 0.002	< 0.002	< 0.0070	NA

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{f/}	Date Sampled	Benzene (µg/L) ^{g/}	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX ^{h/} (µg/L)	Naphthalene (µg/L)
GMW-4 Source Area 22 - 32	21.2 21.42 21.97 23.06	Jan-91	290	3,300	240	5,200	9,030	NA
		Jul-96	< 500	7,210	1,820	8,020	17,300	NA
		Jul-97	13.4	2,450	1,730	8,340	12,500	624
		Feb-98	< 5	1,400	1,200	5,900	8,500	NA
		Aug-98	< 5	840	920	4,020	5,780	NA
		Feb-99	BDL ^{h/}	700	850	4,000	5,550	NA
GMW-44 180 ft d/g ^{i/} from Source NA	21.37 19.68 19.8 20.35 21.36	Sep-94	43	7	12	25	87	NA
		Jul-96	37.3	189	152	423	801	NA
		Jul-97	7.44	68.8	251	839	1,170	56.2
		Feb-98	< 5	11	92	470	576	NA
		Aug-98	1	1	8	14	24	NA
		Feb-99	BDL	BDL	BDL	BDL	BDL	BDL
GMW-3 Source Area 22 - 32	20.7 20.8 21.33 22.43	Jan-91	33	39	31	120	223	NA
		Jul-96	1.1	< 1	< 1	3	5	NA
		Jul-97	< 5	< 5	< 5	< 5	< 10	< 18
		Aug-98	2	3	3	8	16	NA
		Feb-99	17	BDL	6	BDL	25	NA

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} NA = not analyzed or not available.

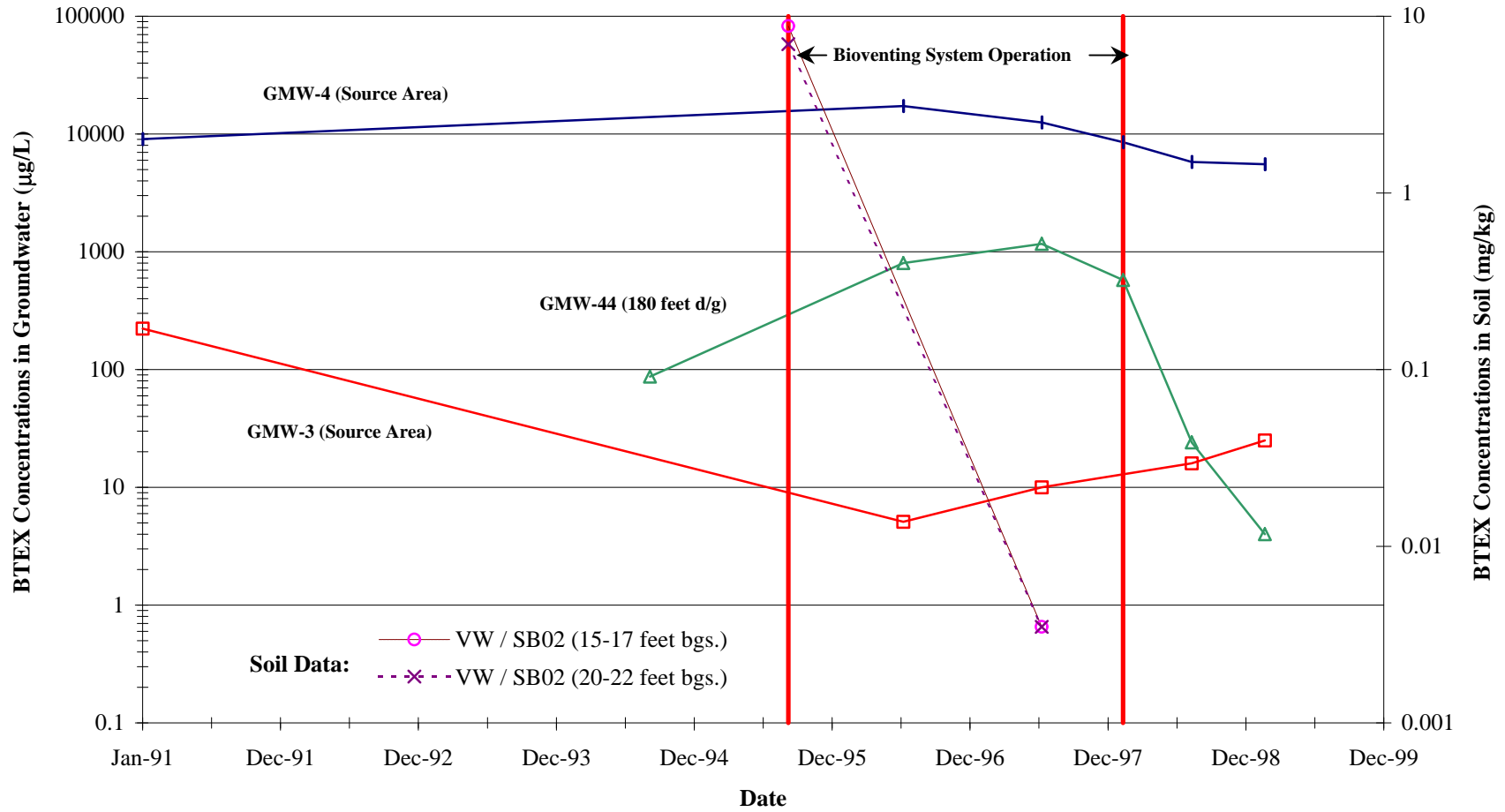
^{f/} ft btoc = feet below top of casing.

^{g/} µg/L = micrograms per liter.

^{h/} BDL = below detection limit. Value of 1 used for graphing purposes.

^{i/} d/g = downgradient.

FIGURE 3.2
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SITE ST-001, MAXWELL AFB, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY



period prior to initiation of the bioventing system. More recent data appear to reflect the beneficial effects of the bioventing system, at least locally.

The S statistic and Sen's slope calculated for BTEX data for well GMW-4 are -10 and -3,160, respectively, indicating a decreasing trend (Table 3.4). Similarly, the S statistic and trend-line slope calculated for well GMW-44 are -8 and -272, respectively, also indicating a decreasing trend. The decreases at this well were not apparent until the end of the bioventing period, most likely due to the time necessary for less-contaminated groundwater to migrate from the biovented source area to this downgradient location. In contrast, the S statistic of 4 and Sen's slope of 6 for source area well GMW-3 reflect the slight increases in BTEX concentrations measured at this well since the initiation of bioventing; however, concentrations at this well, which is located west of (cross-gradient from) the former USTs near the edge of the inferred source area (Appendix A), are relatively low (5 to 25 micrograms per liter [$\mu\text{g/L}$]).

The decreasing dissolved BTEX concentrations measured in groundwater at downgradient well GMW-44 suggest that the BTEX plume is shrinking. Based on limited pre-bioventing groundwater quality data, plume shrinkage has largely occurred since the 1995 startup of the bioventing system, and is likely due to the resulting remediation of the vadose zone. However, the plume length has not been defined; therefore, the degree to which the plume may be receding toward the source area cannot be discerned.

TABLE 3.4
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE ST-001
MAXWELL AFB, ALABAMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} ($\mu\text{g/L}$) ^{d/}	Most recent BTEX ^{e/} ($\mu\text{g/L}$)
GMW-4	Source	-- ^{f/}	-10	--	-3,160	9,030 (4.7 yr)	5,550 (3.4 yr)
GMW-3	Source	--	4	--	6	223 (4.7 yr)	25 (3.4 yr)
GMW-44	180 feet d/g ^{g/}	--	-8	--	-272	87 (1.0 yr)	4 (3.4 yr)

^{a/} S Statistic computed using the Mann-Kendall method (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method (positive value indicates increasing trend, negative value indicates decreasing trend).

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} $\mu\text{g/L}$ = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = Insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

3.2.2.4 Effectiveness Summary

Available information indicates that the bioventing system at Site ST-001 has had a noticeable, beneficial impact on groundwater quality. It should be noted that free product has reportedly never been present at this site; therefore, it is unlikely that a significant smear zone at the water table existed. In addition, the subsurface contaminant source(s) (USTs and pipelines) probably released most of the contamination into deeper, more permeable soils that are easily biovented.

3.2.3 Westover Air Reserve Base (ARB), Massachusetts (Site FT-03)

Westover ARB is located in the Connecticut River Valley in the west-central portion of Massachusetts.

3.2.3.1 Site Description

Site FT-03 was used from 1940 to 1964 for fire training exercises, during which unknown volumes of waste fuels and solvents were released onto the ground surface. The site is covered by sparsely vegetated, sandy, gravelly soil with no visible evidence of the former fire training area or fuel hydrocarbon contamination. Past investigations have identified soil contamination in the former burn area to depths of up to 15 feet bgs.

The shallowest sediments at Site FT-03 consist of fine- to medium-grained sands that range in thickness from 0 to 20 feet, and appear to represent disturbed Base fill. Underlying the surficial soils is a 10- to 40-foot-thick, well-sorted, interbedded sand and sandy gravel, with some clean, coarse gravel seams. Below the sand and gravel are layers of fine sand and silty sand. The water table is present in these sands at a depth of 40 to 45 feet bgs. At approximately 80 feet bgs, lacustrine varved silts and clays are present. These sediments are up to 40 feet thick and form an aquitard. The average hydraulic conductivity of the sands at the water table was computed to be 3.4 ft/day based on slug tests. The average groundwater flow velocity at the site was estimated to be approximately 63 ft/yr. Using the maximum measured hydraulic conductivity value, the maximum advective groundwater flow velocity is approximately 220 ft/yr.

A full-scale bioventing system began operating at the site in May 1995. The system is still operating.

3.2.3.2 Soil Quality

Total BTEX concentrations detected in 12 soil samples collected from the burn pit area in 1991 and 1993 ranged up to 41.7 mg/kg and averaged 4.8 mg/kg (Table 3.5). An evaluation of the effectiveness of the existing bioventing system, including a review of soil, soil gas, and groundwater sampling results collected from 1987 to 1998, was performed in 1998. Based on soil and soil gas results, the full-scale bioventing system installed in May 1995 had effectively accelerated degradation of VOCs across the site. Overall, concentrations in the central burn area had decreased to a point where bioventing was no longer needed. Therefore, the evaluation recommended that bioventing be

**TABLE 3.5
ANALYTICAL DATA SUMMARY FOR SITE FT-03
WESTOVER ARB, MASSACHUSETTS
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Soil Data

Location ID	Depth of Sample (ft bgs) ^{c/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	BTEX ^{a/b/} (mg/kg)	Naphthalene (mg/kg)
CTF-1	0	1991/1993	NA ^{e/}	NA	NA	NA	0.078	NA
CTF-2	5	1991/1993	NA	NA	NA	NA	1.10	NA
CTF-4	NA	1991/1993	NA	NA	NA	NA	0.001	NA
CTF-5	5	1991/1993	NA	NA	NA	NA	41.7	NA
CTF-6	0	1991/1993	NA	NA	NA	NA	4.32	NA
CTF-7	0	1991/1993	NA	NA	NA	NA	0.213	NA
CTF-9	5	1991/1993	NA	NA	NA	NA	4.20	NA
CTF-11	5	1991/1993	NA	NA	NA	NA	4.40	NA
CTF-12	7	1991/1993	NA	NA	NA	NA	0.790	NA
CTF-13	0	1991/1993	NA	NA	NA	NA	0.280	NA
CTA-2	3	1991/1993	NA	NA	NA	NA	0.380	NA
CTA-5	5	1991/1993	NA	NA	NA	NA	0.290	NA
B10	1.5-3.5	Jan-Mar 1999	0.051 U ^{e/}	0.039 J ^{g/}	0.051 U	0.068 J	0.158 J	0.051 U
B8	7-9	Jan-Mar 1999	0.05 U	0.05 U	0.05 U	0.05 U	0.100 U	0.05 U
C10	0-2	Jan-Mar 1999	0.047	0.09	0.022	0.139	0.298	0.019 U
C8	3-5	Jan-Mar 1999	0.062 U	0.18	0.064	0.246 J	0.521 J	0.038 U
BC7	39-41	Jan-Mar 1999	0.05 U	0.05 U	0.05 U	0.05 U	0.100 U	0.05 U
D8	7-9	Jan-Mar 1999	0.052 U	0.052 U	0.052 U	0.052 U	0.104 U	0.052 U
D7	9-11	Jan-Mar 1999	0.072	0.035 J	0.048 J	0.072 U	0.191 J	0.072 U
D6	9-11	Jan-Mar 1999	0.31 J	1.7 J	0.69 J	3.77 J	6.47 J	0.52
D5	11-13	Jan-Mar 1999	0.059	0.054	0.05 U	0.077	0.215 U	0.013 J
D4	0-2	Jan-Mar 1999	0.056 U	0.056 U	0.056 U	0.056 U	0.112 U	0.036 J
E7	9-11	Jan-Mar 1999	0.059 U	0.059 U	0.059 U	0.08 J	0.169 J	0.059 U
E6	7-9	Jan-Mar 1999	0.078 U	0.023 J	0.036 J	0.11 J	0.208 J	0.078 U
E5	6-8	Jan-Mar 1999	0.069 U	0.069 U	0.069 U	0.069 U	0.138 U	0.069 U
E4	6-8	Jan-Mar 1999	0.073 U	0.025 J	0.073 U	0.099 J	0.197 J	0.073 U
F8	0-2	Jan-Mar 1999	0.67 U	0.67 U	0.67 U	0.67 U	1.34 U	0.018 J
F7	4-6	Jan-Mar 1999	0.058 U	0.058 U	0.058 U	0.058 U	0.116 U	0.058 U
F6	0-2	Jan-Mar 1999	0.062 U	0.023 BJ ^{h/}	0.062 U	0.062 U	0.116 BJ	0.062 U

TABLE 3.5 (Continued)
ANALYTICAL DATA SUMMARY FOR SITE FT-03
WESTOVER ARB, MASSACHUSETTS
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{i/}	Date Sampled	Benzene (µg/L) ^{j/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)				
TF-2 Source Area 68.5 - 83.5	44.74	Jan-87	0.29	ND	ND	NA	0.29	NA				
		Feb-87	ND	ND	ND	NA	ND	NA				
		Jun-94	ND	ND	ND	ND	ND	ND				
		May-95	7.84	39.4	11.5	44.8	104	NA				
		May-96	ND	ND	ND	ND	ND	NA				
		Jan-96	ND	ND	ND	ND	ND	NA				
		Jul-96	ND	ND	ND	ND	ND	NA				
		Nov-97	ND	ND	ND	ND	ND	NA				
		Jan-99	2.0	UJ ^{v/}	ND	2.00	UJ	ND	NA			
TF-5 130 ft d/g ^{m/} from Source 35 - 50	42.92	Jun-93	ND	ND	22.0	7.6	29.6	ND				
		Jun-94	ND	ND	1.5	ND	1.5	ND				
		May-95	2.29	19.4	46.7	55.8	124	NA				
		Jan-96	ND	ND	ND	ND	ND	NA				
		May-96	0.1	0.13	2	0.85	3.1	NA				
		Jul-96	< 1.0	< 1.0	1.2	ND	2.2	NA				
		Nov-97	ND	ND	ND	ND	ND	NA				
Jan-99	2.0	ND	2.00	ND	4.0	NA						
TF-11 270 ft d/g from Source NA	44.07	Jun-93	ND	0.28	13.0	12.0	25.3	ND				
		Jun-94	1.4	J	0.94	J	69	2.7	74.0	J	4.6	J
		May-95	1.99	11.6	39.8	23.6	76.9	NA				
		Jan-96	ND	ND	ND	ND	ND	NA				
		May-96	ND	ND	2.4	0.47	2.9	NA				
		Jul-96	ND	ND	ND	ND	ND	NA				
		Jan-99	2.0	UJ	ND	2.00	UJ	ND	4.0	UJ	NA	
TF-8 400 ft d/g from Source 38.7 - 53.7	45.95	Jun-93	ND	0.39	ND	1.4	1.8	ND				
		Jun-94	ND	ND	ND	ND	ND	ND				
		May-95	< 1.0	5.81	2.12	7.97	16.4	NA				
		Jan-96	ND	ND	ND	ND	ND	NA				
		May-96	ND	ND	ND	ND	ND	NA				
		Jul-96	ND	ND	ND	ND	ND	NA				
		Jan-99	NA	NA	NA	NA	NA	NA				
TF-13 200 ft d/g 35 - 45	41.91	May-95	3.71	42.3	16.5	61.6	124	NA				
		Jul-96	ND	ND	ND	ND	ND	NA				

TABLE 3.5 (Concluded)
ANALYTICAL DATA SUMMARY FOR SITE FT-03
WESTOVER ARB, MASSACHUSETTS
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data (Concluded)

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc)	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
TF-16	44.15	May-95	3.46	32.8	11.3	40.8	88.4	NA
330 ft d/g from Source	42.5	May-96	ND	ND	ND	ND	ND	NA
40 - 50		Jul-96	ND	ND	ND	ND	ND	NA
		Jan-99	NA	NA	NA	NA	NA	NA

^a BTEX = benzene, toluene, ethylbenzene, and xylenes.

^b In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^c ft bgs = feet below ground surface.

^d mg/kg = milligrams per kilogram.

^e NA = not analyzed or not available.

^f U = Compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^g J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.
The data should be considered as a basis for decision-making and are usable for many purposes.

^h BJ = B = Analyte found in associated method blank. J = Estimated value.

ⁱ ft btoc = feet below top of casing.

^j µg/L = micrograms per liter.

^k ND = Not detected. 1 used for graphing purposes.

^l UJ = The analyte was not present above the SQL. The associated numerical value may not accurately or precisely represent the concentration necessary to detect the analyte in the sample.

^m d/g = downgradient.

ⁿ BLQ = below limit of quantification.

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

discontinued, and that soil samples be collected to confirm that further engineered remediation is not warranted.

Additional soil samples were collected in early 1999 (January-March). Total BTEX concentrations detected in 17 soil samples collected from the same area as the 12 previously collected samples ranged up to 6.5 mg/kg and averaged 0.6 mg/kg (Table 3.5). These data indicate an order-of-magnitude reduction in average total BTEX concentrations during the 6 years from 1993 through 1999.

3.2.3.3 Groundwater Quality

Groundwater quality data collected over a 12-year period from 1987 to 1999 are summarized on Table 3.5, and selected data are plotted on Figure 3.3. As noted on this figure, 1987 BTEX concentrations reported for well TF-2A likely are biased low because xylenes data for these two samples were not available. Dissolved BTEX data for source area well TF-2A, obtained between June 1993 and May 1995, suggest a decreasing trend prior to initiation of bioventing in 1995. In contrast, pre-1995 data for downgradient wells TF-11 and TF-5 do not suggest decreasing trends.

These observations are supported by pre-bioventing trend statistics for these wells, as reported in Table 3.6. Calculated MK statistics for the pre-bioventing period ranged from -1 at TF-2A (indicating a decreasing trend) to 3 at TF-11 (indicating an increasing trend). The 1987 data for well TF-2A were not used in the statistical calculations for the reason stated above. Sen's slope estimates for the pre-bioventing period range from -520 for well TF-2A (again indicating a decreasing trend) to 46 for well TF-5 (again indicating an increasing trend).

The MK trend statistics calculated for groundwater quality data collected from May 1995 to January 1999 (after initiation of bioventing) ranged from -6 at source area well TF-2A to -3 at downgradient well TF-11, indicating decreasing trends. Sen's slope estimates for this time period ranged from -323 at source area well TF-2A to -0.4 at downgradient well TF-11. Comparison of the slopes computed for well TF-2A using data collected both prior to and after initiation of bioventing do not indicate more rapid decreases in dissolved BTEX concentrations due to bioventing. In contrast, the magnitudes of the slopes computed for downgradient wells TF-5 and TF-11 decreased slightly (became either less positive or more negative) after initiation of bioventing, suggesting that groundwater quality in these downgradient areas was impacted by the bioventing system.

Dissolved BTEX concentrations at well TF-11, located 270 feet downgradient from the source area, decreased from an average of 59 µg/L during and prior to May 1995 to nondetect within 1 year of system startup. Similarly, concentrations at well TF-5, located 130 feet downgradient from the source area, decreased from an average of 53 µg/L to nondetect within 1 year of system startup. The post-system-startup Sen's slopes computed for these two downgradient wells do not reflect these abrupt decreases because the slopes are influenced by the relatively low BTEX concentrations uniformly detected at these wells during the most recent sampling events. These rapid reductions could conceivably be related to operation of the bioventing system given the maximum groundwater velocity estimated for the site of 220 ft/yr and the effects of dispersion, which causes groundwater to move faster than the calculated average linear groundwater velocity.

FIGURE 3.3
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SITE FT-03, WESTOVER ARB, MASSACHUSETTS
SOURCE-REDUCTION EFFECTIVENESS STUDY

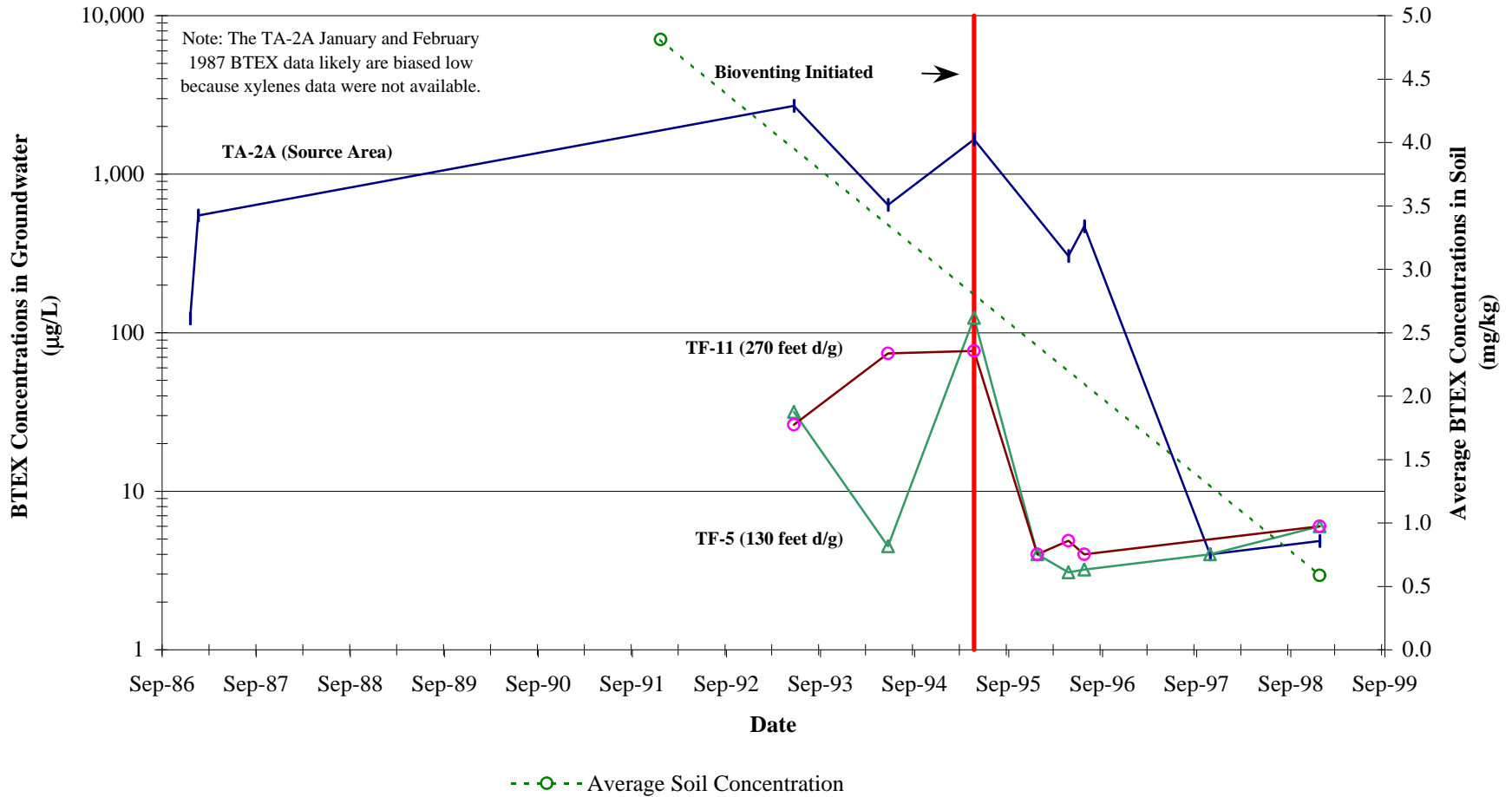


TABLE 3.6
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE FT-03
WESTOVER ARB, MASSACHUSETTS
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{e/} (µg/L)
TF-2A	Source	-1	-6	-520	-323	1,660 (0.0 yr)	4.9 (3.7 yr)
TF-5	130 feet d/g ^{f/}	1	-4	46	0	124 (0.0 yr)	6 (3.7 yr)
TF-11	270 feet d/g	3	-3	25	-0.4	77 (0.0 yr)	<6 (3.7 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method (positive value indicates increasing trend, negative value indicates decreasing trend).

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} d/g = downgradient.

The rapid decrease in dissolved BTEX concentrations measured at downgradient wells TF-5, TF-11, and TF-8 (Table 3.5) since May 1995 suggest that the areal extent of the BTEX plume has decreased substantially during the last 4 years. BTEX plume maps constructed using May 1995 data (Parsons ES, 1997) indicate that the 10-µg/L BTEX isopleth extended approximately 500 feet downgradient from source area well TF-2A. In contrast, July 1996 data suggest that the 1-µg/L BTEX isopleth extended only approximately 150 feet downgradient from this well during that sampling event.

3.2.3.4 Effectiveness Summary

The information presented above indicates that remediation of the vadose zone via bioventing has reduced the extent and magnitude of the dissolved BTEX plume. This conclusion is not supported by comparison of Sen's slopes for source area well TF-2A calculated for the periods prior to and after the May 1995 initiation of bioventing. However, this may be due to the limited amount of pre-bioventing data points for this well (total of three). Because the water table at this site is relatively deep (40-45 feet bgs), significant soil contamination did not extend to the water table, and a free-product smear zone that extended below the average water table did not develop. These site characteristics, combined with the permeable, well-drained nature of the vadose zone, enabled the bioventing system to rapidly reduce BTEX concentrations in subsurface soils.

The remaining dissolved contamination is being rapidly biodegraded (calculated BTEX half-life is 0.6 year [Parsons ES, 1997]).

3.3 SVE/BIOVENTING SITES

3.3.1 Patrick AFB, Florida (Site ST-29)

Patrick AFB is located east of Orlando on a barrier island situated off the Atlantic coast of Florida.

3.3.1.1 Site Description

Site ST-29 consists of the BX Service Station, including a small food market (Building 736), a gasoline dispensing area, and a car wash facility (Building 737). The BX Service Station has been in operation since 1954. Four 10,000-gallon fiberglass motor vehicle gasoline (MOGAS) USTs and one 1,000-gallon waste oil aboveground storage tank (AST) are currently used to dispense or store petroleum products.

The original service station, located northeast of Building 736, consisted of four former 5,000-gallon steel USTs that contained MOGAS, a former 4,000-gallon steel UST that contained diesel fuel, and two former dispenser islands and associated piping. The former dispenser islands were located above the USTs. During a major renovation in 1973, the dispenser islands were removed. The original USTs were abandoned in place, and the original service station area was paved with asphaltic concrete.

New fueling facilities consisting of dispenser islands, five 10,000-gallon fiberglass USTs for MOGAS, and associated piping were installed at their current locations west and southwest of Building 736. In 1985, a leak was detected in a fiberglass fuel line, and in 1986, one of the 10,000-gallon fiberglass USTs was removed due to leakage. It is estimated that approximately 700 gallons of MOGAS was released into the subsurface as a result of the fuel line and UST leaks. In February 1992, a 500-gallon UST southeast of Building 736 was removed and replaced with the 1,000-gallon waste oil AST. In 1993, the five abandoned USTs located northeast of Building 736 were excavated and removed along with some excessively contaminated soils.

Soils at this site consist of predominantly unconsolidated, poorly to moderately sorted, fine- to coarse-grained quartz sand with up to 40-percent shell fragments. Shallow groundwater at the site is typically encountered at approximately 4 to 6 feet bgs. Results of slug tests suggest that the average hydraulic conductivity of the shallow portion of the aquifer is approximately 75 ft/day, and the average advective velocity was estimated to be 160 ft/yr.

A pilot-scale remediation system consisting of one horizontal vent well was installed, and an air-injection bioventing pilot test was performed in March 1993. To reduce the initial high levels of TVH in the soil gas, the pilot system was run in SVE mode from October 1993 to January 1994. The pilot-scale air-injection bioventing system was then operated from January 1994 through November 1994. In July 1995, the pilot-scale system was expanded to include two additional horizontal vent wells. The expanded system was operated from July 1995 to July 1998 prior to final confirmation soil sampling.

3.3.1.2 Soil Quality

Site investigations identified a large area of contaminated soil west and southwest of Building 736. Petroleum-contaminated soil was estimated to extend approximately 220 feet downgradient from the source area. Much of the petroleum contamination was present in saturated soils. Historical soil BTEX concentrations for selected samples collected at adjacent locations over time are summarized in Table 3.7 and depicted on Figure 3.4.

In November 1996, soil gas sampling and respiration testing were performed following approximately 15 months of expanded-scale bioventing system operation. Results indicated that BTEX concentrations in vadose zone soils had been significantly reduced, but that elevated TVH and depleted oxygen levels, indicative of remaining fuel contamination, were observed at one of the sampling locations (Table 3.7). Results of the final confirmation soil sampling performed in July 1998 indicated that remediation activities at the site had reduced all target compounds, with the exception of total recoverable petroleum hydrocarbons (TRPH) at one location, to levels below closure standards in vadose zone soils. However, because the groundwater surface at the time of the final soil sampling event was 0.5 to 2.5 feet higher than previously encountered, unsaturated soil samples could not be collected at depths below 3.2 feet bgs.

3.3.1.3 Groundwater Quality

Groundwater quality data for the period prior to installation of the SVE/bioventing system are not available. Selected groundwater quality data for 1992 to 1997 are summarized in Table 3.7 and Figure 3.4. Groundwater quality data for source area well CPT-3S indicate the presence of a significant, continuing BTEX source. Dissolved BTEX concentrations at downgradient well CPT-04D also have increased substantially. In contrast, substantial reductions in BTEX concentrations are evident at source area well CPT-2S and downgradient well CPT-9D. Available information indicates that the BTEX plume is migrating downward beneath monitoring point CPT-9D prior to migrating upward toward CPT-4D.

MK trend statistics were computed for dissolved BTEX concentrations at wells CPT-3S, CPT-2S, CPT-9D, and CPT-4D are 3, -3, -6, and 2, respectively (Table 3.8). These statistics support increasing trends at source area well CPT-3S and downgradient well CPT-4D, and decreasing trends at source area well CPT-2S and downgradient well CPT-9D. The Sen's slopes are consistent with the MK statistics, ranging from 7,570 at CPT-3S (indicating significant concentration increases over time) to -529 at CPT-2S.

Historical groundwater quality data obtained in 1994 through 1996 indicate that the areal extent of the plume was decreasing during this period. The inferred downgradient extents of the 5- μ g/L dissolved BTEX isopleth in March 1994, March/May 1995, and January 1996 were approximately 600 feet, 375 feet, and 275 feet, respectively. However, data for March 1998 (e.g., for CPT-4D) indicate that the BTEX plume had expanded: the 5- μ g/L BTEX isopleth appeared to extend approximately 400 feet

**TABLE 3.7
ANALYTICAL DATA SUMMARY FOR SITE ST-29
PATRICK AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Soil Data

Location ID	Depth of Sample (ft bgs) ^{c/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	BTEX ^{a/b/} (mg/kg)	Naphthalene (mg/kg)
MPF	3.5	Jul-95	0.47	0.57	7.4	9	17.4	NA ^{g/}
SB15	3	Jul-98	0.001 U ^{e/}	0.001 J ^{f/}	0.0185	0.0105	0.031 J	0.00128 U
MPE	3.5	Jul-95	0.075	< 0.05	20	160	180	NA
SP14	3	Jul-98	0.0011 U	0.0022 U	0.0022 U	0.0049 J	0.0077 J	1,320 U
MPC	3.5	Mar-93	< 0.31	< 0.36	< 0.26	5.7	6.17	NA
	3.5	Dec-94	0.13	0.15	0.16	0.49	0.93	NA
SB9	3	Jul-98	0.001 U	0.0011 U	0.0021 U	0.0045 J	0.0066 J	1.25 U

Soil Gas Data

Location ID	Depth of Sample (ft bgs)	Date Sampled	Benzene (ppmv) ^{h/}	Toluene (ppmv)	Ethyl-benzene (ppmv)	Xylenes (ppmv)	BTEX ^{a/b/} (ppmv)	TVH ^{a/} (ppmv)	Field Screening Data	
									Oxygen (%)	TVH (ppmv)
MPA	3.5	Mar-93	< 5.3	110	46	310	469	100,000	0.0	> 20,000
		Dec-94	0.033	0.003	0.008	0.46	0.50	6.9	11.8	230
		Jul-95	NA	NA	NA	NA	NA	NA	11.0	50
		Nov-96	NA	NA	NA	NA	NA	NA	10.7	156
MPB	3.5	Mar-93	NA	NA	NA	NA	NA	NA	0.0	> 20,000
		Dec-94	NA	NA	NA	NA	NA	NA	3.5	560
		Jul-95	NA	NA	NA	NA	NA	NA	4.2	50
		Nov-96	< 0.002	< 0.002	< 0.002	< 0.002	< 0.004	0.17	7.5	340
MPC	3.5	Mar-93	< 2.1	8.3	12	83	104	38,000	0.0	> 20,000
		Dec-94	0.02	< 0.002	< 0.002	< 0.002	0.02	1.7	14.2	200
		Jul-95	NA	NA	NA	NA	NA	NA	11.3	40
		Nov-96	< 0.002	< 0.002	< 0.002	< 0.002	< 0.004	0.13	12.5	164
MPE	3.5	Jul-95	88	130	240	1200	1,660	27,100	0.0	19,000
		Nov-96	< 0.005	0.11 M ^{i/}	0.24	1.6	1.95 M	9.9	8.2	196
MPF	3.5	Jul-95	98	67	300	210	675	27,500	0.0	20,000
		Nov-96	0.16	0.53	0.39	0.65	1.73	2,200	0.0	1020

TABLE 3.7 (Concluded)
ANALYTICAL DATA SUMMARY FOR SITE ST-29
PATRICK AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{j/}	Date Sampled	Benzene (µg/L) ^{k/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
CPT-03S Source Area 4.6 - 7.9	4.86	Mar-94	724	737	823	5,020	7,300	NA
		Mar-95	1,500	1,530	2,250	8,820	14,100	NA
		Mar-98	692	1,860	3,960	15,700	22,400	NA
CPT-02S Source Area 4.4 - 7.7	5.39	Mar-94	375	18.9	165	638	1,200	NA
		Mar-95	167	6.25	133	260	566	NA
		Jan-96	64.3	5.2	53.3	16.3	139	NA
CPT-09S 220 ft d/g ^{l/} from Source 7.7 - 8.0	4.57	Mar-94	2	4	< 1	< 3	8	NA
		Mar-95	1.09	< 1	1.29	5.00	8	NA
		Jan-96	ND ^{m/}	ND	ND	ND	ND	NA
		Mar-98	< 1	ND	< 1	< 1	< 2	NA
CPT-09D 220 ft d/g from Source 11.72 - 15		Mar-94	427	14.1	2.9	33.5	478	NA
		Mar-95	45	4.35	0.98	14.2	64.3	NA
		Jan-96	28.9	10.4	1.9	18.2	59.4	NA
		Mar-98	14.1	6.9	< 1	17.9	39.4	NA
CPT-04S 340 ft d/g from Source 6.6 - 9.9	5.04	Mar-94	< 1	3.7	< 1	< 3	6.2	NA
		Mar-95	< 1	0.97	< 1	3.58	5.6	NA
		Jan-96	ND	ND	< 1	< 3	< 2.0	NA
		Mar-98	< 1	< 1	3.7	5.4	10.1	NA
CPT-14D 250 ft d/g from Source 13.45 - 16.73		Mar-94	960	16.6	11.5	120	1,110	NA

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} U = Compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{f/} J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.

The data should be considered as a basis for decision-making and are usable for many purposes.

^{g/} NA = not analyzed or not available.

^{h/} ppmv = parts per million by volume.

^{i/} M = Laboratory reported value may be biased due to apparent matrix interferences.

^{j/} ft btoc = feet below top of casing.

^{k/} µg/L = micrograms per liter.

^{l/} d/g = downgradient.

^{m/} ND = not detected. Value of 1 used for graphing purposes.

FIGURE 3.4
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SITE ST-29, PATRICK AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY

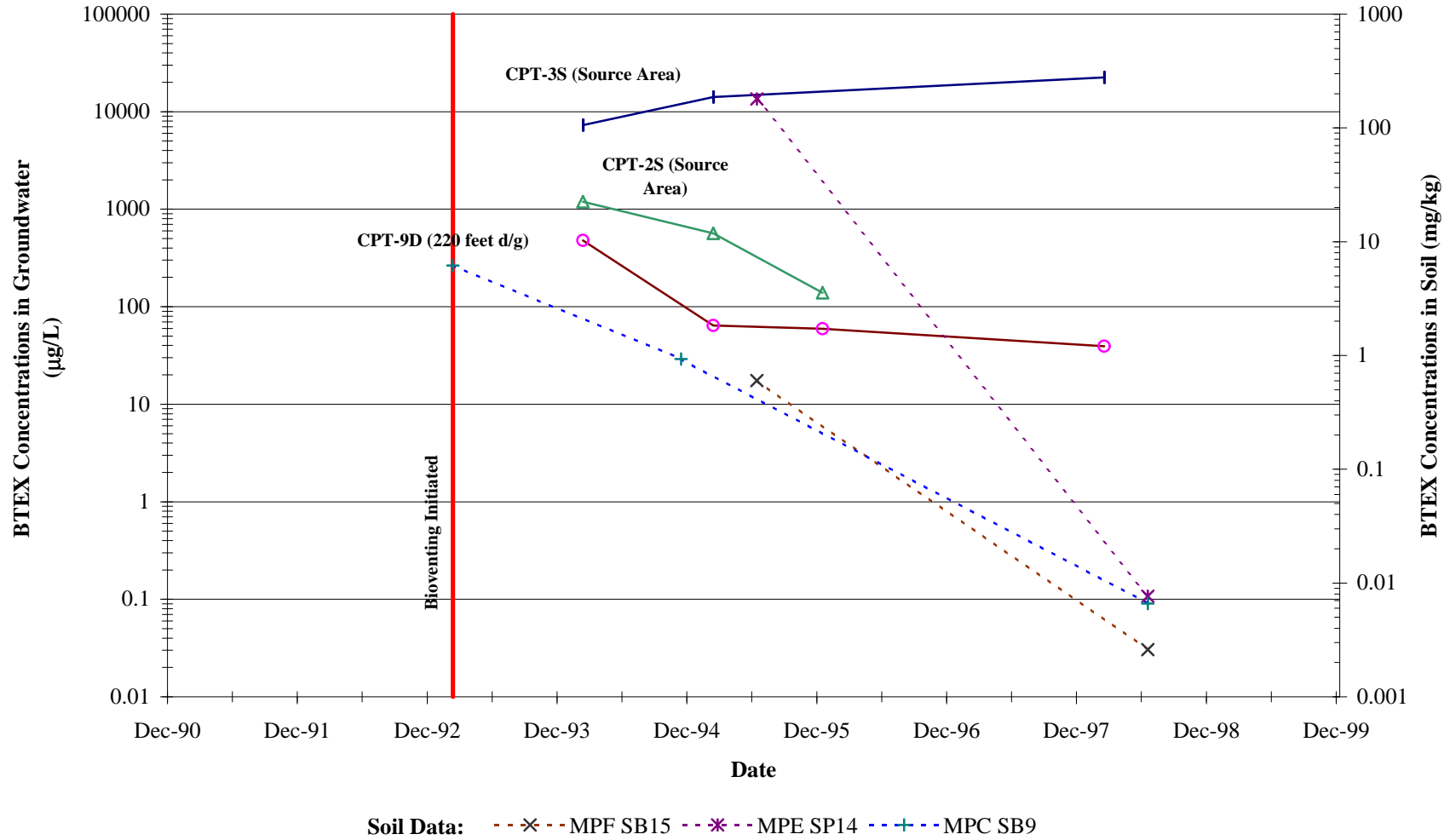


TABLE 3.8
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE ST-29
PATRICK AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{e/} (µg/L)
CPT-3S	Source	-- ^{f/}	3	--	7,570	--	22,400 (5.0 yr)
CPT-2S	Source	--	-3	--	-529	--	139 (2.8 yr)
CPT-9D	220 feet d/g ^{g/}	--	-6	--	-83	--	39 (5.0 yr)
CPT-4D	330 feet d/g ^{g/}	--	2	--	196	--	1,180 (5.0 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

downgradient from the source area. The apparent expansion may be due to enhanced leaching of BTEX from the smear zone as a result of the rising water table.

3.3.1.4 Effectiveness Summary

The data presented above indicate that the effectiveness of bioventing system in remediating residual fuel contamination at Site ST-29 has been mixed due to the continuing presence of a significant contaminant smear zone beneath the water table. The inability of the bioventing system to remediate this zone appears to have been exacerbated by a rising water table.

3.3.2 Charleston AFB, South Carolina (Site ST-27)

Charleston AFB is located approximately 10 miles north of the Charleston Harbor and downtown Charleston along the Atlantic coast of South Carolina.

3.3.2.1 Site Description

Several petroleum USTs have been or currently are operated at Site ST-27. These USTs have been used to store JP-4 jet fuel, MOGAS, and diesel fuel. Free product was detected in one site monitoring well in 1990, and in two wells in 1995. During leak testing in 1996, it was discovered that both MOGAS and diesel fuel were leaking from USTs or

associated piping. A suspected leak in a 3,000-gallon JP-4 UST was confirmed in January 1998. The leaking JP-4 UST was excavated, and some contaminated soils were removed. The diesel UST was emptied and removed from service, and the MOGAS leak was repaired.

The site is underlain by undifferentiated, moderately sorted sands and silty to clayey, fine- to medium-grained sands. The water table in the surficial aquifer tends to occur in a clayey sand unit at a depth of approximately 4 to 6 feet bgs. Water level data indicate that the water table at this site can fluctuate from 1 to 3 feet on a seasonal basis. The average hydraulic conductivity calculated for the upper few feet of the surficial aquifer based on slug test results is 2.6 ft/day. The average advective groundwater flow velocity was calculated to be approximately 7 ft/yr based on an average hydraulic conductivity of 2.6 ft/day (from slug tests), a hydraulic gradient of 0.0014 foot per foot, and an estimated effective porosity of 0.20.

A pilot-scale SVE system was installed in February 1996 and operated for 170 days, removing over 3,000 pounds of volatile fuel hydrocarbons. In May 1997, two horizontal vent wells were connected to an air-injection blower, and the system was converted to a bioventing system, which is currently operating.

3.3.2.2 Soil Quality

Soil and soil gas samples were collected in October 1998 to assess the progress of soil remediation. Selected soil quality results are summarized in Table 3.9 and depicted on Figure 3.5. Based on the October 1998 sampling results, operation of the bioventing system was continued, and additional soil samples were collected in October 1999. As of the date of this report, analytical results for the October 1999 samples were not available; they will be added to the final report.

Comparison of analytical results for the soil gas samples collected in October 1998 and January 1995 show a one- to three-order-of-magnitude decrease in volatile hydrocarbon concentrations in soil gas during this time period (Table 3.9). However, respiration testing results indicated that adequate fuel residuals remained in site soils in October 1998 to sustain aerobic biodegradation. Based on initial oxygen levels, it appeared that areas more than 50 feet from the vent wells were not receiving enough oxygen to sustain aerobic biodegradation. However, site characterization data indicate that there is little contamination beyond this 50-foot radius. The maximum and average concentrations of chemicals of concern (COCs) in soils decreased one to two orders of magnitude from 1995 to 1998. Of the seven COCs, only naphthalene still exceeded its target cleanup level.

The soil source area at Site ST-27 is covered with 14 inches of reinforced concrete that likely prevents significant percolation of precipitation through the vadose zone. Consequently, the only significant contaminant mass transport mechanism that may mobilize sorbed hydrocarbons in subsurface soils is seasonal changes in the water table elevation, which fluctuates about 1 to 3 feet per year.

3.3.2.3 Groundwater Quality

Groundwater quality data collected from 1987 to 1994 indicate a gradual decrease in dissolved BTEX concentrations prior to installation of the SVE/bioventing system at

**TABLE 3.9
ANALYTICAL DATA SUMMARY FOR SITE ST-27
CHARLESTON AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Soil Data

Location ID	Depth of Sample (ft bgs) ^{c/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	BTEX ^{a/b/} (mg/kg)	Naphthalene (mg/kg)
MP-4 / GP-1	3 / 3	Jul-95 / Oct-98	14 / 0.0024 U ^{e/}	250 / 0.0024 U	130 / 0.0024 U	540 / 0.0060 U	934 / 0.0078 U	19 / 0.23
MP-4 / GP-1	5 / 5	Jul-95 / Oct-98	34 / 0.071	320 / 0.01	150 / 0.25	620 / 0.52	1,120 / 0.85	3.5 / 0.52
MP-2 / GP-4	3 / 3	Jul-95 / Oct-98	1.9 J ^{f/} / 0.0027 U	490 / 0.0027 U	35 / 0.0027 U	160 / 0.012	687 J / 0.016	0.38 U / 0.088
MP-5 / GP-2	3 / 3	Jul-95 / Oct-98	1.4 J / 0.0025 U	21 / 0.0025 U	74 / 0.0025 U	240 / 0.0063 U	336 J / 0.0069 U	16 / 0.0063 U
MP-5 / GP-2	5 / 5	Jul-95 / Oct-98	2.1 J / 1.3 U	27 / 1.3 U	100 / 12	310 / 41	439 J / 54.3	15 / 8.4

Soil Gas Data

Location ID	Date Sampled	Benzene (ppmv) ^{g/}	Toluene (ppmv)	Ethyl-benzene (ppmv)	Xylenes (ppmv)	BTEX ^{a/b/} (ppmv)	TVH ^{h/} (ppmv)
MP-A	Jan-95 / Oct-98	488 / 190	2,110 / 81	296 / 480	882 / 1,200 M ^{h/}	3,770 / 1,950 M	120,000 / 8,500
MP-3	Jan-95 / Oct-98	390 / 0.39	370 / 0.85	480 / 3	880 / 9.9	2,120 / 14.1	66,000 / 340
MP-4	Jan-95 / Oct-98	2,100 / 180	3,000 / 99	320 / 290	4,100 / 530 M	9,520 / 1,100 M	200,000 / 10,000
MP-5	Jan-95 / Oct-98	1,400 / 0.15	720 / 0.35	1,200 / 1.5	2,500 / 4.3 M	5,820 / 6.30 M	110,000 / 100

TABLE 3.9 (Continued)
ANALYTICAL DATA SUMMARY FOR SITE ST-27
CHARLESTON AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{i/}	Date Sampled	Benzene (µg/L) ^{j/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
MW20-11 Source Area 2.0 - 12.0	-	Jun-93	5,900	6,100	2,400	2,300	16,700	240
	4.55	Aug-95	6,900	10,000	2,400	6,100	25,400	270
	NA ^{k/}	Sep-97	4,500	4,400	1,700	3,300	13,900	340
	4.52	Jul-98	3,350	5,850	1,850	3,810	14,900	374
	4.35	Oct-98	4,110	8,100	2,540	5,330	20,100	552
MW20-1 Source Area 3.0 - 8.0	-	Jun-88	2,450	5,770	1,110	6,660	16,000	NA
	-	Aug-90	2,800	2,000	1,200	5,400	11,400	NA
	4.29	Aug-95	640	81	740	570	2,030	260
	NA	Sep-97	470	48	760	130	1,410	470
MW20-3 120 ft d/g ^{l/} from Source 4.0 - 8.0	-	Jun-88	5,120	24,000	2,110	12,400	43,600	NA
	-	Aug-90	4,000	18,000	2,600	9,700	34,300	190
	5.77	Aug-95	2,000	8,800	1,600	5,100	17,500	210
	NA	Sep-97	2,500	7,500	1,900	6,400	18,300	520
	5.41	Jul-98	4,430	52	2,240	1,560	8,280	392
	5.25	Oct-98	5,620	41	2,800	1,630	9,890	606
MW20-9 Source Area NA	-	Jun-93	6,100	16,000	2,400	7,700	32,200	280
	4.79	Aug-95	3,900	7,800	1,100	2,900	15,700	230
MW20-5 Source Area 3.0 - 8.0	-	Jun-88	868	85	520	1,950	3,420	NA
	-	Aug-90	270	ND	990	2,040	3,300	NA
	3.65	Aug-95	160	51	610	660	1,480	NA
	4.46	Jul-98	48	1	441	55	545	711
	4.00	Oct-98	81	1	482	183	746	627

TABLE 3.9 (Concluded)
ANALYTICAL DATA SUMMARY FOR SITE ST-27
CHARLESTON AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data (Continued)

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc)	Date Sampled	Benzene (µg/L) ^{j/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
MW20-12 Source Area NA		Jun-93	170	2 J	43	98	313 J	24
		Jul-94	1,700	360 J	440 J	NA	2,500 J	75
		Aug-95	610	56	97	5,100	5,860	29
		Jan-96	1,500	130	400	360	2,390	
		Sep-97	230	14	53	< 30	312	22
		Jul-98	472	2.5	66.2	17.2	558	55.3
		Oct-98	476	476	2.05	44.5	12.6	535
MW20-16 170 ft d/g from Source NA	5.48	Aug-95	450	29	54	87	620	44
	NA	Sep-97	1,300	12	550	530	2,390	200
	5.33	Jul-98	831	12.9	565	442	1,850	153
	5.12	Oct-98	1,160	8.09	784	584	2,540	203

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; TVH = total volatile hydrocarbons.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} U = Compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{f/} J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample. The data should be considered as a basis for decision-making and are usable for many purposes.

^{g/} ppmv = parts per million by volume.

^{h/} M = Laboratory reported value may be biased due to apparent matrix interferences.

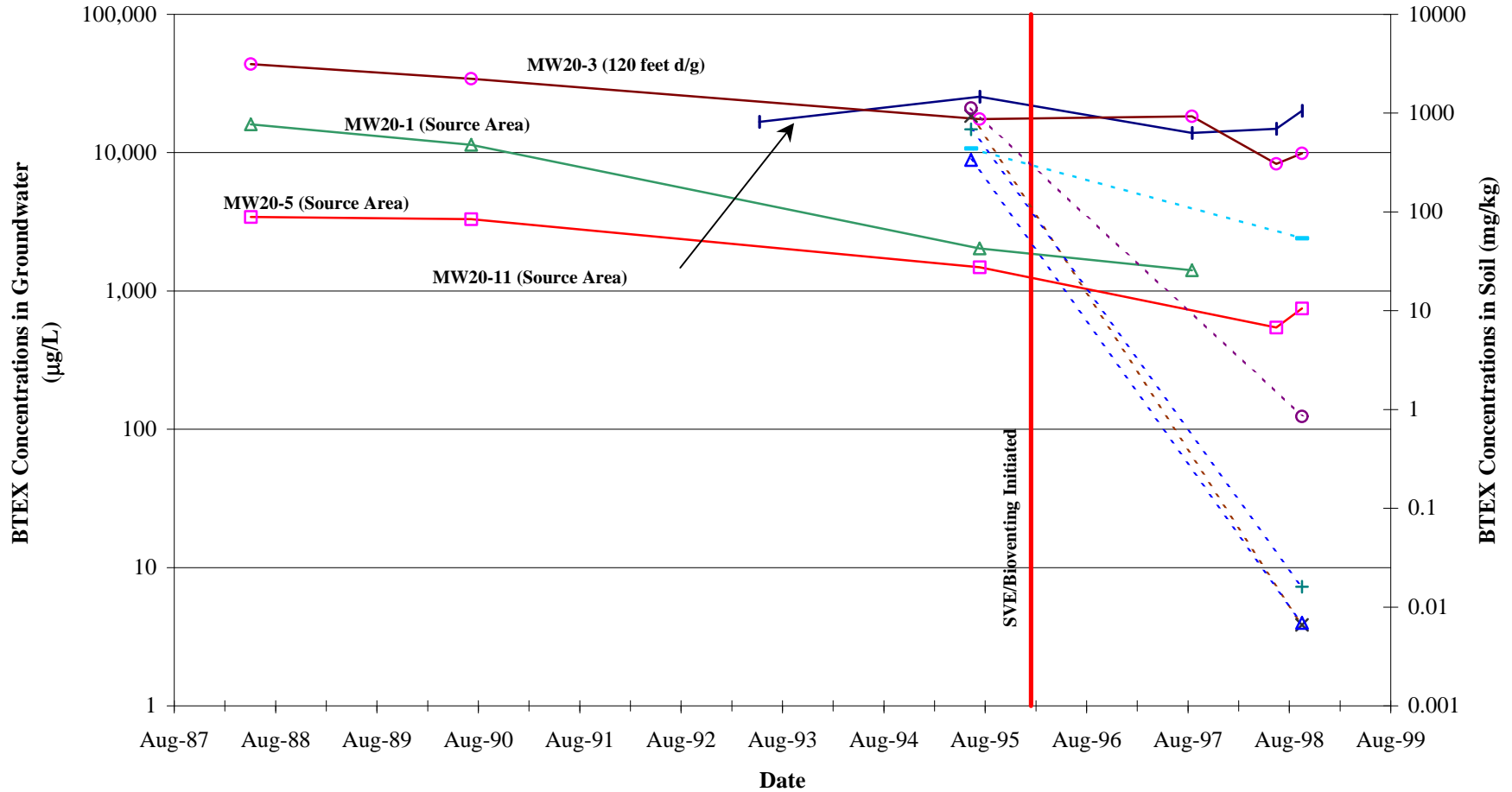
^{i/} ft btoc = feet below top of casing.

^{j/} µg/L = micrograms per liter.

^{k/} NA = Not analyzed or not available.

^{l/} d/g = downgradient.

FIGURE 3.5
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY



Soil Data:

- - x - - MP-4 / GP-1 (3 feet bgs)
- - o - - MP-4 / GP-1 (5 feet bgs)
- - + - - MP-2 / GP-4 (3 feet bgs)
- - Δ - - MP-5 / GP-2 (3 feet bgs)
- - □ - - MP-5 / GP-2 (5 feet bgs)

most locations (Table 3.9 and Figure 3.5). These decreases are reflected in the negative MK trend statistics calculated for two source area wells and one downgradient well and the negative Sen's slopes calculated for the same wells (Table 3.10). However, limited pre-remediation data for source area well MW20-11 suggested that dissolved BTEX concentrations at this location were increasing.

Groundwater quality data obtained since initiation of SVE/bioventing do not indicate that dissolved BTEX concentrations are decreasing more rapidly. For two of the four wells listed in Table 3.10, the Sen's slopes became less negative following startup of the remedial system. At a third well (MW20-11), an overall decreasing trend in dissolved BTEX concentrations is evident since the February 1996 startup of the remedial system, suggesting that groundwater quality at this location was impacted by the bioventing system.

TABLE 3.10
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE ST-27
CHARLESTON AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{e/} (µg/L)
MW20-1	Source	-3	-- ^{f/}	-6,980	--	2,030 (0.5 yr)	1,410 (1.6 yr)
MW20-5	Source	-3	-1	-971	-368	1,480 (0.5 yr)	746 (2.7 yr)
MW20-11	Source	--	0	--	-407	25,400 (0.5 yr)	20,100 (2.7 yr)
MW20-3	120 feet d/g ^{g/}	-3	-2	-13,100	-3,370	17,500 (0.5 yr)	9,890 (2.7 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

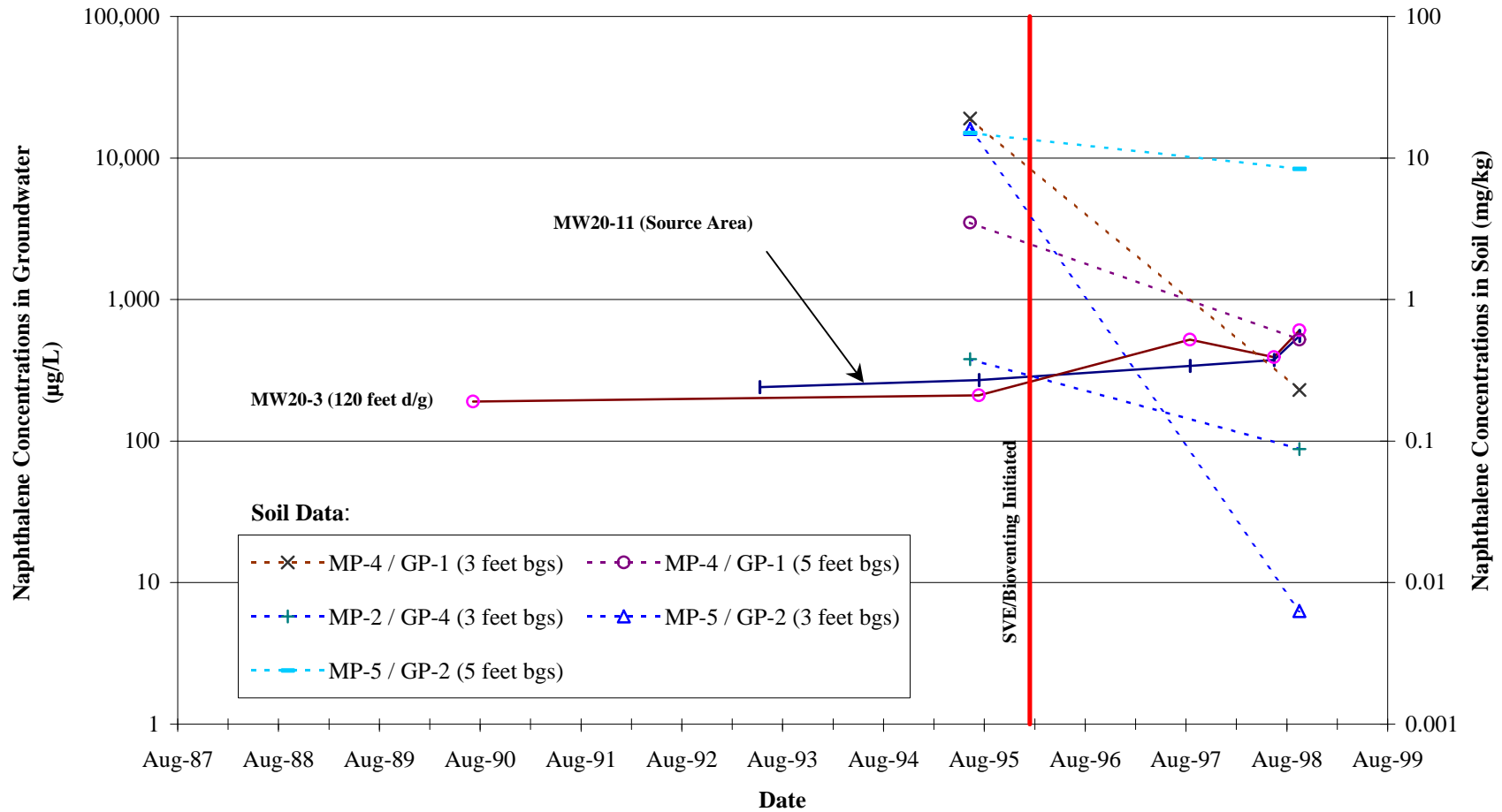
^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

Historical groundwater quality data indicate that the areal extent of the dissolved BTEX plume did not change significantly prior to startup of the SVE/bioventing system. In addition, the post-SVE/bioventing data summarized above suggest that the remedial system has not caused the areal extent of the BTEX plume to change substantially. Groundwater quality improvements related to the source-reduction system will not be evidenced at downgradient locations in the near term due to the very low average groundwater velocity at this site.

FIGURE 3.6
NAPHTHALENE CONCENTRATIONS IN GROUNDWATER
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY



Historical dissolved naphthalene concentrations at wells MW20-11 and MW20-3 are plotted on Figure 3.6. The Sen's slope estimates for post-system-startup naphthalene concentrations at MW20-11 and MW20-3 (43 and 106, respectively) indicate an overall increasing trend, despite the apparent presence of decreasing trends in dissolved BTEX concentrations during the same time period.

3.3.2.4 Effectiveness Summary

The available information indicates that the removal of BTEX from unsaturated soils has not yet impacted dissolved BTEX concentrations at Site ST-27. The shallow water table, presence of submerged sources (i.e., USTs) and free product, and evidence of seasonal groundwater level fluctuations of up to 3 feet at this site support the development of a significant smear zone below the water table. It is likely that at least a portion of this smear zone persists and acts as a continuing source of groundwater contamination. The relative stability of dissolved naphthalene concentrations following initiation of SVE/bioventing may reflect the fact that this compound is less volatile than the BTEX compounds, less readily biodegraded, and sorbs more strongly to soil particles. Therefore, it is less readily remediated by the SVE/bioventing system and more persistent in site soils and groundwater.

3.3.3 Eglin AFB, Florida (Seventh Street Service Station)

Eglin AFB is located in the Florida panhandle along the Gulf coast.

3.3.3.1 Site Description

The Seventh Street Service Station opened in 1955 as a retail gasoline and automobile service station. The USTs, all but one of which were removed, stored leaded and unleaded gasoline. The remaining UST was abandoned in place. Retail fuel sales were discontinued in July 1993. A fuel leak from the UST system, reported in 1983, released an estimated 3,600 gallons of unleaded gasoline over a period of years. Free product was detected on the water table, and a product and groundwater recovery system was installed and became operational in the fall of 1989. Groundwater pumping is still occurring; however, free product has not been observed since before the March 1998 sampling event. A recirculating SVE/bioventing system was installed in May 1992 to remediate soil contamination. The system consists of two vapor-extraction wells and two recirculation/reinjection trenches. The site is underlain primarily by uniform sand, and the water table is present at a depth of 5 to 8 feet bgs. The average hydraulic conductivity was calculated to be 21 ft/day based on slug and pumping tests. The average advective groundwater flow velocity at the site was estimated to be 120 ft/yr.

3.3.3.2 Soil Quality

Soil samples were initially collected at the site in May 1992 and May 1993 in conjunction with installation and operation of the SVE/bioventing system. A third soil sampling event was performed in March 1998, nearly 6 years after the initiation of SVE/bioventing, to assess current conditions. Three of the 1998 sampling locations coincided with the 1992/1993 locations; data for these samples are shown in Table 3.11 and on Figure 3.7. Although soil BTEX concentrations generally have been reduced, the presence of a continuing source is indicated. The five highest soil BTEX concentrations

TABLE 3.11
ANALYTICAL DATA SUMMARY FOR THE SEVENTH STREET SERVICE STATION
EGLIN AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Soil Data

Location ID	Depth of Sample (ft bgs) ^{e/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	BTEX ^{a/b/} (mg/kg)	Naphthalene (mg/kg)
VEW-1	5.5	May-92	ND ^{e/}	4.76	23	56.7	84.5	NA ^{f/}
		May-93	ND	1.1	5.5	18	24.6	NA
		Mar-98	< 2.4	< 2.4	2.4	28	32.8	NA
VEW-2	5.5	May-92	1.19 ^{J/}	7.62	6.43	32.1	47.3	NA
		May-93	< 5.4	22	8.9	150	184	NA
		Mar-98	< 0.0058	< 0.0058	< 0.0023	< 0.0058	< 0.0099	NA
VMP-2	5.5	May-92	26.5	152	55.3	274	508	NA
		May-93	< 5.4	73	38	340	454	NA
		Mar-98	< 2.3	2.3	0.94	18	< 22.4	NA

TABLE 3.11 (Concluded)
ANALYTICAL DATA SUMMARY FOR THE SEVENTH STREET SERVICE STATION
EGLIN AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{h/}	Date Sampled	Benzene (µg/L) ^{i/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX (µg/L)	Naphthalene (µg/L)
MW-1 Source Area 5-10	6.55	Dec-94	1,300	5,000	2,100	14,800	23,200	NA
		Apr-95	110	5,300	1,300	18,400	25,100	1100
		Jul-95	210	2,800	920	6,800	10,700	630
		Nov-95	40	2,000	600	9,400	12,000	750
		Feb-96	39	1,700	510	5,900	8,150	480
		Jun-96	52	1,500	720	6,100	8,370	380
		Jan-97	20	1,700	620	8,300	10,600	410
		Mar-98	23	1,000	490	6,600	8,110	370
MW-2 120 ft d/g ^{j/} from Source 5-10	7.23	Dec-94	2,400	10,000	1,100	8,200	21,700	NA
		Apr-95	2,200	9,500	1,100	9,900	22,700	670
		Jul-95	5,100	32,000	2,800	21,200	61,100	700
		Nov-95	2,500	25,000	2,100	18,300	47,900	540
		Feb-96	1,800	20,000	1,900	15,400	39,100	770
		Jun-96	2,300	23,000	2,100	16,200	43,600	700
		Jan-97	1,100	18,000	1,800	13,700	34,600	500
		Mar-98	42	8,400	660	6,300	15,400	280
GWRW-4 250 ft d/g from Source NA	8.4	Dec-94	1,800	5,900	570	4,100	12,400	NA
		Apr-95	1,300	90	790	2,000	4,180	NA
		Mar-98	23	590	80	650	1,340	32
MP-2 Source Area 4-9		Mar-98	86 J	11,000	1,600	13,000	25,700 J	510

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} ND = Not detected.

^{f/} NA = Not analyzed or not available.

^{g/} J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.

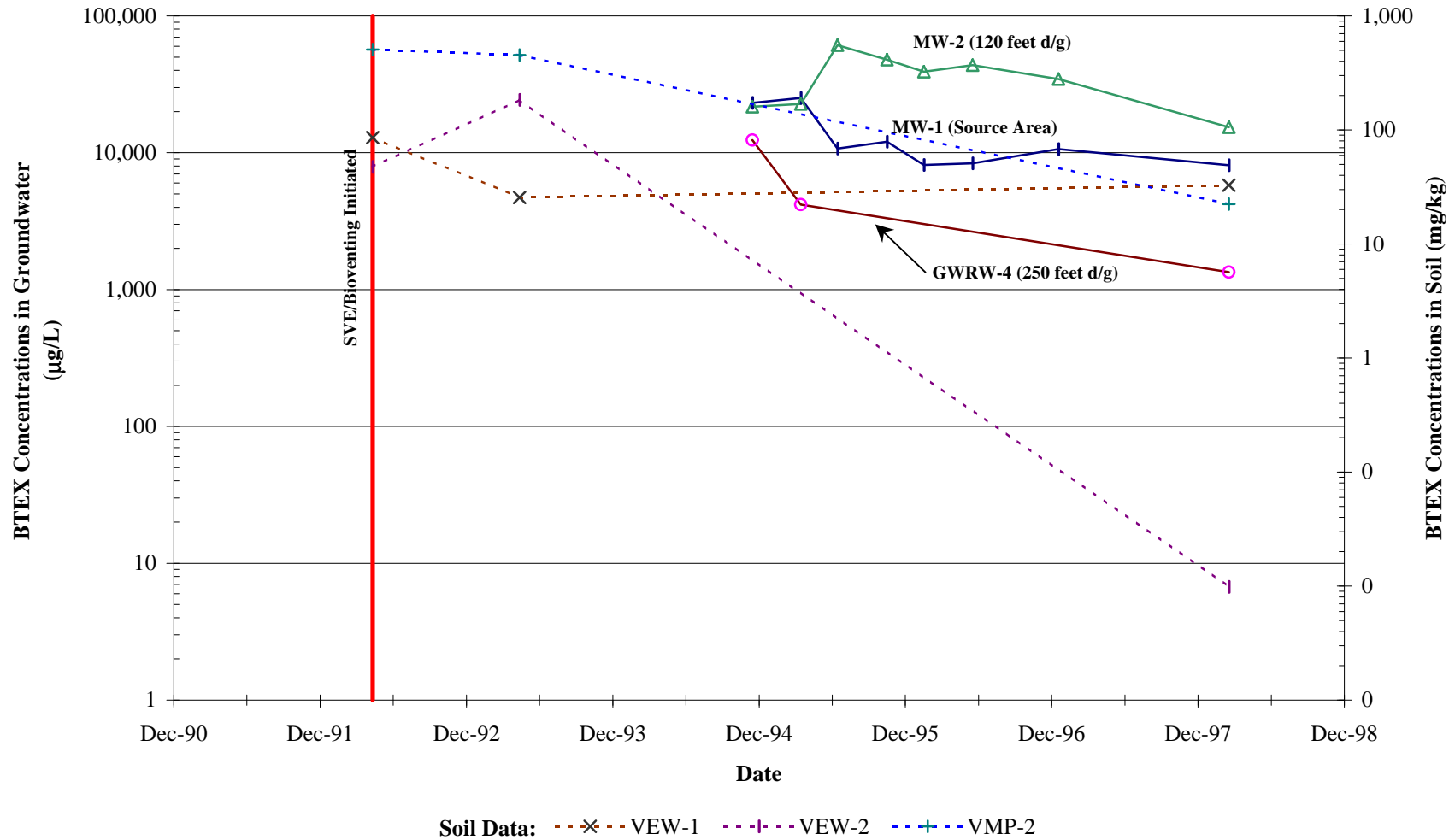
The data should be considered as a basis for decision-making and are useable for many purposes.

^{h/} ft btoc = feet below top of casing.

^{i/} µg/L = micrograms per liter.

^{j/} d/g = downgradient.

FIGURE 3.7
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SEVENTH STREET SERVICE STATION, EGLIN AFB, FLORIDA
SOURCE REDUCTION EFFECTIVENESS STUDY



and two highest soil naphthalene concentrations detected in 1998 occurred in soil samples collected between 5 and 9 feet bgs, 0.5 to 3 feet below the estimated water table. Soil BTEX were detected at concentrations ranging up to 2,190 mg/kg, indicating that a significant contaminant mass persists in the smear zone below the water table.

3.3.3.3 Groundwater Quality

Groundwater quality data for the period between the reporting of the fuel spill in 1983 and installation of the SVE/bioventing system in 1992 are not available. Groundwater quality data collected starting in December 1994 indicate an overall decreasing trend in dissolved BTEX concentrations both in the source area and at monitoring and recovery wells located 120 to 250 feet downgradient from the source area (Table 3.11 and Figure 3.7). MK statistics and estimated linear trend line slopes for the three wells depicted on Figure 3.7 are all negative, indicating decreasing trends (Table 3.12). The slope estimates indicate that the most significant decreases are occurring at downgradient recovery well GWRW-4, perhaps reflecting the migration of less contaminated groundwater from outside the plume core to this well due to pumping. Although they are decreasing, dissolved BTEX concentrations still substantially exceed target cleanup levels for the site after 6 years of SVE/bioventing, indicating the continuing presence of a significant source.

TABLE 3.12
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT THE SEVENTH
STREET SERVICE STATION
EGLIN AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{c/} (µg/L)
MW-1	Source	-- ^{f/}	-18	--	-1,680	--	8,110 (5.8 yr)
MW-2	120 feet d/g ^{g/}	--	-4	--	-1,960	--	15,400 (5.8 yr)
GWRW-4	250 feet d/g	--	-3	--	-5,510	--	1,340 (5.8 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

The areal extent of the dissolved BTEX plume is hydraulically controlled by the groundwater extraction system. Therefore, the changes in the areal extent of the plume due to operation of the SVE/bioventing system cannot be discerned.

The only polynuclear aromatic hydrocarbon (PAH) identified as a COC in site groundwater is naphthalene. Concentrations of this compound in site groundwater also have exhibited decreases over time (Table 3.11 and Figure 3.8). The estimated slopes of the best-fit linear trend lines for naphthalene at MW-1 and MW-2, using data collected from April 1995 to March 1998, are -95 and -65, respectively. These slopes are substantially lower than the slope estimates for BTEX calculated for approximately the same time period. As described for Charleston AFB in Section 3.3.2.4, the lower naphthalene reduction rates likely reflect differences in the rates at which residual naphthalene and BTEX concentrations in the smear zone are decreased via biodegradation, leaching, and volatilization.

3.3.3.4 Effectiveness Summary

Soil and groundwater quality data indicate the continuing presence of a significant fuel hydrocarbon smear zone beneath the average water table that has not been impacted by the SVE/bioventing system. Dissolved BTEX concentrations ranging up to 25,000 µg/L were present near the source area after 6 years of system operation (Table 3.11). The subsurface location(s) of the source(s) (i.e., USTs and associated pipelines) and large volume of the release, combined with the permeable, sandy soils; shallow depth to groundwater; and seasonal water table fluctuations all contributed to the formation of a substantial smear zone.

3.3.4 Carswell AFB, Texas (ST14A)

Carswell AFB is located approximately 6 miles west of downtown Fort Worth, Texas. Air Force Plant 4, which shares the Base runway, is located west of the Base. The Base has recently undergone realignment, and is now Naval Air Station Fort Worth Joint Reserve Base.

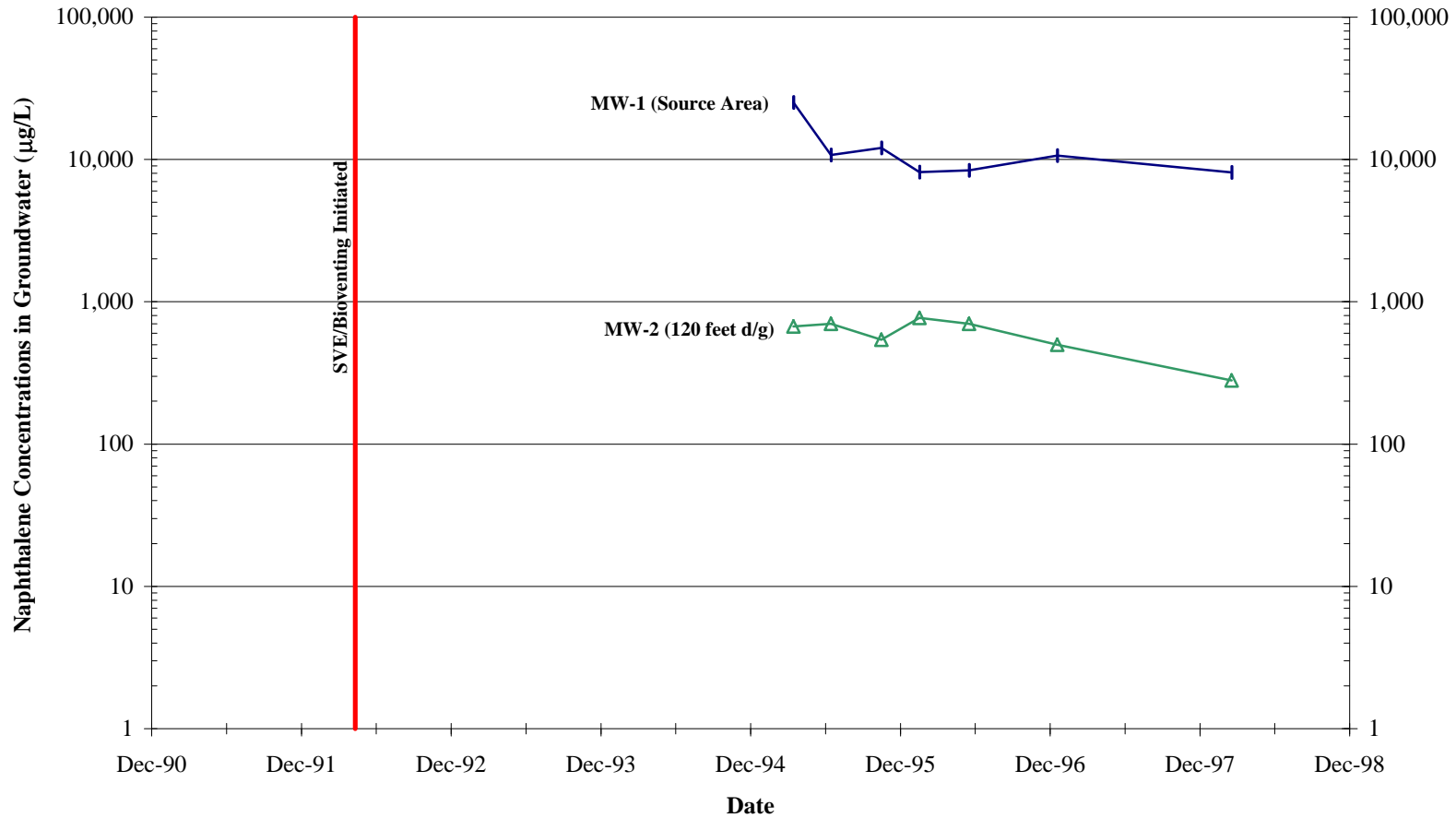
3.3.4.1 Site Description

Site ST14 has been used for aboveground fuel storage during most of the Base's operating history (i.e., from 1942 to the present). Site ST14A consists of the fuel loading area and the area downgradient from this area. During the early 1960s, JP-4 jet fuel was discovered in soil and groundwater at and downgradient from the site. More than 2 feet of free product was encountered in a source area monitoring well in 1990; the average product thickness measured in this well in 1993 and 1994 was 0.75 inch. More recently, periodic bailing of product from this well appears to have eliminated free product from this well.

The shallow stratigraphy at Site ST14 consists of 8 to 20 feet of sandy clay with some interbedded gravel and silt, underlain by 3 to 11 feet of sand and gravel. The depth to groundwater ranges from 6 to 16 feet, and shallow groundwater occurs predominantly in the sand and gravel zone. Based on slug test results, hydraulic conductivities in the Upper Zone Aquifer are highly variable, ranging from 0.02 to 61 ft/day. Based on these data, the range of calculated advective groundwater flow velocities is 10 to 150 ft/yr.

A bioventing pilot test was completed at Site ST14A in May 1993 to assess the applicability of this technology at this site. Based on the results of the pilot test, a full-

FIGURE 3.8
NAPHTHALENE CONCENTRATIONS IN GROUNDWATER
SEVENTH STREET SERVICE STATION, EGLIN AFB, FLORIDA
SOURCE-REDUCTION EFFECTIVENESS STUDY



scale bioventing system consisting of 16 air-injection wells was installed at Site ST14A. Operation of the full-scale system began in April 1995, and ceased in March 1998.

3.3.4.2 Soil Quality

Elevated concentrations of fuel hydrocarbons have historically extended from the surface or near-surface to a depth of approximately 12 feet bgs. Most detectable concentrations were found between 8 and 11 feet bgs. Analytical results for 21 soil samples collected in June 1993, and for 22 soil samples collected in March 1998, are summarized in Table 3.13. Total soil BTEX concentrations in 1993 ranged from 1.66 mg/kg to 125 mg/kg and averaged 31 mg/kg. BTEX concentrations measured in 1998 ranged from not detected (<0.02 mg/kg) to 15.8 mg/kg and averaged 1.8 mg/kg. The arithmetic mean BTEX concentrations computed for these two data sets are plotted on Figure 3.9. The data indicate that the biosparging/bioventing system has substantially reduced, and in many cases eliminated, residual BTEX concentrations in the vadose zone.

3.3.4.3 Groundwater Quality

As shown in Table 3.13 and on Figure 3.9, dissolved BTEX concentrations have decreased significantly since the pre-remediation (September 1994) sampling event. However, given the scarcity of pre-remediation groundwater quality data, it is not possible to determine the degree to which the measured decreases have resulted from operation of the bioventing system. Dissolved BTEX concentrations measured after the January 1997 sampling event appear to have stabilized, through some increases are evident (e.g., at downgradient well ST14-MW29).

These increases cause the MK statistics and Sen's slopes for wells MW29, MW16, and MW04 to be greater than zero (Table 3.14). However, the low magnitude of the estimated trend-line slopes reflect the fact that, after January 1997, dissolved BTEX concentrations remained relatively low (maximum of 24 µg/L). The abrupt decrease in dissolved BTEX concentrations in groundwater from source area well MW16 (from 66 µg/L in January 1997 to 9 µg/L in April 1997) may have been caused by the bioventing system. However, similar decreases were observed during the same time period at wells up to 800 feet downgradient from the source area. Therefore, the decreases are probably more reflective of the effects of natural processes. Measured groundwater BTEX concentrations are compared to concentrations predicted by the first-order BTEX attenuation rate computed for the site of 0.0014 per day (day⁻¹) on Figure 3.10.

Groundwater quality data for downgradient wells near the fringe of the plume (e.g., at wells ST14-MW21, ST14-MW28, and ST14-MW29) suggest that the plume may be shrinking. However, the degree to which this is caused by the engineered source-reduction activities cannot be discerned.

3.3.4.4 Effectiveness Summary

Although significant reductions in dissolved BTEX concentrations occurred throughout the plume area within the first year of bioventing system operation, the widespread nature of these reductions indicates that they may be due more to natural attenuation and/or seasonal variation than to operation of the bioventing system.

TABLE 3.13
ANALYTICAL DATA SUMMARY FOR SITE ST14
CARSWELL AFB, TEXAS
SOURCE-REDUCTION EFFECTIVENESS STUDY

Soil Data

Location ID	Depth of Sample (ft bgs) ^{c/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	Total BTEX ^{a/b/} (mg/kg)
VW-1	10-11	Jun-93	0.27	0.53	1.4	8.8	11.0
VW-2	10-11	Jun-93	< 0.2	19	5.2	25	49.3
VW-3	10-11	Jun-93	1	12	3.6	18	34.6
VW-4	10-11	Jun-93	0.16	0.57	1.5	6.9	9.1
VW-5	10-11	Jun-93	< 0.01	0.44	< 0.01	1.2	1.7
VW-6	9-10	Jun-93	0.95	0.31	0.98	1.8	4.0
VW-7	9-10	Jun-93	< 1	19	3.6	4.8	27.9
VW-8	10-11	Jun-93	2	2.6	1.2	5	10.8
VW-9	9-10	Jun-93	0.2	3.6	0.9	4.8	9.5
VW10	10-11	Jun-93	0.47	0.74	1.1	5.2	7.5
VW-12	10-11	Jun-93	3.8	2.6	2.7	5.9	15.0
VW-13	9-10	Jun-93	< 2	54	17	52	124
VW-14	9-10	Jun-93	0.89	2.9	1.5	7.1	12.4
VW-15	11-12	Jun-93	< 1	10	3.4	14	27.9
VW-16	9-10	Jun-93	2.8	11	6.6	32	52.4
MPA	9-10	Jun-93	1.8	3.7	5.3	36	46.8
MPB	9-10	Jun-93	2.8	4.1	7	26	39.9
MPC	10-11	Jun-93	< 0.2	10	2.6	17	29.7
MPBG1	10-11	Jun-93	67	< 5	14	7.7	91.2
SB2	10-11	Jun-93	0.053	0.6	< 0.01	2	2.7
SB3	9-10	Jun-93	5.4	15	4.1	24	48.5
Soil: 1993	Arithmetic Avg.	Jun-93	4.48	8.46	3.99	14.5	31.5
	Geometric Mean	Jun-93	0.782	3.56	1.76	9.27	15.4
	Median	Jun-93	1	3.7	2.7	7.7	15.1
GP1	9	Mar-98	< 0.006	< 0.006	< 0.006	< 0.006	< 0.012
GP2	9	Mar-98	< 0.77	< 0.77	< 0.77	< 0.77	< 1.54
GP3	9	Mar-98	3.3	< 0.75	4.8	7	15.5
GP4	9	Mar-98	< 0.72	< 0.72	< 0.72	< 0.72	< 1.44
GP5	8	Mar-98	< 0.015	< 0.015	< 0.015	< 0.015	< 0.030
GP6	8	Mar-98	< 0.031	< 0.031	< 0.031	< 0.031	< 0.062
GP7	7	Mar-98	< 0.03	< 0.03	< 0.03	< 0.03	< 0.060
GP8	9	Mar-98	< 0.72	< 0.72	< 0.72	< 0.72	< 1.44
GP9	9	Mar-98	< 0.029	< 0.029	< 0.029	< 0.029	< 0.058
GP10	9	Mar-98	0.8 J ^{e/}	< 0.76	0.01 J	< 0.76	1.57 J
GP11	9	Mar-98	< 0.0062	< 0.0062	< 0.0062	< 0.0062	< 0.012
GP12	9	Mar-98	< 0.75	< 0.75	< 0.75	< 0.75	< 1.50
GP13	9	Mar-98	< 0.015	< 0.015	< 0.015	< 0.015	< 0.030
GP14	9	Mar-98	< 0.032	< 0.032	< 0.032	< 0.032	< 0.064
GP15	8	Mar-98	< 0.03	< 0.03	< 0.03	< 0.03	< 0.060
GP16	9	Mar-98	< 0.0061	< 0.0061	< 0.0061	< 0.0061	< 0.012
GP17	9	Mar-98	< 0.032	0.007 J	< 0.032	< 0.032	0.055
GP18	9	Mar-98	< 0.029	< 0.029	0.098	0.02 J	0.147
GP19	9	Mar-98	< 0.74	< 0.74	< 0.74	< 0.74	< 1.48
GP20	9	Mar-98	< 0.031	< 0.031	< 0.031	< 0.31	< 0.202
GP21	9	Mar-98	< 0.81	< 0.81	< 0.81	< 0.81	< 1.62
GP22	9	Mar-98	< 0.73	< 0.73	< 0.73	< 0.73	< 1.46
Soil: 1998	Arithmetic Avg.	Mar-98	0.438	0.319	0.47	0.617	1.85
	Geometric Mean	Mar-98	0.0912	0.0794	0.0803	0.103	0.354
	Median	Mar-98	0.0315	0.031	0.0315	0.032	0.126

TABLE 3.13 (Continued)
ANALYTICAL DATA SUMMARY FOR SITE ST14
CARSWELL AFB, TEXAS
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{f/}	Date Sampled	Benzene (µg/L) ^{g/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	Total BTEX ^{a/b/} (µg/L)
ST14-MW16 Source Area 7-19		Sep-94	110	2.9 J	16	20.0	149 J
		Jan-97	59.9	ND ^{b/}	ND	4.36	64.3
		Apr-97	5.96 J	ND	ND	0.87 F ^{h/}	6.83 JF ^{j/}
		Jul-97	6.6 J	0.53 F	ND	ND	7.1 JF
		Oct-97	6	ND	ND	ND	6
		Jan-98	9.4 J	ND	ND	ND	9.4 J
		Apr-98	21 J	ND	0.66 F	1.2	22.9 JF
		Jul-98	7.4 J	ND	ND	ND	7.4 J
		Oct-98	9.3 J	ND	ND	ND	9.3 J
		Jan-99	9 J	ND	ND	ND	9 J
ST14-MW17M 300 ft d/g ^{i/} from Source NA	10.39	Sep-94	2 U ^{k/}	9.5 J	6.5 J	46	63 J
		Jan-97	NA ^{m/}	NA	NA	NA	NA
		Apr-97	ND	ND	0.77 J	2.65 J	3.42 J
		Jul-97	0.39 F	0.35 F	0.42 F	0.95 F	2.11 F
		Oct-97	1.9 F	1.7 F	ND	ND	3.6
		Jan-98	ND	ND	ND	ND	ND
		Apr-98	3.4 J	1.0 J	ND	4.2 J	8.6 J
		Jul-98	NA	NA	NA	NA	NA
		Oct-98	ND	ND	ND	1.7 J	1.7 J
		Jan-99	3.7 J	ND	1.8 J	8.2 J	13.7 J
ST14-MW-19 450 ft d/g 7-16		Sep-94	45	5.3	17	15	82.3
ST14-MW04 600 ft d/g from Source NA	10.39	Sep-94	0.4 U	4 U	25	110	137
		Jan-97	ND	ND	6.25	21.9	28.1
		Apr-97	ND	0.28 J	0.65 J	1.08 J	2.01 J
		Jul-97	0.63 F	0.31 F	ND	ND	0.94 F
		Oct-97	ND	1.6 F	ND	ND	1.6 F
		Jan-98	ND	ND	ND	ND	ND
		Apr-98	2.1 F	3.4 F	2.4 F	3.8	11.7 F
		Jul-98	4.6 J	ND	ND	2.6 J	7.2 J
		Oct-98	ND	ND	ND	ND	ND
		Jan-99	NA	NA	NA	NA	NA
ST14-MW28 750 ft d/g from Source 7.0 - 17.0		Apr-95	1.8 J	0.4 J	38	4	44.2 J
		Jan-97	ND	ND	7.16	11.8	19.0
		Apr-97	ND	4.76 J	ND	ND	4.76 J
		Jul-97	0.48 F	ND	0.54 F	1.5 F	2.5 F
		Oct-97	ND	1.3 F	ND	0.75 F	2.1 F
		Jan-98	ND	ND	ND	ND	ND
		Apr-98	2.4 F	3.4 F	2.7 F	5.6	14.1 F
		Jul-98	ND	ND	0.84 J	3.4 J	4.2 J
		Oct-98	5 J	ND	1.2 J	8.2 J	14.4 J
		Jan-99	2.6 J	ND	0.95 F	4.7	8.3 JF
ST14-MW29 800 ft d/g from Source 6-11		Apr-95	4 U	40 U	6.2 J	40 U	48.2 J
		Jan-97	ND	ND	7.39	20.7	28.1
		Apr-97	ND	ND	1.5 J	ND	1.5 J
		Jul-97	0.41 F	0.24 F	ND	1 F	1.65 F
		Oct-97	ND	ND	ND	0.71 F	0.71 F
		Jan-98	ND	ND	ND	ND	ND
		Apr-98	0.96 F	0.9 F	0.64 F	5.8	8.3 F
		Jul-98	ND	ND	ND	6.8	6.8
		Oct-98	ND	ND	ND	7.9 J	7.9 J
		Jan-99	1.5 J	0.6 F	ND	13 J	15.1 JF

TABLE 3.13 (Concluded)
ANALYTICAL DATA SUMMARY FOR SITE ST14
CARSWELL AFB, TEXAS
SOURCE-REDUCTION EFFECTIVENESS STUDY

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc)	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	Total BTEX ^{a,b/} (µg/L)
ST14-MW21 750 ft d/g from Source 8.0 - 17.0	572.91	Sep-94	0.4 U	0.6 J	0.5 J	2.6 J	3.9 J
		Jan-97	20.4	ND	1.9 F	ND	22.3 F
		Apr-97	ND	0.25 J	1 J	1.28 J	2.53 J
		Jul-97	9.3 J	0.89 F	ND	ND	10.2 JF
		Oct-97	1.2 F	ND	ND	ND	1.2 F
		Jan-98	ND	ND	ND	ND	ND
		Apr-98	4.1	0.61 F	ND	ND	4.7 F
		Jul-98	ND	ND	ND	ND	ND
		Oct-98	ND	ND	ND	ND	ND
		Jan-99	NA	NA	NA	NA	NA

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} J = Estimated value.

^{f/} ft btoc = feet below top of casing.

^{g/} µg/L = micrograms per liter.

^{h/} ND = Not detected.

^{i/} F = Value is between detection limit and reporting limit.

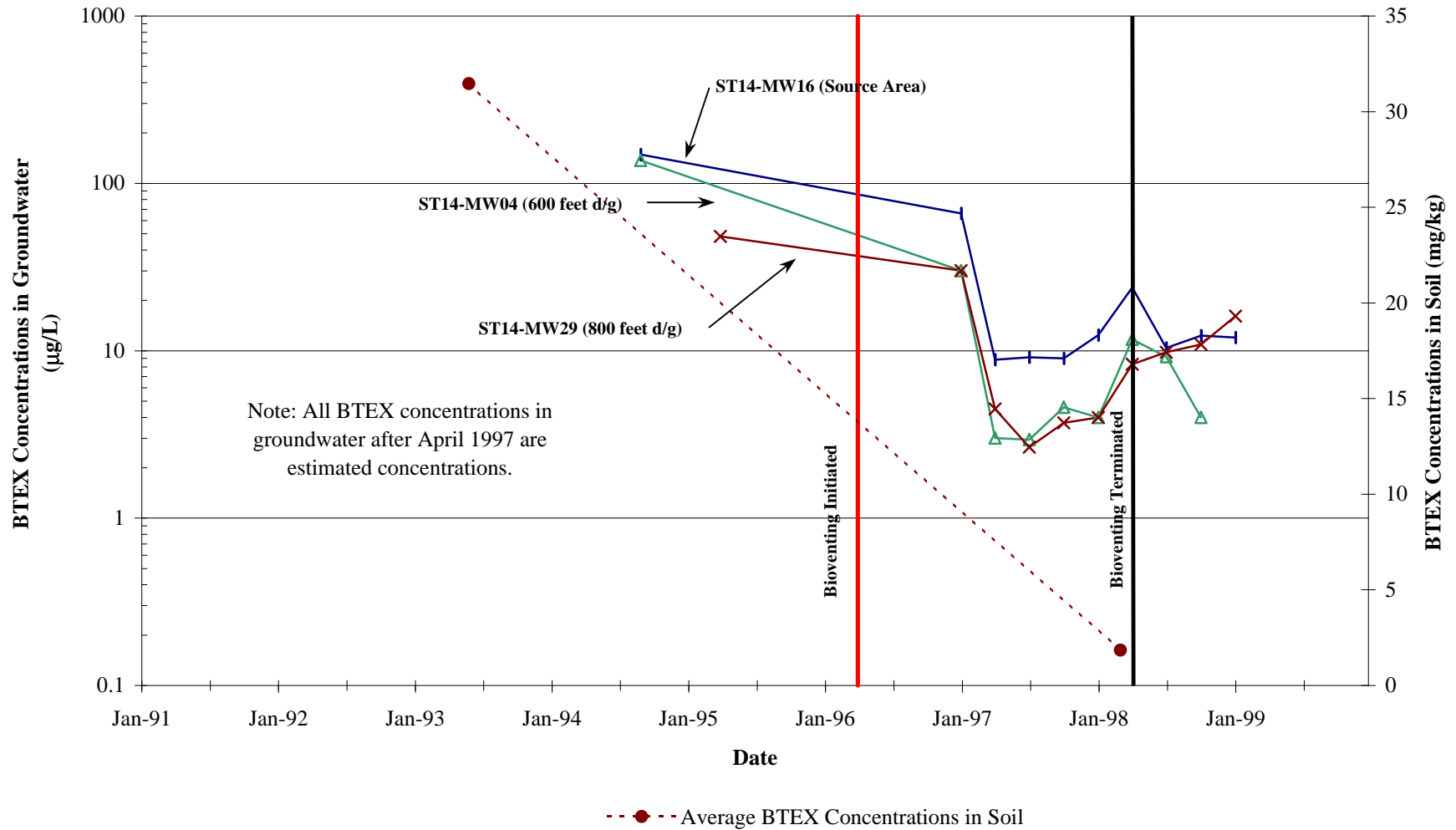
^{j/} J = Estimated value. F = Value is between detection limit and reporting limit.

^{k/} U = compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{l/} d/g = downgradient.

^{m/} NA = not analyzed or not available.

FIGURE 3.9
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
ST14, CARSWELL AFB, TEXAS
SOURCE-REDUCTION EFFECTIVENESS STUDY



**TABLE 3.14
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE ST14
CARSWELL AFB, TEXAS**

SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{e/} (µg/L)
MW-16	Source	-- ^{f/}	2	--	0.3	149 (1.6 yr)	12 (2.8 yr)
MW-04	600 feet d/g ^{g/}	--	3	--	0.1	137 (1.6 yr)	<4 (2.8 yr)
MW-29	800 feet d/g	--	12	--	1	48 (1.0 yr)	16 (2.8 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

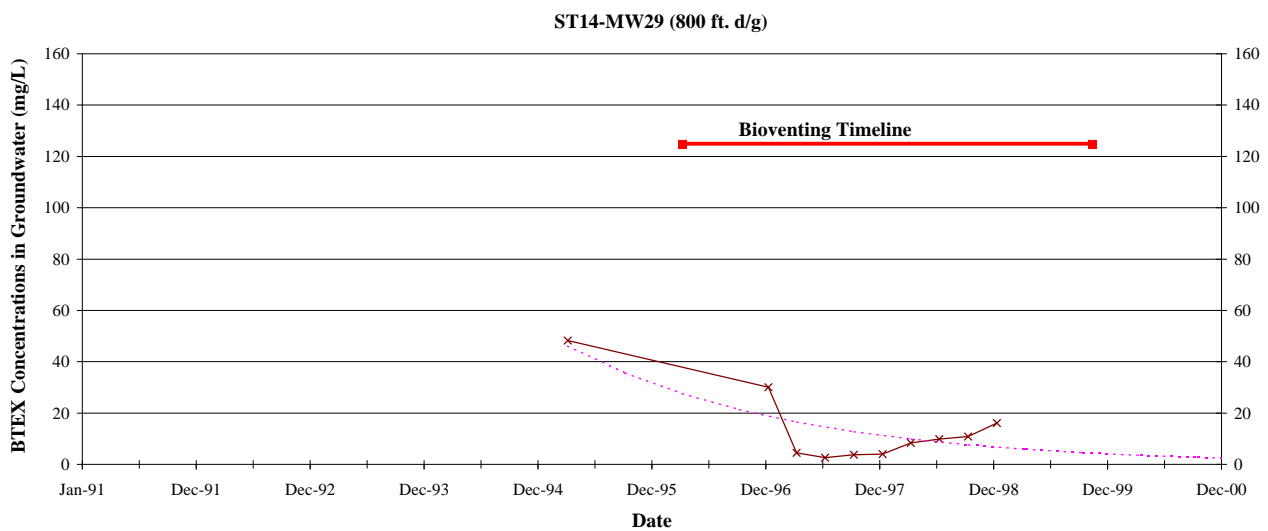
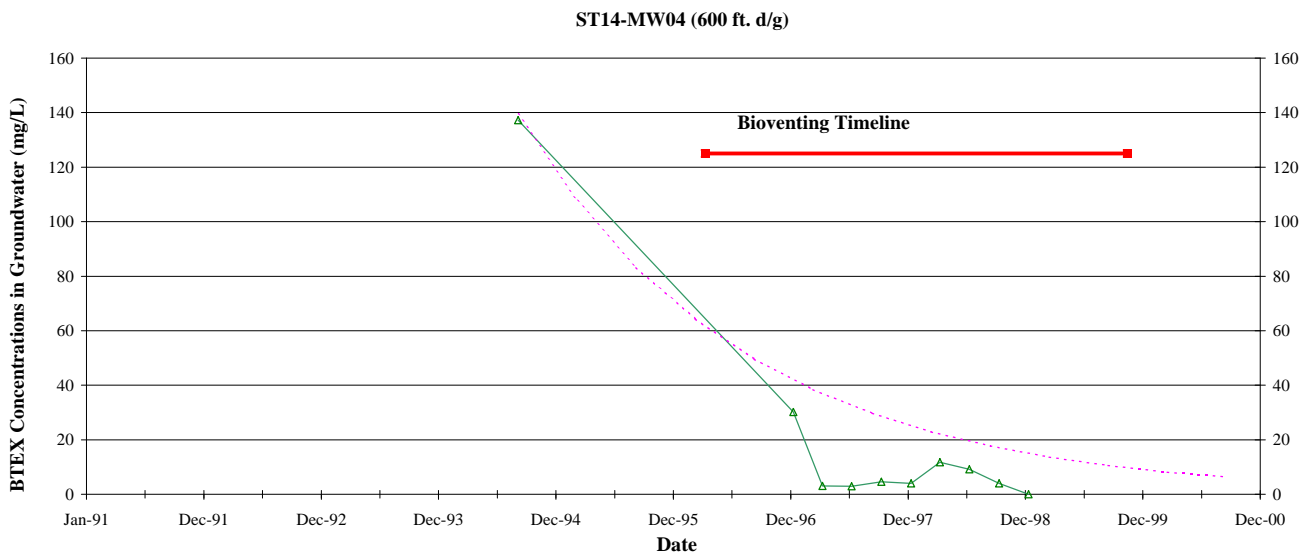
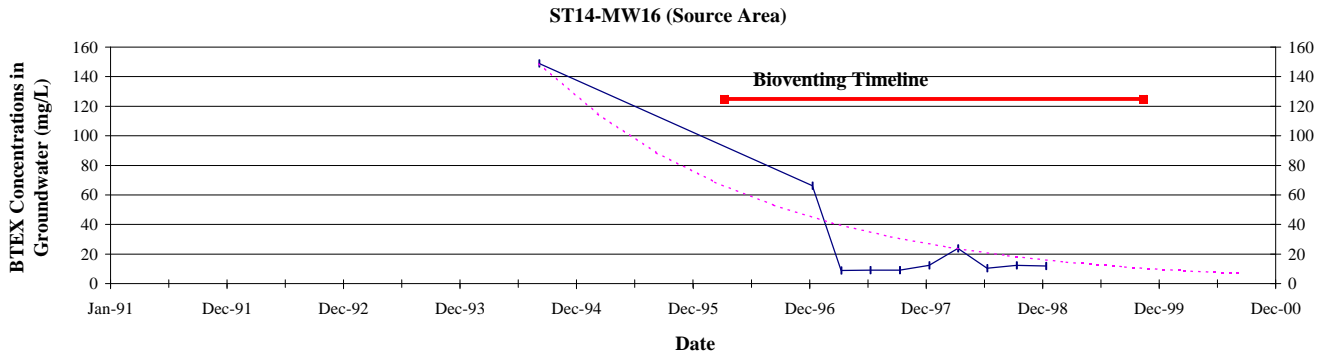
^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

FIGURE 3.10
BTEX CONCENTRATIONS IN GROUNDWATER COMPARED WITH CALCULATED, SITE-SPECIFIC FIRST-ORDER DECAY RATE
SOURCE-REDUCTION EFFECTIVENESS STUDY



----- Site-Specific First Order Decay Rate (0.00141 /day)

Although the bioventing system has removed significant BTEX mass from the subsurface, the short-term impact on dissolved BTEX could not be identified. The primary long-term groundwater benefit from this source reduction likely will be reductions of dissolved BTEX concentrations in the source area.

3.4 BIOSPARGING SITES

3.4.1 Myrtle Beach AFB, South Carolina (MOGAS Site)

Myrtle Beach AFB is located along the Atlantic coast near the South Carolina/North Carolina boundary.

3.4.1.1 Site Description

The MOGAS site was the location of the former motor pool, which provided fueling and repair services for motor vehicles on the Base. Four 5,000-gallon USTs were used to store gasoline and diesel fuel. In 1983, a fuel sheen was observed in a nearby drainage ditch. During subsequent investigations, subsurface soils were found to be saturated with fuel, and free product was observed on the groundwater surface. The leaking USTs and associated delivery lines were removed in April 1993. During excavation, large quantities of contaminated soil were encountered; the majority of these soils were left in place. Subsequent soil sampling, performed in 1995, indicated the presence a residual product smear zone extending from the former UST locations to the edge of the nearby drainage ditch, which constitutes a groundwater discharge point. However, free product was not observed during the 1995 investigations.

Across the majority of the site, interlayered sands, silty sands, silt, and clay occur from ground surface to about 5 to 10 feet bgs. Below this stratum lies a 4- to 10-foot-thick unit of relatively clean sand. A 3- to 7-foot-thick silty sand unit occurs beneath the clean sand and overlies a 10- to 15-foot-thick calcareous silt and clay. Groundwater is present at depths ranging from 1 foot bgs adjacent to the drainage ditch to 12 feet bgs near the source area.

An SVE pilot test was initiated in October 1995 and run over a 3-month period to evaluate the feasibility of removing VOCs and reducing contaminant mass in the source area using this technology. A bioventing pilot test was conducted at the site in November 1995. Significant oxygen utilization was observed in site soils, indicating a very active microbial population capable of degrading fuel residuals.

Based on the presence of significant soil contamination below the water table, installation of a biosparging system was recommended to remediate the residual contamination. A 41-day biosparging pilot test was performed in December and January 1998, and a full-scale biosparging system was installed and became operational in June 1998. The full-scale system consisted of 40 small-diameter sparging points screened in the sand zone approximately 5 to 7 feet below the water table. This system is still operating.

3.4.1.2 Soil and Soil Gas Quality

Analytical results for soil samples collected from 1988 to 1995 indicated the presence of significant contamination. BTEX concentrations detected in 1995 ranged up to 1,900

mg/kg. Soil sampling has not been performed since the biosparging system became operational. Therefore, the degree to which soil contamination has been remediated must be inferred based on soil gas and groundwater quality data. Soil gas sampling results for 1995 and 1999 are summarized in Table 3.15. These data indicate that oxygenation of the vadose zone via biosparging has resulted in substantial decreases in vadose zone contaminant concentrations.

3.4.1.3 Groundwater Quality

Groundwater quality data listed in Table 3.15 and graphed on Figure 3.11 strongly indicate that the biosparging system has caused dissolved BTEX concentrations to decrease in site groundwater. Analytical results for groundwater samples collected in January 1999, after the sparging system had been shut off for at least 30 days, indicate that residual BTEX contamination in soils is also being reduced, as minimal “rebound” occurred during the 30-day equilibration period. The effectiveness of the biosparging system is supported by historical surface water quality data for the adjacent drainage ditch. Maximum benzene concentrations in surface water samples have decreased from 580 µg/L prior to initiation of biosparging to less than 1 µg/L in August 1999.

The MK statistics and Sen’s slopes estimated for three source area wells indicate increasing trends prior to initiation of biosparging and decreasing trends after initiation of biosparging (Table 3.16). As described in Section 3.4.1.1, the contaminant source area at the MOGAS site extended from the former UST locations to the downgradient drainage ditch, into which the plume discharges, due to the past migration of free product on the water table. Therefore, the biosparging system was installed throughout the BTEX plume area to remediate the smear zone, and rapid effects were observable in all of the monitoring wells.

The areal extent of the dissolved BTEX plume at the MOGAS site is limited by the bounding downgradient drainage ditch, which is located approximately 100 feet from the former UST locations. Therefore, the maximum plume length observed at the site was only about 100 feet, and the length has not changed significantly since initiation of biosparging.

Dissolved naphthalene concentrations detected from July 1998 to August 1999 also decreased. The Sen’s slope estimates for the best-fit linear-trend lines through the naphthalene data for MW-112, MW-113, and MW-04 were -30, -2, and -1, respectively. These slopes indicate slower reduction rates than the corresponding slopes for BTEX listed in Table 3.16; however, initial dissolved naphthalene concentrations were generally substantially lower than dissolved BTEX concentrations. Insufficient data are available to assess pre-biosparging trends in dissolved naphthalene concentrations.

3.4.1.4 Effectiveness Summary

The combination of sandy soils, shallow depth to groundwater, and closely spaced (25 to 30 feet) sparging points distributed throughout the source area have contributed to the

**TABLE 3.15
ANALYTICAL DATA SUMMARY FOR THE MOGAS SITE
MYRTLE BEACH AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Soil Gas Data

Location ID	Depth of Sample (ft bgs) ^{d/}	Date Sampled	Benzene (ppmv) ^{e/}	Toluene (ppmv)	Ethyl-benzene (ppmv)	Xylenes (ppmv)	BTEX ^{a/b/} (ppmv)	TPH ^{c/} (ppmv)
Vent-01	NA ^{v/}	Sept/Oct-95	1,300	910	62	120	2,190	180,000
	NA	Oct-99	1.1	4.4	1.2	8.6	15.3	75
Vent-02	NA	Sept/Oct-95	1,300	2,000	200	410	3,910	100,000
	NA	Oct-99	64	7.2	1.8	5.5	78.5	1,500

Groundwater Data

Location ID	Plume Region	Groundwater Elevation (ft msl) ^{e/}	Screened Interval (ft bgs)	Date Sampled	Benzene (µg/L) ^{h/}	Toluene (µg/L)	Ethyl-benzene (µg/L)	Xylenes (µg/L)	BTEX (µg/L)	Naphthalene (µg/L)					
MW-112	Source (West)	7.47	3.0 - 13.0	Jan-95	5,430	23,400	2,430	10,843	42,100	NA					
				Aug-95	5,000	26,000	2,300	14,000	47,300	NA					
		8.01		Oct-97	3,600	24,000	1,800	13,700	43,100	510					
		14.71		Jul-98	34	J ^{i/}	1,000	150	1,240	2,420	J	140			
				Oct-98	330		9,400	1,100	8,800	19,600		760			
				Jan-99	23.1	J	1,140	257	2,830	4,250	J	25	U ^{j/}		
				Aug-99	8.3		25	D ^{k/}	23	D	104	D	150	D	
MW-113	Source (East)		7.88	3.0 - 13.0	Jan-95	773	379	117	264	1,530	NA				
		Aug-95			3,000	2,100	200	860	6,160	NA					
		8.43	Oct-97		4,400	660	440	880	6,380	150					
		14.79	Jul-98		160	U	10	U	17	15.5	JU ^{i/}	198	JU	6.1	J
			Oct-98		31	J	0.73	J	11	2.47	J	45.2	JU	8.4	
			Jan-99		1.39	U	1	U	0.609	J	2	3.50	JU	25	U
			May-99		1.6	J	0.24	J	0.25	JB ^{m/}	0.33	J	2.4	JB	0.36
Aug-99	1.4		U	1	U	0.54	J	2	3.4	J	0.56	J			
MW-04	Source Area	9.09	4.7 - 14.7	Jan-95	3.82	1	U	4.11	3.2	11.6	NA				
				Aug-95	63	14		22	27	126	NA				
		9.56		Oct-97	68	21		64	41	194	ND	n/			
		14.42		Aug-98	52	3.8		20	15.7	91.5		3.5			
				Oct-98	9.1	U	1	U	1	U	10.6	760			
				Jan-99	3.95	U	1	U	1	U	5.95	1.25			
				May-99	3.4	U	1	U	1	U	4.9	16	B ^{o/}		
				Aug-99	3	U	1	U	1	U	5.0	1	U		
		MOC-7		Source (between two source areas)	24.24	11.0 - 14.0	Jan-95	NA	NA	NA	NA	NA	NA		
Aug-95	40		8.3				2.5	8.2	59.0	NA					
9.48	Oct-97		24		ND		ND	ND	24	ND					
14.29	Oct-98		4.4		U		1	U	1	U	5.9	1	U		
	Jan-99		1.92		U		1	U	1	U	2	3.92	1	U	
	Aug-99		12		U		1	U	2.5	2	16.0	1	U		

TABLE 3.15 (Concluded)
GROUNDWATER QUALITY DATA FOR THE MOGAS SITE
MYRTLE BEACH AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data (Continued)

Location ID	Plume Region	Groundwater Elevation (ft msl)	Screened Interval (ft bgs)	Date Sampled	Benzene ^{a/} (µg/L)	Toluene ^{a/} (µg/L)	Ethylbenzene ^{a/} (µg/L)	Xylenes ^{a/} (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
MOC-5		NM		Jan-95	4,850	6,800	912	3,540	16,100	NA
				Aug-95	3,900	5,200	450	2,600	12,200	NA
				Aug-98	0.83 J	1 U	1 U	1 U	2.33 J	NA
				Oct-98	25	0.27 JB	2	1.75	29.0 JB	NA
				Aug-99	NA	NA	NA	NA	NA	NA
MOC-20		14.57		Aug-95	1.5	0.4 U	0.4 U	0.4 U	2.1	NA
				Aug-99	NA	NA	NA	NA	NA	NA

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} TPH = total petroleum hydrocarbons.

^{d/} ft bgs = feet below ground surface.

^{e/} ppmv = parts per million by volume.

^{f/} NA = not analyzed or not available.

^{g/} ft msl = feet above mean sea level.

^{h/} µg/L = micrograms per liter.

^{i/} J = Estimated value.

^{j/} U = compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{k/} D = Dilution.

^{l/} JU = Matrix interference - not detected.

^{m/} JB = Organic; blank contamination; either trace hit or matrix interference.

^{n/} ND = Not detected. 1 used for graphic purposes.

^{o/} B = Blank contamination.

FIGURE 3.11
BTEX CONCENTRATIONS IN GROUNDWATER
MOGAS SITE, MYRTLE BEACH, SOUTH CAROLINA
SOURCE REDUCTION EFFECTIVENESS STUDY

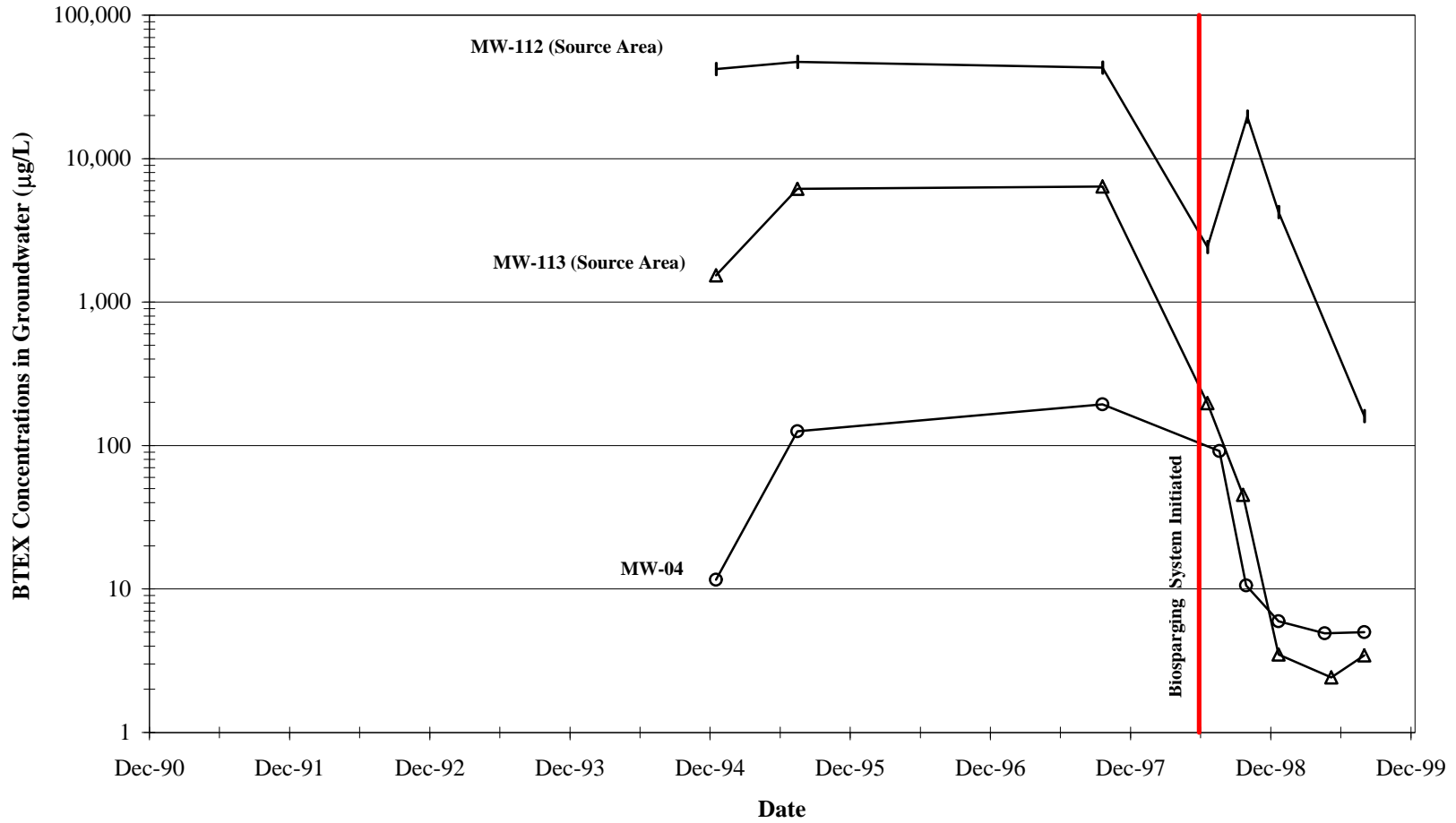


TABLE 3.16
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT THE MOGAS SITE
MYRTLE BEACH AFB, SOUTH CAROLINA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{c/} (µg/L)
MW-112	Source	1	-2	498	-2,420	43,100 (0.5 yr)	160 (1.3 yr)
MW-113	Source	3	-8	2,420	-32	6,380 (0.5 yr)	3 (1.3 yr)
MW-04	Source	3	-8	91	-4	194 (0.5 yr)	5 (1.3 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

success of this biosparging system. Groundwater quality results for this site strongly indicate that where a significant smear zone exists below the water table, closely spaced biosparging points may be more effective than bioventing or SVE at remediating BTEX and naphthalene concentrations in submerged soils and groundwater (assuming that other site conditions [e.g., soil type] are suitable). However, the apparent success of the biosparging system at the MOGAS Site should not be interpreted to mean that similar results will necessarily be obtained at other sites. As described in Section 2.3, channeling of injected air due to the presence of stratigraphic variability may result in localized and non-uniform remediation of the contaminated zone. Biosparging will probably be most successful in relatively homogenous, sandy aquifers.

3.4.2 CHEVRON AIR SPARGING SITES

Air Sparging Technical Bulletins issued by Chevron Petroleum Corporation (1995 and 1996) summarize “lessons learned” from the application of air sparging at numerous sites. Conclusions derived from these applications included the following:

- The effectiveness of air sparging is diminished at sites characterized by a relatively low-permeability water-bearing zone, such as unfractured silt/clay and weathered claystone/shale.
- Successfully applied air sparging systems are characterized by relatively closely spaced air-injection points (20- to 30-foot spacing) localized primarily in the source area.

- The presence of a low-permeability layer between the sparging-well screened interval and the water table appears to limit the effectiveness of the system, because it blocks air flow to the remediation target area (typically in the upper portion of the saturated zone/capillary fringe at fuel-release sites).
- Of the nine sparging sites with sufficient post-operational monitoring data to evaluate the effectiveness of the system, four may be considered “successful” applications of the technology, as evidenced by a decline in dissolved BTEX and total gasoline-range petroleum hydrocarbons with no rebound apparent in groundwater samples collected at least 3 months following system shutoff.
- Limited data indicate some success with remediating dissolved diesel fuel compounds via air sparging, but to a lesser degree than volative organics, probably due to the relatively low volatility and desorption rate of diesel components from the soil matrix.
- Air sparging is apparently effective in the removal of methyl *tert*-butyl ether (MTBE) from groundwater based on data from a single site. However, concurrent increases in MTBE concentrations in crossgradient and downgradient wells were noted, perhaps indicating transport of volatilized MTBE within induced air channels, with subsequent dissolution in the vicinity of these wells.

3.5 VACUUM-ENHANCED EXTRACTION SITES

3.5.1 Langley AFB, Virginia (SS-04)

Langley AFB is located in southeastern Virginia, within the Outer Coastal Plain physiographic province. The Base is approximately 12 miles north-northwest of Norfolk, Virginia and 3 miles west of Chesapeake Bay.

3.5.1.1 Site Description

Site SS-04 is the location of an abandoned UST farm that was formerly used to store JP-4 aviation fuel. All 24 USTs were abandoned in 1987. Leaks from the former tanks and the JP-4 distribution and transfer pipelines appear to have been the source of fuel contamination at the site.

The subsurface sediments beneath the site consist mostly of silt and sand mixtures containing variable amounts of gravel, clay, and shell fragments. The groundwater surface is present at depths ranging from 3 to 8 feet bgs. The average hydraulic conductivity of these subsurface materials, as determined from slug tests, is 8 ft/day, and the average advective groundwater velocity was computed to be 44 ft/yr.

Sixteen vacuum-enhanced recovery wells were installed in 1992 to lower the water table and recover free product. After product was separated from the recovered fluids, the groundwater was treated via air stripping. The system became operational in July 1992, and was shut down in April 1996 after nearly nondetectable BTEX concentrations were reported in the air-stripper influent throughout a 2-year period. Over the operational period, a significant decrease in thickness of free product was observed; however, the areal extent of free product appeared to increase. In September 1996, free product was

measured in three monitoring wells at thicknesses ranging from 0.01 to 0.16 feet. In November 1996 and October 1997, free product was measured in only one well at thicknesses of 0.16 feet and 0.61 feet, respectively.

3.5.1.2 Soil Quality

Selected soil quality data from 1990 and 1996 are listed in Table 3.17. The soil samples included in this table were collected at adjacent locations over time. In 1990, total soil BTEX concentrations ranged up to 43.6 mg/kg and averaged 9.7 mg/kg. In 1996, soil BTEX concentrations ranged from 0.16 mg/kg to 425 mg/kg and averaged 105 mg/kg. These average BTEX concentrations are plotted on Figure 3.12. All of the samples were collected from the zone of residual fuel contamination bordering the water table, and indicate the presence of a continuing source of groundwater BTEX contamination that has not been remediated by the source-reduction system.

3.5.1.3 Groundwater Quality

Insufficient data are available for the pre-source-reduction period to evaluate temporal trends. However, data collected during and after April 1996, when the remediation system was shut off, mostly indicate substantial reductions in dissolved BTEX concentrations (Table 3.17 and Figure 3.12). The MK statistic and Sen's slopes computed for source area well OW7 were negative, and are indicative of a decreasing trend (Table 3.18). Dissolved BTEX concentrations in well 4MP-5S decreased from 1,810 µg/L to 8 µg/L within an 11-month period. In addition, the areal extent of the dissolved BTEX plume appeared to decrease substantially between October 1996 (4.9 acres) and October 1997 (1.8 acres). Similarly, the estimated length of the major axis of the BTEX plume decreased from 820 feet in October 1996 to 600 feet in October 1997. These data indicate that the remaining source is insufficient to overcome the effects of biodegradation of dissolved BTEX; consequently, the plume is shrinking.

3.5.1.4 Effectiveness Summary

Groundwater quality data for this site are limited, and no data are available for the operational period of the vacuum-enhanced extraction system. However, limited post-remediation data indicate rapid decreases in dissolved BTEX concentrations that may be related to source remediation and vacuum-enhanced extraction of contaminated groundwater.

TABLE 3.17
ANALYTICAL DATA SUMMARY FOR SITE SS-04
LANGLEY AFB, VIRGINIA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Soil Data

Location ID	Depth of Sample (ft bgs) ^{c/}	Date Sampled	Benzene (mg/kg) ^{d/}	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	BTEX ^{a/b/} (mg/kg)	Naphthalene (mg/kg)
SB-14-1	4	May-90	0.75 U+ ^{e/}	0.75 U+	0.75 U+	0.75 U+	1.50 U+	NA ^{f/}
		Dec-90	0.62 U+	1.7 *B ^{f/}	0.62 U ^{h/}	41 S ^{i/}	43.3 BS ^{j/}	NA
SB-14-2	4.5	May-90	0.3 U+	0.3 U+	0.3 U+	8 + ^{k/}	8.5 +	NA
		Dec-90	0.3 U+	0.3 U	0.3 U	7	7.5	NA
SB-14-3	5	May-90	0.0003 U+	0.0003 U+	0.0003 U+	0.0004 *+ ^{l/}	0.0049 +	NA
		Dec-90	0.0034 U	0.015 *B	0.0034 U	0.0034 U	0.020 *B	NA
SB-14-4	5.5	May-90	0.0007 *+	0.0049 +	0.0003 U+	0.0031 +	0.009 +	NA
		Dec-90	0.0029 U	0.0089 * ^{mv/}	0.0029 U	0.0029 U	0.013	NA
SB-14-5	4.5	May-90	0.3 U+	0.3 U+	0.3 U+	0.78 *+	1.23 +	NA
		Dec-90	3.5 U	3.5 U	3.5 U	21	26.3	NA
	Arithmetic Avg		0.6	0.7	0.6	7.9	9.7	NA
	Geometric Mean		0.0496	0.0866	0.0456	0.226	0.408	NA
	Median		0.3	0.3	0.3	0.765	1.7	NA
4-MP5	4-6	Oct-96	0.0067	0.66 U	6.8	37	44.1	NA
4MP-12	5.75-6.25	Oct-96	0.0025 U	0.0025 U	0.056	0.097	0.16	NA
4MP-14	5.75-6.25	Oct-96	0.33	17	4	28	49.3	NA
4MP-15	3.5-4.0	Oct-96	15	150	140	120	425	NA
4MP-16	4.75-5.25	Oct-96	0.049	0.075	0.056	0.12	0.3	NA
	Arithmetic Avg		3.08	33.5	30.2	37.0	104	NA
	Geometric Mean		0.0835	0.794	1.64	4.29	6.8	NA
	Median		0.049	0.66	4	28	32.7	NA

TABLE 3.17 (Concluded)
ANALYTICAL DATA SUMMARY FOR SITE SS-04
LANGLEY AFB, VIRGINIA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Groundwater Data

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft btoc) ^{n/}	Date Sampled	Benzene (µg/L) ^{o/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
S-4B Source Area NA		Jul-84	6,180	6,700	5,860	1,020	19,800	NA
4MP-15 Source Area 23.0 - 26.0	7.99	Nov-96 Oct-97	7 0.4 U	0.4 U 0.4 U	30 2.1	1.8 0.98	39 3	NA NA
S-4F Source Area NA		Jul-84	428	122	16.2	286	852	NA
4MP-5S Source Area 2.8 - 8.8	7.94	Nov-96 Oct-97	1,300 0.4 U	8 U 0.4 U	96 2	410 5.4	1,810 8	NA NA
RW-6 Source Area NA	3.92 5.82	Oct-96 Oct-97	12 43	3.3 0.4 U	1.3 2.8	4.4 5.5	21 52	NA NA
P4 Source Area NA	3.51 5.21	Nov-96 Oct-97	25 170	0.4 U 0.4 U	41 140	13 8.9	79 319	NA NA
OW-7 Source Area NA	8.47	Apr-96 Oct-96 Oct-97	320 97 32	< 5 0.7 0.4 U	< 5 3.8 4.1	< 5 6.1 9	328 108 45	NA NA NA

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} mg/kg = milligrams per kilogram.

^{e/} U+ = Analyzed for and not detected; estimated value.

^{f/} NA = Not analyzed or not available.

^{g/} *B = Quantitation estimated; value reported may be biased high or a false positive based upon applicable method blank.

^{h/} U = Compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{i/} S = Estimated value; surrogate recovery above control limits.

^{j/} BS = Quantitation estimated; value reported may be biased high or a false positive based upon applicable method blank. Estimated value; surrogate recovery above control limits.

^{k/} + = Estimated value; alternate method used.

^{l/} *+ = Quantitation estimated. Estimated value; alternative method used.

^{m/} * = Quantitation estimated.

^{n/} ft btoc = feet below top of casing.

^{o/} µg/L = micrograms per liter.

FIGURE 3.12
BTEX CONCENTRATIONS IN GROUNDWATER AND SOIL
SITE SS-04, LANGLEY AFB, VIRGINIA
SOURCE-REDUCTION EFFECTIVENESS STUDY

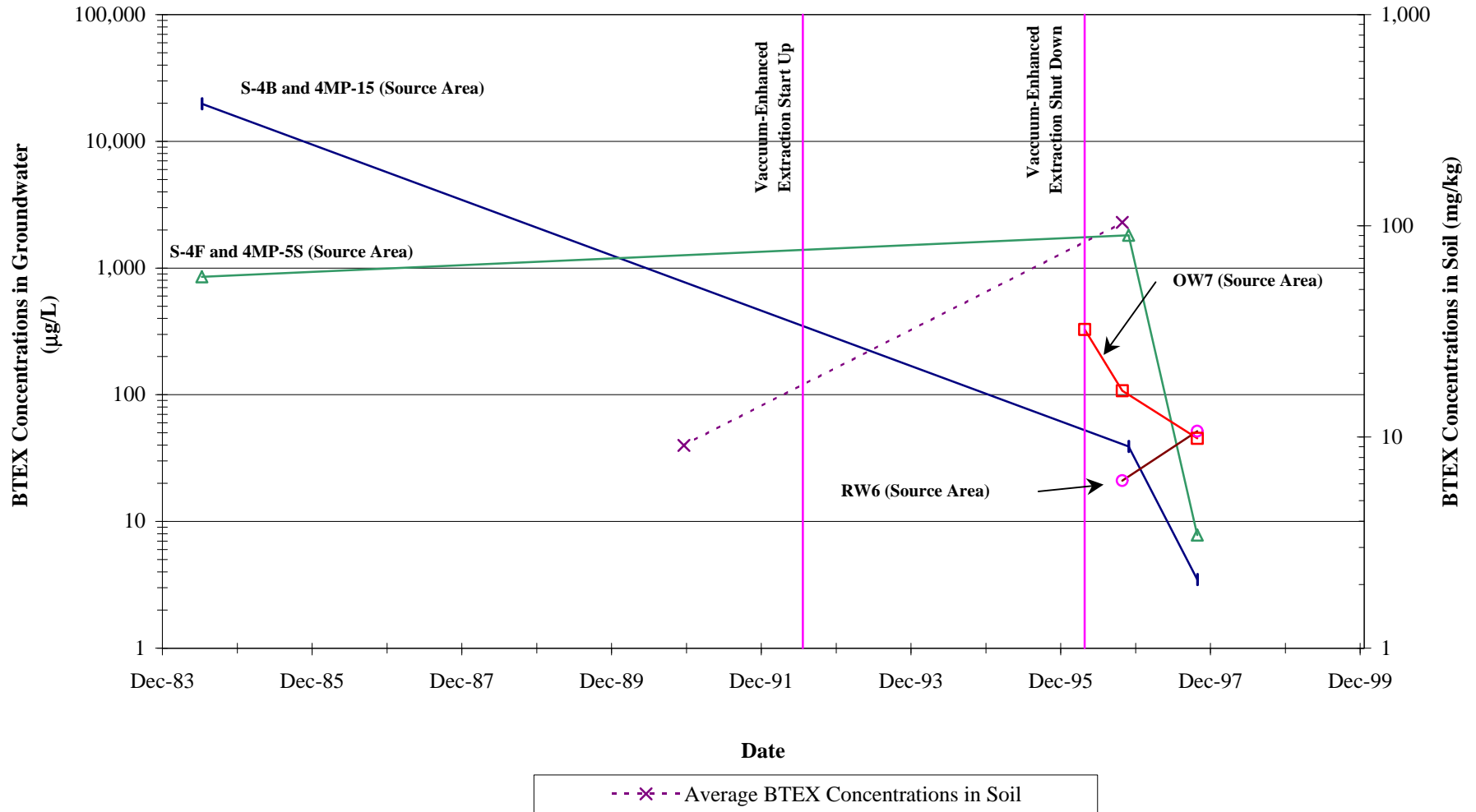


TABLE 3.18
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE SS-04
LANGLEY AFB, VIRGINIA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{e/} (µg/L)
4-MP15	Source	-- ^{f/}	--	--	--	19,760 (8.0 yr)	3 (5.3 yr)
4-MP5S	Source	--	--	--	--	852 (8.0 yr)	8 (5.3 yr)
RW6	Source	--	--	--	--	--	52 (5.3 yr)
OW7	Source	--	-3	--	-142	--	45 (5.3 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

3.5.2 Tinker AFB, Oklahoma (Area A Service Station)

Tinker AFB covers approximately 5,000 acres in the southeastern Oklahoma City metropolitan area in central Oklahoma.

3.5.2.1 Site Description

Area A was the location of the Base service station facility for military vehicles from 1942 to 1991. Two 12,000-gallon USTs were installed in 1942 to store leaded gasoline, and later were used to store unleaded fuel. Two additional USTs were installed in 1975 to store unleaded gasoline and diesel fuel. In 1978, the two older USTs were suspected of leaking, and were taken out of service. In 1982, the newer UST used to store unleaded gasoline developed a leak and was replaced with a new tank. The two remaining USTs were taken out of service in October 1990, and the service station was closed in April 1991. All four USTs and associated piping were removed from the site in January 1996.

Approximately 10 to 20 feet of clay, silty clay, and clayey silt are present at the surface. Beneath this clay unit are approximately 15 to 28 feet of fine-grained sands, with discontinuous silt and clay lenses peripheral to the area immediately beneath the service station. An aquitard, consisting of a 5- to 7-foot-thick interval with high clay content and cemented siltstone, underlies the sand unit. Interbedded fine-grained sands, clays, and clayey silts underlie the aquitard.

The groundwater surface is present at a depth of approximately 10 to 20 feet bgs within the fine-grained sand unit. Slug test results indicate that the hydraulic conductivity of the upper saturated zone ranges from 0.04 to 3.6 ft/day, and the advective groundwater velocity is calculated to range from 1.1 to 99 ft/yr.

Three groundwater and free-product recovery wells with pneumatic total-fluids pumps were installed in September 1992, and were operated until January 1996. During the last 4 months of operation, only 3.5 gallons of free product were recovered. A Phase I vacuum-enhanced pumping (VEP) system consisting of eight wells was installed and operated briefly in early 1996 to obtain design parameters for an expanded system. The objective of the VEP system was to simultaneously recover contaminated groundwater, free product, and soil vapor. An additional four VEP wells were brought on-line in June 1997, and two eductor wells were installed in August and September 1997 to recover groundwater via a jet-pump-type eductor system. The eductor wells were installed to capture solvent contamination at the base of the shallow groundwater zone and to control vertical migration of any fuel contaminants that may seep through the confining layer that underlies the shallow groundwater zone. The eductor wells were taken off-line in July 1999 pending pump upgrades, and the system became operational again in August 1999. The entire VEP system was shut down again in October 1999 because it appeared that sustained cleanup levels for fuel hydrocarbons had been attained. If contaminant levels do not rebound significantly during the next 6 months, the site should meet regulatory cleanup requirements for fuel contaminants.

3.5.2.2 Soil Quality

A substantial number of site soil samples were collected and analyzed from 1991 through 1994. However, no recent soil quality data are available to evaluate the effectiveness of the VEP system.

3.5.2.3 Groundwater Quality

Groundwater quality data for selected monitoring wells, collected from January 1994 through June 1998, are summarized in Table 3.19. As shown on Figure 3.13, substantial reductions in dissolved BTEX concentrations have occurred since startup of the VEP system, indicating that the system quickly improved groundwater quality.

The MK statistics computed for three source area wells are negative for both the pre- and post-source-reduction periods, indicating decreasing trends (Table 3.20). Comparison of the Sen's slope estimates for the pre- and post-source-reduction periods for source area wells MW2-004 and MW2-002 indicates that maximum dissolved BTEX concentrations were decreasing more rapidly after the June 1997 startup of the expanded VEP system. It should be noted that the May 1997 data were used to calculate both the pre- and post-system-startup statistics. The post-system-startup Sen's slopes for wells MW-002 and MW-003 after June 1997 were computed using data from May 1997 to January 1998 and May 1997 to December 1997, respectively. Use of the more recent sampling results (which were either nondetect or of very low magnitude) would have biased the slopes to indicate little or no trends in BTEX concentrations, thus masking the effects of the VEP system.

TABLE 3.19
GROUNDWATER QUALITY DATA FOR AREA A SERVICE STATION
TINKER AFB, OKLAHOMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Location ID	Plume Region	Depth to Groundwater (ft btoc) ^{c/}	Screened Interval (ft bgs) ^{d/}	Date Sampled	Benzene (µg/L) ^{e/}	Toluene (µg/L)	Ethyl-benzene (µg/L)	Xylenes (µg/L)	BTEX ^{h/} (µg/L)	Naphthalene (µg/L)	MTBE ^{i/} (µg/L)				
2-2 (MW2-002)	Upgradient ~10 ft from Source	14	7.0 - 23.0	Jan-94	330	32	79	81.0	522	2.4	NA ^{f/}				
				Jan-95	1,100	130	740	730	2,700	56	NA				
				Oct-95	390	ND ^{g/}	14	ND	404	ND	NA				
				Aug-96	400	< 12	< 12	< 12	418	16	NA				
				Apr-97	453	12.3	136	35.4	637	NA	NA				
				May-97	236	16	72	35	359	3	J ^{h/} NA				
				Sep-97	20	ND	ND	ND	20	ND	ND				
		Jan-98	ND	ND	ND	ND	ND	NA	ND						
		Apr-98	ND	ND	ND	ND	ND	ND	ND						
		Mar-99	ND	ND	ND	ND	ND	NA	ND						
		Jun-99	< 1	ND	ND	ND	< 1	NA	ND						
		2-3 (MW2-003)	80 ft d/g ^{j/} from Source	14.01	9.5 - 24.5	Aug-94	3,700	16	6.2	27	3,750	4.4	NA		
						Jan-95	920	< 1	< 1	< 1	922	<4	NA		
						Oct-95	110	25	250	102	487	76	NA		
Aug-96	110					25	210	89	434	86	NA				
Apr-97	476					10.8	96.5	34.3	618	NA	NA				
May-97	459					9	42	13	523	4	J NA				
Jul-97	98					ND	11	6	115	ND	NA				
Aug-97	28					ND	ND	ND	28	ND	NA				
Sep-97	14					J	ND	17	J	31	J	2	J	23	
Nov-97	46					J	ND	ND	ND	46	ND	ND	80	J	
Dec-97	ND					J	ND	ND	ND	ND	ND	ND	24	J	
Jan-98	ND					J	ND	ND	ND	ND	ND	ND	ND	ND	
Feb-98	ND					J	ND	ND	ND	ND	ND	ND	ND	NA	
Mar-98	ND					J	ND	ND	ND	ND	ND	ND	ND	6.9	J
Apr-98	4.9					J	ND	ND	ND	3.7	J	8.6	J	ND	ND
Jun-98	1					J	ND	ND	ND	ND	J	1	J	ND	ND
Mar-99	< 1					J	ND	ND	ND	ND	J	< 1	J	<	1
2-4 (MW2-004)	Source	16.64	5.0 - 20.0	Jan-94	6,500	16,000	1,700	8,700	32,900	470	NA				
				Oct-95	6,500	13,000	1,700	10,100	31,300	1,000	NA				
				Aug-96	9,800	14,000	1,700	9,100	34,600	940	NA				
				May-97	8,410	11,400	1,060	5,280	26,200	145	NA				
		14.02	Sep-97	140	34	8	44	226	5	J	21				
			Dec-97	ND	ND	ND	ND	ND	ND	ND	ND				
			Jun-99	109	95	9.4	3.1	217	ND	ND	6.8				
			Jan-94	15,000	24,000	2,000	9,200	50,200	410	NA					
2-50B (MW2-050B)	150 ft d/g from Source	15.02	8.0 - 17.9	Aug-96	12,000	17,000	2,200	9,300	40,500	980	NA				
				Apr-97	14,200	17,500	1,800	9,240	42,700	NA	NA				

TABLE 3.19 (Concluded)
GROUNDWATER QUALITY DATA FOR AREA A SERVICE STATION
TINKER AFB, OKLAHOMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Location ID	Plume Region	Depth to Groundwater (ft btoc)	Screened Interval (ft bgs)	Date Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX (µg/L)	Naphthalene (µg/L)	MTBE (µg/L)
2-51B (MW2-051B)	Upgradient ~40 ft from Source	11.09	8.0 - 17.9	Jan-94	1,400	17	23	51	1,490	5.6	NA
				Jan-95	530	6	18	11	565	3	NA
				Oct-95	1,100	ND	90	ND	1,190	ND	NA
				Aug-96	81	< 5	8	15	107	24	NA
				Apr-97	182	2.5	25.8	36.2	247	NA	NA
				May-97	240	ND	15	11	266	ND	NA
		9.86	Jul-97	395	ND	44	10	449	5	J	NA
			Aug-97	245	ND	48	8	301	6	J	NA
			Sep-97	340	4 J	11	4 J	359 J	6 J	J	ND
			Nov-97	500	ND	28	ND	528	6	J	ND
			Dec-97	200	2 J	5 J	2 J	209 J	ND		ND
			Jan-98	450	ND	11	ND	461	ND		ND
			Feb-98	NA	NA	NA	NA	NA	ND		ND
			Mar-98	28	ND	2.1	0.68	31	ND		ND
			Apr-98	340	5.3 J	7.8 J	3.9 J	357 J	ND		ND
			Jun-98	500	7 J	26 J	6.8 J	540 J	ND		ND
			Jun-99	1.4	< 1	5.2	13.6	21			4.7

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; MTBE = methyl tert-butyl ether.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft btoc = feet below top of casing.

^{d/} ft bgs = feet below ground surface.

^{e/} µg/L = micrograms per liter.

^{f/} NA = Not analyzed or not available.

^{g/} ND = Not detected. 1 used for ND for graphing purposes.

^{h/} J = The analyte was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample. The data should be considered as a basis for decision making and are usable for many purposes.

^{i/} d/g = Downgradient.

FIGURE 3.13
BTEX CONCENTRATIONS IN GROUNDWATER
AREA A SERVICE STATION, TINKER AFB, OKLAHOMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

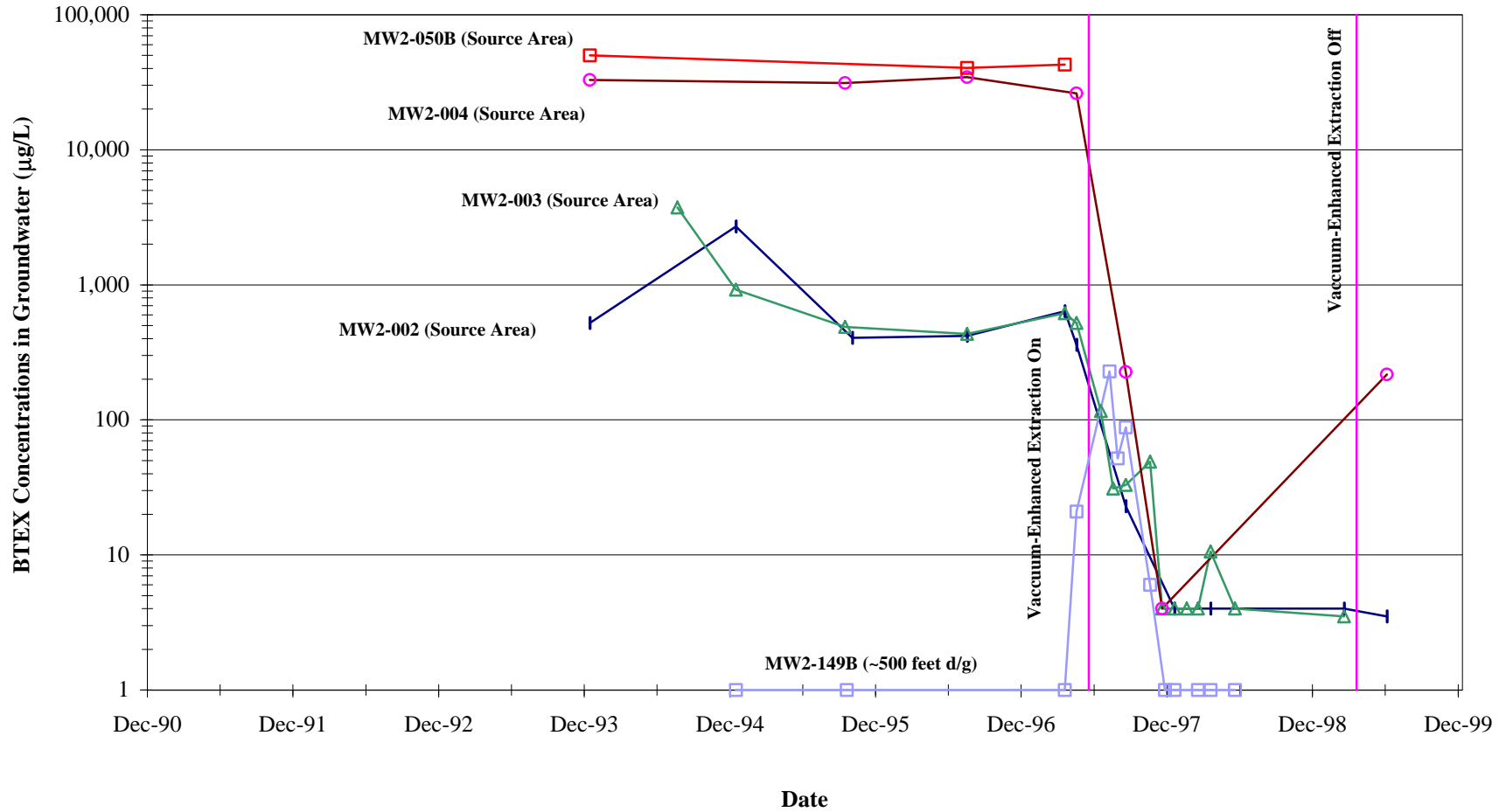


TABLE 3.20
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT THE AREA A
SERVICE STATION
TINKER AFB, OKLAHOMA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{e/} (µg/L)
MW2-004	Source	-2	-4	-1,930	-4,430	26,200 (0.1 yr)	217 (2.2 yr)
MW2-002	Source	-5	-3	-33	-178	359 (0.1 yr)	4 (2.2 yr)
MW2-050B	Source	-1	--	-3,750	--	42,700 (0.2 yr)	--
MW2-003	20 feet d/g ^{f/}	-7	-9	-101	-42	618 (0.1 yr)	4 (1.9 yr)
2-149B	700 feet d/g	--	-2	--	-4	ND	6

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} d/g = downgradient.

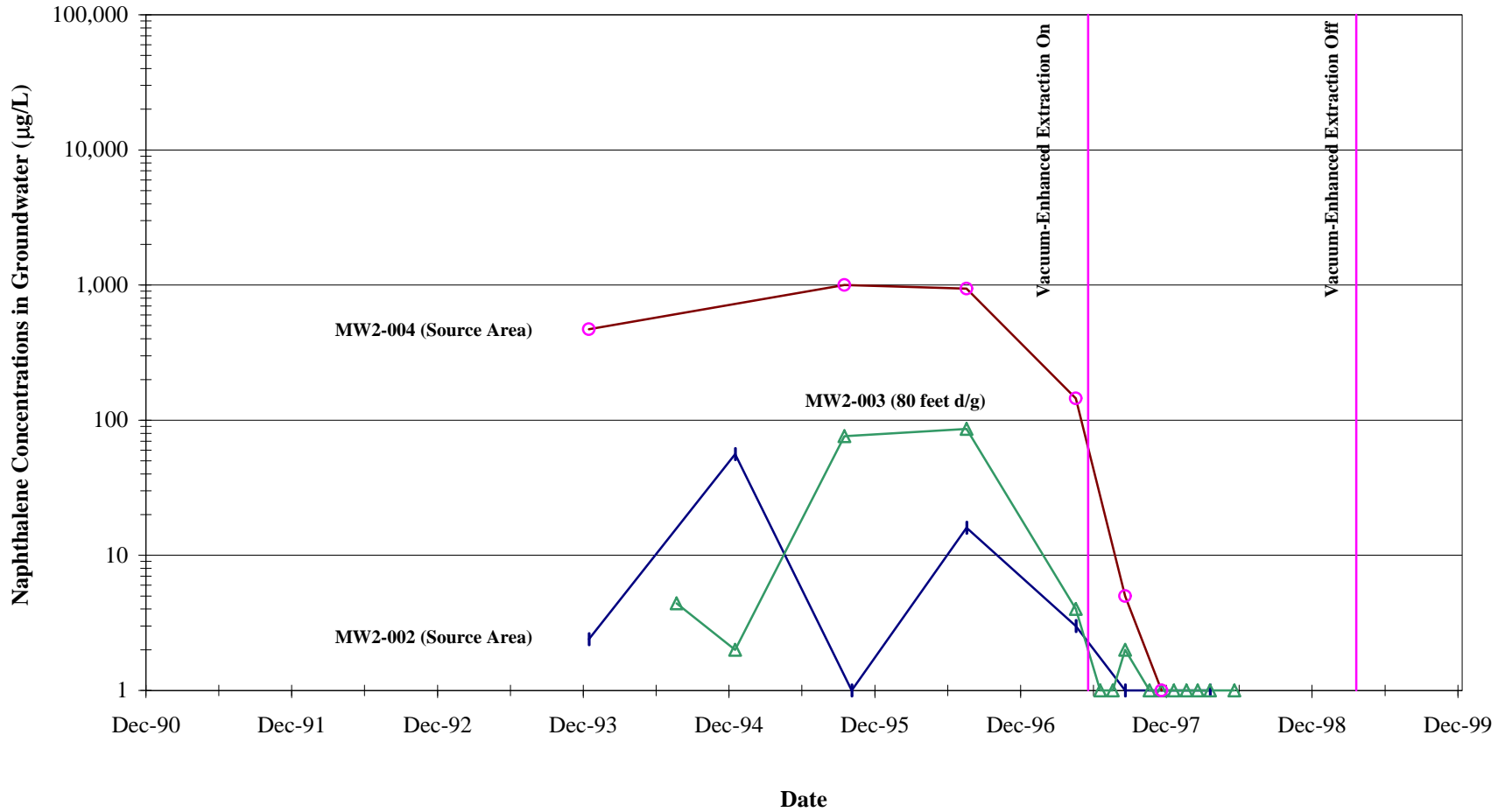
^{f/} "--" = insufficient data available to compute the indicated value.

Although the dissolved BTEX concentration at downgradient well MW2-003 decreased substantially from August 1994 to October 1995, concentrations were relatively stable from October 1995 to May 1997. After May 1997, BTEX concentrations again decreased substantially (from 523 µg/L to 49 µg/L in 6 months), reflecting the influence of the remediation system. Dissolved BTEX data for downgradient well 2-149B indicate that the plume had reached this well by May 1997, but that the hydraulic control exerted by the VEP system caused the plume to retreat toward the source area after July 1997.

Available information indicates that the vacuum-enhanced extraction system operation has substantially reduced the areal extent of the dissolved BTEX plume. In May 1997, the total length of the long axis of the dissolved benzene plume in the upper saturated zone, as defined by the 5-µg/L isopleth, was inferred to be approximately 750 feet. In contrast, the total length of the dissolved BTEX plume in January 1998 was inferred to be less than 300 feet.

Substantial reductions in dissolved naphthalene concentrations also occurred following initiation of the VEP system (Figure 3.14). However, groundwater quality data indicate

FIGURE 3.14
NAPHTHALENE CONCENTRATIONS IN GROUNDWATER
AREA A SERVICE STATION, TINKER AFB, OKLAHOMA
SOURCE-REDUCTION EFFECTIVENESS STUDY



that naphthalene concentrations also were decreasing substantially prior to the June 1997 startup of the expanded VEP system. The fact that dissolved naphthalene concentrations have consistently remained below 10 µg/L since June 1997 reflects the effects of the VEP system.

3.5.2.4 Effectiveness Summary

The groundwater quality data for Area A indicate that the vacuum-enhanced, multi-phase extraction system rapidly and substantially impacted groundwater quality. It should be noted that the observed impacts are due in part to direct groundwater and free product extraction rather than to remediation of contaminated soils. The effectiveness of this remediation method at reducing BTEX concentrations in soils cannot be evaluated until the site groundwater has reached equilibrium with source area soils. It should also be noted that groundwater extraction, together with the accompanying reductions in dissolved fuel hydrocarbon concentrations, can cause the groundwater system in the contaminated area to become more aerobic. This is especially significant where fuel hydrocarbons are commingled with chlorinated solvents, because some solvents (e.g., tetrachloroethene [PCE] and trichloroethene [TCE]) can be reductively dechlorinated under anaerobic conditions, but are relatively recalcitrant (not biodegradable) under aerobic conditions. Therefore, groundwater extraction has the potential to disrupt natural biodegradation processes.

3.6 EXCAVATION SITES

3.6.1 Travis AFB, California (North and South Gas Stations)

Travis AFB is located midway between the cities of San Francisco and Sacramento, approximately 3 miles east of the town of Fairfield, California.

3.6.1.1 Site Description

The site consists of two BX Service Stations located on different corners of the same intersection. Fuel leaks from tanks and piping have occurred at both stations, which have been in operation since the mid 1960s. The fuel leaks were detected at both gas stations in 1988, and free product was detected on the groundwater adjacent to UST pits at both stations.

At the South Gas Station (SGS), a leaking distribution line was identified and repaired in 1988 following a product inventory loss of 3,800 gallons of unleaded gasoline. In 1993, a short-term bioventing pilot test was conducted in the area around the SGS UST complex. In July and August 1994, all six USTs and associated piping at the SGS were removed, and new USTs were installed. Contaminated soils were excavated from the tank pit to approximately 13 feet bgs and from beneath the distribution piping to approximately 5 feet bgs. A total of approximately 10,000 gallons of groundwater and 1,700 cubic yards (cy) of soil were removed. Also in 1994, one product-extraction well was installed downgradient from the SGS tank pit.

At the North Gas Station (NGS), contaminated soil and all three USTs were removed and replaced in 1988. Contaminated soil was removed to approximately 20 feet bgs. A product-extraction well was installed downgradient from the NGS tank pit in 1994.

Groundwater sampling activities indicated that a dissolved contaminant plume originating from the NGS had merged with the plume originating from the SGS.

A surficial clay unit containing localized sand lenses is present to a depth of 10 to 15 feet bgs. This clay acts locally as an aquitard. Underlying the clay is an alluvial aquifer consisting of fine- to coarse-grained sand and/or silt with localized clay lenses. The maximum soil contamination was found at or near the interface between these two units, indicating that fuel contamination has migrated on the groundwater below the confining clay layer. Bedrock consisting of weathered shale is encountered at depths of 20 to 40 feet bgs. Groundwater levels measured at the site have varied from 7 to 14 feet bgs. The average hydraulic conductivity of the alluvial sediments was computed to be approximately 7 ft/day based on slug and pump tests, and the average advective groundwater velocity was computed to be 40 ft/yr.

3.6.1.2 Soil and Soil Gas Quality

Soil vapor screening at the NGS, performed in December 1989 after excavation activities were complete, indicated TVH concentrations ranging from below detection limits to a maximum of 99 µg/L in shallow soils (<4 feet bgs) within 75 feet of the removed USTs. In deeper soils (<12 feet bgs), TVH concentrations ranged from 6 µg/L to 158,000 µg/L. Post-excavation soil sampling at the NGS, performed in 1991 and 1994, indicated the presence of BTEX and TVH at concentrations ranging up to 15 mg/kg and 2,120 mg/kg, respectively. Tabular summaries of these data were not available to be included in this report

Soil samples were collected at the SGS from the bottom of the UST excavation trenches and from around the pump islands in July 1994 (Appendix B). BTEX and TVH concentrations ranged up to 1,020 mg/kg and 5,400 mg/kg, respectively. No additional overexcavation was performed to remove these contaminated soils. The available soil gas and soil quality data indicate the continued presence of a source of groundwater contamination that was not removed during the various excavation activities.

3.6.1.3 Groundwater Quality

Historical groundwater quality data for selected wells are summarized in Table 3.21 and depicted on Figure 3.15. Pre-excavation data are limited to two apiece for wells MW-138, MW-139, and MW-141. These limited data suggest that dissolved BTEX concentrations were increasing substantially prior to the 1994 SGS excavation at SGS source area well MW-138, and were decreasing at SGS source area well MW-141 and downgradient well MW-139.

MK statistics and Sen's slopes calculated for the post-excavation periods indicated decreasing trends with the exception of well MW-210, which exhibited a relatively neutral trend (Table 3.22). BTEX concentrations detected in groundwater from well MW-138, located in the SGS source area, decreased from 103,000 µg/L at the time of the SGS excavation in 1994 to 1,830 µg/L in June 1999. Similarly, BTEX concentrations at SGS source area well MW-141 decreased from 67,000 µg/L in August 1995 (1 year after the SGS excavation) to 420 µg/L in June 1999. The pre-excavation data for MW-138 suggest that BTEX concentrations were increasing at this location prior to the 1994 excavation event. The substantial post-excavation decreases indicate that the majority of

**TABLE 3.21
GROUNDWATER QUALITY DATA FOR THE NORTH AND SOUTH GAS STATIONS
TRAVIS AFB, CALIFORNIA
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Location ID, Plume Region, Screened Interval (ft bgs) ^{c/}	Depth to Groundwater (ft bgs) ^{f/}	Date Sampled	Benzene (µg/L) ^{d/}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Xylenes (µg/L)	BTEX ^{a,b/} (µg/L)	MTBE ^{d/} (µg/L)	
MW-135 Source Area North Station 9.0 - 24.0	13.06	Jul-94	NA ^{c/}	NA	NA	NA	9,150	NA	
		Sep-95	2,600	99	2,000	7,000	11,700	NA	
		Sep-96	138	2.01	199	290	629	2,800	
		Sep-97	560	10	U ^{f/}	1,100	687	2,360	3,400
		Apr-98	490	17	1,300	810	2,620	5,300	
		Sep-98	120	9	480	200	809	830	
		Jun-99	66.3	16.7	957	476	1,520	798	
MW-137 120 ft d/g ^{g/} from North Station 11.5 - 26.5	12.91	Jul-94	NA	NA	NA	NA	613	NA	
		Sep-95	690	84	54	65	893	NA	
		Sep-98	390	0	51	22	463	10	
		Jun-99	180	8.9	47.9	27.2	264	49.2	
		Jul-94	NA	NA	NA	NA	5,050	NA	
MW-206NS 170 ft d/g from North Station NA	13.07	Sep-95	4,400	470	270	450	5,590	NA	
		Sep-98	800	4	97	22	923	5,400	
		Jun-99	180	8.9	47.9	27.2	264	49.2	
		Dec-89	3,000	2,400	900	4,400	10,700	NA	
MW-138 Source Area South Station 10.5 - 25.5	12.93	Jul-94	NA	NA	NA	NA	103,000	NA	
		Sep-95	4,000	5,800	1,700	12,000	23,500	NA	
		Sep-96	1,940	581	958	5,230	8,710	1,087	
		Sep-97	NA	NA	NA	NA	4,370	610	
		Apr-98	1,700	210	500	1,230	3,640	560	
		Sep-98	500	42	200	363	1,105	220	
		Jun-99	850	67.3	329	586	1,832	173	

TABLE 3.21 (Concluded)
GROUNDWATER QUALITY DATA FOR THE NORTH AND SOUTH GAS STATIONS
TRAVIS AFB, CALIFORNIA
SOURCE REDUCTION EFFECTIVENESS STUDY

Location ID, Plume Region, Screened Interval (ft bgs)	Depth to Groundwater (ft bgs)	Date Sampled	Benzene ^{a/} (µg/L)	Toluene ^{a/} (µg/L)	Ethyl- benzene ^{a/} (µg/L)	Xylenes ^{a/} (µg/L)	BTEX ^{a,b/} (µg/L)	MTBE (µg/L)
MW-141 Source Area South Station NA		Dec-89	54,000	91,000	6,600	32,000	184,000	NA
		Jul-94	7,380	11,600	1,640	7,210	27,800	NA
		Sep-95	32,000	25,000	1,400	8,600	67,000	NA
		Sep-96	5,220	4,630	615	3,070	13,500	< 9
		Sep-97	3,400	860	360	1,160	5,780	J ND ^{i/}
		Apr-98	9,900	D ^{f/} 5,900	D 640	DJ ^{k/} 2,480	D 18,900	DJ ND
		Sep-98	19	2	0.2	4	25	< 0.12
		Jun-99	309	20.9	49.5	40.2	420	3.8
		MW-139 160 ft d/g from South Station 9.0 - 24.0	10.17	Dec-89	750	1,800	4,700	1,800
Feb-90	NA			NA	NA	NA	NA	NA
Jul-94	840			520	600	1,170	3,130	NA
Sep-95	2,700			29	450	79	3,260	NA
Sep-96	501			44.4	362	232	1,140	39
Sep-97	6			0.8	J 14	5	25.8	J 110
Apr-98	5			J 0	8	J 0	13	J 420
Sep-98	0.5			0	0.9	0.6	2	240
Jun-99	< 1			< 1	2.1	< 1	4	111
MW-210 320 ft d/g from South Station 8.0 - 24.0	9.17	Jul-94	NA	NA	NA	NA	NA	NA
		Sep-95	670	650	560	1,600	3,480	NA
		Sep-96	399	288	443	1,200	2,330	< 1.8
		Sep-97	NA	88	240	590	918	ND
		Apr-98	480	D 180	D 1,600	D 1,210	D 3,470	D 30
		Sep-98	430	290	1,700	1,210	3,630	110
		Jun-99	53.8	25.2	647	294	1,020	572
MW-211 380 ft d/g from South Station 10.0 - 20.0	9.32	Dec-94	67.8	60.4	71.4	247	447	NA
		Sep-95	33	8.1	26	29	96.1	NA
		Sep-96	10.7	0	18.3	0	29.0	1.33
		Sep-97	8	2	23	17	50.0	2
		Apr-98	45	D 2	34	D 13	94.0	D 3
		Sep-98	8	0	6	0.8	14.8	9
		Jun-99	16.5	< 1	4.3	1	22.3	29.1

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; MTBE = methyl tert-butyl ether.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} µg/L = micrograms per liter.

^{e/} NA = not analyzed or not available.

^{f/} U = compound analyzed for and is not present above the reported sample quantitation limit (SQL).

^{g/} d/g = Downgradient.

^{h/} J = Estimated value.

^{i/} ND = Not detected.

^{j/} D = Dilution.

^{k/} D = Dilution. J = Estimated value.

FIGURE 3.15
BTEX CONCENTRATIONS IN GROUNDWATER
NORTH AND SOUTH GAS STATIONS, TRAVIS AFB, CALIFORNIA
SOURCE-REDUCTION EFFECTIVENESS STUDY

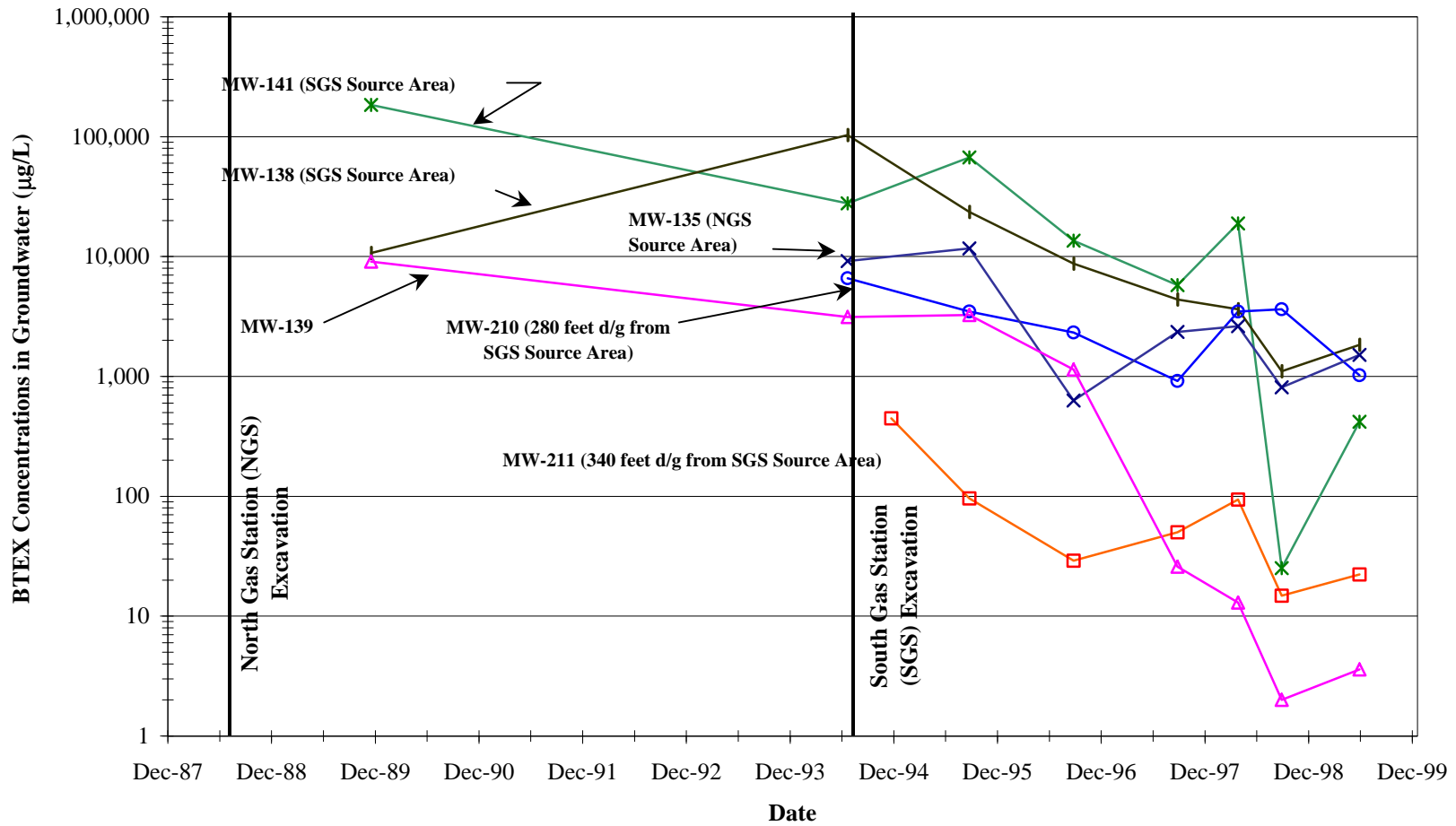


TABLE 3.22
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT THE NORTH AND
SOUTH GAS STATIONS
TRAVIS AFB, CALIFORNIA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{c/} (µg/L)
MW-135	NGS Source	-- ^{f/}	-7	--	-1,270	--	1,520 (10.8 yr)
MW-141	SGS Source	--	-13	--	-5,560	27,800 (0.1 yr)	420 (4.8 yr)
MW-138	SGS Source	--	-19	--	-4,340	103,000 (0.1 yr)	1,830 (4.8 yr)
MW-139	150 feet d/g ^{g/} from SGS	--	-17	--	-563	3,130 (0.1 yr)	4 (4.8 yr)
MW-210	280 feet d/g from SGS	--	-1	--	1	6,580 (0.1 yr)	1,020 (4.8 yr)
MW-211	340 feet d/g from SGS	--	-13	--	-20	--	22 (4.8 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

the contaminant source at the SGS was removed during the excavation, and that advective transport and biodegradation are rapidly depleting dissolved BTEX concentrations in the SGS source area.

The decreases in dissolved BTEX concentrations measured at downgradient wells MW-210 and MW-211 have been less dramatic than those observed at source area wells, suggesting that they are due more to natural attenuation than excavation. Between 1994 and 1999, dissolved BTEX concentrations in MW-210 and MW-211 decreased by 5,560 µg/L and 425 µg/L, respectively (Table 3.21). The presence of nearly 12,000 µg/L of dissolved BTEX at NGS source area well MW-135 in September 1995, 7 years after the excavation at that station, indicates the continued presence of a significant contaminant source.

Available groundwater quality data indicate that the dissolved BTEX plume is stable and that dissolved BTEX concentrations within the plume are decreasing due to the excavation, product recovery and the effects of natural attenuation. This attenuation is indicated by data for three wells located downgradient from the SGS. In August/September 1995, the dissolved BTEX concentrations detected at wells MW-139, MW-210, and MW-211 were 3,260 µg/L, 3,480 µg/L, and 96 µg/L, respectively (Table 3.21). In June 1999, the BTEX concentrations detected at these wells were 4 µg/L, 1,020 µg/L, and 22 µg/L, respectively.

MTBE concentrations in groundwater at the North and South Gas Stations have been monitored since September 1996 (Table 3.21). The post-excavation dissolved MTBE concentrations in the source areas have fluctuated. Concentrations at NGS source area well MW-135 increased from September 1996 to April 1998, and have decreased since April 1998 (Figure 3.16). In contrast, MTBE concentrations at SGS source area well MW-138 have consistently decreased from 1996 through 1999. The Sen's slope estimates computed using post-excavation MTBE concentrations at source area wells MW-135, MW-141, and MW-138 are -579, -0.3, and -212, respectively, indicating overall decreasing trends. However, comparison with the post-excavation slopes computed for dissolved BTEX suggests that MTBE concentrations in source area groundwater are decreasing at a slower rate than BTEX concentrations.

MTBE concentrations at downgradient wells MW-210 and MW-211 have increased during the monitoring period, while BTEX concentrations have decreased (Table 3.21). Overall, these data indicate that the remaining contaminant source is becoming depleted of MTBE, and that the center of mass of the MTBE plume is slowly moving downgradient from the source area.

3.6.1.4 Effectiveness Summary

Groundwater quality data for the North and South Gas Stations indicate that excavation of contaminated soils can rapidly and substantially impact dissolved BTEX concentrations in groundwater. However, incomplete removal of contaminated soils can cause elevated dissolved BTEX concentrations to persist. Excavation (or another source-reduction method) may not rapidly impact dissolved MTBE concentrations because maximum concentrations of this highly soluble and mobile compound may be located farther downgradient from the source area than the dissolved BTEX plume.

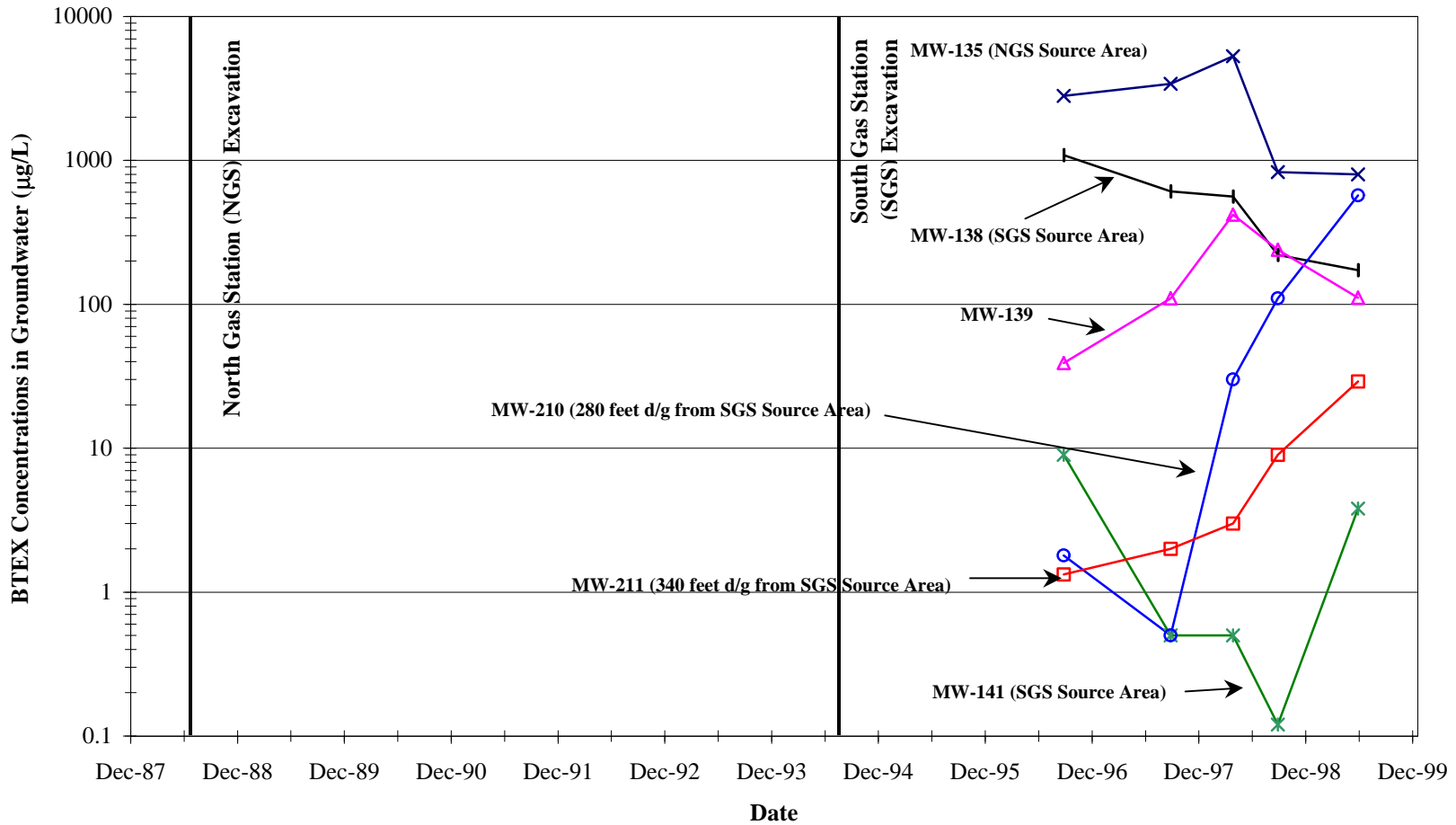
3.6.1 King Salmon Airport, Alaska (Site FT01)

King Salmon Airport is located on the upper, northwestern side of the Alaskan Peninsula, approximately 280 miles southwest of Anchorage.

3.6.2.1 Site Description

Site FT01 was used from 1980 to 1992 for fire training exercises that involved the use of fuels, solvents, oils, and fire-retardant chemicals. A second contaminant source (possibly a former UST and AST associated with a demolished building) is believed to have existed at the adjacent RAPCON site, located approximately 500 feet downgradient from the fire training area. Groundwater contamination from Site FT01 potentially commingles with groundwater contamination from the RAPCON site.

FIGURE 3.16
MTBE CONCENTRATIONS IN GROUNDWATER
NORTH AND SOUTH GAS STATIONS, TRAVIS AFB, CALIFORNIA
SOURCE-REDUCTION EFFECTIVENESS STUDY



The surficial deposits at Site FT01 consist of homogeneous, fine- to medium-grained sands containing isolated layers of pebbles or silty clay that are several inches thick. The site is bounded on the downgradient side by Red Fox Creek. Depths to groundwater vary from 0 feet bgs along Red Fox Creek to 20 feet bgs beneath a topographically elevated area between the former fire training area and the creek. The depth to groundwater beneath the fire training area is approximately 12 feet bgs. Based on slug test results, the shallow sand aquifer has an average hydraulic conductivity of 59 ft/day, and the average advective groundwater flow velocity beneath the site is approximately 190 ft/yr.

Approximately 2,030 cy of contaminated soil were excavated and removed from Site FT01 from June to August 1995. The excavation diameter was 140 feet, and soils were removed to the water table, at a depth of 12 feet. A 0.25-inch-thick layer of free product was encountered and removed from the groundwater surface during the excavation. However, no free product has been detected in site monitoring wells.

3.6.2.2 Soil Quality

Soil samples were collected from the sidewalls and bottom of the excavation during progressive removal of soils. However, confirmation soil data from the final excavation limits are not available. BTEX results for soil samples collected in October 1994 ranged from 138 mg/kg at 10 to 12 feet bgs to 5 mg/kg at 14 feet bgs (Appendix B). Available information indicates that the majority of soil contamination was believed to have been removed during the excavation process. It should be noted that in 1993, DRO were detected in soil samples collected from the uppermost 1.5 feet of soil at locations distant from the fire training pit. These concentrations ranged from 45 mg/kg to 443 mg/kg (Appendix B). In addition, soil samples collected at the RAPCON site in May 1995 contained maximum concentrations of TPH and DRO ranging up to 9,700 mg/kg and 5,480 mg/kg, respectively, at a depth of 10 feet bgs. Concentrations of DRO and TPH were detected in all soil samples collected in this area from 5.5 to 16.5 feet bgs. These soils were not excavated.

3.6.2.3 Groundwater Quality

Groundwater quality data for selected monitoring wells are summarized in Table 3.23, and temporal trends in dissolved BTEX concentrations at one source-area well and two downgradient wells are depicted on Figure 3.17. Limited pre-excavation data do not indicate consistent decreasing trends in dissolved BTEX concentrations. Insufficient data are available to compute MK statistics or Sen's slopes for the pre-excavation period.

The post-excavation MK statistics computed for source area well ESMW-1A and downgradient well MW-95 were both -3 , indicating decreasing trends (Table 3.24). The substantial and consistent decreases in dissolved BTEX concentrations at ESMW-1A during the three years following the excavation event (8,620 $\mu\text{g/L}$ to 2,090 $\mu\text{g/L}$) may reflect the impacts of the excavation (as opposed to natural attenuation); however, there are insufficient data to confirm this observation. The data suggest that BTEX concentrations at MW-95 were increasing during the year prior to the excavation, and began to decrease shortly after the excavation occurred, again potentially reflecting the beneficial effects of source reduction. BTEX concentrations at well ESMW-5A, located 350 feet downgradient from the fire training area, decreased from September 1994 to July 1995 (prior to the excavation), then increased following the excavation, indicating that

**TABLE 3.23
GROUNDWATER QUALITY DATA FOR FT-01
KING SALMON AIRPORT, ALASKA
SOURCE-REDUCTION EFFECTIVENESS STUDY**

Location ID, Plume Region Screened Interval (ft bgs) ^{c/}	Depth to Groundwater (ft bgs)	Date Sampled	Benzene (µg/L) ^{d/}	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX ^{a/b/} (µg/L)	Naphthalene (µg/L)
ESMW-1A Source Area 13.0 - 18.0	11.31	Sep-94	1,050	6,470	358	2,260	10,100	NA ^{e/}
	13.30	Jul-95	796	5,400	399	2,020	8,620	69
	14.40	Sep-96	432 Y ^{f/}	2,620 Y	205 Y	1,260	4,510 Y	
		Sep-98	75.2	ND ^{g/}	276	1,740	2.09	59.7
ESMW-1B Source Area 31.1 - 38.1	11.32	Sep-94	5.6	59.1	20.9	< 2	87	NA
		Jul-95	< 1	1.2	ND	3.9	5.6	< 10
	14.31	Sep-96	ND	0.128	0.0371 J ^{h/}	0.144	0.309 J	NA
		Sep-98	ND	1.8	ND	1.1	2.9	ND
MW-95 150 ft d/g ^{i/} from Source 7.5 - 27.5	10.38	Sep-94	180	470	32.7	211	894	NA
	11.89	Jul-95	349	1,010	90.3	569	2,020	25.4
		Sep-96	194	581	79.5	380	1,230	NA
	13.13	Sep-98	68.3	611	63.6	427	1,170	20.8
ESMW-5A 350 ft d/g from Source 4.0 - 9.0	4.07	Sep-94	45.5	8.1	38.5	622	714	NA
	5.48	Jul-95	14.3	16.8	7.6	46.8	85.5	21.3
		Sep-96	327	128	81.1	407	943	NA
	3.52	Sep-98	419	3.4	99.8	600	1,120	30.5
435 500 ft d/g from Source 15.0 - 25.0	15.88	Sep-94	58.6	7.1	67.6	356	490	NA
	17.15	Jul-95	28.2	1.4	17.7	33.9	81.2	13.1
		Sep-96	570 Y	20.7 Y	94.6 Y	580 Y	1,270 Y	NA
		Sep-98	NA	NA	NA	NA	NA	NA

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes; MTBE = methyl tert-butyl ether.

^{b/} In cases where at least one BTEX compound was detected, total BTEX was calculated by adding the detected concentration(s) plus one-half the reporting limit for non-detected compounds.

^{c/} ft bgs = feet below ground surface.

^{d/} µg/L = micrograms per liter.

^{e/} NA = Not analyzed or not available.

^{f/} Y = Samples were received at pH values greater than 2.

^{g/} ND = Not detected.

^{h/} J = Reported analyte concentration is less than the sample-specific detection limit.

^{i/} d/g = Downgradient.

FIGURE 3.17
BTEX CONCENTRATIONS IN GROUNDWATER
SITE FT-01, KING SALMON AIRPORT, ALASKA
SOURCE-REDUCTION EFFECTIVENESS STUDY

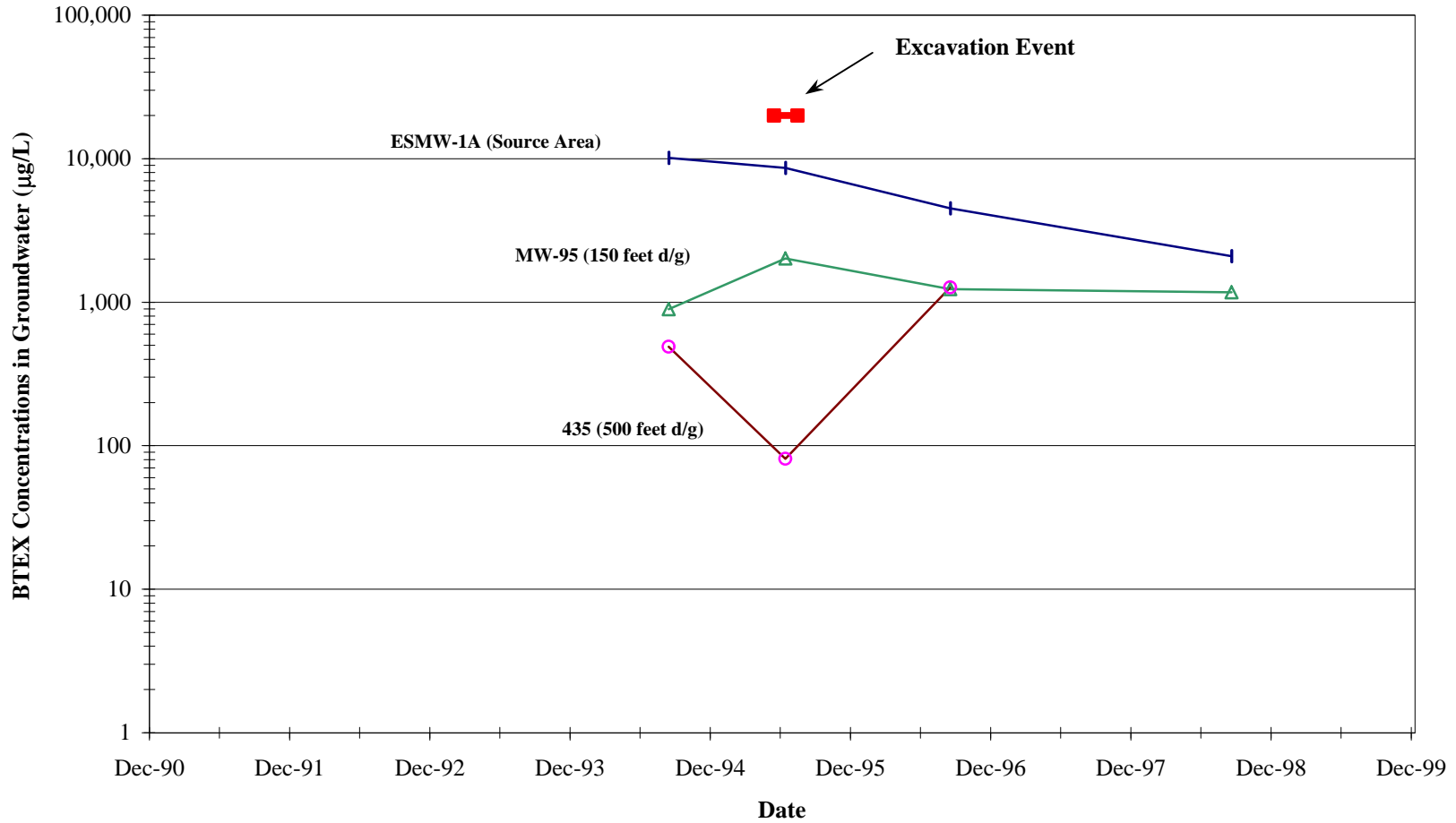


TABLE 3.24
STATISTICAL SUMMARY FOR DISSOLVED BTEX AT SITE FT-01
KING SALMON AIRPORT, ALASKA
SOURCE-REDUCTION EFFECTIVENESS STUDY

Well ID	Well Location	Pre-Remed. MK Result ^{a/}	Post-Remed. MK Result ^{a/}	Pre-Remed. Slope ^{b/}	Post-Remed. Slope ^{b/}	Pre-Remed. BTEX ^{c/} (µg/L) ^{d/}	Most recent BTEX ^{c/} (µg/L)
ESMW-1A	Source	-- ^{f/}	-3	--	-3,260	8,620 (0.0 yr)	2,090 (3.1 yr)
MW-95	150 feet d/g ^{g/} Source	--	-3	--	-424	2,020 (0.0 yr)	1,170 (3.1 yr)
435	500 feet d/g	--	--	--	--	81 (0.0 yr)	1,270 (1.1 yr)

^{a/} S Statistic computed using the Mann-Kendall test (positive value indicates increasing trend, negative value indicates decreasing trend).

^{b/} Estimated slope of a best-fit linear trend line computed using the Sen (1968) method.

^{c/} Most recent dissolved BTEX concentration prior to initiation of engineered remediation (and number of years prior to engineered remediation).

^{d/} µg/L = micrograms per liter.

^{e/} Number in parentheses is the number of years after initiation of engineered remediation that sample was collected.

^{f/} "--" = insufficient data available to compute the indicated value.

^{g/} d/g = downgradient.

the beneficial effects of the excavation had not been felt this far downgradient by September 1998. The available post-excavation groundwater quality data are insufficient to determine whether the plume extent has diminished due to the source-removal actions.

3.6.2.4 Effectiveness Summary

The limited data available for Site FT-01 suggest that excavation of contaminated soils resulted in diminishing dissolved BTEX concentrations in groundwater beneath the source area and up to 150 feet downgradient from the source area. However, further monitoring is required to confirm these observations.

SECTION 4

SUMMARY AND CONCLUSIONS

4.1 EFFECTIVENESS OF SOURCE-REDUCTION TECHNOLOGIES

Observations and conclusions derived from the case studies presented in Section 3 are presented in the following subsections. In addition, the “lessons learned” from these case studies were used to construct a flowchart outlining a methodology for evaluating the potential effectiveness of source-reduction actions at reducing the magnitude and extent of dissolved fuel constituents (Figure 4.1). This figure does not address the full range of available source-reduction techniques, but focuses on the most commonly applied technologies for fuel spill source reduction.

It should be emphasized that Figure 4.1 is not intended to present hard and fast rules to be followed cookbook-style. Rather, the purpose of the flowchart is to identify issues that should be considered when selecting a source reduction approach. For example, Figure 4.1 indicates that the presence of more than 1 inch of free product should lead to the use of source reduction techniques that would remove the product. However, if the product proves to be unrecoverable or is weathered to the point where it does not constitute a significant continuing source of groundwater contamination, then removal may not be necessary. A more detailed analysis of free product recovery options will be required in many cases. A discussion of product recoverability is presented in AFCEE (1997).

The threshold distances, volumes, or thicknesses identified in the figure (i.e., >1 foot below the water table, >1 inch of free product, and 500 cubic yards of soil) are intended to be approximate guidelines and not rules. These guidelines are based on source reduction experience at over 200 Air Force bioventing and natural attenuation sites. However, site-specific conditions may warrant the use of different threshold values.

4.1.1 Dissolved BTEX

4.1.1.1 Bioventing and SVE

The primary factor influencing the degree to which bioventing and SVE influence dissolved BTEX concentrations appears to be the presence or absence of a contaminant smear zone that extends below the average water table and that is infrequently exposed and aerated as a result of seasonal groundwater surface fluctuations. The ability of bioventing and SVE to remediate such a zone is questionable, and the resulting persistence of the smear zone causes elevated dissolved BTEX concentrations to persist in the source area. This is especially true for SVE, which can cause mounding of the water table due to extraction of air from the vadose zone. Similarly, if there are very

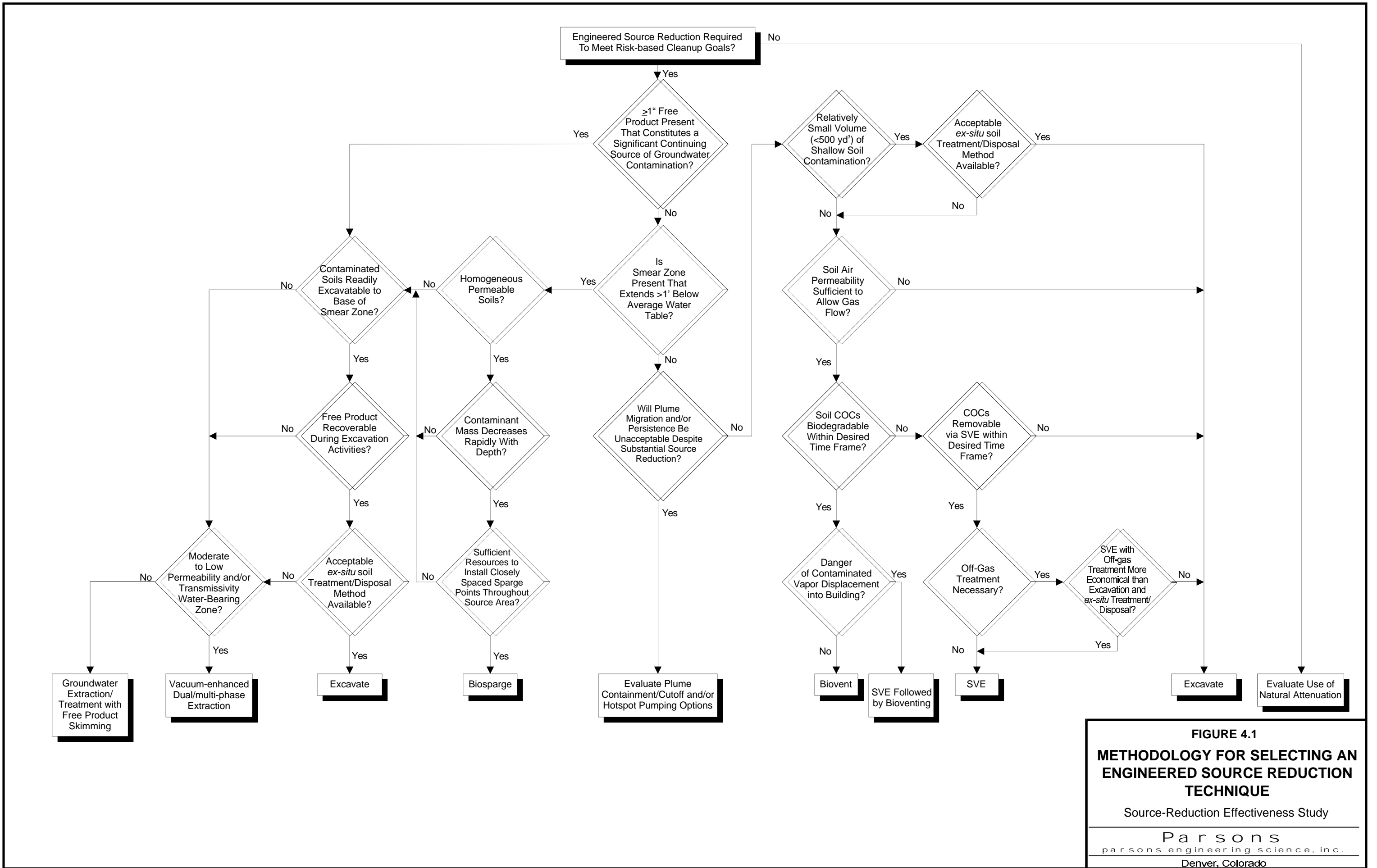


FIGURE 4.1
METHODOLOGY FOR SELECTING AN ENGINEERED SOURCE REDUCTION TECHNIQUE
 Source-Reduction Effectiveness Study
 Parsons
 parsons engineering science, inc.
 Denver, Colorado

moist to wet zones in the vadose zone (e.g., clayey zones that create perched groundwater or retard the downward migration of recharge water percolating from above), they may not be effectively remediated because they are not readily permeable to airflow.

The observations described above are supported by the average dissolved BTEX reduction rates at Charleston AFB Site ST-27 both prior to and after initiation of the source-reduction action (estimated by computing the Sen's slopes, as described in Section 3.1.2). Comparison of the Sen's slopes for these two periods indicates that BTEX reduction rates after initiation of the bioventing/SVE system did not increase relative to pre-remediation rates.

These limiting factors highlight the need for careful site characterization prior to selection of a remedial approach. Advancement of soil boreholes to the water table may not be sufficient to characterize the vertical extent of soil contamination, especially if the water table is seasonally high. Boreholes should be advanced (and soil samples collected) below the water table to confirm the presence or absence of a smear zone. If a smear zone is present, its thickness should be assessed via a combination of visual observation and field screening/laboratory analysis of soil samples.

4.1.1.2 Biosparging

In cases where a significant amount of residual fuel contamination is present below the average water table, the potential effectiveness of biosparging should be assessed. Biosparging is most effective in sandy, homogeneous soils that do not promote channeling of injected air. The results obtained at the Myrtle Beach AFB MOGAS site (Section 3.4.1) indicate that biosparging can cause rapid decreases in dissolved BTEX concentrations if the proper subsurface conditions are present. Air-injection wells should be as closely spaced as possible throughout the source area to achieve the maximum effects. Well spacing of 20 feet or less is recommended. In addition, biosparging is most effective at sites where dissolved contaminant concentrations decrease rapidly with depth, making air injection within the top 10 feet of the saturated zone feasible. As described in Section 3.4.2, the presence of a low-permeability layer or significant stratification between the air-injection horizon and the water table can substantially reduce the effectiveness of a biosparging system. In addition, air channeling that results in very localized and non-uniform remediation of the contaminated interval may occur due to the presence of stratigraphic variability (e.g., a non-uniform permeability distribution that creates preferential pathways for air flow). As noted for bioventing and SVE in Section 4.1.1.1, adequate site characterization is important in predicting the potential effectiveness of biosparging at reducing dissolved contaminant concentrations.

The potential effectiveness of biosparging is highlighted by results from the Myrtle Beach AFB MOGAS site, which is a very similar site to the Charleston AFB site discussed in Section 4.1.1.1. Comparison of dissolved BTEX reduction rates at Myrtle Beach AFB, estimated for the periods before and after system startup, indicates that rates increased by 101 percent to 586 percent after initiation of biosparging.

It should be noted that aeration of the groundwater system can inhibit the biodegradation of highly chlorinated solvents (e.g., PCE and TCE). Therefore, technologies such as biosparging that increase the dissolved oxygen content of the groundwater should be used with caution at solvent-contaminated sites where anaerobic

reductive dechlorination is occurring. In contrast, less-chlorinated solvents, particularly vinyl chloride, can biodegrade in aerobic environments.

4.1.1.3 Vacuum-Enhanced Extraction

Vacuum-enhanced extraction of groundwater, free product (if present), and soil vapor also can rapidly and substantially impact dissolved BTEX concentrations in groundwater. This technology should be considered at sites characterized by thin saturated zones, low- to moderate-permeability soils, and/or free product layers. This approach is relatively aggressive in that all contaminated media are simultaneously addressed; however, unless drawdowns are sufficient to dewater any smear zone, dissolved contaminant concentrations may rebound substantially following system shutdown.

The potential effectiveness of vacuum-enhanced, multi-phase extraction is highlighted by results from Tinker AFB Area A. Comparison of dissolved BTEX reduction rates for the periods before and after system startup indicate a 130- to 439-percent increase in the removal rates at two source area wells following initiation of vacuum-enhanced extraction.

Groundwater extraction can draw relatively oxygenated groundwater into the dissolved contaminant plume, inhibiting the anaerobic biodegradation of some chlorinated solvents. Therefore, as noted for biosparging in Section 4.1.1.2, this approach should be used with caution at solvent-contaminated sites where anaerobic reductive dechlorination is occurring.

4.1.1.4 Excavation

The effectiveness of excavation at remediating dissolved BTEX contamination is highly dependent on the degree to which contaminated soils are removed; therefore, the results of this approach are highly variable. If free product is present and is not removed during the excavation, then a significant, continuing source of groundwater contamination remains. Therefore, an effort should be made to remove any free product encountered. Excavation below the water table can be problematic, especially in non-cohesive soils that are subject to sloughing and caving. In addition, visual inspection of the completeness of contaminated soil removal below the water table can be difficult. In cases where removal of a large percentage of the contaminant source is accomplished, then the effects on dissolved contaminant concentrations can be substantial, as evidenced in some monitoring wells at Travis AFB (Section 3.6.1).

4.1.2 Dissolved Naphthalene

Available information indicates that the source-reduction actions described in Section 3 were less effective at reducing dissolved naphthalene concentrations than dissolved BTEX concentrations. At Charleston AFB, dissolved naphthalene concentrations were increasing following initiation of SVE/bioventing while dissolved BTEX concentrations were decreasing. At Eglin and Myrtle Beach AFBs, dissolved naphthalene reduction rates were 75 to 99 percent (average 92 percent) slower than the corresponding rates for BTEX at the same well (based on a comparison of post-system-startup Sen's slopes). The lower reduction rates for naphthalene reflect the lower volatility, increased recalcitrance to biodegradation, and higher degree of sorption exhibited by heavier fuel hydrocarbons relative to BTEX. In contrast, naphthalene concentrations were reduced relatively rapidly

at Tinker AFB Area A following initiation of the expanded vacuum-enhanced extraction system.

4.1.3 Dissolved MTBE

Only one site (Travis AFB) had sufficient MTBE data to enable assessment of temporal trends. At this site, Sen's slope estimates suggest that post-excavation MTBE reduction rates at two source area wells were 54 to 95 percent slower than the corresponding BTEX reduction rates at the same well. This observation suggests that vadose zone source-removal actions are less likely to result in rapid reductions in dissolved MTBE concentrations than in dissolved BTEX concentrations, perhaps reflecting the relative recalcitrance of dissolved MTBE to biodegradation observed by many researchers (Parsons ES, 1999c). Due to its high solubility, MTBE will preferentially partition out of gasoline and into the aqueous phase. Therefore, MTBE in residual fuel sources is rapidly depleted, and subsequent source reduction actions may not significantly accelerate the reduction of MTBE concentrations in groundwater.

SECTION 5

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APPENDIX A

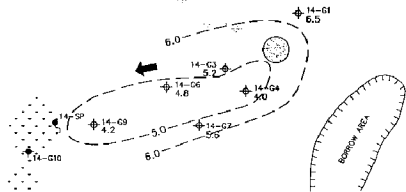
SITE FIGURES

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c/o Bruce Henry
1700 Broadway, Suite 900
Denver, CO 80290**

THIRTIETH TO HARRAND CREEK

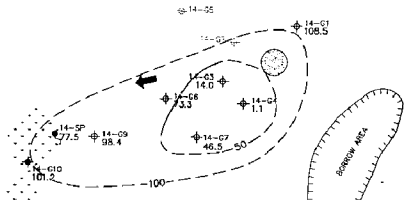
FAULKNER ROAD



DISSOLVED OXYGEN

THIRTIETH TO HARRAND CREEK

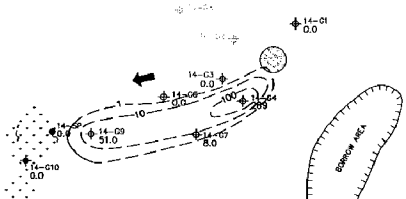
FAULKNER ROAD



REDOX POTENTIAL

THIRTIETH TO HARRAND CREEK

FAULKNER ROAD



TOTAL BTEX

LEGEND

- 14-SP ● SPRING
- 14-G3 ⊕ EXISTING GROUNDWATER MONITORING WELL (SAMPLED)
- 14-G9 ⊕ EXISTING GROUNDWATER MONITORING WELL (NOT SAMPLED)
- 14-G10 ⊕ NEW POC WELL LOCATION
- 5.0 - ISOPLETH (LINE OF EQUAL CONCENTRATION)
- ⊙ APPROXIMATE LOCATION OF FORMER WASTE POND PIT
- ➔ APPROXIMATE GROUNDWATER FLOW DIRECTION
- ⋯ SWAMPY AREA WITH SPRINGS AND SEEPS

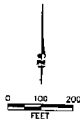
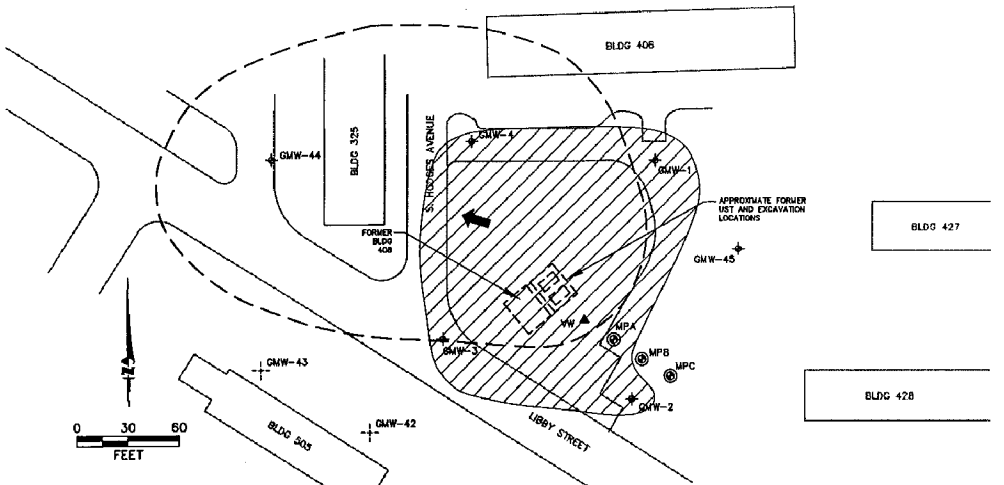


FIGURE 6.3
CONCENTRATION OF DISSOLVED OXYGEN, REDOX POTENTIAL, AND TOTAL BTEX APRIL 1999

SWMU 14
 Fort Rucker, Alabama

PARSONS
 PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

K:\AFCEE\728876\GUNTER\9708083_10/21/97 at 13:44



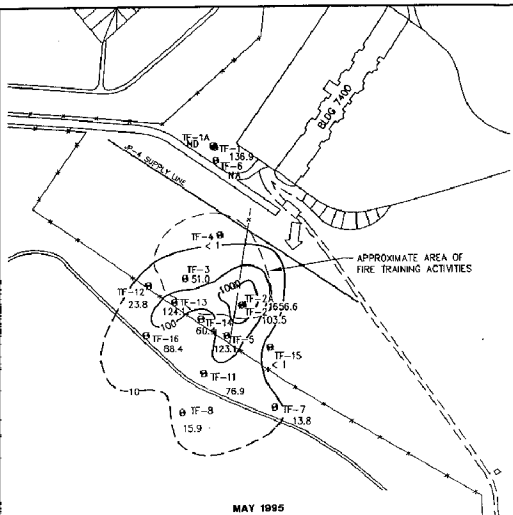
LEGEND

- VVW ▲ AIR INJECTION VENT WELL AND BLOWER UNIT
- MPA ⊙ SOIL GAS MONITORING POINT
- GMW-1 ⊕ GROUNDWATER MONITORING WELL
- ← GROUNDWATER FLOW DIRECTION
- ▨ 1995 ESTIMATED AREA EXCEEDING 100 mg/kg TPH IN SOIL
- - - 1996 ESTIMATED EXTENT OF DISSOLVED BTEX GROUNDWATER CONTAMINATION EXCEEDING 4 ug/L
- + + FORMER GROUNDWATER MONITORING WELL LOCATION

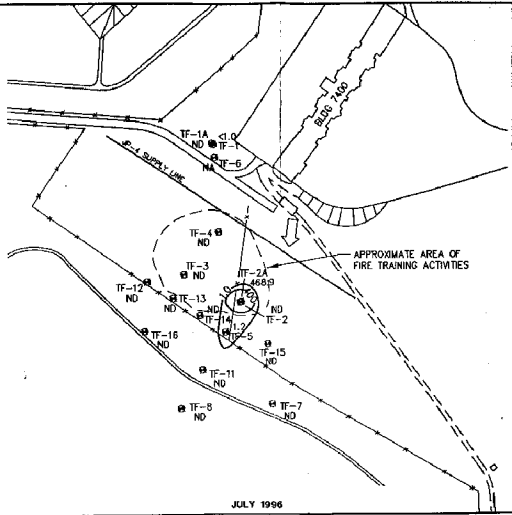
FIGURE 2.4
ESTIMATED EXTENT OF SOIL AND GROUNDWATER CONTAMINATION

Site ST-001, Gunter Annex
 Maxwell AFB, Alabama

PARSONS
ENGINEERING SCIENCE, INC.
 Denver, Colorado



MAY 1995



JULY 1996

LEGEND

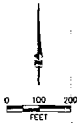
- TF-8
15.9 MONITORING WELL LOCATION WITH TOTAL BTEX CONCENTRATION (ug/L)
- 100— LINE OF EQUAL BTEX CONCENTRATION (ug/L) (DASHED WHERE INFERRED)
- ➔ GROUNDWATER FLOW DIRECTION
- x—x—x— FENCE

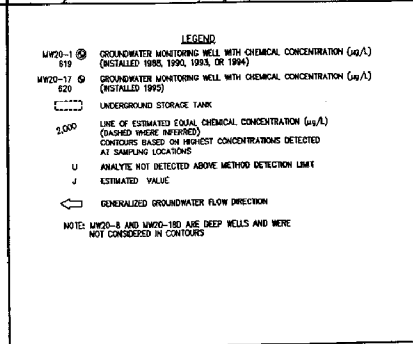
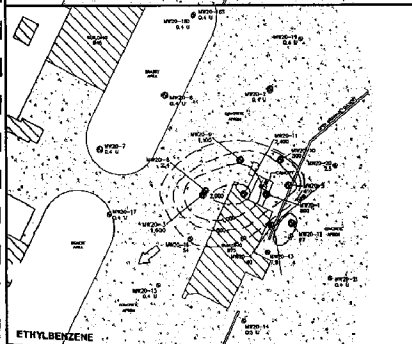
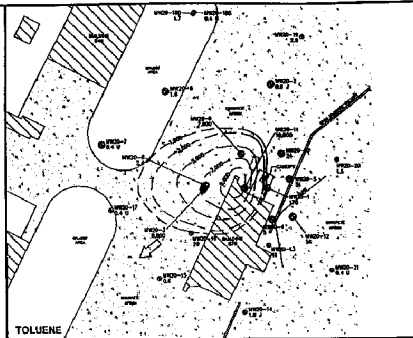
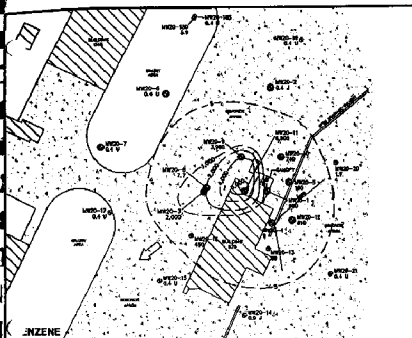
- NA NOT ANALYZED
- BLQ BELOW LIMIT OF QUANTATION
- NOTE: SHALLOW GROUNDWATER CONCENTRATIONS WERE USED FOR CONTOURING

FIGURE 4.2
TOTAL BTEX ISOPLETH
MAPS FOR GROUNDWATER

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

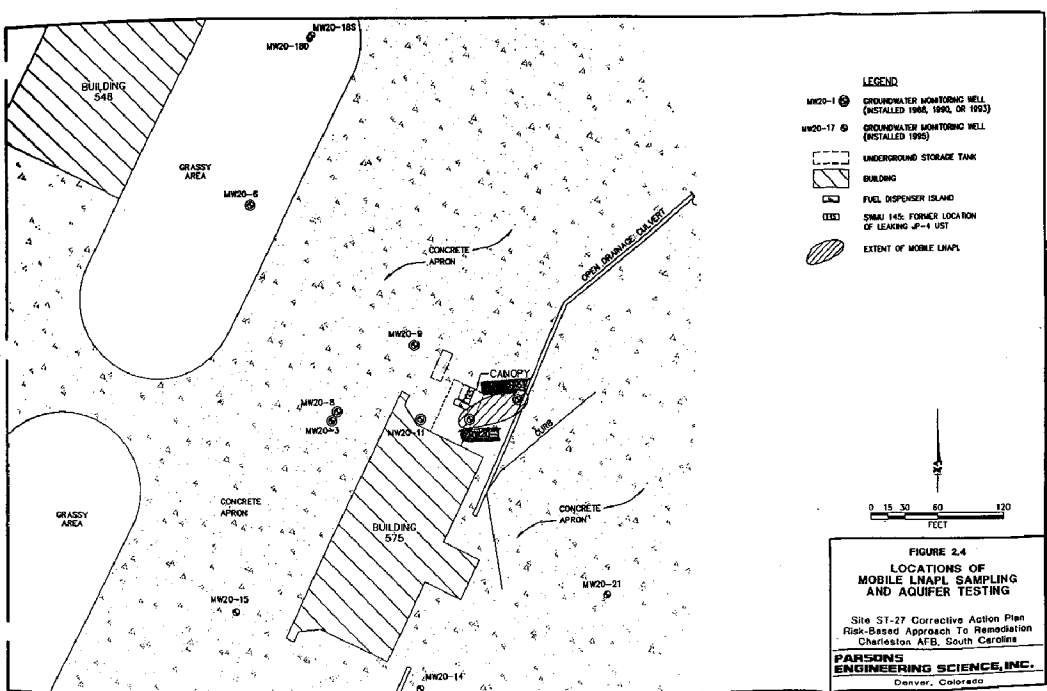
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Denver, Colorado






 0 65 130 260
 FEET

FIGURE 5.6
1995 BENZENE, TOLUENE,
AND ETHYLBENZENE
CONCENTRATIONS
IN GROUNDWATER
 Site ST-27 Corrective Action Plan
 Risk-Based Approach To Remediation
 Charleston AFB, South Carolina
PARSONS
ENGINEERING SCIENCE, INC.
 Denver, Colorado



GRASSY AREA

CONCRETE APRON

OPEN GRAVITATION COLLECTOR

CONCRETE APRON

BUILDING 575

CONCRETE APRON

2'-4' BELOW GROUND SURFACE

GRASSY AREA

CONCRETE APRON

OPEN GRAVITATION COLLECTOR

CONCRETE APRON

BUILDING 575

CONCRETE APRON

4'-8" BELOW GROUND SURFACE

LEGEND

- MW20-8 GROUNDWATER MONITORING WELL (INSTALLED 1990 OR 1995)
- VW VENT WELL
- ASW-1 AIR SPARGING TEST WELL
- MP-6 SOIL SAMPLING LOCATION
DEPTH IN INTERVAL (FT BGS);
TOTAL BTEX CONCENTRATION (mg/kg)
- ESTIMATED VALUE

- ND ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
- FUEL DISPENSER ISLAND
- 145 SMU 145: FORMER LOCATION OF LEAKING JP-4 UST
- UNDERGROUND STORAGE TANK
- 500 LINE OF ESTIMATED EQUAL TOTAL BTEX CONCENTRATION IN SOILS (mg/kg) (DASHED WHERE INFERRED)
- CONTOURS BASED ON HIGHEST CONCENTRATIONS DETECTED AT SAMPLING LOCATIONS

NOTE: CONTOURS BASED ON HIGHEST CONCENTRATIONS DETECTED AT SAMPLING LOCATIONS.

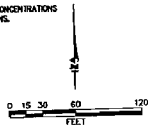
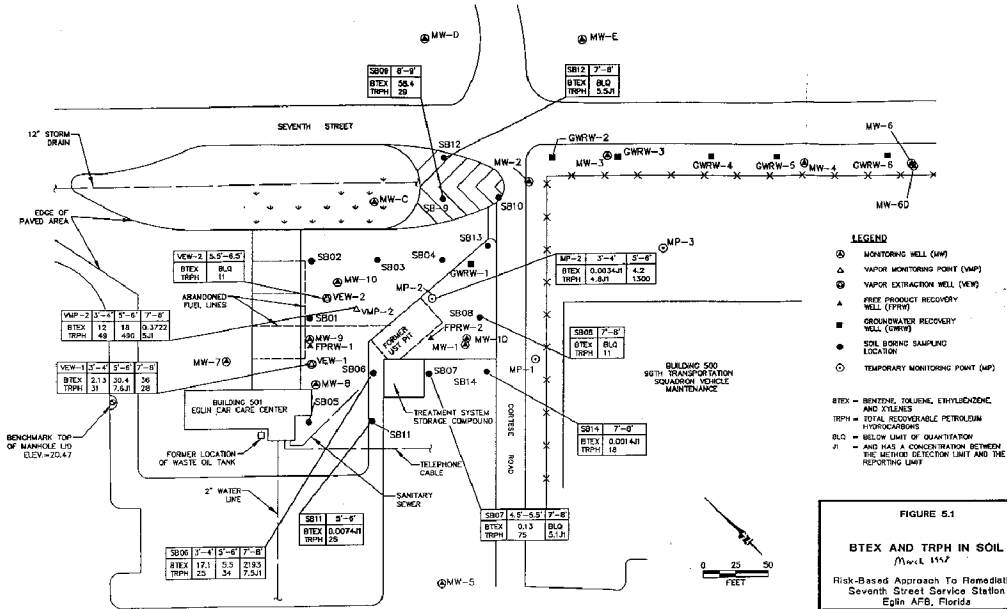
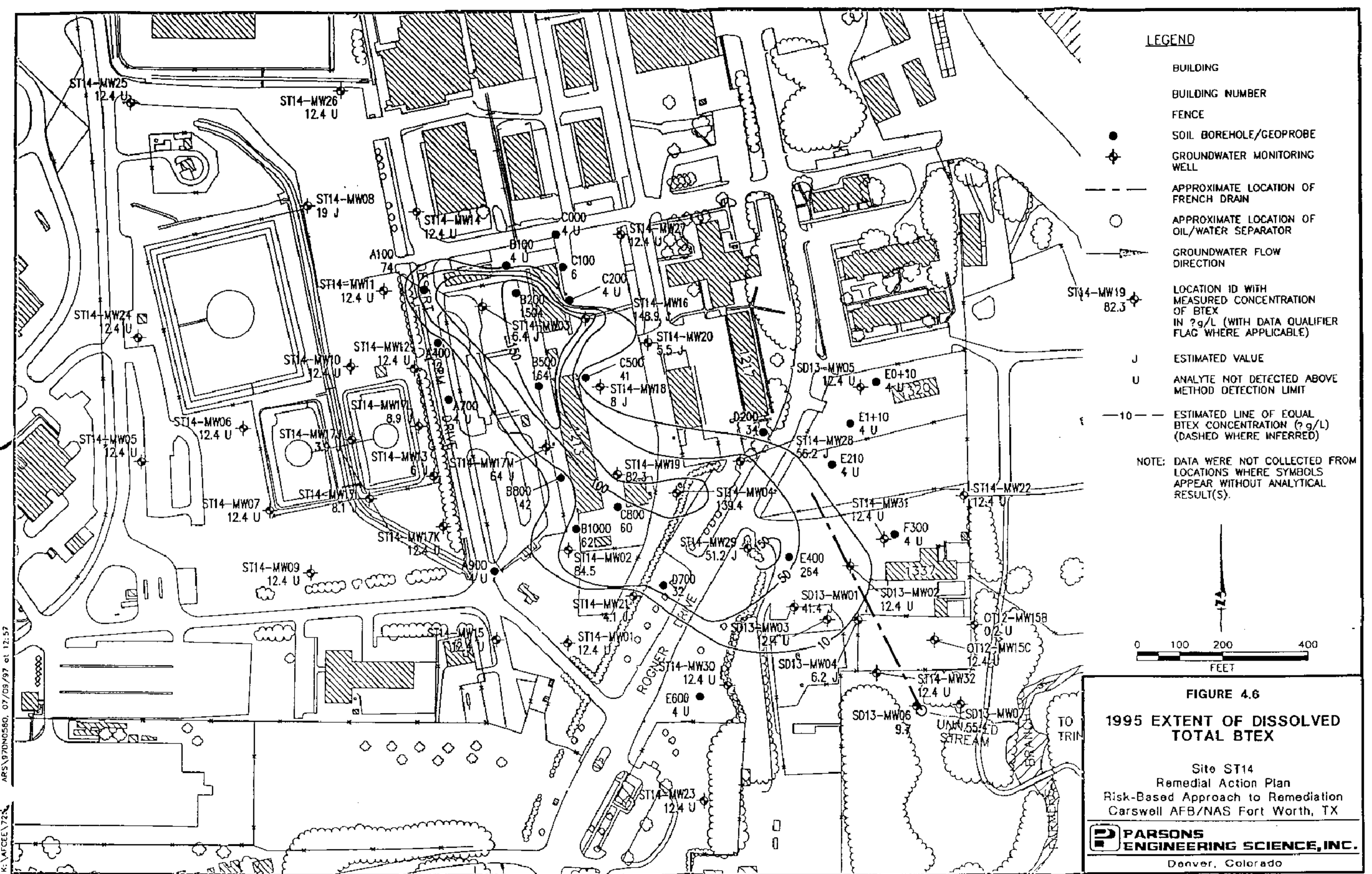


FIGURE 5.3

SOIL BTEX CONCENTRATIONS
1/95 (per bioactivity)Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South CarolinaPARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado





- LEGEND**
- BUILDING
 - BUILDING NUMBER
 - FENCE
 - SOIL BOREHOLE/GEOPROBE
 - ⊕ GROUNDWATER MONITORING WELL
 - - - APPROXIMATE LOCATION OF FRENCH DRAIN
 - APPROXIMATE LOCATION OF OIL/WATER SEPARATOR
 - GROUNDWATER FLOW DIRECTION
 - LOCATION ID WITH MEASURED CONCENTRATION OF BTEX IN ?g/L (WITH DATA QUALIFIER FLAG WHERE APPLICABLE)
 - J ESTIMATED VALUE
 - U ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
 - 10- ESTIMATED LINE OF EQUAL BTEX CONCENTRATION (g/L) (DASHED WHERE INFERRED)
- NOTE: DATA WERE NOT COLLECTED FROM LOCATIONS WHERE SYMBOLS APPEAR WITHOUT ANALYTICAL RESULT(S).

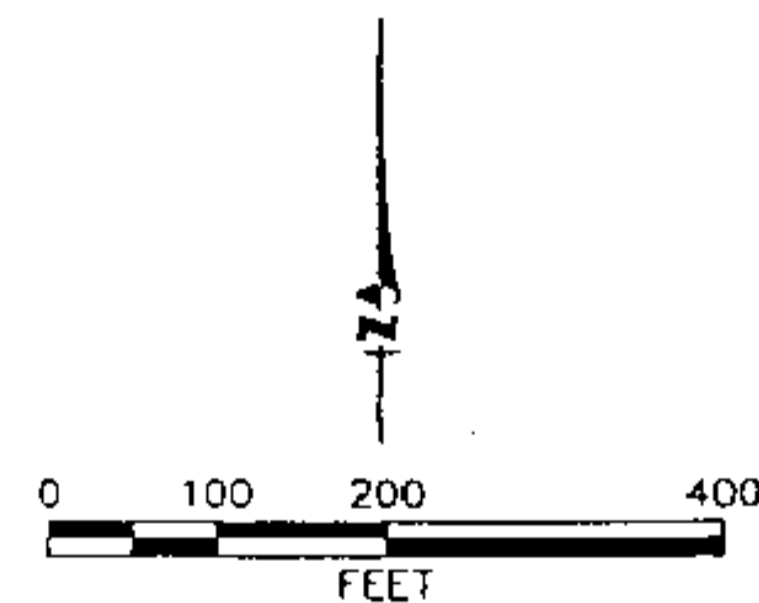
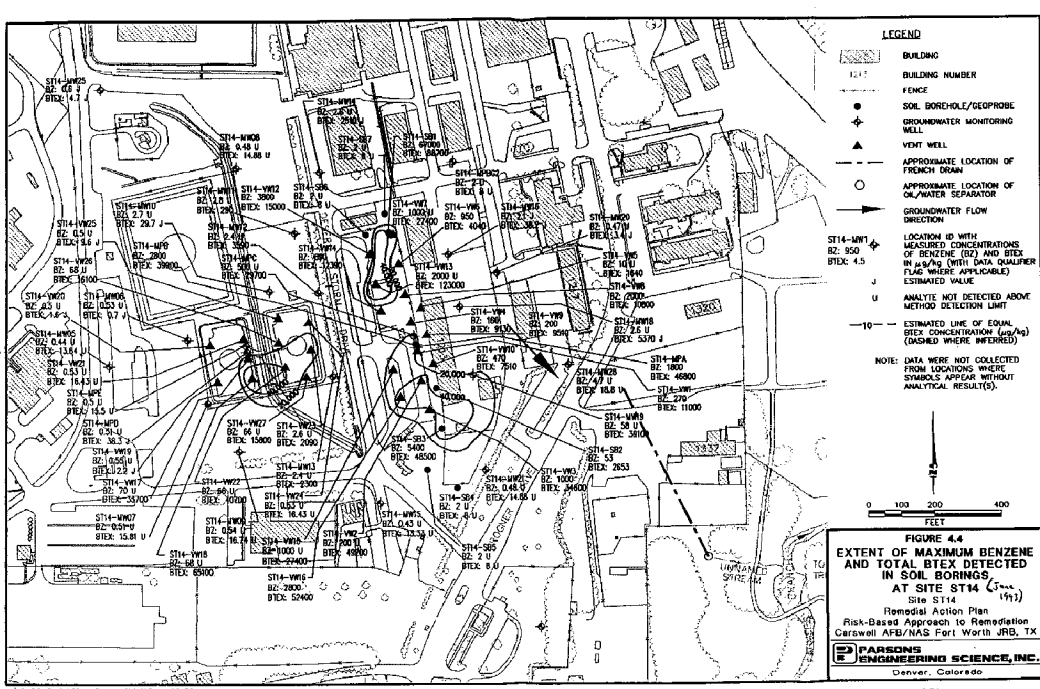


FIGURE 4.6
1995 EXTENT OF DISSOLVED TOTAL BTEX

Site ST14
 Remedial Action Plan
 Risk-Based Approach to Remediation
 Carswell AFB/NAS Fort Worth, TX

PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

ARS 97000580, 07/08/97 at 12:57
 K:\AFCE\72



LEGEND

- BUILDING
 - BUILDING NUMBER
 - FENCE
 - SOIL BOREHOLE/GEOPROBE
 - GROUNDWATER MONITORING WELL
 - VENT WELL
 - APPROXIMATE LOCATION OF FRENCH DRAIN
 - APPROXIMATE LOCATION OF OIL/WATER SEPARATOR
 - GROUNDWATER FLOW DIRECTION
- ST14-W11
BZ: 950
BTEX: 4.5
- J
- U
- 10—
- NOTE: DATA WERE NOT COLLECTED FROM LOCATIONS WHERE SYMBOLS APPEAR WITHOUT ANALYTICAL RESULT(S).

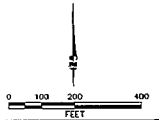


FIGURE 4.4
EXTENT OF MAXIMUM BENZENE AND TOTAL BTEX DETECTED IN SOIL BORINGS AT SITE ST14
 Site ST14
 Remedial Action Plan
 Risk-Based Approach to Remediation
 Carswell AFB/NAS Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

LEGEND

- DRAINAGE DITCH WITH FLOW DIRECTION
- SANITARY SEWER
- STORM SEWER
- FENCE
- FORMER UST LOCATION
- MW-113 3,160
GROUNDWATER MONITORING WELL (INSTALLED 1988 OR 1994) WITH DISSOLVED BTX CONCENTRATION (µg/L)
- MW-06 26.6
GROUNDWATER MONITORING WELL (INSTALLED 1995) WITH DISSOLVED BTX CONCENTRATION (µg/L)
- MOC-11 7.2
GROUNDWATER MONITORING POINT WITH DISSOLVED BTX CONCENTRATION (µg/L)
- AS-01 123
AIR SPARING PILOT TEST WELL WITH DISSOLVED BTX CONCENTRATION (µg/L)
- 100
LINE OF EQUAL DISSOLVED BTX CONCENTRATION (µg/L), (DASHED WHERE INFERRED)
- * SAMPLED JANUARY 1995
- NO NOT DETECTED ABOVE THE METHOD DETECTION LIMIT
- U NOT DETECTED, DETECTION LIMIT UNKNOWN
- ↓ GRASSY AREAS
- ☁ FORESTED AREAS
- ← ESTIMATED GROUNDWATER FLOW DIRECTION



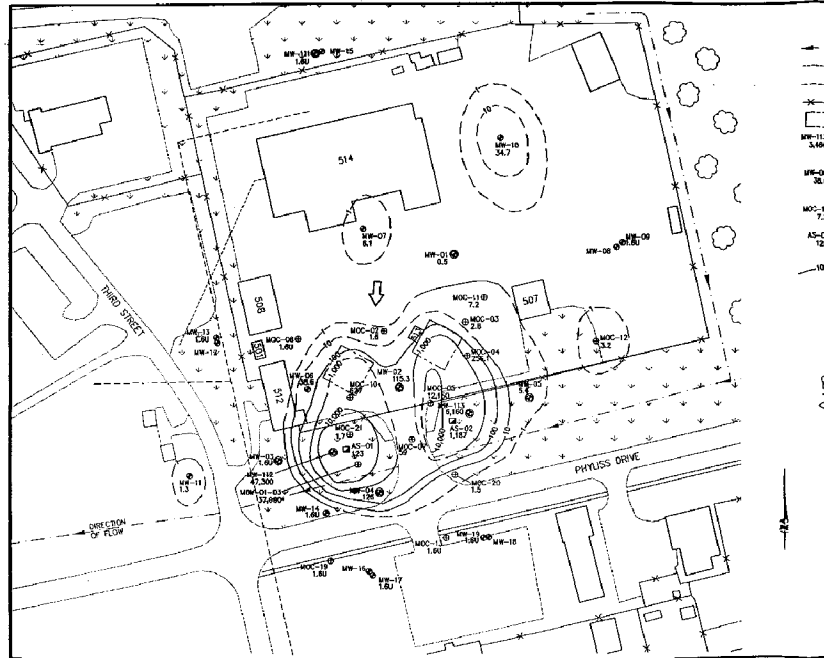
FIGURE 5.9

**DISSOLVED BTX CONCENTRATIONS
IN SHALLOW GROUNDWATER
PHASE II-AUGUST/SEPTEMBER 1995**

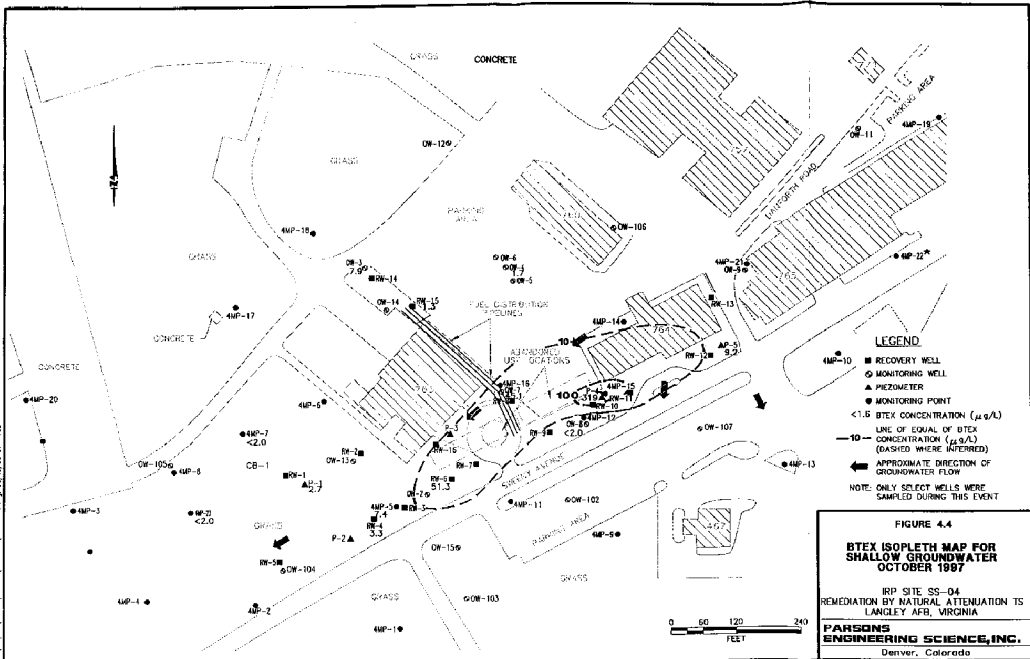
MOGAS Site Corrective Action Plan
Risk-Based Approach to Remediation
Myrtle Beach AFB, South Carolina

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado



37398813.A01.ENVIRONMENTAL.00/12/78 @ 14.02
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LEGEND

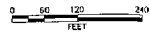
- RECOVERY WELL
- MONITORING WELL
- ▲ PIEZOMETER
- MONITORING POINT
- <1.5 BTEX CONCENTRATION ($\mu\text{g/L}$)
- 10— LINE OF EQUAL OF BTEX CONCENTRATION ($\mu\text{g/L}$) (DASHED WHERE INFERRED)
- ← APPROXIMATE DIRECTION OF GROUNDWATER FLOW
- NOTE: ONLY SELECT WELLS WERE SAMPLED DURING THIS EVENT

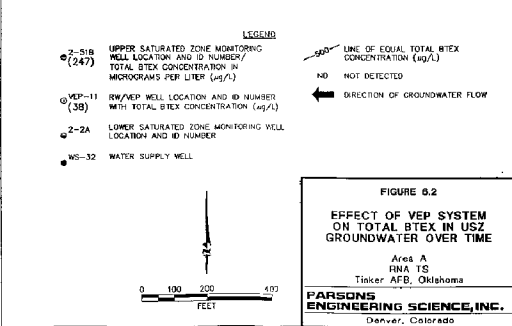
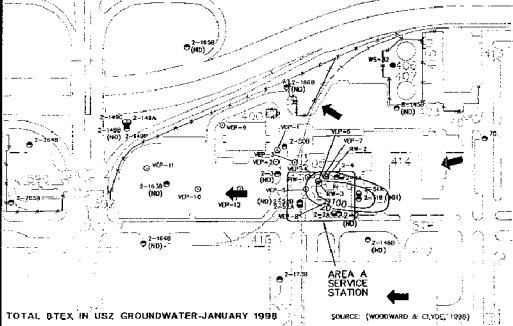
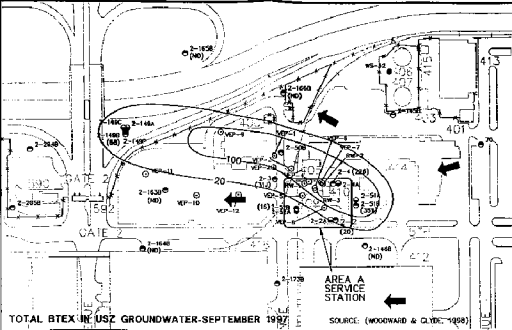
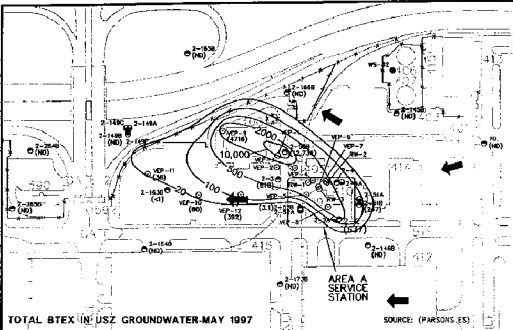
FIGURE 4.4

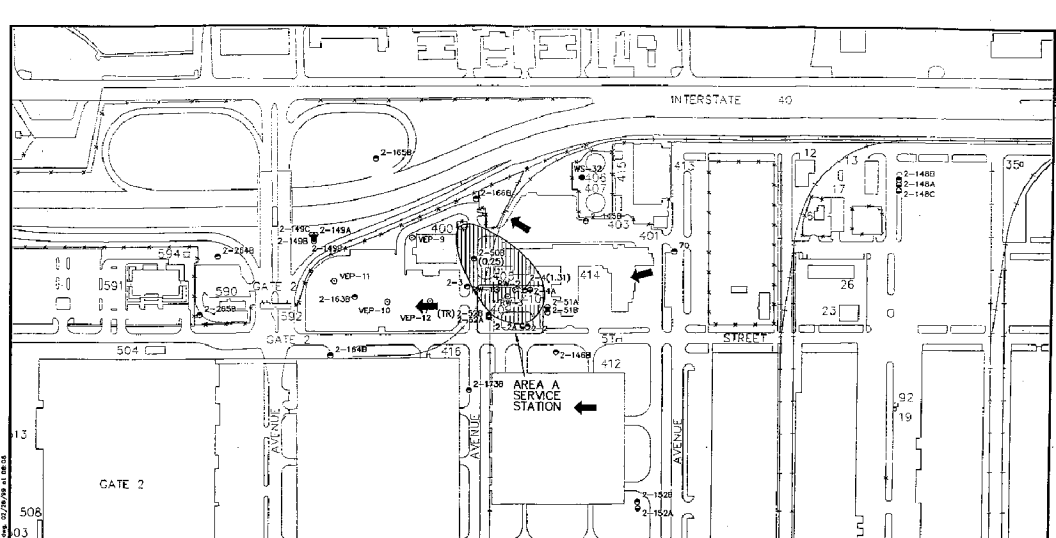
BTEX ISOPLETH MAP FOR SHALLOW GROUNDWATER OCTOBER 1987

IRP SITE SS-04
 REMEDIATION BY NATURAL ATTENUATION IS
 LANGLEY AFB, VIRGINIA

PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado







LEGEND

- 2-50B (0.25) UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER/FREE PRODUCT THICKNESS (FEET)
- 2-2A LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- RW-1 RW/VEP WELL LOCATION AND ID NUMBER
- WS-32 WATER SUPPLY WELL

- TR TRACE OF FREE PRODUCT
- ← DIRECTION OF GROUNDWATER FLOW
- ▨ ESTIMATED EXTENT OF FREE PRODUCT

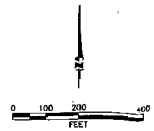
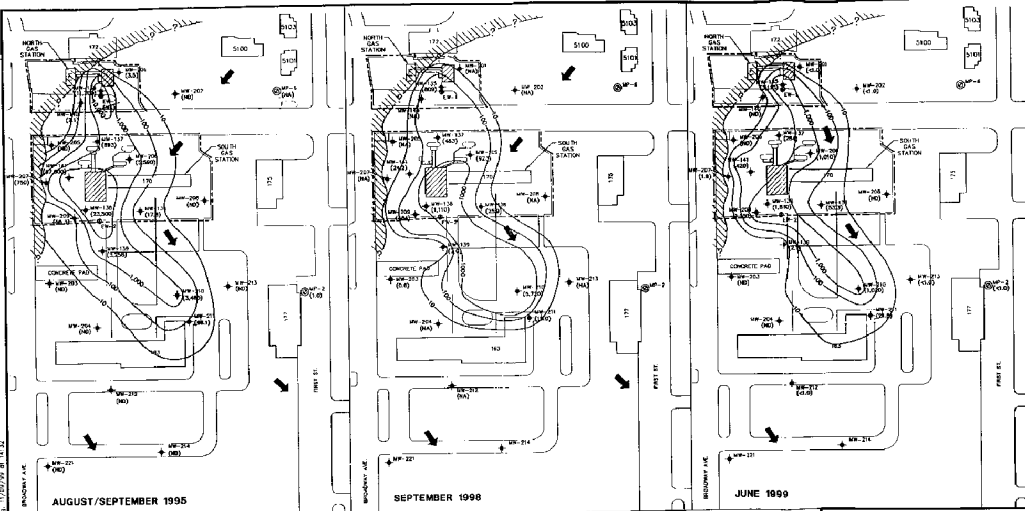


FIGURE 4.3
FREE PRODUCT (LNAPL) PLUME IN USZ GROUNDWATER MAY 1997
 Area A
 RNA TS
 Tinker AFB, Oklahoma
PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

E:\V\Comp\GROVE\51881\1\hatched\168402237.dwg 02/27/98 11:08:03

S:\GIS\user\42787\315251\1\total\BTEX0464.dwg, 11/20/2009 01:16:32



AUGUST/SEPTEMBER 1995

SEPTEMBER 1998

JUNE 1999

- 171 STRUCTURE
- GAS PUMP ISLAND
- MW-6 MONITORING POINT
- MW-204 EXISTING MONITORING WELL
- MW-2 EXTRACTION WELL (6" CASING)
- UST COMPLEX
- PRODUCT LINE

LEGEND

- SITE BOUNDARY
- BEDROCK AT GROUNDWATER DEPTH
- BTEX CONCENTRATION ISOPLETH (DASHED WHERE INFERRED) (µg/L)
- (3,480) BTEX CONCENTRATION (µg/L)
- (ND) BTEX NOT DETECTED
- (NA) NOT ANALYZED
- INFERRED DIRECTION OF GROUNDWATER FLOW

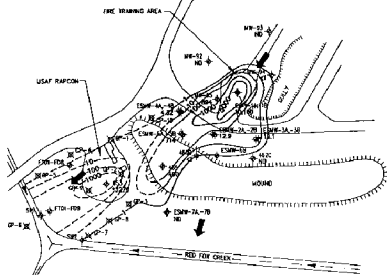
FIGURE 4-2

TOTAL BTEX ISOPLETHS FOR GROUNDWATER

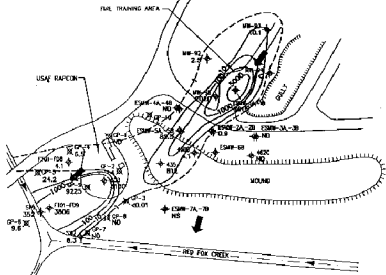
North and South Gas Stations
Travis AFB, California

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

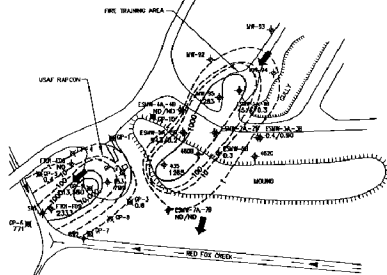




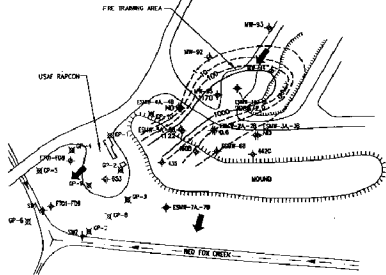
SEPTEMBER 1994



JULY 1995



SEPTEMBER 1996



SEPTEMBER 1998

LEGEND

- MW-95 ◆ MONITORING WELL BTEX CONCENTRATION (ug/L)
- SW ◆ SURFACE WATER SAMPLING LOCATION
- GP-1 X TEMPORARY MONITORING WELL (JULY 1995)
- 10- LINE OF EQUAL BTEX CONCENTRATION (ug/L) (DASHED WHERE INFERRED)
- ← ESTIMATED GROUNDWATER FLOW DIRECTION

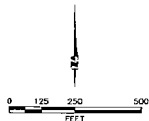


FIGURE 3

TOTAL BTEX CONCENTRATIONS IN GROUNDWATER

Fire Training Area 1 (FT01)
Intrinsic Remediation TS Addendum
King Salmon Airport, Alaska

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

APPENDIX B

**SOIL QUALITY DATA FOR TRAVIS AFB AND KING SALMON
AIRPORT**

Fuel Hydrocarbon Compounds in Soil at the South Gas Station
July 1994
Intrinsic Bioremediation Results
North and South Gas Stations, Travis AFB, California

Analyses:		Total Hydrocarbons					BTEX			
Method:		SW8015M					SW8020			
Sample ID	Location	Depth (feet bgs)	TPH-g	TPH-d	TPH- motor oil	Benzene	Toluene	Ethylbenzene	Total Xylenes ¹	Total BTEX
mg/Kg										
F1-S	North end tank F	14	230	<20	<10	<0.50	4	5	28	37
F2-S	North end tank F	19	2.6	<20	<10	0.084	0.006	0.018	0.026	0
F1S/F2S	Composite		79	NA	NA	1.1	2.1	1.7	9.5	14
E-S	South end tank E	15	<0.5	NA	NA	<0.005	0.0055	<0.005	0.0082	0
D1-S	South end tank D	14	120	<20	<10	2	5.2	2.4	13	23
D2-S	South end tank D	19	<0.005	<10	<10	0.014	<0.005	0.022	<0.50	0
D1S/D2S	Composite		42	NA	NA	1.8	3.1	1	5.1	11
C-S	South end tank C	14	2,400	NA	NA	33	170	83	350	616
B-S	South end tank B	14	4,300	NA	NA	45	260	100	570	975
A1-S	South end tank A	14	2,600	<20	19	8	100	51	370	529
A2-S	South end tank A	19	72	<10	<10	1.6	2.3	1.2	7	12
A1S/A2S	Composite		420	NA	NA	2.4	18	8.1	58	87
A1-N	North end tank A	13	4,400	<50	180	15	170	130	840	955
A2-N	North end tank A	18	<0.50	<10	<10	<0.005	0.011	<0.005	0.021	0
A1N/A2N	Composite		3,000	NA	NA	24	180	130	550	884
B-N	North end tank B	13	2,600	NA	NA	37	180	75	380	672
C-N	North end tank C	13	5,400	NA	NA	74	320	120	510	1,024
D1-N	North end tank D	13	2,400	<20	13	30	170	83	310	573
D2-N	North end tank D	18	1.1	<10	<10	<10	0.2	0.053	0.26	1
D1N/D2N	Composite		470	NA	NA	10	45	16	81	152
E-N	North end tank E	13	1,200	NA	NA	19	72	31	150	272
F1-N	North end tank F	13	480	<20	<10	0.99	11	13	64	89
F2-N	North end tank F	18	<0.5	<10	<10	0.0064	0.021	0.015	0.084	0
F1N/F2N	Composite		37	NA	NA	0.25	1.5	1.3	6.4	9
A1	East end of SE pump island	5	4.1	NA	NA	0.18	0.022	0.1	0.34	1
B1	East end of NE pump island	8	2,800	NA	NA	12	46	30	190	278
B2	West end of NE pump island	5	530	NA	NA	<0.5	4.7	9.1	32	46
A2	West end of SE pump island	5	6.1	NA	NA	0.19	0.011	0.11	0.18	0
A3	Product piping btwn Tank F and SE pump island	5	8	NA	NA	0.35	0.02	0.29	0.63	1
AV	Vent piping	5	90	NA	NA	0.82	0.11	2	6.1	9
A4	Product piping btwn tank E and NE pump island	5	12	NA	NA	0.022	0.011	0.32	0.81	1
A5	Soil east of pump NE pump island	5	360	NA	NA	0.78	1.8	9.7	28	40
TR1	Product piping btwn. NE pump island and NW pump island	5	38	NA	NA	0.13	0.092	0.37	1.2	2
TR2	East end of NW pump island	5	4.5	NA	NA	0.2	0.08	0.13	0.43	1
TR3	West end of NW pump island	5	780	NA	NA	8.9	20	14	55	98
TR4	East end of SW pump island	5	1,100	NA	NA	24	95	29	140	288
TR5	West end of SW pump island	5	360	NA	NA	20	48	12	56	136
TR6	Product piping btwn tank D and NW pump island	5	420	NA	NA	7.8	12	10	46	76

Source: Tank Closure Report Site 170; Environmental Corporation, January 1995

Notes:

☐ : Not detected at indicated concentration
 NA : Not Analyzed

1. Tank A is located farthest from bldg 170 and tank F is located closest to bldg 170.
2. Bottom of removed USTS were at 11 feet bgs.

3. Groundwater in excavation was at 17 feet bgs.

4. Samples taken on July 18 and July 19, 1994 after USTs were removed.

TABLE 4.1
FUEL HYDROCARBON COMPOUNDS DETECTED IN SOIL
FIRE TRAINING AREA 1 (FT01)
INTRINSIC REMEDIATION TS
KING SALMON AIRPORT, ALASKA

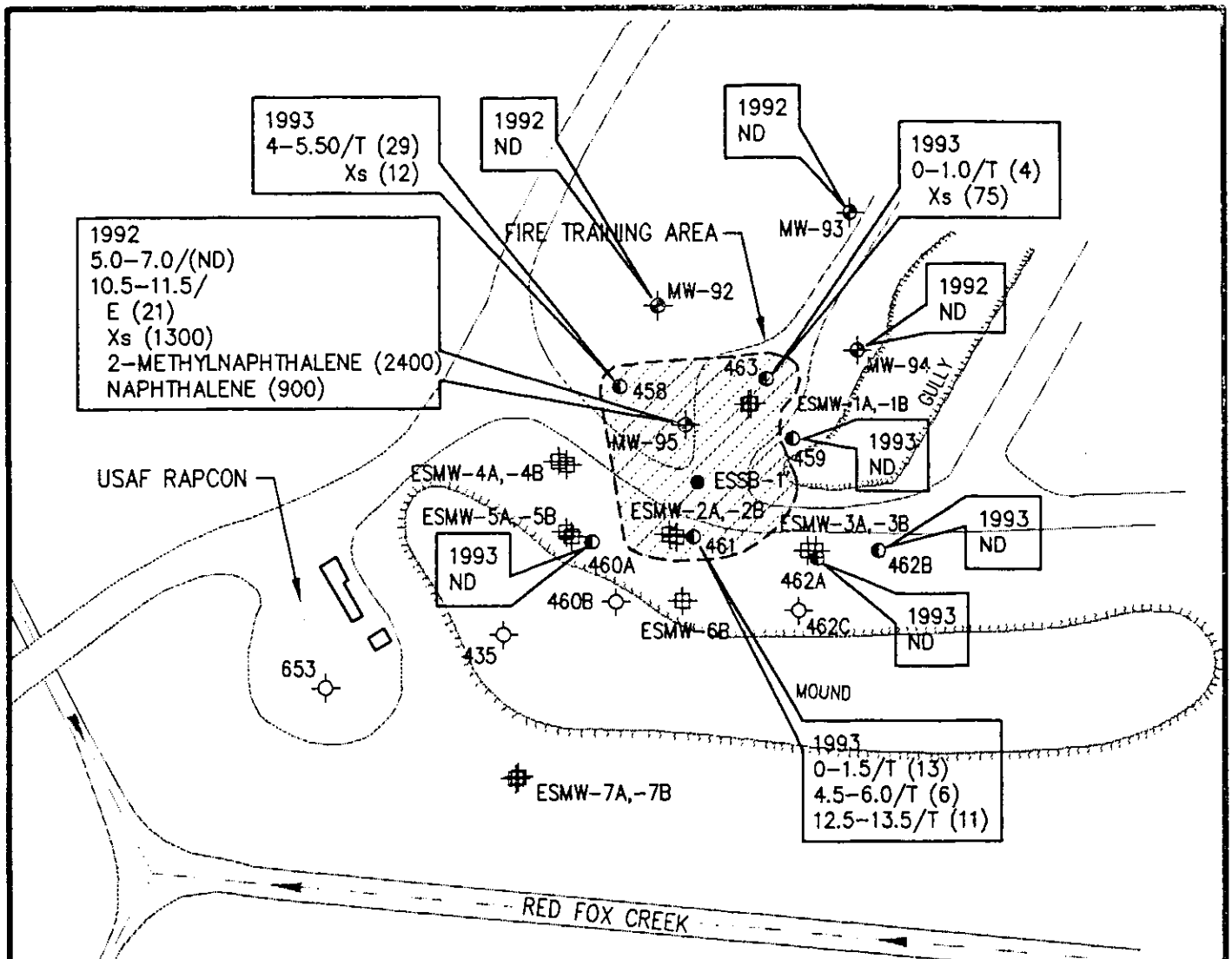
Sample Location	Sample Date	Sample Depth (ft bgs)	JP-4 ^{a/} (mg/kg)	Fuel Carbon (mg/kg)	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	p-xylene (mg/kg)	m-Xylene (mg/kg)	o-Xylene (mg/kg)	Total Xylenes (mg/kg)	Total BTEX (mg/kg)	1,3,5-TMB (mg/kg)	1,2,4-TMB (mg/kg)	1,2,3-TMB (mg/kg)
ESSB-1	10/94	14.5-16	1.80E-01	1.50E-01	<0.02	7.17E-03	<0.02	<0.02	7.94E-03	6.15E-03	1.41E-02	2.13E-02	<0.02	6.53E-03	<0.02
ESMW-1B	10/94	10-12	2130	1810	1.61E+00	5.13E+01	1.31E+01	1.40E+01	4.03E+01	1.76E+01	7.19E+01	1.38E+02	1.09E+01	2.31E+01	8.91E+00
ESMW-1B	10/94	12-14	8.03	6.83	8.62E-01	2.76E+00	2.26E-01	2.54E-01	6.81E-01	3.85E-01	1.32E+00	5.17E+00	8.09E-02	2.40E-01	1.20E-01
ESMW-2B	10/94	13-15	0.09	0.08	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	ND ^{b/}	<0.02	<0.02
ESMW-2B	10/94	17-19	0.07	0.06	ND	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	ND	ND	ND
ESMW-2B	10/94	40-42	0.38	0.33	<0.02	<0.02	ND	ND	ND	ND	ND	<0.02	ND	ND	ND
ESMW-3B	10/94	13-15	0.27	0.23	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	ND	ND	ND
ESMW-5B	10/94	13-15	0.03	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	ND	<0.02	<0.02
ESMW-5B	10/94	16-18	0.32	0.27	ND	<0.02	ND	ND	ND	ND	ND	<0.02	ND	ND	ND
ESMW-7B	10/94	NA ^{c/}	0.83	0.71	1.48E-02	1.06E-01	1.76E-02	2.03E-02	5.54E-02	2.94E-02	1.05E-01	2.44E-01	1.15E-02	2.88E-02	1.24E-02
ESMW-7B	10/94	11-13	0.13	0.11	ND	<0.02	ND	ND	ND	ND	ND	<0.02	ND	ND	ND
SS1	7/95	Sediment	NA	NA	1.22E+00	4.43E+00	9.73E+00	1.19E+01	2.20E+01	1.03E+01	4.42E+01	5.96E+01	1.19E+00	3.29E+00	8.69E-01
SS2	7/95	Sediment	NA	NA	ND	BLQ ^{d/}	ND	ND	ND	ND	ND	ND	ND	ND	ND

^{a/} JP-4 = JP-4 Jet fuel

^{b/} ND = Not detected

^{c/} NA = Not available

^{d/} BLQ = Below Limit of Quantitation; 0.05 µg/mL



1992
5.0-7.0/(ND)
10.5-11.5/
E (21)
Xs (1300)
2-METHYLNAPHTHALENE (2400)
NAPHTHALENE (900)

1993
4-5.50/T (29)
Xs (12)

1992
ND

1992
ND

1993
0-1.0/T (4)
Xs (75)

1992
ND

1993
ND

1993
ND

1993
ND

1993
0-1.5/T (13)
4.5-6.0/T (6)
12.5-13.5/T (11)

LEGEND

- MW-92 MONITORING WELL INSTALLED PRIOR TO FALL 1993
- 460 MONITORING WELL INSTALLED FALL 1993
- 461 SOIL BORING
- ESMW-6A MONITORING WELL INSTALLED SEPTEMBER 1994
- ESSB-1 SOIL BORING SEPTEMBER 1994
- VOC OR SVOC COMPOUNDS ABOVE DETECTABLE LIMITS
- 5.0-7.0/ (ND) SAMPLE DEPTH-FEET BELOW GROUND SURFACE/ANALYTE CONCENTRATION (ug/kg). ND = NOT DETECTED
- T TOLUENE
- E ETHYLBENZENE
- Xs XYLENES

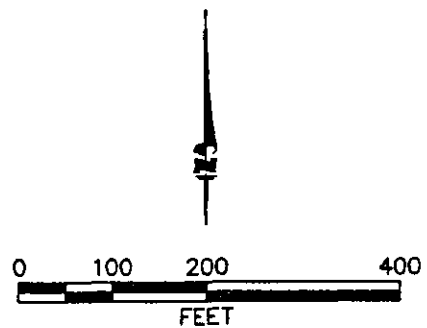
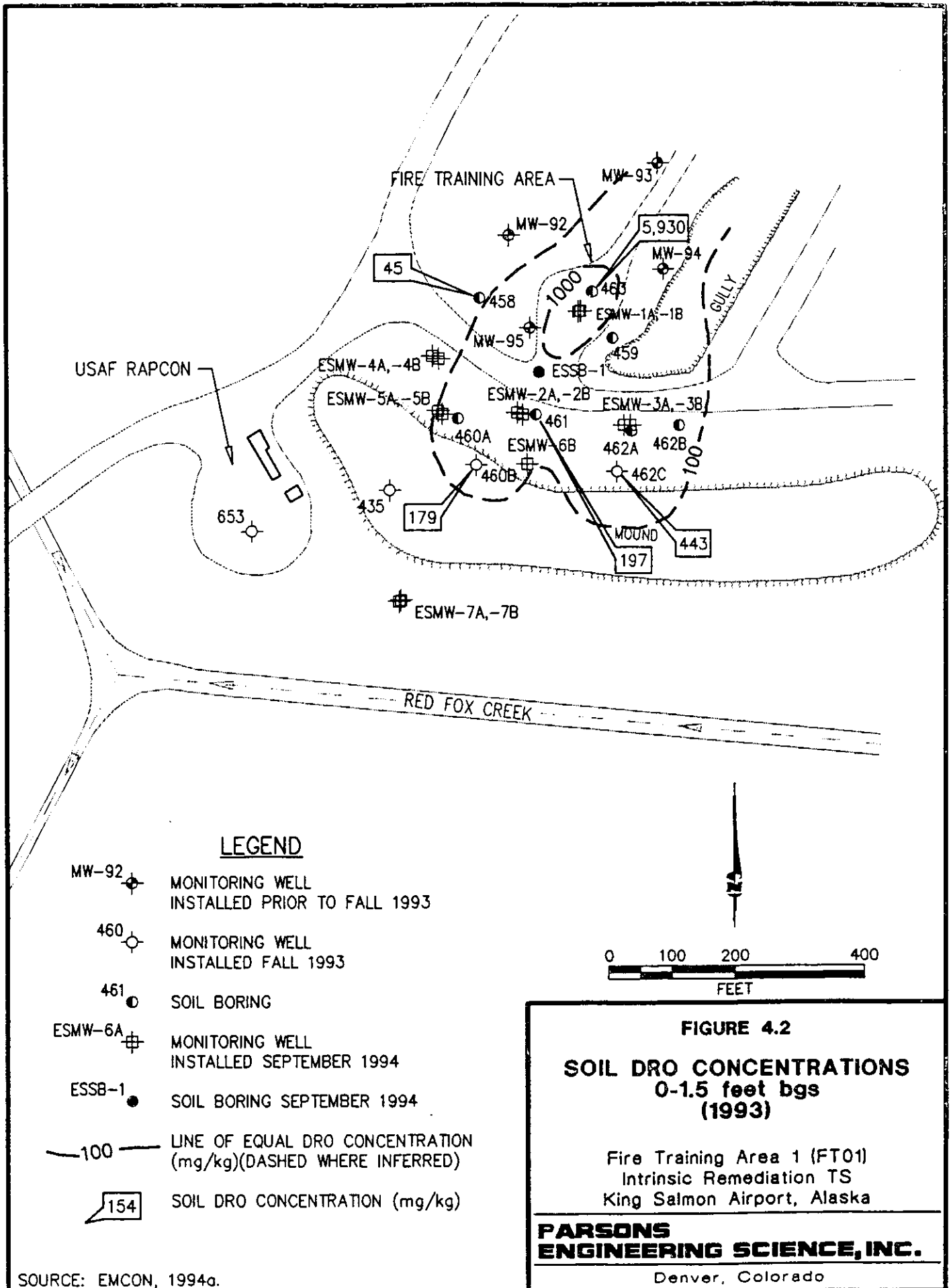








FIGURE 4.1
VOC AND SVOC CONCENTRATIONS IN SOIL (1992 and 1993)
Fire Training Area 1 (FT01)
Intrinsic Remediation TS
King Salmon Airport, Alaska
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

SOURCE: SAIC, 1993b, EMCON 1994a



LEGEND

- MW-92  MONITORING WELL
INSTALLED PRIOR TO FALL 1993
- 460  MONITORING WELL
INSTALLED FALL 1993
- 461  SOIL BORING
- ESMW-6A  MONITORING WELL
INSTALLED SEPTEMBER 1994
- ESSB-1  SOIL BORING SEPTEMBER 1994
- 100— LINE OF EQUAL DRO CONCENTRATION
(mg/kg)(DASHED WHERE INFERRED)
-  SOIL DRO CONCENTRATION (mg/kg)

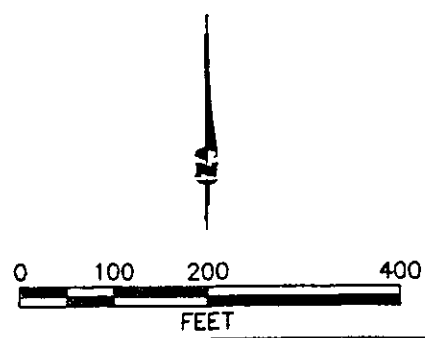


FIGURE 4.2
SOIL DRO CONCENTRATIONS
0-1.5 feet bgs
(1993)

Fire Training Area 1 (FT01)
 Intrinsic Remediation TS
 King Salmon Airport, Alaska

PARSONS
ENGINEERING SCIENCE, INC.
 Denver, Colorado

SOURCE: EMCON, 1994a.

