

FINAL
Remedial Action Plan
for the Risk-Based Remediation of
Site OT45



Wurtsmith Air Force Base
Michigan

Prepared For

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

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Walton, Norman

From: Hansen, Jerry E, Mr, HQAFCEE [Jerry.Hansen@HQAFCEE.brooks.af.mil]

Sent: Tuesday, August 08, 2000 10:16 AM

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EXECUTIVE SUMMARY

A comprehensive site investigation addressing soils and groundwater contaminated with heating fuel oil hydrocarbon compounds at Installation Restoration Program Site OT45, was conducted at Wurtsmith Air Force Base (AFB), Michigan, by Parsons Engineering Science, Inc. (Parsons ES). Wurtsmith AFB was officially closed as a military facility on June 30, 1993. Field work was conducted to complete a remedial action plan (RAP) in support of a risk-based remediation decision for Site OT45. Initial risk-based characterization field efforts for this investigation were conducted in September and October 1994. Groundwater monitoring data were collected in September 1995, November 1996, and June 1997 to verify the natural biodegradation of site contaminants. Additional soil sampling was completed in July/August 1996.

The risk-based approach for remediation of Site OT45 is sponsored by the United States (US) Air Force Center for Environmental Excellence (AFCEE) at Brooks AFB, Texas under contract F41624-93-C-8044. The Site OT45 risk-based remedial evaluation is a component of the multi-site AFCEE initiative to demonstrate how quantitative fate and transport calculations and risk analysis, based on site-specific data, can be integrated. Consequently, this integration allows for rapid determination of the type and magnitude of remedial action required at a site to minimize contaminant migration, receptor exposure, and subsequent health risks to potential receptors. Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source reduction technologies such as *in situ* bioventing, as necessary, to economically reduce potential risks to human health and the environment posed by a subsurface petroleum fuel release.

Site OT45 is located in the northern portion of the former Base adjacent to Building 5608, within the confines of the former Defense Reutilization and Marketing Office (DRMO) storage facility. The site is located within a remote area of the Base, and consists of four storage buildings, an abandoned office building, and covered and uncovered staging areas. A former underground storage tank (UST) located on the northern side of Building 5608 is suspected of having leaked heating fuel oil when it failed tank integrity testing in the fall of 1991. The tank was purged in October 1991, and it remained empty until its removal in May 1992 (ICF Technology, Inc., 1993).

The RAP for Site OT45 follows Michigan Department of Environmental Quality (MDEQ, 1994a) guidance per Part 201 of Public Act (PA) 451, the revised Operational Memoranda #8 and #14 (MDEQ, 1995a and 1995b) on implementing risk-based remedial actions in the state, and the American Society for Testing and Materials (ASTM, 1995) *Emergency Standard Guide for Risk-Based Corrective Actions Applied at Petroleum Release Sites*. These guidance documents outline a tiered approach for establishing remedial action requirements at specific sites. The tiered approach is based on an evaluation of potentially completed receptor exposure pathways from contaminated site media under both current and future land use scenarios.

One objective of the RAP is to document any potential current risks to human health and the environment (i.e., ecological receptors) due to exposure to chemical contaminants originating from Site OT45. The RAP also addresses the potential future

risks to human and ecological receptors due to exposure to chemical contaminants over time, accounting for the effects of natural chemical attenuation processes. The overall objective of the RAP is to develop and present a recommended risk-based remedial approach for fuel hydrocarbon contamination in soils and groundwater at and downgradient from Site OT45 that is protective of both human health and the environment.

Overview of Project Activities

It is the intent of the Air Force to document in this RAP attainment of MDEQ (1995b) nonsite-specific, land use-based (i.e., generic) industrial and commercial subcategory IV cleanup criteria (i.e., Tier 1 levels) at Site OT45. The activities conducted pursuant to establishing the level of evaluation necessary to define risk-reduction requirements at this site included characterizing:

- The nature and extent of fuel hydrocarbon contamination at the site;
- The location of potential groundwater recharge and discharge areas;
- The local geology, hydrogeology, and hydrology that may affect contaminant transport;
- The proximity of the site to drinking water aquifers, surface water bodies, and other sensitive environmental resources;
- The expected persistence, mobility, chemical form, and environmental fate of hazardous substances in soils and groundwater under the influence of natural physical, chemical, and biological processes;
- The current and potential future uses of the site and its vicinity, including groundwater, and the likelihood of exposure of receptors to potentially impacted environmental media over time;
- The potential risks associated with chemical contamination under current and foreseeable future conditions;
- The long-term target remedial objectives and chemical-specific concentration goals required to protect human health and the environment; and
- The treatability of residual and dissolved fuel hydrocarbon contamination using low-cost source reduction technologies such as bioventing and bioparging.

Summary of Proposed Type of Cleanup

The current and foreseeable land use scenarios at Site OT45 are both industrial and commercial in nature. The site is currently abandoned, except for occasional environmental restoration personnel. The current land use thus can be classified as industrial in nature. The reuse plan for Wurtsmith AFB designates the land at Site OT45 to be used for convention/tourist services (US Air Force, 1993). Any construction activities undertaken pursuant to future land use scenarios also will be

industrial in nature. However, the nature of planned activities at the potential convention/tourist facility are representative of the types of activities outlined by MDEQ (1995b) for commercial subcategory IV sites. Consequently, the current and future land use at Site OT45 will be first industrial and then commercial in nature. Hypothetical current receptors include nonintrusive and intrusive industrial workers. Hypothetical future onsite receptors could include visitors to the planned convention center and any office personnel. Therefore, site contaminant concentrations were compared to both the MDEQ (1995b) generic industrial and commercial subcategory IV criteria to determine whether any risk reduction activities were warranted at Site OT45 to protect current and potential future receptors.

Soil concentrations of phenanthrene and 1,2,4-trimethylbenzene (1,2,4-TMB) were the only contaminants measured during the 1994 risk-based investigation at Site OT45 that exceeded the most stringent of the MDEQ (1995b) generic industrial/commercial cleanup criteria. These generic, or nonsite-specific, risk-based cleanup criteria were used as a screening tool to initially identify any chemicals of potential concern (COPCs). Soil concentrations of phenanthrene and 1,2,4-TMB exceeded only their respective generic industrial/commercial soil leaching criteria during the 1994 sampling event. The generic soil leaching cleanup criteria are calculated by multiplying the target groundwater cleanup criteria, which are based on an ingestion exposure route, by 20. These generic soil leaching criteria may be overly restrictive relative to the site-specific conditions that appear to be governing the rate of leaching of phenanthrene and 1,2,4-TMB at Site OT45 and the actual beneficial use of the impacted groundwater. Although both phenanthrene and 1,2,4-TMB were measured at concentrations greater than the generic soil leaching criteria that are developed to be protective of potable groundwater, phenanthrene and 1,2,4-TMB were not detected in groundwater samples at concentrations exceeding the most restrictive generic industrial cleanup criteria. It is likely that the generic soil leaching cleanup criteria algorithm does not accurately describe how chemicals leach from impacted media at Site OT45. A compliance soil sampling effort was conducted which included collecting several soil samples to confirm that contaminants have been attenuated to a point where the concentrations are below generic soil leaching criteria. This 1996 sampling event indicated that no concentrations of site contaminants in soil currently exceed the most stringent of the MDEQ (1995a) generic residential criteria.

No fuel-related compound was detected in groundwater in 1994, 1995, 1996, or 1997 at concentrations above the MDEQ generic industrial/commercial cleanup criteria. A screening-level chemical fate assessment was completed only to identify the potential for site-related contaminants to migrate off-Base at in groundwater concentrations greater than MDEQ (1995a) generic residential cleanup criteria. Site characterization data relevant to documenting natural chemical attenuation, specifically bioattenuation, were collected and are documented in this RAP. The simple chemical fate and transport calculations include those natural physical, chemical, and biological attenuation processes documented to be occurring at the site.

Concentrations of dissolved fuel-related contaminants in the groundwater underlying Site OT45 have been observed to decrease via naturally occurring chemical attenuation mechanisms, and thereby to remain at concentrations that are protective of current and future onsite receptors. Historical data collected from 1992 through 1997 confirm reductions in contaminant concentrations and minimal forward migration in

groundwater. No dissolved contaminants currently exist at the site at concentrations exceeding MDEQ (1995a) generic residential cleanup criteria for groundwater. Additionally, the screening-level chemical fate assessment and verification sampling indicates that soil contaminants are not present at concentrations sufficient to impact groundwater and elevate onsite dissolved contaminant concentrations to levels that exceed MDEQ (1995b) generic residential groundwater cleanup criteria.

In summary, site analytical data and simple chemical fate calculations indicate that no fuel-related compound is present onsite at concentrations above the most restrictive generic cleanup criteria appropriate for the exposure points (i.e., industrial/commercial onsite and residential offsite). Additionally, confirmatory sampling events subsequent to the 1994 risk-based investigation indicate that no fuel-related compounds is currently present on-site at concentrations above the most restrictive generic cleanup criteria for unrestricted use (i.e., residential on-site and off-site). Consequently, this RAP documents that no additional remediation is necessary to achieve appropriate generic cleanup criteria and to protect onsite and offsite receptors, and that the site may be eligible for immediate unrestricted closure.

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SECTION 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

Parsons Engineering Science, Inc. (Parsons ES) was retained by the United States (US) Air Force Center for Environmental Excellence (AFCEE) to prepare a remedial action plan (RAP) in support of a risk-based remediation decision for soil and groundwater contaminated with heating fuel oil hydrocarbons at Installation Restoration Program (IRP) Site OT45 at Wurtsmith Air Force Base (AFB), Michigan. The Base was formally closed as a military facility on June 30, 1993. A historical release from a former underground storage tank (UST) at a former Defense Reutilization and Marketing Office (DRMO) located near the northern boundary of Wurtsmith AFB is suspected as having contaminated the surrounding subsurface with heating fuel oil hydrocarbons. The UST had been used to store heating fuel oil to support the heating requirements of the DRMO.

Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source reduction technologies such as *in situ* bioventing, as necessary, to economically reduce potential risks to human health and the environment posed by subsurface petroleum fuel spills. This RAP is prepared as part of a multi-site initiative sponsored by AFCEE to develop a protocol on how risk information and quantitative fate and transport calculations based on site-specific data can be integrated to quickly determine the type and magnitude of remedial action required at fuel-contaminated sites in order to minimize contaminant migration and potential receptor risks. Site OT45 is one of several sites nationwide that will be used as a case study in the development of the protocol.

This RAP provides the documentation elements specified by Michigan Department of Environmental Quality (MDEQ, 1994a) guidance per Part 201 of Public Act (PA) 451 Section 20120(a), the 1995 revised editions of MDEQ Operational Memoranda #8 and #14 (MDEQ, 1995a and 1995b), and is consistent with the American Society for Testing and Materials (ASTM, 1995) *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. These guidance documents outline a tiered approach for establishing remedial action requirements at specific sites based on an evaluation of potential receptor exposures to chemical contamination at or migrating from the release site. The need for corrective action at a site is first determined by conducting a Tier 1 evaluation. A Tier 1 evaluation is essentially a generic screening-level assessment during which contaminant concentrations measured in site media are compared to nonsite-specific (i.e., generic) values, based on conservative receptor exposure factors, potential receptor exposure pathways, and land use assumptions. Tier

1 risk-based screening levels (RBSLs) have been defined by the MDEQ for industrial, commercial, and residential land use assumptions.

This RAP documents that no site-related contaminant concentrations at IRP Site OT45 exceed Tier 1 (generic) health-based industrial or commercial subcategory IV cleanup criteria (MDEQ, 1995b). Only two fuel-related compounds [i.e., phenanthrene and 1,2,4-trimethylbenzene (1,2,4-TMB)] were measured in soil at concentrations above the generic soil criteria developed to be protective of underlying groundwater. Neither of these compounds were detected in groundwater in 1994 or 1995 above generic industrial or commercial Subcategory IV criteria. The RAP also demonstrates that minimal potential risk to future human and ecological receptors exist or will exist by estimating the effects of chemical attenuation and transport processes on the mass, mobility, and the fate of the contaminants of potential concern (COPCs). The RAP recommends no further action for this site.

1.2 REPORT ORGANIZATION

This RAP consists of eight sections, including this introduction, and seven appendices. Site background, including operational history and a review of environmental site investigations conducted to date, are provided in the remainder of this section. Section 2 summarizes the 1994, 1995, 1996, and 1997 site characterization activities performed by Parsons ES. Physical characteristics of Site OT45 and surrounding environs are described in Section 3. A Tier 1 evaluation is completed in Section 4 to identify those site contaminants that are considered COPCs. Section 5 summarizes the nature and extent of residual COPC contamination in soils and dissolved aromatic hydrocarbons in groundwater at the site. Section 6 briefly describes the observed and predicted reduction in contaminant concentrations. Section 7 presents the recommended compliance sampling effort to verify attainment of appropriate generic cleanup criteria. Additionally, Section 7 includes a request for an MDEQ-approved closure of Site OT45 under generic cleanup standards. Section 8 lists the references cited in this RAP.

Appendix A contains the boring logs, well construction diagrams, and well development data for sampling activities completed in 1994. Appendix B presents soil, groundwater, soil gas flux test, and soil gas analytical results and data validation results for the initial 1994 risk-based investigation, the 1995 and 1996 groundwater monitoring results, and the 1996 soil confirmation sampling results. Aquifer test data and analyses are presented in Appendix C. Appendix D contains the quantitative calculations relevant to documenting the effectiveness of naturally occurring physical, chemical, and biological processes on reducing the mass, mobility, and toxicity of site-related contaminants. Pilot test results from source reduction treatability testing are presented in Appendix E. Chemical profiles for each COPC evaluated as part of this RAP are included in Appendix F.

1.3 SITE BACKGROUND

Wurtsmith AFB is located approximately 2 miles west of Oscoda, Michigan, within Iosco County (Figure 1.1). The Base is bounded on the north by Van Etten Lake, on

the south by the Au Sable River and the Huron National Forest, on the east and the southeast by the cities of Oscoda and Au Sable, respectively, and on the west by the Alpena State Forest. The Base is less than 1 mile west of the western shore of Lake Huron. Van Etten Lake is a manmade lake that is surrounded by recreational cottages and local residential communities. The cities of Oscoda and Au Sable have a combined population of about 11,000 people [ICF Technology, Inc. (ICF), 1993 and 1994]. Wurtsmith AFB was placed on the 1991 Department of Defense Base Closure and Realignment Commission's list for closure. The Base was officially closed on June 30, 1993.

1.3.1 Operational History

Site OT45 is located in the northern portion of the Base, and is the site of a former 1,000-gallon heating fuel oil underground storage tank (UST). The UST was located adjacent to Building 5608 in the DRMO complex. Figure 1.2 shows the location of Site OT45. After the heating oil UST failed a Tracer Tight™ tank test, it was purged in October 1991, and remained empty until it was removed in May 1992 (ICF, 1993).

1.3.1 Previous Remedial Investigations

Two groundwater monitoring wells (W-OT45 and E-OT45) were installed at each end of the former UST location in 1992 when the UST was removed. Figure 1.3 shows the sampling locations used to characterize the site under previous investigations. Composite soil samples were collected during this effort, and analyzed for benzene, toluene, ethylbenzene, and total xylenes (BTEX) and polynuclear aromatic hydrocarbon (PAH) compounds. The only compound detected was 4-nitroaniline, which was measured near the reported detection limit (ICF, 1993 and 1994).

Site OT45 was also partially characterized during a 1992 remedial investigation (RI) and a 1993 draft feasibility study (FS) under the Air Force IRP by ICF (1993 and 1994). As part of the RI, seven soil boreholes were drilled to depths up to 13 feet (ft) below ground surface (bgs) (Figure 1.3), and sampled for BTEX, PAHs, methyl butyl ether (MTBE), and lead. Site-related contaminants were detected only in soil samples collected from the interval immediately above the water table (smear zone) during the 1992 RI. Ethylbenzene, toluene, total xylenes, fluorene, naphthalene, and phenanthrene were the only contaminants detected in soil samples collected during the 1992 RI (ICF, 1993). Ethylbenzene, phenanthrene, naphthalene, and total xylenes concentrations in soil samples collected from the smear zone exceeded MDEQ (1995b) generic industrial soil leaching criteria (ICF, 1993).

Three of the seven RI boreholes were completed as groundwater monitoring wells (MW-1, MW-2, and MW-3). Groundwater samples were collected from the five existing monitoring wells during the RI (ICF, 1993). All collected samples were analyzed for BTEX, MTBE, and PAHs. Fluorene, naphthalene, phenanthrene, and the BTEX compounds were the only contaminants detected in groundwater samples collected during the 1992 RI (ICF, 1993). Naphthalene and phenanthrene were detected at concentrations that exceeded MDEQ (1995b) industrial/commercial health-based cleanup criteria. Benzene was detected during the RI at concentrations that exceeded its federal maximum contaminant level (MCL), but did not exceed the MDEQ (1995b) generic industrial/commercial health-based cleanup criterion.

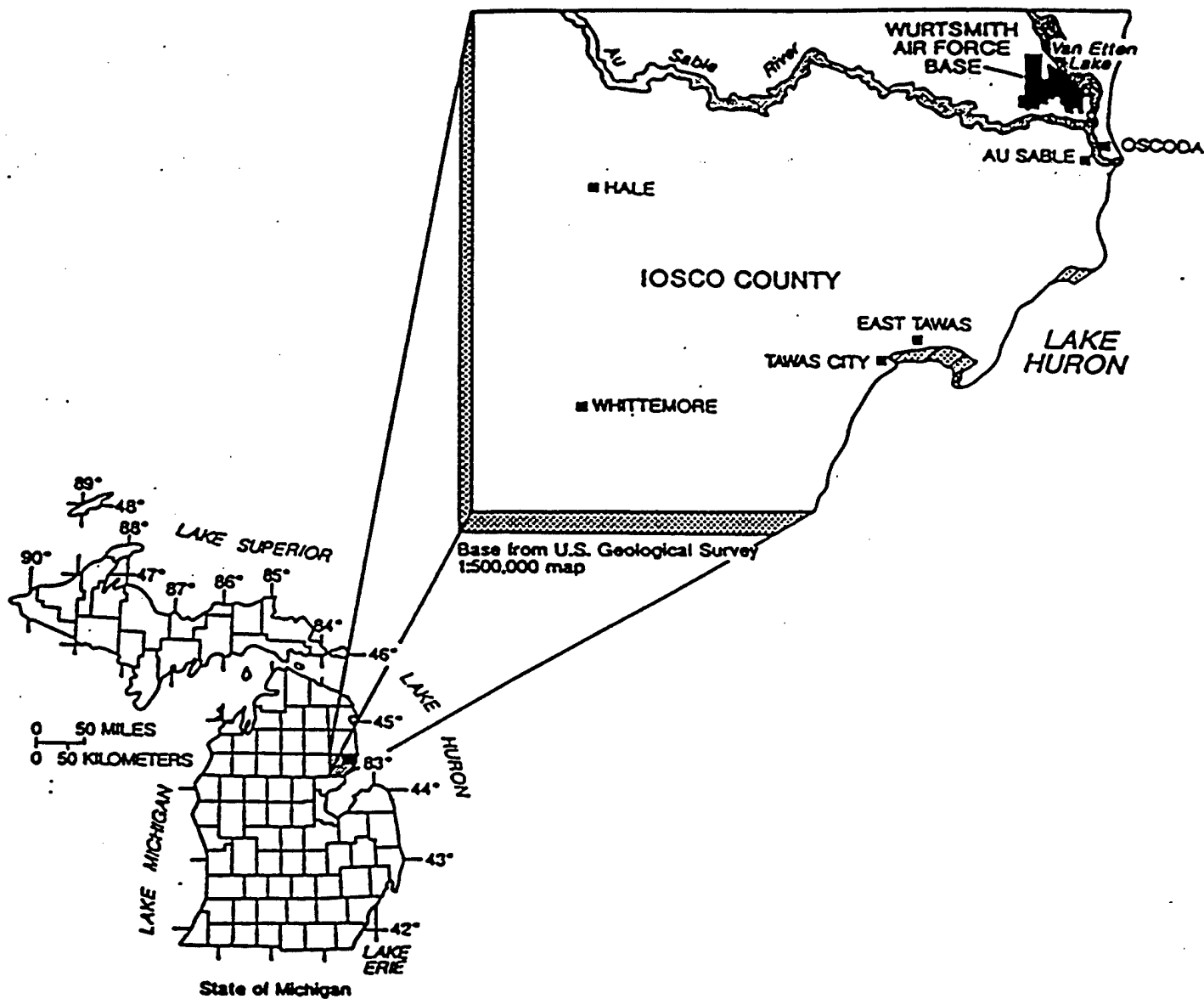


FIGURE 1.1

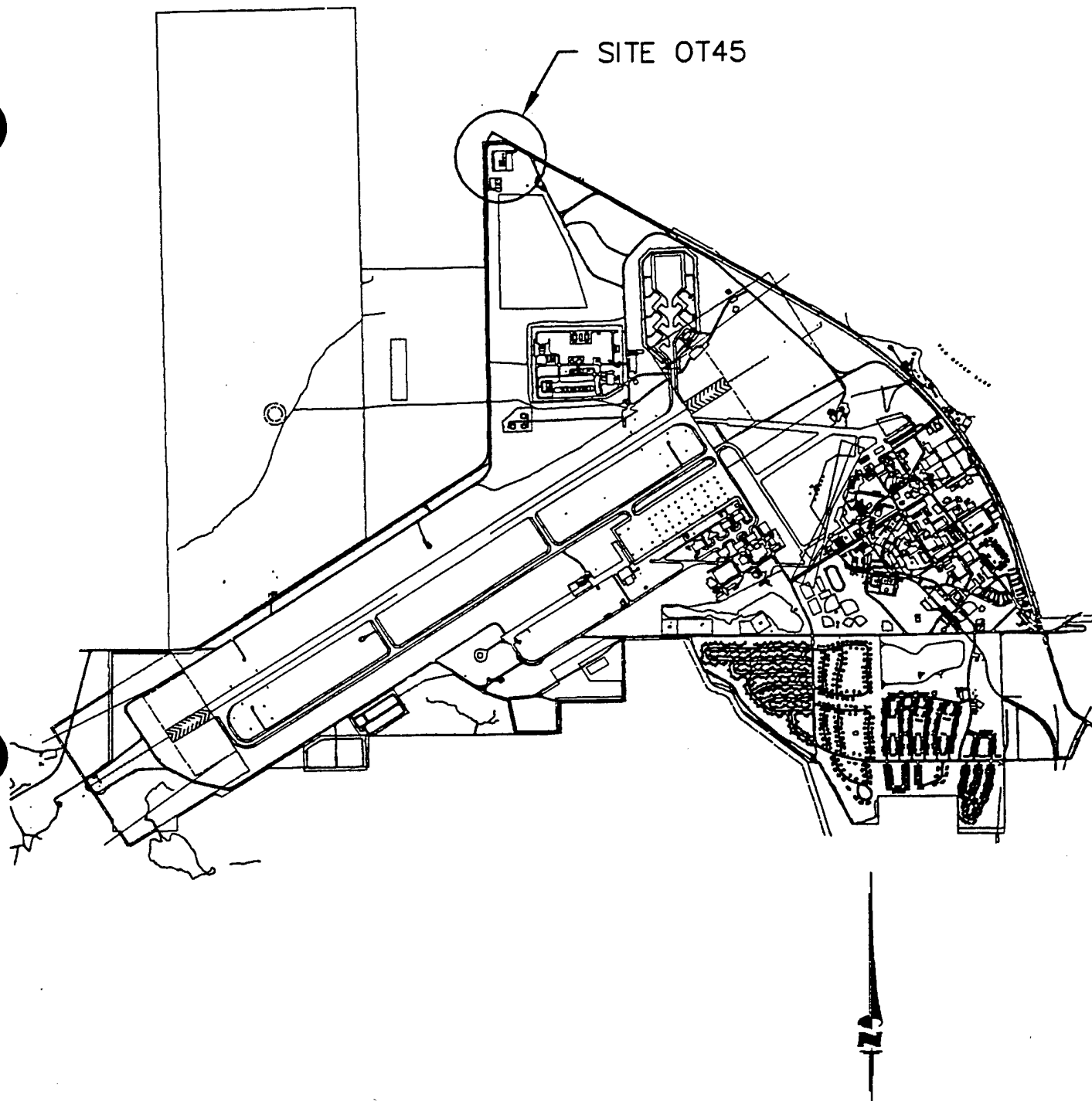
REGIONAL MAP

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan



**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado



Not to Scale

FIGURE 1.2

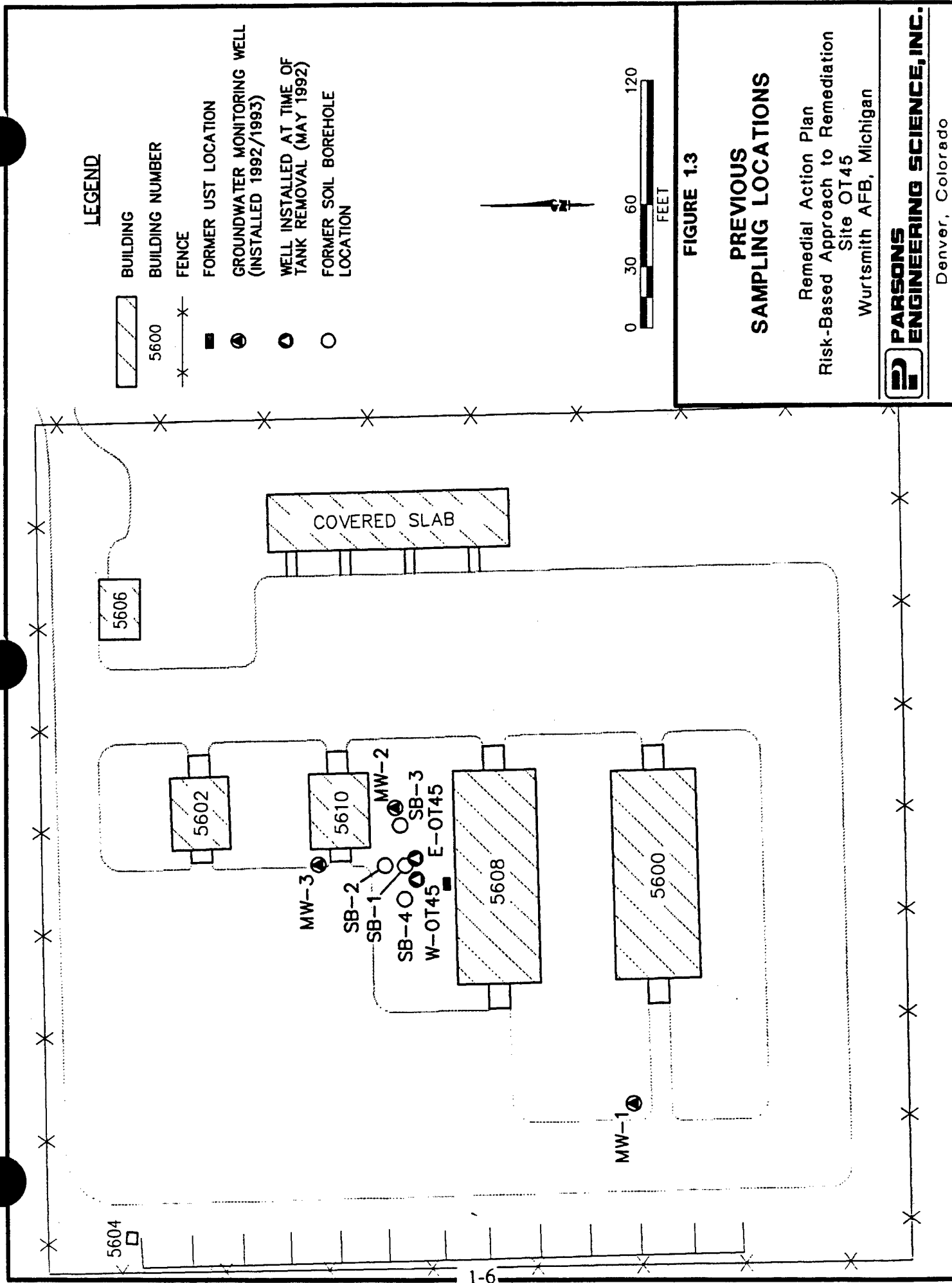
**LOCATION OF SITE OT45
WITHIN WURTSMITH AFB**

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan



**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado



The FS (ICF, 1994) concluded that, although the approximate extent of soil contamination was determined, the downgradient extent of the groundwater contaminant plume had not been adequately defined. The FS also concluded that natural attenuation of contaminants in impacted soils at Site OT45 would be considered protective of human health and the environment, but that measured concentrations of hazardous substances in the groundwater may present an unacceptable threat to offsite receptors unless an active remediation technology, such as groundwater extraction and treatment or biosparging, was implemented (ICF, 1994). The closest potential receptors are located more than 1 mile downgradient from Site OT45, and calculated risks to offsite receptors due to exposure to contaminated groundwater were based on onsite sampling data. The RI baseline risk assessment (BRA) and the development of site-specific industrial/commercial criteria for Site OT45 did not consider the effects of natural attenuation processes on groundwater contaminant mass over time and distance. The RI and the FS reports both stated that the likelihood that potential offsite receptors would be exposed to hazardous substances at hazardous concentrations was very small to virtually negligible (ICF, 1993 and 1994). Consequently, the focused site investigation described in this RAP was designed to fully define the nature and extent of soil and groundwater contamination at Site OT45, and to re-evaluate the need for active remediation to protect human and ecological receptors potentially exposed to affected media. This RAP specifically documents the effects of naturally occurring physical, chemical, and biological processes on site-related contaminant persistence, mobility, mass, and toxicity over time and distance.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

To fully define the downgradient extent of heating oil hydrocarbons in groundwater and collect site-specific data documenting the effects of naturally occurring contaminant attenuation processes and the feasibility of low-cost source removal technologies, a field investigation was conducted by Parsons ES at Site OT45 from September through October 1994. Sufficient data were collected to conduct a quantitative source and release analysis, perform an exposure pathways analysis, and evaluate the potential treatability of contaminated media using low-cost remedial technologies. Emphasis was placed on filling data gaps identified during the previous RI (ICF, 1993) and on collecting data relevant to documenting the biodegradation of heating oil hydrocarbons in soil and groundwater. Data also were collected during September 1995, November 1996, and June 1997 as part of a groundwater monitoring program performed at Site OT45. Additional soil samples were collected in July/August 1996. These data are used to document observed reductions in contaminant concentrations over time, and to verify the accuracy of initial contaminant migration calculations that were based on the 1994 risk-based field investigation data.

2.1 SCOPE OF DATA COLLECTION ACTIVITIES

The field investigations focused on collecting data on the specific chemical constituents that may drive potential risks and impact the final remedial efforts for Site OT45. The initial target chemicals for Site OT45 were identified based on the results of the RI and BRA (ICF, 1993) and the chemical composition of the heating oil. Heating oil is a form of diesel fuel that consists of that fraction of petroleum that distills after kerosene in the 200-degree-Celsius ($^{\circ}\text{C}$) to 400°C range. Heating oil is predominantly a mixture of C_{10} through C_{19} hydrocarbons. The major component categories (and their represented percentages by weight) in heating oil are straight-chain alkanes and cycloalkanes (64 percent); aromatic hydrocarbons, including alkylbenzenes (35 percent); and olefinic hydrocarbons (1 to 2 percent) (Arthur D. Little, Inc. 1987). Other nonhydrocarbons are generally not important components in heating oil by weight. No lead or MTBE was detected in soil or groundwater samples collected at Site OT45 during the RI (ICF, 1993 and 1994).

Based on the environmental behavior of each group of specific hydrocarbons and the results of previous site characterization activities at Site OT45, the fuel-related chemicals targeted as part of this investigation included the BTEX compounds and the PAH compounds naphthalene, fluorene, fluoranthene, and phenanthrene. All analytical data collected on these chemicals were obtained using fixed-base analytical methods. Fixed-base analytical results were provided by Evergreen Analytical, Inc., located in Wheat Ridge, Colorado. Field and other fixed-base analytical data relevant to

documenting biodegradation and assessing the effectiveness of low-cost source removal technologies also were collected.

2.1.1 1994 Risk-Based Investigation Activities

The investigation completed at Site OT45 under the initial 1994 risk-based remediation field test was conducted using the approach and methodologies presented in the *Work Plan for a Remedial Action Plan in Support of the Risk-Based Approach to Remediation at Site OT45* (Parsons ES, 1994a) (hereinafter referred to as the work plan). The following planned sampling and testing activities were performed by Parsons ES at Site OT45 as part of this field test:

- Collection of soil gas samples at 3 locations (Figure 2.1);
- Collection of soil gas flux samples at 4 locations, including a background location (Figure 2.1);
- Drilling and installation of 8 permanent groundwater monitoring wells, 2 soil gas (vapor) monitoring points, 1 air injection bioventing test well, and 1 biosparging point (Figure 2.2);
- Collection of 3 surface soil and 14 discrete subsurface soil samples from 12 new soil boreholes for field screening and fixed-base analytical evaluation (Figure 2.2);
- Collection of 14 groundwater samples from different sampling locations for field and/or fixed-base analytical evaluation (Figure 2.2);
- Aquifer slug testing at 5 sampling locations (MW-4, MW-7, MW-10, MW-11, and MPA; Figure 2.2);
- Completion of an air permeability test and an oxygen influence test to assess the effectiveness of bioventing technology at stimulating natural biodegradation of heating oil hydrocarbons in unsaturated soil; and
- Completion of initial testing at the biosparging point to define optimum operational parameters in the event that a full-scale biosparging system is required to promote rapid natural biodegradation of heating oil hydrocarbons in saturated soils and shallow groundwater.

2.1.2 1995 Groundwater Monitoring Activities

In addition to the 1994 risk-based investigation, groundwater sampling was performed at select wells as part of a limited groundwater monitoring program sponsored by AFCEE to document reductions in concentration and extent of migration of site-related contamination over time. After evaluating the 1994 risk-based investigation results, seven groundwater monitoring wells and one monitoring point [MW-2, MW-4, MW-5, MW-7, MW-10, MW-11, MPB, and VW-1 (W-OT45)] were

LEGEND

-  BUILDING
-  BUILDING NUMBER
-  FENCE
-  FORMER UST LOCATION
-  SOIL GAS AND SURFACE SOIL GAS FLUX SAMPLE LOCATION
-  BACKGROUND SOIL GAS FLUX SAMPLING LOCATION

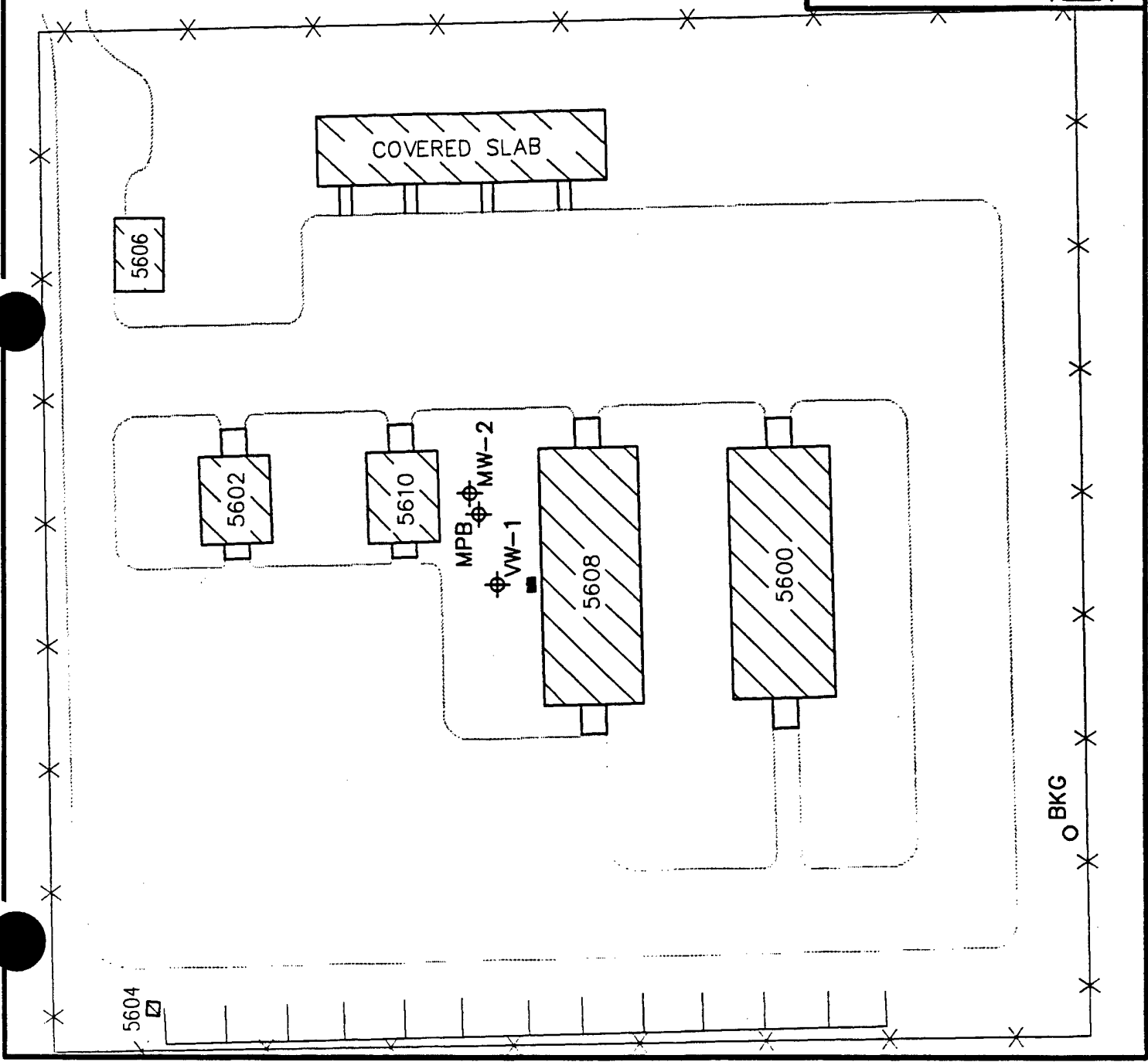
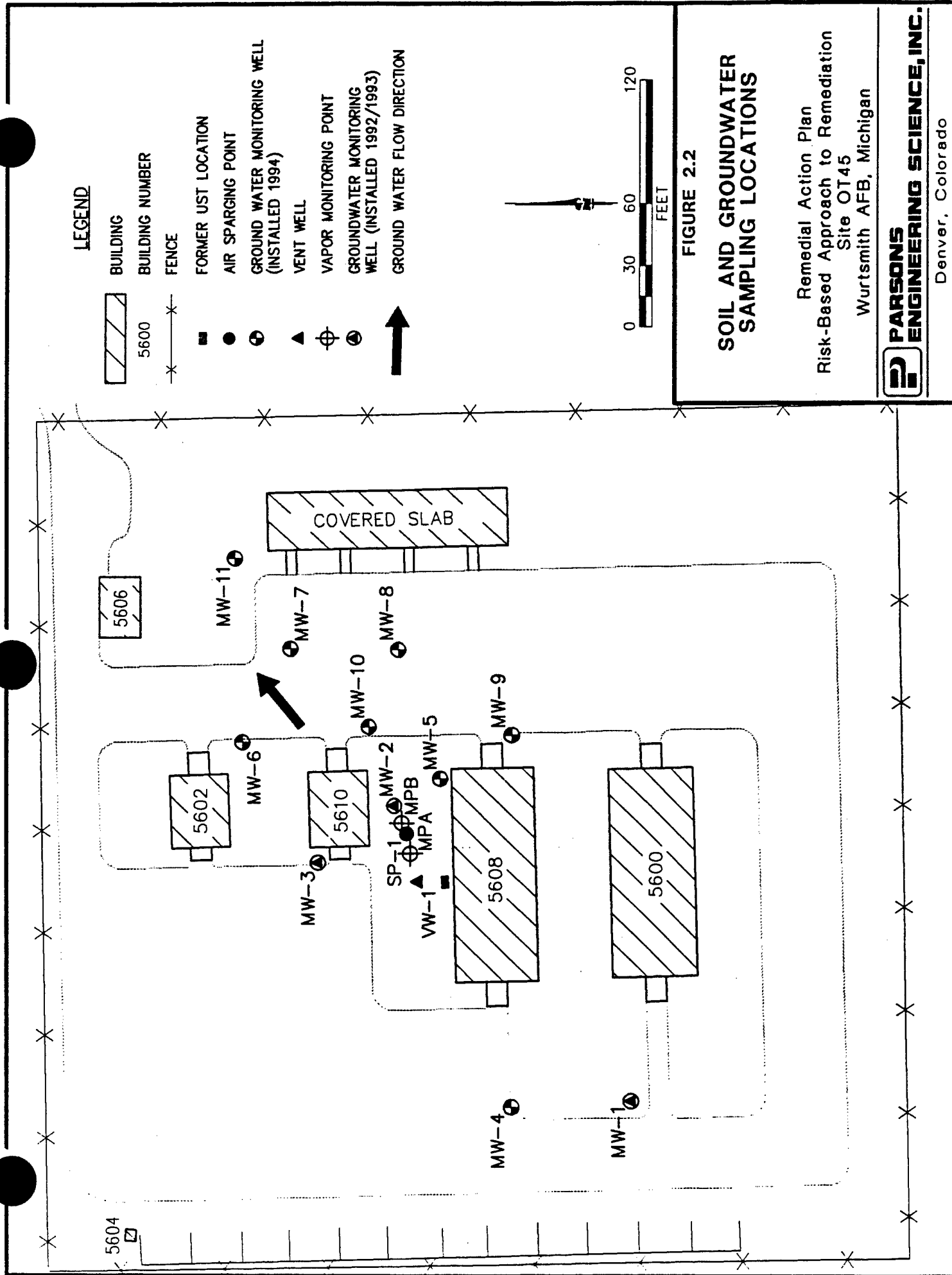


FIGURE 2.1

SOIL GAS AND SOIL GAS FLUX SAMPLING LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan

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



selected to monitor potential contaminant migration over time. Groundwater was collected from these sampling locations in September 1995 for fixed-based analytical analysis and field screening tests.

2.1.3 1996/1997 Groundwater Monitoring Activities

In an effort to verify the model predictions of reduction in the concentrations and migration of the site-related contamination over time, limited groundwater sampling was completed in November 1996 [MW-2 and MW-7] and June 1997 [MW-2, MW-5, and VW-1]. Groundwater was collected from these sampling locations for fixed-based analytical analysis.

2.1.4 1996 Soil Sampling Activities

In addition to the 1994 risk-based investigation, soil sampling was performed as part of a confirmation sampling plan sponsored by AFCEE to document reductions in concentration and extent of site-related contamination over time. Soil sample locations were selected based on the results of the 1995 risk-based evaluation (Figure 2.3). Soil samples were collected from these sampling locations in July/August 1996 for fixed-based analytical analysis.

2.1.5 Summary of Sampling Methodology

A descriptive summary of all of the field and fixed-base analytical methods used at Site OT45 is presented in Table 2.1. All analytical methods and their program-specific method detection limits (MDLs) are identical to those recommended by MDEQ (1994b) in Operational Memorandum #6, Revision 3. Further details on analytical methods and data validation procedures are presented in Appendix B. Table 2.2 summarizes the field and fixed-base analytical methods used at each sampling location. Field sampling and testing activities are summarized briefly in the following sections.

2.2 SOIL GAS AND SURFACE FLUX MEASUREMENTS

Soil gas and soil gas flux sampling was performed during the 1994 risk-based investigation to estimate the extent of subsurface soil contamination, determine the potential for lateral and upward diffusion of contaminated soil gas, and assess the feasibility of using bioventing to reduce source contamination at the site. The purpose of soil gas flux sampling is to measure the upward diffusion of volatile chemicals from the soil into the atmosphere and potentially into buildings within or adjacent to Site OT45. Soil gas flux data are used to determine if the air migration pathway is complete for site-related chemicals, and to assess any potential risk to receptors that could be exposed to contaminants in vapor emissions.

2.2.1 Soil Gas Sampling

Soil gas samples were collected by Parsons ES in September 1994 from the three sampling locations shown on Figure 2.1. Soil gas samples were collected from the source area soil gas monitoring point MPB, groundwater monitoring well MW-2, and bioventing test well VW-1. All soil gas samples were screened for fuel hydrocarbons, oxygen, and carbon dioxide using the test equipment and methods specified for field

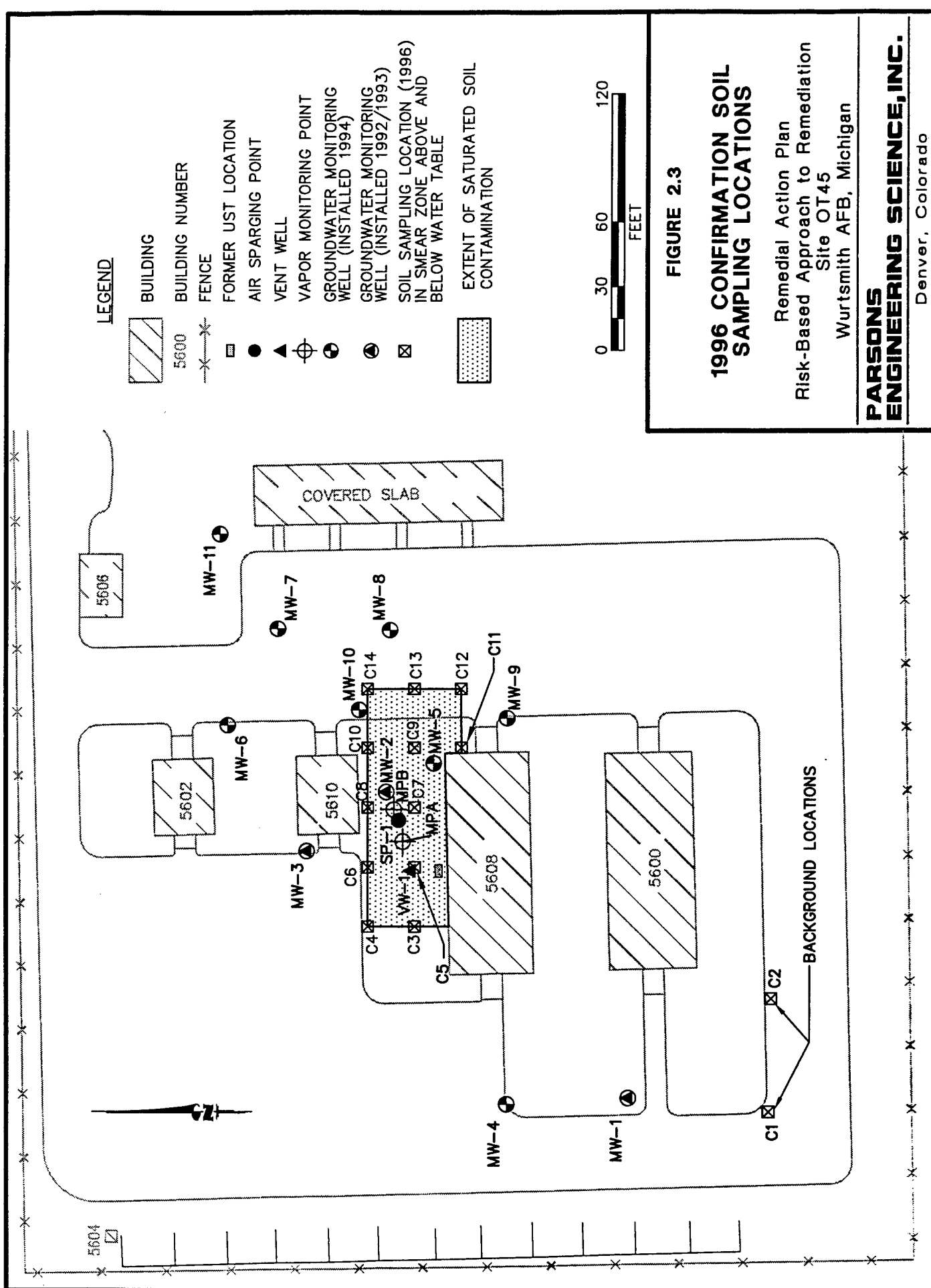


TABLE 2.1
ANALYTE REPORTING LIMITS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE 0145, WURSMITH AFB, MICHIGAN

Compound	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	MDNR Soil Required MDL'	Soil Reporting Limit	Soil Units	Site-Specific Water MDL	MDNR Water Required MDL'	Water Reporting Limit	Water Units
Benzene	TO3	Fixed-Base	0.006	mg/L								
Toluene	TO3	Fixed-Base	0.008	mg/L								
Ethylbenzene	TO3	Fixed-Base	0.009	mg/L								
Xylene (Total)	TO3	Fixed-Base	0.009	mg/L								
Petroleum Hydrocarbons	TO3	Fixed-Base	0.130	mg/L								
Total Extractable Hydrocarbons	M8015	Fixed-Base							0.522		5.000	µg/L
Total Volatile Hydrocarbons	M8015	Fixed-Base			5.840		110.000	µg/kg	0.089		1.000	µg/L
Benzene	SW8020	Fixed-Base							0.283	1.000	0.400	µg/L
Toluene	SW8020	Fixed-Base			0.400	10.000		µg/kg	0.257	1.000	4.000	µg/L
Ethylbenzene	SW8020	Fixed-Base			0.400	10.000		µg/kg	0.283	1.000	4.000	µg/L
Xylene (Total)	SW8020	Fixed-Base			0.400	30.000		µg/kg	0.247	3.000	4.000	µg/L
1,2,3-Trimethylbenzene	SW8020	Fixed-Base			0.400			µg/kg	0.153	1.000	4.000	µg/L
1,2,4-Trimethylbenzene	SW8020	Fixed-Base			0.400	10.000		µg/kg	0.168		4.000	µg/L
1,3,5-Trimethylbenzene	SW8020	Fixed-Base			0.400			µg/kg	0.168		4.000	µg/L
2-Methylnaphthalene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.010	5.000	10.000	µg/L
Acenaphthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.430	5.000	10.000	µg/L
Acenaphthylene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.270	5.000	10.000	µg/L
Anthracene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.320	5.000	10.000	µg/L
Benz(a)anthracene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.350	5.000	10.000	µg/L
Benzo(b)pyrene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.370	5.000	10.000	µg/L
Benzo(k)fluoranthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.440	5.000	10.000	µg/L
Benzo(a)pyrene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.200	5.000	10.000	µg/L
Benzo(g,h,i)perylene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.510	5.000	10.000	µg/L
Benzo(k)fluoranthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.330	5.000	10.000	µg/L
Chrysene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.580	5.000	10.000	µg/L
Dibenz(a,h)anthracene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.010	5.000	10.000	µg/L
Dibenzofuran	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.410	5.000	10.000	µg/L
Fluoranthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.420	5.000	10.000	µg/L
Indeno(1,2,3-cd)pyrene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.470	5.000	10.000	µg/L
Naphthalene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.380	5.000	10.000	µg/L
Phenanthrene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.190	5.000	10.000	µg/L
Pyrene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.370	5.000	10.000	µg/L
pH	SW9045	Fixed-Base					0.010	pH Units				
Total Organic Carbon	SW9060	Fixed-Base			0.015		0.050	Percent				
Moisture, Percent	E160.3	Fixed-Base					0.100	Percent				
Phosphorus, Total Orthophosphate (as P)	E300.0	Fixed-Base			0.510		2.500	mg/kg				
Alkalinity, Total (as CaCO ₃)	E310.1	Fixed-Base					25.000	mg/kg				
Nitrogen, Total Kjeldahl	E351.3	Fixed-Base			5.000		5.000	mg/kg				
Iron	SW6010	Fixed-Base			0.032	2.000	1.600	mg/kg				
Benzene	SW8240	Fixed-Base							0.330	1.000	0.400	µg/L
Toluene	SW8240	Fixed-Base							0.380	1.000	5.000	µg/L
Ethylbenzene	SW8240	Fixed-Base							0.450	1.000	5.000	µg/L
Xylene (Total)	SW8240	Fixed-Base							0.220	3.000	5.000	µg/L

TABLE 2.1 (Concluded)
ANALYTE REPORTING LIMITS
REMEDIATION ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE 0T45, WURSMITH AFB, MICHIGAN

Compound	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	MDNR Soil Required MDL [✓]	Soil Reporting Limit	Soil Units	Site-Specific Water MDL	MDNR Water Required MDL [✓]	Water Reporting Limit	Water Units
1,2,3-Trimethylbenzene	SW8240	Fixed-Base							0.200	1.000	5.000	µg/L
1,2,4-Trimethylbenzene	SW8240	Fixed-Base							0.200		5.000	µg/L
1,3,5-Trimethylbenzene	SW8240	Fixed-Base							0.200		5.000	µg/L
Benzene	SW8260	Fixed-Base							0.500	1.000	5.000	µg/L
Toluene	SW8260	Fixed-Base							0.500	1.000	5.000	µg/L
Ethylbenzene	SW8260	Fixed-Base							0.500	1.000	5.000	µg/L
Xylene (Total)	SW8260	Fixed-Base							0.500	3.000	5.000	µg/L
1,2,3-Trimethylbenzene	SW8260	Fixed-Base							0.500	1.000	5.000	µg/L
1,2,4-Trimethylbenzene	SW8260	Fixed-Base							0.500		5.000	µg/L
1,3,5-Trimethylbenzene	SW8260	Fixed-Base							0.500		5.000	µg/L
Electrical Conductivity	FCOIND	Field									0.020	mmhos/cm
Dissolved Oxygen	FDO	Field									0.500	mg/L
pH	FPH	Field									0.000	pH Units
Redox Potential	FREDOX	Field									0.000	pE Units
Temperature	FTEMP	Field									1.000	°C
Iron	H8008	Field							0.010	0.100	0.024	mg/L
Nitrate	H8039	Field							0.010		0.066	mg/L
Nitrite	H8040	Field							0.005		0.010	mg/L
Sulfate	H8051	Field							0.010		0.010	mg/L
Hydrogen Sulfide	H8131	Field							0.010	0.200	0.024	mg/L
Iron, Ferrous	H8146	Field							0.010		0.024	mg/L
Alkalinity, Total (as CaCO ₃)	H8221	Field							0.010		20.000	mg/L
Carbon Dioxide	H8223	Field							0.010		1.250	mg/L
Manganese	HMANG	Field							0.010	0.020	0.050	mg/L
Carbon Dioxide	COU-02	Fixed-Base									5.000	mg/L
Methane	RSK175	Fixed-Base							4.000	0.004	0.004	mg/L

[✓] Source: MDNR (1994C) Interoffice Communication Memorandum #6, Revision 3, Analytical Detection Limit Guidance (dated February 4, 1994).

TABLE 2.2
FIXED-BASE ANALYSES AND FIELD MEASUREMENTS BY SAMPLING LOCATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

SAMPLING LOCATION	NORTHING	EASTING	SAMPLE MATRIX	SAMPLE DEPTH (ft. bgs)	SCREENED ANALYTES AND FIELD PARAMETERS										IRON	SOIL pH	SOIL TOC
					BTEX	PNA	TVH/TEH	ELECTRON ACCEPTORS	MOISTURE CONTENT	PHOS	ALK	CO ₂	CH ₄	NITROGEN			
BKG				NA	1 ^a												
MPA	423602.29	2246385.61	Soil Gas Flux	0-25		X											
			Soil	8-9.5	2 ^b		X		X				X			X	
MPB ^c	423606.49	2246400.48	Soil Gas	9-9.5	1												
			Soil Gas Flux	NA	1												
			Soil	0-25		X											
				8-9.5	2	X	X		X	X	X			X		X	
MW1	423496.87	2246264.70	Ground Water	NA	2	X		X									
MW2 ^{d,e}	423610.18	2246408.92	Ground Water	NA	2	X	X	X			X	X					
			Soil Gas Flux	5-10	1												
			Soil Gas	NA	1												
			Ground Water	NA	2	X	X										
			Drill Cuttings	12-15	2	X	X										
MW3	423647.43	2246381.06	Ground Water	NA	2	X	X	X				X	X				
MW4 ^e	423553.65	2246261.74	Soil	8-9.5	2	X											X
			Ground Water	NA	2			X									
MW5 ^e	423587.70	2246422.21	Soil	10-13	2	X											
			Ground Water	NA	2	X		X									
MW6	423684.09	2246440.02	Soil	8-9.5	2	X											X
			Ground Water	NA	2	X		X									
MW7 ^e	423660.84	2246486.03	Soil	8-9	2	X	X										
			Ground Water	NA	2	X	X	X				X	X				
MW8	423608.05	2246485.58	Soil	8-9.5	2	X											X
MW9	423553.39	2246443.59	Ground Water	NA	2	X		X									
			Soil	8-9.5	2	X											
MW10 ^e	423622.64	2246447.63	Ground Water	NA	2			X									
			Soil	68-70						X				X		X	X
				9-11	2	X											
MW11 ^e	423687.81	2246530.32	Ground Water	NA	2	X		X									
			Soil	10-12	2	X											
				12-14													X
VW1 ^e	423598.95	2246371.88	Ground Water	NA	2 & 3 ^e			X									
			Soil Gas	5-10	1												
			Soil Gas Flux	NA	1												
			Soil	0-25		X											
				8-9.5	2	X			X	X	X			X		X	
			Ground Water	NA	2		X	X									

^a 1 = TO3: Determination of Volatile Organic Compounds in Ambient Air

^b 2 = SW8020: Purgeable Aromatics

^c This well was sampled during both the 1994 and 1995 sampling events. Only groundwater samples were collected during the 1995 sampling event. Groundwater samples collected during the 1995 sampling event were analyzed for BTEX, PAHs, and electron acceptors.

^d This well was sampled for purgeable organics (SW8020) in 1996

^e This well was sampled for purgeable organics (SW8020) in 1997.

Note: Soil samples collected in 1996 were analyzed for purgeable organics (SW8020) and PNAs (SW8270).

soil gas surveys in the AFCEE protocol documents Test Plan and Technical Protocol for a Field Treatability Test for Bioventing (Hinchee et al., 1992) and Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing: Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential (Downey et al., 1994).

Soil gas samples also were collected and analyzed using the fixed-base analytical US Environmental Protection Agency (EPA) Method TO-3 for specific volatile chemicals (i.e., the BTEX compounds) and total volatile hydrocarbons (TVH). Table 2.2 identifies the field and fixed-base analytical data collected at each soil gas sampling location. Two field duplicate samples of soil gas was collected and analyzed for BTEX and TVH using EPA Method TO-3. All sample handling and field quality assurance (QA)/quality control (QC) procedures for soil gas are specified in Appendix A of the work plan (Parsons ES, 1994a). Analytical results for soil gas samples are summarized in Section 5 and presented in tabular form in Appendix B.

2.2.2 Soil Gas Flux Sampling

Seven soil gas flux samples were collected at four separate locations at Site OT45 to determine if soil contamination could potentially release volatile organic compounds (VOCs) into the atmosphere or nearby buildings and impact ambient air quality. Flux samples were collected at Site OT45 using the equipment and procedures outlined by EPA (1986) in the guidance document, *Measurement of Gaseous Emissions Rates from Land Surfaces Using a Emission Isolation Flux Chamber*. Samples were collected in a flux chamber and transferred to 1-liter SUMMA® canisters for laboratory BTEX and TVH analyses using EPA Method TO-3. One field duplicate soil gas flux sample was collected and analyzed for BTEX and TVH using EPA Method TO-3. If significant emissions are measured, data from the flux chamber can then be combined with a simple dispersion model to identify potential ambient air quality impacts, as described in the work plan (Parsons ES, 1994a).

Soil gas flux samples were collected from a background location (i.e., area upgradient from the site and presumably unaffected by site-related contamination), within the potential source area, and from areas overlying potential dissolved groundwater contamination. The background location (approximately 250 feet southeast of the source area) and all other soil gas flux sample locations are identified on Figure 2.1. All non-background soil gas flux samples were collected adjacent to soil gas sampling locations. Two sampling events were conducted at each location in the immediate site area (i.e. excluding the background point); one event was conducted before the biosparging test, and the other took place near the end of the test. By sampling in this manner, any increase in flux emissions caused by biosparging air injection could be quantified. Analytical results for soil gas flux samples are summarized in Section 5 and presented in tabular form in Appendix B.

2.3 SURFACE AND SUBSURFACE SOIL SAMPLING

Surface and discrete subsurface soil samples were collected in 1994 at Site OT45 to confirm the absence of surface soil contamination and to further delineate the nature and extent of unsaturated and saturated soil contamination at the site. Soil boreholes were drilled with the goals of collecting these samples, expanding the existing

groundwater well network and associated contaminant database, and conducting treatability tests for bioventing and biosparging. Surface soil sampling was accomplished by collecting surface scrapings from the top 6 inches of the soil column at the sampling location. Drilling of all boreholes and installation of wells took place between September 28 and October 6, 1994. All drilling and subsurface soil sampling was accomplished using a hollow-stem auger (HSA) and using the procedures described in the work plan (Parsons ES, 1994a). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). One field replicate, one equipment rinseate blank, and two trip blanks were collected as QC samples for soil at Site OT45.

The three surface soil samples collected at different locations at Site OT45 are listed in Table 2.2 and identified on Figure 2.2. Fourteen subsurface samples were collected from 12 new soil boreholes. Table 2.2 presents the coordinates and sample interval for each of the subsurface soil sampling locations sampled as part of this field test at Site OT45. This table also lists the field and fixed-base analytical methods used to evaluate each of the soil samples. Eight of these 12 new soil boreholes were completed as permanent 2-inch-diameter groundwater monitoring wells (MW-4 through MW-11). Two of the new 12 soil boreholes were completed as soil gas monitoring points (MPA and MPB) for the bioventing pilot test. The remaining 2 soil boreholes were completed as an air injection bioventing test well (VW-1) and a biosparging point (SP-1). Figure 2.2 shows the locations of the subsurface soil sampling locations. Borehole logs, well completion diagrams, and well development records are included in Appendix A. Geological data are presented in Section 3 to characterize the physical setting of the site. Analytical results for soil are used in Section 4 to identify soil COPCs at Site OT45.

In 1996, discrete subsurface soil samples were collected from 12 locations near the at Site OT45 source area to verify the temporal reduction of saturated soil contamination identified during the 1994 risk-based investigation at the site. Soil boreholes were drilled with the goals of collecting these samples in and near the smear zone above and below the water table. Soil sampling was completed between July 27 and August 4, 1996. All soil sampling was accomplished using a Geoprobe® and using the procedures described in the work plan (Parson ES, 1994a). Two field replicates, two equipment reinstatement blanks, one field blank, one water blank, and one trip blank were collected as QC samples for soil sampling at Site OT45.

2.4 GROUNDWATER INVESTIGATIONS

Groundwater samples were collected from previously and newly installed wells to define the nature and extent of source area and downgradient contamination during both the 1994 risk-based investigation and the 1995, 1996, and 1997 groundwater monitoring event. As part of the 1994 risk-based investigation groundwater samples were collected from the 14 different sampling locations listed in Table 2.2 and shown on Figure 2.2. Groundwater samples were collected as a part of the 1995 risk-based investigation from an upgradient location and locations that produced groundwater samples containing elevated concentrations of site-related contamination during the 1994 investigation.

Geochemical data relevant to documenting the potential for biodegradation of dissolved fuel hydrocarbons and quantitatively investigating chemical fate and transport also were collected. Groundwater samples were collected during both sampling events using the procedures described in the work plan (Parsons ES, 1994a). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). One field duplicate, one second-column confirmation sample, and two trip blanks were collected as QC samples for groundwater samples collected at Site OT45 during the 1994 risk-based investigation. One field duplicate, one second-column confirmation sample, and one trip blank were collected at Site OT45 during the 1995 sampling event. One equipment blank and one trip blank were collected at Site OT45 during the 1996 sampling event. One equipment blank and one trip blank were collected at Site OT45 during the 1997 sampling event.

Field and fixed-base analytical data were collected at each groundwater sampling location, as summarized in Table 2.2. All groundwater samples collected in 1995, including QA/QC samples, were analyzed for the BTEX compounds using EPA Method SW8020. EPA Method SW8270 was used to quantify target PAH compounds. Field screening and analytical data were collected in support of demonstrating natural attenuation processes in accordance with the draft AFCEE document *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved Fuel Contamination in Groundwater*, which was prepared by Parsons ES and the EPA's Bioremediation Team at National Risk Management Research Laboratory (NRMRL) (Wiedemeier *et al.*, 1995). Groundwater samples were collected in 1996 and 1997 from near the source area and in a downgradient location and were analyzed for BTEX using EPA Method SW8260. Table 2.1 summarizes the types of field measurements completed at Site OT45 as part of this field test. Hydrogeological characterization data are presented in Section 3 to characterize the physical setting of the site. Fixed-base analytical results for groundwater are used in Section 4 to identify groundwater COPCs.

2.5 AQUIFER TESTING

Aquifer slug tests were conducted at five locations at Site OT45 during the 1994 risk-based investigation to estimate the hydraulic conductivity of the shallow saturated zone. Aquifer slug tests were completed using groundwater monitoring wells MW-4, MW-7, MW-10, and MW-11, and soil gas monitoring point MPA (Figure 2.2). Rising and falling head slug tests were performed at each location. An automatic data recording instrument (Hermit Environmental Data Logger®, In-Situ, Inc. Model SE1000B) was used to record water level changes during the slug tests. Aquifer test results are described in Section 3, and test data and analyses are presented in Appendix C.

2.6 SOURCE REDUCTION FEASIBILITY TESTING

Bioventing is an innovative technology which uses low rates of air injection to supply oxygen to soil bacteria employed in the biodegradation of fuel hydrocarbons. A bioventing pilot test was originally planned for Site OT45 to assess whether this low-cost source reduction technology could be used to remediate contaminated soil if necessary. Two vapor monitoring points and one air injection bioventing test well were

drilled and installed at the site. An air permeability test and an oxygen influence test were completed in accordance with the procedures described in the AFCEE protocol documents (Hinchee *et al.*, 1992; Downey *et al.*, 1994). The results of these tests are presented in Appendix E. An *in situ* respiration test was not performed at this site because initial soil gas oxygen readings at the site were elevated, suggesting that this technology would not be necessary to stimulate aerobic biodegradation of fuel hydrocarbons in vadose zone soil. Boring logs, well and monitoring point completion diagrams, and well development data are included in Appendix A.

Biosparging involves the injection of air into saturated soils with the purpose of promoting volatilization of contaminants from saturated soils and increasing dissolved oxygen (DO) concentrations in groundwater to enhance aerobic biodegradation of fuel hydrocarbons. A single biosparging test well (SP-1) was constructed at Site OT45 as part of the 1994 effort to measure the potential upgradient and downgradient impact of air injection. The goal of the initial test was to measure the increase in the DO concentrations in groundwater created by sparging and to determine the air injection flow rates required for a full-scale biosparging system in the event that this type of remediation is warranted. The results of the biosparging test completed at Site OT45 are included in Appendix E.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of Site OT45 as determined from data collected during previous investigations conducted under the IRP and by Parsons ES as part of the 1994 risk-based investigation. Data incorporated into this section from previous investigations were taken from the RI (ICF, 1993) and the FS (ICF, 1994) reports for Site OT45. A summary of site characterization activities completed by Parsons ES to supplement existing data is presented in Section 2 of this RAP.

3.1 REGIONAL TOPOGRAPHY AND SURFACE WATER HYDROGEOLOGY

Wurtsmith AFB lies on the relatively flat Oscoda Lake plain physiographic district near the eastern shore of Michigan [US Geological Survey (USGS), 1990]. This plain extends approximately 5 miles from the shore of Lake Huron to 80-foot-high bluffs west of the Base. Elevations in this area range from approximately 580 feet above mean sea level (msl) at Lake Huron to 650 feet above msl near the base of the bluffs. The Base and surrounding area have relatively flat topography, with the northern portion of the Base, including Site OT45, sloping very gently to the northeast toward Van Etten Lake. Surface elevations in the vicinity of Site OT45 range from approximately 617 feet above msl at Site OT45 to 588 feet above msl at Van Etten Lake. The topography and major surface water features of the environs near Wurtsmith AFB are shown on Figure 3.1.

The main surface water bodies in the vicinity of Wurtsmith AFB are Dry Creek, Van Etten Lake, Lake Huron, and the Au Sable River. Dry Creek drains a swampy area located west of the Base and flows into Van Etten Lake. Van Etten Lake is fed by the Pine River from the north, and discharges into Van Etten Creek, located at the southeastern end of the lake. Van Etten Creek is a tributary to the Au Sable River, which drains a large area of Michigan west of the Base and discharges into Lake Huron.

There are no major surface water features on Wurtsmith AFB. Because the topography is relatively flat and the soils beneath the Base are sandy, most precipitation infiltrates into the groundwater system. Runoff from paved areas is collected via a storm sewer system, treated at the Wurtsmith AFB sewage treatment plant, and then discharged into settling ponds located near the southern Base boundary (ICF, 1994). Limited amounts of surface water runoff drain northeast into Van Etten Lake and south into the Au Sable River.

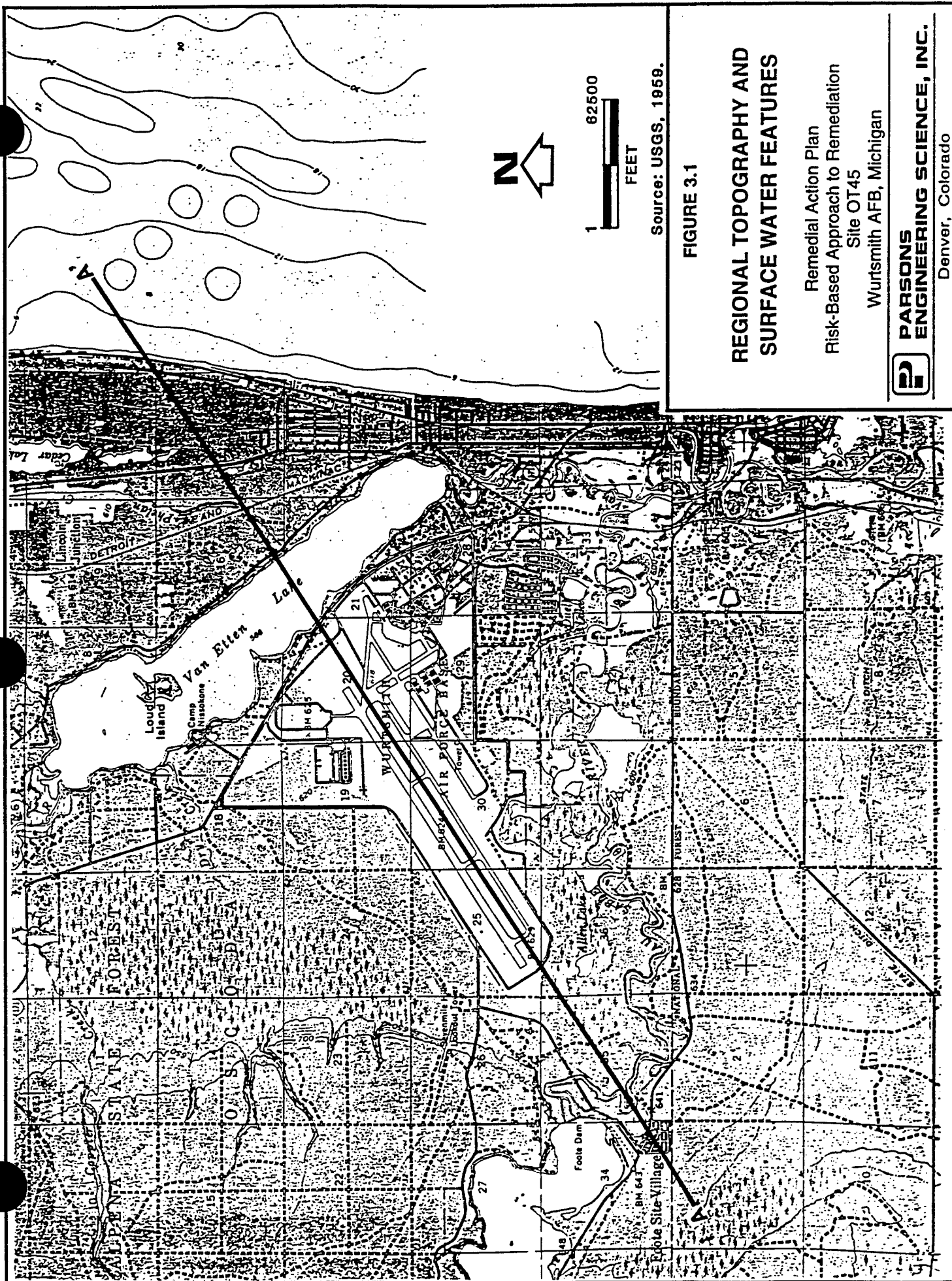


FIGURE 3.1

REGIONAL TOPOGRAPHY AND SURFACE WATER FEATURES

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan



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3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.2.1 Geology

The regional geology consists of approximately 100 to more than 250 feet of unconsolidated glacial, deltaic, and lacustrine deposits overlying the Mississippian-aged Marshall Formation sandstone and Coldwater Shale bedrock (Rama Rao and Alfred, Inc., 1992). A generalized geologic cross section of the Base and adjacent area is presented in Figure 3.2. The location of the cross section A-A' is shown on Figure 3.1. The glacially eroded bedrock surface dips gently from west to east toward Lake Huron, and is overlain by unconsolidated Pleistocene and younger deposits. The unconsolidated deposits, progressing upward from the upper bedrock surface, consist of glacial till; lacustrine silt and clay; and beach, eolian, and alluvial sand and gravel deposits.

Glacial till, consisting of clay-rich silt, sand, and gravel, directly overlies the eroded bedrock surface. Above the glacial till is a continuous layer of silty clay lake sediments ranging in thickness from approximately 95 to more than 200 feet. This silty clay layer forms the lower confining layer for the regional, shallow sand and gravel aquifer. The shallowest deposits, extending from the surface to depths of approximately 30 to 80 feet bgs, consist of fine to very coarse sand with occasional gravelly layers. This interval of alluvial, beach, and eolian deposits forms the regional shallow groundwater aquifer, and is the interval of primary interest for this study.

The Soil Conservation Service has identified the Grayling sand as the primary soil association at Wurtsmith AFB (ICF, 1993). The Grayling series consists of excessively drained soils formed in sandy glaciofluvial sediments, with slopes ranging from 0 to 6 percent.

3.2.2 Hydrogeology

Groundwater occurs predominantly in two aquifers, the shallow sands and deeper glacial deposits, separated by the intervening lacustrine clay and silt layer. The clay and silt layer forms an aquitard between the two water-bearing zones and retards downward migration of contaminant plumes (ICF, 1994).

The surficial sand and gravel deposits comprise the principal aquifer in the vicinity of Wurtsmith AFB. Groundwater occurs at depths ranging from less than 10 feet bgs at places in the western part of the Base, to 25 feet bgs near Van Etten Lake. Groundwater levels fluctuate 1 to 3 feet annually. The shallow aquifer is under unconfined water table conditions. Most groundwater beneath Wurtsmith AFB flows to the northeast, toward Van Etten Lake, and a smaller portion, beneath the southern portion of the Base, flows to the south toward the Au Sable River.

Studies performed by the USGS (1990) in 1979-81 and 1982-85 indicated that average groundwater velocities range from 0.8 foot per day (ft/day) in the eastern part of the Base to 0.3 ft/day in the western part. However, results of the 1982-85 study indicated velocities as high as 5 ft/day at some locations.

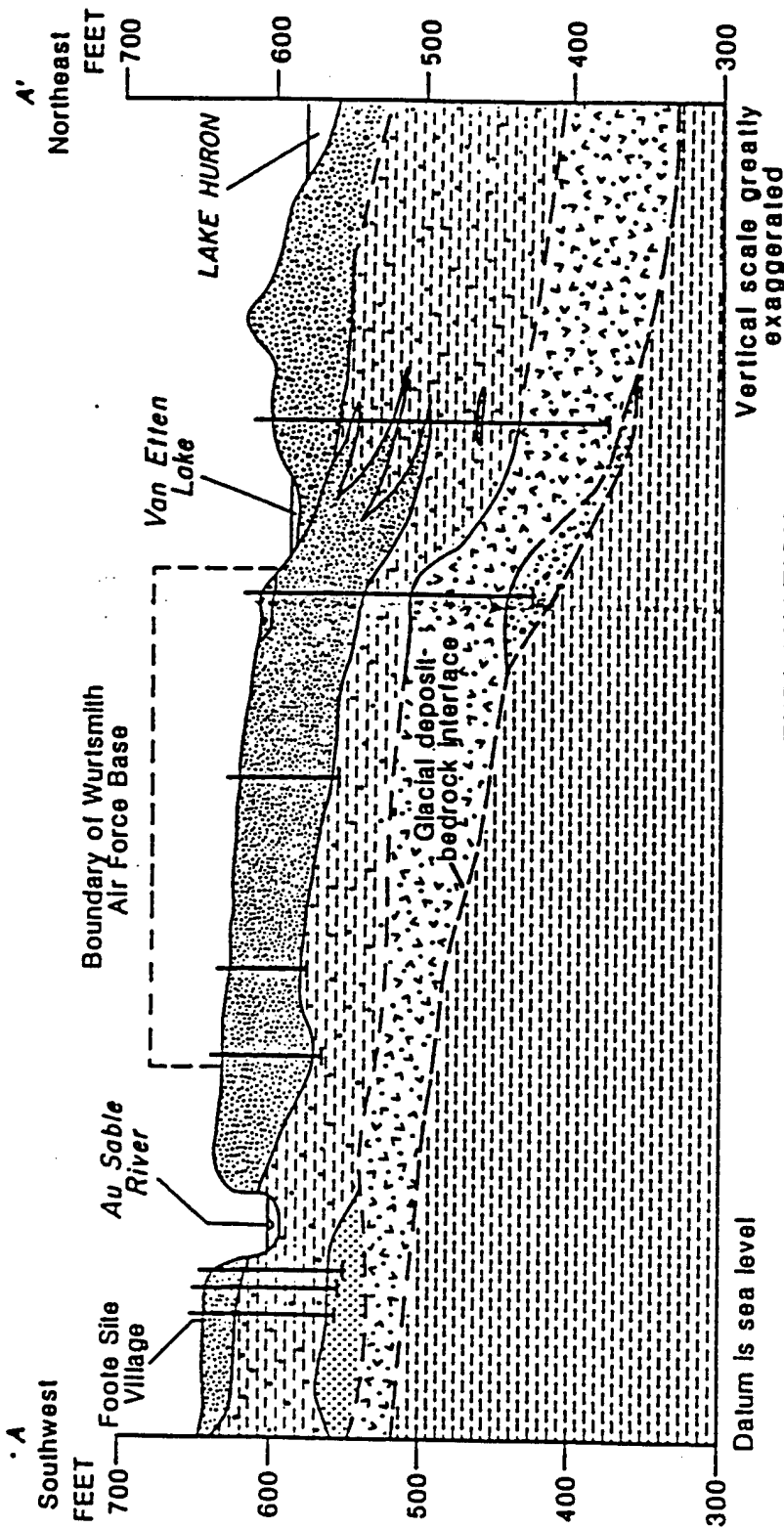


FIGURE 3.2

REGIONAL GEOLOGIC CROSS SECTION A-A'

Remedial Action Plan
 Risk-Based Approach to Remediation
 Site OT45
 Wurtsmith AFB, Michigan



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3.3 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

Site OT45 and the surrounding area is generally flat, with a surface elevation of approximately 620 feet above msl. Surface features at the site include grass and wooded areas; concrete, asphalt, crushed rock, and steel mesh driveways and parking areas; an office building; and several storage buildings. The northern part of the Base, including Site OT45, slopes very gently to the northeast toward Van Etten Lake, with an average slope of approximately 0.003 foot per foot (ft/ft).

Because of the flat topography and well-drained, sandy soils, most precipitation infiltrates the sandy soils, and as a result, there are no well-developed surface drainage features. There are no bodies of surface water in the immediate vicinity of Site OT45. The bodies of surface water closest to the site are Dry Creek (1,400 feet north) and Van Etten Lake (3,000 feet northeast).

3.4 SITE GEOLOGY AND HYDROGEOLOGY

The vadose zone and shallow aquifer system at Site OT45 were characterized by Parsons ES as part of the initial risk-based investigation during September and October 1994. Data collected as part of this field test were used to supplement geologic and hydrogeologic data collected under the IRP by ICF (1993).

3.4.1 Lithology and Stratigraphic Relationships

Drilling and soil sampling results show that the deposits from the surface to a depth of approximately 70 feet bgs consist predominantly of medium- to very coarse-grained sand overlying slightly silty clay. Figure 3.3 shows the location of cross section B-B' (Figure 3.4), oriented through the center of the source area and parallel to the direction of groundwater flow. The sand deposits are the Pleistocene and younger beach, eolian, and alluvial deposits previously discussed. The sand deposits are poorly to moderately sorted and generally increase in grain size with depth. Occasional gravelly layers were encountered within the sand, with the highest percentage of gravel occurring just above the underlying silty clay layer. A few, thin (generally less than 1 inch thick) silt and silty clay layers were encountered in the upper 20 feet of the sand. One laterally extensive silty clay layer (less than 2 inches thick) was encountered in most soil boreholes at or just below the top of the saturated zone. The sand is a light to medium, yellow- or orange-brown color with iron staining in the upper 10 to 15 feet. In the source area, fuel contamination and biological activity have stained the sand a medium gray to gray-brown.

A clay layer was encountered at depths of between 66 and 70 feet bgs in three soil boreholes (MW-2, MW-3, and MW-10). This clay appears to be the top of the regionally continuous lacustrine clay layer that overlies the glacial till. No soil boreholes were drilled deeper than the top of the clay layer at a depth of 70 feet bgs. The clay layer is a gray, very stiff to hard, silty clay. The hard texture and high clay content of the clay layer indicates very low permeability to groundwater flow.

LEGEND

BUILDING

BUILDING NUMBER

FENCE

FORMER UST LOCATION

GROUNDWATER MONITORING WELL (INSTALLED 1992/1993)

GROUNDWATER MONITORING WELL (INSTALLED 1994)

VENT WELL

VAPOR MONITORING POINT

AIR SPARGING POINT

SAMPLING LOCATION

MW-8

B' B

LOCATION OF HYDROGEOLOGIC CROSS SECTION (FIG 3.4)



FIGURE 3.3

LOCATION OF HYDROGEOLOGIC CROSS SECTION B-B' FOR SITE OT45

Remedial Action Plan

Risk-Based Approach to Remediation

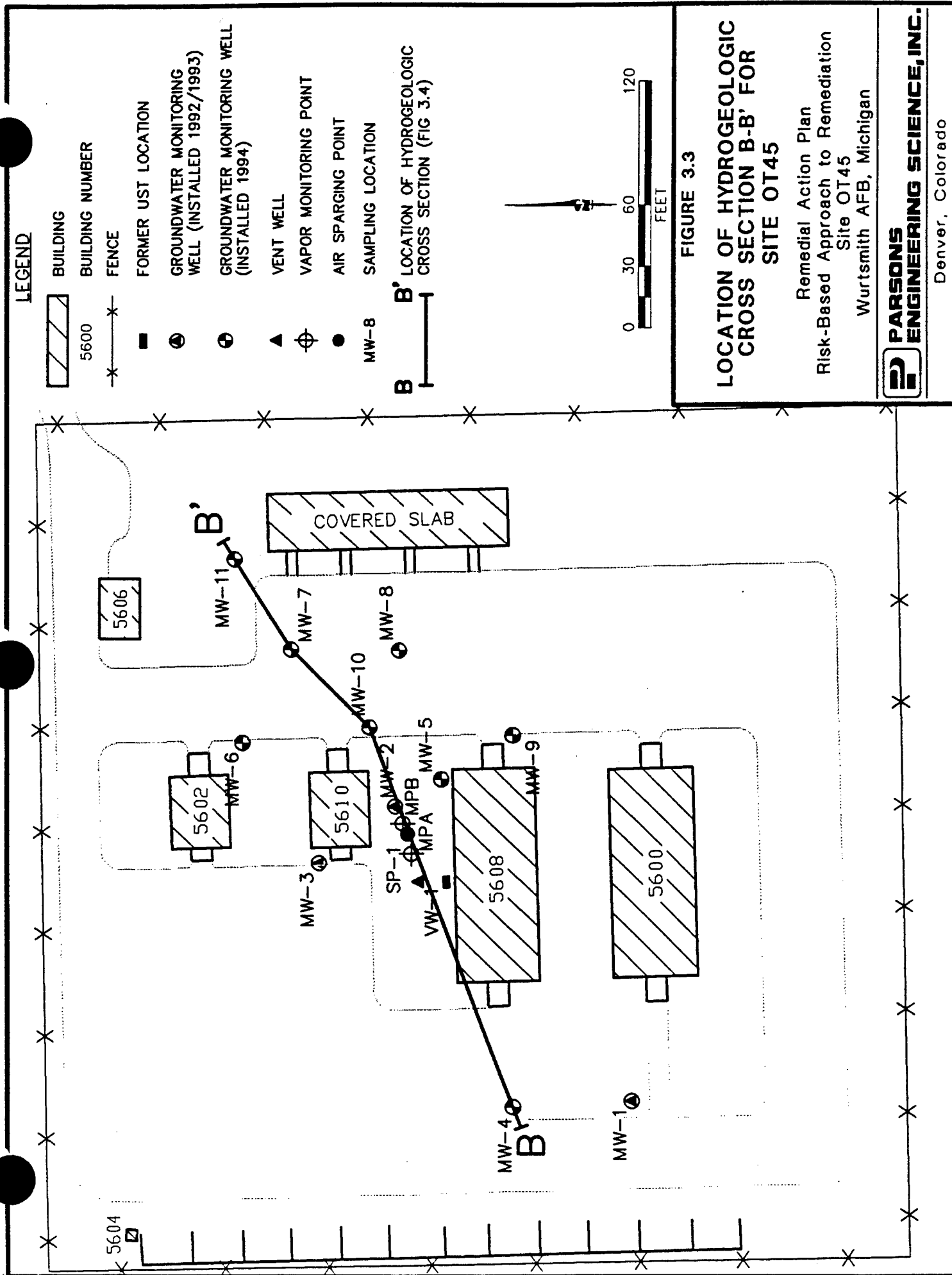
Site OT45

Wurtsmith AFB, Michigan



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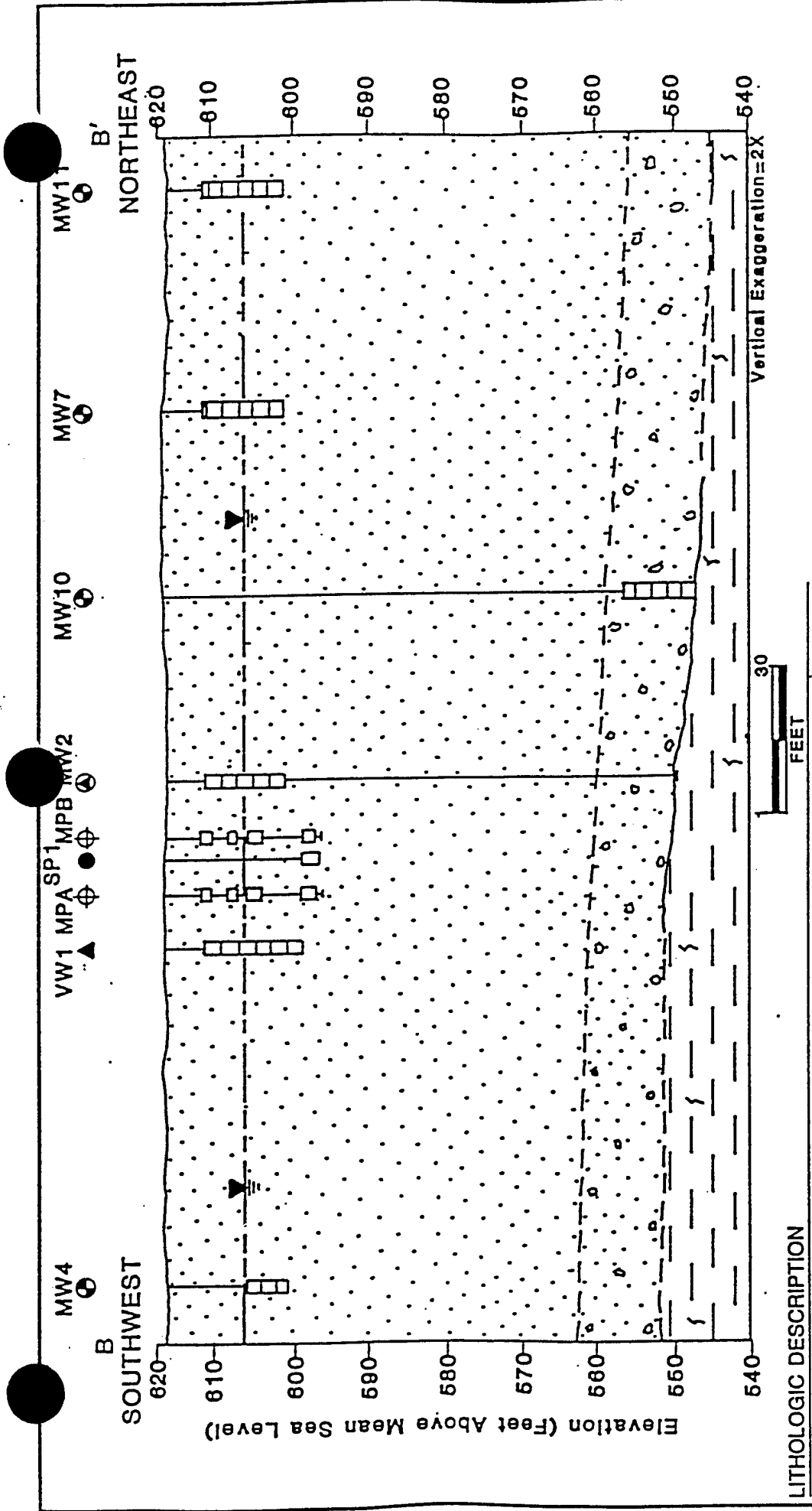


FIGURE 3.4

HYDROGEOLOGIC CROSS SECTION B-B'

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Site OT45
Wurtsmith AFB, Michigan

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LITHOLOGIC DESCRIPTION	
	SAND
	GRAVELLY SAND WITH CLAY SENSES
	SILTY CLAY
LEGEND	
	GROUNDWATER MONITORING WELL (1994)
	VENT WELL
	AIR SPARGING POINT
	VAPOR MONITORING POINT
	GROUNDWATER MONITORING WELL (1992/1993)

	GROUNDWATER ELEVATION;
	DASHED WHERE INFERRED
	GEOLOGIC CONTACT, DASHED WHERE INFERRED
	SCREENED INTERVAL

3.4.2 Site Hydrogeology

The water table depth at the time of well installation was approximately 10 feet bgs. Groundwater elevation data collected in October 1994 were used to construct the map of the approximate groundwater surface at Site OT45 presented in Figure 3.5. According to historic groundwater elevation data, water table elevations fluctuate approximately 1 to 3 feet annually, depending on precipitation (USGS, 1990).

Based on groundwater levels measured in site wells on October 21, 1994, shallow groundwater flow is generally to the east-northeast toward Van Etten Lake with a hydraulic gradient of 0.0042 ft/ft. The gradient appears to be uniform across the site.

The average hydraulic conductivity in the upper portion of the shallow aquifer was determined to be 110 ft/day based on slug tests performed at MPA, MW-4, MW-7, and MW-11. Hydraulic conductivity values ranged from 81 ft/day at MPA to 147 ft/day at MW-7. The average groundwater linear velocity in the shallow portion of the aquifer was calculated to be approximately 1.3 ft/day based on an average hydraulic conductivity of 110 ft/day, a gradient of 0.0042 ft/ft, and an assumed porosity of 0.35. The hydraulic conductivity in the deep portion of the shallow aquifer was determined to be 48 ft/day based on slug tests performed at MW-10. The groundwater linear velocity in the deep portion of the aquifer was determined to be 0.58 ft/day based on a hydraulic conductivity of 48 ft/day, an assumed porosity of 0.35, and assuming a hydraulic gradient of 0.0042 ft/ft (i.e., the gradient for the shallow portion of the aquifer).

3.5 CLIMATOLOGICAL CHARACTERISTICS

The climate at Wurtsmith AFB is humid with cold winters and short, mild summers. Mean monthly temperatures range from 21 degrees Fahrenheit (°F) in January to 68°F in July, with a mean annual temperature of 44°F. The maximum recorded temperature is 102°F, and the minimum is -22°F. Average yearly precipitation is about 30 inches, including approximately 50 inches of snow. The highest monthly precipitation (3.1 inches) normally occurs in June, and the lowest (1.6 inches) occurs in January. The prevailing wind is from the east (Lake Huron).

3.6 LAND USE

3.6.1 Site Access

Site OT45 is located near the center of the former DRMO yard, which is completely enclosed by an 8-foot-high chain-link fence topped with barbed wire. The only site access is through a locked gate located along the northern fence line near the northwest corner of the site. The interior areas of the DRMO compound are accessed via gravel driveways and staging areas. The site area is within the boundaries of Wurtsmith AFB, which is completely enclosed by a similar chain-link fence. The main access to the Base is through the main gate located on County Road F-41. The guard station at the main gate is manned 24 hours per day, 7 days per week.

LEGEND

BUILDING

BUILDING NUMBER

FENCE

FORMER UST LOCATION

GROUNDWATER MONITORING WELL (INSTALLED 1992/1993)

GROUNDWATER MONITORING WELL (INSTALLED 1994)

VENT WELL

VAPOR MONITORING POINT

AIR SPARGING POINT

LINE OF EQUAL ESTIMATED GROUNDWATER ELEVATION (FEET ABOVE MSL)

GROUNDWATER FLOW DIRECTION



5600



FIGURE 3.5

GROUNDWATER SURFACE ELEVATION MAP OT45 OCTOBER 21, 1994

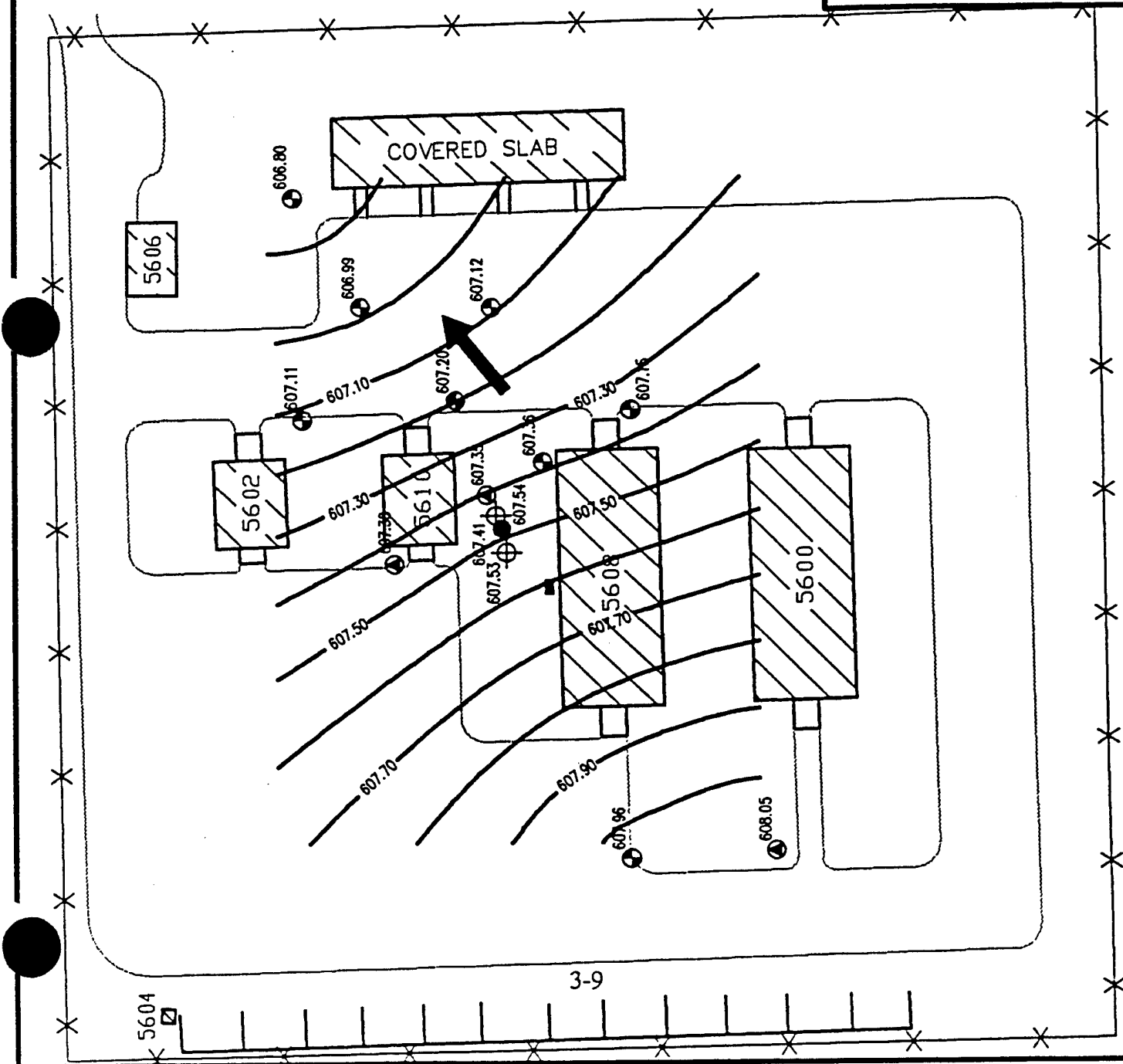
Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45

Wurtsmith AFB, Michigan



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3.6.2 Current Land Use

Site OT45, the former DRMO yard, has effectively been an unused property since the heating oil UST was removed in May 1992. However, due to the site's proximity to other facilities in the northern part of the Base, the current land use at Site OT45 could be conservatively classified as industrial. The site has been made available for several short-term RIs and treatability studies to develop data to be used to support land use/property disposal decisions.

Parcels of land immediately adjacent to Site OT45 to the north and northeast are owned by either the federal government or the State of Michigan. These parcels are zoned as forestry land, and are currently used as public facilities and/or recreation areas. The only occupied building in the vicinity of Site OT45 is the MDEQ field office located approximately 400 feet to the northeast (across County Road F-41) from the Base boundary, and 900 feet from Building 5608 (former UST location). The only other human habitation in the downgradient groundwater direction is at Camp Nissokone, a YMCA camp on Van Etten Lake, located approximately 2,500 feet from Site OT45. The nearest residential population is located approximately 3,000 feet north of Site OT45 near Van Etten Lake.

3.6.3 Proposed Land Use

Wurtsmith AFB was placed on the 1991 Department of Defense Base Closure and Realignment Commission's list for closure. Wurtsmith AFB was officially closed on June 30, 1993. The Air Force plans to dispose of excess and surplus real property and facilities as soon as environmental restoration is achieved, and pursuant to specific federal property disposal regulations and local community reuse plans (US Air Force, 1993). The Air Force is prepared to execute interim or long-term leases that provide maximum control over the property for some portions of the Base, and some restrictions may be necessary to ensure the protection of human health.

The Air Force, as part of the land disposal and reuse process, has been required to consult with the governor of Michigan and heads of local governments while developing conceptual property reuse plans for Wurtsmith AFB. The redevelopment agency and advisory group, authorized in January 1992 to develop potential reuse options for Wurtsmith AFB, is the Wurtsmith Area Economic Adjustment Commission (WAEAC). WAEAC is composed of a Coordinating Committee (whose membership consists of one representative each from the Boards of Trustees of Oscoda, Au Sable, and Greenbush Townships; one each from the Boards of Commissioners of Iosco and Alcona Counties; and two from the Oscoda community at large), community advisory committees, and a management and liaison office.

WAEAC makes land use recommendations to the Oscoda Township Board of Trustees, who have the authority to make decisions regarding land use options. Any recommendations from the Oscoda Township Board of Trustees on land use related to Wurtsmith AFB property are referred to the Air Force Base Conversion Agency (AFBCA), which acts as the holding agency for receipt, maintenance, and disposition of Base property under the authority of the Michigan Department of Commerce. WAEAC and the Oscoda Township Board of Trustees selected The Pathfinders, Inc. to develop a final land reuse plan for Wurtsmith AFB property. The final plan (US Air

Force, 1993) was approved by the Oscoda Township Board of Trustees in December 1992.

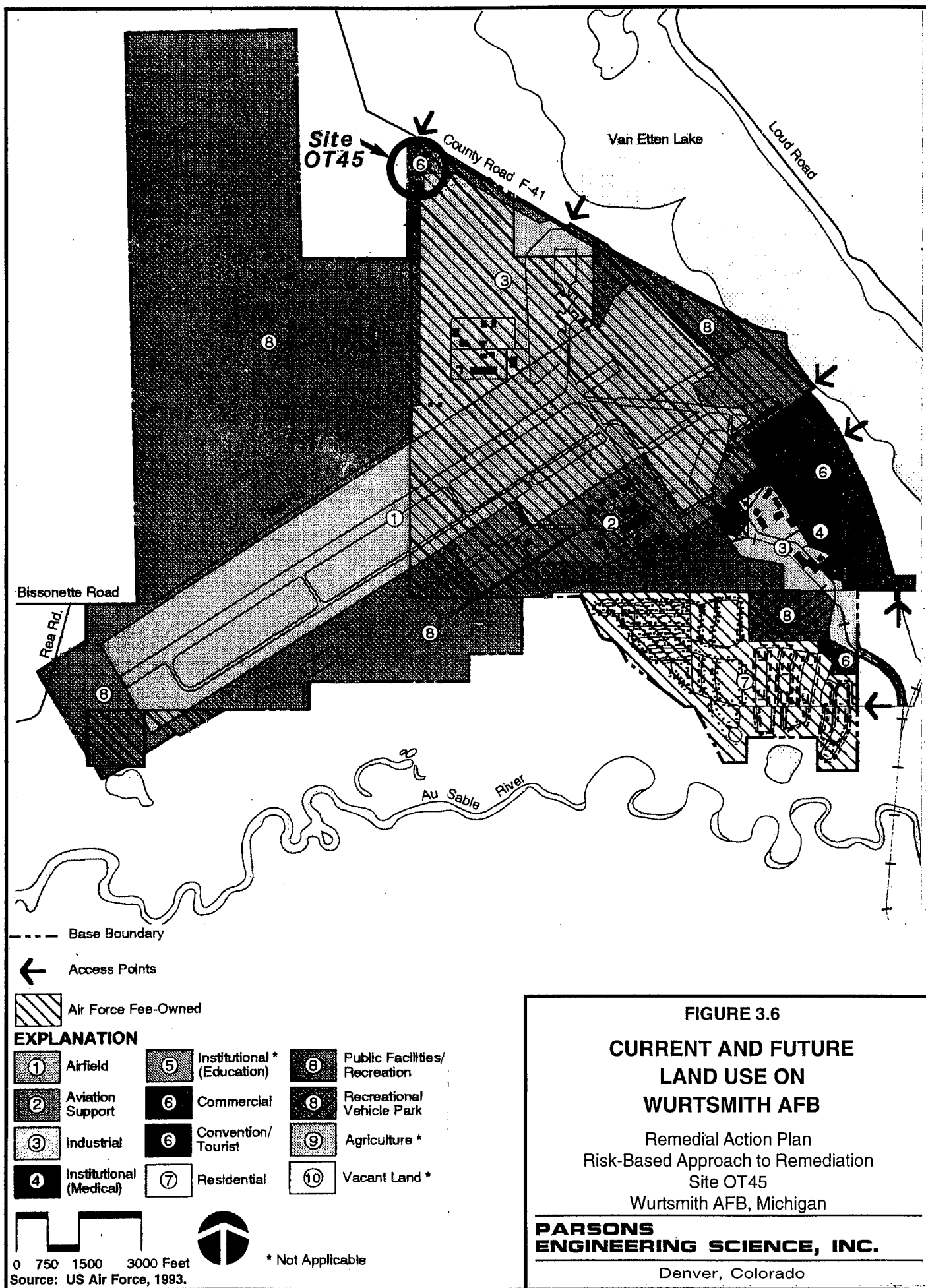
Based on the approved final Environmental Impact Statement, and land reuse plan, Site OT45 is proposed to be reused as a commercial property dedicated to convention/tourist services (US Air Force, 1993). The planned use of this site will result in unrestricted public access, but actual occupancy will be nonresidential, intermittent in frequency, and of short duration. Most of the proposed activities will be conducted indoors, and outdoors activities will be minimal. Properties immediately to the southeast and south are proposed to be reused as industrial property, specifically light industrial, warehousing, and light manufacturing. These workers could spend the majority of their workdays outside, although most primary duties will be restricted to buildings and paved areas. Figures 3.6 and 3.7 show the proposed land use for Site OT45 and adjacent environs as described in the *Preliminary Final Environmental Impact Statement: Disposal and Reuse of Wurtsmith Air Force Base, Michigan* (US Air Force, 1993).

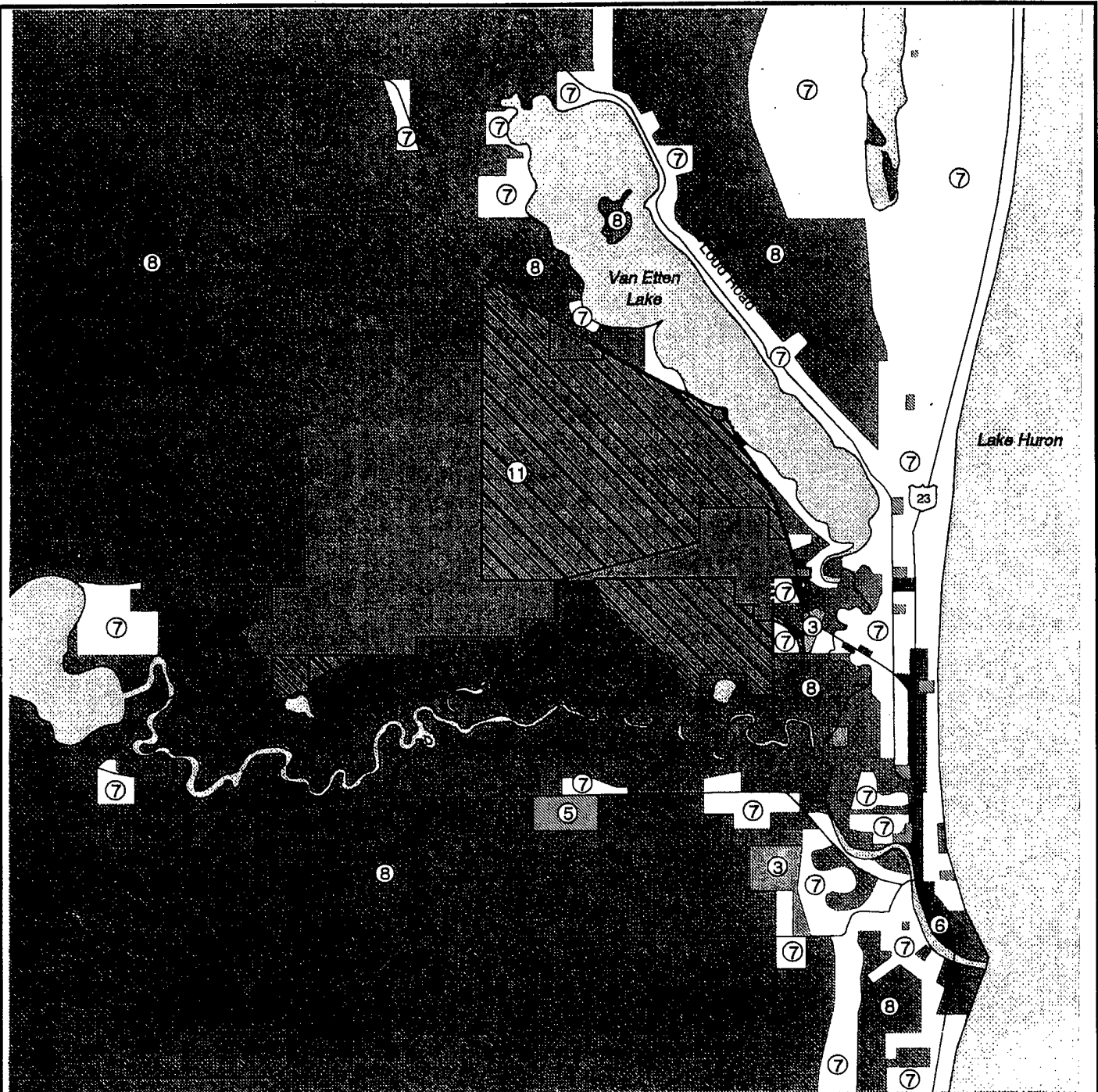
3.6.4 Groundwater Use

Two separate water supply systems are available to meet potable and nonpotable off-Base water demands. The Oscoda Township water supply serves Oscoda and Au Sable using groundwater drawn from a shallow-aquifer well field located on the south side of the Au Sable River, which is south of the Base. Shallow groundwater is used to meet potable water demands in this area because the groundwater in the hydrogeologic units beneath the silty clay aquitard generally has high dissolved solids or high chloride concentrations, thus making it an unsuitable drinking water supply. The East Tawas water system, which serves Tawas City, the city of East Tawas, and a part of Baldwin Township, draws its water from Lake Huron (Figure 1.1).

The water supply for Base facilities is currently derived from two on-Base groundwater wells drilled and installed within the shallow groundwater aquifer. These wells are located over 8,000 feet from Site OT45 and are not impacted by the limited groundwater contamination at OT45. Groundwater use restrictions have been imposed on areas where shallow groundwater contamination exists or is suspected to exist. All current lease transfers or future deed transfers on Wurtsmith AFB include prohibitions on groundwater use in potentially contaminated areas. Extracted groundwater is currently treated via chlorination before it is routed to the Base water distribution system.

The Base system is scheduled to be deactivated in 1996 and replaced with the local water supply systems. Therefore, there is no need (or plan) to continue extraction of groundwater from the shallow aquifer at Site OT45 (or any area on-Base) to meet future water supply demands. However, the Michigan Department of Public Health has indicated that the existing on-Base wells could be used after closure, provided that extensive testing is conducted to monitor water quality (US Air Force, 1993). Previous site investigations have identified an abandoned, low-capacity pumping well within the Site OT45 fenced area. The proper sealing of this well is recommended in the selected remedial alternative.





EXPLANATION

① Airfield*	⑤ Institutional (Education)	⑨ Agriculture *
② Aviation Support*	⑥ Commercial	⑩ Vacant Land *
③ Industrial	⑦ Residential	⑪ Base Property
④ Institutional (Medical)*	⑧ Public Facilities/ Recreation	▨ Air Force Fee-Owned
0 1375 2750 5500 Feet	⬆	--- Base Boundary
		* Not Applicable

Source: US Air Force, 1993.

FIGURE 3.7

CURRENT LAND USE SURROUNDING WURTSMITH AFB

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan

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SECTION 4

TIER 1 ANALYSIS AND IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN

This section provides an overview of the regulatory requirements for implementing a risk-based approach at Site OT45. Figure 4.1 is a conceptual site model (CSM) that has been developed for Site OT45 as a means of selecting appropriate generic cleanup criteria to be used to identify COPCs in affected site media. The COPCs for Site OT45 are identified during this Tier 1 or screening-level analysis by comparing maximum detected contaminant concentrations to the applicable MDEQ (1995a and 1995b) generic cleanup criteria. Those chemicals that exceed the generic cleanup criteria are identified as COPCs. The nature and extent of the COPCs are characterized in Section 5, and these chemicals are the focus of the brief chemical fate assessment evaluation presented in Section 6 of this RAP.

4.1 OVERVIEW OF THE TIERED APPROACH

Through Part 201 of PA 451 and associated guidance materials, the MDEQ (1994a, 1995a, and 1995b) has issued generic cleanup criteria for different land use scenarios for petroleum analytes in various media. These generic cleanup criteria are nonsite-specific in that they are based on simple algorithms and reasonable maximum exposure (RME) assumptions for the specified land use. Generic cleanup criteria for soil and groundwater are presented in a "look-up" table for industrial and commercial subcategory IV (MDEQ, 1995a) land use scenarios. The MDEQ anticipates that RAPs based on the generic approach (i.e., use of the generic cleanup criteria as the target remedial goals) will require less effort to prepare, review, and approve (MDEQ, 1995a). However, the MDEQ also provides for the preparation, review, and approval of RAPs based on a more site-specific evaluation to identify the appropriate level of remediation warranted at a particular site to protect human and ecological receptors. This tiered approach to determining potential risk reduction requirements is analogous to the approach set forth in the ASTM (1995) *Standard Guide for Risk-Based Corrective Actions Applied at Petroleum Release Sites*. The generic cleanup approach developed by the MDEQ is similar to ASTM's Tier 1 or nonsite-specific evaluation; the site-specific approach described by the MDEQ is similar to ASTM's Tier 2 or site-specific evaluation.

The MDEQ-defined generic cleanup criteria are first used as a screening tool to focus any comprehensive remedial action evaluation on only those compounds and environmental media that could potentially pose a threat to human health or the environment. If no measured site concentration exceeds the applicable generic cleanup criteria, no type of remediation is warranted and a streamlined RAP documenting compliance with the generic cleanup standards can be prepared. If measured site

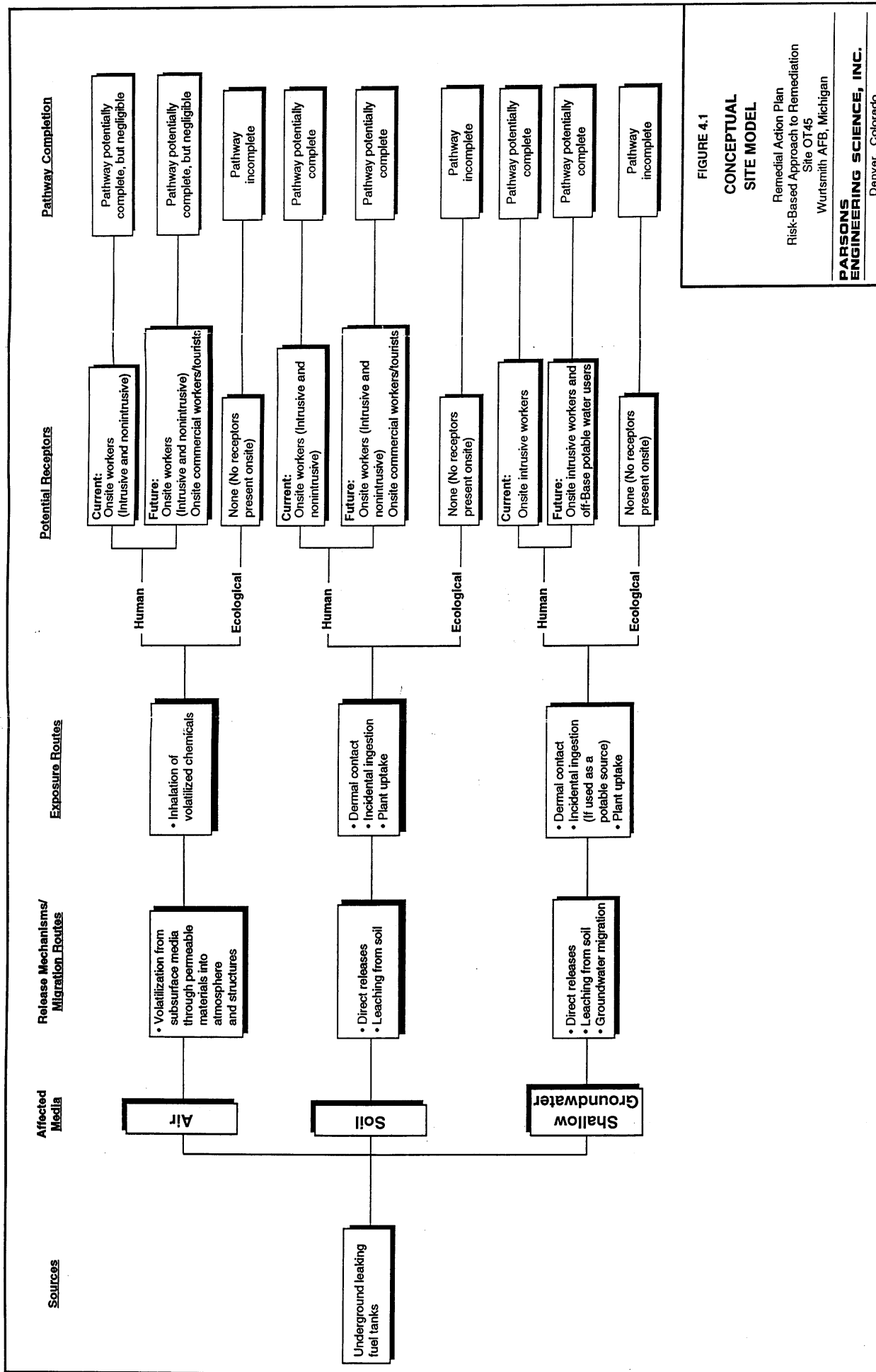


FIGURE 4.1
CONCEPTUAL
SITE MODEL
 Remedial Action Plan
 Risk-Based Approach to Remediation
 Site OT45
 Wurtsmith AFB, Michigan
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concentrations exceed the applicable generic cleanup criteria, however, a more site-specific evaluation can be conducted to determine whether (1) any actual unacceptable exposures could occur, and (2) what effect natural chemical attenuation processes would have on minimizing the potential for receptor exposure and reducing contaminant persistence, mass, mobility, and toxicity.

Section 4.2 describes the CSM for Site OT45 that is used to help identify the applicable generic cleanup criteria. Section 4.3 presents the methodology used to identify the applicable generic cleanup criteria for this site, and Section 4.4 summarizes the analytes with site concentrations that exceed the selected generic cleanup criteria (i.e., the site COPCs).

4.2 PRELIMINARY CONCEPTUAL SITE MODEL REVIEW

Figure 4.1 presents the CSM developed for Site OT45. The model presented in Figure 4.1 was developed using data collected during the previous site investigations and based on a review of potential receptors and feasible exposure scenarios. The purpose of developing a CSM is to evaluate available information on site characteristics, including:

- Potential contaminant sources;
- Media affected by contaminant releases;
- Mechanisms of contaminant release (e.g., leaching and volatilization);
- Potential human and ecological receptors;
- Potential receptor exposure points based on conservative, reasonable land use assumptions; and
- Routes of possible receptor exposure (e.g., inhalation, ingestion, or dermal contact).

The CSM has been constructed to identify potentially completed receptor exposure pathways. For an exposure pathway to be completed, there must be a contaminant source, a release mechanism and a contaminant migration pathway, an exposure point, a receptor, and an exposure route. If any of these components is missing, the pathway is incomplete, and receptors are not at risk from exposure to site contaminants.

Based on the CSM, air, soil, and shallow groundwater represent the potentially affected physical media at Site OT45 (Figure 4.1). No surface water is present within approximately 1,400 feet of the site, and available data indicate that no contaminant migration pathway from the site to surface water, either through overland runoff or groundwater discharge, is completed. Therefore, surface water is not considered to be an affected medium.

Wurtsmith AFB was officially closed on June 30, 1993. Based on the approved final land reuse plan, Site OT45 has been set aside for potential commercial development (convention center) (US Air Force, 1993). Surrounding land use is

primarily industrial. The site was formerly used as a storage and staging area for DRMO operations, and is currently vacant except for intermittent remediation investigations and efforts. Site OT45 is located about 200 feet upgradient from the nearest Base property boundary, which borders US government and State of Michigan parcels that are zoned forestry land, and are currently used as recreation areas/public facilities (Figure 3.6). Additionally, there are some residences outside of the Base boundary near Van Etten Lake, which is approximately 3,000 feet downgradient from the site.

Considering the land use plans for this site and the limited activities currently taking place in the area, the site will continue to be maintained as an industrial area until completion of any convention/tourist center. After completion of the convention/tourist facilities, site activities are anticipated to be similar to the activities and exposure assumptions for the commercial subcategory IV site described in Operational Memorandum #14 (MDEQ, 1995b).

Based on these land use assumptions, onsite industrial workers and eventually commercial subcategory IV workers and visitor populations are the only current or likely future onsite human receptors. As there are no long-term plans for the use of groundwater from the shallow affected aquifer, and as depth to groundwater at the site is about 10 feet bgs, current onsite workers could reasonably be exposed only to impacted surface soils and to air potentially affected by chemicals volatilizing from subsurface media in the absence of any deep (10 feet bgs or more) excavation activities. However, future workers could also include those involved in construction or other intrusive maintenance activities. Therefore, future onsite workers could be exposed to contaminants in surface and subsurface soils, air, and, conservatively, shallow groundwater. No exposure pathways to current offsite receptors are believed to be completed. In light of the existence of off-Base potable water wells completed in the affected shallow aquifer, future offsite human receptors could potentially be exposed to site contaminants through ingestion or inhalation of, or dermal contact with, contaminants in groundwater extracted for potable use (Figure 4.1). However, the nearest residential area using shallow groundwater is over 3,000 feet from the site, and downgradient contaminant migration from the site to date is less than 200 feet.

Although numerous plant and wildlife species are known to occur on and near Wurtsmith AFB, the absence of contaminant migration pathways in media to which wildlife or plants could readily be exposed (e.g., surface water and shallow soils) indicates that no ecological receptors are likely to be exposed to contaminants in site media under current or anticipated future land uses.

4.3 TIER 1 SCREENING ANALYSIS

It is the intention of the Air Force to demonstrate attainment of Tier 1 nonsite-specific cleanup criteria at Site OT45. The detected chemicals must first be compared to appropriate generic cleanup criteria to identify the final remedial requirements for this site.

4.3.1 Selection of Appropriate Generic Cleanup Criteria

The MDEQ (1995a and 1995b) generic cleanup criteria are based on 1) analyte-specific toxicity data; 2) an exposure-pathway-specific target carcinogenic risk limit of 10^{-5} (i.e., there is an added lifetime cancer risk for people near the site of one additional cancer above the normal background level in 100,000 people) and a noncancer hazard quotient of less than or equal to 1; and 3) RME assumptions appropriate for the specific receptor group. Regarding the second criterion, note that USEPA (1994) states that cancer occurs randomly within any population in the United States at a rate of about one in three persons (30-35 percent), and this is defined as the "normal background cancer level." Regarding the third criterion, the degree to which the generic exposure assumptions are representative of the activities of human receptors at a specific site depends on site-specific conditions and actual land use and exposure controls.

Based on the land use assumptions and potential receptors reviewed in Section 4.2, the MDEQ (1995b) generic industrial and commercial subcategory IV cleanup criteria were selected as the applicable Tier 1 or screening values for Site OT45. The general characteristics of these land use categories, as defined by MDEQ (1995b), are similar to those encountered at the site. The site is currently unoccupied, and access to the site is reliably restricted. The current zoning of the site is industrial, and the planned future land use for the site is commercial for convention/tourist services. Figures 3.6 and 3.7 depict the current and anticipated land uses at Site OT45 and adjacent environs.

The water supply for Base facilities is derived from two on-Base groundwater wells drilled and installed within the shallow aquifer. Extracted groundwater is treated using chlorination before it is routed to the Base water distribution system. Neither of these groundwater wells is located within 8,000 feet of Site OT45. This on-Base water supply system is to be deactivated in 1996 and replaced with local water supply systems. This means that groundwater from the shallow aquifer underlying or immediately downgradient from Site OT45 is not and will not be extracted to meet future potable water supply demands.

However, because shallow groundwater has been extracted from on-Base locations and used as a source of potable water, and because shallow groundwater is withdrawn from two well fields located south of the Au Sable River and just north of the southeastern shore of Van Etten Lake (both locations are up- and cross-gradient from Site OT45) to meet the Oscoda Township potable water supply, the shallow groundwater could be classified as a generic potential source of offsite drinking water (MDEQ, 1995a). This means attainment of generic residential groundwater cleanup criteria will not be necessary at Site OT45 (due to commercial/industrial land use), but attainment of generic residential cleanup criteria at the property boundary may be required to protect offsite groundwater resources. The screening-level chemical fate and transport assessment (Section 6) is part of a more comprehensive analysis to ascertain whether site-related contamination could migrate at concentrations above the generic residential cleanup criteria to site or property boundaries.

4.3.1.1 Generic Cleanup Criteria for Soil

The MDEQ (1995b) industrial cleanup criteria for the fuel-related hydrocarbons detected in soils at Site OT45 are presented in Table 4.1. These health-based generic cleanup criteria for soils were developed to protect onsite industrial and commercial workers from long-term, systemic health effects associated with incidental ingestion of and direct contact with chemical contamination in soils. These generic cleanup criteria are best applied to shallow soils (i.e., the nonintrusive worker scenario). The MDEQ (1995b) guidance states that it is possible to develop alternate cleanup criteria for deeper soils that would be protective of receptors engaged in more intrusive activities (e.g., excavation) at the site. However, rather than modify the generic algorithms developed by the MDEQ for soil criteria, the industrial and commercial subcategory IV health-based soil cleanup criteria were compared against all site soil sampling data collected at the site, regardless of sampling depth. This conservative approach to identifying contaminants that may pose potential unacceptable risks to onsite nonintrusive or intrusive workers assumes that workers and/or patrons/visitors are exposed to the maximum concentrations of site-related contaminants throughout the exposure duration. The algorithms and assumptions used to calculate the health-based soil cleanup criteria are presented in MDEQ's (1995b) Operational Memorandum #14, Revision 2.

Generic soil industrial cleanup criteria that are protective of groundwater quality (i.e., that ensure groundwater will remain suitable for potable use) also have been developed by the MDEQ. These soil cleanup criteria are "back calculated" by multiplying the generic groundwater cleanup criteria by a factor of 20 (Section 4.3.1.3; Table 4.2) to determine the allowable contaminant leachate concentrations that could be released from soils into underlying groundwater without causing exceedances of applicable groundwater cleanup criteria.

This general broad-based methodology for calculation of generic soil leaching criteria may be overly protective when applied to contaminated saturated soils at Site OT45. Groundwater is not currently extracted or planned to be extracted from the shallow aquifer underlying Site OT45 to support any type of potable water demands. Therefore, onsite workers are not likely to ingest contaminated groundwater on a routine basis. Some incidental ingestion could occur by intrusive construction workers, but the rate of incidental ingestion is likely to be far less than the rate of ingestion assuming groundwater is used as a potable source. Therefore, the methodology for determining generic soil leaching criteria will generally yield overly conservative allowable soil concentrations to protect industrial/commercial subcategory IV workers at Site OT45.

4.3.1.2 Generic Cleanup Criteria for Groundwater

The range of generic industrial/commercial cleanup criteria for the fuel-related compounds detected in site groundwater, as defined by MDEQ (1995b), are presented in Table 4.2. Additionally, residential health-based and aesthetic groundwater cleanup criteria have been included in the Tier 1 screening criteria (Table 4.2) to determine which chemicals, if any, are present at concentrations exceeding levels that are protective of any potential offsite receptors. For the Tier 1 analysis, chemical-specific groundwater cleanup criteria for industrial/commercial sites can be defined as either (1)

TABLE 4.1
GENERIC CLEANUP CRITERIA FOR SOILS AT COMMERCIAL/INDUSTRIAL SITES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Detected Analytes	Commercial Subcategory IV Direct Contact ^{a/}	Industrial Direct Contact ^{a/}	Commercial/Industrial Soil Leaching (20 Times GW Conc.) ^{b/}	Units
1,2,3-Trimethylbenzene	-- ^{c/}	--	--	µg/kg
1,2,4-Trimethylbenzene	8.50E+06	3.10E+06	1,720	µg/kg
1,3,5-Trimethylbenzene	6.40E+06	2.30E+06	1,300	µg/kg
2-Methylnaphthalene	5.40E+08	1.60E+08	15,000	µg/kg
Acenaphthene	1.00E+09	8.18E+08	76,000	µg/kg
Benzo(a)anthracene	6.80E+05	2.10E+05	96	µg/kg
Benzo(a)pyrene	6.80E+04	2.10E+04	59	µg/kg
Benzo(b)fluoranthene	6.80E+05	2.10E+05	96	µg/kg
Benzo(g,h,i)perylene	5.40E+07	1.60E+07	1,500	µg/kg
Benzo(k)fluoranthene	6.80E+06	2.10E+06	960	µg/kg
Chrysene	6.80E+07	2.10E+07	9,600	µg/kg
Dibenzofuran	--	--	--	µg/kg
Ethylbenzene	2.00E+08	7.20E+07	1,480	µg/kg
Fluoranthene	1.00E+09	5.40E+08	50,000	µg/kg
Fluorene	1.00E+09	5.40E+08	50,000	µg/kg
Indeno(1,2,3-cd)pyrene	6.80E+05	2.10E+05	96	µg/kg
Naphthalene	5.40E+08	1.60E+08	15,000	µg/kg
Phenanthrene	5.40E+07	1.60E+07	1,500	µg/kg
Pyrene	1.00E+09	3.40E+08	32,000	µg/kg
Toluene	4.60E+08	1.60E+08	15,800	µg/kg
Total xylenes	1.00E+09	1.00E+09	5,600	µg/kg

Source: MDNR, 1995b.

^{a/} Health-protective value to protect workers from long-term, systemic health effects from incidental ingestion and dermal absorption of chemicals in soil.

^{b/} Soil leaching criterion that is protective of underlying groundwater quality. Appropriate value calculated as 20 times the industrial groundwater criterion (Table 4.2).

^{c/} Not available/not applicable.

TABLE 4.2
GENERIC CLEANUP CRITERIA FOR GROUNDWATER AT COMMERCIAL/INDUSTRIAL SITES

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Detected Analytes	Industrial/Commercial Health-Based Criterion ^{a/}	Residential Health-Based Criterion	Aesthetic Criterion ^{b/}	State Drinking Water Standards ^{c/}	Units
1,2,3-Trimethylbenzene	-- ^{d/}	--	--	--	µg/L
1,2,4-Trimethylbenzene	86	30	--	--	µg/L
1,3,5-Trimethylbenzene	65	23	--	--	µg/L
1,2,3,4-Tetramethylbenzene	--	--	--	--	µg/L
2-Methylnaphthalene	750	260	--	--	µg/L
Acenaphthene	3,800	1,300	--	--	µg/L
Anthracene	21,000	7,300	--	--	µg/L
Benzene	120 ^{e/}	29.37	--	5	µg/L
Ethylbenzene	2,086 ^{e/}	730	74	700	µg/L
Fluorene	2,500	880	--	--	µg/L
Naphthalene	750	260	--	--	µg/L
Phenanthrene	75	26	--	--	µg/L
Toluene	4,171 ^{e/}	1,460	790	1,000	µg/L
Total xylenes	41,714 ^{e/}	14,600	280	10,000	µg/L

Source: MDNR, 1995a and 1995b.

- ^{a/} Health-based values are designed to protect onsite workers whose drinking water is from an onsite groundwater source.
- ^{b/} Aesthetic values designed to protect against adverse taste and odor impacts. This criterion must be met onsite if groundwater is used as an onsite potable water source and the criterion is more restrictive than the health-based value.
- ^{c/} The state drinking water standard must be met onsite if groundwater is used as an onsite potable water source, and the standard is more restrictive than the health-based or aesthetic criteria.
- ^{d/} Not available/not applicable.
- ^{e/} Value was calculated using the generic industrial cleanup criteria algorithm for groundwater ingestion.

a toxicity-based concentration, (2) a concentration that will prevent adverse aesthetic (i.e., taste and odor) impacts, or (3) the state drinking water standards, as presented in the state's Primary Drinking Water Regulations. The toxicity-based concentration is based on an algorithm developed by MDEQ (1995b) to protect onsite industrial workers whose drinking water is from an onsite groundwater resource. If the affected groundwater is the source of drinking water at an industrial site, the aesthetic criterion must also be met unless an alternative criterion can be justified. Additionally, according to MDEQ (1995b), if a more restrictive state drinking water standard is available for a particular chemical, the promulgated standard must be attained if the onsite groundwater is used as a potable water source. The derivations of these generic cleanup criteria for groundwater are presented in MDEQ's (1995b) Operational Memorandum #14, Revision 2.

It is important to note that if onsite groundwater is not used as a potable water resource, but the shallow aquifer is a source of offsite drinking water, the need for and type and magnitude of remediation will depend upon chemical fate. Site-related chemicals could remain in onsite groundwater at concentrations above the generic industrial cleanup criteria and be adequately protective as long as no chemical concentration above the generic residential cleanup criteria migrates beyond the property boundary (Part 201 of PA 451). This scenario is representative of the type of exposure that could occur at and downgradient from Site OT45. Onsite groundwater is not used to meet potable demands, but the shallow groundwater is extracted at other on- and off-Base locations for potable uses. As part of the Tier 1 analysis, however, onsite analytical data are conservatively compared to the generic industrial/commercial cleanup criteria for groundwater that are based on a potable water use assumption. Section 6 briefly evaluates whether onsite contaminant concentrations could present an unacceptable risk to either onsite or offsite receptors, considering site-specific chemical fate and exposure data.

4.3.2 Screening to Identify COPCs in Soils and Groundwater

The COPCs to be evaluated in detail in this RAP are based on a comparison of measured site concentrations to generic cleanup criteria for soil and groundwater. As discussed above, generic cleanup criteria for industrial/commercial subcategory IV sites were selected as the appropriate set of Tier 1 screening tools. Tables 4.3 and 4.4 compare the maximum detected concentrations for each compound measured in soil and groundwater, respectively, at Site OT45 during recent sampling events to the appropriate generic cleanup criteria. Maximum concentrations were selected to provide a conservative comparison to MDEQ cleanup criteria. If the maximum measured site concentration does not exceed the most restrictive generic industrial/commercial cleanup criteria, the compound is not identified as a COPC, and it is not retained for further evaluation. No additional remediation would be warranted for such compounds to protect human health and the environment from exposures to these compounds given the current and foreseeable future uses of the site. If the maximum measured site concentration exceeds the appropriate generic industrial/commercial cleanup criteria, the compound is identified as a COPC and retained for further quantitative fate and transport and site-specific risk analyses. Additionally, if a chemical was detected in groundwater at concentrations above the generic residential health-based or aesthetic cleanup criteria (Table 4.2), it is retained for the Tier 1 chemical fate and transport analysis. However, groundwater contaminants that exceed generic residential criteria

TABLE 4.3
IDENTIFICATION OF SOIL CONTAMINANT
GENERIC CLEANUP CRITERIA EXCEEDANCES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Analytes	Maximum Detected Concentrations		Commercial				Industrial		Commercial/Industrial		Residential		1996 Max. Conc.	
	1996	1994	Subcategory IV Direct	Contact ^a	Direct	Contact ^a	Direct	Contact ^a	Soil Leaching (20 Times GW Conc.) ^b	Direct	Contact	Soil Leaching (20 Times GW Conc.) ^b	Exceeds Any Criteria	Units
1,2,3-Trimethylbenzene	1.3	1,400	— ^c	—	—	—	—	—	—	—	—	—	—	µg/kg
1,2,4-Trimethylbenzene	2.7	2,200	8.50E+06	3.10E+06	3.10E+06	4.50E+05	4.50E+05	600	600	4.50E+05	4.50E+05	600	No	µg/kg
1,3,5-Trimethylbenzene	2.3	1,300	6.40E+06	2.30E+06	2.30E+06	3.40E+05	3.40E+05	460	460	3.40E+05	3.40E+05	460	No	µg/kg
2-Methylnaphthalene	110	7,000	5.40E+08	1.60E+08	1.60E+08	1.50E+07	1.50E+07	5,200	5,200	1.50E+07	1.50E+07	5,200	—	µg/kg
Acenaphthene	<420	380	1.00E+09	8.18E+08	8.18E+08	7.60E+07	7.60E+07	26,000	26,000	7.60E+07	7.60E+07	26,000	No	µg/kg
Benzo(a)anthracene	<420	33	6.80E+05	2.10E+05	2.10E+05	14,000	14,000	{E}	{E}	14,000	14,000	{E}	No	µg/kg
Benzo(a)pyrene	<420	34	6.80E+04	2.10E+04	2.10E+04	1,400	1,400	{E}	{E}	1,400	1,400	{E}	No	µg/kg
Benzo(b)fluoranthene	<420	57	6.80E+05	2.10E+05	2.10E+05	14,000	14,000	{E}	{E}	14,000	14,000	{E}	No	µg/kg
Benzo(g,h,i)perylene	<420	30	5.40E+07	1.60E+07	1.60E+07	1.50E+06	1.50E+06	{E}	{E}	1.50E+06	1.50E+06	{E}	No	µg/kg
Benzo(k)fluoranthene	<420	22	6.80E+06	2.10E+06	2.10E+06	1.40E+05	1.40E+05	{E}	{E}	1.40E+05	1.40E+05	{E}	No	µg/kg
Chrysene	<420	41	6.80E+07	2.10E+07	2.10E+07	1.40E+06	1.40E+06	{E}	{E}	1.40E+06	1.40E+06	{E}	No	µg/kg
Dibenzofuran	<420	110	—	—	—	—	—	—	—	—	—	—	—	µg/kg
Ethylbenzene	0.6	160	2.00E+08	7.20E+07	7.20E+07	1.10E+07	1.10E+07	1,480	1,480	1.10E+07	1.10E+07	1,500	No	µg/kg
Fluoranthene	<420	38	1.00E+09	5.40E+08	5.40E+08	5.10E+07	5.10E+07	50,000	50,000	5.10E+07	5.10E+07	18,000	No	µg/kg
Fluorene	<420	550	1.00E+09	5.40E+08	5.40E+08	5.10E+07	5.10E+07	50,000	50,000	5.10E+07	5.10E+07	18,000	No	µg/kg
Indeno(1,2,3-cd)pyrene	<420	32	6.80E+05	2.10E+05	2.10E+05	14,000	14,000	{E}	{E}	14,000	14,000	{E}	No	µg/kg
Naphthalene	35	1,400	5.40E+08	1.60E+08	1.60E+08	1.50E+07	1.50E+07	15,000	15,000	1.50E+07	1.50E+07	5,200	No	µg/kg
Phenanthrene	21	1,600	5.40E+07	1.60E+07	1.60E+07	1.50E+06	1.50E+06	1,500	1,500	1.50E+06	1.50E+06	520	No	µg/kg
Pyrene	58	180	1.00E+09	3.40E+08	3.40E+08	3.20E+07	3.20E+07	32,000	32,000	3.20E+07	3.20E+07	11,000	No	µg/kg
Toluene	0.9	31	4.60E+08	1.60E+08	1.60E+08	2.40E+07	2.40E+07	15,800	15,800	2.40E+07	2.40E+07	16,000	No	µg/kg
Total xylenes	2.3	890	1.00E+09	1.00E+09	1.00E+09	2.00E+08	2.00E+08	5,600	5,600	2.00E+08	2.00E+08	5,600	No	µg/kg

Source: MDNR, 1995a and 1995b.

^a Health-protective value to protect workers from long-term, systemic health effects from incidental ingestion and dermal absorption of chemicals in soil.

^b Soil leaching criterion that is protective of underlying groundwater quality. Appropriate value calculated as 20 times the appropriate groundwater criterion (Table 4.2).

^c Not available/not applicable.

{E} = Chemical, due to its physiochemical properties, is not expected to leach through soils to groundwater under normal conditions.

TABLE 4.4
IDENTIFICATION OF GROUNDWATER
CONTAMINANT GENERIC CLEANUP CRITERIA EXCEEDANCES
 REMEDIAL ACTION PLAN
 RISK-BASED APPROACH TO REMEDIATION
 SITE OT45, WURTSMITH AFB, MICHIGAN

Analytes	Maximum Detected Concentration				Industrial/Commercial Health-Based Criterion ^a	Residential Health-Based Criterion	Aesthetic Criteria ^b	State Drinking Water Standards ^c	1997 Max. Conc.	
	1997	1996	1995	1994					Exceeds Any Criteria	Units
1,2,3-Trimethylbenzene	<0.5	1	26	37	— ^d	—	—	—	—	µg/L
1,2,4-Trimethylbenzene	<0.5	1	48	82	86	30	—	—	No	µg/L
1,3,5-Trimethylbenzene ^e	<0.5	6	8.7	43	65	23	—	—	No	µg/L
1,2,3,4-Tetramethylbenzene	7.4	NA	66	NA	—	—	—	—	—	µg/L
2-Methylnaphthalene	NA	NA	NA	230	—	—	—	—	—	µg/L
Acenaphthene	NA	NA	NA	19	3,800	1,300	—	—	No	µg/L
Anthracene	NA	NA	NA	5	21,000	7,300	—	—	No	µg/L
Benzene	<0.5	<5	1.3	1.7	120 ^e	29.37	—	5	No	µg/L
Ethylbenzene	<0.5	7	11	7.2	2086 ^e	730	74	700	No	µg/L
Fluorene	NA	NA	NA	26	2,500	880	—	—	No	µg/L
Naphthalene	NA	NA	130	150	750	260	—	—	No	µg/L
Phenanthrene ^e	NA	NA	6	70	75	26	—	—	No	µg/L
Toluene	<0.5	<5	1.8	4.3	4171 ^e	1,460	790	1,000	No	µg/L
Total xylenes	<0.5	2	21	23	41714 ^e	14,600	280	10,000	No	µg/L

Source: MDNR, 1995b.

^a Health-based values are designed to protect onsite workers whose drinking water is from an onsite groundwater source.

^b Aesthetic values designed to protect against adverse taste and odor impacts. This criterion must be met onsite if groundwater is used as an onsite potable water source and the criterion is more restrictive than the health-based value.

^c The state drinking water standard must be met onsite if groundwater is used as an onsite potable water source, and the standard is more restrictive than the health-based or aesthetic criteria.

^d Not available/not applicable.

^e 1994 concentrations of 123-TMB and Phenanthrene exceed health-based criteria. However, more recent concentrations of these contaminants measured in 1995, 1996, and 1997 were substantially below health-based criteria.

^f Value was calculated using the generic industrial cleanup criteria algorithm for groundwater ingestion.

are not identified as COPCs, because these contaminants do not and will not pose a risk to onsite human receptors.

4.4 SUMMARY OF SITE OT45 COPCS

Table 4.5 summarizes the COPCs in soil and chemicals with concentrations in groundwater above the residential cleanup criteria at Site OT45. No detected compound in soil exceeded the most stringent residential cleanup criteria for soils in the 1996 sampling event. However, phenanthrene and 1,2,4-TMB exceeded their respective generic industrial/commercial cleanup criteria for potential leachability from soil to groundwater during the 1994 risk-based investigation. This means that these compounds were present in soils at concentrations that may be high enough to potentially generate leachate concentrations in exceedance of generic industrial/commercial groundwater cleanup criteria.

No groundwater COPCs were identified, based on comparisons of the maximum detected site chemical concentrations to the most restrictive generic industrial/commercial cleanup criteria for groundwater. However, dissolved concentrations of phenanthrene, 1,2,4-TMB, and 1,3,5-TMB measured in 1994 exceeded the residential health-based groundwater cleanup criteria. The maximum 1995 concentration of 1,2,4-TMB also exceeded its criterion, though the concentration decreased significantly from 1994. These chemicals are not strictly identified as groundwater COPCs because they do not currently pose a risk to human health or the environment given the current and foreseeable uses of the site. Additionally, maximum dissolved concentrations of both phenanthrene and 1,3,5-TMB measured as part of the 1995 risk-based investigation are below the most stringent groundwater cleanup criteria (residential health-based criteria). Maximum dissolved concentrations of 1,2,4-TMB measured as part of the 1996 and 1997 sampling events are below the most stringent groundwater cleanup criteria (residential health-based criteria).

The nature and extent of these contaminants are described more fully in Section 5. The potential for these contaminants to migrate offsite at concentrations greater than generic residential groundwater cleanup criteria is quantitatively investigated as part of the Tier 1 screening-level fate and transport analysis in Section 6.

TABLE 4.5
SUMMARY OF CONTAMINANTS RETAINED FOR FURTHER ANALYSIS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Chemicals of Potential Concern	Rationale ^{a/}
Soil	NO COPCs WERE DETECTED IN SOIL DURING THE 1996 INVESTIGATIONS
Groundwater	NO COPCs WERE DETECTED IN GROUNDWATER DURING THE 1996 OR 1997 INVESTIGATIONS
Chemicals of Interest that Exceed Cleanup Criteria	Rationale ^{a/}
Soil	
Phenanthrene	1994 risk-based maximum concentration > MDEQ industrial/commercial leaching criterion
1,2,4-Trimethylbenzene	1994 risk-based maximum concentration > MDEQ industrial/commercial leaching criterion
Groundwater	
Phenanthrene	1994 risk-based maximum concentration > MDEQ residential health-based criterion
1,3,5-Trimethylbenzene	1994 risk-based maximum concentration > MDEQ residential health-based criterion
1,2,4-Trimethylbenzene	1994 & 1995 risk-based maximum concentration > MDEQ residential health-based criterion

^{a/} See Tables 4.3 and 4.4

SECTION 5

NATURE AND EXTENT OF CONTAMINATION

5.1 OVERVIEW

This section summarizes the nature and extent of chemicals of interest in soil and the dissolved chemicals in site groundwater. Analytical data for only these chemicals are presented in order to focus the remainder of this RAP on these chemicals that could pose a risk to human health. The analytical data presented in this section include results from the 1992 RI, the 1994 risk-based remediation field investigation, the 1995, 1996, and 1997 groundwater sampling events and the 1996 soil sampling event. Additionally, soil gas and soil flux sampling data, which are used to estimate the areal extent of soil contamination and to identify completed exposure pathways are summarized in this section.

5.2 SOURCES OF CONTAMINATION

Contamination at Site OT45 was confirmed to be the result of an underground spill from a former 1,000-gallon UST used to store heating fuel. The tank was taken out of service in October 1991, and removed in 1992 (ICF, 1993). Site characterization efforts conducted at the site previous to 1994 indicated that soil was contaminated with ethylbenzene, toluene, total xylenes, fluorene, naphthalene, and phenanthrene. These investigations suggested that concentrations of ethylbenzene, phenanthrene, naphthalene, and fluorene in soil may act as a source of groundwater contamination. However, results of the 1994 risk-based investigation indicate that only phenanthrene and 1,2,4-TMB were present in site soils at concentrations that may adversely impact groundwater (i.e., measured at concentrations above the MDEQ generic industrial/commercial leaching criteria, Tables 4.1 and 4.3).

5.3 SOIL GAS SAMPLING RESULTS

Soil gas samples collected at Site OT45 during the 1994 risk-based field effort were analyzed for volatile BTEX compounds and TVH contamination. Soil gas samples can be used as secondary confirmation of the nature and extent of soil contamination at a site. Soil gas samples can be used to obtain a better representation of soil contamination because the sample is extracted from a larger volume of soil than discrete soil grab samples. Analytical results from soil samples are usually nonhomogenous and can vary from sampling location to sampling location. Thus, soil gas samples provide a valuable indication of the type and magnitude of volatile organic contamination in the soil.

Soil gas samples were collected from VW-1, MPB, and MW-2 in October 1994. Benzene was not detected in any of the three soil gas samples. This is consistent with soil data collected at the site. The only BTEX compounds detected in soil gas samples were ethylbenzene and total xylenes. These compounds were detected in all three soil gas samples collected at Site OT45 during the 1994 risk-based investigation. The maximum concentration of ethylbenzene [1.4 milligrams per cubic meter (mg/m^3)] was detected in the soil gas sample collected at MPB; the minimum concentration ($0.17 \text{ mg}/\text{m}^3$) was measured at MW-2. The maximum concentration of total xylenes ($3.2 \text{ mg}/\text{m}^3$) was measured at MPB; the minimum ($1 \text{ mg}/\text{m}^3$) was measured at MW-2.

These results support the 1994 soil sampling analytical results, which indicate minimal BTEX soil contamination. All of the measured soil gas concentrations are well below the time-weighted-average (TWA), 8-hour permissible exposure limits (PELs) defined for air contaminants by the Occupational Safety and Health Administration (OSHA, 1995). Consequently, if future excavation of these soils proves to be necessary to support remedial or construction activities, soil gas concentrations are not expected to pose a significant risk to potential human receptors. All analytical results for soil gas samples collected during the 1994 field effort are presented in Appendix B.

5.4 SOIL GAS FLUX SAMPLING RESULTS

Soil gas flux samples were also collected at Site OT45 during the risk-based investigation in October 1994, and analyzed for the volatile BTEX compounds and TVH. Analytical results for the soil gas flux samples were used to calculate actual gaseous emission concentrations in accordance with the procedures described in EPA's (1986) guidance document entitled *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber* (EPA/600/8-86/008). The calculation transforms concentration data into emission rate data. The uncorrected flux sample analytical data and the calculation sheets for actual soil gas flux emission at Site OT45 are presented in Appendix B.

Low concentrations of toluene and xylenes were measured at flux sampling locations near VW-1, MPB, and MW-2. The maximum calculated emission rate for toluene was 3.6 micrograms per minute per square meter of land surface ($\mu\text{g}/\text{min}\cdot\text{m}^2$) at MPB. The maximum calculated emission rate for total xylenes near the source area was $1.4 \mu\text{g}/\text{min}\cdot\text{m}^2$, which is lower than that measured at the background sampling location.

Assuming no atmospheric dispersion, these measured soil gas flux concentrations will not result in concentrations within the breathing zone above the OSHA (1994) TWA, 8-hour PEL for each specific compound. For example, the maximum concentration of toluene expected in the breathing zone above the source area over an 8-hour time period, assuming no atmospheric dispersion, would be $1.7 \text{ mg}/\text{m}^3$. This is significantly below the OSHA (1995) TWA PEL of $375 \text{ mg}/\text{m}^3$ for toluene. Based on these results, it is highly unlikely that soil gas flux emissions represent a source of risk. The low rates of emission suggest that the volatilization release mechanism is not significant at Site OT45.

5.5 SOIL CHEMISTRY

The following sections summarize analytical data results for the chemicals of interest measured in soil samples collected during the 1992 RI and 1994 sampling events. Contaminants were not detected in unsaturated soils at concentrations above the most stringent soil cleanup criteria during the 1992 or the 1994 sampling events. Soil chemicals of interest appear to be limited to saturated and capillary fringe soils, and were not detected in unsaturated soil samples collected during either the 1992 or the 1994 sampling events. During the 1996 confirmation soil sampling event, no chemicals of interest were detected in the saturated and capillary fringe soils above the most stringent soil cleanup criteria. All analytical results for soil samples collected during the 1992 RI, the 1994 risk-based field efforts, and the 1996 confirmation soil sampling event are presented in Appendix B.

5.5.1 Phenanthrene Soil Contamination

Phenanthrene was detected in saturated soil samples collected as part of the 1992 RI at Site OT45 at concentrations exceeding MDEQ (1995b) industrial/commercial groundwater leaching criterion (Tables 4.1 and 4.3) at locations within and immediately downgradient from the suspected source area. In 1992, phenanthrene was measured at 29,000 µg/kg at MW2, 3,700 µg/kg at SB-2, and 11,000 µg/kg at SB-3 (Table 5.1 and Figure 1.3). Additionally, phenanthrene was detected in a soil sample collected from SB-1 at 500 µg/kg, which is below the generic industrial/commercial soil leaching criterion. Phenanthrene was not detected in any other soil samples collected at Site OT45 as part of the 1992 RI sampling event (ICF, 1993). All soil samples with elevated concentrations of phenanthrene collected as part of the 1992 RI were collected from depths (9 - 12 feet bgs) that coincide with the water table elevation (approximately 9 - 10 feet bgs across the site) and the capillary fringe. Conclusions of the 1992 RI indicate that phenanthrene soil contamination at Site OT45 is limited to a narrow band of saturated soils near the water table.

The 1994 risk-based investigation further characterized the soil contamination at Site OT45. One saturated soil sample collected as part of the 1994 investigation at a depth of 10 to 13 feet bgs, near the water table, during the installation of monitoring well MW-5 contained phenanthrene at 1,600 µg/kg. This concentration of phenanthrene exceeds the generic industrial/commercial soil leaching criterion (Table 4.3). Ten additional subsurface soil samples were collected as part of the 1994 risk-based investigation. These samples were intentionally collected from depths that coincided with the water table elevation from boreholes located throughout the site in order to fully delineate the extent of soil contamination at Site OT45. None of these soil samples contained detectable concentrations of phenanthrene (Figure 5.1). Moreover, phenanthrene was not detected in three surface soil scrapings collected near the suspected source area as part of the 1994 investigation. These results, when coupled with 1992 RI soil data, indicate that phenanthrene soil contamination at Site OT45 was likely limited to a narrow band of saturated soils within and immediately downgradient from the former source area (Figure 5.1).

TABLE 5.1
SOIL CONCENTRATIONS OF
CHEMICALS OF INTEREST^{a/}
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

WELLS	COMPOUND	ANALYTICAL RESULTS (FT BGS)			UNITS
		Oct-92	Oct-94	Jul/Aug-96	
MW-11	1,2,4-Trimethylbenzene	NA ^{b/}	4.8 U ^{c/} (10-12)	NA	µg/kg
	Phenanthrene	NA	360 U (10-12)	NA	µg/kg
MW-7	1,2,4-Trimethylbenzene	NA	4.7 UJ ^{d/} (8-9)	NA	µg/kg
	Phenanthrene	NA	330 U (8-9)	NA	µg/kg
MW-10	1,2,4-Trimethylbenzene	NA	4.6 U (9-11)	NA	µg/kg
	Phenanthrene	NA	380 U (9-11)	NA	µg/kg
MW-5	1,2,4-Trimethylbenzene	NA	2200 J ^{e/} (10-13)	NA	µg/kg
	Phenanthrene	NA	1600 (10-13)	NA	µg/kg
MPA (SB1 & SB3) ^{f/}	1,2,4-Trimethylbenzene	NA	4.6 U (8-9.5)	NA	µg/kg
	Phenanthrene	500 (11.5-13.5) & 11,000 (10-12)	370 U (8-9.5)	NA	µg/kg
VW-1 (SB4) ^{f/}	1,2,4-Trimethylbenzene	NA	4.5 U (8-9.5)	NA	µg/kg
	Phenanthrene	210 U (10-12)	330 U (8-9.5)	NA	µg/kg
MPB (MW-2 & SB2) ^{f/}	1,2,4-Trimethylbenzene	NA	900 (8-9.5)	NA	µg/kg
	Phenanthrene	29,000 (9-11) & 3700 (10-12)	330 U (8-9.5)	NA	µg/kg
MW-3 ^{f/}	1,2,4-Trimethylbenzene	NA	NS	NA	µg/kg
	Phenanthrene	180 U (8-10)	NS	NA	µg/kg
MW-6	1,2,4-Trimethylbenzene	NA	4.9 U (8-9.5)	NA	µg/kg
	Phenanthrene	NA	410 U (8-9.5)	NA	µg/kg
MW-8	1,2,4-Trimethylbenzene	NA	4.8 U (8-9.5)	NA	µg/kg
	Phenanthrene	NA	400 U (8-9.5)	NA	µg/kg
MW-9	1,2,4-Trimethylbenzene	NA	0.7 J (8-9.5)	NA	µg/kg
	Phenanthrene	NA	380 U (8-9.5)	NA	µg/kg
MW-1 ^{f/}	1,2,4-Trimethylbenzene	NA	NS	NA	µg/kg
	Phenanthrene	210 U (10-12)	NS	NA	µg/kg
MW-4	1,2,4-Trimethylbenzene	NA	4.8 U (8-9.5)	NA	µg/kg
	Phenanthrene	NA	350 U (8-9.5)	NA	µg/kg
C1	1,2,4-Trimethylbenzene	NA	NA	5.1U (8-11)	µg/kg
	Phenanthrene	NA	NA	420U (8-11)	µg/kg
C2	1,2,4-Trimethylbenzene	NA	NA	4.7U (8-11)	µg/kg
	Phenanthrene	NA	NA	390U (8-11)	µg/kg

TABLE 5.1 (Continued)
SOIL CONCENTRATIONS OF
CHEMICALS OF INTEREST^{b/}
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

WELLS	COMPOUND	ANALYTICAL RESULTS (FT BGS)			UNITS
		Oct-92	Oct-94	Jul/Aug-96	
C3	1,2,4-Trimethylbenzene	NA	NA	4.5U (8-11)	µg/kg
	Phenanthrene	NA	NA	370U (8-11)	µg/kg
C4	1,2,4-Trimethylbenzene	NA	NA	4.5U (8-11)	µg/kg
	Phenanthrene	NA	NA	370U (8-11)	µg/kg
C5	1,2,4-Trimethylbenzene	NA	NA	4.6U (8-11)	µg/kg
	Phenanthrene	NA	NA	380U (8-11)	µg/kg
C6	1,2,4-Trimethylbenzene	NA	NA	4.6U (8-11)	µg/kg
	Phenanthrene	NA	NA	380U (8-11)	µg/kg
C7	Phenanthrene	NA	NA	2.7J (8-11)	µg/kg
	1,2,4-Trimethylbenzene	NA	NA	21J (8-11)	µg/kg
C8	1,2,4-Trimethylbenzene	NA	NA	4.6U (8-11)	µg/kg
	Phenanthrene	NA	NA	380U (8-11)	µg/kg
C9	1,2,4-Trimethylbenzene	NA	NA	4.7U (8-11)	µg/kg
	Phenanthrene	NA	NA	390U (8-11)	µg/kg
C10	1,2,4-Trimethylbenzene	NA	NA	4.8U (8-11)	µg/kg
	Phenanthrene	NA	NA	390U (8-11)	µg/kg
C11	1,2,4-Trimethylbenzene	NA	NA	4.8U (8-11)	µg/kg
	Phenanthrene	NA	NA	400U (8-11)	µg/kg
C12	1,2,4-Trimethylbenzene	NA	NA	4.7U (8-11)	µg/kg
	Phenanthrene	NA	NA	390U (8-11)	µg/kg
C13	1,2,4-Trimethylbenzene	NA	NA	4.5U (8-11)	µg/kg
	Phenanthrene	NA	NA	380U (8-11)	µg/kg
C14	1,2,4-Trimethylbenzene	NA	NA	4.6U (8-11)	µg/kg
	Phenanthrene	NA	NA	380U (8-11)	µg/kg

^{b/} NA = Data not available for comparison.

^{c/} U = Analyte not detected above method detection limit.

^{d/} UJ = Analyte concentrations estimated to be below method detection limit.

^{e/} J = Estimated value.

^{f/} Sampling location during the 1992 investigation (ICF, 1993).

LEGEND

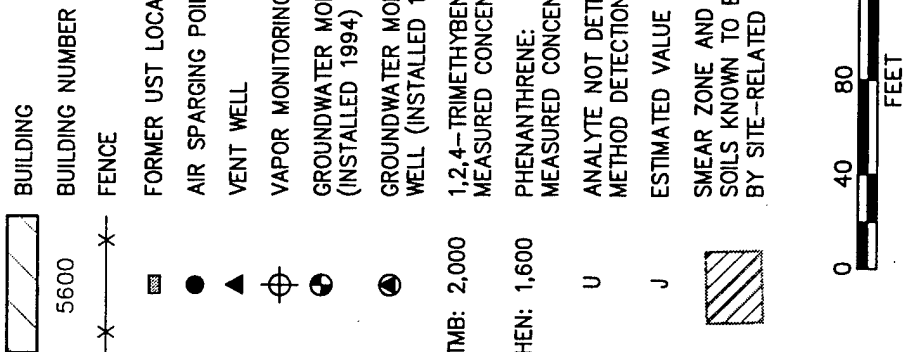


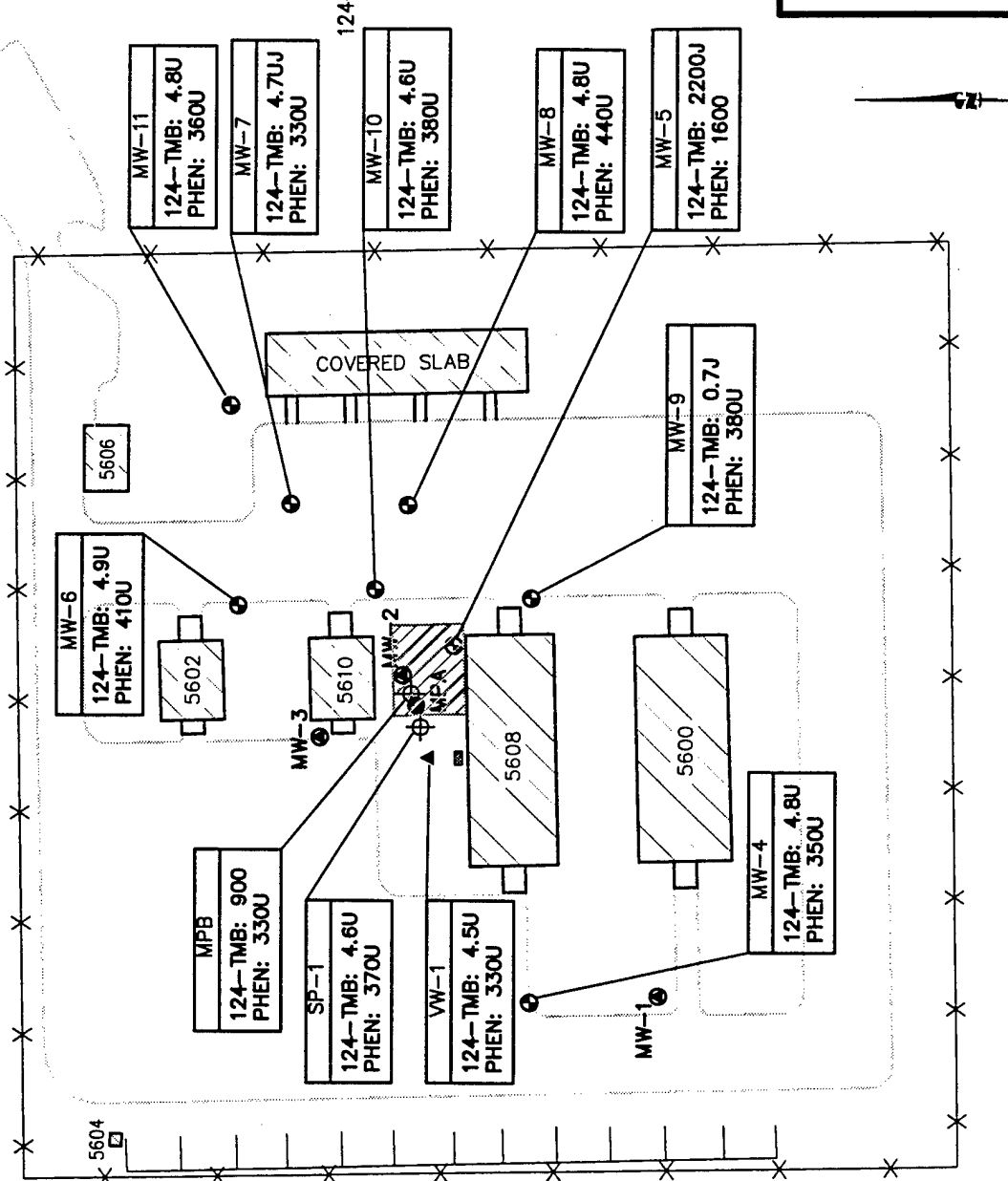
FIGURE 5.1

SOIL CONCENTRATIONS (1994)

Remedial Action Plan
 Risk-Based Approach to Remediation
 Site OT45
 Wurtsmith AFB, Michigan

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The 1996 confirmation soil sampling event was completed to verify model predictions of reductions in contaminant concentrations with time at the site. Twelve soil samples near the source area and two background samples were collected from the smear zone just above and below the groundwater surface (Figure 5.2). The only detectable level of phenanthrene in the soil was at soil sample location C7 at a concentration of 21 µg/kg which was below the laboratory reporting limit. Therefore, there are currently no concentrations of 1,2,4-TMB in site soil above the most stringent residential soil cleanup criteria. As discussed in Section 6, these reductions in contaminant concentrations is consistent with that predicted and verifies the low risk potential existing at the site.

5.5.2 1,2,4-TMB Soil Contamination

Soil samples collected during the 1992 RI were not analyzed for 1,2,4-TMB. However, soil samples collected during the 1994 risk-based investigation contained concentrations of 1,2,4-TMB that exceeded the MDEQ generic industrial/commercial soil leaching criterion of 1,720 µg/kg (Table 4.3).

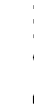
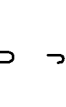
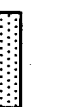
1,2,4-TMB was detected in 3 of 11 subsurface samples collected as part of the 1994 risk-based investigation. 1,2,4-TMB was measured at a maximum concentration of 2,200 µg/kg in a saturated soil sample collected from a depth coinciding with the water table during the installation of MW-5 (Table 5.1). This result represents the only detected concentration of 1,2,4-TMB that exceeded MDEQ generic industrial/commercial soil leaching criterion. Lower concentrations of 1,2,4-TMB were detected in saturated samples collected during the installation of MPB and MW-9 at concentrations of 900 µg/kg and 0.7 µg/kg, respectively (Table 5.1 and Figure 5.1). These samples were also collected at or slightly below the water table. The extent of 1,2,4-TMB contamination appears to mirror the extent of phenanthrene contamination at the site (Figure 5.1). 1,2,4-TMB contamination appears to be limited to a narrow band of saturated soils within and immediately downgradient from the source area.

1,2,4-TMB was detected in one of the fourteen soil samples collected during the 1996 confirmation soil sampling event. 1,2,4-TMB was detected at 2.7 µg/kg, which is below the laboratory reporting limit, at soil sample location C7. Therefore, there are currently no concentrations of 1,2,4-TMB in site soil above the most stringent residential soil cleanup criteria. As discussed in Section 6, these reductions in contaminant concentrations is consistent with that predicted and verifies the low risk potential existing at the site.

5.6 GROUNDWATER CHEMISTRY

The following sections describe the results of groundwater sampling events conducted during the 1992 RI, and the 1994/1995 risk-based field investigations, and the 1996/1997 groundwater verification sampling event. Only chemicals in groundwater that are present onsite at concentrations exceeding any of the MDEQ (1995a) generic residential groundwater cleanup criteria during the previous investigations are described in detail. No groundwater COPCs were identified as part of the Tier 1 evaluation for Site OT45 (see Section 4). No free product [light nonaqueous-phase liquid (LNAPL)] has been observed at the site. Detectable contamination in groundwater is limited to dissolved constituents only.

LEGEND

-  BUILDING
-  BUILDING NUMBER
-  FENCE
-  FORMER UST LOCATION
-  AIR SPARGING POINT
-  VENT WELL
-  VAPOR MONITORING POINT
-  GROUNDWATER MONITORING WELL (INSTALLED 1994)
-  GROUNDWATER MONITORING WELL (INSTALLED 1992/1993)
-  SOIL SAMPLING LOCATION (1996) IN SMEAR ZONE ABOVE AND BELOW WATER TABLE
- 
- 
- 
- 
- 

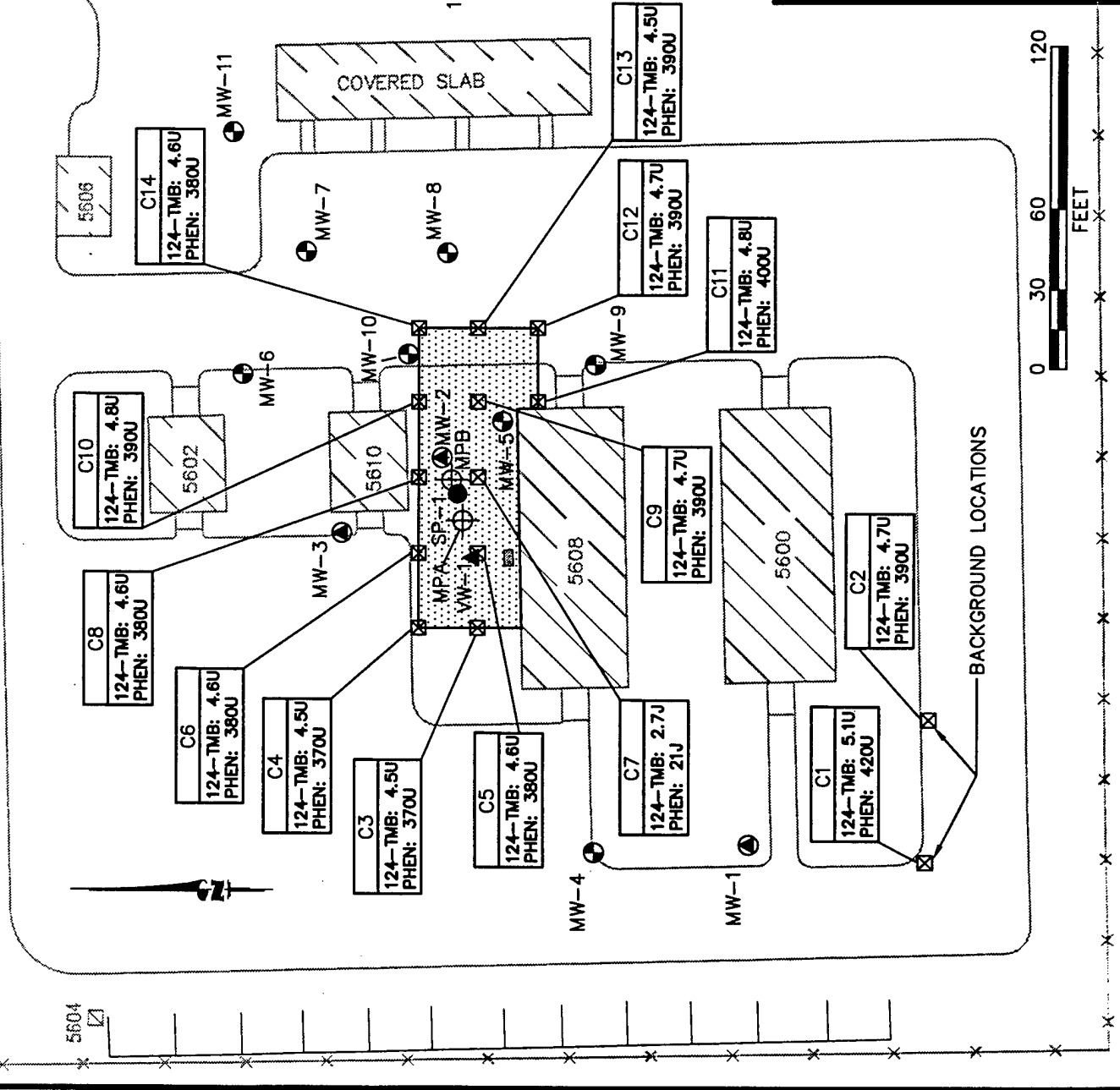


FIGURE 5.2

CONFIRMATION SOIL SAMPLING CONCENTRATIONS (1996)

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan

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5.6.1 1992-1994 Sampling Events

Results of samples collected as part of the 1992 RI indicated that phenanthrene was present at concentrations exceeding both generic industrial/commercial and generic residential groundwater cleanup criteria. In 1992, phenanthrene was detected in a groundwater sample collected from MW-2 at a concentration of 1,500 µg/L (Table 4.4). Phenanthrene was not detected in groundwater samples collected from the other four groundwater monitoring wells installed as part of the RI at Site OT45 (Figure 1.3). However, the downgradient extent was not delineated during this investigation. Analytical data were not collected for dissolved TMB isomers.

Phenanthrene, 1,2,4-TMB, and 1,3,5-TMB were detected in groundwater samples collected during the 1994 risk-based investigation at concentrations exceeding their respective generic health-based residential cleanup criteria (Table 4.4). The maximum concentration of phenanthrene of 70 µg/L was detected in a groundwater sample collected from MW-2. Groundwater samples collected from VW-1, MPB, and MW-5 contained phenanthrene concentrations below MDEQ generic residential health-based cleanup criteria (Table 5.2 and Figure 5.3). Phenanthrene was not detected in any other groundwater samples collected during the 1994 risk-based investigation.

The maximum concentration of 1,2,4-TMB (82 µg/L) was measured in a groundwater sample collected from VW-1. Groundwater samples collected from MPB and MW-5 also contained dissolved concentrations of 1,2,4-TMB that exceeded the MDEQ (1995a) generic residential cleanup criterion (Figure 5.3). 1,2,4-TMB was detected in a groundwater sample collected from MW-7 at concentrations below the generic residential groundwater criterion. 1,2,4-TMB was not detected in any other groundwater sample collected as part of the 1994 risk-based investigation.

The maximum concentration of 1,3,5-TMB also was detected in a groundwater sample collected from VW-1. Groundwater samples collected from MW-7, MW-5, and MPB also contained elevated concentrations of 1,3,5-TMB below MDEQ's generic residential cleanup criteria (Tables 4.4 and 5.2). 1,3,5-TMB was not detected in the other groundwater samples collected as part of the 1994 investigation. All analytical groundwater sampling results collected during the 1994 investigation are presented in Appendix B.

5.6.2 1995 Sampling Event

The results of the October 1995 sampling event demonstrate that concentrations of dissolved chemicals are rapidly decreasing at Site OT45. 1,2,4-TMB was the only dissolved chemical detected in onsite groundwater at concentrations greater than its residential health-based cleanup criterion (Table 4.4). Groundwater sampling locations (MW-2, MW-4, MW-5, MW-7, MW-10, MW-11, MPB, and VW-1 [W-OT45]) were selected based on a review of the 1994 risk-based investigation results. 1,2,4-TMB was detected only in the vicinity of the former UST. The maximum concentration of 1,2,4-TMB (48 µg/L) was measured at MW-2. The MDEQ generic health-based residential cleanup criterion for 1,2,4-TMB is 30 µg/L. All other concentrations of 1,2,4-TMB measured in groundwater samples collected during the 1995 sampling event were less than 7 µg/L (Figure 5.3).

TABLE 5.2
DISSOLVED CONCENTRATIONS OF
CHEMICALS OF INTEREST^{a/}

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

WELLS	COMPOUND	ANALYTICAL RESULTS					UNITS
		Oct-92	Oct-94	Oct-95	Nov-96	Jun-97	
MW-11	1,3,5-Trimethylbenzene	NA ^{b/}	5 U ^{c/}	0.5 U	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	5 U	0.5 U	NA	NA	µg/L
	Phenanthrene	NA	NS ^{d/}	0.5 U	NA	NA	µg/L
MW-7	1,3,5-Trimethylbenzene	NA	1.3 J ^{e/}	5.4	6	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	1.8	15	NA	µg/L
	Phenanthrene	NA	10 U	0.5 U	NA	NA	µg/L
MW-10 (deep well)	1,3,5-Trimethylbenzene	NA	4 U	0.4 U	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	0.4 U	NA	NA	µg/L
	Phenanthrene	NA	10 U	0.5 U	NA	NA	µg/L
MW-5	1,3,5-Trimethylbenzene	NA	19	4.3	NA	0.5U	µg/L
	1,2,4-Trimethylbenzene	NA	63	15	NA	0.5U	µg/L
	Phenanthrene	NA	1 J	0.5 U	NA	NA	µg/L
MPB	1,3,5-Trimethylbenzene	NA	17	0.4 U	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	36	1.5	NA	NA	µg/L
	Phenanthrene	5 U	7 J	0.5 U	NA	NA	µg/L
VW-1 (W-OT45) ^{f/}	1,3,5-Trimethylbenzene	NA	43	2.4	NA	0.5U	µg/L
	1,2,4-Trimethylbenzene	NA	82	6.4	NA	0.5U	µg/L
	Phenanthrene	25 U	19	0.5 U	NA	NA	µg/L
MW-2	1,3,5-Trimethylbenzene	NA	4 U	8.7	0.2U	0.5U	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	48	0.2U	0.5U	µg/L
	Phenanthrene	1500	70	6 J	NA	NA	µg/L
MW-3	1,3,5-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	Phenanthrene	5 U	NS	NS	NA	NA	µg/L
MW-6	1,3,5-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	Phenanthrene	NA	10 U	NS	NA	NA	µg/L

TABLE 5.2 (Continued)
DISSOLVED CONCENTRATIONS OF
CHEMICALS OF INTEREST^{a/}
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

WELLS	COMPOUND	ANALYTICAL RESULTS					UNITS
		Oct-92	Oct-94	Oct-95	Nov-96	Jun-97	
MW-8	1,3,5-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	Phenanthrene	NA	10 U	NS	NA	NA	µg/L
MW-9	1,3,5-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	Phenanthrene	NA	NS	NS	NA	NA	µg/L
MW-1	1,3,5-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	NS	NA	NA	µg/L
	Phenanthrene	5 U	10 U	NS	NA	NA	µg/L
MW-4	1,3,5-Trimethylbenzene	NA	4 U	0.4 U	NA	NA	µg/L
	1,2,4-Trimethylbenzene	NA	4 U	0.4 U	NA	NA	µg/L
	Phenanthrene	NA	NS	0.5 U	NA	NA	µg/L

^{a/} The contaminants reported in this table exceed generic residential groundwater cleanup criteria (Table 4.4), but not not industrial/commercial groundwater cleanup criteria.

^{b/} NA = Data not available for comparison.

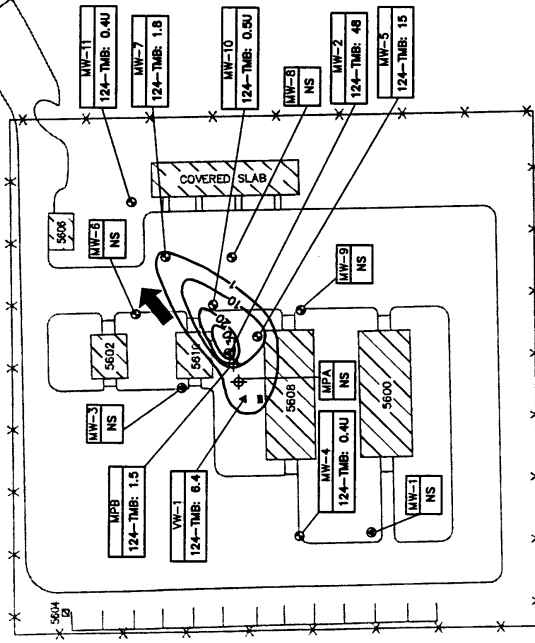
^{c/} U = Analyte not detected above method detection limit.

^{d/} NS = Not sampled.

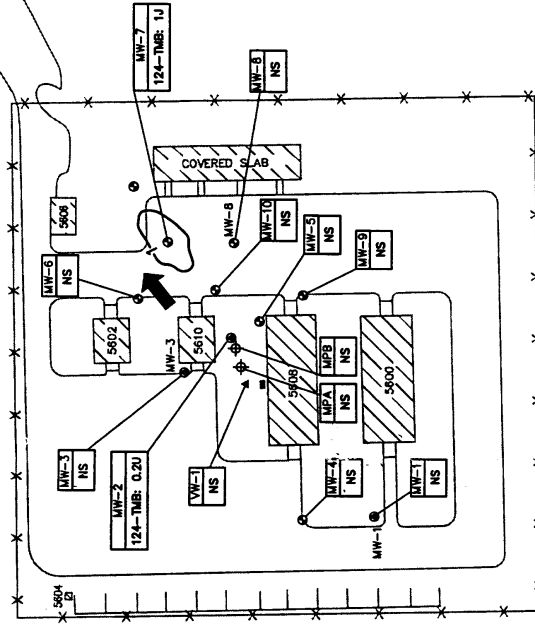
^{e/} J = Estimated value.

^{f/} Temporary sampling location used during the 1992 investigation (ICF, 1993).

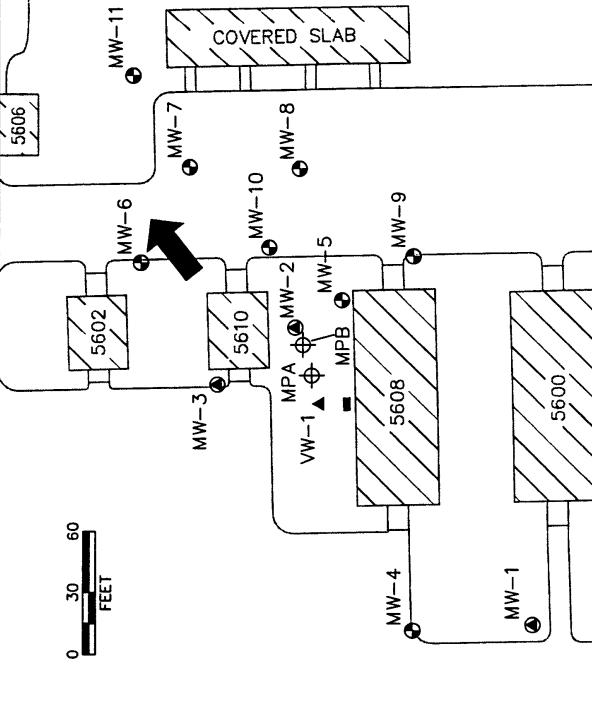
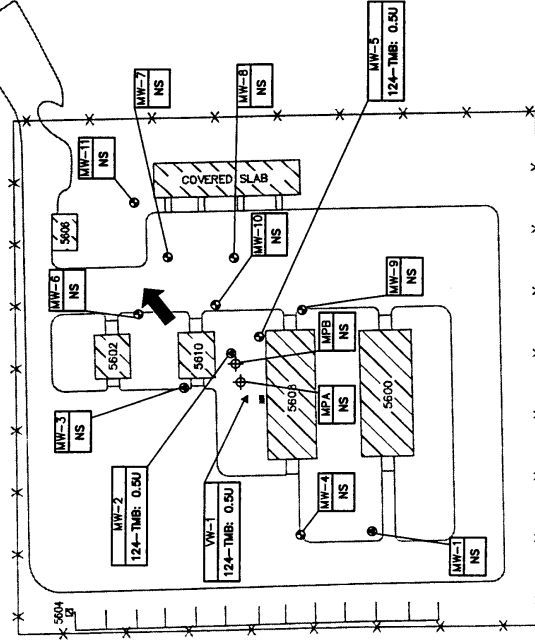
1,2,4-TRIMETHYLBENZENE GROUNDWATER CONCENTRATIONS (1995)



1,2,4-TRIMETHYLBENZENE GROUNDWATER CONCENTRATIONS (1996)



1,2,4-TRIMETHYLBENZENE GROUNDWATER CONCENTRATIONS (1997)



LEGEND

- BUILDING
- BUILDING NUMBER
- FENCE
- FORMER UST LOCATION
- VENT WELL (BOVENTING)
- VAPOR MONITORING POINT
- GROUNDWATER MONITORING WELL (INSTALLED 1994)
- GROUNDWATER MONITORING WELL (INSTALLED 1992/1993)
- 1,2,4-TRIMETHYLBENZENE MEASURED CONCENTRATION IN $\mu\text{g/L}$
- ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
- ESTIMATED VALUE
- NOT SAMPLED
- GROUND WATER FLOW DIRECTION



FIGURE 5.3
1,2,4-TRIMETHYLBENZENE GROUNDWATER CONCENTRATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

5.6.3 1996/1997 Sampling Event

The results of the November 1996 and June 1997 sampling events further demonstrate that concentrations of dissolved chemicals are rapidly decreasing at Site OT45. A limited number of sampling locations were selected based on the previous sampling events (1994 and 1995). Wells near the source area and downgradient of the source area were sampled during 1996 event. No detectable levels of 1,2,4-TMB or 1,3,5-TMB were detected near the source area (MW-2) during the 1996 sampling event. 1,2,4-TMB and 1,3,5-TMB were detected at concentrations of 1 µg/L and 6 µg/L, respectively, downgradient of the source area (MW-7) during the 1996 sampling event (Table 5.2). Three wells near the source area (MW-2, MW-5, and VW-1) were sampled during the 1997 sampling event. No detectable levels of 1,2,4-TMB or 1,3,5-TMB were found in any of the samples collected during the 1997 sampling event (Table 5.2). Both the 1996 and 1997 sampling events indicate that no dissolved phase 1,2,4-TMB or 1,3,5-TMB exist at concentrations above the most restrictive MDEQ (1995a) generic health-based residential groundwater cleanup criterion of 30 µg/L and 23 µg/L, respectively (Figure 5.3).

Based on the 1995 sampling results, concentrations of phenanthrene and 1,3,5-TMB, which were measured in 1994 at concentrations above the MDEQ generic residential groundwater cleanup criteria, have been reduced below generic residential groundwater criteria. Phenanthrene was detected only in monitoring well, MW-2 (near the source area) during the 1995 sampling event. Phenanthrene was detected at 6 µg/L, which is well below the generic health-based residential cleanup criterion of 26 µg/L. 1,3,5-TMB was detected in groundwater samples collected from locations near and immediately downgradient from the former source area during the 1995 sampling event. 1,3,5-TMB was detected at MW-7, MW-5, MW-2, and VW-1 at concentrations of 5.4 µg/L, 4.3 µg/L, 8.7 µg/L, and 2.4 µg/L, respectively (Table 5.2). However, these detections of 1,3,5-TMB are well below the MDEQ (1995a) generic health-based residential groundwater cleanup criterion of 23 µg/L.

5.7 SUMMARY

Site OT45 has very little soil and groundwater contamination remaining. No evidence of LNAPL has been reported at the site. Residual heating oil contamination in smear zone soil at the former UST location appears to be acting as a limited continuing source of groundwater contamination. COPCs in soil conservatively include phenanthrene and 1,2,4-TMB. Soil contamination is limited to an area of approximately 50 feet in diameter around the former UST. Average concentrations of phenanthrene appear to have decreased by an order of magnitude between the 1992 RI (ICF, 1993) and the 1994 risk-based investigation (from 11,000 µg/kg to 565 µg/kg). The significant decrease observed in source area soil concentrations of phenanthrene may be indicative of the positive effects of natural attenuation processes. 1,2,4-TMB soil data were collected during the 1994 risk-based investigation only.

No chemicals in excess of industrial/commercial criteria are present in groundwater underlying Site OT45. However, dissolved concentrations of 1,3,5-TMB, 1,2,4-TMB, and phenanthrene in excess of generic residential health-based cleanup criteria were detected onsite during the 1994 risk-based investigation. Dissolved concentrations of these analytes appear to be rapidly decreasing onsite. Dissolved concentrations of both

phenanthrene and 1,3,5-TMB have decreased to levels below generic residential cleanup criteria between the 1994 and the 1995 sampling events. 1,2,4-TMB was measured at only one 1995 sampling location at the MDEQ generic residential health-based cleanup criterion of 30 µg/L. Detectable concentrations of 1,2,4-TMB, 1,3,5-TMB, and phenanthrene are limited to an area less than 180 feet downgradient from the location of the former UST.

Based on available site data, only a few chemicals persist in onsite environmental media at concentrations above the most stringent but potentially applicable MDEQ generic cleanup criteria. No contaminant was measured in soils at concentrations above health-based criteria for onsite workers. Rather, soil COPCs were identified based on exceedences of MDEQ generic industrial/commercial soil leaching criteria. These cleanup criteria, which are designed to prevent adverse cross-media impacts, were derived by multiplying target groundwater concentrations by 20, per MDEQ guidance. Understanding how chemicals actually partition from onsite soils and dissolve into underlying groundwater is important in determining whether any adverse cross-media impacts are expected from residual levels of soil contamination. Consequently, the short- and long-term fate of soil COPCs is briefly evaluated in Section 6.

Additionally, only 1,2,4-TMB was measured in onsite groundwater at concentrations above the most restrictive residential cleanup criteria. Although residential cleanup criteria are not appropriate for this site, these levels were used as a conservative screening tool to identify which, if any, chemicals are present in onsite groundwater at concentrations that may pose a potential risk to off-site receptors. The fate of onsite chemicals in groundwater is briefly evaluated in Section 6 to (1) determine whether 1,2,4-TMB is likely to migrate to the Base boundary at concentrations above its MDEQ generic health-based cleanup criterion, and (2) estimate when onsite concentrations of 1,2,4-TMB are expected to fall below the most stringent MDEQ generic cleanup criteria.

SECTION 6

SCREENING-LEVEL CHEMICAL FATE ASSESSMENT

6.1 INTRODUCTION

Section 3 of this RAP is devoted to describing the physical site conditions. Section 4 details the Tier 1 screening of site-related contaminants and established the adsorbed and dissolved contaminants that could potentially pose a risk to offsite receptors. Section 5 summarizes the limited nature and extent of site-related contamination in saturated soils and groundwater at Site OT45. This section briefly explores what effect natural attenuation processes have had and will have on chemicals of interest detected in saturated soil and groundwater. The objectives of this section are to (1) document evidence of natural processes at Site OT45 that can facilitate the removal of hazardous substances from fuel-contaminated soil and groundwater, and (2) demonstrate that no onsite or offsite receptors will be exposed to unacceptable concentrations of fuel-related compounds.

6.2 OPERATIVE MECHANISMS OF CONTAMINANT ATTENUATION

Understanding the fate of phenanthrene, 1,2,4-TMB, and 1,3,5-TMB in environmental media is critical to evaluating and predicting contaminant distribution patterns. Although not a chemical of interest in soil, 1,3,5-TMB is discussed to illustrate the natural attenuation pattern of TMB isomers. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater. These processes are reviewed in the following subsections.

6.2.1 Basic Nondestructive Attenuation Processes

The relative solubility and sorptive nature of a chemical will govern the effectiveness of nondestructive attenuation processes at Site OT45. Nondestructive attenuation processes can be described as those physical and chemical processes that may inhibit significant contaminant migration but may not result in a permanent reduction in contaminant mass. Examples of nondestructive attenuation processes include volatilization, sorption, advection, and dispersion. Results of soil gas and soil flux sampling performed as part of the 1994 risk-based investigation indicate that volatilization is not a significant transport process acting to pose an unacceptable risk to human health and the environment at Site OT45 (Sections 5.3 and 5.4).

The water solubility of a chemical species defines how that particular chemical could partition (leach) from a contaminant source and dissolve into and migrate with groundwater. VOCs are typically more water soluble than PAHs, which have a fairly limited water solubility. For example, the water solubilities of 1,2,4-TMB, 1,3,5-

TMB, phenanthrene are 60 mg/L, 20 mg/L, 1.6 mg/L, respectively (TOMES, 1995; Verschueren, 1983). In contrast, the solubility of benzene is 1,700 mg/L (Bohon and Claussen, 1951).

Sorption also can govern how a compound is attenuated in soil and groundwater. If a contaminant can be strongly sorbed to the aquifer matrix, the compound will be less mobile and less likely to be transported great distances from the source area. Lower-molecular-weight compounds (e.g., TMB isomers and other VOCs) tend to sorb less readily than heavier molecular-weight SVOC compounds. Because heavier hydrocarbons such as many of the PAHs sorb more strongly to the soil matrix, migration is limited both in soil and in groundwater. Phenanthrene sorbs very strongly to soil, and in many cases can be rendered almost immobile (Vershueren, 1983). The TMB isomers tend to sorbs less strongly than phenanthrene but more strongly benzene.

The organic carbon content of both unsaturated and saturated soils at Site OT45 was measured as part of the 1994 field test. The TOC content ranged from 0.06 percent to 0.16 percent (Appendix B). The measured background concentration of TOC in soils was determined to be 0.15 percent at MW-4. Organic contaminants sorb primarily to that portion of the soil matrix that is composed of organic carbon. The low levels of organic carbon present at this site are not likely to significantly retard chemical migration, but are sufficient to slow contaminant leaching and migration to some degree. Due to the lack of silts and clays in this aquifer material, inorganic sorption is expected to be minimal at this site (Mehran *et al.*, 1987). The effects of sorption are expected to be most pronounced for phenanthrene, and slightly less pronounced for the TMB isomers.

Advective transport of contaminants is the movement of dissolved contaminants by virtue of their presence in groundwater that is moving. After contaminants enter groundwater, they advectively migrate in the direction of groundwater flow at a rate that is retarded as a result of sorption to organic carbon found in aquifer matrix. Subsurface features that control the direction and rate of groundwater flow also control the direction and rate of advective contaminant migration. Whereas advection is controlled by macroscopic movement of groundwater, dispersion is typically govern by molecular diffusion and/or tortuosity of groundwater flow through pore spaces. Dispersive transport of contaminants tends to cause contaminant plumes to spread radially relative to the primary direction of groundwater flow. Dispersive migration of contamination typically broadens a contaminant plume in the downgradient direction. Advective transport processes tend to have a more pronounced effect on contaminant migration than dispersive transport processes. For this reason, elongation of contaminant plumes in the downgradient direction is typically more pronounced than radial broadening of contaminant plumes. Advection and dispersion of dissolved contaminants in groundwater underlying Site OT45 will tend to reduced measurable concentrations over time but will not bring about a reduction in overall contaminant mass. Reductions in the overall dissolved contaminant mass in groundwater can only be attained via destructive attenuation mechanisms.

6.2.2 Destructive Attenuation Processes

Destructive attenuation processes result in the permanent removal of contaminant mass from the environment and may reduce the time required to attain cleanup goals.

Distinguishing and documenting the effects of destructive attenuation processes, such as biodegradation, from nondestructive attenuation processes are critical to evaluating the potential for intrinsic remediation to bring about a continual reduction in contaminant mass over time. The effectiveness of destructive attenuation processes at reducing contaminant mass at a site depends on elimination of continuing sources of contamination, on how amenable contaminants are to biodegradation, and on whether the site is characterized by physical, chemical, and biological conditions favorable to biodegradation.

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of heating oil under both aerobic and anaerobic conditions (e.g., Jobson *et al.*, 1972; Perry, 1977; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, 1990; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989, 1990; Leahy and Colwell, 1990; Park *et al.*, 1990; Stieber *et al.*, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons will occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the soil and groundwater, and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms. Soils and groundwater with a history of exposure to fuel hydrocarbon compounds generally exhibit microbial populations competent to facilitate biodegradation reactions (e.g., Zobell, 1946; Litchfield and Clark, 1973; Borden, 1994; Seech *et al.*, 1994; Simpkin and Gresbrecht, 1994). The chemical basis for the biodegradation of fuel hydrocarbon compounds is described briefly in Section 6.4, where geochemical data relevant to documenting biodegradation at the field scale at Site OT45 are presented.

6.3 EVIDENCE OF FIELD-SCALE CONTAMINANT ATTENUATION

6.3.1 Historical Evidence of Contaminant Mass Loss from Soils

A comparison of the maximum and average soil concentrations of contaminants collected during the 1992, 1994, and 1996 investigations at Site OT45 can be a useful indicator that soil contamination is undergoing natural attenuation. Analytical soil data were not collected during the 1995 sampling event. Although direct, point-to-point comparisons of soil data can be problematic and questionable due to the lack of reproducibility inherent in soil sampling results (due to matrix heterogeneity), an overall perspective on contaminant loss from soils can be gained by examining the trends of maximum and average concentrations detected at a site. Examination of soil data indicates that phenanthrene and 1,2,4-TMB in soils appears to be rapidly attenuating.

Phenanthrene contamination appears to be located in a narrow band of saturated soils within and immediately downgradient from the former tank bed area at Site OT45 (Section 5.5 and Figure 5.1). Maximum concentrations of phenanthrene within this region appear to have decreased by an order of magnitude between the 1992 and 1994 sampling events. In 1992, five boreholes were installed within and immediately

downgradient from the suspected source area. The maximum concentration of phenanthrene (29,000 µg/kg) was detected in a saturated soil sample collected during the installation of MW-2 at a depth of 9-11 feet bgs (ICF, 1993). Six additional boreholes were completed within and immediately downgradient from the source area during the 1994 risk-based investigation. Soil samples were collected from the same narrow band of saturated soils determined to be most contaminated during the 1992 investigation. Results of this 1994 sampling event indicated that the maximum concentration of phenanthrene in this general area was 1,600 µg/kg. Maximum concentrations in this region appear to have decreased two orders of magnitude between the 1994 and 1996 sampling events. Results of the 1996 sampling event indicated that the maximum concentration of phenanthrene in this general area was 21 µg/kg.

The average concentration of phenanthrene measured at Site OT45 also decreased by an order of magnitude. For the purpose of this discussion, the average concentration of phenanthrene within contaminated soils at the site was calculated by summing the results of all samples collected from the narrow band of saturated soil contamination and dividing this sum by the total number of samples collected from this region. Because samples collected from this narrow band of saturated soil during 1992 and 1994 include all detected concentrations of phenanthrene, the average phenanthrene concentration calculated by this method is inclusive of all phenanthrene soil contamination detected at Site OT45. In 1992, the average concentration of phenanthrene within contaminated saturated soils was 11,050 µg/kg based on the results of the RI. In 1994, the average concentration of phenanthrene within contaminated saturated soils was 565 µg/kg. Only one soil sample location detected concentrations of phenanthrene in soil at 21 µg/kg during the 1996 sampling event. This observed trend in decreasing soil concentrations of phenanthrene is likely the combined result of phenanthrene being flushed from the saturated soil matrix by flowing groundwater, and of biodegradation within groundwater and the saturated soil matrix.

6.3.2 Historical Evidence of Contaminant Mass Loss from Groundwater

There are no groundwater COPCs for Site OT45 because no chemicals were detected during the 1995, 1996, and 1997 sampling events at concentrations in excess of MDEQ (1995b) most stringent industrial/commercial subcategory IV cleanup criteria (Section 4). However, the maximum dissolved concentrations of phenanthrene, 1,2,4-TMB, and 1,3,5-TMB detected in groundwater samples collected as part of the 1994 risk-based investigation exceeded generic residential screening criteria (MDEQ, 1995a). Because these contaminants may have the potential to migrate offsite at concentrations that exceed generic residential screening criteria, they have been retained for a brief chemical fate analysis.

Concentrations of these fuel-related chemicals detected in groundwater samples collected during the 1992, 1994, 1995, 1996, and/or 1997 sampling events provide significant evidence that dissolved fuel hydrocarbons are being effectively attenuated. Phenanthrene concentrations significantly decreased between the 1992 RI and the 1995 sampling event. In 1992, phenanthrene was detected only at MW-2 at a concentration of 1,500 µg/L (ICF, 1993). In 1994, the maximum detected concentration of phenanthrene of 70 µg/L was also measured at MW-2. Three other groundwater samples collected from sampling locations MPB, MW-5, and VW-1, which are located immediately downgradient from the source area, contained detectable concentrations of

phenanthrene that did not exceed the generic residential groundwater screening criterion of 26 µg/L (MDEQ, 1995a). In 1995, the maximum detected concentration of phenanthrene of 6 µg/L was measured at MW-2. Phenanthrene concentrations measured in groundwater samples collected from other locations near the source area also decreased between 1992 and 1995 (Table 5.2). The most recent 1995 analytical results indicate that dissolved phenanthrene is no longer present in onsite groundwater at concentrations above the most stringent MDEQ (1995a) generic residential groundwater criterion.

Analytical results for TMB isomers were not collected during the 1992 RI. However, data collected during the 1994, 1995, 1996, and 1997 sampling events indicate that dissolved concentrations of the TMB isomers also are decreasing. The maximum concentration of 1,2,4-TMB decreased from 82 µg/L to less than 0.5 µg/L in 3 years. The maximum concentration of 1,3,5-TMB decreased from 43 µg/L to less than 0.5 µg/L over this same time. No 1,3,5-TMB was measured in groundwater in 1995 above the most stringent MDEQ generic residential groundwater criterion (Table 5.2). Only the maximum concentration of 48 µg/L of 1,2,4-TMB, measured at well MW-2 in 1995, continued to exceed the most stringent MDEQ (1995a) generic residential groundwater criterion of 30 µg/L. No groundwater sample collected in 1996 and 1997 exceeded the most stringent MDEQ (1995a) generic residential groundwater criterion.

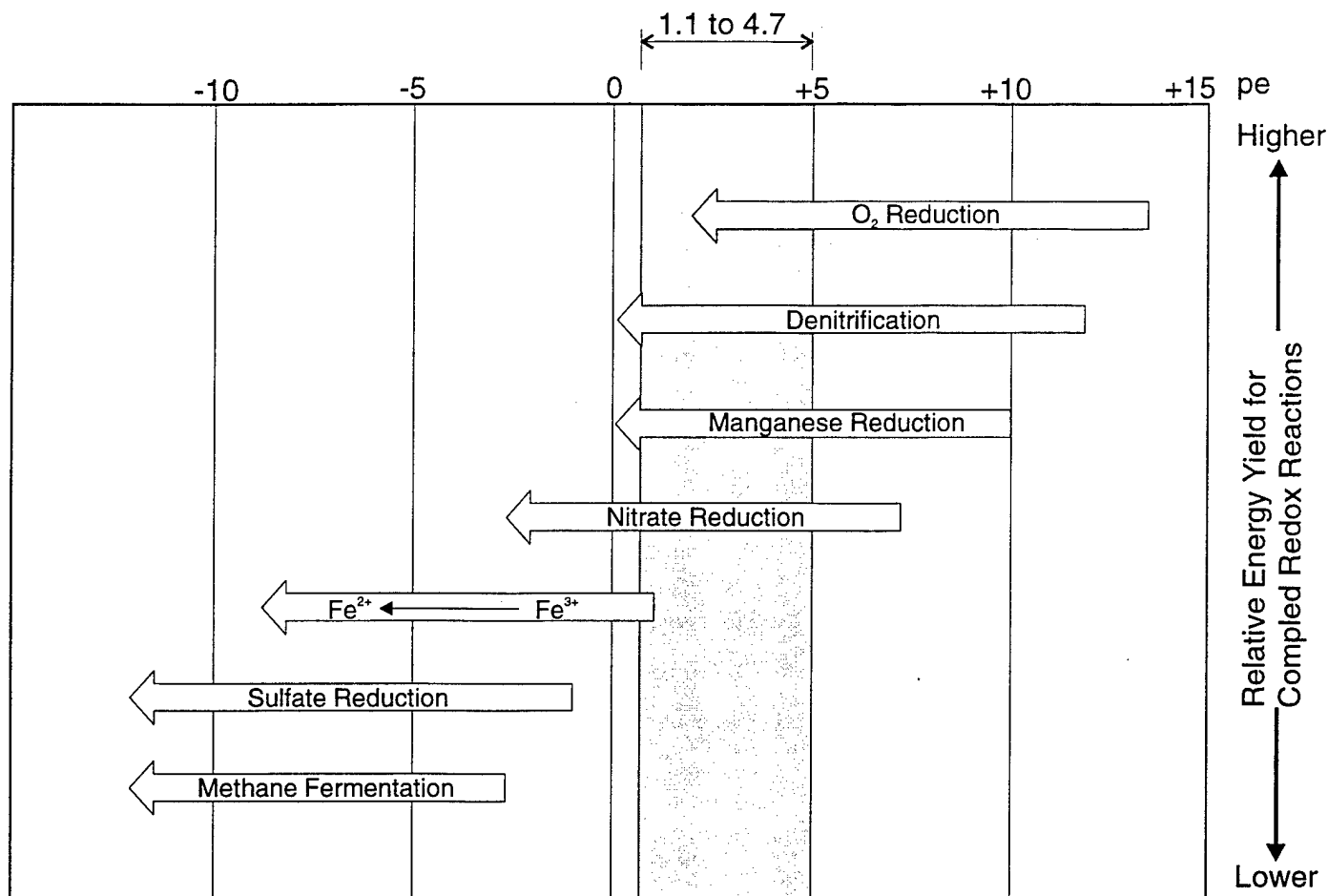
6.4 EVIDENCE OF CONTAMINANT BIODEGRADATION VIA MICROBIALLY CATALYZED REDOX REACTIONS

Because AFCEE and Parsons ES have been working in cooperation with the USEPA NRMRL to develop a protocol for documenting the potential for biodegradation of fuel hydrocarbons in saturated media at petroleum release site, data relevant to such quantitative investigations were collected at Site OT45. Because no fuel-related compounds were measured in onsite groundwater at or above concentrations that protect reasonable current and future receptors, there is no need to exhaustively document ongoing contaminant destruction via biological processes. However, these processes will influence the likelihood that site-related contamination could migrate to the Base boundary at concentrations above the most restrictive MDEQ target groundwater criteria (i.e., residential). Therefore, these data are summarized briefly herein in order to estimate the potential for offsite migration. A more complete explanation of these site data in terms of biodegradation potential is presented in Appendix D.

Figure 6.1 shows that oxygen, nitrate, manganese, and ferric iron may be available to be used as electron acceptors to biodegrade fuel hydrocarbon contaminants in saturated media at Site OT45. Analytical data on oxidized and reduced species are presented in the next subsections to illustrate which electron acceptors are likely being used to biodegrade residual concentrations of phenanthrene, 1,2,4-TMB, and 1,3,5-TMB in saturated soil and groundwater at Site OT45.

6.4.1 Dissolved Oxygen Concentrations

Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water



Notes

 Range of E_h (expressed as pe) measured at Site OT45

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.
2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the pe of the system.
3. The pe of the system determines which electron acceptors are available for fuel contaminant oxidation.
4. Redox sequence is paralleled by an ecological succession of biological mediators.

FIGURE 6.1

SEQUENCE OF MICROBIALY MEDIATED REDOX PROCESSES

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith, AFB, Michigan



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under aerobic conditions involves the use of oxygen as a cosubstrate during the initial stages of metabolism, and as a terminal electron acceptor during the later stages of metabolism for energy production (Higgins and Gilbert, 1978; Gibson and Subramanian, 1984; Young, 1984). The reduction of molecular oxygen during the oxidation of fuel hydrocarbon compounds yields a significant amount of free energy to the system that the microorganisms could utilize.

DO concentrations were measured at groundwater wells in 1994 and 1995. Because 1995 results did not differ significantly from 1994 results, Figure 6.2 presents only the 1994 analytical results for DO by sampling location. MW-10 is screened beneath and outside the contaminated groundwater plume, and therefore results collected from MW-10 are not reported in Figure 6.2. There is a strong correlation between areas of detected hydrocarbon concentrations and areas depleted of DO relative to measured background levels. The co-occurrence of low concentrations of DO with or near the detectable concentrations of fuel hydrocarbons indicates that oxygen is functioning as an electron acceptor during microbially mediated degradation of fuel hydrocarbons. The reduction of molecular oxygen during the degradation of fuel hydrocarbons will bring about a change in the types of processes and microorganisms involved in the biodegradation of onsite organic substrate.

6.4.2 Dissolved Nitrate and Nitrite Concentrations

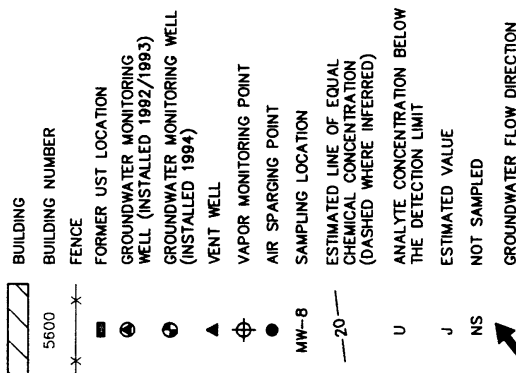
Once anaerobic conditions prevail in the groundwater, nitrate can be used as an electron acceptor by facultative anaerobic microorganisms to mineralize fuel hydrocarbon compounds via either denitrification or nitrate reduction processes. Denitrification is the most energetically favorable of the redox reactions likely to be involved in the oxidation of the contaminants (Figure 6.1 and Appendix D). Although the oxidation of the fuel hydrocarbon compounds by nitrate reduction also will yield significant amounts of free energy for microbial use, nitrate reduction is not as energetically favorable as other potential redox reactions. However, nitrate reduction may take precedence over denitrification at Site OT45 as the groundwater becomes more reducing.

Concentrations of both nitrate and nitrite were measured at groundwater wells in 1994 and 1995. Because 1995 results did not differ significantly from the 1994 results, Figures 6.2 and 6.3 present only the 1994 analytical data for nitrate and nitrite, respectively (excluding data from MW-10). There is a general correlation between areas of detectable fuel hydrocarbon concentrations and areas depleted in nitrate relative to measured background concentrations. Low concentrations of nitrate (the oxidized electron acceptor) and elevated concentrations of nitrite (the partially reduced electron acceptor) relative to background levels suggest that nitrate may be functioning as an electron acceptor.

6.4.3 Dissolved Manganese Concentrations

Manganese also can be used as an electron acceptor to facilitate the oxidation of fuel hydrocarbon compounds under anaerobic and slightly reducing conditions. In fact, as Figure 6.1 shows, manganese reduction can be microbially facilitated in groundwater conditions similar to those required to support denitrification.

LEGEND



NOTE: ANALYTICAL DATA AND CONCENTRATION CONTOURS FOR 1,2,4-TRIMETHYLBENZENE ARE PRESENTED FOR GROUNDWATER SAMPLES COLLECTED AS PART OF THE 1995 RISK-BASED INVESTIGATION. GEOCHEMICAL INDICATOR CONCENTRATIONS WERE CONSISTENT IN GROUNDWATER SAMPLES COLLECTED AS PART OF BOTH THE 1994 AND 1995 RISK-BASED INVESTIGATION FIELD EFFORTS, AND THEREFORE ONLY THE 1994 DATA ARE PRESENTED HERE.

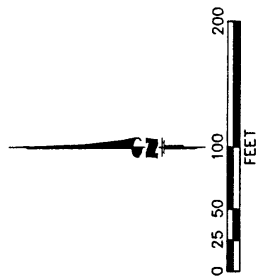
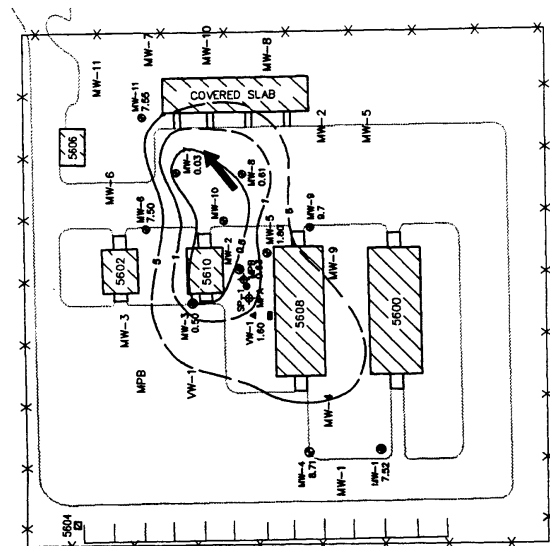


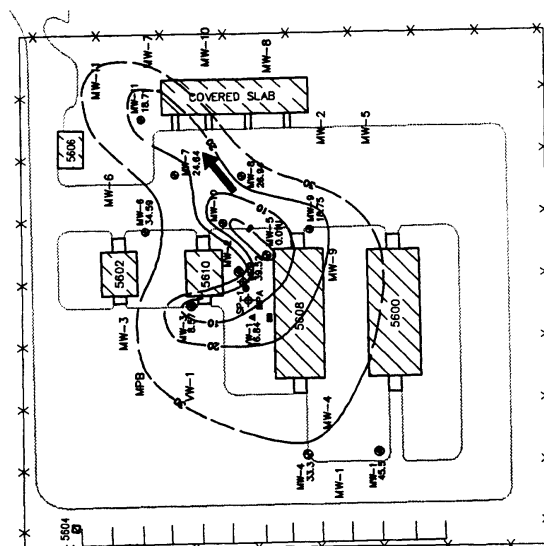
FIGURE 6.2
EXTENT OF OXIDIZED
ELECTRON ACCEPTORS
(1994)

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Site OT45
Wurtsmith AFB, Michigan

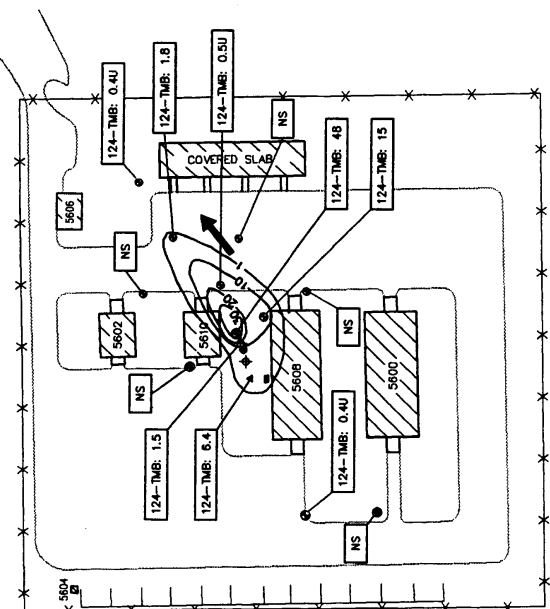
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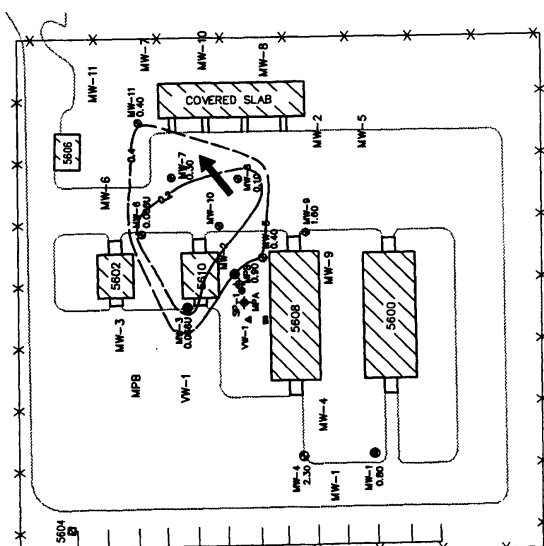
DISSOLVED OXYGEN (mg/L)



SULFATE (mg/L)

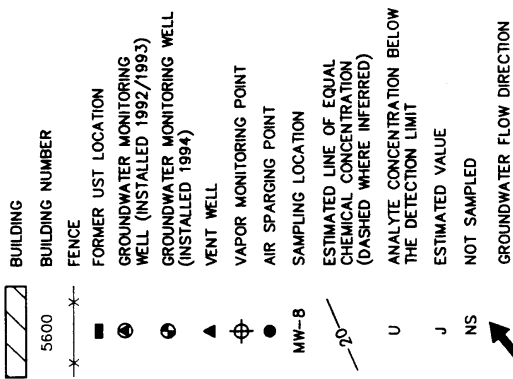


1,2,4-TRIMETHYLBENZENE (µg/L)



NITRATE (mg/L)

LEGEND



NOTE:
 ANALYTICAL DATA AND CONCENTRATION CONTOURS FOR 1,2,4-TRIMETHYLBENZENE ARE PRESENTED FOR GROUNDWATER SAMPLES COLLECTED AS PART OF THE 1995 RISK-BASED INVESTIGATION. GEOCHEMICAL INDICATOR CONCENTRATIONS WERE CONSISTENT IN GROUNDWATER SAMPLES COLLECTED AS PART OF BOTH THE 1984 AND 1995 RISK-BASED INVESTIGATION FIELD EFFORTS, AND THEREFORE ONLY THE 1994 DATA ARE PRESENTED HERE.



FIGURE 6.3

EXTENT OF BYPRODUCTS OF ELECTRON ACCEPTOR REDUCTION (1994)

Remedial Action Plan
 Risk-Based Approach to Remediation
 Site OT45
 Wurtsmith AFB, Michigan



MANGANESE (mg/L)

METHANE (mg/L)

NITRITE (mg/L)

SULFIDE (mg/L)

1,2,4-TRIMETHYLBENZENE (μ g/L)

FERROUS IRON (mg/L)

Reduced forms of manganese were measured at groundwater wells in 1994 and 1995. Figure 6.3 shows the 1994 analytical results for reduced manganese measured in groundwater by sampling location. Because manganese (Mn^{3+}) is used as an electron acceptor in the oxidation of onsite organic compounds such as fuel hydrocarbons, an increase in the total concentration of dissolved reduced manganese (Mn^{2+}) is a good geochemical indicator that contaminants are being biodegraded via manganese reduction. This is the data trend observed at Site OT45. Elevated concentrations of reduced forms of manganese relative to measured background concentrations correlate well with areas of detected concentrations of fuel hydrocarbon compounds in saturated soil and groundwater. Thus, these analytical data indicate that manganese is being used as an electron acceptor in biodegradation reactions at Site OT45.

6.4.4 Ferrous Iron Concentrations

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). To determine if ferric iron is being used as an electron acceptor at Site OT45, ferrous iron concentrations were measured at groundwater wells in 1994 and 1995. Figure 6.3 presents the 1994 analytical results for dissolved ferrous iron in groundwater at the site (1995 results were similar to those from 1994). As with manganese, areas characterized by detected concentrations of fuel hydrocarbons correspond well with areas of elevated concentrations of ferrous iron relative to measured background concentrations. These analytical data suggest that iron-reducing microorganisms are present in the saturated soil and groundwater at the site, and that these microorganisms are using ferric iron to oxidize organic compounds such as hydrocarbons.

6.4.5 Sulfate Concentrations

Sulfate also may be used as an electron acceptor during microbial degradation of fuel hydrocarbons under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. The presence of decreased concentrations of sulfate in the source area relative to background concentrations indicates that sulfate may be used to oxidize (degrade) organic compounds at the site.

Figure 6.2 shows the 1994 analytical results for sulfate in groundwater. In general, areas where detectable concentrations of fuel hydrocarbons were measured are depleted in sulfate concentrations relative to measured background concentrations. This depletion of sulfate within the previous source area suggests that this compound is acting as an electron acceptor. Complete reduction of sulfate should yield sulfide ions. However, no clear trend of sulfide production can be discerned from field data collected as part of the 1994 investigation (Figure 6.3).

6.4.6 Methane Concentrations

The carbon dioxide-methane (CO_2-CH_4) redox couple also can be used to oxidize fuel hydrocarbon compounds to carbon dioxide and water once the groundwater is sufficiently reducing. To attain these reducing levels, other highly oxidizing chemical species such as oxygen, nitrate, and manganese must be reduced. This redox reaction is called methanogenesis or methane fermentation. Methanogenesis yields the least free

energy to the system in comparison to other chemical species (Figure 6.1 and Appendix D). The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

Methane concentrations were measured at groundwater monitoring wells in September 1994. Figure 6.3 presents the analytical data for methane by sampling location. Methane was detected at only one groundwater sampling location near the detection limit (MW-3). No methane was detected in groundwater samples from within or immediately downgradient from the former UST site. The absence of methane in groundwater at Site OT45 indicates that biodegradation processes are not occurring via methanogenesis. This is likely due to the relatively low concentrations of contaminants at the site. The mass of reactive organic material present in the saturated soil and groundwater is insufficient to reduce the oxidizing capacity to levels required for methanogenesis.

6.5 PREDICTING CHEMICAL FATE OVER TIME

The behavior of contaminants under the influence of natural attenuation processes must be estimated to predict the extent that any chemical could migrate, and to assess the effects on chemical persistence, mass, concentration, and toxicity over time at a site. If destructive and nondestructive attenuation processes can sufficiently minimize or eliminate the concentrations of contaminants to which any receptor could be exposed, remedial action may not be warranted because no reasonable exposure pathway exists or completion of the exposure pathway would result in insignificant risks. The focus of this final section is to demonstrate that no chemicals measured in onsite media at Site OT45 will migrate to the Base boundary at concentrations above the most stringent MDEQ cleanup criteria, and in fact, that onsite concentrations of both chemicals of interest in soil and in groundwater are verified to have already decreased below the most restrictive MDEQ residential criteria.

6.5.1 Contaminant Partitioning from Soils

Phenanthrene and 1,2,4-TMB were measured in saturated soils in 1994 at concentrations above the respective industrial/commercial subcategory IV soil leaching criteria (Table 4.3). However, concentrations of phenanthrene and 1,2,4-TMB measured in groundwater during the 1994 sampling event suggest that the formula for calculating the generic soil leachate criteria (Table 4.1) may overestimate the allowable concentrations of soil contaminants that are protective of underlying groundwater. Maximum concentrations of both contaminants detected in groundwater samples collected in 1994 were below generic industrial/commercial subcategory IV groundwater cleanup criteria (Table 4.4).

Defining how phenanthrene and 1,2,4-TMB partition from saturated soil and dissolve into groundwater based on site-specific analytical data can provide valuable insight as to whether residual soil contamination poses a threat to groundwater quality. Desorption of phenanthrene and 1,2,4-TMB from saturated soils into groundwater can be approximated by a simple equilibrium partitioning relationship. The most common equilibrium model used to describe the amount of contaminant that will remain sorbed to the soil and the amount of contaminant that will dissolve into groundwater is the distribution partition coefficient (K_D). The linear distribution partition coefficient is

calculated by multiplying the chemical's solubility in water normalized for TOC content (K_{oc}) and the fractional organic carbon content (f_{oc}) of the soil matrix. Appendix D presents the calculated site-specific K_D values for phenanthrene and 1,2,4-TMB.

Leaching from saturated soils into groundwater was simulated for Site OT45 using a K_D -based equilibrium relationship that accounts for groundwater movement through the affected soil over time. Uncontaminated groundwater flows into the contaminated volume of saturated source soils at the linear velocity of the shallow aquifer. Contaminants sorbed to the soil matrix would leach from the soil into the uncontaminated groundwater, which would then flow from the downgradient edge of the contaminated source soils. The amount of contaminant that would leach from the source soils into each new volume of uncontaminated groundwater depends upon the residual concentration of contaminant in the soil and the chemical-specific K_D . The leaching model calculations and input values are more fully described in Appendix D.

These calculations were calibrated by matching maximum 1992 soil concentrations of phenanthrene (sorbed mass) to maximum 1992 groundwater concentrations of phenanthrene (dissolved mass). The amount of contaminant that was predicted to have partitioned from the soil and dissolved into groundwater was in good agreement with 1992 groundwater analytical results. This simple relationship was then used to predict the amount of phenanthrene that should have been measured in soil and groundwater during the 1994 and 1995 sampling events (i.e., 690 and 1040 days from the 1992 sampling event). Changes in 1,2,4-TMB soil and groundwater concentrations measured as part of the 1994 and 1995 sampling events were used to verify the reasonableness of this calculation. The predicted concentrations of phenanthrene and 1,2,4-TMB were in good agreement with the maximum concentrations measured in 1994 and 1995.

Table 6.1 presents the results of these calculations. It is important to note that this calculation only accounts for the physical and chemical processes involved in contaminant leaching from saturated soils. This calculation does not consider how much contaminant mass could be biodegraded in saturated soils over time.

These calculations indicate that both soil COPCs should have been reduced below the generic industrial/commercial subcategory IV soil leaching criterion in late 1994 or early 1995. The calculation also indicates that operative nondestructive contaminant attenuation processes are expected to have been sufficient to reduce residual soil COPC concentrations to levels at or below MDEQ generic residential soil leaching criteria by mid-1996. This has been verified by the 1996 soil sampling event.

6.5.2 Anticipated Extent of Migration in Groundwater

One of the stated objectives of this evaluation was to determine whether onsite concentrations of dissolved, detectable chemicals could migrate in groundwater to the Base boundary at concentrations above the most stringent MDEQ (1995a) residential criteria.

TABLE 6.1
SATURATED SOIL LEACHING CALCULATIONS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Days	Phenanthrene Soil Concn.	Phenanthrene Water Concn.	1,2,4-TMB Soil Concn.	1,2,4-TMB Water Concn.
0 (1992)	29000.0	1528.3	29000.0	1491.0
2.5	28712.7	1513.1	28719.7	1476.6
5	28428.2	1498.1	28442.1	1462.3
7.5	28146.6	1483.3	28167.2	1448.2
10	27867.7	1468.6	27894.9	1434.2
12.5	27591.6	1454.1	27625.3	1420.3
15	27318.2	1439.7	27358.3	1406.6
17.5	27047.6	1425.4	27093.8	1393.0
20	26779.6	1411.3	26831.9	1379.5
22.5	26514.3	1397.3	26572.6	1366.2
25	26251.6	1383.4	26315.7	1353.0
27.5	25991.5	1369.7	26061.4	1339.9
30	25734.0	1356.2	25809.5	1327.0
725 (1994)	1615.8	85.1	2200.0	81.7
745	1592.1	78.6	2080.0	77.3
812.5	1140.3	60.1	1221.4	64.0
1010	519.1	27.4	989.5	36.8
1095 (1995)	370.2	19.5	779.7	29.0
1230	216.2	11.4	517.9	20.8

Dark shade boxes indicate when soil concentrations are expected to no longer exceed generic industrial/commercial subcategory IV leaching criteria.
 Light shade boxes indicate when soil concentrations are expected to no longer exceed generic residential leaching criteria.

Based on 1992, 1994, 1995, 1996, and 1997 analytical data reviewed in this RAP, concentrations of fuel hydrocarbon compounds have been decreasing over time due to both destructive and nondestructive attenuation processes. Site analytical data on electron acceptors (Section 6.4) and simple, site-specific biodegradation rate estimates (Appendix D) demonstrate that biodegradation has been and is expected to be a major process involved in the environmental fate of contaminants in saturated soils and groundwater at Site OT45.

As indicated by 1995 sampling results, natural chemical attenuation mechanisms acting at Site OT45 have already reduced concentrations of phenanthrene and 1,3,5-TMB in onsite groundwater to below the most stringent MDEQ residential groundwater cleanup criteria. Additionally, partitioning estimates indicate that the rates of dissolution of soil contaminants into groundwater are and will continue to decline. Therefore, 1,2,4-TMB was the only chemical measured in groundwater in 1995 that could even conceivably migrate to the Base boundary at concentrations above the MDEQ most restrictive residential groundwater criterion.

Based on information developed in this section and in Appendix D, 1,2,4-TMB is not expected to persist in onsite groundwater at concentrations above their MDEQ generic residential criteria. This has been verified during the 1996 and 1997 sampling events.

6.6 CONCLUSIONS

The important points of this section are summarized as follow:

- Historical contaminant reductions and geochemical evidence suggests that organic compounds such as phenanthrene, 1,2,4-TMB, and 1,3,5-TMB are biodegrading in saturated soils and groundwater at Site OT45 via oxygen reduction, nitrate reduction, manganese reduction, ferric iron reduction, and sulfate reduction;
- Simple soil/water partitioning estimates verified by field sampling indicate that residual concentrations of soil chemicals of interest do not present a threat to underlying groundwater quality; and
- No detected fuel hydrocarbon compound will continue to exist in the dissolved phase at concentrations above its most stringent generic residential cleanup criteria as verified in the 1995, 1996, and 1997 sampling events.

Available site analytical data and these simple chemical fate estimates indicate that residual concentrations of fuel-related compounds have been already reduced onsite to concentrations that are adequately protective of potential onsite and downgradient receptors. Therefore, Site OT45 is eligible for closure pursuant to the intent of PA 451.

SECTION 7

IMPLEMENTATION PLAN FOR SITE CLOSURE

This section summarizes the recommendation for no further action at Site OT45.

7.1 RECOMMENDATION FOR CLOSURE

Soil chemicals of interest conservatively identified based on data collected in 1994 include phenanthrene and 1,2,4-TMB. Maximum concentrations of phenanthrene and 1,2,4-TMB measured in saturated soil samples collected in 1994 exceeded MDEQ generic industrial/commercial subcategory IV soil leaching criteria (Table 4.1). No other chemicals were detected at concentrations above health-protective soil criteria. Confirmation sampling completed in 1996 indicate no contaminant exists in saturated soils above the MDEQ generic industrial/commercial subcategory IV soil leaching criteria (Table 4.1).

Groundwater analytical data collected during the 1994 and 1995 sampling events suggest that the generic soil leaching criteria do not accurately represent the allowable residual soil concentrations that are protective of underlying groundwater quality. None of these chemicals were measured in groundwater in 1995 at concentrations above those defined by MDEQ (1995b) to be protective of onsite industrial/commercial receptors who use groundwater as a drinking source. Furthermore, simple soil/water equilibrium partitioning calculations (Section 6) and the confirmation sampling indicate that the maximum concentrations of soil chemicals of interest have been reduced below generic industrial/commercial subcategory IV soil leaching criteria (MDEQ, 1995a) and generic residential soil leaching criteria as a result of natural chemical attenuation processes. Therefore, no further action is required to remediate site soils.

No groundwater COPCs were identified as part of either the 1994 or 1995 sampling events. Groundwater analytical data, collected during the October 1995 sampling event, indicate that 1,2,4-TMB was the only chemical detected in groundwater at concentrations above even the most restrictive MDEQ generic residential groundwater cleanup criteria, which are not levels necessary to achieve to protect current and hypothetical future onsite receptors. Section 6 demonstrates that ongoing nondestructive and destructive attenuation mechanisms are expected to prevent concentrations of 1,2,4-TMB in excess of generic residential cleanup criteria from even approaching the downgradient Base boundary. This has been verified by sampling events in 1996 and 1997.

7.1.1 Land and Groundwater Use Controls

An important element of any decision to close a site is verifying that residual contaminant concentrations are adequately protective of onsite receptors, both now and in the future. Based on soil (1996) and groundwater (1996 and 1997) data, the site is currently acceptable for unrestricted use (provided onsite activities will result in receptor exposures similar to those assumed in the generic algorithms). It is recommended that the land use at the site be unrestricted.

7.1.2 Preparation of Closure Request Documentation

Based on the results and conclusions of this RAP, site closure will be pursued with the MDEQ. To assist the MDEQ project manager in assessing current site conditions and reviewing the recommendation for closure, a No Further Remedial Action Planned Decision Document will be completed and submitted under separate cover to the MDEQ for review and processing. This closure report will summarize site characteristics, site assessment activities, the tiered evaluation, and verification sampling results.

REFERENCES

- Altenschmidt, U. and Fuchs, G., 1991, Anaerobic degradation of toluene in denitrifying *Pseudomonas* sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: *Arch. Microbial.*, vol. 156, p. 152-158.
- Alvarez, P.J.J., and Vogel, T.M., 1991, Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: *Applied and Environmental Microbiology*, vol. 57, p. 2981-2985.
- American Society for Testing and Materials (ASTM), 1995, Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, ES 38-94.
- Arthur D. Little, 1987, *The Installation Restoration Program Toxicology Guide*. Vol. 3. P. 64-7 - 64-14. June.
- Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons - an environmental perspective: *Microbiological Reviews*, vol. 45, no. 1, p. 180-209.
- Atlas, R.M., 1984, *Petroleum Microbiology*: Macmillan Publishing Company, New York.
- Atlas, R.M., 1988, *Microbiology - Fundamentals and Applications*: Macmillan Publishing Company, New York.
- Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M., 1988, The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species and geochemical facies, In: G.E. Mallard, and SE. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.
- Baedecker, M.J., and Cozzarelli, I.M., 1991, Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.
- Bartha, R., 1986, Biotechnology of petroleum pollutant biodegradation: *Microbial Ecology*, vol. 12, p. 155-172.
- Bauman, B, 1991, Biodegradation research of the American Petroleum Institute. Presented at: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. San Diego, CA. March 19-21, 1991.
- Beller, H.R. Reinhard, M., and Grbic-Galic, D., 1992, Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: *Appl. Environ. Microbiol.*, vol. 58, p. 3192-3195.

- Bohon, R.L., and Claussen, W.F., 1951, The solubility of aromatic hydrocarbons in water: *Journal of American Chemical Society*, vol. 73, no. 4, p.1571-1578.
- Borden, R.C., 1991, Simulation of enhanced in situ bioremediation of petroleum hydrocarbons. In: *In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation*. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 529-534.
- Borden, R.C., 1994, Natural Bioremediation of Hydrocarbon-Contaminated Ground Water: In: *Handbook of Bioremediation*. Lewis Publishers. Boca Raton, FL. 1994.
- Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants, In: Mitchell, R., ed.: *Environmental Microbiology*. Wiley-Liss, New York, New York.
- Brown, R.A., Dey, J.C. and McFarland, W.E., 1991, Integrated site remediation combining groundwater treatment, soil vapor extraction, and bioremediation, In: *In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation*. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 444-449.
- Buschech, T.E. and Alcantar, C.M., 1995, Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation. *Proceedings of the Battelle In Situ and On-Site Bioreclamation Symposium*, April 24-27, 1995. San Diego, California.
- Chapelle, F.H., 1993, *Ground-water Microbiology and Geochemistry*. John Wiley and Sons, Inc., New York, NY.
- Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L., 1989, Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: *Ground Water*, vol. 27, no. 6, p. 823-834.
- Davis, J.W., Klier, N.J., and Carpenter, 1994, Natural biological attenuation of benzene in ground water beneath a manufacturing facility: *Ground Water*, vol. 32, no. 2, p. 215-226.
- Downey, D.C., and Hall, J.F. 1994. Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing - Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential. Prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas.
- Edwards, E.A., and Grbic-Galic, D., 1992, Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: *Appl. Environ. Microbiol.*, vol. 58, p. 2663-2666.
- Gibson, D.T., and Subramanian, V., 1984, Microbial degradation of aromatic hydrocarbons, In: *Microbial Degradation of Organic Compounds*, Ed., D.T. Gibson, Marcel Dekker, Inc., p. 181-252.
- Grbic-Galic, D., 1989, Microbial degradation of homocyclic and heterocyclic aromatic hydrocarbons under conditions: *Dev. Ind. Microbiol.*, vol. 30, p. 237-253.

- Grbic-Galic, D., 1990, Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments, In: Bollag, J.M., and Stotzky, G., eds.: Soil Biochemistry: Marcel Dekker, Inc., New York, NY. p. 117-189.
- Haag, F., Reinhard, M., and McCarty, P.L., 1991, Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: Environ. Toxicol. Chem., vol. 10, p. 1379-1389.
- Higgins, I.J., and Gilbert, P.D., 1978, The biodegradation of hydrocarbons, In: K.W.A. Chator and H.J. Somerville, editors, The Oil Industry and Microbial Ecosystems: Heyden and Sons, London, p. 80-114.
- Hinchee, R.E., Ong, S.K., Miller, R.N., Downey, D.C., and Frandt, R. 1992. Test Plan and Technical Protocol for a Field Treatability Test for Bioventing. Prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas. January.
- Hutchins, S.R., and Wilson, J.T., 1991, Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 157-172.
- ICF Technology, Inc. 1993. Draft Remedial Investigation Report, Delivery Order 10. Prepared for Wurtsmith Air Force Base, Oscoda, Michigan. April 7.
- ICF Technology, Inc. 1994. Draft Feasibility Study Report, Delivery Order Number 10, Sites: OT41/SS-42, OT-45, OT-46. Prepared for Wurtsmith Air Force Base, Oscoda, Michigan. January 5.
- Jobson, A.F., Cook, F.D., and Westlake, D.W., 1972, Microbial utilization of crude oil. Applied and Environmental Microbiology, vol. 23, p. 1082-1089.
- Leahy, J.G., and Colewell, R.R., 1990, Microbial Degradation of Hydrocarbons in the Environment: Microbiological Reviews, vo. 53, no. 3, p. 305-315.
- Lee, M.D., 1988, Biore Restoration of Aquifers Contaminated with Organic Compounds: CRC Critical Reviews in Environmental Control. vol. 18. p. 29-89.
- Litchfield, J.H., and Clark, L.C., 1973, Bacterial Activities in Ground Waters Containing Petroleum Products. American Petroleum Institute. Pub. No. 4211.
- Lovley, D.R., and Phillips, E.J.P., 1988, Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron or manganese. Applied and Environmental Microbiology, vol. 56, no. 6, p. 1472-1480.
- Malone, D.R., Kao, C.M., and Borden, R.C., 1993, Dissolution and biore restoration of nonaqueous phase hydrocarbons - models development and laboratory evaluation: Water Resources Research, vol. 29, no. 7, p. 2003-2213.
- Mehran, M., Olsen, R.L., and Rector, B.M., 1987, Distribution Coefficient of Trichloroethylene in Soil-Water Systems. Groundwater. 25(3).

Michigan Department of Environmental Quality (MDEQ) (formerly Michigan Department of Natural Resources [MDNR]), Environmental Response Division (ERD). 1990. Interoffice Communication, To: All Environmental Response Division Field Staff, From: James G. Truchan, Chief Environmental Response Division, Subject: Act 307 Rule Implementation Manual. November 30.

Michigan Department of Environmental Quality (MDEQ) (formerly Michigan Department of Natural Resources [MDNR]), Environmental Response Division (ERD). 1994a. Interoffice Communication, To: Environmental Response Division Staff, From: Alan J. Howard, Chief, Environmental Response Division, Subject: MERA Operational Memorandum #6, Revision #3 - Analytical Detection Level Guidance for Environmental Contamination Response Activities under Act 307 Rules, February 4.

Michigan Department of Environmental Quality (MDEQ) (formerly Michigan Department of Natural Resources [MDNR]), Environmental Response Division (ERD). 1994b. Guidance Document, Verification of Soil Remediation, Revision 1. Prepared by the Waste Management Division. April.

Michigan Department of Environmental Quality (MDEQ) Environmental Response Division (ERD). 1995a. Interoffice Communication, To: Environmental Response Division Staff, From: Alan J. Howard, Chief, Environmental Response Division, Subject: MERA Operational Memorandum #8, Revision 4 - Generic Residential Cleanup Criteria, June 5.

Michigan Department of Environmental Quality (MDEQ) (formerly Michigan Department of Natural Resources [MDNR]), Environmental Response Division (ERD). 1995b. Interoffice Communication, To: Environmental Response Division Staff, From: Alan J. Howard, Chief, Environmental Response Division, Subject: MERA Operational Memorandum #14, Revision 2 - Remedial Action Plans Using Generic Industrial or Generic Commercial Cleanup Criteria and Other Requirements, June 6.

Montgomery, John H. and Welkom, Linda M. 1990. Groundwater Chemicals Desk Reference. Lewis Publishers, Michigan.

Occupational Safety and Health Administration (OSHA), 1994.

Park, K.S., Sims, RC, and Dupont, R.R., 1990, Transformation of PAHs in Soil Systems, Journal of Environmental Engineering, Vol. 116, no. 3, pp. 632-640.

Parsons Engineering Science, Inc. 1994a. Final Work Plan for a Remedial Action Plan in Support of the Risk-Based Approach to Remediation at Site OT45, Wurtsmith Air Force Base, Oscoda, Michigan. Prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas. December.

Parsons Engineering Science, Inc. 1994b, Draft Intrinsic Remediation Engineering Evaluation/Cost Analysis for the Site FT-002. Prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas and Plattsburgh Air Force Base, New York. November.

Perry, J.J., 1977, Microbial metabolism of cyclic hydrocarbons and related compounds, Critical Reviews in Microbiology, vol., 5, p. 387-412.

- Rama Rao & Alfred, Inc. 1992. Final Study Report Hydrogeological Survey, Wurtsmith Air Force Base, Oscoda, Michigan. May 22.
- Reinhard, M., Goodman, N.L., and Barker, J.F., 1984, Occurrence and distribution of organic chemicals in two landfill leachate plumes: *Environ. Sci. Technol.*, vol. 18, no. 12, p. 953-961.
- Seech, A.G., Marvan I.J., and Trevors, J.T., 1994, Bioremediation of Industrial Soils Containing Chlorinated Phenols and Polycyclic Aromatic Hydrocarbons *in* Bioremediation of Chlorinated and Polycyclic Aromatic Hydrocarbon Compounds. Eds., E. Hinchee, A. Leeson, L. Simprini, and S.K. Ong. Lewis Publishers, Ann Arbor.
- Simpkin, T.J., and Gresbrecht, G., 1994, Bioremediation of Polycyclic Aromatic Hydrocarbons in Sediments from and Industrial Complex *in* Bioremediation of Chlorinated and Polycyclic Aromatic Hydrocarbon Compounds. Eds., E. Hinchee, A. Leeson, L. Simprini, and S.K. Ong. Lewis Publishers, Ann Arbor.
- Stieber, M., K. Böckle, P. Werner, and F.H. Frimmel. 1990. "Biodegradation of Polycyclic Aromatic Hydrocarbons (PAH) in the Subsurface." IN F. Arend, M. Hinseveld, and W. J. Van den Brink (Eds.), *Contaminated Soil 1990*, pp. 473-479. Kluwer Academic Publishers, Netherlands.
- Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M., 1992, Natural degradation rates of BTEX compounds and naphthalene in a sulfate reducing ground water environment, In: *In-Situ Bioremediation Symposium "92"*. Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.
- TOMES (Micromedex, Inc.), 1995, Toxicological Occupational Medicine, and Environmental Series (TOMES) plus Database, Vol 25. Denver, Colorado.
- US Air Force. 1993. Preliminary Final Environmental Impact Statement, Disposal and Reuse of Wurtsmith Air Force Base, Michigan. Internal Working Draft, Not for Public Release, June 1993.
- US Environmental Protection Agency (EPA). 1986. Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber. User's Guide Prepared by M.R. Klenbusch under EPA Contract No. 68-02-3889.
- US Environmental Protection Agency. 1987. Compendium of Superfund Field Operations Methods. Office of Emergency and Remedial Response. EPA/540/P-87/001. (OSWER Directive 9355.0-14)
- US Environmental Protection Agency. 1994. Fact Sheet, Health Risk Assessments for Superfund Sites, Region VIII.
- US Geological Survey (USGS). 1990. Installation Restoration Program Phase II - Confirmation/Quantification Stage 2, Wurtsmith Air Force Base, Michigan: Hydrogeology Near Wurtsmith Air Force Base, Michigan. Prepared for Air Force Environmental Quality Branch Headquarters, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. September.

- Verschueren, K., 1983, Handbook of Environmental Data on Organic Chemicals. Van Nostrand Reinhold Co., New York, New York.
- Weidemeier, T.H., Downey, D.C., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E. 1995. Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-term Monitoring Option for Dissolved-phase Fuel Contamination in Ground Water. Prepared by the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas.
- Wilson, B.H., Smith, G.B., and Rees, J.F., 1986, Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: Environmental Science and Technology, 20(10):997-1002.
- Wilson, B.H., Bledsoe, B., and Kampbell, D., 1987, Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, Chemical Quality of Water and the Hydrologic Cycle. Lewis Publishers, Chelsea, Michigan, p.125-137.
- Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M., 1990, Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: Geomicrobiology Journal, 8:225-240.
- Young, L.Y., 1984, Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: Microbial Degradation of Aromatic Compounds. Marcel-Dekker, New York.
- Zobell, C.E., 1946, Action of microorganisms on hydrocarbons: Bacterial. Review. vol. 10, p. 1-49.

APPENDIX A
BORING LOGS, WELL CONSTRUCTION DIAGRAMS, AND
WELL DEVELOPMENT DATA

BOREHOLE LOG

SITE NAME AND LOCATION		DRILLING METHOD: HSA		BORING NO.	
Jurtsmith AFB				MW4-0745	
C-45				SHEET	
		SAMPLING METHOD: Split spoon		1 OF 1	
				DRILLING	
				START	FINISH
		WATER LEVEL	9.5	TIME	TIME
		TIME		15:15	16:00
		DATE		DATE	DATE
		CASING DEPTH		9/29/90	9/29/90

collected MS-HSD
 Temporary well - completed as permanent well

ATUM _____ ELEVATION _____

[illegible]

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION Wurtsmith AFB C-45				DRILLING METHOD: HSA				BORING NO. MW 7-0745	
				SAMPLING METHOD: Split spoon				SHEET 5	
								(1 OF 1)	
				DRILLING					
				START		FINISH			
WATER LEVEL 9.5				TIME		TIME			
TIME				0738		09:00			
DATE				DATE		DATE			
CASING DEPTH				9/29/94		9/29/94			

Samples BTEX PWA
 2-202 1-202
 ATUM ELEVATION

BELL RIG							SURFACE CONDITIONS							
ANGLE BEARING														
AMPLE HAMMER TORQUE FT.-LBS														
DEPTH/FEET (ELEVATION)	BLOWS/ AN ON SAMPLER (RECOVERY)	CORES				SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		PERMEABILITY CM./SEC.
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH IN FEET	FROM	

Depth (ft)	Soil Description	Test Results
0 - 4	Sand, dk brn Sand, orange-br Sand, tan, m-gr SAA, f m-gr, f-gr	3777 56 16 32 20
4 - 8	SAA, md-gr ~1" clay layer	3 5 6ppm
8 - 10	SAA m-c gr	18ppm
10 - 12	Cuttings, gray fuel odor	10b 24ppm
12 - 16	TD=16	13 15 6ppm

Figure A.1
Geologic Boring Log

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION

Wurtsmith AFB

DRILLING METHOD:

HSA 3 1/4 ID

BORING NO.

MW 7

Change 2' to 4' 4"

SHEET

1 of 1

SAMPLING METHOD:

0-8 5' core barrel

DRILLING

8- 2' split spec.

START

FINISH

WATER LEVEL 9.0

TIME

TIME

TIME

1650

0

DATE

DATE

DATE

CASING DEPTH

9/27

9/28

DATUM

ELEVATION

DRILL RIG ACER SOIL MAX

SURFACE CONDITIONS

ANGLE

BEARING

SAMPLE HAMMER TORQUE

FT.-LBS

DEPTH (FEET)	BLOWS/AN ON SAMPLER (RECOVERY)	CORES				SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH IN FEET	TO	PERMEABILITY (CM/SEC)
0						Gravel pavement						0	2.5	15 ppm
2						SAND, f-m, tan-orange-brn lam. no odor, moist								
4						SAA - 5' light color, ~ 1/2" silt @ ~ 7'						2.5	7.5	8 ppm
6	44					SAND, f-m, thin silty clayey silt lenses ~ 1/2" stain, no odor		WL drilled - 9'				8	10	10 ppm lab
8	34					SAND, f-m, tan wet no odor								
10	33													
12														
14														
16	23					SAA, incr. gr size coarse-VC @ 17'		TOC 15' 1823						
18	65													

CTI
DRILLING CONTR

RL

LOGGED BY JFH

DATE 9/27/94 CHK'D BY

Figure A.1
Geologic Boring Log

Cont'd. # water in bag 20-30 ppm

BOREHOLE LOG

SITE NAME AND LOCATION Wurtsmith AFB T45		DRILLING METHOD: HSA				BORING NO. MW8-0745	
		SAMPLING METHOD: Split spoon				SHEET 1 OF 1	
						DRILLING	
		WATER LEVEL 9.5				START	FINISH
						TIME 13:55	TIME
DATE				DATE 9/29/94	DATE 9/29/94		
ELEVATION		CASING DEPTH					

DRILL RIG		SURFACE CONDITIONS	
ANGLE		BEARING	
SAMPLE HAMMER TORQUE		FT.-LBS	

DEPTH (FEET)	BLOWS/BLANK ON SAMPLER (RECOVERY)	CORES				SOL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH IN FEET		PERMEABILITY CM/SEC.
												FROM	TO	

2					6" Gravel SAND - f-mgr		orange-brn								
4															
1	2				SAND, f-mgr orange-tan, Fe stain, moist							5	7	12ppm	
5	5														
10	46				SAND 9' Fast stain 9.5 SAND, fgr & silt SAA md brn 11' m-cgr 1" silt @ ~11'		Wet @ 9-9.5 brn - orange brn no odor					8	10	lab 12ppm	
12	1247											10	12	9ppm	
	417				SAND f-mgr md brn wet no odor		TD=15'					13	15	10ppm	

Figure A.1
Geologic Boring Log

DRILLING CONTR **CTI**
 LOGGED BY **JFH**
 DATE **9/29/94** CHK'D BY **RL**

BOREHOLE LOG

SITE NAME AND LOCATION Wurtsmith AFB T45 N. of bldg 5608		DRILLING METHOD: HSA				BORING NO. MW90T45	
						SHEET 1 OF 1	
		SAMPLING METHOD: Split Spoon					
						DRILLING	
						START	FINISH
WATER LEVEL		9.5				TIME 0910	TIME 10:00
TIME						DATE 9/29/94	DATE 9/29/94
DATE							
CASING DEPTH							

REEL RIG		SURFACE CONDITIONS	
ANGLE		BEARING	
SAMPLE HAMMER TORQUE		FT.-LBS	

DEPTH (FEET)	BLOWS/AN ON SAMPLER (RECOVERY)	RUN NO.	CORES			SOL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
			NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH IN FEET		PERMEABILITY CM./SEC.
												FROM	TO	

2					6" Gravel Pavement										
4					SAND orange-brn.										
6	36				SAND f-m gr. lt								5	7	3ppm 6ppm
8	36				SAR								8	10	4ppm
10	36				-1" clor @ -9.5'								10	12	3ppm
12					SAND f-c gr. tan								13	15	
	612				SAR f-m gr										
	157														

DRILLING CONTR **CTI**

AL

LOGGED BY **JFH**

DATE **9/29/94** CHK'D BY

Figure A.1
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION Wurtsmith T-45	DRILLING METHOD: Hollow Stem					BORING NO. MUC100	
	Auger						
	SAMPLING METHOD: 2-inch					SHEET 1 OF 2	
	Split Spoon						
						START	FINISH
	WATER LEVEL					TIME 1:05	TIME 1:55
TIME							
DATE					DATE	DATE	
CASING DEPTH					10-3-90		

RIG <i>Acker Drill Max</i>	SURFACE CONDITIONS
E BEARING	
PILE HAMMER TORQUE	FT.-LBS

[illegible]

11' 20" 60" Sand fine - dry
Very pale Brown 10YR 7/3
Med Dense

11' 5' 5" 24" 20" Sand med wet
Yellowish Brown 10Y 5/4
Med Dense

1
2
3
4
5
6
7
8
9
10
11
12

Figure A.1
Geologic Boring Log

Figure A.1
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION <i>Smith</i>	DRILLING METHOD:				BORING NO.	
	<i>Hollow Stem Auger</i>				<i>M. 10100</i>	
	SAMPLING METHOD: <i>2-inch Split</i>				SHEET	
	<i>- Spoon</i>				<i>2 of 6</i>	
					DRILLING	
					START	FINISH
WATER LEVEL				TIME		TIME
TIME				DATE		DATE
DATE				DATE		DATE
CASING DEPTH						

RIG		SURFACE CONDITIONS	
BEARING			
HAMMER TORQUE		FT.-LBS	

BLOWS/ MIN. ON SAMPLER (RECOVERY)	CORES				SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
	RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD/P.D.							DEPTH IN FEET		PERMEABILITY CM./SEC.
											FROM	TO	

18 23	3	1	66	20	Same as above						13		
21 18 23 30	4	1	100	29	Sand Med-coarse trace fine gravel Wet yellowish Brown 10YR 5/4 Very Dense						14		

Figure A.1
Geologic Boring Log

DRILLING CONTR

LOGGED BY _____
DATE _____ CHK'D BY *RL*

[illegible]

DRILLING CONTR

AL

LOGGED BY

DATE _____ CHK'D BY _____

Figure A.1
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION Wurtsmith OT-45	DRILLING METHOD: <u>Hollow Stem</u>				BORING NO. <u>MW610D</u>	
	<u>Auger</u>				SHEET <u>4 of 7</u>	
	SAMPLING METHOD: <u>2-inch Split</u>				DRILLING	
	<u>Spoon</u>				START	FINISH
	WATER LEVEL				TIME	TIME
	TIME				<u>7:50</u>	
DATE				DATE	DATE	
CASING DEPTH				<u>10-5-4</u>		

ELEVATION		SURFACE CONDITIONS	
BEARING			
HAMMER TORQUE		FT.-LBS	

BLOWS/ AN ON SAMPLER (RECOVERY)	RUN NO.	CORES			SOL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
		NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD/PC							DEPTH IN FEET		PERMEABILITY CM./SEC.
											FROM	TO	

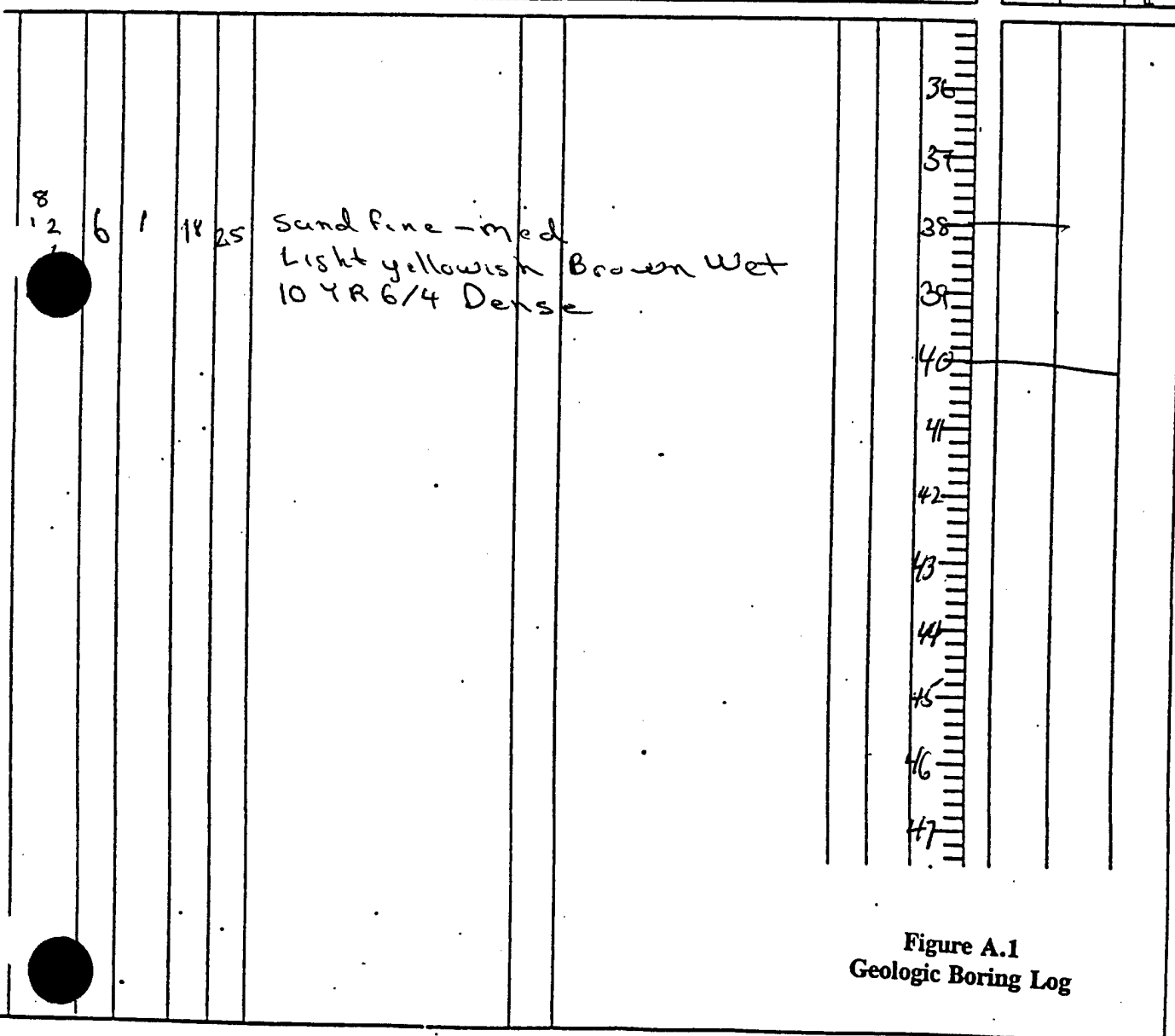


Figure A.1
Geologic Boring Log

DRILLING CONTR

LOGGED BY

RL

DATE CHK'D BY

BOREHOLE LOG

NAME AND LOCATION

DILLING METHOD:

Hollow Stem

BORING NO.

MW010 D

Auger

SHEET

5 of 6

SAMPLING METHOD:

2-inch

Split Spoon

DILLING

START

FINISH

WATER LEVEL

TIME

TIME

TIME

11:50

DATE

DATE

DATE

CASING DEPTH

10-590

IN

ELEVATION

RIG

SURFACE CONDITIONS

E

BEARING

PLE HAMMER TORQUE

FT.-LBS

BLOWS/ AN
ON SAMPLER
(RECOVERY)

CORES

RUN NO.

NO. AND SIZE
OF

CORE PIECES

% RECOVERY

RQD / P

SOIL DESCRIPTION
OR
ROCK LITHOLOGY

SYMBOL

ROCK
STRUCTURE

SAMPLER AND BIT

CASINO TYPE

BLOWS/FOOT
ON CASINO

TEST RESULTS

DEPTH
IN
FEET

PERMEABILITY
CM. / SEC.

FROM

TO

DILLING CONTR

RL

LOGGED BY

DATE CHK'D BY

14
13
13
19

7

1

1006.8

Sand fine-med wet
same as above

8
12
15
21

8

1

601.2

Sand med
1-2 3/4 from bottom
Fine to med gravel wet
Light yellowish Brown
104 @ 6/4 dense

48
49
50
51
52
53
54
55
56
57
58
59
60

on next

Figure A.1 pgs -
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION

DRILLING METHOD:

BORING NO.

MW010D

SHEET

6 of 6

SAMPLING METHOD:

DRILLING

START

FINISH

TIME

TIME

DATE

DATE

DATE

WATER LEVEL

TIME

DATE

CASING DEPTH

ELEVATION

SURFACE CONDITIONS

BEARING

PILE HAMMER TORQUE

FT.-LBS

BLOWS/ AM ON SAMPLER (RECOVERY)	CORES				SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASINO TYPE	BLOWS/FOOT ON CASINO	TEST RESULTS			
	RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD/P						SOIL DESCRIPTION OR ROCK LITHOLOGY	DEPTH IN FEET		PERMEABILITY CM./SEC.
											FROM	TO	

15					Hand								
17	8	1	100	0.6	Very stiff / Very Dense						61		
18					Tip of spoon bottom 2-inches						62		
26					Clay gray wet						63		
					Remainder of spoon same						64		
					as above						65		
6					Sand Bottom. six inches						66		
6	9	1	100	0.0	gray silt trace clay wet						67		
					remainder same as above						68		
					Very stiff / Dense						69		
12					Same as above						70		
17													
18	10	1	100	0.0									
15													
13													
10													
10	11	1	100	3.1	4 inches of gray silt								
16					Clay at tip of spoon								
					Remainder sand wet								
					Hard								
					EOB								

DRILLING CONTR

RL

LOGGED BY

DATE CHK'D BY

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION 0T45 Critt Smith AFB		DRILLING METHOD: HSA		BORING NO. MW 10-OT45	
Collected BTEX, PNA, TOC down gradient of MW 7		SAMPLING METHOD: Split spoon		SHEET 1 OF 1	
				DRILLING	
WATER LEVEL		9		START	FINISH
TIME				TIME	TIME
DATE				DATE	DATE
CASING DEPTH				10/6/94	10/6/94

SURFACE CONDITIONS	
ANGLE	BEARING
AMPLE HAMMER TORQUE	FT.-LBS

DEPTH (FEET)	BLOWS/BLANK ON SAMPLER (RECOVERY)	CORES				SOL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH (FEET)	PERMEABILITY (CM./SEC.)	

2						SAND, f-mgr dk brn		moist							
4															
6	3455					SAND, v-f, t SILT		orange-tan, moist				5	7	2ppm	
8	222					SAND, f-mgr, orange wet @ 8' festain		-tan, v. moist				8	10	2ppm	
10	2445					9.5' CLAY SILT		md brn, wet, soft				10	12	51	2ppm
12	3669					SAND, f-c gr. lt		brn, wet				12	14	52	4ppm
14						SAA		WL drilled 9'							TOC
16								TO=15'							

DRILLING CONTR CTI

RL

LOGGED BY JFH
DATE 10/6/94 CHK'D BY

Figure A.1
Geologic Boring Log

water blank 8ppm

BOREHOLE LOG

SITE NAME AND LOCATION VW1-0745 Wootsmith AFB		DRILLING METHOD: HSA				BORING NO. VW1-0745	
						SHEET 1 OF 1	
		SAMPLING METHOD: Split Spoon					
						DRILLING	
						START	FINISH
		WATER LEVEL 9.5				TIME	TIME
ATUM		ELEVATION		DATE		DATE	
REL RIG				9/28/94		9/28/94	
ANGLE		BEARING		Casing Depth			
SAMPLE HAMMER TORQUE		FT.-LBS		SURFACE CONDITIONS			

REL. RIG						SURFACE CONDITIONS									
ANGLE						BEARING									
AMPLE HAMMER TORQUE						FT.-LBS									
DEPTH (ELEVATION)	BLOWS/ FEET ON SAMPLER (RECOVERY)	CORES				SOL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS			
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH IN FEET		PERMEABILITY CM./SEC.	
												FROM	TO		
2						SAND, f-m gr, upper 6" dk brn then tan, orange, moist no odor						3	5	15 ppm	
4															
6															
8						SAND, md gr, lt brn to 9.5 then gray diesel odor. @ top of sat zone, 9.5 thin SILT layer Fe Stain						7.5	9.5	30 ppm	
10															
12															
14															
16						SAND, lt brn, m gr, to VC. no odor						15	17		

Figure A.1
Geologic Boring Log

WL drilled 9.5'

DRILLING CONTR CTH

RL

LOGGED BY JFH

DATE 9/28/94 CHK'D BY

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION <i>Wurtsmith AFB</i> <i>T45</i>		DRILLING METHOD: <i>HSA</i>				BORING NO. <i>MPA-OT 45</i>	
						SHEET <i>1 OF 1</i>	
		SAMPLING METHOD: <i>Split Spoon</i>					
						DRILLING	
						START	FINISH
		WATER LEVEL				TIME	TIME
		TIME				<i>10:50</i>	
		DATE				DATE	DATE
		CASING DEPTH				<i>9/28/94</i>	<i>9/28/94</i>

DATUM _____ ELEVATION _____

DRELL RIG _____ SURFACE CONDITIONS _____

ANGLE _____ BEARING _____

SAMPLE HAMMER TORQUE _____ FT.-LBS _____

DEPTH IN FEET (ELEVATION)	BLOWS/BLANK ON SAMPLER (RECOVERY)	CORES				SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY	ROD							DEPTH IN FEET		PERMEABILITY CM./SEC.
												FROM	TO	

2						SAND, LT brn, fgr. moist								
4	13					SAA some Fe stain						3	5	4 ppm
6														
8	4					SAA sl odor, f-m gr								
10	23					9' SAA - gray, odor		U.C. drilled 9-9.5						10 ppm
12	47					SAND, M-gr, gray								
14	23					fuel odor ~ 1/2" silt +								
16	79					c ~ 11', vf-gr @ 12'								
18	71					SAND, f-UC, tr f gravel								
20	21					fuel odor, lt brn + gray								
	14					SAND, M-UC, lt brn								
	79					SAA, f-c								
	13					SAA								
	16													
	14					SAA, 4 1/2" silt layer		TD = 20						
	14					@ ~ 19'								

Figure A.1
Geologic Boring Log

DRILLING CONTR *CTI*

LOGGED BY *JFH*
DATE *9/28/94* CHK'D BY *RL*

BOREHOLE LOG

SITE NAME AND LOCATION Wurtsmith AFB 0T45		DRILLING METHOD: HSA				BORING NO. MPB-0T45							
		6 1/2" ID				SHEET 1 OF 1							
		SAMPLING METHOD: Split Spoon				DRILLING							
						START	FINISH						
		WATER LEVEL	9.5			TIME	TIME						
		TIME				14:10	15:10						
DATE					DATE	DATE							
CASING DEPTH					9/28/94	9/28/94							
ATUM		ELEVATION		SURFACE CONDITIONS									
REL RIG													
ANGLE		BEARING											
AMPLE HAMMER TORQUE		FT.-LBS											
DEPTH (ELEVATION)	BLOWS/AN ON SAMPLER (RECOVERY)	CORES			SOL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS		
		RUN NO.	NO. AND SIZE OF CORE PIECES	% RECOVERY							ROD	DEPTH IN FEET	PERMEABILITY CM./SEC.
											FROM	TO	
2					SAND, dk brn, moist		Soil Zone						
4	24.6				SAND f-m, orange-brn moist		brn, moist no odor				3	5	10 ppm
6					SAND, f-m, lt orange-		brn, moist, no odor						
8					SAND, f, lt orange								
10	35				SAND, f-m, orange-brn		moist, wet at 9.5				7.5	9.5	8 ppm
12	10				fuel odor 8-9.5'		w/c drilled - 9.5						
14					SAND, f-m, gray		wet fuel odor				10	12	
16					- 1/2" silt, clay layer		at 11.5'						
18					SAA - brn-gray		fuel odor				15	17	
20	12				16-16.5 coarse-gr								
	14				16.5-17 fine-gr								
	15												
					SAND M-UC, tan		fuel odor				18	20	
	7				tr gravel		TD=20						
	11												
	14												
	19												

DRILLING CONTR

AL

LOGGED BY JFH

DATE 9/28/94 CHK'D BY

Figure A.1
Geologic Boring Log

LOCATION MAP
Wurtsmith AFB
OT 45

ENGINEERING-SCIENCE, INC. WELL LOG PAGE 1 OF 3

WELL NUMBER MW0100 LOCATION OT-45
DATE 10-5-94 WEATHER sunny 60 °F
LOGGED BY W. Marcelle H. DRILLED BY CTI
DRILLING METHOD Hollow Stem Auger SAMPLING METHOD 2-inch split
GRAVEL PACK SEAL Grout/Bentonite

CASING TYPE Schedule 80 PVC 20 DIAMETER 10-inch LENGTH 20/59 HOLE DIA. 12"
Schedule 40 PVC 59 DIAMETER 2-inch
SCREEN TYPE Schedule 40 PVC SLOT 10-slot DIAMETER 2-inch LENGTH 10 ft TOTAL DEPTH 70'

SAMPLE NO.	ORGANIC VAPORS (PPM)	DEPTH	SAMPLE RECOVERY	PENETRATION RESISTANCE	LITHOLOGY/REMARKS (COLOR, SOIL, TYPE, SORTING, MOISTURE, PLASTICITY)	LITHO. PROFILE	WELL COMPLETION
		0					
		1					
		2					
		3					
		4					
		5					
		6					
		7					
		8					
		9					
		10					
		11					
		12					
		13					
		14					
		15					
		16					
		17					
		18					
		19					
		20					
		21					
		22					
		23					
		24					
		25					

LOGGED BY DATE DRAWN BY
UPDATE # 0

WELL NUMBER *MW0100*LOCATION *OT-45*

DATE

WEATHER

LOGGED BY

DRILLED BY

DRILLING METHOD

SAMPLING METHOD

GRAVEL PACK

SEAL

CASING TYPE

DIAMETER

LENGTH

HOLE DIA.

SCREEN TYPE

SLOT

DIAMETER

LENGTH

TOTAL DEPTH

SAMPLE NO.

ORGANIC VAPORS (PPM)

DEPTH

SAMPLE RECOVERY

PENETRATION RESISTANCE

LITHOLOGY/REMARKS
(COLOR, SOIL, TYPE, SORTING, MOISTURE, PLASTICITY)

LITHO. PROFILE

WELL COMPLETION

25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
5025
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

← Ground

Riser
No ScreenCIVIL/02
JOB#

DATE

DRAWN BY

UPDATE # 0

LOCATION MAP		ENGINEERING-SCIENCE, INC. WELL LOG		PAGE ³ 2 OF 3
WELL NUMBER MW0100		LOCATION OT-45		
DATE		WEATHER ° F		
LOGGED BY		DRILLED BY		
DRILLING METHOD		SAMPLING METHOD		
GRAVEL PACK		SEAL		

CASING TYPE	DIAMETER	LENGTH	HOLE DIA.
SCREEN TYPE	SLOT	DIAMETER	LENGTH
			TOTAL DEPTH

SAMPLE NO.	ORGANIC VAPORS (PPM)	DEPTH	SAMPLE RECOVERY	PENETRATION TEST - RESISTANCE	LITHOLOGY/REMARKS (COLOR, SOIL, TYPE, SORTING, MOISTURE, PLASTICITY)	UTHO. PROFILE	WELL COMPLETION	
		25						
		26						
		27						
		28						
		29						
		30						
		31						
		32						
		33						
		34						
		35						
		36						
		37						
		38						
		39						
		40						
		41						
		42						
		43						
		44						
		45						
		46						
		47						
		48						
		49						
		50						

REVISION	DATE	DRAWN BY
UPDATE # 0		

grou
San.
pac

FLUSH MOUNT RISER BOX

LOCKABLE CAP

GROUND SURFACE
(618.09' MSL)

TOC (617.94' MSL)

BENTONITE

2" DIA. SCH. 40 PVC
SURFACE CASING

9.0

10.0

15.0

15.0

SAND

2" DIA. SCH. 40 PVC SCREEN
W/THREADED JOINTS
SLOT SIZE = 0.010"

8" DIA. BOREHOLE

END CAP

**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW4-OT45**

SITE: OT45

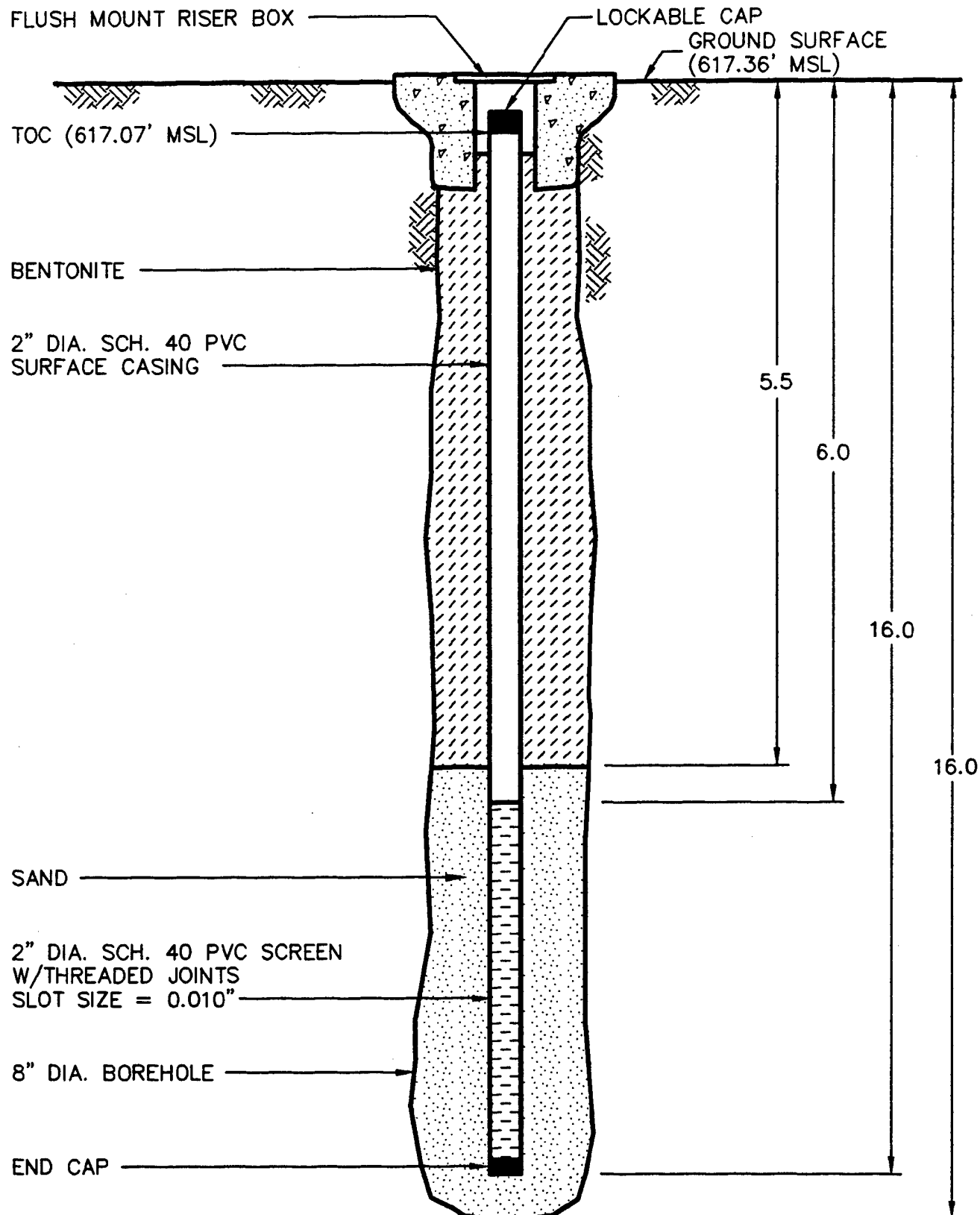
GEOLOGIST: JFH

DATE COMPLETED: 09/29/94

WURTSMITH AFB, MI



**PARSONS
ENGINEERING SCIENCE, INC.**



**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW5**

SITE: OT45
GEOLOGIST: JFH
DATE COMPLETED: 09/29/94
WURTSMITH AFB, MI

**PARSONS
ENGINEERING SCIENCE, INC.**

FLUSH MOUNT RISER BOX

LOCKABLE CAP

GROUND SURFACE
(617.19' MSL)

TOC (616.91' MSL)

BENTONITE

2" DIA. SCH. 40 PVC
SURFACE CASING

4.5

5.0

15.0

15.0

SAND

2" DIA. SCH. 40 PVC SCREEN
W/THREADED JOINTS
SLOT SIZE = 0.010"

8" DIA. BOREHOLE

END CAP

**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW6**

SITE: OT45

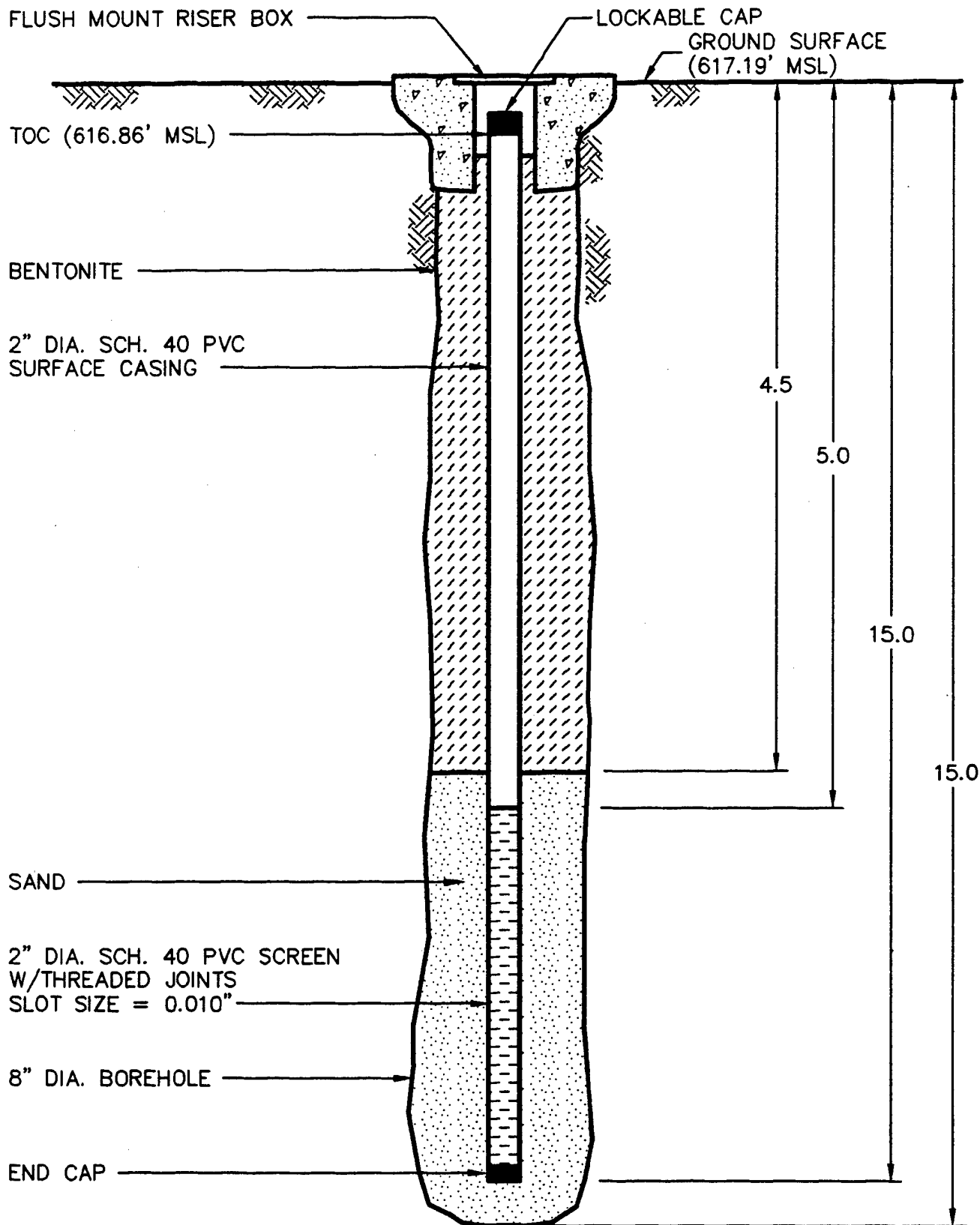
GEOLOGIST: JFH

DATE COMPLETED: 09/28/94

WURTSMITH AFB, MI



**PARSONS
ENGINEERING SCIENCE, INC.**



**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW7**

SITE: OT45
GEOLOGIST: JFH
DATE COMPLETED: 09/28/94
WURTSMITH AFB, MI

**PARSONS
ENGINEERING SCIENCE, INC.**

FLUSH MOUNT RISER BOX

LOCKABLE CAP

GROUND SURFACE
(617.30' MSL)

TOC (617.06' MSL)

BENTONITE

2" DIA. SCH. 40 PVC
SURFACE CASING

4.5

5.0

15.0

15.0

SAND

2" DIA. SCH. 40 PVC SCREEN
W/THREADED JOINTS
SLOT SIZE = 0.010"

8" DIA. BOREHOLE

END CAP

**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW8**

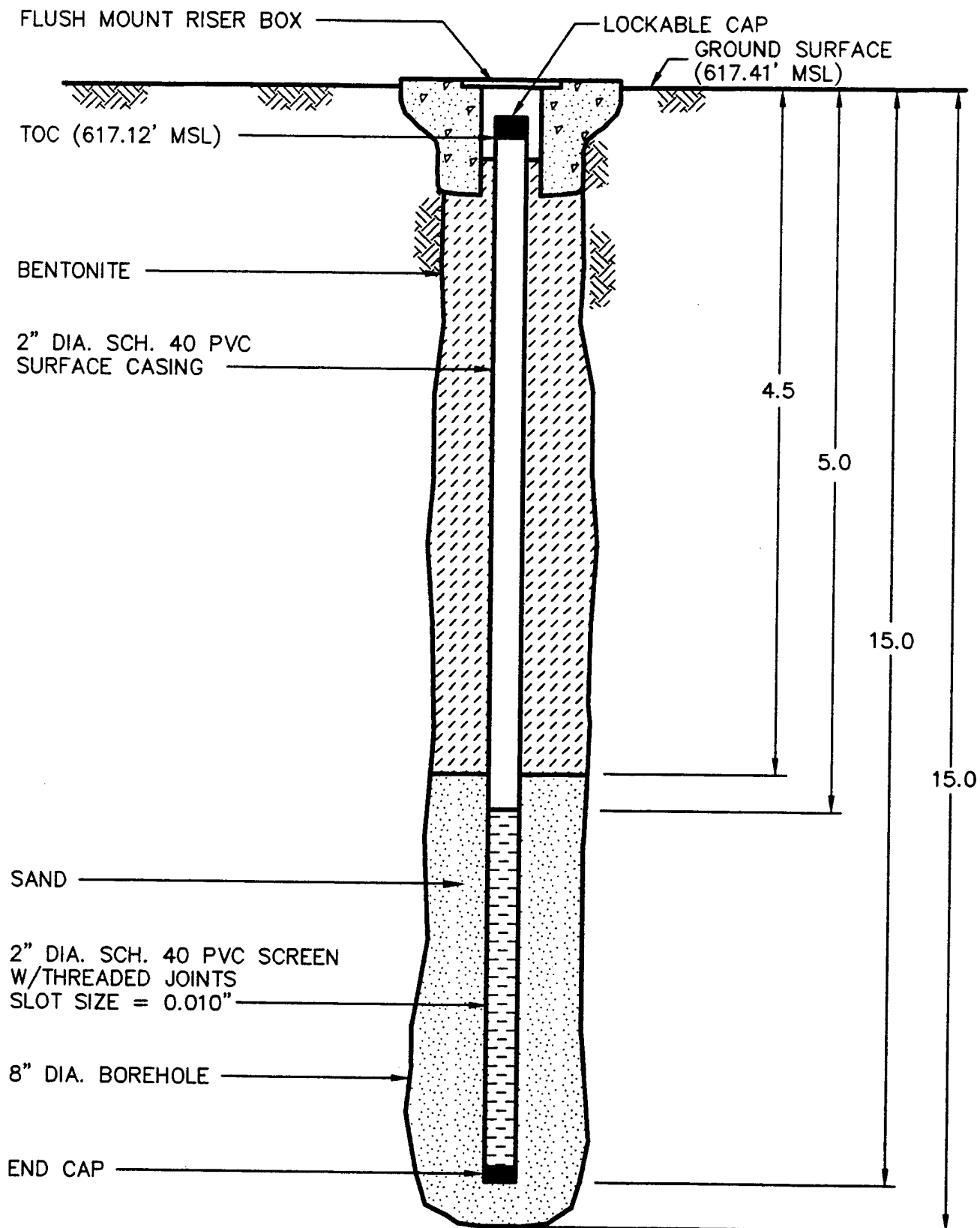
SITE: OT45

GEOLOGIST: JFH

DATE COMPLETED: 09/28/94

WURTSMITH AFB, MI

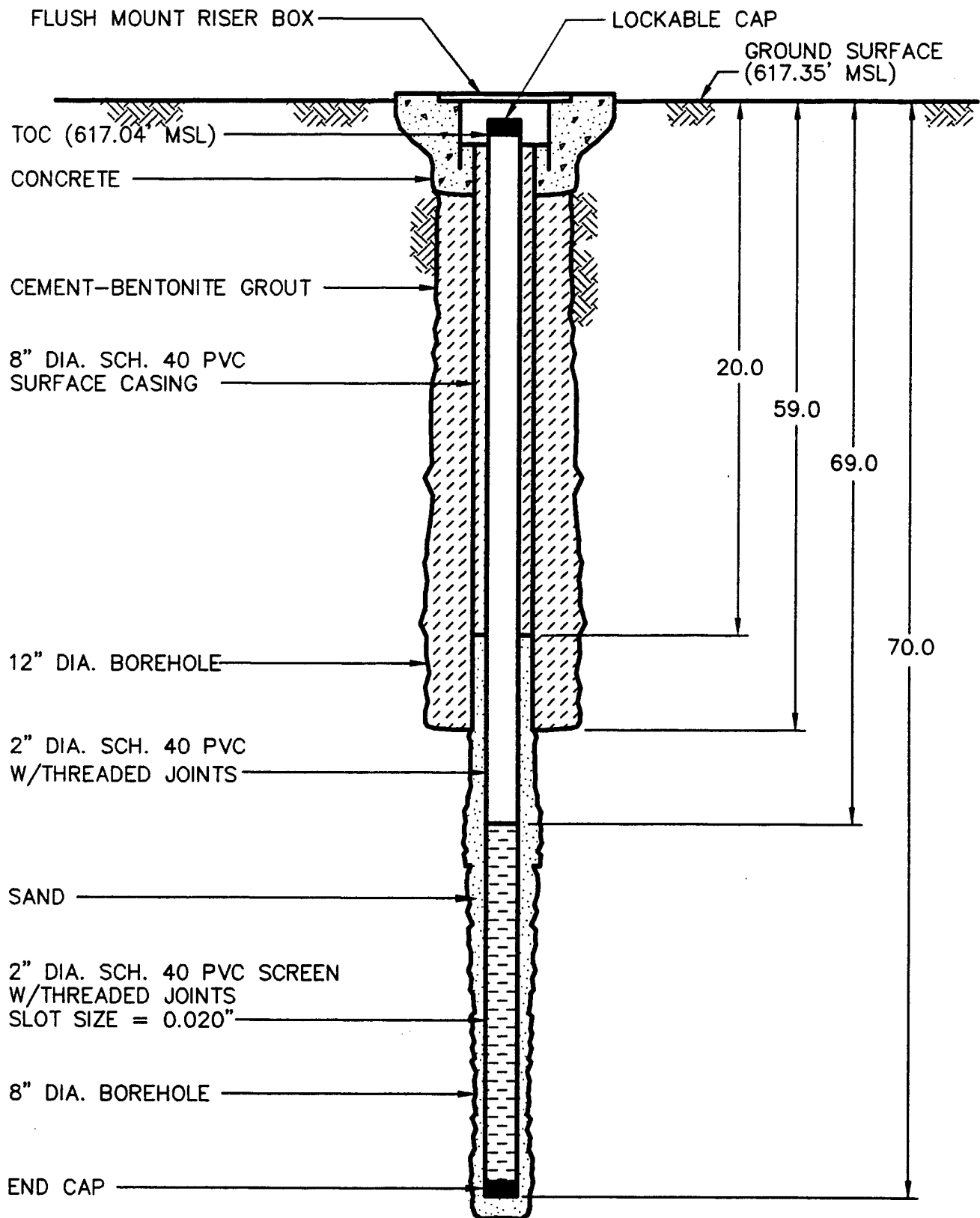
**PARSONS
ENGINEERING SCIENCE, INC.**



**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW9**

SITE: OT45
GEOLOGIST: JFH
DATE COMPLETED: 09/29/94
WURTSMITH AFB, MI

**PARSONS
ENGINEERING SCIENCE, INC.**



MONITORING WELL DESIGN DETAIL WELL NO. MW10

SITE: OT45
GEOLOGIST: NM
DATE COMPLETED: 10/05/94
WURTSMITH AFB, MI

FLUSH MOUNT RISER BOX

LOCKABLE CAP

GROUND SURFACE
(616.90' MSL)

TOC (616.68' MSL)

BENTONITE

2" DIA. SCH. 40 PVC
SURFACE CASING

4.5

5.0

15.0

15.0

SAND

2" DIA. SCH. 40 PVC SCREEN
W/THREADED JOINTS
SLOT SIZE = 0.010"

8" DIA. BOREHOLE

END CAP

**FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. MW11**

SITE: OT45

GEOLOGIST: JFH

DATE COMPLETED: 10/06/94

WURTSMITH AFB, MI

**PARSONS
ENGINEERING SCIENCE, INC.**

FLUSH MOUNT RISER BOX

LOCKABLE CAP

GROUND SURFACE
(617.88' MSL)

TOC (617.61' MSL)

BENTONITE

4" DIA. SCH. 40 PVC
SURFACE CASING

4.5

5.0

15.0

SAND

4" DIA. SCH. 40 PVC SCREEN
W/THREADED JOINTS
SLOT SIZE = 0.010"

11" DIA. BOREHOLE

END CAP

**FLUSH-MOUNTED
VENT WELL DESIGN DETAIL
WELL NO. VW-1**

SITE: OT45

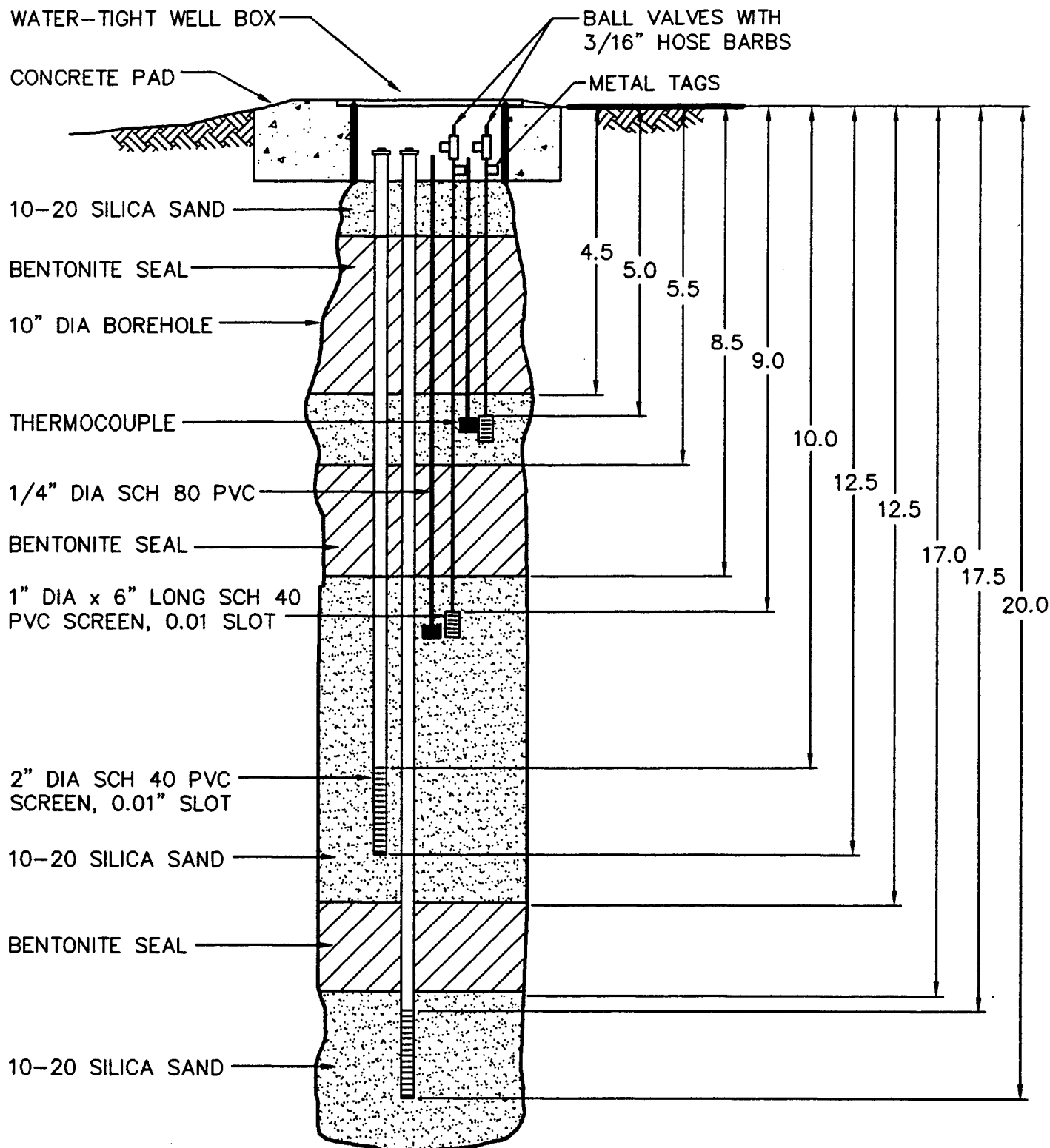
GEOLOGIST: JFH

DATE COMPLETED: 09/28/94

WURTSMITH AFB, MI

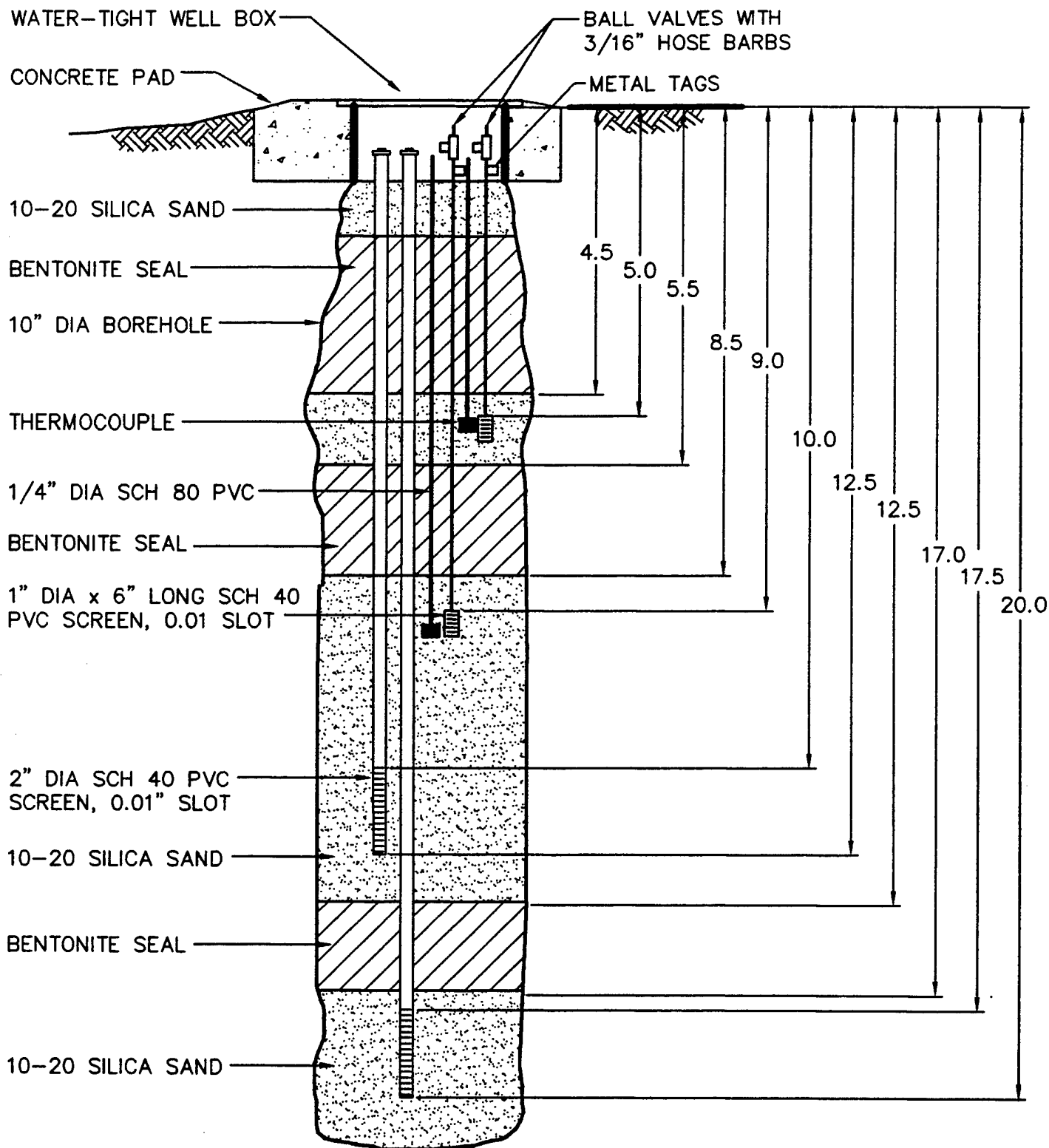


**PARSONS
ENGINEERING SCIENCE, INC.**



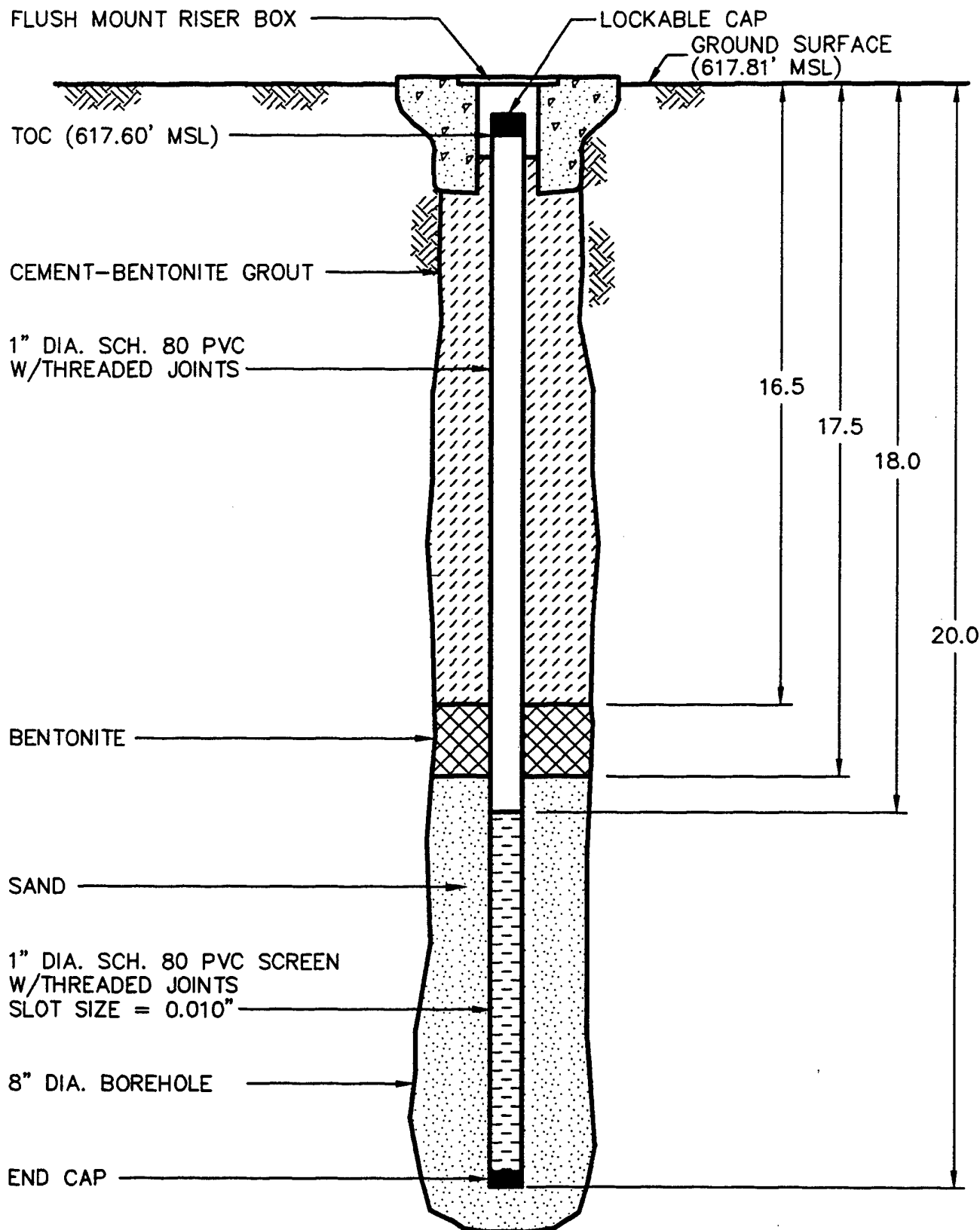
**MONITORING POINT
CONSTRUCTION DETAIL
WELL NO. MPA**

SITE: OT45
GEOLOGIST: JFH
DATE COMPLETED: 09/28/94
WURTSMITH AFB, MI



MONITORING POINT CONSTRUCTION DETAIL WELL NO. MPB

SITE: OT45
GEOLOGIST: JFH
DATE COMPLETED: 09/28/94
WURTSMITH AFB, MI



**FLUSH-MOUNTED
AIR SPARGING WELL DESIGN DETAIL
WELL NO. SP1**

SITE: OT45
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

**PARSONS
ENGINEERING SCIENCE, INC.**

WELL DEVELOPMENT RECORD

Well Designation VW1-0T45 Developed By J. Hall Date 9/30/44

Time Started 13:20 Time Ended 13:40

Development Method:

BAIL X PUMP X SURGE X AIR LIFT

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start)						
2 gal	62.8	7.22	348			
10 gal	61.0	7.64	269			
20	57.8	7.66	255			
30	58.8	7.70	241			
(Finish)						

Comments:

Strong sheen & diesel oil odor

WELL DEVELOPMENT RECORD

Well Designation MPA-0T45S Developed By J. Hall Date 9/30/44

Time Started 13:00 Time Ended 13:10

Development Method:

BAIL PUMP SURGE AIR LIFT

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start) 2 gal	68.0	7.70	380			V cloudy
10 gal	63.4	7.72	383			
12 gal	62.5	7.84	393			S cloudy
(Finish)						

Comments:

Sheen on water surface, diesel odor

WELL DEVELOPMENT RECORD

Well Designation MPA-0T45D Developed By J. Hall Date 9/30/94

Time Started 13:10 Time Ended 13:20

Development Method:

BAIL 7 PUMP 2 SURGE 7 AIR LIFT

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start) 2 gal	61.0	8.10	200			
10 gal	57.0	8.17	170			
15 gal	55.8	8.21	168			
(Finish)						

Comments:

no noticeable stain or odor

WELL DEVELOPMENT RECORD

Well Designation MPB-OT45 S Developed By J. Hall Date 9/30/94

Time Started 11:30 Time Ended 12:00

Development Method:

BAIL _____ PUMP _____ SURGE _____ AIR LIFT _____

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start)						
2 gal	64.0	6.80	330			
10	60.9	6.30	452			
		7.09*	41			
20	59.6	7.50	418			
(Finish)						

Comments:

Comments: Sheen on water diesel
oil odor

* re-calibrated pH meter

WELL DEVELOPMENT RECORD

Well Designation MPB-0745 D Developed By _____ Date 7/31/99

Time Started 12:00 Time Ended 12:20

Development Method:

BAIL + PUMP + SURGE 1 AIR LIFT

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

[illegible]

Comments:

re-calibrated pH meter,
no shown

9/29/94

Date 9/30/48

Time Ended 09:45

15.1 TD

BAIL + PUMP + SURGE + AIR LIFT

OTHER (SPECIFY) 04:28

Casing Volume _____ Approximate Volume Removed _____

(Finish)

Comments:

WELL DEVELOPMENT RECORD

Well Designation MW5-0T45 Developed By J. Hall Date 9/30/84

Time Started 10:50 Time Ended 11:20

WL 9.63 TD 15.70 TUC

Development Method:

BAIL 2 PUMP 2 SURGE 2 AIR LIFT

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start)						
5 gal	54.9	7.39	270			V-Cloudy
30	50.8	7.15	260			sl cloudy
45	54.6	6.95	268			sl cloudy
(Finish)						

Comments:

oil on water
film

WELL DEVELOPMENT RECORD

Well Designation MW6 Developed By JFH/11 Date 9/30/94

Time Started 0840 Time Ended 09:10
 WL 9.73 TD 14.60 TDC

Development Method:

BAIL X PUMP X SURGE _____ AIR LIFT _____

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start) 2 gal	43	8.40	189			Muddy
18	49.2	8.96	106			V. cloudy
25	52.8	8.75	175			cloudy
37	53.7	7.40*	179			"
45	54.2	7.28	173			S/ cloudy
(Finish)						

Comments:

* re-calibrated pH - tends to increase w ↑ temp

Figure A.6
Well Development Record

Page 1 of 1

Job Number 725523
Location OT45
Well Number MW 8

Job Name L. J. Smith
By JFH Date 7/30/94
Measurement Datum TOC

Pre-Development Information

Time (Start):

Water Level: 9.87

Total Depth of Well: 14.45

Water Characteristics

Color _____ Clear _____ Cloudy _____
Odor: None _____ Weak _____ Moderate _____ Strong _____
Any Films or Immiscible Material _____
pH _____ Temperature (°F °C) _____
Specific Conductance (µS/cm) _____

Interim Water Characteristics

Gallons Removed

pH

Temperature (°F °C)

Specific Conductance (µS/cm)

Post-Development Information

Time (Finish):

Water Level:

Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color _____ Clear _____ Cloudy _____
Odor: None _____ Weak _____ Moderate _____ Strong _____
Any Films or Immiscible Material _____
pH _____ Temperature (°F °C) _____
Specific Conductance (µS/cm) _____

Comments:

WELL DEVELOPMENT RECORD

Well Designation MWB-OT 45 Developed By _____ Date 9/30/49

Time Started _____ Time Ended _____

Development Method:

BAIL _____ PUMP alt pump X blow air SURGE _____ AIR LIFT _____

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start) 2 gal	41.5	7.13	300	muddy		Muddy,
~8 gal	48.5	7.40	314			"
15	51.7	7.51	311			31 cloudy,
25	51.2	7.65	310			
30	51.6	7.63	310			
(Finish)						

Comments:

WELL DEVELOPMENT RECORD

Well Designation MW9-0745 Developed By J. Hall Date 9/30/44

Time Started 10:00Time Ended 10:30

WL 9.70 TD 14.50

Development Method:

BAIL X PUMP X SURGE X AIR LIFT

OTHER (SPECIFY) _____

Casing Volume _____ Approximate Volume Removed _____

TIME/ BAILER NO.	TEMPERATURE	pH	ELECTRICAL CONDUCTIVITY	TURBIDITY	HNU	VISUAL APPEARANCE
(Start) 2 gal	55.5	7.45	299			Muddy
10	55.9	7.67	285			cloudy
15	57.31	7.65	285			
25	57.8	7.74	283			
47	56.1	7.85	268			
(Finish)						

Comments:

Figure A.6
Well Development Record

Page of

Job Number
Location
Well Number MW11-0745

Job Name
By Date 10/6/94
Measurement Datum

Pre-Development Information

Time (Start): 11:50

Water Level: 9.87

Total Depth of Well: 14.55

Water Characteristics

Color brn Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material No
pH Temperature ($^{\circ}\text{F}$ $^{\circ}\text{C}$)
Specific Conductance ($\mu\text{S}/\text{cm}$)

Interim Water Characteristics

Gallons Removed	5	20	30	35
pH	9.04	9.04	8.95	8.65
Temperature ($^{\circ}\text{F}$ $^{\circ}\text{C}$)	58.4	58.1	57.2	56.9
Specific Conductance ($\mu\text{S}/\text{cm}$)	270	301	298	302

Post-Development Information

Time (Finish):

Water Level: 9.87

Total Depth of Well: 14.60

Approximate Volume Removed: 35 gal

Water Characteristics

Color brn sl cloudy Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material No
pH 8.65 Temperature ($^{\circ}\text{F}$ $^{\circ}\text{C}$) 56.9
Specific Conductance ($\mu\text{S}/\text{cm}$) 302

Comments:

APPENDIX B
ANALYTICAL DATA

TABLE B.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
DC-OT45 (MW2)	28-Sep-94	12.00 - 15.00	Total Extractable Hydrocarbons	550 J ^a	mg/kg	M8015
			Benzene	2.3 U ^a	µg/kg	SW8020
			Toluene	23 U	µg/kg	SW8020
			Ethylbenzene	6.9 J	µg/kg	SW8020
			Xylenes (Total)	30	µg/kg	SW8020
			1,3,5-Trimethylbenzene	160	µg/kg	SW8020
			1,2,4-Trimethylbenzene	240	µg/kg	SW8020
			1,2,3-Trimethylbenzene	240	µg/kg	SW8020
MPA-OT45	28-Sep-94	8.00 - 9.50	Total Extractable Hydrocarbons	100 UJ ^a	mg/kg	M8015
			Benzene	0.46 U	µg/kg	SW8020
			Toluene	0.5 J	µg/kg	SW8020
			Ethylbenzene	4.6 U	µg/kg	SW8020
			Xylenes (Total)	4.6 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.6 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.6 U	µg/kg	SW8020
MPB-OT45	28-Sep-94	8.00 - 9.50	Total Extractable Hydrocarbons	12000 J	mg/kg	M8015
			Benzene	2.2 U	µg/kg	SW8020
			Toluene	22 U	µg/kg	SW8020
			Ethylbenzene	8.2 J	µg/kg	SW8020
			Xylenes (Total)	25	µg/kg	SW8020
			1,3,5-Trimethylbenzene	390	µg/kg	SW8020
			1,2,4-Trimethylbenzene	900	µg/kg	SW8020
			1,2,3-Trimethylbenzene	540	µg/kg	SW8020
MW4-OT45	29-Sep-94	8.00 - 9.50	Benzene	0.48 U	µg/kg	SW8020
			Toluene	4.8 U	µg/kg	SW8020
			Ethylbenzene	4.8 U	µg/kg	SW8020
			Xylenes (Total)	4.8 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020
MW5-OT45	29-Sep-94	10.00 - 13.00	Benzene	2.3 U	µg/kg	SW8020
			Toluene	31	µg/kg	SW8020
			Ethylbenzene	160	µg/kg	SW8020
			Xylenes (Total)	890	µg/kg	SW8020
			1,3,5-Trimethylbenzene	1300 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	2200 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	1400 J	µg/kg	SW8020
MW6-OT45	29-Sep-94	8.00 - 9.50	Benzene	0.49 U	µg/kg	SW8020
			Toluene	4.9 U	µg/kg	SW8020
			Ethylbenzene	4.9 U	µg/kg	SW8020
			Xylenes (Total)	4.9 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.9 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.9 U	µg/kg	SW8020
MW7-OT45	27-Sep-94	8.00 - 9.00	Total Extractable Hydrocarbons	35 J	mg/kg	M8015
			Benzene	0.47 UJ	µg/kg	SW8020
			Toluene	4.7 UJ	µg/kg	SW8020
			Ethylbenzene	4.7 UJ	µg/kg	SW8020
			Xylenes (Total)	4.7 UJ	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.9 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.7 UJ	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.7 UJ	µg/kg	SW8020
MW8-OT45	29-Sep-94	8.00 - 9.50	Benzene	0.48 U	µg/kg	SW8020
			Toluene	4.8 U	µg/kg	SW8020
			Ethylbenzene	4.8 U	µg/kg	SW8020
			Xylenes (Total)	4.8 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020

TABLE B.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
MW9-OT45	29-Sep-94	8.00 - 9.50	Benzene	0.47 U	µg/kg	SW8020
			Toluene	4.7 U	µg/kg	SW8020
			Ethylbenzene	4.7 U	µg/kg	SW8020
			Xylenes (Total)	4.7 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.7 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	0.7 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	0.5 J	µg/kg	SW8020
MW10-OT45	3-Oct-94	9.00 - 11.00	Benzene	0.46 U	µg/kg	SW8020
			Toluene	4.6 U	µg/kg	SW8020
			Ethylbenzene	4.6 U	µg/kg	SW8020
			Xylenes (Total)	4.6 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.6 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.6 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.6 U	µg/kg	SW8020
MW11-OT45	6-Oct-94	10.00 - 12.00	Benzene	0.48 U	µg/kg	SW8020
			Toluene	4.8 U	µg/kg	SW8020
			Ethylbenzene	4.8 U	µg/kg	SW8020
			Xylenes (Total)	4.8 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020
VW1-OT45	28-Sep-94	8.00 - 9.50	Total Extractable Hydrocarbons	45 J	mg/kg	M8015
			Benzene	0.45 U	µg/kg	SW8020
			Toluene	4.5 U	µg/kg	SW8020
			Ethylbenzene	4.5 U	µg/kg	SW8020
			Xylenes (Total)	4.5 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	0.7 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.5 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.5 U	µg/kg	SW8020

“ J= estimated value

“ U= analyte not detected above method detection limit

“ UJ=estimated concentration of analyte not detected above method detection limit

TABLE B.2
VALIDATED SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
DC-OT45 (MW2)	28-Sep-94	12.00 - 15.00	Naphthalene	790	µg/kg	SW8270
			2-Methylnaphthalene	380 U ^a	µg/kg	SW8270
			Acenaphthylene	380 U	µg/kg	SW8270
			Acenaphthene	220 J ^a	µg/kg	SW8270
			Dibenzofuran	110 J	µg/kg	SW8270
			Fluorene	310 J	µg/kg	SW8270
			Phenanthrene	380 U	µg/kg	SW8270
			Anthracene	380 U	µg/kg	SW8270
			Fluoranthene	380 U	µg/kg	SW8270
			Pyrene	45 J	µg/kg	SW8270
			Benzo(a)anthracene	380 U	µg/kg	SW8270
			Chrysene	380 U	µg/kg	SW8270
			Benzo(b)fluoranthene	380 U	µg/kg	SW8270
			Benzo(k)fluoranthene	380 U	µg/kg	SW8270
			Benzo(a)pyrene	380 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	380 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	380 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	380 U	µg/kg	SW8270
MPA-OT45	28-Sep-94	8.00 - 9.50	Naphthalene	370 U	µg/kg	SW8270
			2-Methylnaphthalene	370 U	µg/kg	SW8270
			Acenaphthylene	370 U	µg/kg	SW8270
			Acenaphthene	370 U	µg/kg	SW8270
			Dibenzofuran	370 U	µg/kg	SW8270
			Fluorene	370 U	µg/kg	SW8270
			Phenanthrene	370 U	µg/kg	SW8270
			Anthracene	370 U	µg/kg	SW8270
			Fluoranthene	370 U	µg/kg	SW8270
			Pyrene	370 U	µg/kg	SW8270
			Benzo(a)anthracene	370 U	µg/kg	SW8270
			Chrysene	370 U	µg/kg	SW8270
			Benzo(b)fluoranthene	370 U	µg/kg	SW8270
			Benzo(k)fluoranthene	370 U	µg/kg	SW8270
			Benzo(a)pyrene	370 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	370 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	370 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	370 U	µg/kg	SW8270
MPB-OT45	28-Sep-94	8.00 - 9.50	Naphthalene	330 U	µg/kg	SW8270
			2-Methylnaphthalene	330 U	µg/kg	SW8270
			Acenaphthylene	330 U	µg/kg	SW8270
			Acenaphthene	330 U	µg/kg	SW8270
			Dibenzofuran	330 U	µg/kg	SW8270
			Fluorene	330 U	µg/kg	SW8270
			Phenanthrene	330 U	µg/kg	SW8270
			Anthracene	330 U	µg/kg	SW8270
			Fluoranthene	330 U	µg/kg	SW8270
			Pyrene	180 J	µg/kg	SW8270
			Benzo(a)anthracene	330 U	µg/kg	SW8270
			Chrysene	330 U	µg/kg	SW8270
			Benzo(b)fluoranthene	330 U	µg/kg	SW8270
			Benzo(k)fluoranthene	330 U	µg/kg	SW8270
			Benzo(a)pyrene	330 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	330 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	330 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	330 U	µg/kg	SW8270
MW4-OT45	29-Sep-94	8.00 - 9.50	Naphthalene	350 U	µg/kg	SW8270

TABLE B.2
VALIDATED SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
MW4-OT45	29-Sep-94	8.00 - 9.50	2-Methylnaphthalene	350 U	µg/kg	SW8270
			Acenaphthylene	350 U	µg/kg	SW8270
			Acenaphthene	350 U	µg/kg	SW8270
			Dibenzofuran	350 U	µg/kg	SW8270
			Fluorene	350 U	µg/kg	SW8270
			Phenanthrene	350 U	µg/kg	SW8270
			Anthracene	350 U	µg/kg	SW8270
			Fluoranthene	350 U	µg/kg	SW8270
			Pyrene	350 U	µg/kg	SW8270
			Benzo(a)anthracene	350 U	µg/kg	SW8270
			Chrysene	350 U	µg/kg	SW8270
			Benzo(b)fluoranthene	350 U	µg/kg	SW8270
			Benzo(k)fluoranthene	350 U	µg/kg	SW8270
			Benzo(a)pyrene	350 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	350 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	350 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	350 U	µg/kg	SW8270
MW5-OT45	29-Sep-94	10.00 - 13.00	Naphthalene	1400	µg/kg	SW8270
			2-Methylnaphthalene	7000	µg/kg	SW8270
			Acenaphthylene	390 U	µg/kg	SW8270
			Acenaphthene	380 J	µg/kg	SW8270
			Dibenzofuran	390 U	µg/kg	SW8270
			Fluorene	550	µg/kg	SW8270
			Phenanthrene	1600	µg/kg	SW8270
			Anthracene	390 U	µg/kg	SW8270
			Fluoranthene	390 U	µg/kg	SW8270
			Pyrene	51 J	µg/kg	SW8270
			Benzo(a)anthracene	390 U	µg/kg	SW8270
			Chrysene	390 U	µg/kg	SW8270
			Benzo(b)fluoranthene	390 U	µg/kg	SW8270
			Benzo(k)fluoranthene	390 U	µg/kg	SW8270
			Benzo(a)pyrene	390 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	390 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	390 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	390 U	µg/kg	SW8270
MW6-OT45	29-Sep-94	8.00 - 9.50	Naphthalene	410 U	µg/kg	SW8270
			2-Methylnaphthalene	410 U	µg/kg	SW8270
			Acenaphthylene	410 U	µg/kg	SW8270
			Acenaphthene	410 U	µg/kg	SW8270
			Dibenzofuran	410 U	µg/kg	SW8270
			Fluorene	410 U	µg/kg	SW8270
			Phenanthrene	410 U	µg/kg	SW8270
			Anthracene	410 U	µg/kg	SW8270
			Fluoranthene	410 U	µg/kg	SW8270
			Pyrene	410 U	µg/kg	SW8270
			Benzo(a)anthracene	410 U	µg/kg	SW8270
			Chrysene	410 U	µg/kg	SW8270
			Benzo(b)fluoranthene	410 U	µg/kg	SW8270
			Benzo(k)fluoranthene	410 U	µg/kg	SW8270
			Benzo(a)pyrene	410 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	410 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	410 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	410 U	µg/kg	SW8270
MW7-OT45	27-Sep-94	8.00 - 9.00	Naphthalene	330 U	µg/kg	SW8270
			2-Methylnaphthalene	330 U	µg/kg	SW8270

TABLE B.2
VALIDATED SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
MW7-OT45	27-Sep-94	8.00 - 9.00	Acenaphthylene	330 U	µg/kg	SW8270
			Acenaphthene	330 U	µg/kg	SW8270
			Dibenzofuran	330 U	µg/kg	SW8270
			Fluorene	330 U	µg/kg	SW8270
			Phenanthrene	330 U	µg/kg	SW8270
			Anthracene	330 U	µg/kg	SW8270
			Fluoranthene	330 U	µg/kg	SW8270
			Pyrene	330 U	µg/kg	SW8270
			Benzo(a)anthracene	330 U	µg/kg	SW8270
			Chrysene	330 U	µg/kg	SW8270
			Benzo(b)fluoranthene	330 U	µg/kg	SW8270
			Benzo(k)fluoranthene	330 U	µg/kg	SW8270
			Benzo(a)pyrene	330 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	330 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	330 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	330 U	µg/kg	SW8270
MW8-OT45	29-Sep-94	8.00 - 9.50	Naphthalene	400 U	µg/kg	SW8270
			2-Methylnaphthalene	400 U	µg/kg	SW8270
			Acenaphthylene	400 U	µg/kg	SW8270
			Acenaphthene	400 U	µg/kg	SW8270
			Dibenzofuran	400 U	µg/kg	SW8270
			Fluorene	400 U	µg/kg	SW8270
			Phenanthrene	400 U	µg/kg	SW8270
			Anthracene	400 U	µg/kg	SW8270
			Fluoranthene	400 U	µg/kg	SW8270
			Pyrene	400 U	µg/kg	SW8270
			Benzo(a)anthracene	400 U	µg/kg	SW8270
			Chrysene	400 U	µg/kg	SW8270
			Benzo(b)fluoranthene	400 U	µg/kg	SW8270
			Benzo(k)fluoranthene	400 U	µg/kg	SW8270
			Benzo(a)pyrene	400 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	400 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	400 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	400 U	µg/kg	SW8270
MW9-OT45	29-Sep-94	8.00 - 9.50	Naphthalene	380 U	µg/kg	SW8270
			2-Methylnaphthalene	380 U	µg/kg	SW8270
			Acenaphthylene	380 U	µg/kg	SW8270
			Acenaphthene	380 U	µg/kg	SW8270
			Dibenzofuran	380 U	µg/kg	SW8270
			Fluorene	380 U	µg/kg	SW8270
			Phenanthrene	380 U	µg/kg	SW8270
			Anthracene	380 U	µg/kg	SW8270
			Fluoranthene	380 U	µg/kg	SW8270
			Pyrene	380 U	µg/kg	SW8270
			Benzo(a)anthracene	380 U	µg/kg	SW8270
			Chrysene	380 U	µg/kg	SW8270
			Benzo(b)fluoranthene	380 U	µg/kg	SW8270
			Benzo(k)fluoranthene	380 U	µg/kg	SW8270
			Benzo(a)pyrene	380 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	380 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	380 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	380 U	µg/kg	SW8270
MW10-OT45	3-Oct-94	9.00 - 11.00	Naphthalene	380 U	µg/kg	SW8270
			2-Methylnaphthalene	380 U	µg/kg	SW8270
			Acenaphthylene	380 U	µg/kg	SW8270

TABLE B.2
VALIDATED SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
MW10-OT45	3-Oct-94	9.00 - 11.00	Acenaphthene	380 U	µg/kg	SW8270
			Dibenzofuran	380 U	µg/kg	SW8270
			Fluorene	380 U	µg/kg	SW8270
			Phenanthrene	380 U	µg/kg	SW8270
			Anthracene	380 U	µg/kg	SW8270
			Fluoranthene	380 U	µg/kg	SW8270
			Pyrene	380 U	µg/kg	SW8270
			Benzo(a)anthracene	380 U	µg/kg	SW8270
			Chrysene	380 U	µg/kg	SW8270
			Benzo(b)fluoranthene	380 U	µg/kg	SW8270
			Benzo(k)fluoranthene	380 U	µg/kg	SW8270
			Benzo(a)pyrene	380 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	380 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	380 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	380 U	µg/kg	SW8270
MW11-OT45	6-Oct-94	10.00 - 12.00	Naphthalene	360 U	µg/kg	SW8270
			2-Methylnaphthalene	360 U	µg/kg	SW8270
			Acenaphthylene	360 U	µg/kg	SW8270
			Acenaphthene	360 U	µg/kg	SW8270
			Dibenzofuran	360 U	µg/kg	SW8270
			Fluorene	360 U	µg/kg	SW8270
			Phenanthrene	360 U	µg/kg	SW8270
			Anthracene	360 U	µg/kg	SW8270
			Fluoranthene	360 U	µg/kg	SW8270
			Pyrene	360 U	µg/kg	SW8270
			Benzo(a)anthracene	360 U	µg/kg	SW8270
			Chrysene	360 U	µg/kg	SW8270
			Benzo(b)fluoranthene	360 U	µg/kg	SW8270
			Benzo(k)fluoranthene	360 U	µg/kg	SW8270
			Benzo(a)pyrene	360 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	360 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	360 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	360 U	µg/kg	SW8270
VW1-OT45	28-Sep-94	8.00 - 9.50	Naphthalene	330 U	µg/kg	SW8270
			2-Methylnaphthalene	330 U	µg/kg	SW8270
			Acenaphthylene	330 U	µg/kg	SW8270
			Acenaphthene	330 U	µg/kg	SW8270
			Dibenzofuran	330 U	µg/kg	SW8270
			Fluorene	330 U	µg/kg	SW8270
			Phenanthrene	330 U	µg/kg	SW8270
			Anthracene	330 U	µg/kg	SW8270
			Fluoranthene	330 U	µg/kg	SW8270
			Pyrene	330 U	µg/kg	SW8270
			Benzo(a)anthracene	330 U	µg/kg	SW8270
			Chrysene	330 U	µg/kg	SW8270
			Benzo(b)fluoranthene	330 U	µg/kg	SW8270
			Benzo(k)fluoranthene	330 U	µg/kg	SW8270
			Benzo(a)pyrene	330 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	330 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	330 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	330 U	µg/kg	SW8270
MPA-OT45	7-Oct-94	0.00 - .25	Naphthalene	360 U	µg/kg	SW8270
			2-Methylnaphthalene	360 U	µg/kg	SW8270
			Acenaphthylene	360 U	µg/kg	SW8270
			Acenaphthene	360 U	µg/kg	SW8270

TABLE B.2
VALIDATED SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
			Dibenzofuran	360 U	µg/kg	SW8270
			Fluorene	360 U	µg/kg	SW8270
			Phenanthrene	360 U	µg/kg	SW8270
			Anthracene	360 U	µg/kg	SW8270
			Fluoranthene	38 J	µg/kg	SW8270
			Pyrene	56 J	µg/kg	SW8270
			Benzo(a)anthracene	33 J	µg/kg	SW8270
			Chrysene	41 J	µg/kg	SW8270
			Benzo(b)fluoranthene	57 J	µg/kg	SW8270
			Benzo(k)fluoranthene	22 J	µg/kg	SW8270
			Benzo(a)pyrene	34 J	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	32 J	µg/kg	SW8270
			Dibenz(a,h)anthracene	360 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	30 J	µg/kg	SW8270
MPB-OT45	7-Oct-94	0.00 - .25	Naphthalene	410 U	µg/kg	SW8270
			2-Methylnaphthalene	410 U	µg/kg	SW8270
			Acenaphthylene	410 U	µg/kg	SW8270
			Acenaphthene	410 U	µg/kg	SW8270
			Dibenzofuran	410 U	µg/kg	SW8270
			Fluorene	410 U	µg/kg	SW8270
			Phenanthrene	410 U	µg/kg	SW8270
			Anthracene	410 U	µg/kg	SW8270
			Fluoranthene	33 J	µg/kg	SW8270
			Pyrene	47 J	µg/kg	SW8270
			Benzo(a)anthracene	27 J	µg/kg	SW8270
			Chrysene	26 J	µg/kg	SW8270
			Benzo(b)fluoranthene	34 J	µg/kg	SW8270
			Benzo(k)fluoranthene	410 U	µg/kg	SW8270
			Benzo(a)pyrene	21 J	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	410 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	410 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	410 U	µg/kg	SW8270
VW1-OT45	7-Oct-94	0.00 - .25	Naphthalene	360 U	µg/kg	SW8270
			2-Methylnaphthalene	360 U	µg/kg	SW8270
			Acenaphthylene	360 U	µg/kg	SW8270
			Acenaphthene	360 U	µg/kg	SW8270
			Dibenzofuran	360 U	µg/kg	SW8270
			Fluorene	360 U	µg/kg	SW8270
			Phenanthrene	360 U	µg/kg	SW8270
			Anthracene	360 U	µg/kg	SW8270
			Fluoranthene	360 U	µg/kg	SW8270
			Pyrene	360 U	µg/kg	SW8270
			Benzo(a)anthracene	360 U	µg/kg	SW8270
			Chrysene	360 U	µg/kg	SW8270
			Benzo(b)fluoranthene	360 U	µg/kg	SW8270
			Benzo(k)fluoranthene	360 U	µg/kg	SW8270
			Benzo(a)pyrene	360 U	µg/kg	SW8270
			Indeno(1,2,3-cd)pyrene	360 U	µg/kg	SW8270
			Dibenz(a,h)anthracene	360 U	µg/kg	SW8270
			Benzo(g,h,i)perylene	360 U	µg/kg	SW8270

* U= analyte not detected above method detection limit

* J= estimated value

TABLE B.3
VALIDATED SOIL DATA FOR OTHER ANALYSIS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
MPA-OT45	28-Sep-94	8.00 - 9.50	Moisture, Percent	10	%	E160.3
			Phosphorus, Total Orthophosphate	2.78 U *	mg/kg	E300.0
			Nitrogen, Total Kjeldahl	5.35 U	mg/kg	E351.3
			pH	7.83	pH units	SW9045
MPB-OT45	28-Sep-94	8.00 - 9.50	Moisture, Percent	9.1	%	E160.3
			Phosphorus, Total Orthophosphate	2.75 U	mg/kg	E300.0
			Nitrogen, Total Kjeldahl	5.4 U	mg/kg	E351.3
			Iron	1300	mg/kg	SW6010
			Alkalinity, Carbonate	27.5 U	mg/kg	E310.1
			pH	7.22	pH units	SW9045
MW4-OT45	29-Sep-94	8.00 - 9.50	Nitrogen, Total Kjeldahl	5.75 U	mg/kg	E351.3
			Total Organic Carbon	0.15	%	SW9060
MW6-OT45	29-Sep-94	8.00 - 9.50	Total Organic Carbon	0.06	%	SW9060
MW8-OT45	29-Sep-94	8.00 - 9.50	Total Organic Carbon	0.06	%	SW9060
MW10-OT45	6-Oct-94	68 - 70	Phosphorus, Total Orthophosphate	2.98 U	mg/kg	E300.0
			Nitrogen, Total Kjeldahl	195	mg/kg	E351.3
			pH	9.28	pH units	SW9045
			Total Organic Carbon	0.16	%	SW9060
MW11-OT45	7-Oct-94	12.00 - 14.00	Total Organic Carbon	0.05 U	%	SW9060
VW1-OT45	28-Sep-94	8.00 - 9.50	Moisture, Percent	11.5	%	E160.3
			Phosphorus, Total Orthophosphate	2.84 U	mg/kg	E300.0
			Nitrogen, Total Kjeldahl	5.51 U	mg/kg	E351.3
			Iron	1500	mg/kg	SW6010
			Alkalinity, Carbonate	28.2 U	mg/kg	E310.1
			pH	7.86	pH units	SW9045

* U= analyte not detected above method detection limit

TABLE B.4
VALIDATED SOIL GAS DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
MPB-OT45	11-Oct-94	9.00 - 9.50	Benzene	0.017 U*	µg/L	TO3
			Toluene	0.02 U	µg/L	TO3
			Ethylbenzene	1.4	µg/L	TO3
			Xylenes (Total)	3.2	µg/L	TO3
			Petroleum Hydrocarbons	2100	µg/L	TO3
MW2-OT45	8-Oct-94	5.00 - 10.00	Benzene	0.006 U	µg/L	TO3
			Toluene	0.008 U	µg/L	TO3
			Ethylbenzene	0.17	µg/L	TO3
			Xylenes (Total)	0.53	µg/L	TO3
			Petroleum Hydrocarbons	380	µg/L	TO3
VW1-OT45	8-Oct-94	5.00 - 10.00	Benzene	0.006 U	µg/L	TO3
			Toluene	0.008 U	µg/L	TO3
			Ethylbenzene	0.26	µg/L	TO3
			Xylenes (Total)	1	µg/L	TO3
			Petroleum Hydrocarbons	910	µg/L	TO3

* U= analyte not detected above method detection limit

TABLE B.5
VALIDATED SOIL FLUX DATA FOR VOLATILE ORGANIC COMPOUNDS
AND TOTAL PETROLEUM HYDROCARBONS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
BKG-OT45	11-Oct-94	Benzene	0.006 U ^a	µg/L	TO3
		Toluene	0.008 U	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.031	µg/L	TO3
		Petroleum Hydrocarbons	13	µg/L	TO3
MPB-OT45	11-Oct-94	Benzene	0.006 U	µg/L	TO3
		Toluene	0.034	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.013	µg/L	TO3
		Petroleum Hydrocarbons	1.6	µg/L	TO3
MPB-OT45	18-Oct-94	Benzene	0.007 U	µg/L	TO3
		Toluene	0.008 U	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.009 U	µg/L	TO3
		Petroleum Hydrocarbons	1.4	µg/L	TO3
MW2-OT45	11-Oct-94	Benzene	0.006 U	µg/L	TO3
		Toluene	0.008	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.009 U	µg/L	TO3
		Petroleum Hydrocarbons	4.9	µg/L	TO3
MW2-OT45	18-Oct-94	Benzene	0.007 U	µg/L	TO3
		Toluene	0.023	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.009 U	µg/L	TO3
		Petroleum Hydrocarbons	3.1	µg/L	TO3
VW1-OT45	11-Oct-94	Benzene	0.006 U	µg/L	TO3
		Toluene	0.038	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.009 U	µg/L	TO3
		Petroleum Hydrocarbons	2.6	µg/L	TO3
VW1-OT45	18-Oct-94	Benzene	0.007 U	µg/L	TO3
		Toluene	0.008	µg/L	TO3
		Ethylbenzene	0.009 U	µg/L	TO3
		Xylenes (Total)	0.009 U	µg/L	TO3
		Petroleum Hydrocarbons	1	µg/L	TO3

^a U= analyte not detected above method detection limit

TABLE B.5
FLUX CALCULATIONS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

[illegible]

TABLE B.6
VALIDATED GROUND WATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MW6-OT45	30-Sep-94	1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW7-OT45	28-Sep-94	Benzene	1.7 J	µg/L	SW8020
		Toluene	0.4 J	µg/L	SW8020
		Ethylbenzene	1 J	µg/L	SW8020
		Xylenes (Total)	0.6 J	µg/L	SW8020
		1,3,5-Trimethylbenzene	1.3 J	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
	12-Oct-94	Total Extractable Hydrocarbons	5 U	mg/L	M8015
		Total Volatile Hydrocarbons	1 U	mg/L	M8015
MW8-OT45	30-Sep-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW9-OT45	12-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW10-OT45	5-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	0.9 J	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW11-OT45	12-Oct-94	Benzene	1 J	µg/L	SW8240
		Toluene	5 U	µg/L	SW8240
		Ethylbenzene	5 U	µg/L	SW8240
		Xylenes (Total)	5 U	µg/L	SW8240
		1,3,5-Trimethylbenzene	5 U	µg/L	SW8240
		1,2,4-Trimethylbenzene	5 U	µg/L	SW8240
		1,2,3-Trimethylbenzene	5 U	µg/L	SW8240
VW1-OT45	10-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	1.5 J	µg/L	SW8020
		Ethylbenzene	7.2	µg/L	SW8020
		Xylenes (Total)	23	µg/L	SW8020
		1,3,5-Trimethylbenzene	43	µg/L	SW8020
		1,2,4-Trimethylbenzene	82	µg/L	SW8020
		1,2,3-Trimethylbenzene	36	µg/L	SW8020
	12-Oct-94	Total Extractable Hydrocarbons	5 U	mg/L	M8015
		Total Volatile Hydrocarbons	1 U	mg/L	M8015

^u U= analyte not detected above method detection limit

^j J= estimated value

^{uj} UJ=estimated concentration of analyte not detected above method detection limit

TABLE B.7
VALIDATED GROUND WATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MPB-OT45	10-Oct-94	Naphthalene	9 J ^a	µg/L	SW8270
		2-Methylnaphthalene	35	µg/L	SW8270
		Acenaphthylene	10 U ^b	µg/L	SW8270
		Acenaphthene	2 J	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	3 J	µg/L	SW8270
		Phenanthrene	7 J	µg/L	SW8270
		Anthracene	1 J	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW1-OT45	13-Oct-94	Naphthalene	10 U	µg/L	SW8270
		2-Methylnaphthalene	10 U	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	10 U	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	10 U	µg/L	SW8270
		Phenanthrene	10 U	µg/L	SW8270
		Anthracene	10 U	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW2-OT45	10-Oct-94	Naphthalene	150	µg/L	SW8270
		2-Methylnaphthalene	230	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	19	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	26	µg/L	SW8270
		Phenanthrene	70	µg/L	SW8270
		Anthracene	5 J	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270

TABLE B.6
VALIDATED GROUND WATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MPB-OT45	10-Oct-94	Benzene	0.4 U ^u	µg/L	SW8020
		Toluene	4.3	µg/L	SW8020
		Ethylbenzene	2.6 J ^u	µg/L	SW8020
		Xylenes (Total)	14	µg/L	SW8020
		1,3,5-Trimethylbenzene	17	µg/L	SW8020
		1,2,4-Trimethylbenzene	36	µg/L	SW8020
		1,2,3-Trimethylbenzene	25	µg/L	SW8020
MW1-OT45	13-Oct-94	Total Extractable Hydrocarbons	5 U	mg/L	M8015
		Total Volatile Hydrocarbons	1 U	mg/L	M8015
		Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW2-OT45	10-Oct-94	Total Extractable Hydrocarbons	20 J	mg/L	M8015
		Total Volatile Hydrocarbons	0.5 J	mg/L	M8015
		Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW3-OT45	10-Oct-94	Total Extractable Hydrocarbons	5 UJ ^u	mg/L	M8015
		Total Volatile Hydrocarbons	1.1	mg/L	M8015
		Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW4-OT45	13-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
MW5-OT45	11-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	1.5 J	µg/L	SW8020
		Ethylbenzene	6.3	µg/L	SW8020
		Xylenes (Total)	23	µg/L	SW8020
		1,3,5-Trimethylbenzene	19	µg/L	SW8020
		1,2,4-Trimethylbenzene	63	µg/L	SW8020
		1,2,3-Trimethylbenzene	37	µg/L	SW8020
MW6-OT45	30-Sep-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	0.4 J	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020
		Xylenes (Total)	4 U	µg/L	SW8020
		1,3,5-Trimethylbenzene	4 U	µg/L	SW8020

TABLE B.7
VALIDATED GROUND WATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MW2-OT45	10-Oct-94	Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW5-OT45	11-Oct-94	Naphthalene	32	µg/L	SW8270
		2-Methylnaphthalene	23	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	1 J	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	2 J	µg/L	SW8270
		Phenanthrene	1 J	µg/L	SW8270
		Anthracene	10 U	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW6-OT45	30-Sep-94	Naphthalene	10 U	µg/L	SW8270
		2-Methylnaphthalene	10 U	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	10 U	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	10 U	µg/L	SW8270
		Phenanthrene	10 U	µg/L	SW8270
		Anthracene	10 U	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW7-OT45	28-Sep-94	Naphthalene	64	µg/L	SW8270
		2-Methylnaphthalene	1 J	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	10 U	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	10 U	µg/L	SW8270

TABLE B.7
VALIDATED GROUND WATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MW7-OT45	28-Sep-94	Phenanthrene	10 U	µg/L	SW8270
		Anthracene	10 U	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW8-OT45	30-Sep-94	Naphthalene	10 U	µg/L	SW8270
		2-Methylnaphthalene	10 U	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	10 U	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	10 U	µg/L	SW8270
		Phenanthrene	10 U	µg/L	SW8270
		Anthracene	10 U	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
MW10-OT45	5-Oct-94	Naphthalene	10 U	µg/L	SW8270
		2-Methylnaphthalene	10 U	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	10 U	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	10 U	µg/L	SW8270
		Phenanthrene	10 U	µg/L	SW8270
		Anthracene	10 U	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270

TABLE B.7
VALIDATED GROUND WATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
VW1-OT45	10-Oct-94	Naphthalene	13	µg/L	SW8270
		2-Methylnaphthalene	41	µg/L	SW8270
		Acenaphthylene	10 U	µg/L	SW8270
		Acenaphthene	7 J	µg/L	SW8270
		Dibenzofuran	10 U	µg/L	SW8270
		Fluorene	9 J	µg/L	SW8270
		Phenanthrene	19	µg/L	SW8270
		Anthracene	1 J	µg/L	SW8270
		Fluoranthene	10 U	µg/L	SW8270
		Pyrene	10 U	µg/L	SW8270
		Benzo(a)anthracene	10 U	µg/L	SW8270
		Chrysene	10 U	µg/L	SW8270
		Benzo(b)fluoranthene	10 U	µg/L	SW8270
		Benzo(k)fluoranthene	10 U	µg/L	SW8270
		Benzo(a)pyrene	10 U	µg/L	SW8270
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270

^{a/} J= estimated value

^{b/} U= analyte not detected above method detection limit

TABLE B.8
VALIDATED GROUND WATER DATA FOR OTHER RELEVANT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MPB-OT45	10-Oct-94	Dissolved Oxygen	0.63	mg/L	FDO
	12-Oct-94	Iron	1.99	mg/L	H8008
		Nitrate	0.9	mg/L	H8039
		Sulfate	39.52	mg/L	H8051
		Hydrogen Sulfide	0.1	mg/L	H8131
		Iron, Ferrous	1.47	mg/L	H8146
		Carbon Dioxide	200	mg/L	H8223
		Nitrite	0.005 U ^a	mg/L	H8507
		Manganese	1.3	mg/L	HMANG
MW1-OT45	13-Oct-94	Carbon Dioxide	132	mg/L	COU-O2
		Dissolved Oxygen	7.52	mg/L	FDO
		Iron	0.01	mg/L	H8008
		Nitrate	0.8	mg/L	H8039
		Sulfate	45.5	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.02	mg/L	H8146
		Carbon Dioxide	41.25	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.05 U	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
MW2-OT45	10-Oct-94	Carbon Dioxide	209	mg/L	COU-O2
		Methane	0.001 U	mg/L	METHAN
MW3-OT45	10-Oct-94	Carbon Dioxide	48	mg/L	COU-O2
		Dissolved Oxygen	0.5	mg/L	FDO
		Methane	0.002	mg/L	METHAN
	13-Oct-94	Iron	0.04	mg/L	H8008
		Nitrate	0.066 U	mg/L	H8039
		Sulfate	8.57	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.01	mg/L	H8146
		Carbon Dioxide	5	mg/L	H8223
		Nitrite	0.001	mg/L	H8507
		Manganese	0.05 U	mg/L	HMANG
MW4-OT45	13-Oct-94	Dissolved Oxygen	8.71	mg/L	FDO
		Iron	0.16	mg/L	H8008
		Nitrate	2.3	mg/L	H8039
		Sulfate	33.3	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.04	mg/L	H8146
		Carbon Dioxide	8.75	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.1	mg/L	HMANG
MW5-OT45	11-Oct-94	Dissolved Oxygen	1.8	mg/L	FDO
		Iron	0.74	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	0.01 U	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.72	mg/L	H8146

TABLE B.8
VALIDATED GROUND WATER DATA FOR OTHER RELEVANT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MW5-OT45	11-Oct-94	Carbon Dioxide	58.75	mg/L	H8223
		Nitrite	0.026	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
MW6-OT45	13-Oct-94	Dissolved Oxygen	7.5	mg/L	FDO
		Iron	0.92	mg/L	H8008
		Nitrate	0.066 U	mg/L	H8039
		Sulfate	34.59	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.05	mg/L	H8146
		Carbon Dioxide	8.75	mg/L	H8223
		Nitrite	0.002	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
MW7-OT45	12-Oct-94	Carbon Dioxide	205	mg/L	COU-O2
		Dissolved Oxygen	0.03	mg/L	FDO
		Iron	0.19	mg/L	H8008
		Nitrate	0.3	mg/L	H8039
		Sulfate	24.64	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.05	mg/L	H8146
		Carbon Dioxide	27.5	mg/L	H8223
		Nitrite	0.013	mg/L	H8507
		Manganese	1.1	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
MW8-OT45	13-Oct-94	Dissolved Oxygen	0.61	mg/L	FDO
		Iron	0.76	mg/L	H8008
		Nitrate	0.1	mg/L	H8039
		Sulfate	26.94	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.07	mg/L	H8146
		Carbon Dioxide	16.25	mg/L	H8223
		Nitrite	0.005	mg/L	H8507
		Manganese	0.6	mg/L	HMANG
MW9-OT45	12-Oct-94	Iron	0.01	mg/L	H8008
		Nitrate	1.6	mg/L	H8039
		Sulfate	18.75	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.02	mg/L	H8146
		Carbon Dioxide	10	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.3	mg/L	HMANG
MW10-OT45	5-Oct-94	Dissolved Oxygen	0.4	mg/L	FDO
	11-Oct-94	Iron	0.22	mg/L	H8008
		Nitrate	0.1	mg/L	H8039
		Sulfate	6.41	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
MW10-OT45	11-Oct-94	Iron, Ferrous	0.2	mg/L	H8146
		Carbon Dioxide	16.25	mg/L	H8223
		Nitrite	0.002	mg/L	H8507

TABLE B.8
VALIDATED GROUND WATER DATA FOR OTHER RELEVANT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MW10-OT45	11-Oct-94	Manganese	0.05 U	mg/L	HMANG
MW11-OT45	12-Oct-94	Dissolved Oxygen	7.55	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	18.71	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.01	mg/L	H8146
		Carbon Dioxide	12.5	mg/L	H8223
		Nitrite	0.013	mg/L	H8507
		Manganese	0.3	mg/L	HMANG
VW1-OT45	10-Oct-94	Dissolved Oxygen	1.6	mg/L	FDO
	12-Oct-94	Iron	1.75	mg/L	H8008
		Nitrate	0.8	mg/L	H8039
		Sulfate	16.84	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	1.42	mg/L	H8146
		Carbon Dioxide	38.75	mg/L	H8223
		Nitrite	0.005	mg/L	H8507
		Manganese	0.8	mg/L	HMANG

^{a/} U = Analyte Not Detected Above Method Detection Limit

TABLE B.9
GEOCHEMICAL DATA MEASURED IN THE FIELD
REMEDIATION ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MPB-OT45	10-Oct-94	Electrical Conductivity	0.404 J ^{F29}	mmhos/cm	FCOND
		pH	6.34 J	pH units	FPH
		Redox potential	2.85835 J	pE units	FREDOX
		Temperature	13.4 J	°C	FTEMP
	12-Oct-94	Alkalinity, Carbonate	220 J	mg/L	H8221
MW1-OT45	13-Oct-94	Electrical Conductivity	0.333 J	mmhos/cm	FCOND
		pH	6.48 J	pH units	FPH
		Redox potential	2.42224 J	pE units	FREDOX
		Temperature	14.1 J	°C	FTEMP
		Alkalinity, Carbonate	100 J	mg/L	H8221
MW3-OT45	10-Oct-94	Electrical Conductivity	0.17 J	mmhos/cm	FCOND
		pH	8.7 J	pH units	FPH
	13-Oct-94	Alkalinity, Carbonate	80 J	mg/L	H8221
MW4-OT45	13-Oct-94	Electrical Conductivity	0.255 J	mmhos/cm	FCOND
		pH	7.29 J	pH units	FPH
		Redox potential	2.89723 J	pE units	FREDOX
		Temperature	13.7 J	°C	FTEMP
		Alkalinity, Carbonate	80 J	mg/L	H8221
MW5-OT45	11-Oct-94	Electrical Conductivity	0.322 J	mmhos/cm	FCOND
		pH	7.02 J	pH units	FPH
		Redox potential	2.94963 J	pE units	FREDOX
		Temperature	11.8 J	°C	FTEMP
		Alkalinity, Carbonate	160 J	mg/L	H8221
MW6-OT45	13-Oct-94	Electrical Conductivity	0.184 J	mmhos/cm	FCOND
		pH	8.01 J	pH units	FPH
		Redox potential	2.44929 J	pE units	FREDOX
		Temperature	13.3 J	°C	FTEMP
		Alkalinity, Carbonate	80 J	mg/L	H8221
MW7-OT45	12-Oct-94	Electrical Conductivity	0.556 J	mmhos/cm	FCOND
		pH	7.16 J	pH units	FPH
		Redox potential	3.39249 J	pE units	FREDOX
		Temperature	13.5 J	°C	FTEMP
		Alkalinity, Carbonate	180 J	mg/L	H8221
MW8-OT45	13-Oct-94	Electrical Conductivity	0.384 J	mmhos/cm	FCOND
		pH	7.48 J	pH units	FPH
		Redox potential	2.69439 J	pE units	FREDOX
		Temperature	13.1 J	°C	FTEMP
		Alkalinity, Carbonate	180 J	mg/L	H8221
MW9-OT45	12-Oct-94	Electrical Conductivity	0.318 J	mmhos/cm	FCOND
		pH	7.49 J	pH units	FPH
		Redox potential	4.74814 J	pE units	FREDOX
		Temperature	13.3 J	°C	FTEMP
		Alkalinity, Carbonate	160 J	mg/L	H8221
MW10-OT45	5-Oct-94	Electrical Conductivity	0.265 J	mmhos/cm	FCOND
		pH	8.05 J	pH units	FPH
		Redox potential	1.13252 J	pE units	FREDOX

TABLE B.9
GEOCHEMICAL DATA MEASURED IN THE FIELD
REMEDIATION ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
MW10-OT45	5-Oct-94	Temperature	10.8 J	°C	FTEMP
	11-Oct-94	Alkalinity, Carbonate	160 J	mg/L	H8221
MW11-OT45	12-Oct-94	Electrical Conductivity	0.353 J	mmhos/cm	FCOND
		pH	7.52 J	pH units	FPH
		Redox potential	4.09398 J	pE units	FREDOX
		Temperature	13.3 J	°C	FTEMP
		Alkalinity, Carbonate	180 J	mg/L	H8221
VW1-OT45	10-Oct-94	Electrical Conductivity	0.309 J	mmhos/cm	FCOND
		pH	6.82 J	pH units	FPH
		Redox potential	3.43475 J	pE units	FREDOX
		Temperature	12.2 J	°C	FTEMP
	12-Oct-94	Alkalinity, Carbonate	160 J	mg/L	H8221

^{a/} J= estimated value

TABLE B.10
QA/QC WATER BLANKS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Type	Sample Date	Matrix
Equipment Blank	29-Sep-94	Water
Field Blank	29-Sep-94	Water
Trip Blank	06-Oct-94	Water
Trip Blank	28-Sep-94	Water
Trip Blank	03-Oct-94	Water
Trip Blank	14-Oct-94	Water
Water Supply Blank	29-Sep-94	Water

Note:

- 1) Trip blanks were associated by date.
- 2) No samples were qualified due rinsate contamination because no analytes were detected in any of the blanks.

TABLE B.11
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Matrix	Analytical Method	Laboratory Result ^a	Holding Time Flag ^{b/}	Method Blank Flag ^{c/}	PQL Flag ^{d/}	Final Report
DC-OT45	28-Sep-94	Total Extractable Hydrocarbons	Drill Cutting	M8015	=	J		J	J
		Ethylbenzene	Drill Cutting	SW8020	=				J
		Acenaphthene	Drill Cutting	SW8270	=				J
		Dibenzofuran	Drill Cutting	SW8270	=				J
		Fluorene	Drill Cutting	SW8270	=				J
		Pyrene	Drill Cutting	SW8270	=				J
MPA-OT45	28-Sep-94 07-Oct-94	Total Extractable Hydrocarbons	Soil	M8015	ND	J			UJ
		Toluene	Soil	SW8020	=				J
		Benzo(a)anthracene	Soil	SW8270	=				J
		Benzo(a)pyrene	Soil	SW8270	=				J
		Benzo(b)fluoranthene	Soil	SW8270	=				J
		Benzo(g,h,i)perylene	Soil	SW8270	=				J
		Benzo(k)fluoranthene	Soil	SW8270	=				J
		Chrysene	Soil	SW8270	=				J
		Fluoranthene	Soil	SW8270	=				J
		Indeno(1,2,3-cd)pyrene	Soil	SW8270	=				J
		Pyrene	Soil	SW8270	=				J
		Total Extractable Hydrocarbons	Soil	M8015	=				J
		Ethylbenzene	Soil	SW8020	=				J
		Benzo(a)anthracene	Soil	SW8270	=				J
MPB-OT45	28-Sep-94 07-Oct-94	Benzo(a)pyrene	Soil	SW8270	=				J
		Benzo(b)fluoranthene	Soil	SW8270	=				J
		Chrysene	Soil	SW8270	=				J
		Fluoranthene	Soil	SW8270	=				J
		Pyrene	Soil	SW8270	=				J
		Pyrene	Soil	SW8270	=				J

TABLE B.11
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITEOT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Matrix	Analytical Method	Laboratory Result ^{a/}	Holding Time Flag ^{b/}	Method Blank Flag ^{c/}	PQL Flag ^{d/}	Final Report
MW10-OT45	03-Oct-94	1,2,3-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		1,2,4-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		1,3,5-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		Benzene	Soil	SW8020	ND	J			UJ
		Ethylbenzene	Soil	SW8020	ND	J			UJ
		Toluene	Soil	SW8020	=		U	J	U
		Toluene	Soil	SW8020	ND	J		J	UJ
		Xylenes (Total)	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	ND	J			UJ
MW5-OT45	29-Sep-94	1,2,3-Trimethylbenzene	Soil	SW8020	=	J			J
		1,2,4-Trimethylbenzene	Soil	SW8020	=	J			J
		1,3,5-Trimethylbenzene	Soil	SW8020	=	J			J
		Acenaphthene	Soil	SW8270	=			J	J
		Pyrene	Soil	SW8270	=			J	J
MW6-OT45	29-Sep-94	Toluene	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	=		U	J	U
MW7-OT45	27-Sep-94	Total Extractable Hydrocarbons	Soil	M8015	=	J		J	J
		1,2,3-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		1,2,4-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		1,3,5-Trimethylbenzene	Soil	SW8020	=	J		J	J
		Benzene	Soil	SW8020	ND	J			UJ
		Ethylbenzene	Soil	SW8020	ND	J			UJ
		Toluene	Soil	SW8020	=	J	U	J	UJ
		Xylenes (Total)	Soil	SW8020	=	J	U	J	UJ
MW9-OT45	29-Sep-94	1,2,3-Trimethylbenzene	Soil	SW8020	=			J	J
		1,2,4-Trimethylbenzene	Soil	SW8020	=			J	J

TABLE B.11
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITEOT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Matrix	Analytical Method	Laboratory Result ^{a/}	Holding Time Flag ^{b/}	Method Blank Flag ^{c/}	PQL Flag ^{d/}	Final Report
MW9-OT45	29-Sep-94	Xylenes (Total)	Soil	SW8020	=		U	J	U
VW1-OT45	28-Sep-94	Total Extractable Hydrocarbons	Soil	M8015	=	J		J	J
		1,3,5-Trimethylbenzene	Soil	SW8020	=			J	J
		Toluene	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	=		U	J	U
MPB-OT45	10-Oct-94	Ethylbenzene	Water	SW8020	=			J	J
		Acenaphthene	Water	SW8270	=			J	J
		Anthracene	Water	SW8270	=			J	J
		Fluorene	Water	SW8270	=			J	J
		Naphthalene	Water	SW8270	=			J	J
		Phenanthrene	Water	SW8270	=			J	J
MW1-OT45	13-Oct-94	Iron	Water	H8008	=			J	J
MW10-OT45	11-Oct-94 05-Oct-94	Iron, Ferrous	Water	H8146	=			J	J
		Nitrite	Water	H8507	=			J	J
		Toluene	Water	SW8020	=			J	J
		Xylenes (Total)	Water	SW8020	=		U	J	U
MW11-OT45	12-Oct-94	Iron, Ferrous	Water	H8146	=			J	J
		Nitrite	Water	H8507	=			J	J
		Benzene	Water	SW8020	=			J	J
		Benzene	Water	SW8240	=			J	J
MW2-OT45	10-Oct-94	Total Extractable Hydrocarbons	Water	M8015	=	J			J
		Total Volatile Hydrocarbons	Water	M8015	=			J	J
		Xylenes (Total)	Water	SW8020	=		U	J	U
		Anthracene	Water	SW8270	=			J	J
MW3-OT45	13-Oct-94	Iron	Water	H8008	=			J	J
		Iron, Ferrous	Water	H8146	=			J	J

TABLE B.11
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Matrix	Analytical Method	Laboratory Result ^a	Holding Time Flag ^b	Method Blank Flag ^c	PQL Flag ^d	Final Report
MW3-OT45	13-Oct-94	Nitrite	Water	H8507	=	J		J	J
		Total Extractable Hydrocarbons	Water	M8015	ND				
		Methane	Water	RSK175	=				
MW4-OT45	13-Oct-94	Iron, Ferrous	Water	H8146	=			J	J
MW5-OT45	11-Oct-94	Nitrite	Water	H8507	=			J	J
		Toluene	Water	SW8020	=			J	J
		Acenaphthene	Water	SW8270	=			J	J
		Fluorene	Water	SW8270	=			J	J
		Phenanthrene	Water	SW8270	=			J	J
MW6-OT45	13-Oct-94 30-Sep-94	Nitrite	Water	H8507	=			J	J
		Toluene	Water	SW8020	=			J	J
MW7-OT45	12-Oct-94 28-Sep-94	Nitrite	Water	H8507	=			J	J
		1,3,5-Trimethylbenzene	Water	SW8020	=			J	J
		Benzene	Water	SW8020	=			J	J
		Ethylbenzene	Water	SW8020	=			J	J
		Toluene	Water	SW8020	=			J	J
		Xylenes (Total)	Water	SW8020	=			J	J
MW8-OT45	13-Oct-94	2-Methylnaphthalene	Water	SW8270	=			J	J
		Nitrite	Water	H8507	=			J	J
MW9-OT45	12-Oct-94	Iron	Water	H8008	=			J	J
		Iron, Ferrous	Water	H8146	=			J	J
VW1-OT45	12-Oct-94 10-Oct-94	Nitrite	Water	H8507	=			J	J
		Toluene	Water	SW8020	=			J	J
		Acenaphthene	Water	SW8270	=			J	J
		Anthracene	Water	SW8270	=			J	J
		Fluorene	Water	SW8270	=			J	J

TABLE B.11
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITEOT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Matrix	Analytical Method	Laboratory Result ^{a/}	Holding Time Flag ^{b/}	Method Blank Flag ^{c/}	PQL Flag ^{d/}	Final Report
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^{a/} = Result reported by analytical laboratory. ND = not detected. "-" = An real value was reported.

^{b/} = A flag was applied to the data because sample holding time was exceeded.

^{c/} = A flag was applied because an analyte was detected during the analysis of a method blank.

^{d/} = A flag was applied because the reported value was above the MDL and below the PQL.

TABLE B.12
DUPLICATE AND REPLICATE SAMPLE RESULTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Matrix	Analytical Method	Sample Interval (ft bgs: beginning-ending)	Analyte	Real Sample Result	Duplicate Sample Result	Units	RPD ^{a/}
MPB-OT45	11-Oct-94	Soil Gas	TO3	9 - 9.5	Benzene	0.017 U	0.017 U	µg/L	
			TO3	9 - 9.5	Toluene	0.02 U	0.02 U	µg/L	
			TO3	9 - 9.5	Ethylbenzene	1.4	1.7	µg/L	9.68
			TO3	9 - 9.5	Petroleum Hydrocarbons	2100	2100	µg/L	0.00
			TO3	9 - 9.5	Xylenes (Total)	3.2	3.4	µg/L	3.03
VW1-OT45	08-Oct-94	Soil Gas	TO3	5 - 10	Benzene	0.006 U	0.006 U	µg/L	
			TO3	5 - 10	Toluene	0.008 U	0.008 U	µg/L	
			TO3	5 - 10	Ethylbenzene	0.26	0.3	µg/L	7.14
			TO3	5 - 10	Petroleum Hydrocarbons	910	910	µg/L	0.00
			TO3	5 - 10	Xylenes (Total)	1	1.2	µg/L	9.09
MW2-OT45	18-Oct-94	Soil Gas Flux	TO3	0 - 0	Benzene	0.007 U	0.007 U	µg/L	
			TO3	0 - 0	Toluene	0.023	0.015	µg/L	21.05
			TO3	0 - 0	Ethylbenzene	0.009 U	0.009 U	µg/L	
			TO3	0 - 0	Petroleum Hydrocarbons	3.1	2.5	µg/L	10.71
			TO3	0 - 0	Xylenes (Total)	0.009 U	0.009 U	µg/L	
MW10-OT45	03-Oct-94	Soil	SW8020	9 - 11	Benzene	0.46 U	0.4 UJ	µg/kg	
			SW8020	9 - 11	Toluene	4.6 U	4 UJ	µg/kg	
			SW8020	9 - 11	Ethylbenzene	4.6 U	4 UJ	µg/kg	
			SW8020	9 - 11	1,2,3-Trimethylbenzene	4.6 U	4 UJ	µg/kg	
			SW8020	9 - 11	1,2,4-Trimethylbenzene	4.6 U	4 UJ	µg/kg	
			SW8020	9 - 11	1,3,5-Trimethylbenzene	4.6 U	4 UJ	µg/kg	
			SW8020	9 - 11	Xylenes (Total)	4.6 U	4 UJ	µg/kg	
			SW8270	9 - 11	Acenaphthene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Acenaphthylene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Anthracene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Benzo(a)anthracene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Benzo(a)pyrene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Benzo(b)fluoranthene	380 U	350 U	µg/kg	

TABLE B.12
DUPLICATE AND REPLICATE SAMPLE RESULTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Matrix	Analytical Method	Sample Interval (ft bgs: beginning-ending)	Analyte	Real Sample Result	Duplicate Sample Result	Units	RPD ^{a/}
MW10-OT45	03-Oct-94	Soil	SW8270	9 - 11	Benzo(g,h,i)perylene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Benzo(k)fluoranthene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Chrysene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Dibenz(a,h)anthracene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Dibenzofuran	380 U	350 U	µg/kg	
			SW8270	9 - 11	Fluorene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Fluoranthene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Indeno(1,2,3-cd)pyrene	380 U	350 U	µg/kg	
			SW8270	9 - 11	2-Methylnaphthalene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Naphthalene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Phenanthrene	380 U	350 U	µg/kg	
			SW8270	9 - 11	Pyrene	380 U	350 U	µg/kg	

^{a/} RPD = relative percent difference between real and duplicate sample.

TABLE B.13
DETECTED ANALYTES IN GROUNDWATER FOR VOLATILE ORGANIC
COMPOUND AND SEMIVOLATILE COMPOUND ANALYSES
(1995 DETECTED ANALYTES ONLY)
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT-45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
OT45-MW11	17-Oct-95	Benzene	1.3	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	2.9	µg/L	SW8020
OT45-MW11	17-Oct-95	Benzene	1.1	µg/L	SW8260
		1,2,3,4-Tetramethylbenzene	4.3	µg/L	SW8260
OT45-MW11	17-Oct-95	Naphthalene	1	µg/L	SW8270
OT45-MW5	17-Oct-95	Ethyl Benzene	5.0	µg/L	SW8020
		Total Xylenes (m,p & o)	11	µg/L	SW8020
		1,3,5-Trimethylbenzene	4.3	µg/L	SW8020
		1,2,4-Trimethylbenzene	15	µg/L	SW8020
		1,2,3-Trimethylbenzene	7.3	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	13	µg/L	SW8020
OT45-MW7	17-Oct-95	Benzene	1.3	µg/L	SW8020
		Ethyl Benzene	11	µg/L	SW8020
		Total Xylenes (m,p & o)	1.2	µg/L	SW8020
		1,3,5-Trimethylbenzene	5.4	µg/L	SW8020
		1,2,4-Trimethylbenzene	1.8	µg/L	SW8020
		1,2,3-Trimethylbenzene	1.8	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	26	µg/L	SW8020
OT45-MW12	17-Oct-95	Ethyl Benzene	2.8	µg/L	SW8020
		Total Xylenes (m,p & o)	5.4	µg/L	SW8020
		1,3,5-Trimethylbenzene	2.3	µg/L	SW8020
		1,2,4-Trimethylbenzene	7.6	µg/L	SW8020
		1,2,3-Trimethylbenzene	4.4	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	7.4	µg/L	SW8020
OT45-MW12	17-Oct-95	Naphthalene	18	µg/L	SW8270
OT45-MW4	17-Oct-95	1,2,3-Trimethylbenzene	0.8	µg/L	SW8020
OT45-MW10	18-Oct-95	Total Xylenes (m,p & o)	1.3	µg/L	SW8020
OT45-MPB	18-Oct-95	Ethyl Benzene	0.6	µg/L	SW8020
		Total Xylenes (m,p & o)	2.6	µg/L	SW8020
		1,2,4-Trimethylbenzene	1.5	µg/L	SW8020
		1,2,3-Trimethylbenzene	1.3	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	2.1	µg/L	SW8020
OT45-VW1	18-Oct-95	Ethyl Benzene	0.8	µg/L	SW8020
		Total Xylenes (m,p & o)	3.2	µg/L	SW8020
		1,3,5-Trimethylbenzene	2.4	µg/L	SW8020
		1,2,4-Trimethylbenzene	6.4	µg/L	SW8020
		1,2,3-Trimethylbenzene	2.3	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	9.4	µg/L	SW8020

TABLE B.13 (Continued)
DETECTED ANALYTES IN GROUNDWATER FOR VOLATILE ORGANIC
COMPOUND AND SEMIVOLATILE COMPOUND ANALYSES
(1995 DETECTED ANALYTES ONLY)
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT-45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
OT45-MW2	18-Oct-95	Toluene	1.8	µg/L	SW8020
		Ethyl Benzene	10	µg/L	SW8020
		Total Xylenes (m,p & o)	21	µg/L	SW8020
		1,3,5-Trimethylbenzene	8.7	µg/L	SW8020
		1,2,4-Trimethylbenzene	48	µg/L	SW8020
		1,2,3-Trimethylbenzene	26	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	66	µg/L	SW8020
OT45-BP4	18-Oct-95	Toluene	1.9	µg/L	SW8020
		Ethyl Benzene	0.6	µg/L	SW8020
		Total Xylenes (m,p & o)	2.1	µg/L	SW8020
OT45-BP1	18-Oct-95	Toluene	3.9	µg/L	SW8020
		Total Xylenes (m,p & o)	1.2	µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	1.2	µg/L	SW8020
OT45-BP2	18-Oct-95	Benzene	0.5	µg/L	SW8020
		Toluene	4.2	µg/L	SW8020
OT45-BP3	18-Oct-95	Toluene	6.7	µg/L	SW8020
		Ethyl Benzene	1.5	µg/L	SW8020
		Total Xylenes (m,p & o)	9.8	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.7	µg/L	SW8020
		1,2,4-Trimethylbenzene	1.7	µg/L	SW8020
OT45-VW1	18-Oct-95	Naphthalene	22	µg/L	SW8270
OT45-MW2	18-Oct-95	Naphthalene	130	µg/L	SW8270
		Phenanthrene	6	µg/L	SW8270
OT45-MW5	17-Oct-95	Naphthalene	11	µg/L	SW8270

TABLE B.14
DETECTED ANALYTES IN GROUNDWATER FOR VOLATILE ORGANIC
COMPOUND AND SEMIVOLATILE COMPOUND ANALYSES
(1996 - 1997 DETECTED ANALYTES ONLY)
REMEDIATION ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT-45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
OT45-MW7	6-Nov-96	Trichloroethene	3J	µg/L	SW8260
		Ethyl Benzene	7	µg/L	SW8260
		Total Xylenes (m,p & o)	2J	µg/L	SW8260
		1,3,5-Trimethylbenzene	6	µg/L	SW8260
		1,2,4-Trimethylbenzene	1J	µg/L	SW8260
		1,2,3-Trimethylbenzene	1J	µg/L	SW8260
OT45-MW2	24-Jun-97	1,2,3,4-Tetramethylbenzene	7.4	µg/L	SW8260?

J = indicates a laboratory estimated value; compound was detected, but below the laboratory reporting limit or estimated quantitation limit.

TABLE B.15
QA/QC WATER BLANKS
(1996 - 1997)
REMEDIATION ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT-45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Type/Analyte	Result	Units	Analytical Method
OT45-MW7	6-Nov-96	Equipment Blank			
		Trichloroethene	U	µg/L	SW8260
		Ethyl Benzene	U	µg/L	SW8260
		Total Xylenes (m,p & o)	U	µg/L	SW8260
		1,3,5-Trimethylbenzene	U	µg/L	SW8260
		1,2,4-Trimethylbenzene	U	µg/L	SW8260
		1,2,3-Trimethylbenzene	U	µg/L	SW8260
OT45-MW7	6-Nov-96	Trip Blank			
		Trichloroethene	U	µg/L	SW8260
		Ethyl Benzene	U	µg/L	SW8260
		Total Xylenes (m,p & o)	U	µg/L	SW8260
		1,3,5-Trimethylbenzene	U	µg/L	SW8260
		1,2,4-Trimethylbenzene	U	µg/L	SW8260
		1,2,3-Trimethylbenzene	U	µg/L	SW8260
OT45-MW7	6-Nov-96	Matrix Spike			
		Trichloroethene	22	µg/L	SW8260
		Ethyl Benzene	28	µg/L	SW8260
		Total Xylenes (m,p & o)	21	µg/L	SW8260
		1,3,5-Trimethylbenzene	-- ¹	µg/L	SW8260
		1,2,4-Trimethylbenzene	-- ¹	µg/L	SW8260
		1,2,3-Trimethylbenzene	-- ¹	µg/L	SW8260
OT45-MW2	6-Nov-96	Matrix Spike Duplicate			
		Trichloroethene	18	µg/L	SW8260
		Ethyl Benzene	20	µg/L	SW8260
		Total Xylenes (m,p & o)	20	µg/L	SW8260
		1,3,5-Trimethylbenzene	20	µg/L	SW8260
		1,2,4-Trimethylbenzene	20	µg/L	SW8260
		1,2,3-Trimethylbenzene	19	µg/L	SW8260
OT45-EB10	24-Jun-97	Equipment Blank			
		1,2,3,4-Tetramethylbenzene	U	µg/L	SW8260
OT45	24-Jun-97	Trip Blank			
		1,2,3,4-Tetramethylbenzene	U	µg/L	SW8260
OT45-VW1 ²	24-Jun-97	Matrix Spike Duplicate			
		1,2,3,4-Tetramethylbenzene	20	µg/L	SW8260

U = compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water.

¹-- matrix spike analyses were not performed for the methylbenzenes using OT45-MW7 sample data.

²-- no matrix spike analyses was performed using MW2 sample information.

TABLE B.16
DETECTED ANALYTES IN SOIL FOR VOLATILE ORGANIC COMPOUND
AND SEMIVOLATILE COMPOUND ANALYSES
(1996 DETECTED ANALYTES ONLY)
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT-45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
C1	27-Jul-96	Toluene	0.9J	µg/kg	SW8020
		Total Xylenes (m,p & o)	1J	µg/kg	SW8020
C2	27-Jul-96	1,2,3,4-Tetramethylbenzene	0.7J	µg/kg	SW8020
C3	27-Jul-96	Toluene	0.8J	µg/kg	SW8020
		Total Xylenes (m, p & o)	0.7J	µg/kg	SW8020
		Pyrene	58J	µg/kg	SW8270
C4	28-Jul-96	Pyrene	34J	µg/kg	SW8270
C7	28-Jul-96	Ethylbenzene	0.6J	µg/kg	SW8020
		Total Xylenes (m, p & o)	2.3J	µg/kg	SW8020
		1,2,3-Trimethylbenzene	1.3J	µg/kg	SW8020
		1,2,4-Trimethylbenzene	2.7J	µg/kg	SW8020
		1,3,5-Trimethylbenzene	2.3J	µg/kg	SW8020
		1,2,3,4-Tetramethylbenzene	30	µg/kg	SW8020
		2-Methylnaphthalene	47J	µg/kg	SW8270
		Naphthalene	35J	µg/kg	SW8270
		Phenanthrene	21J	µg/kg	SW8270
C8	28-Jul-96	Pyrene	58J	µg/kg	SW8270
		1,3,5-Trimethylbenzene	0.7J	µg/kg	SW8020
C10	28-Jul-96	2-Methylnaphthalene	110J	µg/kg	SW8270
		Total Xylenes (m, p & o)	0.6J	µg/kg	SW8020
C13	4-Aug-96	1,3,5-Trimethylbenzene	0.5J	µg/kg	SW8020
		Total Xylenes (m, p & o)	0.6J	µg/kg	SW8020
C14	4-Aug-96	1,3,5-Trimethylbenzene	0.5J	µg/kg	SW8020
		Total Xylenes (m, p & o)	0.5J	µg/kg	SW8020
		1,2,3,4-Tetramethylbenzene	1.0J	µg/kg	SW8020

J = indicates a laboratory estimated value; compound was detected, but below the laboratory reporting limit or estimated quantitation limit.

TABLE B.17
QA/QC SOIL BLANKS
(1996)
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT-45, WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Type/Analyte	Result	Units	Matrix
OT45-R1	4-Aug-96	Replicate			Water
		Benzene	U	µg/L	
		Ethyl Benzene	U	µg/L	
		Toluene	U	µg/L	
		Total Xylenes (m,p & o)	U	µg/L	
		Chlorobenzene	U	µg/L	
		1,3,5-Trimethylbenzene	U	µg/L	
		1,2,4-Trimethylbenzene	U	µg/L	
		1,2,3-Trimethylbenzene	U	µg/L	
OT45-R2	4-Aug-96	1,2,3,4-Tetramethylbenzene	0.6	µg/L	Water
		Replicate			
		Benzene	U	µg/L	
		Ethyl Benzene	U	µg/L	
		Toluene	U	µg/L	
		Total Xylenes (m,p & o)	U	µg/L	
		Chlorobenzene	U	µg/L	
		1,3,5-Trimethylbenzene	U	µg/L	
		1,2,4-Trimethylbenzene	U	µg/L	
OT45-TB	4-Aug-96	1,2,3-Trimethylbenzene	U	µg/L	Water
		1,2,3,4-Tetramethylbenzene	U	µg/L	
		Trip Blank			
		Benzene	U	µg/L	
		Ethyl Benzene	U	µg/L	
		Toluene	U	µg/L	
		Total Xylenes (m,p & o)	U	µg/L	
		Chlorobenzene	U	µg/L	
		1,3,5-Trimethylbenzene	U	µg/L	
OT45-FB	4-Aug-96	1,2,4-Trimethylbenzene	U	µg/L	Water
		1,2,3-Trimethylbenzene	U	µg/L	
		1,2,3,4-Tetramethylbenzene	U	µg/L	
		Field Blank			
		Benzene	U	µg/L	
		Ethyl Benzene	U	µg/L	
		Toluene	U	µg/L	
		Total Xylenes (m,p & o)	U	µg/L	
		Chlorobenzene	U	µg/L	
OT45-W1	4-Aug-96	1,3,5-Trimethylbenzene	U	µg/L	Water
		1,2,4-Trimethylbenzene	U	µg/L	
		1,2,3-Trimethylbenzene	U	µg/L	
		1,2,3,4-Tetramethylbenzene	U	µg/L	
		Water Blank			
		Benzene	U	µg/L	
		Ethyl Benzene	U	µg/L	
		Toluene	U	µg/L	
		Total Xylenes (m,p & o)	U	µg/L	
		Chlorobenzene	U	µg/L	
		1,3,5-Trimethylbenzene	U	µg/L	
		1,2,4-Trimethylbenzene	U	µg/L	
		1,2,3-Trimethylbenzene	U	µg/L	
		1,2,3,4-Tetramethylbenzene	U	µg/L	

U = compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water.

EVERGREEN ANALYTICAL, INC.
4036 Youngfield St. Wheat Ridge, CO 80033
(303) 425-6021

Method 602 Data Report

Client Sample Number	: MW-11	Client Project No.	: 725520.500 Wurtsmith
Lab Sample Number	: X05424	Lab Project No.	: 95-1136
Date Sampled	: 4/6/95	Dilution Factor	: 1.00
Date Received	: 4/7/95	Method	: 602
Date Prepared	: 4/12/95	Matrix	: Water
Date Analyzed	: 4/12/95	Lab File No.	: BX2041210
		Method Blank No.	: MB041295

Compound Name	Cas Number	Sample Concentration ug/L	RL ug/L
Benzene	71-43-2	0.9	0.4
Toluene	108-88-3	U	0.4
Chlorobenzene	108-90-7	U	0.4
Ethyl Benzene	100-41-4	U	0.4
Total Xylenes (m, p & o)	108-38-3, 106-42-3 and 95-47-6	U	0.4
Trimethylbenzene	108-67-8	U	0.4
1,2,4-Trimethylbenzene	95-63-6	U	0.4
1,2,3-Trimethylbenzene	526-73-8	U	0.4
1,2,3,4-Tetramethylbenzene	488-23-3	4.7	0.4
Surrogate Recovery (α,α,α -Trifluorotoluene):		91%	70%-130% (QC limits)

Note: Total Xylenes consist of three isomers, two of which co-elute.
The Xylene RL is for a single peak.

QUALIFIERS:

E = Extrapolated value.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
RL = Reporting Limit.
NA = Not Available/Not Applicable.


Analyst


Approved

1994 VALIDATION RESULTS

**MS/MSD SAMPLES &
GC/MS CONFIRMATION SAMPLES**

GCMS CONFIRMATION

Sample Number	: MW-11	Client I.D.	: 725520.500/
Sample Number	: X05424		WURTSMITH
Date Sampled	: 04/06/95	Lab Project No.	: 95-1136
Date Received	: 04/07/95	Effective Dilution	: 1.00
Date Extracted/Prepared	: 04/10/95	Method	: 8240(8260)
Date Analyzed	: 04/10/95	Matrix	: WATER
Methanol Extract?	: N	Lab File No.	: >V6324
Percent Loss on Drying	: NA	Method Blank No.	: RB041095

Compound Name	Cas Number	Conc. ug/L	PQL* ug/L
Benzene	71-43-2	U	5
Toluene	108-88-3	U	5
Ethyl Benzene	100-41-4	U	5
Total Xylenes	1330-20-7	U	5
Chlorobenzene	108-90-7	U	5
1,2,4-Trimethylbenzene	95-63-6	U	10
1,2,3-Trimethylbenzene	526-73-8	U	10
1,3,5-Trimethylbenzene (Mesitylene)	108-67-8	U	10
1,2,3,4-Tetramethylbenzene	488-23-3	3	10
Styrene	100-42-5	U	5

Surrogate Recoveries:

QC Limits

1,2 Dichloroethane-d4	101%	(83-112)
Toluene-d8	101%	(93-104)
Bromofluorobenzene	103%	(87-105)

Qualifiers:

- U = Compound analyzed for, but not detected above the reporting limit(0.2 ppb)
Reporting limits are roughly the method detection limits in reagent water.
J = Indicates an estimated value when the compound is detected, but is below the Practical Quantitation Limit (PQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Practical Quantitation Limits listed are approximately 10 times the detection limits for reagent water.

Unless otherwise noted all concentrations and PQL's for soils are quantitated on an as is basis.

NA = Not applicable or not available

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(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: W407-SS51S	Client Project No.	: 725524.03000
Lab Sample No.	: X95774		Wurtsmith AFB
Date Sampled	: 10/3/94	Lab Project No.	: 94-3825
Date Received	: 10/6/94	EPA Method No.	: 8020
Date Prepared	: 10/17/94	Matrix	: Water
Date Analyzed	: 10/18/94	Lab File Number(s)	: BX2101723,24
		Method Blank	: MB101794

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	0	16.3	81.5	65-121
Toluene	20	0.8	15.1	71.5	69-117
Ethyl Benzene	20	0	14.6	73	68-118
m/p-Xylene	20	1.3	15.1	69	66-116
o-Xylene	20	0.5	15.1	73	73-117
1,3,5-TMB	20	0	14.5	72.5	65-121
1,2,4-TMB	20	0	14.9	74.5	65-121
1,2,3-TMB	20	0	15.5	77.5	65-121

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MS %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	19.4	97	17.4	17.4	65-121
Toluene	20	18.6	89	21.8 *	15.8	69-117
Ethyl Benzene	20	18.2	91	22.0 *	11.9	68-118
m/p-Xylene	20	19.1	89	25.3 *	15.4	66-116
o-Xylene	20	18.4	89.5	20.3 *	15.9	73-117
1,3,5-TMB	20	17.9	89.5	21.0 *	17.4	65-121
1,2,4-TMB	20	17.9	89.5	18.3 *	17.4	65-121
1,2,3-TMB	20	19.1	95.5	20.8 *	17.4	65-121

* = Values outside of QC limits.

RPD: 7 out of (8) outside limits.

Spike Recovery: 0 out of (16) outside limits.

Comments: CJC
MS surrogate recovery: 81%. MSD surrogate recovery: 97%.

SOIL SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.
 Lab Project No.: 94-3825
 Lab Sample No.: X95774
 Lab File Ids.: >26914,5

Client I.D.: 725524.03000-
 WURTSMITH AFB
 Client Sample No.: W407-SS51S
 Date Extracted: 10/13/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Phenol	200	0.00	166.99	83	26-90
2-Chlorophenol	200	0.00	145.49	73	25-102
1,4-Dichlorobenzene	100	0.00	70.17	70	28-104
N-Nitrosodipropylamine	100	0.00	89.58	90	41-126
1,2,4-Trichlorobenzene	100	0.00	62.01	62	38-107
4-Chloro-3-methylphenol	200	0.00	149.32	75	26-103
Acenaphthene	100	0.00	74.64	75	31-137
4-Nitrophenol	200	0.00	175.70	88	11-114
2,4-Dinitrotoluene	100	0.00	74.61	75	28-89
Pentachlorophenol	200	0.00	166.96	83	17-109
Pyrene	100	0.00	80.91	81	35-142

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS	
					RPD	%REC
Phenol	200	179.46	90	7.2	35	26-90
2-Chlorophenol	200	156.84	78	7.5	50	25-102
1,4-Dichlorobenzene	100	76.62	77	8.8	27	28-104
N-Nitrosodipropylamine	100	96.76	97	7.7	38	41-126
1,2,4-Trichlorobenzene	100	67.27	67	8.1	23	38-107
4-Chloro-3-methylphenol	200	159.29	80	6.5	33	26-103
Acenaphthene	100	80.11	80	7.1	19	31-137
4-Nitrophenol	200	155.41	78	12	50	11-114
2,4-Dinitrotoluene	100	79.32	79	6.1	47	28-89
Pentachlorophenol	200	166.05	83	0.55	47	17-109
Pyrene	100	89.80	90	10	36	35-142

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 11 outside limits.

Spike Recovery: 0 out of 22 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

Evergreen Analytical, Inc.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: MPA-OT45S	Client Project No.	: 725523.03000
Lab Sample No.	: X95429	Lab Project No.	: 94-3750
Date Sampled	: 9/28/94	EPA Method No.	: 8020
Date Received	: 9/30/94	Matrix	: Water
Date Prepared	: 10/9/94	Lab File Number(s)	: BX2100921,22
Date Analyzed	: 10/10/94	Method Blank	: MB100994

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	0	17.1	85.5	65-121
Toluene	20	0.4	12.2	59*	69-117
Ethyl Benzene	20	0	15.9	79.5	68-118
m/p-Xylene	20	0	15.3	76.5	66-116
o-Xylene	20	0	16	80	73-117
1,3,5-TMB	20	0	15.7	78.5	65-121
1,2,4-TMB	20	0	14.6	73	65-121
1,2,3-TMB	20	0	15.7	78.5	65-121

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MSD %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	16.9	84.5	1.2	17.4	65-121
Toluene	20	12.8	62*	5.0	15.8	69-117
Ethyl Benzene	20	15.9	79.5	0.0	11.9	68-118
m/p-Xylene	20	15.2	76	0.7	15.4	66-116
o-Xylene	20	15.7	78.5	1.9	13.2	73-117
1,3,5-TMB	20	15.1	75.5	3.9	17.4	65-121
1,2,4-TMB	20	14.0	70	4.2	17.4	65-121
1,2,3-TMB	20	14.8	74	5.9	17.4	65-121

*= Values outside of QC limits.

RPD: 0 out of (8) outside limits.

Spike Recovery: 2 out of (16) outside limits.

Comments: CJC

Evergreen Analytical, Inc.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: MW-7OT45W	Client Project No.	: 725523.03000
Lab Sample No.	: X95433	Lab Project No.	: 94-3750
Date Sampled	: 9/28/94	EPA Method No.	: 8020
Date Received	: 9/30/94	Matrix	: Water
Date Prepared	: 10/1/94	Lab File Number(s)	: BX1093026,27
Date Analyzed	: 10/1/94	Method Blank	: MB093094

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	1.7	15.2	67.5	65-121
Toluene	20	0.4	14.3	69.5	69-117
Ethyl Benzene	20	1	14.9	69.5	68-118
m/p-Xylene	20	0.6	14.6	70	66-116
o-Xylene	20	0	14.6	73	73-117

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MSD %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	17.7	80	16.9 *	17.4	65-121
Toluene	20	16.7	81.5	15.9	15.8	69-117
Ethyl Benzene	20	17.3	81.5	15.9	11.9	68-118
m/p-Xylene	20	16.7	80.5	14.0 *	15.4	66-116
o-Xylene	20	16.6	83	12.8 *	13.2	73-117

*= Values outside of QC limits.

RPD: 3 out of (5) outside limits.

Spike Recovery: 0 out of (10) outside limits.

Comments: CJC Surrogate recoveries: MS=67%, MSD=81%.
All Spike recoveries are acceptable. Poor purge cycle during analysis of MS caused poor surrogate and unacceptable RPD results. No rerun was performed.

SOIL SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.

Lab Project No.: 94-3750

Lab Sample No. : X95429

Lab File Ids. : >26787,26802

Client I.D. : 725523.03000

Client Sample No. : MPA-OT45S

Date Extracted : 10/04/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	0.00	67.50	68	NA
1,4-Dichlorobenzene	100	0.00	63.49	63	28-104
N-Nitrosodipropylamine	100	0.00	75.15	75	41-126
1,2,4-Trichlorobenzene	100	0.00	58.09	58	38-107

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS	
					RPD	%REC
Naphthalene	100	74.16	74	9.4	NA	NA
1,4-Dichlorobenzene	100	71.75	72	12	27	28-104
N-Nitrosodipropylamine	100	83.56	84	11	38	41-126
1,2,4-Trichlorobenzene	100	65.23	65	12	23	38-107

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 4 outside limits.Spike Recovery: 0 out of 8 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.

Lab Project No.: 94-3750

Lab Sample No. : X95433

Lab File Ids. : >26779,80

Client I.D. : 725523.03000

Client Sample No. : MW7-OT45S

Date Extracted : 09/30/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	64.42	140.85	76	NA
1,4-Dichlorobenzene	100	0.00	82.39	82	36-97
N-Nitrosodipropylamine	100	0.00	100.13	100	41-116
1,2,4-Trichlorobenzene	100	0.00	76.17	76	39-98

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	%REC
Naphthalene	100	147.74	83	8.6	NA	NA
1,4-Dichlorobenzene	100	87.46	87	6	28	36-97
N-Nitrosodipropylamine	100	102.98	103	2.8	38	41-116
1,2,4-Trichlorobenzene	100	79.81	80	4.7	28	39-98

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 4 outside limits.Spike Recovery: 0 out of 8 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

Evergreen Analytical, Inc.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: MW9-OT45W	Client Project No.	: 725524.03000
Lab Sample No.	: X96712	Lab Project No.	: 94-3984
Date Sampled	: 10/12/94	EPA Method No.	: 602
Date Received	: 10/15/94	Matrix	: Water
Date Prepared	: 10/22/94	Lab File Number(s)	: BX2102219,20
Date Analyzed	: 10/23/94	Method Blank	: MB102294

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	0	19.8	99	65-121
Toluene	20	0	21.1	105.5	69-117
Ethyl Benzene	20	0	20.2	101	68-118
m/p-Xylene	20	0	20.6	103	66-116
o-Xylene	20	0	19.4	97	73-117
Chlorobenzene	20	0	19.3	96.5	65-121
1,3,5-TMB	20	0	19.3	96.5	65-121
1,2,4-TMB	20	0	18.8	94	65-121
1,2,3-TMB	20	0	23.1	115.5	65-121

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MS %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	17.5	87.5	12.3	17.4	65-121
Toluene	20	19	95	10.5	15.8	69-117
Ethyl Benzene	20	18	90	11.5	11.9	68-118
m/p-Xylene	20	18.5	92.5	10.7	15.4	66-116
o-Xylene	20	17.5	87.5	10.3	13.2	73-117
Chlorobenzene	20	17.4	87	10.4	17.4	65-121
1,3,5-TMB	20	17.7	88.5	8.6	17.4	65-121
1,2,4-TMB	20	17.1	85.5	9.5	17.4	65-121
1,2,3-TMB	20	20.5	102.5	11.9	17.4	65-121

* = Values outside of QC limits.

RPD: 0 out of (9) outside limits.

Spike Recovery: 0 out of (18) outside limits.

Comments: CJC

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.
 Lab Project No.: 94-3984
 Lab Sample No.: X96709
 Lab File Ids.: >26978,9

Client I.D.: 725524.03000-WURTSMITH AFE
 Client Sample No.: MW1-OT45W
 Date Extracted: 10/19/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	0.00	93.02	93	NA
1,4-Dichlorobenzene	100	0.00	72.97	73	36-97
N-Nitrosodipropylamine	100	0.00	110.71	111	41-116
1,2,4-Trichlorobenzene	100	0.00	61.74	62	39-98
Acenaphthene	100	0.00	81.66	82	46-118
2,4-Dinitrotoluene	100	0.00	80.11	80	24-96
Pyrene	100	0.00	90.97	91	26-127

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	%REC
Naphthalene	100	82.46	82	12	NA	NA
1,4-Dichlorobenzene	100	62.33	62	16	28	36-97
N-Nitrosodipropylamine	100	101.12	101	9.1	38	41-116
1,2,4-Trichlorobenzene	100	53.07	53	15	28	39-98
Acenaphthene	100	71.84	72	13	31	46-118
2,4-Dinitrotoluene	100	72.23	72	10	38	24-96
Pyrene	100	76.70	77	17	31	26-127

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 7 outside limits.

Spike Recovery: 0 out of 14 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.
 Lab Project No.: 94-3930
 Sample No. : X96364
 File Ids. : >26953,4

Client I.D. : 725523.03000-
 WURTSMITH AFB
 Client Sample No. : MW5-OT45W
 Date Extracted : 10/13/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	31.98	112.90	81	NA
1,4-Dichlorobenzene	100	0.00	80.28	80	36-97
N-Nitrosodipropylamine	100	0.00	105.28	105	41-116
1,2,4-Trichlorobenzene	100	0.00	69.51	70	39-98
Acenaphthene	100	1.24	87.10	86	46-118
2,4-Dinitrotoluene	100	0.00	66.52	67	24-96
Pyrene	100	0.00	87.83	88	26-127

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	%REC
Naphthalene	100	108.91	77	5.1	NA	NA
1,4-Dichlorobenzene	100	79.77	80	0.64	28	36-97
N-Nitrosodipropylamine	100	103.75	104	1.5	38	41-116
1,2,4-Trichlorobenzene	100	67.88	68	2.4	28	39-98
Acenaphthene	100	83.75	84	2.5	31	46-118
2,4-Dinitrotoluene	100	62.03	62	7	38	24-96
Pyrene	100	87.38	86	1.9	31	26-127

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 7 outside limits.

Spike Recovery: 0 out of 14 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

Evergreen Analytical, Inc.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: MW4-OT45S	Client Project No.	: 725523.03000
Lab Sample No.	: X95488	Lab Project No.	: 94-3764
Date Sampled	: 9/29/94	EPA Method No.	: 8020
Date Received	: 10/1/94	Matrix	: Soil
Date Prepared	: 10/10/94	Lab File Number(s)	: BX2101020
Date Analyzed	: 10/11/94	Method Blank	: MB101094

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	0	12.7	63.5*	65-121
Toluene	20	0	12.1	60.5*	69-117
Ethyl Benzene	20	0	10.4	52*	68-118
m/p-Xylene	20	0	9.4	47*	66-116
o-Xylene	20	0	10.6	53*	73-117
1,3,5-TMB	20	0	8.8	44*	65-121
1,2,4-TMB	20	0	8.7	43.5*	65-121
1,2,3-TMB	20	0	10.6	53*	65-121

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MSD %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	NA	NA	NA	17.4	65-121
Toluene	20	NA	NA	NA	15.8	69-117
Ethyl Benzene	20	NA	NA	NA	11.9	68-118
m/p-Xylene	20	NA	NA	NA	15.4	66-116
o-Xylene	20	NA	NA	NA	13.2	73-117
1,3,5-TMB	20	NA	NA	NA	17.4	65-121
1,2,4-TMB	20	NA	NA	NA	17.4	65-121
1,2,3-TMB	20	NA	NA	NA	17.4	65-121

* = Values outside of QC limits.

RPD: NA out of (8) outside limits.

Spike Recovery: 8 out of (16) outside limits.

Comments: CJC
MS surrogate recovery: 58%. MSD did not purge on this run.
MS & MSD analyzed 10/17/94.

Evergreen Analytical, Inc.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: MW4-OT45S	Client Project No.	: 725523.03000
Lab Sample No.	: X95488	Lab Project No.	: 94-3764
Date Sampled	: 9/29/94	EPA Method No.	: 8020
Date Received	: 10/1/94	Matrix	: Soil
Date Prepared	: 10/16/94	Lab File Number(s)	: BX2101620
Date Analyzed	: 10/17/94	Method Blank	: MB101694

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	0	15.4	77	65-121
Toluene	20	0	15.2	76	69-117
Ethyl Benzene	20	0	13.4	67*	68-118
m/p-Xylene	20	0	14.2	71	66-116
o-Xylene	20	0	12.3	61.5*	73-117
1,3,5-TMB	20	0	11.9	59.5*	65-121
1,2,4-TMB	20	0	9.8	49*	65-121
1,2,3-TMB	20	0	7.6	38*	65-121

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MSD %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	NA	NA	NA	17.4	65-121
Toluene	20	NA	NA	NA	15.8	69-117
Ethyl Benzene	20	NA	NA	NA	11.9	68-118
m/p-Xylene	20	NA	NA	NA	15.4	66-116
o-Xylene	20	NA	NA	NA	13.2	73-117
1,3,5-TMB	20	NA	NA	NA	17.4	65-121
1,2,4-TMB	20	NA	NA	NA	17.4	65-121
1,2,3-TMB	20	NA	NA	NA	17.4	65-121

* = Values outside of QC limits.

RPD: NA out of (8) outside limits.

Spike Recovery: 5 out of (16) outside limits.

Comments: CJC
MS surrogate recovery: 78%. MSD did not purge on this run.

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.

Lab Project No.: 94-3764

Lab Sample No. : X95490

Lab File Ids. : >26784,85

Client I.D. : 725523.03000

Client Sample No. : MW8-0T45W

Date Extracted : 10/01/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	0.00	84.12	84	NA
1,4-Dichlorobenzene	100	0.00	71.25	71	36-97
N-Nitrosodipropylamine	100	0.00	98.89	99	41-116
1,2,4-Trichlorobenzene	100	0.00	65.67	66	39-98

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	%REC
Naphthalene	100	88.82	89	5.4	NA	NA
1,4-Dichlorobenzene	100	73.61	74	3.3	28	36-97
N-Nitrosodipropylamine	100	102.25	102	3.3	38	41-116
1,2,4-Trichlorobenzene	100	68.00	68	3.5	28	39-98

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 4 outside limits.Spike Recovery: 0 out of 8 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.

Lab Project No.: 94-3846

Sample No.: X95861

File Ids.: >26892,93

Client I.D.: 725524.03

Client Sample No.: MW10-OT45W

Date Extracted: 10/07/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Phenol	200	0.00	217.01	109 *	12-89
2-Chlorophenol	200	0.00	200.59	100	27-123
1,4-Dichlorobenzene	100	0.00	94.71	95	36-97
N-Nitrosodipropylamine	100	0.00	125.77	126 *	41-116
1,2,4-Trichlorobenzene	100	0.00	81.89	82	39-98
4-Chloro-3-methylphenol	200	0.00	197.60	99 *	23-97
Acenaphthene	100	0.00	99.28	99	46-118
4-Nitrophenol	200	0.00	224.50	112 *	10-80
2,4-Dinitrotoluene	100	0.00	100.19	100 *	24-96
Pentachlorophenol	200	0.00	241.67	121 *	9-103
Pyrene	100	0.00	78.97	79	26-127
NAPHTHALENE	100	0.00	106.14	106	NA

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS %REC
Phenol	200	209.56	105 *	3.5	42
2-Chlorophenol	200	183.58	92	8.9	40
1,4-Dichlorobenzene	100	95.23	95	0.55	28
N-Nitrosodipropylamine	100	122.73	123 *	2.4	38
1,2,4-Trichlorobenzene	100	81.22	81	0.82	28
4-Chloro-3-methylphenol	200	194.80	97 *	1.4	42
Acenaphthene	100	97.34	97	2	31
4-Nitrophenol	200	80.64	40	94 *	50
2,4-Dinitrotoluene	100	94.95	95	5.4	38
Pentachlorophenol	200	111.75	56	74 *	50
Pyrene	100	79.58	80	0.77	31
NAPHTHALENE	100	100.75	101	5.2	NA

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 2 out of 11 outside limits.

Spike Recovery: 9 out of 22 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

Evergreen Analytical, Inc.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: W408-SS51 S	Client Project No.	: 725524.03000
Lab Sample No.	: X96963		Wurtsmith AFB
Date Sampled	: 10/3/94	Lab Project No.	: 94-3869
Date Received	: 10/8/94	EPA Method No.	: 8020
Date Prepared	: 10/19/94	Matrix	: Water
Date Analyzed	: 10/20/94	Lab File Number(s)	: BX2101918,19
		Method Blank	: MB101994

Compound	Spike Added (ug/L)	Sample Concentration (ug/L)	MS Concentration (ug/L)	MS %REC	QC Limits %REC
Benzene	20	0	18.4	92	65-121
Toluene	20	0	17.3	86.5	69-117
Ethyl Benzene	20	0	16.9	84.5	68-118
m/p-Xylene	20	0	16.1	80.5	66-116
o-Xylene	20	0	16.7	83.5	73-117
1,3,5-TMB	20	0	18.2	91	65-121
1,2,4-TMB	20	0	16.5	82.5	65-121
1,2,3-TMB	20	0	19.6	98	65-121

Compound	Spike Added (ug/L)	MSD Concentration (ug/L)	MS %REC	RPD	QC Limits	
					RPD	%REC
Benzene	20	17.8	89	3.3	17.4	65-121
Toluene	20	16.3	81.5	6.0	15.8	69-117
Ethyl Benzene	20	16.5	82.5	2.4	11.9	68-118
m/p-Xylene	20	15.2	76	5.8	15.4	66-116
o-Xylene	20	16.1	80.5	3.7	13.2	73-117
1,3,5-TMB	20	16.9	84.5	7.4	17.4	65-121
1,2,4-TMB	20	15.7	78.5	5.0	17.4	65-121
1,2,3-TMB	20	18.7	93.5	4.7	17.4	65-121

* = Values outside of QC limits.

RPD: 0 out of (8) outside limits.

Spike Recovery: 0 out of (16) outside limits.

Comments: CJC

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.

Lab Project No.: 94-3869

Lab Sample No.: X95962

Lab File Ids.: >26850,1

Client I.D.: 725524.03

Client Sample No.: W409M-SS51W

Date Extracted: 10/10/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	0.00	89.95	90	NA
1,4-Dichlorobenzene	100	0.00	71.59	72	36-97
N-Nitrosodipropylamine	100	0.00	97.66	98	41-116
1,2,4-Trichlorobenzene	100	0.00	60.94	61	39-98

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	%REC
Naphthalene	100	93.64	94	4	NA	NA
1,4-Dichlorobenzene	100	69.70	70	2.7	28	36-97
N-Nitrosodipropylamine	100	103.02	103	5.3	38	41-116
1,2,4-Trichlorobenzene	100	65.40	65	7.1	28	39-98

Column to be used to flag recovery and RPD values with an asterisk

* Values outside of QC limits

RPD: 0 out of 4 outside limits.

Spike Recovery: 0 out of 8 outside limits.

Comments: Values are reported in mg/ml in the liquid concentrate.

1992 RI ANALYTICAL RESULTS

TABLE 4-11

SUMMARY OF SOIL ANALYSIS
SITE 01-45
DRAFT RI DELIVERY ORDER 10
WRIGHTSMITH AIR FORCE BASE

Sample #: S80T45143 S80T45052 S80T45055 S80T45056 S80T45059
Sample Location: MW2-0T45 S81-0T45 S82-0T45 S82-0T45 S83-0T45
Sample Depth (ft.): 9 - 11 11.5 - 13.5 10 - 12 10 - 12 (D) 10 - 12
Sampling Date: 11/09/92 10/23/92 10/23/92 10/23/92 10/23/92

Parameter	Type A ¹	Type B ²	Units	
Ethylbenzene	10	8E+06	µg/kg	4100.00
Fluoranthene	330	1E+07	µg/kg	12000.00
Flourene	330	1E+07	µg/kg	220.00
Naphthalene	330	1E+07	µg/kg	1600.00
Phenanthrene	330	10	µg/kg	3200.00
Toluene	10	2E+07	µg/kg	260.00
Xylenes(total)	30	2E+08	µg/kg	2600.00

D Duplicate

ID Insufficient Data

(1) Michigan Act 307 levels - Background/Method Detection Limits

(2) Michigan Act 307 Direct Contact Levels

TABLE 4-12
SUMMARY OF GROUNDWATER ANALYSIS
SITE OT-45
DRAFT RI DELIVERY ORDER 10
WRIGHTSMITH AIR FORCE BASE

Sample #: GWOT45135 GWOT45136 GWOT45140 GWOT45142 GWOT45W015
Sample Location: HW2-OT45 HW2-OT45 HW2-OT45 HW2-OT45 V-OT45
Sample Depth (Ft.): 9 - 12 19 - 22 52 - 55 58 - 61 13.4
Sampling Date: 11/09/92 11/09/92 11/09/92 11/09/92 10/23/92

Parameter	Type A'	Type B'	Units	
Benzene	1		µg/L	26.00 1.00 2.20
Ethylbenzene	1	700	µg/L	
Fluorene	5	6000	µg/L	7.60 7.00 160.00
Naphthalene	5	600	µg/L	21.00 18.00 160.00
Phenanthrene	5	330	µg/L	13.00 12.00
Toluene	1	1000	µg/L	1.30 19.00 51.00
Xylenes (total)	3	10,000	µg/L	3.20

- (1) Michigan Act 307 Levels - Background/Method Detection Limits
(2) Michigan Act 307 Direct Contact Levels

APPENDIX C
AQUIFER TEST DATA AND ANALYSIS

AQUIFER SLUG TEST RESULTS

Five aquifer slug tests were performed at Site OT45 to estimate the hydraulic conductivity of saturated soils at the site. Slug tests are commonly performed in two steps, the falling head or slug in step and the rising head or slug out step. Both types of tests were performed at Site OT45. In a slug test, a slug of solid material or water is introduced into the well and water levels are monitored over time. This is the falling head portion of the test. Water levels will drop at the well returns to equilibrium. After the well has reached equilibrium the process is reversed during the rising head portion of the test. The slug is removed and water levels are again measured as the elevation head in the well increases. The rate at which the well returns to equilibrium is analogous to the hydraulic conductivity of the surrounding soils.

During the rising and falling head portions of a slug test, data is typically collected using a downhole pressure transducer and a data logger. For the testing performed at Site OT45 a transducer and data logger manufactured by In Situ, Inc. were used (a Model PXD-260 transducer and a Model 1000B Hermit data logger). Data was collected at logarithmic time intervals and downloaded to a personal computer via a RS232 port.

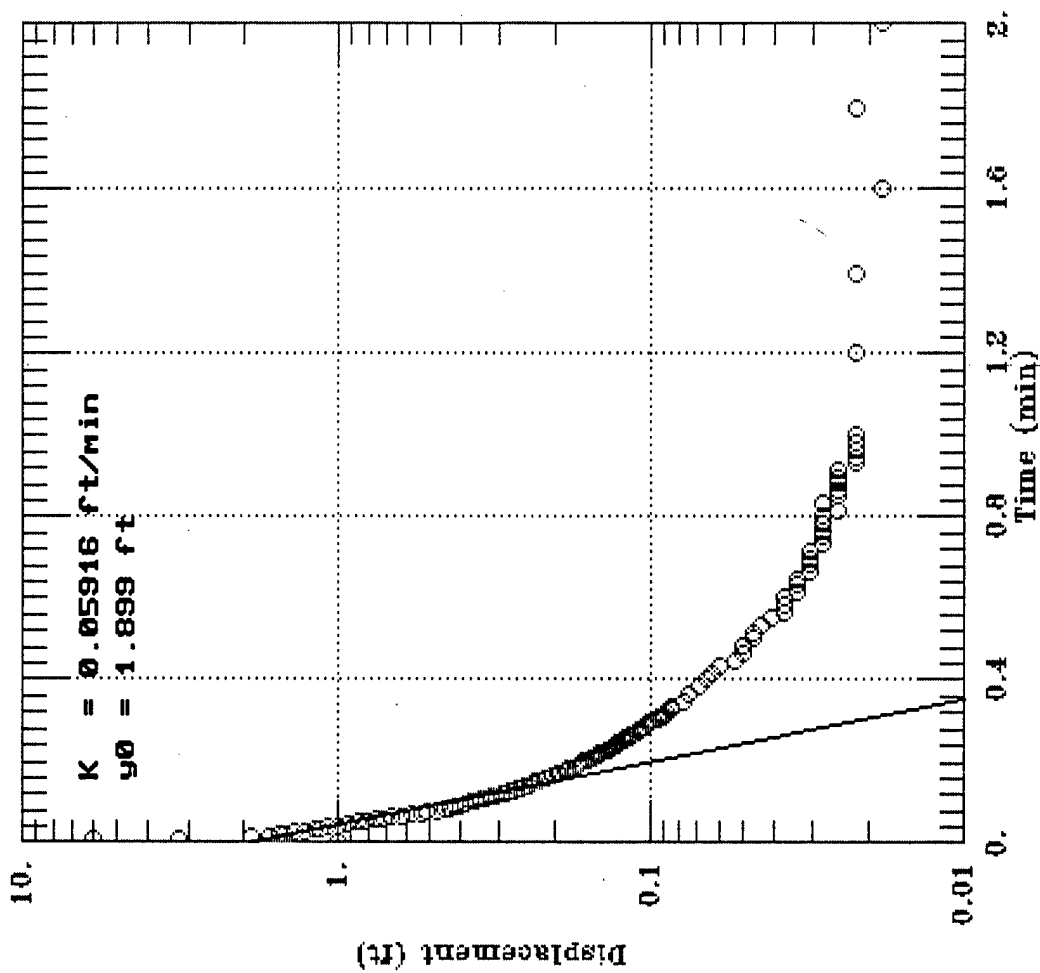
Data collected from the five wells was analyzed using Aqtesolv[®] Version 1.10 software from Geraghty and Miller, Inc. Displacement (i.e., change in water level) was graphed logarithmically versus time and a linear best-fit line was applied visually. The slope of this line corresponds to the observed hydraulic conductivity. The graphical results of the tests are shown at the end of this appendix. Only rising head test data was analyzed for the determination of hydraulic conductivity. Falling head tests can provide erroneous results due to the fact that some water is displaced into the sandpack rather than the surrounding formation. This allows water levels to drop quickly, resulting in an apparent hydraulic conductivity that is greater than that of the surrounding soil. Results from the tests at Site OT45 are shown in Table C.1.

Table C.1

**Aquifer Slug Test Results for Site OT45
Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45, Wurtsmith AFB, Michigan**

Well Number	Test Type	K (ft/min)
MW-4	rising	0.059
MW-7	rising	0.102
MW-10	rising	0.033
MW-11	rising	0.086
MPA	rising	0.056

RISING HEAD SLUG TEST - MW4 (TEST 0)



del Residuals:

Time	Observed	Calculated	Residual	Weight
0.02	1.54	1.4097	0.13026	1
0.0233	1.471	1.3421	0.12887	1
0.0266	1.382	1.2778	0.10424	1
0.03	1.278	1.2147	0.063327	1
0.0333	1.18	1.1564	0.023581	1
0.0366	1.13	1.101	0.029041	1
0.04	1.064	1.0466	0.017401	1
0.0433	0.994	0.99641	-0.0024063	1
0.0466	0.925	0.94862	-0.02362	1
0.05	0.862	0.90178	-0.039782	1
0.0533	0.808	0.85853	-0.050534	1
0.0566	0.754	0.81736	-0.06336	1
0.06	0.71	0.777	-0.067003	1
0.0633	0.663	0.73974	-0.076739	1
0.0666	0.615	0.70426	-0.089262	1
0.07	0.577	0.66949	-0.092489	1
0.0733	0.536	0.63738	-0.10138	1
0.0766	0.511	0.60681	-0.095814	1
0.08	0.479	0.57685	-0.097852	1
0.0833	0.451	0.54919	-0.098188	1
0.0866	0.429	0.52285	-0.093849	1
0.09	0.416	0.49703	-0.081034	1
0.0933	0.404	0.4732	-0.069197	1
0.0966	0.388	0.4505	-0.062503	1
0.1	0.372	0.42826	-0.056259	1
0.1033	0.356	0.40772	-0.051721	1
0.1066	0.344	0.38817	-0.044167	1
0.11	0.331	0.369	-0.038001	1
0.1133	0.318	0.3513	-0.033305	1
0.1166	0.309	0.33446	-0.025457	1
0.12	0.296	0.31794	-0.021943	1
0.1233	0.287	0.30269	-0.015695	1
0.1266	0.281	0.28818	-0.0071781	1
0.13	0.271	0.27395	-0.0029492	1
0.1333	0.265	0.26081	0.0041889	1
0.1366	0.255	0.2483	0.006697	1
0.14	0.249	0.23604	0.012957	1
0.1433	0.243	0.22472	0.018277	1
0.1466	0.236	0.21395	0.022055	1
0.15	0.23	0.20338	0.026618	1
0.1533	0.224	0.19363	0.030372	1
0.1566	0.217	0.18434	0.032658	1
0.16	0.211	0.17524	0.03576	1
0.1633	0.205	0.16684	0.038164	1
0.1666	0.202	0.15883	0.043165	1
0.17	0.195	0.15099	0.044008	1

0.1733	0.192	0.14375	0.048249	1
0.1766	0.186	0.13686	0.049143	1
0.18	0.183	0.1301	0.052901	1
0.1833	0.18	0.12386	0.05614	1
0.1866	0.173	0.11792	0.05508	1
0.19	0.17	0.1121	0.057902	1
0.1933	0.167	0.10672	0.060278	1
0.1966	0.164	0.1016	0.062397	1
0.2	0.161	0.096587	0.064413	1
0.2033	0.157	0.091955	0.065045	1
0.2066	0.154	0.087545	0.066455	1
0.21	0.151	0.083222	0.067778	1
0.2133	0.148	0.079231	0.068769	1
0.2166	0.145	0.075431	0.069569	1
0.22	0.145	0.071707	0.073293	1
0.2233	0.142	0.068268	0.073732	1
0.2266	0.138	0.064994	0.073006	1
0.23	0.135	0.061785	0.073215	1
0.2333	0.132	0.058822	0.073178	1
0.2366	0.132	0.056001	0.075999	1
0.24	0.129	0.053236	0.075764	1
0.2433	0.126	0.050682	0.075318	1
0.2466	0.126	0.048252	0.077748	1
0.25	0.123	0.045869	0.077131	1
0.2533	0.119	0.04367	0.07533	1
0.2566	0.119	0.041575	0.077425	1
0.26	0.116	0.039522	0.076478	1
0.2633	0.116	0.037627	0.078373	1
0.2666	0.113	0.035822	0.077178	1
0.27	0.11	0.034054	0.075946	1
0.2733	0.11	0.032421	0.077579	1
0.2766	0.11	0.030866	0.079134	1
0.28	0.107	0.029342	0.077658	1
0.2833	0.104	0.027935	0.076065	1
0.2866	0.104	0.026595	0.077405	1
0.29	0.101	0.025282	0.075718	1
0.2933	0.101	0.024069	0.076931	1
0.2966	0.101	0.022915	0.078085	1
0.3	0.097	0.021784	0.075216	1
0.3033	0.094	0.020739	0.073261	1
0.3066	0.094	0.019744	0.074256	1
0.31	0.091	0.018769	0.072231	1
0.3133	0.091	0.017869	0.073131	1
0.3166	0.091	0.017012	0.073988	1
0.32	0.088	0.016172	0.071828	1
0.3233	0.088	0.015397	0.072603	1
0.3266	0.085	0.014658	0.070342	1
0.33	0.085	0.013935	0.071065	1
0.3333	0.085	0.013266	0.071734	1
0.35	0.078	0.010345	0.067655	1
0.3666	0.075	0.0080792	0.066921	1
0.3833	0.069	0.0063002	0.0627	1

0.4	0.066	0.0049129	0.061087	1
0.4166	0.063	0.0038368	0.059163	1
0.4333	0.06	0.002992	0.057008	1
0.45	0.053	0.0023332	0.050667	1
0.4666	0.05	0.0018221	0.048178	1
0.4833	0.05	0.0014209	0.048579	1
0.5	0.047	0.001108	0.045892	1
0.5166	0.047	0.00086533	0.046135	1
0.5333	0.044	0.00067479	0.043325	1
0.55	0.041	0.0005262	0.040474	1
0.5666	0.037	0.00041095	0.036589	1
0.5833	0.037	0.00032046	0.03668	1
0.6	0.037	0.0002499	0.03675	1
0.6166	0.034	0.00019516	0.033805	1
0.6333	0.034	0.00015219	0.033848	1
0.65	0.034	0.00011868	0.033881	1
0.6666	0.031	9.2683E-005	0.030907	1
0.6833	0.031	7.2274E-005	0.030928	1
0.7	0.031	5.636E-005	0.030944	1
0.7166	0.031	4.4015E-005	0.030956	1
0.7333	0.028	3.4323E-005	0.027966	1
0.75	0.028	2.6766E-005	0.027973	1
0.7666	0.028	2.0903E-005	0.027979	1
0.7833	0.028	1.63E-005	0.027984	1
0.8	0.028	1.2711E-005	0.027987	1
0.8166	0.025	9.9269E-006	0.02499	1
0.8333	0.028	7.7411E-006	0.027992	1
0.85	0.025	6.0365E-006	0.024994	1
0.8666	0.025	4.7143E-006	0.024995	1
0.8833	0.025	3.6763E-006	0.024996	1
0.9	0.025	2.8668E-006	0.024997	1
0.9166	0.025	2.2389E-006	0.024998	1
0.9333	0.022	1.7459E-006	0.021998	1
0.95	0.022	1.3614E-006	0.021999	1
0.9666	0.022	1.0632E-006	0.021999	1
0.9833	0.022	8.2912E-007	0.021999	1
1	0.022	6.4655E-007	0.021999	1
1.2	0.022	3.2887E-008	0.022	1
1.4	0.022	1.6728E-009	0.022	1
1.6	0.018	8.5088E-011	0.018	1
1.8	0.022	4.328E-012	0.022	1
2	0.018	2.2015E-013	0.018	1

=====

RESULTS FROM VISUAL CURVE MATCHING

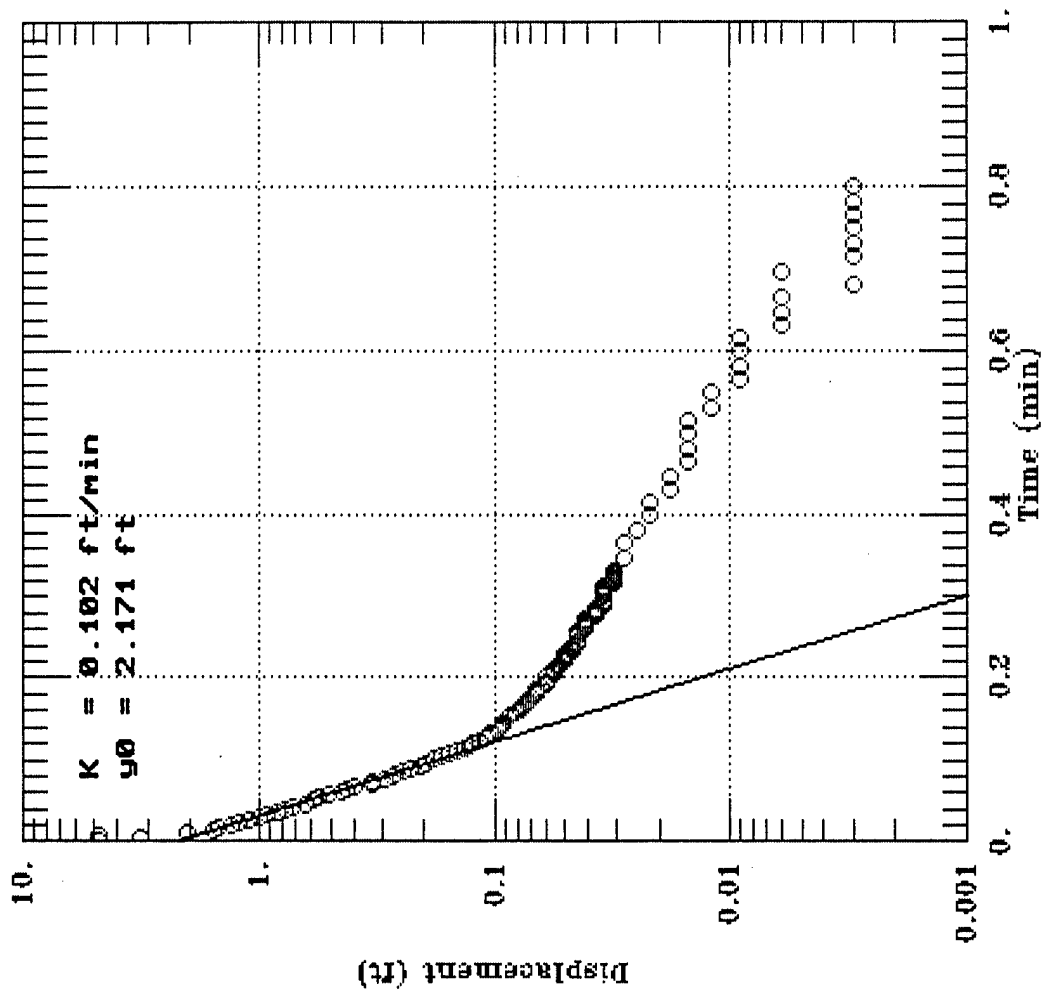
VISUAL MATCH PARAMETER ESTIMATES

Estimate
K = 5.9163E-002

Page 5

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RISING HEAD SLUG TEST - MW7 (TEST 8)



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A Q T E S O L V R E S U L T S
Version 1.10

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TEST DESCRIPTION

Data set..... B:\MW7RH.DAT
Data set title..... RISING HEAD SLUG TEST - MW7 (TEST 8)

Knowns and Constants:

No. of data points.....	128
Radius of well casing.....	0.195
Radius of well.....	0.34
Aquifer saturated thickness.....	5.02
Well screen length.....	10
Static height of water in well.....	5.02
Log(Re/Rw).....	2.106
A, B, C.....	0.000, 0.000, 1.950

=====

ANALYTICAL METHOD

Cover-Rice (Unconfined Aquifer Slug Test)

=====

RESULTS FROM STATISTICAL CURVE MATCHING

STATISTICAL MATCH PARAMETER ESTIMATES

	Estimate	Std. Error
K =	1.0204E-001 +/-	1.0997E-003
y0 =	2.1707E+000 +/-	2.6538E-002

ANALYSIS OF MODEL RESIDUALS

residual = calculated - observed
weighted residual = residual * weight

Weighted Residual Statistics:

Number of residuals.....	33
Number of estimated parameters....	2
Degrees of freedom.....	31
Residual mean.....	0.00311
Residual standard deviation.....	0.0151
Residual variance.....	0.0002279

Model Residuals:

Time	Observed	Calculated	Residual	Weight
0.0233	1.228	1.1986	0.029357	1
0.0266	1.114	1.102	0.012048	1
0.03	1.004	1.0105	-0.0064832	1
0.0333	0.922	0.92897	-0.0069712	1
0.0366	0.852	0.85403	-0.0020344	1
0.04	0.779	0.78314	-0.004144	1
0.0433	0.716	0.71997	-0.0039706	1
0.0466	0.647	0.66189	-0.014893	1
0.05	0.596	0.60695	-0.010952	1
0.0533	0.558	0.55799	8.8274E-006	1
0.0566	0.505	0.51298	-0.00798	1
0.06	0.451	0.4704	-0.019399	1
0.0633	0.426	0.43245	-0.006454	1
0.0666	0.397	0.39757	-0.00056946	1
0.07	0.331	0.36457	-0.033569	1
0.0733	0.328	0.33516	-0.0071602	1
0.0766	0.296	0.30812	-0.012124	1
0.08	0.271	0.28255	-0.011548	1
0.0833	0.262	0.25976	0.0022444	1
0.0866	0.246	0.2388	0.0071979	1
0.09	0.23	0.21898	0.01102	1
0.0933	0.208	0.20132	0.0066844	1
0.0966	0.195	0.18508	0.0099238	1
0.1	0.18	0.16971	0.010286	1
0.1033	0.167	0.15602	0.010976	1
0.1066	0.154	0.14344	0.010562	1
0.11	0.145	0.13153	0.013469	1
0.1133	0.135	0.12092	0.014079	1
0.1166	0.129	0.11117	0.017833	1
0.12	0.123	0.10194	0.021061	1
0.1233	0.116	0.093716	0.022284	1
0.1266	0.11	0.086157	0.023843	1
0.13	0.107	0.079005	0.027995	1

=====

RESULTS FROM VISUAL CURVE MATCHING

VISUAL MATCH PARAMETER ESTIMATES

Estimate
K = 1.0204E-001
y0 = 2.1707E+000

File: MW7RH

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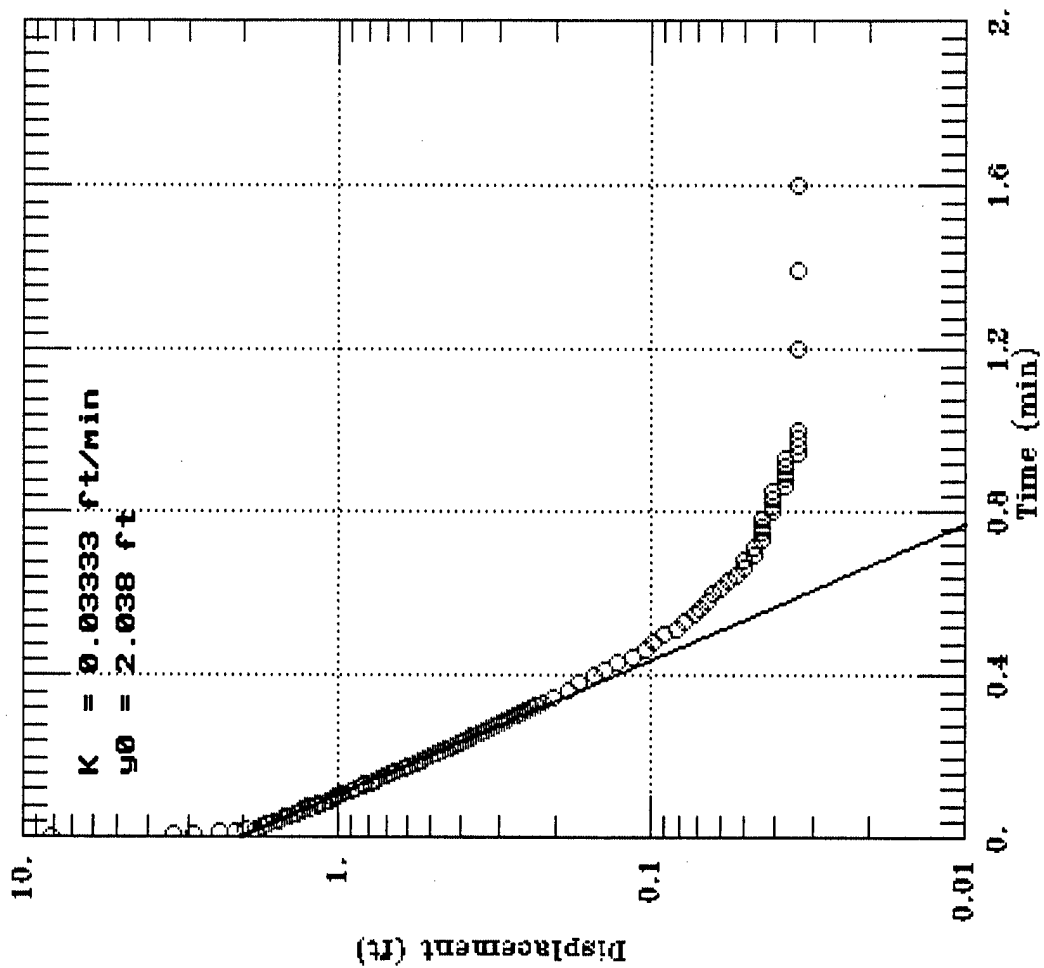
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RISING HEAD SLUG TEST - MW10 (TEST 12)



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A Q T E S O L V R E S U L T S
Version 1.10

12/19/94

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TEST DESCRIPTION

Data set..... B:\MW10RH.DAT
Data set title..... RISING HEAD SLUG TEST - MW10 (TEST 12)

Knowns and Constants:

No. of data points.....	143
Radius of well casing.....	0.195
Radius of well.....	0.34
Aquifer saturated thickness.....	10
Well screen length.....	10
Static height of water in well.....	10
Log(Re/Rw).....	2.553
A, B, C.....	0.000, 0.000, 1.950

=====

ANALYTICAL METHOD

Cooper-Rice (Unconfined Aquifer Slug Test)

=====

RESULTS FROM STATISTICAL CURVE MATCHING

STATISTICAL MATCH PARAMETER ESTIMATES

	Estimate	Std. Error
K =	3.3334E-002 +/-	2.2062E-004
y0 =	2.0382E+000 +/-	1.1457E-002

ANALYSIS OF MODEL RESIDUALS

residual = calculated - observed
weighted residual = residual * weight

Weighted Residual Statistics:

Number of residuals.....	132
Number of estimated parameters....	2
Degrees of freedom.....	130
Residual mean.....	0.009023
Residual standard deviation.....	0.02082
Residual variance.....	0.0004336

M 1 Residuals:

Time	Observed	Calculated	Residual	Weight
0.04	1.595	1.5487	0.046297	1
0.0433	1.544	1.514	0.029993	1
0.0466	1.513	1.4801	0.032912	1
0.05	1.475	1.4459	0.029064	1
0.0533	1.434	1.4135	0.020458	1
0.0566	1.383	1.3819	0.0011264	1
0.06	1.348	1.35	-0.0019876	1
0.0633	1.33	1.3197	0.010257	1
0.0666	1.304	1.2902	0.013824	1
0.07	1.285	1.2604	0.024594	1
0.0733	1.222	1.2322	-0.010169	1
0.0766	1.241	1.2046	0.036436	1
0.08	1.146	1.1768	-0.030769	1
0.0833	1.146	1.1504	-0.0044055	1
0.0866	1.118	1.1246	-0.0066324	1
0.09	1.077	1.0987	-0.021682	1
0.0933	1.061	1.0741	-0.013068	1
0.0966	1.023	1.05	-0.027005	1
0.1	1.017	1.0258	-0.0087767	1
0.1033	0.988	1.0028	-0.014796	1
0.1066	0.969	0.98033	-0.01133	1
0.11	0.95	0.95771	-0.0077091	1
0.1133	0.903	0.93625	-0.033253	1
0.1166	0.909	0.91528	-0.0062777	1
0.12	0.875	0.89416	-0.019158	1
0.1233	0.868	0.87413	-0.006126	1
0.1266	0.834	0.85454	-0.020542	1
0.13	0.818	0.83482	-0.016824	1
0.1333	0.818	0.81612	0.0018786	1
0.1366	0.777	0.79784	-0.020837	1
0.14	0.761	0.77943	-0.018428	1
0.1433	0.742	0.76197	-0.019966	1
0.1466	0.732	0.7449	-0.012895	1
0.15	0.714	0.72771	-0.013707	1
0.1533	0.698	0.7114	-0.013404	1
0.1566	0.679	0.69547	-0.016466	1
0.16	0.666	0.67942	-0.013419	1
0.1633	0.65	0.6642	-0.014197	1
0.1666	0.638	0.64932	-0.011317	1
0.17	0.622	0.63433	-0.012334	1
0.1733	0.609	0.62012	-0.011123	1
0.1766	0.593	0.60623	-0.01323	1
0.18	0.581	0.59224	-0.011242	1
0.1833	0.568	0.57897	-0.010973	1
0.1866	0.556	0.566	-0.010002	1
0.19	0.543	0.55294	-0.0099422	1

0.1933	0.533	0.54055	-0.0075544	1
0.1966	0.521	0.52844	-0.0074441	1
0.2	0.508	0.51625	-0.0082505	1
0.2033	0.499	0.50468	-0.0056847	1
0.2066	0.486	0.49338	-0.007378	1
0.21	0.477	0.48199	-0.0049936	1
0.2133	0.467	0.4712	-0.0041953	1
0.2166	0.458	0.46064	-0.0026388	1
0.22	0.448	0.45001	-0.0020098	1
0.2233	0.436	0.43993	-0.0039281	1
0.2266	0.426	0.43007	-0.0040722	1
0.23	0.42	0.42015	-0.00014847	1
0.2333	0.41	0.41074	-0.00073569	1
0.2366	0.401	0.40153	-0.00053378	1
0.24	0.394	0.39227	0.0017314	1
0.2433	0.385	0.38348	0.0015196	1
0.2466	0.375	0.37489	0.00011086	1
0.25	0.369	0.36624	0.0027612	1
0.2533	0.363	0.35803	0.0049662	1
0.2566	0.353	0.35001	0.0029874	1
0.26	0.347	0.34194	0.0050638	1
0.2633	0.338	0.33428	0.0037244	1
0.2666	0.331	0.32679	0.0042133	1
0.27	0.325	0.31925	0.0057537	1
0.2733	0.319	0.31209	0.0069059	1
0.2766	0.312	0.3051	0.0068979	1
0.28	0.306	0.29806	0.007938	1
0.2833	0.3	0.29138	0.0086156	1
0.2866	0.297	0.28486	0.012144	1
0.29	0.29	0.27828	0.011717	1
0.2933	0.284	0.27205	0.011951	1
0.2966	0.278	0.26595	0.012046	1
0.3	0.271	0.25982	0.011183	1
0.3033	0.265	0.254	0.011003	1
0.3066	0.262	0.24831	0.013694	1
0.31	0.255	0.24258	0.012423	1
0.3133	0.249	0.23714	0.011858	1
0.3166	0.246	0.23183	0.014171	1
0.32	0.24	0.22648	0.01352	1
0.3233	0.236	0.22141	0.014594	1
0.3266	0.23	0.21645	0.013554	1
0.33	0.227	0.21145	0.015549	1
0.3333	0.221	0.20671	0.014286	1
0.35	0.202	0.18432	0.01768	1
0.3666	0.183	0.16446	0.018536	1
0.3833	0.167	0.14665	0.020353	1
0.4	0.151	0.13076	0.02024	1
0.4166	0.139	0.11667	0.022326	1
0.4333	0.126	0.10403	0.021965	1
0.45	0.113	0.092764	0.020236	1
0.4666	0.104	0.082771	0.021229	1
0.4833	0.097	0.073804	0.023196	1

Table with 5 columns: X values (0.5 to 1.6), Y1 values (0.091 to 0.034), Y2 values (0.065809 to 3.4528E-005), Y3 values (0.025191 to 0.033965), and a final column of 1s.

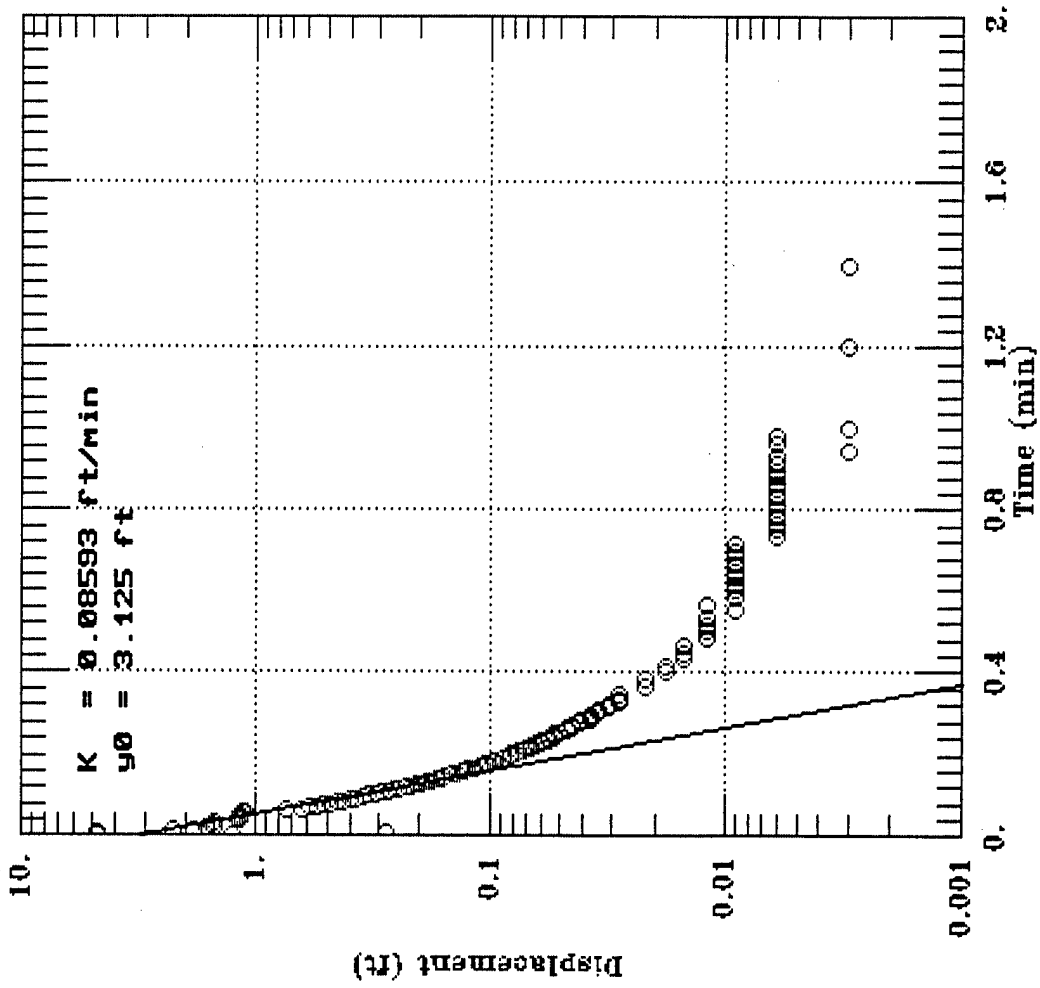
RESULTS FROM VISUAL CURVE MATCHING

VISUAL MATCH PARAMETER ESTIMATES

Estimate
K = 3.3334E-002
y0 = 2.0382E+000

Decorative separator line consisting of a series of less-than and greater-than symbols.

RISING HEAD SLUG TEST MW-11 (TEST 4)



APPENDIX D

NATURAL ATTENUATION CALCULATIONS

Client AFCEE - Site OT45 - RAPJob No. 725573.04000Sheet 1 of 2Subject Calculation of Sub-Specific ContaminantBy A. DrunshbergerDate 04-26-96Velocities and Biodegradation RatesChecked 4/9/96 04-26-96

Rev. _____

1,2,4 TMBContaminant Velocity: Governing Equation

$$V_c = \frac{V_x}{R} \quad \text{where } V_x = \text{Ground water velocity (linear)}$$

$$R = \text{Retardation coefficient (compound specific)}$$

Contaminant velocity, V_c , is calculated by dividing the maximum observed ground water velocity by a compound specific retardation coefficient, R_d , where R_d is found by:

$$R_d = \left[1 + \left(\left(\frac{1-n}{n} \right) * \rho_b * K_d \right) \right]$$

where, n = effective porosity ρ_b = bulk density of soil K_d = $f_{oc} * K_{oc}$ = partitioning coefficient f_{oc} = fractional organic content K_{oc} = Octanol-water partitioning coefficient
(Montgomery & Welkom, 1990)Biodegradation Rate: Governing Equation

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

where, λ = degradation rate V_c = contaminant velocity α_x = dispersivity $\frac{k}{V_c}$ = attenuation distanceSource: Buschek and
Alcantar, 1994Assume: $\alpha_x = 10 \text{ ft}$

Client AFCEE - Site 0745 - RAPJob No. 225523.04000Sheet 2 of 2Subject Calculation of Site-Specific ContaminantBy A. PainsbergerDate 04-26-96Locations and Biodegradation RatesChecked y4/ 04-26-96

Rev. _____

1,2,4 - TMB (cont)Example Calculation: 1,2,4 - TMB

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

$$V_c = .107 \text{ ft/day}$$

$$\alpha_x = 10 \text{ ft}$$

$$k/V_c = .032 \text{ 1/ft (From special regression of 1995 1,2,4-TMB dissolved concentrations. See attached graph.)}$$

$$\lambda = \left(\frac{.107 \text{ ft/day}}{(4)(10 \text{ ft})} \right) \left(\left[1 + (2)(10 \text{ ft}) \left(\frac{.032}{\text{ft}} \right) \right]^2 - 1 \right)$$

$$\lambda = \left(\frac{.0027}{\text{day}} \right) \left([1 + .64]^2 - 1 \right)$$

$$\lambda = \left(\frac{.0027}{\text{day}} \right) (2.69 - 1)$$

$$\therefore \lambda = .0046/\text{day}$$

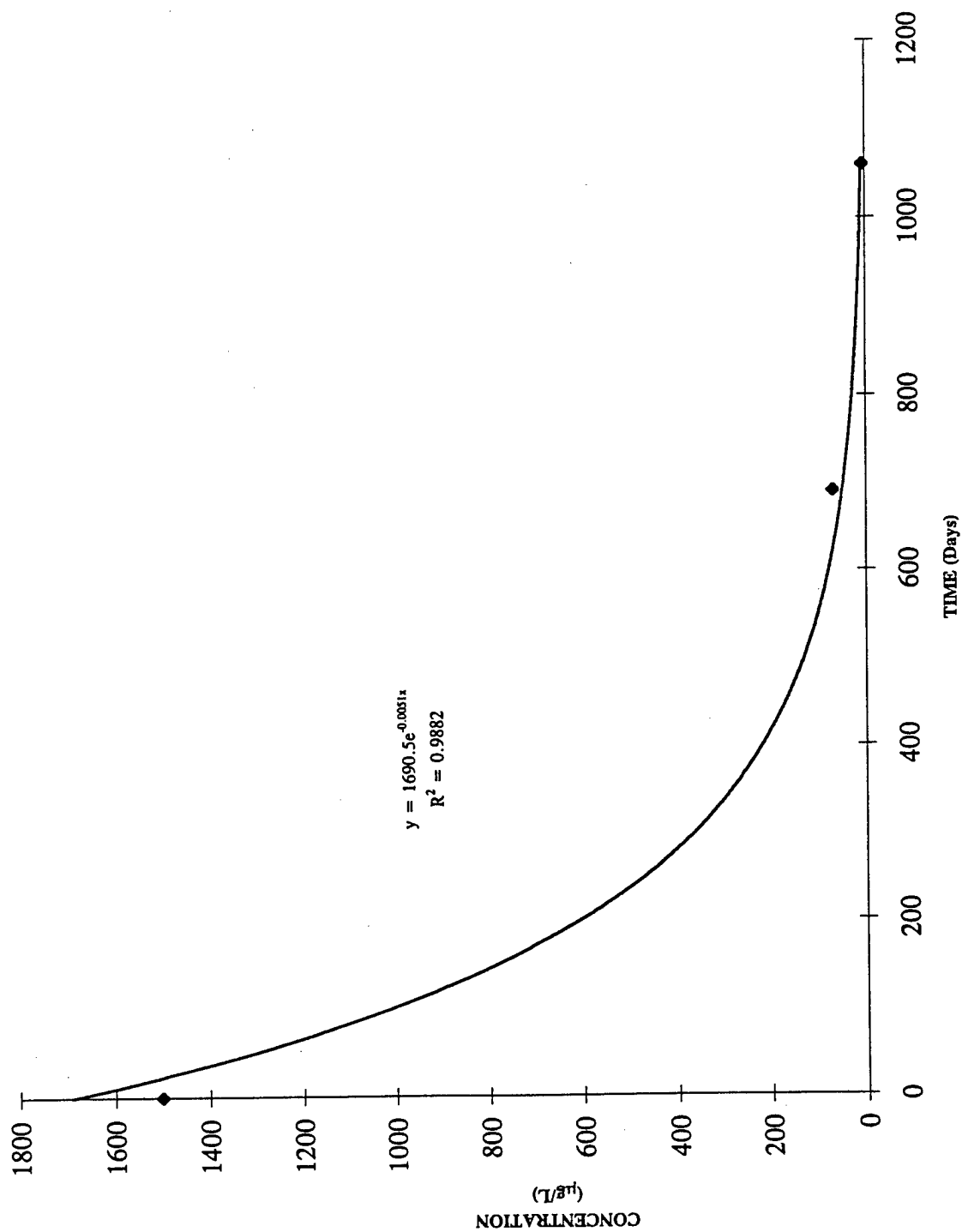
Note: $\frac{k}{V}$ for phenanthrene is calculated by determining (k)

from a regression of phenanthrene concentrations over time (1992, 1994, & 1995),

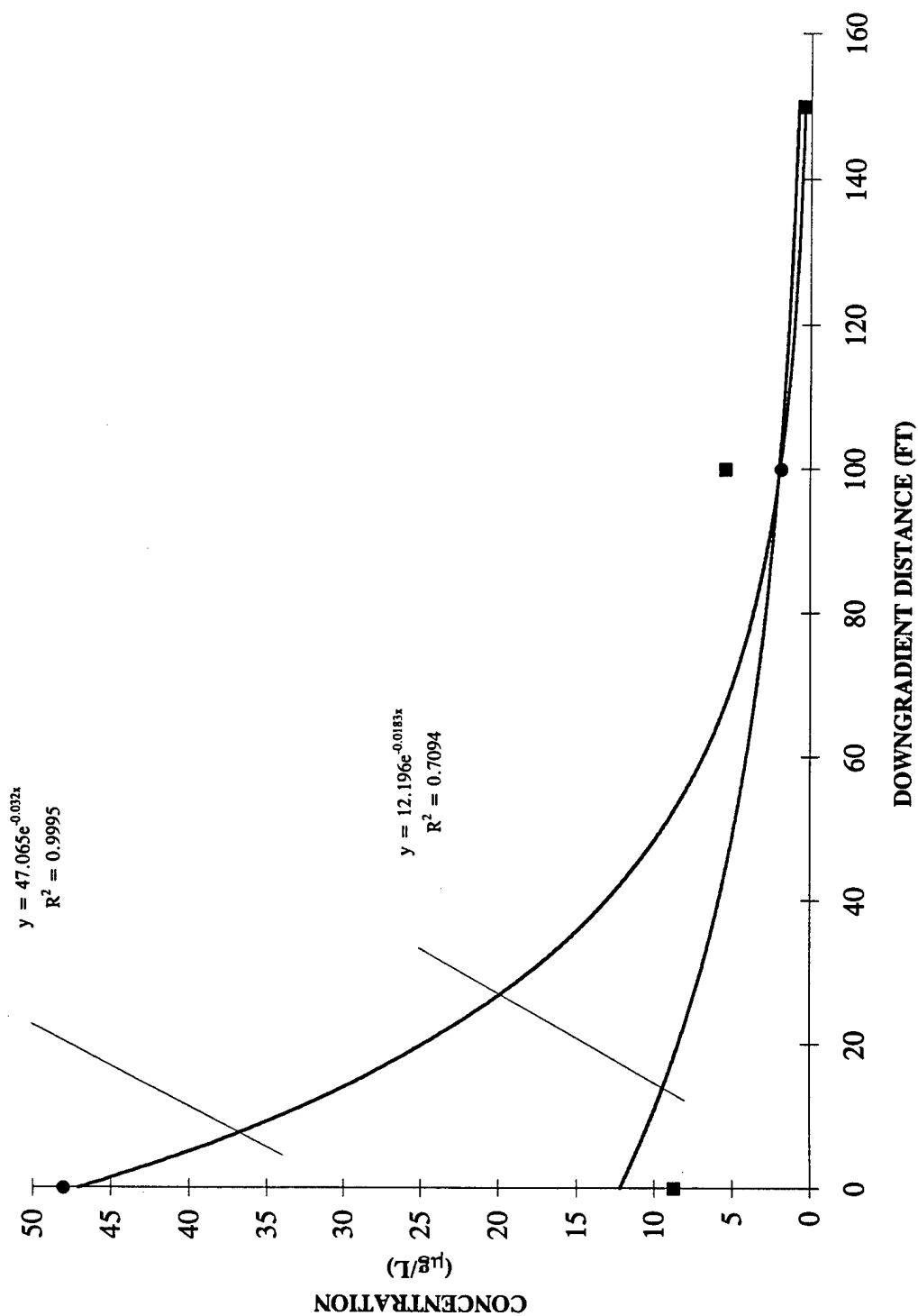
and $V = V_c$ calculated from the maximum observed groundwater velocity and the retardation coefficient, K_R , of

phenanthrene (see above), (Buschek and Alcantar, 1994).

TEMPORAL LINEAR REGRESSION OF PHENANTHRENE DATA COLLECTED FROM MW2



SPATIAL LINEAR REGRESSION OF 1995 TMB DATA



ESTIMATING SITE-SPECIFIC CONTAMINANT BIODEGRADATION RATES

It is important to distinguish between the effects of nondestructive attenuation processes such as advection, dispersion, and sorption, and the effects of destructive attenuation processes such as biodegradation on the mass of dissolved contaminants in the groundwater at Site OT45. Comparison of 1992, 1994, and 1995 data suggest that contaminants are being removed from saturated soils and groundwater by natural attenuation mechanisms. To quantify these effects into nondestructive and destructive attenuation, a spatial regression technique (Buscheck and Alcantar, 1995) was used to estimate the site-specific biodegradation rates of specific groundwater contaminants in saturated soil and groundwater based on analytical data.

The assumption of a first-order decay mechanism is commonly used to approximate biodegradation rates for fuel hydrocarbon compounds in saturated media. The rates of biodegradation of fuel hydrocarbon compounds can be calculated and compared in this manner because the biodegradation processes for each is similar (Chapelle, 1993). The slope of the best fit regression line through measured concentrations versus distance (time for phenanthrene) is used to estimate the amount of attenuation that cannot be explained by advection, dispersion, and sorption (Buscheck and Alcantar, 1995). These spatial and temporal regression techniques are included in this appendix.

Table 1 summarizes the calculated biodegradation rates for phenanthrene, 1,2,4-TMB, and 1,3,5-TMB in saturated media based on analytical data collected at Site OT45. These rates express how much of the contaminant mass is being removed from the saturated media that cannot be explained by nondestructive attenuation processes such as dispersion and adsorption. The biodegradation rate of phenanthrene was calculated using a temporal regression of concentrations measured in the source area (MW-2) during the 1992, 1994, and 1995 investigations. The calculated biological decay rate for phenanthrene from this analysis is 0.011 day^{-1} . Biological degradation rates of phenanthrene have been reported in literature to range from 0.0001 day^{-1} to 0.02 day^{-1} in saturated soil and groundwater (Howard *et al.*, 1991). The rate of phenanthrene degradation calculated from site-related data agrees with the range of data reported in literature. The biodegradation rates of 1,2,4-TMB and 1,3,5-TMB were calculated using a spatial regression of concentrations measured in (MW-2) and downgradient from the source area (MW-7 and MW-11) during the 1995 sampling event. The calculated biological decay rate for 1,3,5-TMB for Site OT45 is 0.002 day^{-1} .

RELEVANCE OF REDOX COUPLES IN BIODEGRADATION

Heterotrophic microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of the fuel hydrocarbon compounds is the result of a series of reduction-oxidation (redox) reactions which maintain the charge balance within the natural environment. These microorganisms facilitate the degradation of fuel hydrocarbon compounds by transferring electrons from the contaminant (electron donor) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and can participate in redox reactions involving fuel hydrocarbon compounds. Electron acceptors that may

Table 1
Calculation of Compound-Specific Biodegradation Rates
Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45, Wurtsmith AFB, Michigan

Compound	Groundwater Velocity (ft/day)	Partition Coefficient (L/kg) ^{a/}	Contaminant Velocity (ft/day) ^{b/}	Site-specific Biodegradation Rate (1/day) ^{c/}
1,2,4-TMB	1.3	3.23	0.107	0.005
1,3,5-TMB	1.3	3.23	0.107	0.002
Phenanthrene	1.3	7.78	0.047	0.011

^{a/} Partition coefficient based on fractional organic carbon content of = 0.0015 and octonal-carbon partition coefficient (Koc) values in Montgomery and Welkom, 1990.

^{b/} Calculated using relationship velocity of groundwater/retardation coefficient, which is defined as $[1 + (((1-n)/n) * \text{density soil} * \text{partition coefficient})]$.

^{c/} Rate calculated using method described in Buscheck and Alcantar, 1995, which is included in this appendix.

be present in saturated soil and groundwater at Site OT45 are oxygen, nitrate, manganese, sulfate, ferric iron, and carbon dioxide.

Microorganisms facilitate biodegradation of fuel hydrocarbons to produce energy for their use. The amount of energy that can be released when a reaction occurs or is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981; Bouwer, 1994; Chapelle, 1993; Godsey, 1994; Mueller *et al.*, 1994; Berg *et al.*, 1994). Microorganisms will facilitate only those redox reactions that will have a net yield of energy. Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes. By coupling the oxidation of fuel hydrocarbon compounds, which require energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide), which yield energy, the overall reaction becomes energy yielding. Detailed information on the redox reactions required to biodegrade fuel hydrocarbon compounds is included in this appendix. The reader is encouraged to review this information to more fully understand the chemical basis of biodegradation.

Figure 6.1 in the RAP illustrates the sequence of microbially-mediated redox processes based on the amount of free energy released for microbial use. In general, more energy-yielding reactions tend to take precedence over processes that are less energy-yielding (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). As Figure 6.1 shows, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, and finally carbon dioxide. Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

The expected sequence of redox processes is also a function of the oxidizing potential (Eh) of the groundwater. The oxidizing potential measures the relative tendency of a solution or chemical reaction to accept or transfer electrons. The oxidizing potential of the groundwater can be measured in the field. This measurement can be used as a crude indicator of which redox reactions may be operating at a site. This field measurement can then be expressed as pe, which is the hypothetical measure of the electron activity associated with a specific Eh. High pe means that the solution or redox couple has a relatively high oxidizing potential.

Microorganisms can only facilitate the biodegradation (oxidation) of the fuel hydrocarbon compounds using redox couples that have a higher oxidizing potential than the contaminants. This appendix includes tables that show that redox couples including nitrate, oxygen, manganese, ferric iron, sulfate, and carbon dioxide all have higher oxidizing potentials than the redox couples including the fuel hydrocarbon compounds. This is why these electron acceptors can be used to oxidize phenanthrene, 1,2,4-TMB, and 1,3,5-TMB. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 6.1, the reduction of

oxygen and nitrate will reduce the oxidizing potential to levels at which manganese and ferric iron (Fe^{3+}) reduction can occur. As each chemical species that can be used to oxidize the contaminants is exhausted, the microorganisms are forced to use other available electron acceptors with lower oxidizing capacity. When sufficiently negative pe levels have been developed by these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

Geochemical data used in the following analyses were collected during the initial 1994 risk-based investigation. Supplemental data on all electron acceptors and reduced species of the electron acceptors were collected as part of the 1995 sampling event to verify the initial trends observed in 1994. Electron acceptor and reduced species data collected in 1995 did not significantly differ from the data collected in 1994.

THEORETICAL ASSIMILATIVE CAPACITY ESTIMATES

Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of contaminants and the reduction of electron acceptors to generate free energy for cell maintenance and production. The question of how much contaminant mass can be biodegraded must be addressed to assess the full potential for long-term intrinsic remediation of the site.

Mass balance relationships can be used to determine how much contaminant mass can be degraded by each of the redox reactions that the microorganisms might use to make free energy available for cell maintenance and production. The stoichiometric relationship between the contaminant and the electron acceptor can be used to estimate the assimilative capacity of the groundwater. Now that the redox reactions that are operating at Site OT45 have been defined, it is possible to estimate how much contaminant mass can be assimilated or oxidized by available electron acceptors. This analysis, when coupled with the biodegradation rate information discussed earlier (Table 1), will provide the basis for determining the potential for continued intrinsic remediation of groundwater contamination at the site.

This appendix presents the coupled redox reactions that may be involved in the biodegradation of phenanthrene, 1,2,4-TMB, and 1,3,5-TMB. These tables also present the stoichiometric mass ratio of electron acceptors needed to oxidize each of these contaminants. These stoichiometric mass ratios can be used to estimate the assimilative capacity of the groundwater at Site OT45. This is accomplished by first determining the mass of each electron acceptor consumed or oxidized species produced as groundwater passes through the source area. Background concentrations of electron acceptors/oxidized species were measured in groundwater samples collected from monitoring wells located upgradient of the site (i.e., sampling locations MW-1 and MW-4) and source area concentrations of geochemical indicators were measured in samples collected from MPB and MW-5. As groundwater migrates downgradient into the source area, electron acceptors are brought into contact with hydrocarbon-degrading microorganisms and site contamination. This influent mass of oxygenated species is reduced (or increased for reduced species) during degradation of organic substrate. The overall change in concentration of the geochemical indicator is divided by the mass of the geochemical species required to mineralize a gram of each individual

contaminant (phenanthrene, 1,2,4-TMB, and 1,3,5-TMB) to estimate the intrinsic capacity of the groundwater to biodegrade these compounds.

The overall change in the mass of electron acceptors within the affected area at Site OT45 are listed in Table 2. This mass differential is used to estimate the expressed assimilative capacity of each electron acceptor for each contaminant (phenanthrene, 1,2,4-TMB, and 1,3,5-TMB) based on the mass stoichiometric relationships presented in detail in this appendix. Based on these calculations, the groundwater at Site OT45 has the intrinsic capacity to oxidize a concentration of about 9,500 µg/L of organic substrate that is exerting and oxidizing demand.

The cumulative concentration of phenanthrene, 1,2,4-TMB, and 1,3,5-TMB do not exceeded the theoretical assimilative capacity of the groundwater at Site OT45. However, this value represents an upper-bound estimate of the assimilative capacity of the saturated soil and groundwater for these contaminants. Not all of the actual electron acceptor mass will be used by microorganisms to facilitate biodegradation of phenanthrene and the TMB isomers. The total reservoir of electron acceptors will not be available to the microorganisms because of mass transfer, kinetic, and other biological and chemical limitations. Additionally, this assimilative capacity will be used to oxidize any available organic substrate, not just these specific compounds.

However, these estimates do show that there is a sufficient supply of electron acceptors in the groundwater at the site to sustain the rate at which contaminant mass at Site OT45 have been biodegrading.

TABLE 2
ESTIMATE OF ASSIMILATIVE CAPACITY OF
SATURATED SOIL AND GROUNDWATER
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Electron Acceptor	1994 Expressed Assimilative Capacity Background-Source Concentration of electron acceptor/oxidized species (ug/L)	Initial Phenanthrene Assimilative Capacity ^{a/} (ug/L)	Initial 1,2,4-TMB Assimilative Capacity ^{a/} (ug/L)	Initial 1,3,5-TMB Assimilative Capacity ^{a/} (ug/L)
Oxygen	6870	2,313.1	2,146.9	2,146.9
Nitrate	1900	413.0	383.1	383.1
Manganese	1200	117.8	69.0	69.0
Ferric iron	1430	70.9	33.4	33.4
Sulfate	33290	7,480.9	6,935.4	6,935.4
Total		10,395.7	9,567.7	9,567.7
1992 Maximum Concentration	1,500.0	NS ^{b/}	NS ^{b/}	NS
1994 Maximum Concentration	70.0	NR ^{c/}	NR ^{c/}	NR
1995 Maximum Concentration	6.0	48.0	48.0	8.7

^{a/} Calculated based on the ratio of the total mass of electron acceptor required to oxidize a given mass contaminant.

^{b/} NS = not sampled.

^{c/} NR = Concentration not reported erroneous results (section 6)

APPENDIX D
Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45, Wurtsmith AFB, Michigan

Electron Donor and Electron Acceptor Half Cell Reactions

HALF-CELL REACTIONS	ΔG°_r (kcal/ equiv)*	ΔG°_r (kJ/ equiv)*	E° (V)	Eh (V)	pe	Conditions for Eh and pe §
ELECTRON-ACCEPTOR (REDUCTION) HALF CELL REACTIONS						
$5e^- + 6H^+ + NO_3^- \Rightarrow 0.5N_2 + 3H_2O$ <i>Denitrification</i>	-28.7	-120.	+1.24	+0.708	+12.0	pH = 7 $\Sigma[N] = 10^{-3}$
$4e^- + 4H^+ + O_2 \Rightarrow 2H_2O$ <i>Aerobic Respiration</i>	-28.3	-119.	+1.23	+0.805	+13.6	pH = 7 $P_{O_2} = 0.21 \text{ atm}$
$2e^- + 4H^+ + MnO_2 \Rightarrow Mn^{2+} + 2H_2O$ <i>Pyrolusite Dissolution/Reduction</i>	-28.3	-119	+1.23	+0.550	+9.27	pH = 7 $\Sigma[Mn] = 10^{-5}$
$CO_2 + e^- + H^+ + MnOOH \Rightarrow MnCO_3 + H_2O$ <i>a Manganite Carbonation/Reduction</i>	-23.1	-96.8	+1.00	+0.408	+6.90	pH = 8 $P_{CO_2} = 10^{-2}$
$e^- + H^+ + MnO_2 \Rightarrow MnOOH$ <i>Pyrolusite Hydrolysis/Reduction</i>	-22.1	-92.5	+0.959	+0.545	+9.21	pH = 7
$e^- + 3H^+ + Fe(OH)_3, \text{amph.} \Rightarrow Fe^{2+} + 2H_2O$ <i>Amorphous "Goethite" Dissolution/Reduction</i>	-21.5	-89.9	+0.932	+0.163	+2.75	pH = 6 $\Sigma[Fe] = 10^{-5}$
$8e^- + 10H^+ + NO_3^- \Rightarrow NH_4^+ + 3H_2O$ <i>Nitrate Reduction</i>	-20.3	-84.9	+0.879	+0.362	+6.12	pH = 7
$2e^- + 2H^+ + NO_3^- \Rightarrow NO_2^- + H_2O$ <i>Nitrate Reduction</i>	-18.9	-78.9	+0.819	+0.404	+6.82	pH = 7
$e^- + 3H^+ + FeOOH \Rightarrow Fe^{2+} + 2H_2O$ <i>"Ferric oxyhydroxide" Dissolution/Reduction</i>	-15.0	-62.9	+0.652	-0.118	-1.99	pH = 6 $\Sigma[Fe] = 10^{-5}$
$e^- + 3H^+ + Fe(OH)_3, \text{line.} \Rightarrow Fe^{2+} + 3H_2O$ <i>Crystallized "Goethite" Dissolution/Reduction</i>	-11.8	-49.2	+0.510	-0.259	-4.38	pH = 6 $\Sigma[Fe] = 10^{-5}$
$e^- + H^+ + CO_{2,g} + Fe(OH)_3, \text{amph.} \Rightarrow FeCO_3 + 2H_2O$ <i>Amorphous "Goethite" Carbonation/Reduction</i>	-11.0	-46.2	+0.479	-0.113	-1.90	pH = 8 $P_{CO_2} = 10^{-2} \text{ atm}$
$8e^- + 9H^+ + SO_4^{2-} \Rightarrow HS^- + 4H_2O$ <i>Sulfate Reduction</i>	-5.74	-24.0	+0.249	-0.278	-4.70	pH = 8
$8e^- + 10H^+ + SO_4^{2-} \Rightarrow H_2S^0 + 4H_2O$ <i>Sulfate Reduction</i>	-6.93	-28.9	+0.301	-0.143	-2.42	pH = 6
$C_2Cl_4 + H^+ + 2e^- \Rightarrow C_2HCl_3 + Cl^-$ <i>PCE Reductive Dechlorination</i>	-14.79	-61.9	+0.642	+0.553	+9.35	pH = 7 $[Cl^-] = 10^{-4}$
$C_2HCl_3 + H^+ + 2e^- \Rightarrow C_2H_2Cl_2 + Cl^-$ <i>TCE Reductive Dechlorination</i>	-14.50	-60.7	+0.629	+0.540	+9.13	pH = 7 $[Cl^-] = 10^{-4}$
$C_2H_2Cl_2 + H^+ + 2e^- \Rightarrow C_2H_3Cl + Cl^-$ <i>c-DCE Reductive Dechlorination</i>	-12.12	-50.7	+0.526	+0.437	+7.39	pH = 7 $[Cl^-] = 10^{-4}$
$C_2H_3Cl + H^+ + 2e^- \Rightarrow C_2H_4 + Cl^-$ <i>VC Reductive Dechlorination</i>	-13.73	-57.4	+0.595	+0.506	+8.55	pH = 7 $[Cl^-] = 10^{-4}$
$8e^- + 8H^+ + CO_{2,g} \Rightarrow CH_4,g + 2H_2O$ <i>Methanogenesis</i>	-3.91	-16.4	+0.169	-0.259	-4.39	pH = 7 $P_{CO_2} = 10^{-2}$ $P_{CH_4} = 10^0$

HALF-CELL REACTIONS	ΔG°_r (kcal/ equiv)*	ΔG°_r (kJ/ equiv)*	E° (V)	Eh (V)	pe	Conditions for Eh and pe §
ELECTRON-DONOR (OXIDATION) HALF CELL REACTIONS						
$12H_2O + C_6H_6 \Rightarrow 6CO_2 + 30H^+ + 30e^-$ Benzene Oxidation	+2.83	+11.8	-0.122	+0.316	+5.34	pH = 7 $P_{CO_2} = 10^{-2}$
$14H_2O + C_6H_5CH_3 \Rightarrow 7CO_2 + 36H^+ + 36e^-$ Toluene Oxidation	+2.96	+12.4	-0.128	+0.309	+5.22	pH = 7 $P_{CO_2} = 10^{-2}$
$16H_2O + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42H^+ + 42e^-$ Ethylbenzene Oxidation	+2.96	+12.4	-0.128	+0.309	+5.21	pH = 7 $P_{CO_2} = 10^{-2}$
$20H_2O + C_{10}H_8 \Rightarrow 10CO_2 + 48H^+ + 48e^-$ Naphthalene Oxidation	+2.98	+12.5	-0.130 ^a	+0.309	+5.22	pH = 7 $P_{CO_2} = 10^{-2}$
$18H_2O + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48H^+ + 48e^-$ 1,3,5-Trimethylbenzene Oxidation	+3.07	+12.8	-0.133 ^a	+0.303	+5.12	pH = 7 $P_{CO_2} = 10^{-2}$
$18H_2O + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48H^+ + 48e^-$ 1,2,4-Trimethylbenzene Oxidation	+3.07	+12.9	-0.134 ^a	+0.302	+5.11	pH = 7 $P_{CO_2} = 10^{-2}$
$4H_2O + C_2H_3Cl \Rightarrow 2CO_2 + 11H^+ + 10e^- + Cl^-$ Vinyl Chloride Oxidation	-0.55	-2.30	+0.024 ^a	-0.455	-7.69	pH = 7 $P_{CO_2} = 10^{-2}$
$12H_2O + C_6H_5Cl \Rightarrow 6CO_2 + 29H^+ + 28e^- + Cl^-$ Chlorobenzene Oxidation	+2.21	+9.26	-0.096 ^a	+0.358	+6.05	pH = 7 $P_{CO_2} = 10^{-2}$

NOTES:

* = ΔG°_r for half cell reaction as shown divided by the number of electrons involved in reaction.

§ = Conditions assumed for the calculation of Eh and pe (pe = Eh/0.05916). Where two dissolved species are involved, other than those mentioned in this column, their activities are taken as equal. Note, this does not affect the free energy values listed.

^a = E° calculated using the following equation; $E^\circ = \Delta G^\circ_r (J/nF) * 1.0365 \times 10^{-5} (VF/J)$ from Stumm and Morgan, 1981

Coupled Oxidation Reactions

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5 O_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 3 H_2O$ <i>Benzene oxidation / aerobic respiration</i>	-765.34	-3202	3.07:1
$6 NO_3^- + 6 H^+ + C_6H_6 \Rightarrow 6 CO_{2,g} + 6 H_2O + 3 N_{2,g}$ <i>Benzene oxidation / denitrification</i>	-775.75	-3245	4.77:1
$30 H^+ + 15 MnO_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 15 Mn^{2+} + 18 H_2O$ <i>Benzene oxidation / manganese reduction</i>	-765.45	-3202	10.56:1
$3.75 NO_3^- + C_6H_6 + 7.5 H^+ + 0.75 H_2O \Rightarrow 6 CO_2 + 3.75 NH_4^+$ <i>Benzene oxidation / nitrate reduction</i>	-524.1	-2193	2.98:1
$60 H^+ + 30 Fe(OH)_{3,a} + C_6H_6 \Rightarrow 6 CO_2 + 30 Fe^{2+} + 78 H_2O$ <i>Benzene oxidation / iron reduction</i>	-560.10	-2343	21.5:1
$7.5 H^+ + 3.75 SO_4^{2-} + C_6H_6 \Rightarrow 6 CO_{2,g} + 3.75 H_2S^0 + 3 H_2O$ <i>Benzene oxidation / sulfate reduction</i>	-122.93	-514.3	4.61:1
$4.5 H_2O + C_6H_6 \Rightarrow 2.25 CO_{2,g} + 3.75 CH_4$ <i>Benzene oxidation / methanogenesis</i>	-32.40	-135.6	0.77:1
$15 C_2Cl_4 + 12 H_2O + C_6H_6 \Rightarrow 15 C_2HCl_3 + 6 CO_2 + 15 H^+ + 15 Cl^-$ <i>Benzene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-358.59	-1500	31.8:1
$15 C_2HCl_3 + 12 H_2O + C_6H_6 \Rightarrow 15 C_2H_2Cl_2 + 6 CO_2 + 15 H^+ + 15 Cl^-$ <i>Benzene oxidation/ Trichloroethylene reductive dehalogenation</i>	-350.04	-1465	25.2:1
$15 C_2H_2Cl_2 + 12 H_2O + C_6H_6 \Rightarrow 15 C_2H_3Cl + 6 CO_2 + 15 H^+ + 15 Cl^-$ <i>Benzene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-278.64	-1166	18.6:1
$15 C_2H_3Cl + 12 H_2O + C_6H_6 \Rightarrow 15 C_2H_4 + 6 CO_2 + 15 H^+ + 15 Cl^-$ <i>Benzene oxidation/ Vinyl chloride reductive dehalogenation</i>	-327.37	-1370	11.9:1

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9 O_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4 H_2O$ <i>Toluene oxidation / aerobic respiration</i>	-913.76	-3823	3.13:1
$7.2 NO_3^- + 7.2 H^+ + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 7.6 H_2O + 3.6 N_{2,g}$ <i>Toluene oxidation / denitrification</i>	-926.31	-3875	4.85:1
$36 H^+ + 18 MnO_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 18 Mn^{2+} + 22 H_2O$ <i>Toluene oxidation / manganese reduction</i>	-913.89	-3824	10.74:1
$72 H^+ + 36 Fe(OH)_{3,a} + C_6H_5CH_3 \Rightarrow 7 CO_2 + 36 Fe^{2+} + 94 H_2O$ <i>Toluene oxidation / iron reduction</i>	-667.21	-2792	21.86:1
$9 H^+ + 4.5 SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4.5 H_2S^0 + 4 H_2O$ <i>Toluene oxidation / sulfate reduction</i>	-142.86	-597.7	4.7:1
$5 H_2O + C_6H_5CH_3 \Rightarrow 2.5 CO_{2,g} + 4.5 CH_4$ <i>Toluene oxidation / methanogenesis</i>	-34.08	-142.6	0.78:1
$18 C_2Cl_4 + 14 H_2O + C_6H_5CH_3 \Rightarrow 18 C_2HCl_3 + 7 CO_2 + 18 H^+ + 18 Cl^-$ <i>Toluene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-425.66	-1781	32.4:1
$18 C_2HCl_3 + 14 H_2O + C_6H_5CH_3 \Rightarrow 18 C_2H_2Cl_2 + 7 CO_2 + 18 H^+ + 18 Cl^-$ <i>Toluene oxidation/ Trichloroethylene reductive dehalogenation</i>	-415.40	-1738	25.7:1
$18 C_2H_2Cl_2 + 14 H_2O + C_6H_5CH_3 \Rightarrow 18 C_2H_3Cl + 7 CO_2 + 18 H^+ + 18 Cl^-$ <i>Toluene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-329.72	-1380	18.9:1
$18 C_2H_3Cl + 14 H_2O + C_6H_5CH_3 \Rightarrow 18 C_2H_4 + 7 CO_2 + 18 H^+ + 18 Cl^-$ <i>Toluene oxidation/ Vinyl chloride reductive dehalogenation</i>	-388.22	-1624	12.1:1

Coupled Ethylbenzene Oxidation reactions	ΔG_r° kcal/mole Ethylbenzene	ΔG_r° kJ/mole Ethylbenzene	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>Ethylbenzene oxidation / aerobic respiration</i>	-1066.13	-4461	3.17:1
$8.4 NO_3 + 8.4 H^+ + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>Ethylbenzene oxidation / denitrification</i>	-1080.76	-4522	4.92:1
$46 H^+ + 22 MnO_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 22 Mn^{2+} + 28 H_2O$ <i>Ethylbenzene oxidation / manganese reduction</i>	-1066.27	-4461	11.39:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_5C_2H_5 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>Ethylbenzene oxidation / iron reduction</i>	-778.48	-3257	22.0:1
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>Ethylbenzene oxidation / sulfate reduction</i>	-166.75	-697.7	4.75:1
$5.5 H_2O + C_6H_5C_2H_5 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>Ethylbenzene oxidation / methanogenesis</i>	-39.83	-166.7	0.79:1
$21 C_2Cl_4 + 16 H_2O + C_6H_5C_2H_5 \Rightarrow 21 C_2HCl_3 + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>Ethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-496.67	-2078	32.8:1
$21 C_2HCl_3 + 16 H_2O + C_6H_5C_2H_5 \Rightarrow 21 C_2H_2Cl_2 + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>Ethylbenzene oxidation/ Trichloroethylene reductive dehalogenation</i>	-484.70	-2028	26.0:1
$21 C_2H_2Cl_2 + 16 H_2O + C_6H_5C_2H_5 \Rightarrow 21 C_2H_3Cl + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>Ethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-384.74	-1610	19.2:1
$21 C_2H_3Cl + 16 H_2O + C_6H_5C_2H_5 \Rightarrow 21 C_2H_4 + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>Ethylbenzene oxidation/ Vinyl chloride reductive dehalogenation</i>	-452.99	-1895	12.3:1

Coupled m-Xylene Oxidation Reactions	ΔG_r° (kcal/mole m-xylene)	ΔG_r° (kJ/mole m-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>m-Xylene oxidation / aerobic respiration</i>	-1063.25	-4448	3.17:1
$8.4 NO_3 + 8.4 H^+ + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>m-Xylene oxidation / denitrification</i>	-1077.81	-4509	4.92:1
$46 H^+ + 22 MnO_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 22 Mn^{2+} + 28 H_2O$ <i>m-Xylene oxidation / manganese reduction</i>	-1063.39	-4449	11.39:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>m-Xylene oxidation / iron reduction</i>	-775.61	-3245	22:1
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>m-Xylene oxidation / sulfate reduction</i>	-163.87	-685.6	4.75:1
$5.5 H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>m-Xylene oxidation / methanogenesis</i>	-36.95	-154.6	0.79:1 ^u
$21 C_2Cl_4 + 16 H_2O + C_6H_4(CH_3)_2 \Rightarrow 21 C_2HCl_3 + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>m-Xylene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-493.79	-2066	32.8:1
$21 C_2HCl_3 + 16 H_2O + C_6H_4(CH_3)_2 \Rightarrow 21 C_2H_2Cl_2 + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>m-Xylene oxidation/ Trichloroethylene reductive dehalogenation</i>	-481.82	-2016	26.0:1
$21 C_2H_2Cl_2 + 16 H_2O + C_6H_4(CH_3)_2 \Rightarrow 21 C_2H_3Cl + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>m-Xylene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-381.86	-1598	19.2:1
$21 C_2H_3Cl + 16 H_2O + C_6H_4(CH_3)_2 \Rightarrow 21 C_2H_4 + 8 CO_2 + 21 H^+ + 21 Cl^-$ <i>m-Xylene oxidation/ Vinyl chloride reductive dehalogenation</i>	-450.11	-1883	12.3:1

Coupled Naphthalene Oxidation Reactions	ΔG°_r (kcal/mole naphthalene)	ΔG°_r (kJ/mole naphthalene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$12O_2 + C_{10}H_8 \Rightarrow 10CO_2 + 4H_2O$ <i>Naphthalene oxidation / aerobic respiration</i>	-1217.40	-5094	3.00:1
$9.6NO_3^- + 9.6H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 8.8H_2O + 4.8N_{2,g}$ <i>Naphthalene oxidation / denitrification</i>	-1234.04	-5163	4.65:1
$24MnO_2 + 48H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 24Mn^{2+} + 28H_2O$ <i>Naphthalene oxidation / manganese reduction</i>	-1217.57	-5094	16.31:1
$48Fe(OH)_{3,a} + 96H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 48Fe^{2+} + 124H_2O$ <i>Naphthalene oxidation / iron reduction</i>	-932.64	-3902	40.13:1
$6SO_4^{2-} + 12H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 6H_2S^0 + 4H_2O$ <i>Naphthalene oxidation / sulfate reduction</i>	-196.98	-824.2	4.50:1
$8H_2O + C_{10}H_8 \Rightarrow 4CO_2 + 6CH_4$ <i>Naphthalene oxidation / methanogenesis</i>	-44.49	-186.1	1.13:1
$24C_2Cl_4 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2HCl_3 + 10CO_2 + 24H^+ + 24Cl^-$ <i>Naphthalene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-566.59	-2371	31.1:1
$24C_2HCl_3 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_2Cl_2 + 10CO_2 + 24H^+ + 24Cl^-$ <i>Naphthalene oxidation/ Trichloroethylene reductive dehalogenation</i>	-552.91	-2313	24.6:1
$24C_2H_2Cl_2 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_3Cl + 10CO_2 + 24H^+ + 24Cl^-$ <i>Naphthalene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-438.67	-1835	18.2:1
$24C_2H_3Cl + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_4 + 10CO_2 + 24H^+ + 24Cl^-$ <i>Naphthalene oxidation/ Vinyl chloride reductive dehalogenation</i>	-516.67	-2162	11.6:1

Coupled 1,3,5-Trimethylbenzene Oxidation Reactions	ΔG°_r (kcal/mole 1,3,5-TMB)	ΔG°_r (kJ/mole 1,3,5-TMB)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$12O_2 + C_9H_7(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O$ <i>1,3,5-Trimethylbenzene oxidation / aerobic respiration</i>	-1213.29	-5076	3.20:1
$9.6NO_3^- + 9.6H^+ + C_9H_7(CH_3)_3 \Rightarrow 9CO_2 + 10.8H_2O + 4.8N_{2,g}$ <i>1,3,5-Trimethylbenzene oxidation / denitrification</i>	-1229.93	-5146	4.96:1
$24MnO_2 + 48H^+ + C_9H_7(CH_3)_3 \Rightarrow 9CO_2 + 30H_2O + 24Mn^{2+}$ <i>1,3,5-Trimethylbenzene oxidation / manganese reduction</i>	-1213.46	-5077	17.40:1
$48Fe(OH)_{3,a} + 96H^+ + C_9H_7(CH_3)_3 \Rightarrow 9CO_2 + 48Fe^{2+} + 126H_2O$ <i>1,3,5-Trimethylbenzene oxidation / iron reduction</i>	-928.53	-3885	42.80:1
$6SO_4^{2-} + 12H^+ + C_9H_7(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O + 6H_2S^0$ <i>1,3,5-Trimethylbenzene oxidation / sulfate reduction</i>	-192.87	-807.0	4.80:1
$6H_2O + C_9H_7(CH_3)_3 \Rightarrow 3CO_2 + 6CH_4$ <i>1,3,5-Trimethylbenzene oxidation / methanogenesis</i>	-40.39	-169.0	0.90:1
$24C_2Cl_4 + 18H_2O + C_9H_7(CH_3)_3 \Rightarrow 24C_2HCl_3 + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,3,5-Trimethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-562.48	-2353	33.2:1
$24C_2HCl_3 + 18H_2O + C_9H_7(CH_3)_3 \Rightarrow 24C_2H_2Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,3,5-Trimethylbenzene oxidation/ Trichloroethylene reductive dehalogenation</i>	-548.80	-2296	26.3:1
$24C_2H_2Cl_2 + 18H_2O + C_9H_7(CH_3)_3 \Rightarrow 24C_2H_3Cl + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,3,5-Trimethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-434.56	-1818	19.4:1
$24C_2H_3Cl + 18H_2O + C_9H_7(CH_3)_3 \Rightarrow 24C_2H_4 + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,3,5-Trimethylbenzene oxidation/ Vinyl chloride reductive dehalogenation</i>	-512.56	-2145	12.4:1

Coupled 1,2,4-Trimethylbenzene Oxidation Reactions	ΔG°_r (kcal/mole 1,2,4-TMB)	ΔG°_r (kJ/mole 1,2,4-TMB)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$12O_2 + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O$ <i>1,2,4-Trimethylbenzene oxidation / aerobic respiration</i>	-1212.92	-5075	3.20:1
$9.6NO_3^- + 9.6H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 10.8H_2O + 4.8N_{2,g}$ <i>1,2,4-Trimethylbenzene oxidation / denitrification</i>	-1229.56	-5144	4.96:1
$24MnO_2 + 48H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 30H_2O + 24Mn^{2+}$ <i>1,2,4-Trimethylbenzene oxidation / manganese reduction</i>	-1213.09	-5076	17.4:1
$48Fe(OH)_{3,a} + 96H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48Fe^{2+} + 126H_2O$ <i>1,2,4-Trimethylbenzene oxidation / iron reduction</i>	-928.16	-3883	42.8:1
$6SO_4^{2-} + 12H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O + 6H_2S^o$ <i>1,2,4-Trimethylbenzene oxidation / sulfate reduction</i>	-192.50	-805.4	4.80:1
$6H_2O + C_6H_3(CH_3)_3 \Rightarrow 3CO_2 + 6CH_4$ <i>1,2,4-Trimethylbenzene oxidation / methanogenesis</i>	-40.02	-167.4	0.90:1
$24C_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2HCl_3 + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,2,4-Trimethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation</i>	-562.11	-2352	33.2:1
$24C_2HCl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_2Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,2,4-Trimethylbenzene oxidation/ Trichloroethylene reductive dehalogenation</i>	-548.43	-2295	26.3:1
$24C_2H_2Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,2,4-Trimethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation</i>	-434.19	-1817	19.4:1
$24C_2H_3Cl + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4 + 9CO_2 + 24H^+ + 24Cl^-$ <i>1,2,4-Trimethylbenzene oxidation/ Vinyl chloride reductive dehalogenation</i>	-512.19	-2143	12.4:1

Coupled Chlorobenzene Oxidation Reactions	ΔG°_r (kcal/mole Chlorobenzene)	ΔG°_r (kJ/mole Chlorobenzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7O_2 + C_6H_5Cl \Rightarrow 6CO_2 + H^+ + 2H_2O + Cl^-$ <i>Chlorobenzene oxidation / aerobic respiration</i>	-731.62	-3061	2.00:1
$5.6NO_3^- + 4.6H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 4.8H_2O + 2.8N_{2,g} + Cl^-$ <i>Chlorobenzene oxidation / denitrification</i>	-741.33	-3102	3.10:1
$14MnO_2 + 27H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 16H_2O + 14Mn^{2+} + Cl^-$ <i>Chlorobenzene oxidation / manganese reduction</i>	-731.72	-3062	10.9:1
$28Fe(OH)_{3,a} + 55H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 72H_2O + 28Fe^{2+} + Cl^-$ <i>Chlorobenzene oxidation / iron reduction</i>	-565.51	-2366	26.8:1
$3.5SO_4^{2-} + 6H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 2H_2O + 3.5H_2S^o + Cl^-$ <i>Chlorobenzene oxidation / sulfate reduction</i>	-136.38	-570.6	3.00:1
$5H_2O + C_6H_5Cl \Rightarrow 2.5CO_2 + 3.5CH_4 + H^+ + Cl^-$ <i>Chlorobenzene oxidation / methanogenesis</i>	-47.43	-198.4	0.80:1

$14C_2Cl_4 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ Chlorobenzene oxidation/ Tetrachloroethylene reductive dehalogenation	-351.99	-1473	20.7:1
$14C_2HCl_3 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ Chlorobenzene oxidation/ Trichloroethylene reductive dehalogenation	-344.01	-1439	16.4:1
$14C_2H_2Cl_2 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ Chlorobenzene oxidation/ cis-Dichloroethylene reductive dehalogenation	-277.37	-1161	12.1:1
$14C_2H_3Cl + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ Chlorobenzene oxidation/ Vinyl chloride reductive dehalogenation	-322.87	-1351	7.75:1

Coupled Vinyl Chloride Oxidation Reactions	ΔG_r° (kcal/mole vinyl chloride)	ΔG_r° (kJ/mole vinyl chloride)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$2.5O_2 + C_2H_3Cl \Rightarrow 2CO_2 + H_2O + H^+ + Cl^-$ Vinyl Chloride oxidation /aerobic respiration	-288.98	-1209	1.29:1
$2NO_3^- + H^+ + C_2H_3Cl \Rightarrow 2CO_2 + 2H_2O + Cl^- + N_{2,g}$ Vinyl Chloride oxidation / denitrification	-292.44	-1224	2.00:1
$5MnO_2 + 9H^+ + C_2H_3Cl \Rightarrow 2CO_2 + 6H_2O + 5Mn^{2+} + Cl^-$ Vinyl Chloride oxidation / manganese reduction	-289.01	-1209	7.02:1
$10Fe(OH)_{3,a} + 19H^+ + C_6H_5(CH_3)_3 \Rightarrow 2CO_2 + 10Fe^{2+} + 26H_2O + Cl^-$ Vinyl Chloride oxidation / iron reduction	-229.65	-960.9	17.3:1
$1.25SO_4^{2-} + 1.5H^+ + C_2H_3Cl \Rightarrow 2CO_2 + H_2O + 1.25H_2S^0 + Cl^-$ Vinyl Chloride oxidation / sulfate reduction	-76.40	-319.7	1.94:1
$1.5H_2O + C_2H_3Cl \Rightarrow .75CO_2 + 1.25CH_4 + H^+ + Cl^-$ Vinyl Chloride oxidation / methanogenesis	-44.62	-186.7	0.44:1
$5C_2Cl_4 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2HCl_3 + 2CO_2 + 6H^+ + 6Cl^-$ Vinyl Chloride oxidation/ Tetrachloroethylene reductive dehalogenation	-153.39	-641.8	13.4:1
$5C_2HCl_3 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_2Cl_2 + 2CO_2 + 6H^+ + 6Cl^-$ Vinyl Chloride oxidation/ Trichloroethylene reductive dehalogenation	-150.54	-629.9	10.6:1
$5C_2H_2Cl_2 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_3Cl + 2CO_2 + 6H^+ + 6Cl^-$ Vinyl Chloride oxidation/ cis-Dichloroethylene reductive dehalogenation	-126.74	-530.3	7.82:1

Gibbs Free Energy of Formation for Species used in Half-Cell reactions
and Coupled Oxidation-Reduction Reactions

Species	State	$\Delta G_{f,298.15}^{\circ}$ (kcal/mole)	Source
e^{-}	i	0	std
H^{+}	i	0	std
O_2	g	0	std
H_2O	l	-56.687	Dean (1972)
Carbon Species			
CO_2	g	-94.26	Dean (1972)
CH_2O , formaldehyde	aq	-31.02	Dean (1972)
C_6H_6 , benzene	l	+29.72	Dean (1972)
CH_4 , methane	g	-12.15	Dean (1972)
$C_6H_5CH_3$, toluene	l	+27.19	Dean (1972)
$C_6H_5C_2H_5$, ethylbenzene	l	+28.61	Dean (1972)
$C_6H_4(CH_3)_2$, o-xylene	l	+26.37	Dean (1972)
$C_6H_4(CH_3)_2$, m-xylene	l	+25.73	Dean (1972)
$C_6H_4(CH_3)_2$, p-xylene	l	+26.31	Dean (1972)
C_2Cl_4 , PCE	l	+1.1	CRC Handbook (1990)
C_2HCl_3 , TCE	l	+2.9	CRC Handbook (1990)
$C_2H_2Cl_2$, c-DCE	l	+5.27	CRC Handbook (1990)
C_2H_4 , ethene	g	+16.28	CRC Handbook (1990)
$C_{10}H_8$, naphthalene	l	+48.05	Dean (1972)
$C_6H_3(CH_3)_3$, 1,3,5-TMB	l	+24.83	Dean (1972)
$C_6H_3(CH_3)_3$, 1,2,4-TMB	l	+24.46	Dean (1972)
C_2H_3Cl , vinyl chloride	g	+12.4	Dean (1972)
C_6H_5Cl , chlorobenzene	l	+21.32	Dean (1972)
$C_{14}H_{10}$, phenanthrene	l	+64.12	Dean (1972)
Nitrogen Species			
NO_3^{-}	i	-26.61	Dean (1972)
N_2	g	0	std
NO_2^{-}	i	-7.7	Dean (1972)
NH_4^{+}	aq	-18.97	Dean (1972)
Sulfur Species			
SO_4^{2-}	i	-177.97	Dean (1972)
H_2S	aq	-6.66	Dean (1972)
H_2S	g	-7.9	Dean (1972)
HS^{-}	i	+2.88	Dean (1972)
Iron Species			
Fe^{2+}	i	-18.85	Dean (1972)
Fe^{3+}	i	-1.1	Dean (1972)
Fe_2O_3 , hematite	c	-177.4	Dean (1972)
$FeOOH$, ferric oxyhydroxide	c	-117.2	Naumov <i>et al.</i> (1974)
$Fe(OH)_3$, goethite	a	-167.416	Langmuir and Whittemore (1971)
$Fe(OH)_3$, goethite	c	-177.148	Langmuir and Whittemore (1971)
$FeCO_3$, siderite	c	-159.35	Dean (1972)
Manganese Species			
Mn^{2+}	i	-54.5	Dean (1972)
MnO_2 , pyrolusite	c	-111.18	Stumm and Morgan (1981)
$MnOOH$, manganite	c	-133.29	Stumm and Morgan (1981)
$MnCO_3$, rhodochrosite	p	-194	Dean (1972)

Chloride Species			
Cl ⁻	aq	-31.37	Dean (1972)

NOTES:

c = crystallized solid

a = amorphous solid (may be partially crystallized - dependent on methods of preparation)

p = freshly precipitated solid

i = dissociated, aqueous ionic species (concentration = 1 m)

aq = undissociated aqueous species

g = gaseous

l = liquid

std = accepted by convention

Wherever possible multiple sources were consulted to eliminate the possibility of typographical error.

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE -Wortsmith AFB, OT45-BAP Job No. 725523.0000
Subject Maximum Travel Distance Prior to By A. Painsburger
Location Below Res. G.W. Cleanup Criteria Checked y/sj, 04-26-96

Sheet 1 of 1
Date 04-26-96
Rev. _____

- Governing 1st order decay equation for biological degradation.

$$C = C_0 e^{-kt}, \text{ where } C_0 = \text{current contaminant concentration (ug/L)}$$

C = resident groundwater cleanup criteria (ug/L)

$-k$ = biodegradation rate (Buschak and Alcantar, 1994)

(see other calculations Appendix D)

- Assumptions: C_0 = maximum contaminant concentration - 1992 RI

C = 1995 concentration (theoretical)

solving for time to attain res. gw. criteria

t = days

- 1,2,4-TMB

$$C = 30 \text{ ug/L}; C_0 = 48 \text{ ug/L}; k = 0.005 \text{ day}^{-1}; t \Rightarrow \text{variable}$$

$$30 = (48) e^{-0.005t}$$

$$t = 94 \text{ days}$$

1,2,4 TMB will persist approximately 94 days in groundwater before maximum 1995 concentrations are reduced below generic residential cleanup criteria.

The maximum travel distance conservatively calculated from site data is:

$$X = V_c t, \text{ where}$$

X = distance

$$V_c = 0.107 \frac{\text{ft}}{\text{day}} \text{ (contaminant velocity see attached Appendix D calculations)}$$

$$t = 94 \text{ days}$$

$$(94 \text{ days})(0.107 \frac{\text{ft}}{\text{day}}) = 10 \text{ feet (when rounded to two sig. figs)}$$

APPENDIX E

PILOT TESTING OF SOURCE REDUCTION TECHNOLOGIES

APPENDIX E

PILOT TESTING OF SOURCE REDUCTION TECHNOLOGIES

Section 6 of this RAP shows that both destructive and nondestructive attenuation processes should be effective at minimizing contaminant migration and reducing contaminant mass. This analysis was based on available site data for soil and groundwater. Other source removal technologies also were evaluated at Site OT45 as part of this field test in the event that engineered source removal is required to protect human health and the environment. Air permeability and biosparging pilot tests were completed by Parsons ES at Site OT45 during October 1994. The complete bioventing pilot test originally proposed was not performed because almost no vadose zone soil contamination was detected during drilling and initial soil gas oxygen concentrations were not significantly depleted. Measured levels of soil gas oxygen ranged from 15.4 to 18.5 percent and are sufficient to sustain *in situ* bioremediation of remaining fuel residuals in the vadose zone. Bioventing is only appropriate for sites with anaerobic, contaminated unsaturated soils.

1.1 AIR PERMEABILITY TEST

1.1.1 Bioventing Well and Vapor Monitoring Point Installation

Installation of VW-1, MPA, and MPB took place on September 28, 1994. Figure 2.2 shows the locations of VW-1, MPA, and MPB, and Figure 3.4 is a hydrogeologic cross section showing the relationships of the screened intervals to the groundwater surface. Boring logs and well construction diagrams are included in Appendix A.

One 4-inch-diameter PVC air injection vent well (VW-1) was installed in contaminated source area soils with the screened interval extending from 5 to 15 feet bgs. The screen was placed with roughly one-half of the screen extended above the groundwater surface for the purpose of air injection, with the remainder below the water surface to enable collection of groundwater samples and to measure DO concentrations during the biosparging test. The groundwater level at the time of well installation was approximately 10 feet bgs.

The two soil vapor monitoring points (MPA and MPB) were screened in the unsaturated zone with 6-inch-long sections of 1-inch-diameter well screen centered at depths of approximately 5 and 9 feet bgs. In addition, two 2-inch-diameter wells were installed in each monitoring point borehole, each with 2.5-foot-long screened sections centered at approximately 11 and 18 feet bgs. These monitoring points were designed to allow collection and measurement of soil gas and groundwater samples to determine chemical changes in these media during the air permeability and biosparging tests.

Thermocouples were installed at the 5- and 9-foot depths at MPA to measure soil temperatures.

1.1.2 Air Permeability Test Procedures

An air permeability test was conducted to determine the ability of injected air (oxygen) to move through Site OT45 soils. The test was completed using procedures described in the AFCEE bioventing protocol document (Hinchee *et al.*, 1992). The test was conducted in three phases. First, air was injected into VW-1 for 10 minutes at a rate of approximately 10 standard cubic feet per minute (scfm) and an average pressure of 3.8 inches of water. Second, after the blower was turned off and pressures were allowed to equalize, air was injected into VW-1 for 10 minutes at a rate of approximately 30 scfm and an average pressure of 13.5 inches of water. The last phase consisted of injecting air for a period of 21 hours at a rate of 10 scfm and an average pressure of 3.8 inches of water. Pressure response was measured at the monitoring points during each air injection period. Changes in soil gas oxygen, carbon dioxide, and TVH concentrations also were measured to help determine the effective radius of oxygen influence for the vent well.

1.1.3 Test Results

The pressure measured at the monitoring points increased rapidly during the first 1 to 3 minutes of the test, then remained at the maximum values for the remainder of the test. Due to the rapid pressure response, the steady-state method of determining air permeability was selected. A radius of pressure influence of at least 48 feet was observed. The maximum pressure responses measured at MW-2, located 35 feet from VW-1, were 0.02 and 0.04 inches of water for flow rates of 10 and 30 scfm, respectively. A soil gas permeability value of 0.95 darcys, was calculated for vadose zone soils at this site. Permeability calculations are included in Appendix E.

Changes in soil gas oxygen, carbon dioxide and TVH were measured during the tests to help determine the effective radius of influence of VW-1. A change in soil gas chemistry indicates soil gas movement induced by injecting air at VW-1. Table 1 presents the change in soil gas oxygen levels that occurred during the 21-hour injection period. This period of air injection produced increases in soil gas oxygen levels at MPA as fresh, oxygenated air displaced the soil gas. Soil gas oxygen concentrations decreased and TVH concentrations increased at all other monitoring locations within 45 feet of VW-1. These changes indicate that the soil gas from the more highly contaminated soils near VW-1 (high TVH, low oxygen) was displaced outward into less contaminated soil. Based on pressure response and changes in soil gas chemistry, the radius of influence of VW-1 exceeded 45 feet, indicating that one vent well is sufficient to influence the entire contaminated vadose zone of the source area.

1.2 BIOSPARGING TEST

Biosparging was evaluated as a remediation technology for removing fuel hydrocarbons from the Site OT45 saturated soil zone. Injecting air into the groundwater beneath the contaminated soil serves two purposes: volatilizing BTEX compounds from the groundwater, and supplying oxygen to the groundwater to enhance biodegradation of less volatile PNA compounds.

TABLE 1
INFLUENCE OF AIR INJECTION AT VENT WELL AND BIOSPARING POINT
ON SOIL GAS OXYGEN AND TOTAL VOLATILE HYDROCARBON CONCENTRATIONS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Location	Depth (feet bgs)	10/8/94 12:00	10/12/94		10/13/94		10/14/94		10/17/94 09:20	10/18/94 17:00	10/21/94 08:30
Concurrent Activity and Comments	---	initial values	15:30	19:00	08:50	12:10	14:30	10:00	15:00	17:20	blower stopped
Oxygen Concentrations (%)			air permeability test (10 SCFM) ----->								
VW-1	5-15	18.3	---	---	---	---	---	---	---	---	---
MPA-5	4.75-5.25	16.5	16.2	16.5	20.2	20.0	20.9	20.3	17.2	18.5	18.5
MPA-9	8.75-9.25	15.4	15.0	11.6	12.5	14.0	17.8	16.2	13.8	19.5	20.6
MPB-5	4.75-5.25	17.0	17.0	16.8	16.0	16.0	16.2	16.7	19.0	20.5	20.6
MPB-9	8.75-9.25	16.0	15.5	15.5	14.5	14.0	14.4	18.0	20.2	20.6	20.0
MW-2	10-15	18.5	18.1	18.2	17.6	17.6	17.9	---	---	---	20.8
MW-5	6-16	---	18.8	19.0	18.7	18.6	18.6	---	---	---	20.4
											18.6
											20.0
											20.2
											18.5
Total Volatile Hydrocarbons (ppmv)											
VW-1	5-15	90	---	---	---	---	---	---	---	---	130
MPA-5	4.75-5.25	105	180	180	160	120	100	100	880	540	320
MPA-9	8.75-9.25	205	300	520	790	780	480	560	670	480	320
MPB-5	4.75-5.25	98	150	190	160	160	160	170	580	600	480
MPB-9	8.75-9.25	115	200	200	190	180	190	180	620	600	170
MW-2	10-15	78	200	200	190	190	180	---	---	---	230
MW-5	6-16	---	140	140	140	130	140	---	---	---	420
											220

The depth and radius of DO increase in the groundwater resulting from air injection into the sparging point during pilot testing is the primary design parameter for full-scale biosparging systems. Optimization of full-scale, multiple sparging point systems requires pilot testing to determine the aeral extent of groundwater that can be oxygenated at a given flow rate and sparging point screen configuration. The following sections summarize the biosparging test procedures and results, and assess the applicability of this technology for source removal at Site OT45.

1.2.1 Biosparging Well Installation

The 1-inch-diameter PVC air sparge well (SP-1) installed at the site was screened from 18 to 20 feet bgs. SP-1 was designed to inject air into the groundwater at the depth interval extending from 8 to 10 feet below the groundwater surface. Monitoring point installation is described in Section 1.1.1. The deep discrete monitoring points at MPA and MPB (MPA-10, MPA-17, MPB-10, and MPB-17), and existing monitoring wells MW-2 and MW-5 were used to measure changes in groundwater DO concentrations and soil gas chemistry. Figure 1 shows the locations of VW-1, MPA, MPB, SP-1, MW2, and MW5. Figure 2 is a hydrogeologic cross-section showing the relationships between the screened intervals and the groundwater surface. Boring logs and well construction diagrams are included in Appendix A in the RAP for Site OT45 (Parsons ES, 1995).

1.2.2 Biosparging Test Procedures

A biosparging pilot test was performed at Site OT45 during the period from October 14 to October 21, 1994. Initial soil gas oxygen, carbon dioxide, and TVH concentrations, and DO concentrations were measured prior to injecting air into SP-1. After initial measurements were recorded, air was injected into SP-1 at varying flow rates and pressures for approximately 6 days. Air injection rates varied between 4 and 8 scfm (Table 1) with an average rate of approximately 6 scfm and average injection pressure of about 105 inches of water.

During the period of air injection, soil gas oxygen, carbon dioxide, and TVH concentrations, and DO concentrations, injection pressure, and flow rates were periodically measured and recorded. These parameters were measured at VW-1, SP-1, MPA, MPB, MW-2, and MW-5. DO concentrations also were measured at MW-4, the control point for this test, located approximately 150 feet upgradient from SP-1.

1.2.3 Biosparging Test Results

1.2.3.1 Radius of DO Influence

Changes in groundwater DO concentrations were used to determine the effective radius of influence of the single sparging point. The biosparging test results are summarized in Table 2.

The maximum DO increase was measured at MPB, which is located 5 feet from SP-1. At MPB, the DO concentration increased from 2.8 to 6.8 mg/L in the monitoring interval from 8 to 10 feet below the groundwater surface. Less pronounced DO increases were obtained in both intervals of MPB, which is located 10 feet from the

LEGEND

BUILDING

BUILDING NUMBER

FENCE

FORMER UST LOCATION

AIR SPARGING POINT

GROUNDWATER & SOIL SAMPLE LOCATIONS

GROUNDWATER MONITORING WELL (INSTALLED 1994)

VENT WELL

VAPOR MONITORING POINT

GROUNDWATER SAMPLING LOCATIONS ONLY

GROUNDWATER MONITORING WELL (INSTALLED 1992/1993)



FIGURE 1

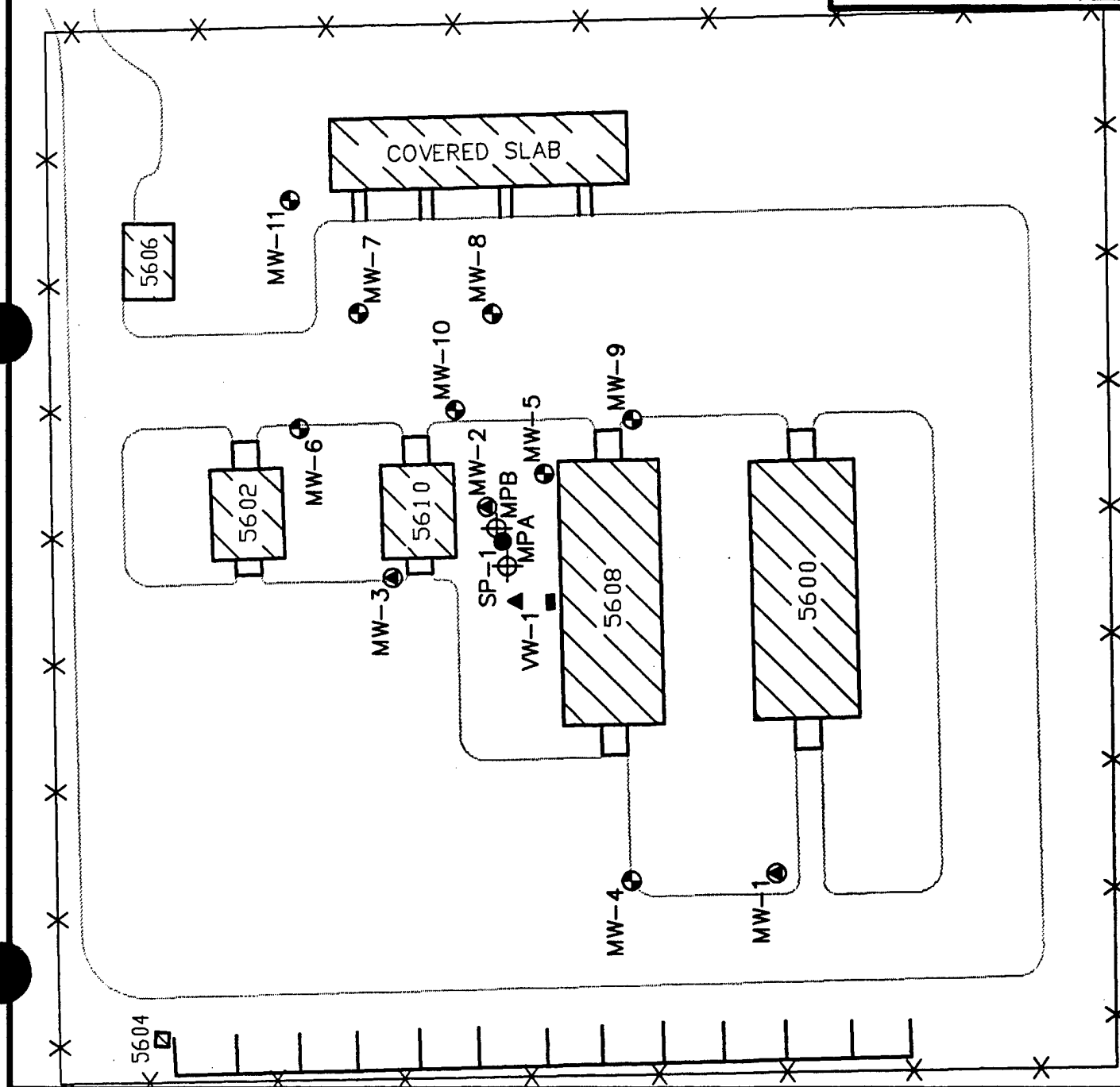
SITE OT45 SOIL AND GROUNDWATER SAMPLING LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45
Wurtsmith AFB, Michigan



PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado



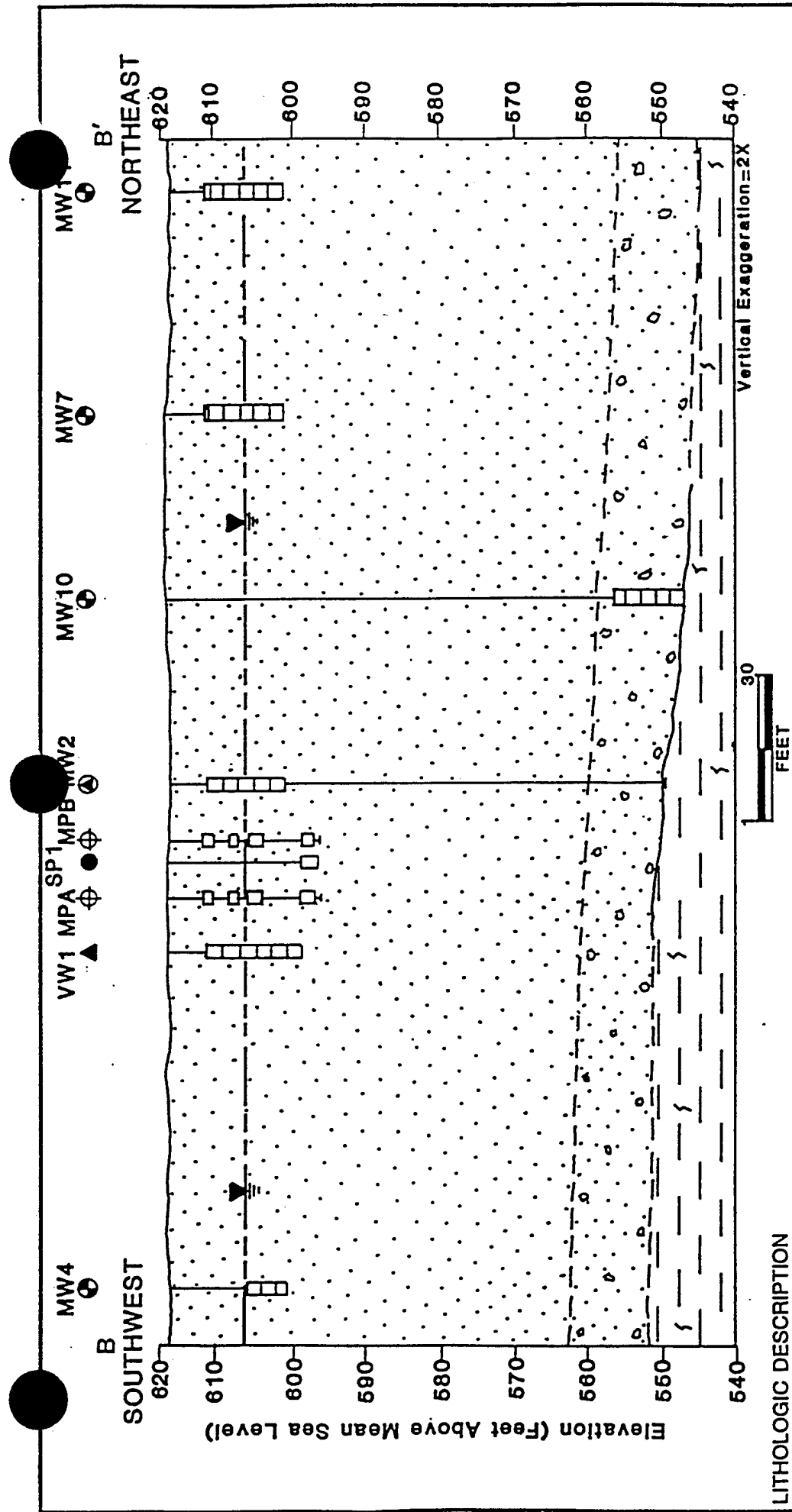


FIGURE 2

HYDROGEOLOGIC CROSS SECTION B-B'

Remedial Action Plan
Risk-Based Approach to Remediation
Site OT45

Wurtsmith AFB, Michigan



**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

LITHOLOGIC DESCRIPTION

	SAND		GRAVELLY SAND WITH CLAY SENSES		SILTY CLAY
--	------	--	--------------------------------	--	------------

LEGEND

	MW-4	GROUNDWATER MONITORING WELL (1994)		GROUNDWATER ELEVATION; DASHED WHERE INFERRED
	VW-1	VENT WELL		GEOLOGIC CONTACT, DASHED WHERE INFERRED
	SP1	AIR SPARGING POINT		SCREENED INTERVAL
	MPA	VAPOR MONITORING POINT		
	MW2	GROUNDWATER MONITORING WELL (1992/1993)		

TABLE 2
BIOSPARGING TREATABILITY TEST RESULTS
FOR DISSOLVED OXYGEN CONCENTRATIONS AND GROUND WATER LEVELS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Location	Depth (feet bgs)	Temperature (°C)	10/14/94										10/15/94		10/17/94		10/18/94		10/19/94		10/21/94	
			10:00 Initial Values	10:30 4 CFM Flow Rate	11:15 4 CFM Flow Rate	12:35 4 CFM Flow Rate	15:50 4 CFM Flow Rate	16:20 8 CFM Flow Rate	16:50 8 CFM Flow Rate	18:10 8 CFM Flow Rate	12:45 8 CFM Flow Rate	09:30 8 CFM Flow Rate	17:30 5 CFM Flow Rate	18:30 4.6 CFM Flow Rate	Blower Off							
Dissolved Oxygen (mg/L)																						
VW-1	5-15	11.5	1.6	---	---	1.4	1.5	---	---	1.6	1.7	1.8	1.7	1.7	0.8	1.2	1.2	1.2	1.2	1.2		
MPA-10	10-12.5	12.0	0.6	---	---	0.6	3.0	4.4	---	---	3.6	5.8	2.6	1.4	0.6	4.3	4.3	0.8	0.8	0.8		
MPA-17.5	17.5-20	10.5	2.2	---	---	2.2	1.2	1.3	---	---	1.2	1.2	1.4	2.2	2.2	2.8	2.8	1.5	1.5	1.5		
MPB-10	10-12.5	12.0	1.6	0.0	0.6	0.6	0.6	0.8	---	---	0.4	0.6	2.3	1.6	1.6	3.2	3.2	2.3	2.3	2.3		
MPB-17.5	17.5-20	10.5	2.8	3.8	3.6	2.8	2.8	2.9	---	---	4.0	4.2	4.9	4.2	2.8	6.8	6.8	6.1	6.1	6.1		
MW-4	10-15	12.0	---	9.4	---	9.5	9.5	9.5	---	---	---	---	9.6	9.7	9.5	10.0	10.0	9.9	9.9	9.9		
MW-5	6-16	10.5	1.8	---	---	2.6	4.2	4.2	---	---	4.2	3.8	3.2	3.6	2.8	4.0	4.0	4.0	4.0	4.0		
Water Levels (feet bgs)																						
VW-1	5-15		10.19	10.02	9.98	---	10.15	10.00	9.93	---	---	---	---	---	10.50	---	---	10.08	10.08	10.08		
MPA-10	10-12.5		10.28	9.97	9.75	---	10.14	10.06	9.76	---	---	---	---	---	10.15	---	---	10.02	10.02	10.02		
MPA-17.5	17.5-20		10.50	10.19	10.17	---	10.60	10.19	10.20	---	---	---	---	---	10.37	---	---	10.42	10.42	10.42		
MPB-10	10-12.5		10.18	9.70	9.60	---	10.30	10.05	9.66	---	---	---	---	---	10.08	---	---	10.08	10.08	10.08		
MPB-17.5	17.5-20		10.28	9.97	9.75	---	10.14	10.06	9.76	---	---	---	---	---	10.12	---	---	10.20	10.20	10.20		
MW-4	10-15		---	10.05	10.01	---	10.02	---	---	---	---	---	---	---	9.93	---	---	9.98	9.98	9.98		
MW-5	6-16		9.80	9.66	9.65	---	9.80	9.66	9.62	---	---	---	---	---	9.67	---	---	9.71	9.71	9.71		

sparge points. At MW-5, located 48 feet from SP-1, DO increased from 1.8 to 4.0 mg/L. DO increases were measured in 5 of the 6 monitoring points. Due to the longer (10 feet) screened interval at MW-5, it is likely that DO increases at this point were caused by random channeling that does not represent a uniform radius of influence. The DO measured at the control point (MW-4) remained within 0.6 mg/L of the initial value of 9.4 mg/L.

On the basis of increased DO concentrations measured in the groundwater at MPA and MPB, an effective treatment radius at least 10 feet was estimated for an average flow rate of approximately 6 scfm for a period of approximately 6 days. Although the uniformity of oxygen distribution cannot be determined from six monitoring points, pilot testing clearly indicates that sparging is an effective method for increasing DO concentrations, thus promoting *in situ* biodegradation of fuel hydrocarbons.

1.2.3.2 Soil Gas Monitoring

Soil gas oxygen and TVH concentrations were measured before and during the biosparging test. These results are summarized in Table 1. There was an initial rapid increase in soil gas TVH concentrations at the beginning of the test, followed by a gradual decrease throughout the remainder of the test. The initial TVH increase may have been the result of air bubbles stripping (sparging) the volatile hydrocarbons from the groundwater or the capillary fringe and transporting these compounds into the vadose zone.

Biosparging also introduced additional oxygen to soil gas in the vadose zone. Increases in soil gas oxygen concentrations were measured at all monitoring locations within 20 feet of SP-1. Increases ranged from 4.3 percent at MPB, located 5 feet from SP-1 to approximately 2 percent at MW-2, located 20 feet from SP-1. Although no anaerobic vadose zone soils were encountered during the 1994 investigations at Site OT45, increased soil gas oxygen concentrations would ensure enhanced biodegradation of remaining vadose soil contamination and any fuel vapors stripped from the groundwater.

1.2.3.3 Potential Air Emissions

The long-term potential for air emissions into the atmosphere from full-scale biosparging operations at this site is low. Emissions would be minimal because of the low air injection rates and because vapors released into the vadose zone would move slowly upward from the biosparging wells and would be biodegraded as they move through the oxygenated vadose soil. The biodegradation of BTEX vapors in soil gas was clearly demonstrated at a gasoline spill site at the Traverse City Michigan Coast Guard Station (Ostendorf, 1989). Soil flux measurements taken before and near the end of the biosparging test at Site OT45 confirm that the BTEX and TVH vapor flux to the atmosphere did not measurably increase as a result of biosparging.

1.2.3.4 Technology Assessment

The value of air sparging as a remediation tool is one of the most controversial topics in the remediation industry. Advocates of this technology cite case studies

where volatile organics are removed and dissolved oxygen transferred to the groundwater in relatively short time frames (Brown, 1991; Marley, 1990). Despite many apparent successful applications of this technology a number of independent researchers have concluded that the use of fully-screened monitoring wells for monitoring sparging efficiency has significantly biased groundwater DO and VOC data. They point out that the monitoring wells may intersect a single channel of air which turns the well into an *in situ* air stripping column, adding DO to the water and stripping VOCs from the well. Independent researchers have also conducted large pilot tests and shown that injected air generally follows preferential channels and is not uniformly distributed, even in sandy aquifer material (Johnson, 1993). Studies on DO distribution have yielded similar results, with uneven DO distribution measured over long-term pilot testing (Johnson, 1994). In these pilot tests DO increased initially and then gradually declined over a 110-day test. This decline was likely the result of increased channeling, which reduces mass transfer of oxygen as smaller channels combine into larger, less efficient channels. Pulsing of air sparging systems has been suggested as a method of maintaining smaller channels and minimizing mass transfer (Johnson, 1994). On the basis of the pilot data gathered at Site OT45 and air sparging research to date, Parsons ES believe that the pulsed operation of air sparging systems can increase DO near the sparge points and provide oxygen to the capillary fringe and vadose zone to enhance natural biodegradation. It is doubtful that air sparging can remove large quantities of volatiles from the groundwater, given mass transfer limitations. The application of biosparging to the relatively uniform sandy soils at Site OT45 is appropriate, although the long-term benefits of sparging remain in question.

Treatability testing indicates that biosparging could be an applicable technology for reducing source area hydrocarbon contamination at Site OT45. Biosparging could also reduce contaminant concentrations in the saturated soils and groundwater due to a combination of physical mass transfer and biological remediation. Increasing DO concentrations in the groundwater would stimulate biodegradation by supplying an additional reservoir of oxygen to be used to biodegrade less volatile fuel hydrocarbons.

APPENDIX F
CHEMICAL PROFILES

BENZENE

CAS NUMBER

71-43-2

COMMON SYNONYMS

None.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 1,791 mg/L [1]

Vapor Pressure: 95.19 mm Hg at 25°C [1]

Henry's Law Constant: 5.43×10^{-3} atm-m³/mole (temperature not given) [1]

Specific Gravity: 0.879 at 15/5°C [2]

Organic Carbon Partition Coefficient: 31 - 143 [1]

FATE DATA: HALF-LIVES

Soil: 5 - 16 days [3]

Air: 2.09 - 20.9 days [3]

Surface Water: 5 - 16 days [3]

Groundwater: 10 days to 2 years [3]

NATURAL SOURCES

Crude oil, volcanoes, forest fires, plants [1].

ARTIFICIAL SOURCES

Gasoline, fuel oils, chemical industry, coke ovens, mining, manufacturing, cigarette smoke [1].

FATE AND TRANSPORT

Benzene will rapidly volatilize from surface soil and water. That which does not volatilize from permeable surface and subsurface soils will be highly to very highly mobile, and can be expected to leach to nearby groundwater which is not protected by a confining layer. It is fairly soluble, and will be carried with the groundwater to discharge points. It may be subject to biodegradation in soils, shallow groundwater, and surface water. Benzene will not be expected to significantly adsorb to sediment, bioconcentrate in aquatic organisms, or hydrolyze. Photodegradation may be a significant removal mechanism in surface waters which are not conducive to microbial degradation. Benzene will undergo significant photodegradation in air, but may be washed out with rain [1].

HUMAN TOXICITY

General. Benzene is absorbed into the body following ingestion, inhalation, and dermal contact, and must undergo metabolic transformation to exert its toxic effects. Metabolism occurs primarily in the liver, and to a lesser extent in the bone marrow [4]. The primary targets of benzene toxicity are the central nervous system and the blood [4,5]. Benzene is genotoxic to humans and the USEPA has placed it in weight-of-evidence cancer Group A, indicating that it is a human carcinogen [6].

Oral Exposure. A chronic oral RfD for benzene is currently under review by the USEPA [6]. Benzene is readily absorbed following oral exposure. The lowest reported fatal dose in humans is 50 mg/kg [5]. Acute oral LD₅₀ values in animals include 930 to 5600 mg/kg in rats, 2000 mg/kg in dogs and 4700 mg/kg in mice [4,5]. Data regarding the ingestion of benzene in humans are limited to acute overexposure. Ingestion of 2 ml (29 mg/kg) has resulted in depression of the central nervous system, while ingestion of 10 ml (143 mg/kg) has been fatal [5]. The cause of death was usually respiratory arrest, central nervous system depression or cardiac collapse [4]. In animals, longer-term oral exposure has resulted in toxic effects on the blood (cytopenia: decrease in various cellular elements of the blood) and the immunological system (decreased white blood cells) [4]. There is no evidence that oral exposure to benzene causes effects on reproduction and development, but studies in animals suggest that benzene may affect fetal development [4]. There is no information regarding carcinogenic effects in humans following oral exposure to benzene, but studies in animals indicate that benzene ingestion causes cancer in various regions of the body [4]. An oral Slope Factor of $0.029 \text{ (mg/kg/day)}^{-1}$ is based on an increase in the incidence of leukemia in occupationally-exposed workers [6]. The oral Slope Factor was extrapolated from the inhalation data.

Inhalation Exposure. A chronic inhalation RfC for benzene is currently under review by the USEPA [6]. Benzene is readily absorbed following inhalation exposure. The lowest reported fatal concentration in humans is 6380 mg/m³ for a 5 minute exposure [5]. Acute inhalation LC₅₀ values in rats ranged from 10,000 ppm for 7 hours to 13,700 ppm for 4 hours [4,5]. Most of the available data regarding benzene exposure involve workers exposed in the workplace. The acute effects of benzene exposure involve the central nervous system. Brief exposure to concentrations of 700 to 3000 ppm can cause drowsiness, dizziness, headaches and unconsciousness, and exposure to concentrations of 10,000 to 20,000 ppm can result in death [4]. In most cases, the effects will end when exposure ceases. The hematopoietic system is the primary target of toxicity following long-term exposure: exposure for several months to years results in pancytopenia (reduction in red blood cells, platelets and white blood cells), while continued exposure for many years results in anemia or leukemia. The lowest concentration resulting in the hematological effects is approximately 10 to 50 ppm [5]. Benzene has been shown to cause chromosomal aberrations in bone marrow and lymphocytes in workers exposed to concentrations > 100 ppm [5]. Chromosomal damage has been found in animals at concentrations as low as 1 ppm [5]. Benzene is not known to be teratogenic (cause birth defects) in humans, but has been found to cause various problems in the developing fetus of animals (low birth weight, delayed

bone formation) [4,5]. Occupational exposure to benzene has resulted in leukemia in exposed workers [4,5]. An inhalation Unit Risk of $8.3 \times 10^{-6} (\text{ug}/\text{m}^3)^{-1}$ is based on the incidence of leukemia in occupationally-exposed workers [6].

Dermal Exposure. Dermal exposure to benzene may cause redness and dermatitis [4,5]. Systemic effects have not been reported following dermal exposure to benzene.

REFERENCES

1. Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.
2. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
4. ATSDR, 1991. Toxicological Profile for Benzene (Draft). Agency for Toxic Substances and Disease Registry. USPHS/USEPA. October 1991.
5. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 2. Cambridge, MA. July 1989.
6. USEPA, 1994. Integrated Risk Information System (IRIS). Data base. Online. February, 1994.

TOLUENE

CAS NUMBER

108-43-2

COMMON SYNONYMS

Methylbenzene.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 534.8 mg/L at 25°C [1]

Vapor Pressure: 28.4 mm Hg at 25°C [1]

Henry's Law Constant: 5.94×10^{-3} atm-m³/mole (temperature not given) [1]

Specific Gravity: 0.866 at 20/4°C [2]

Organic Carbon Partition Coefficient: 37 to 178 [1]

FATE DATA: HALF-LIVES

Soil: 4 to 22 days [3]

Air: 10 hours to 4.3 days [3]

Surface Water: 4 to 22 days [3]

Groundwater: 1 to 4 weeks [3]

NATURAL SOURCES

Volcanoes, forest fires, and crude oil [1].

ARTIFICIAL SOURCES

Gasoline, fuel oils, automobile exhaust, chemical industry, paints and lacquers [1].

FATE AND TRANSPORT

Much of the toluene released to surface soil will be lost to volatilization. It is mobile in soils and will leach to groundwater. Biodegradation occurs slowly in soil and groundwater, but is inhibited by high concentrations. Under ideal conditions of low concentration and acclimated microbial populations, rapid biodegradation may occur. Losses from surface water occur due to volatilization and biodegradation. It will not significantly adsorb to sediment or bioconcentrate in aquatic organisms. In the atmosphere it will degrade or be washed out with rain [1].

HUMAN TOXICITY

General. Toluene acts primarily on the central nervous system [4]. The USEPA has placed toluene in weight-of-evidence Group D; that is, it is not classifiable as to human carcinogenicity [5].

Oral Exposure. A chronic RfD of 0.2 mg/kg/day is based on a NOAEL of 223 mg/kg/day for changes in liver and kidney weights in a subchronic oral study in rats. The LOAEL in this study was a dose of 446 mg/kg/day [5]. Toluene is absorbed more slowly from the gastrointestinal tract than from the lungs [6]. The acute oral LD₅₀ for adult rats is in the range of 5,000 to 7,300 mg/kg [4,6]. Brain damage was noted in mice receiving 1,250 mg/kg/day by gavage for 13 weeks [6].

Inhalation Exposure. The RfC of 0.4 mg/m³ is based on a LOAEL of 88 ppm for central nervous system effects observed in humans following inhalation exposure [5]. Toluene is rapidly absorbed following inhalation by humans and animals [6]. The inhalation LC₅₀ in mice is 5,300 ppm for an 8-hour exposure. Exposure of humans by inhalation to 200 ppm for 8 hours produced mild fatigue, weakness, confusion, lacrimation, and tingling of the skin. At 600 ppm, additional effects included euphoria, headache, dizziness, dilated pupils, convulsions, and nausea. After 8 hours at 800 ppm, symptoms were more pronounced; effects included nervousness, muscular fatigue, and insomnia persisting for several days. Exposure to concentrations of 10,000 to 30,000 ppm could lead to narcosis and death. Chronic abusive inhalation of toluene vapors by humans produces central nervous system impairment and emotional and intellectual disturbances. Uptake in the various brain regions is widespread due to the high lipid solubility of toluene and the high lipid content of the brain. Effects on animals following high levels of exposure include hearing loss, kidney effects, and lung lesions. High level oral intake by animals has resulted in weight increases in the liver and kidney, and brain tissue damage [4].

Dermal Exposure. The absorption of toluene through human skin is slow, falling within the range of 14 to 23 mg/cm²/hour. Dermal contact with toluene by humans may cause skin damage. Application of toluene to the eyes of rabbits reportedly resulted in moderately severe injury [6].

REFERENCES

1. Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.
2. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
4. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 2. Cambridge, MA. July 1989.
5. USEPA, 1994. Integrated Risk Information System (IRIS). On-line data base. February, 1993.

6. ATSDR, 1989. Toxicological Profile for Toluene. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1989.

ETHYLBENZENE

CAS NUMBER

100-41-4

COMMON SYNONYMS

None noted.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 161 mg/l at 25°C [1]

Vapor Pressure: 9.53 mm Hg at 25°C [1]

Henry's Law Constant: 8.44×10^{-3} atm-m³/mole [1]

Specific Gravity: 0.87 at 25/25°C [2]

Organic Carbon Partition Coefficient: 871 [1]

FATE DATA: HALF-LIVES

Soil: 3 to 10 days [3]

Air: 8.56 hours to 3.57 days [3]

Surface Water: 3 to 10 days [3]

Groundwater: 6 to 228 days [3]

NATURAL SOURCES

Coal tar and petroleum [4].

ARTIFICIAL SOURCES

Manufacture of styrene, solvent, petroleum refining, vaporization/spills of gasoline and diesel fuel, auto emissions, paints, inks, insecticides, and cigarette smoke [1,2,4].

FATE AND TRANSPORT

Ethylbenzene released to surface soils will probably undergo partial volatilization and, given its limited ability to sorb to soils ($K_{oc} = 871$), leach to groundwater. Evidence suggests that this material undergoes biodegradation in groundwaters, and may do so in soils if the initial loading doesn't prove toxic to soil-based microorganisms. If released to surface waters, ethylbenzene is expected to volatilize fairly readily. As with groundwaters, rapid biodegradation can be predicted after an initial acclimation period. Ethylbenzene shows only a slight to moderate tendency to adsorb to soils and sediments in waters. Bioconcentration in aquatic organisms is not expected to be significant (BCF for ethylbenzene = 145). Ethylbenzene is expected to exist in the atmosphere primarily as a vapor, based upon its vapor pressure value (9.53 mm Hg). Principally,

ethylbenzene will be removed from the atmosphere via reaction with hydroxyl radicals; some washout via rainfall may be expected. [1]

HUMAN TOXICITY

General. Humans exposed to ethylbenzene may experience eye and throat irritation, decreased movement, and dizziness. Studies in animals have shown liver and kidney damage, nervous system changes, and blood changes [4]. The USEPA has placed ethylbenzene in weight-of-evidence group D, indicating that it is not classifiable as to human carcinogenicity [5].

Oral Exposure. A chronic RfD of 0.1 mg/kg/day is based on a NOEL of 97.1 mg/kg/day and a LOAEL of 291 mg/kg/day determined for liver and kidney toxicity in a rat subchronic to chronic oral bioassay [5]. Studies in animals revealed that ethylbenzene is quickly and effectively absorbed following oral exposure. The oral (gavage) LD₅₀ in rats is reported to be 4,728 mg/kg. No information was located regarding death or health effects in humans following oral exposure [4].

Inhalation Exposure. The RfC of 1 mg/m³ is based on a NOAEL of 434 mg/m³ determined for developmental toxicity in rats and rabbits exposed via inhalation [5]. Ethylbenzene is rapidly and efficiently absorbed via inhalation in humans and animals. A 4-hour LC₅₀ of 4,000 ppm was reported for rats. Exposure-related adverse effects in animals included those to liver and kidney, eye irritation, profuse lacrimation, CNS depression and ataxia. No deaths were reported for humans following inhalation of ethylbenzene. The effects observed in humans included pulmonary and ocular irritation, profuse lacrimation, chest constriction, dizziness, vertigo, and possible hematological alterations. Exposure of pregnant rats to levels above 138 ppm for 24 hours/day for 9 days had adverse developmental effects [4].

Dermal Exposure. Liquid ethylbenzene is rapidly absorbed through the skin; however, absorption of vapors through the skin is minimal. The dermal LD₅₀ in rabbits for liquid ethylbenzene was reportedly 15,415 mg/kg. Ethylbenzene appears to be a slight eye irritant in rabbits [4].

REFERENCES

1. Howard, P.H., 1989. Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Volume I: Large Production and Priority Pollutants. Lewis Publishers, Inc. Chelsea, MI. 574 pp.
2. Merck, 1989. The Merck Index, Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers, Inc. Chelsea, MI. 725 pp.
4. ATSDR, 1990. Toxicological Profile for Ethylbenzene. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1990.
5. USEPA, 1992. INTEGRATED RISK INFORMATION SYSTEM (IRIS). ON-LINE DATA BASE. AUGUST 3, 1992.

XYLENES

CAS NUMBER

1330-20-7

COMMON SYNONYMS

Xylene.

Note: There are three isomers (forms) of xylene: ortho, meta, and para, also known as 1,2-, 1,3-, and 1,4-xylene, respectively.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: 146 - 175 mg/L at 25°C [1]

Vapor Pressure: 6.6 - 8.7 mm Hg at 25°C [1]

Henry's Law Constant: 5.1×10^{-3} to 7.7×10^{-3} atm-m³/mole at 25°C [2]

Specific Gravity: 0.880 at 20/4°C (*o*-xylene) [3]

Organic Carbon Partition Coefficient: 25.4 - 204 [1]

FATE DATA: HALF-LIVES

Soil: 1 - 4 weeks [4]

Air: 2.6 hours - 1.8 days [4]

Surface Water: 1 - 4 weeks [4]

Groundwater: 2 weeks - 1 year [4]

NATURAL SOURCES

All three isomers of xylene occur in petroleum. 1,2-Xylene is found additionally in coal tar, forest fire products, and plants [1].

ARTIFICIAL SOURCES

Gasoline, fuel oils, and their combustion products. Petroleum refining, chemical industry; aerosols of paints, varnishes, and shellacs. Wood-burning stoves and fireplaces [1].

FATE AND TRANSPORT

Xylenes are moderately mobile in soil and may leach to groundwater where they are known to persist for several years despite evidence of biodegradation in both soil and groundwater. The dominant removal process in surface water is volatilization, but this is not a rapid process. Some adsorption to sediment will occur. Once released to the atmosphere, xylenes will undergo photochemical degradation at a moderate rate [1].

HUMAN TOXICITY

General. The primary target of xylenes toxicity is the central nervous system [2,5]. Xylenes are considered to be nongenotoxic. The USEPA has placed xylenes in weight-of-evidence cancer Group D, indicating that they are not classifiable as to human carcinogenicity [6].

Oral Exposure. A chronic oral RfD of 2 mg/kg/day is based on a NOAEL of 250 mg/kg/day for hyperactivity, decreased body weight and increased male mortality in a chronic study in rats [6]. Acute oral LD₅₀ values for xylenes ranged from 3523 to 8600 mg/kg in rats and 5251 to 5627 mg/kg in mice [2,5]. Death in humans has been reported following the ingestion of xylenes, but the fatal dose is not known [2]. Reports of the ingestion of xylenes in humans are generally lacking. In animals, oral exposure to xylenes results in effects on the liver (increased liver enzymes and weight), the kidneys (increased kidney weight), and the nervous system (impairment of visual function, hyperactivity) [4]. Information is not available regarding the effects of ingested xylene on reproduction or development in humans, and the results of developmental studies in animals are inconclusive [2]. There is no conclusive evidence that oral exposure to xylenes causes cancer in humans or animals, therefore, an oral slope factor is not available [6].

Inhalation Exposure. An inhalation RfC for mixed xylenes is considered non-verifiable by the USEPA [7]. Xylenes are readily absorbed following inhalation exposure. Acute inhalation LC₅₀ values of 6350 to 6700 ppm (4-hour exposure) were reported in rats for mixed xylenes [2]. LC₅₀ values for the separate isomers are comparable to the mixture. Cause of death was usually respiratory failure and/or sudden ventricular fibrillation. In humans, inhalation of approximately 10,000 ppm xylenes has been fatal [2]. Exposure of humans to 90 ppm xylene has produced impairment of reaction time, manual coordination and body balance [5]. Brief exposure to concentrations of 200 ppm has caused irritation of the eyes, nose and throat, and exposure to concentrations above 200 ppm has resulted in nausea, vomiting, abdominal pain and loss of appetite [5]. Long-term high-level occupational exposure to xylenes (> 200 ppm) has resulted in central nervous system effects, incoordination, nausea, vomiting, and abdominal pain [5]. Studies in laboratory animals suggest that xylenes have a relatively low chronic toxicity. Some data in animals suggest possible kidney and liver impairment with high level inhalation exposures (>1000 ppm) [5]. Information regarding the effects of xylenes on human reproduction and development are not available, but teratogenicity, fetotoxicity, and maternal toxicity have been observed in animals [2,5]. Xylenes have been found to cross the human placenta, therefore, there is sufficient reason for concern for pregnant women who are exposed to xylenes [2,5]. It is not known whether inhaled xylenes cause cancer in humans or animals, therefore, an inhalation unit risk is not available [6].

Dermal Exposure. Acute dermal LD₅₀ values in rabbits of 14.1 ml/kg and greater than 5.0 ml/kg are reported for m-xylene and mixed xylenes, respectively [5]. Xylene is a skin irritant and causes redness, defatting and dryness. Vesicles may form following prolonged skin contact [2,5].

ECOLOGICAL TOXICITY

General. Xylenes are not a priority pollutant because they have low acute and chronic toxicity. Xylenes move through the soil/groundwater system when present at low concentrations, dissolved in water and adsorbed on soil, or as a separate organic phase resulting from a spill of significant quantities. Xylenes readily volatilize from water, are moderately adsorbed on soil, and have a moderate potential for bioaccumulation [8]. No information on biomagnification of xylenes was available in the technical literature.

Vegetation. Nearly all xylenes (98.8 percent) are expected to be sorbed into the soil. For the portion of xylenes in the gaseous phase of soil (0.5 percent), diffusion through the soil/air pores up to the ground surface and removal by wind will be a significant loss pathway [8]. Review of the technical literature did not produce information regarding the phytotoxic effects of xylenes.

Aquatic Life. The half-life of xylenes in surface water has been calculated as 2.6 to 11.2 days [9]. Under normal environmental conditions, xylenes are not expected to undergo hydrolysis because they contain no hydrolyzable functional groups [8]. The LC₅₀ value for freshwater fish was approximately 30 mg/L [9]. The 96-hour LC₅₀ values for fathead minnows were 26.7 mg/L in soft water and 28.8 mg/L in hard water [10]. The 96-hour LC₅₀ for bluegills was 20.9 mg/L in soft water [10]. There are no federal or state water quality standards established to protect aquatic life [11].

Wildlife. Xylenes are considered to be of low acute and chronic toxicity to birds and mammals [12]. No changes were found in rats, guinea pigs, dogs, and monkeys continuously exposed to 80 ppm for 127 days, nor in rats exposed to 700 ppm for 130 days [8]. Japanese quail showed no signs of toxicity at oral concentrations of 5,000 to 20,000 ppm (approximately 600 to 2,400 mg/kg body weight) [9]. Mallard eggs were immersed in xylene (10%) for 30 seconds and no significant effects on embryonic weight and length were observed when compared to controls [13]. Arthur D. Little, Inc. [8] reported an oral LD₅₀ for rats at 4,300 mg/kg.

REFERENCES

1. Howard, P.H., 1990. Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.
2. ATSDR, 1990. Toxicological Profile for Total Xylenes. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1990.
3. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
4. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
5. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 2. Cambridge, MA. July 1989.
6. USEPA, 1994. Integrated Risk Information system (IRIS). Data base. Online. February, 1994.

7. USEPA, 1993. Health Effects Assessment Summary Tables (HEAST). Office of Emergency and Remedial Response. OHEA ECAO-CIN-909. March, 1993.
8. Arthur D. Little, Inc., 1985. The Installation Restoration Program Toxicology Guide. Volume 1. Cambridge, MA.
9. CH2M Hill, Inc., 1989. Preliminary Endangerment Assessment for Lowry Landfill. Prepared for USEPA. Denver, Colorado.
10. Sax, N.I. (ed.), 1984. Dangerous Properties of Industrial Materials. 6th ed. Van Nostrand Reinhold, New York. p 2728.
11. USEPA, 1991. Water Quality Criteria Summary. Washington, D.C.
12. Clement Associates, Inc., 1985. Chemical, Physical, and Biological Properties of Compounds Present at Hazardous Waste Sites. Prepared for USEPA. September 27, 1985.
13. Micromedex, Inc., 1992. Toxmes Plus System. Toxicology, Occupational Medicine and Environmental Series. Volume 14. Denver, Colorado.

NAPHTHALENE

2-METHYLNAPHTHALENE

GENERAL

There is relatively little information available on 2-methylnaphthalene as compared to naphthalene. Therefore, all information below refers to naphthalene unless explicitly stated otherwise.

CAS NUMBERS

Naphthalene: 91-20-3
2-Methylnaphthalene: 91-57-6

COMMON SYNONYMS

Naphthalene: Naphthene, Tar Camphor.
2-Methylnaphthalene: Beta-methylnaphthalene

ANALYTICAL CLASSIFICATION

Semi-Volatile Organic.

PHYSICAL AND CHEMICAL DATA

	<u>Naphthalene</u>	<u>2-Methylnaphthalene</u>
Water Solubility (mg/L at 20°C) [1]	31.7	ND
Vapor Pressure (mm Hg at 25°C) [1]	0.087	ND
Henry's Law Constant (atm-m ³ /mole) [1]	4.6 x 10 ⁻⁴	ND
Specific Gravity (20/4°C) [1]	1.145	1.0058
Organic Carbon Partition Coefficient [1]	933	ND

FATE DATA: HALF-LIVES

Soil: 16.6 to 48 days [2]
Air: 2.96 to 29.6 hours [2]
Surface Water: 12 hours to 20 days [2]
Groundwater: 1 to 288 days [2]

NATURAL SOURCES

Crude oil; natural, uncontrolled combustion (i.e., forest fires) [3,4].

ARTIFICIAL SOURCES

Naphthalene: Petroleum refining, mothball use and manufacture, coal tar distillation, pitch fumes, chemical intermediate (i.e., phthalic anhydride manufacture), vehicle emissions, combustion processes (i.e., refuse combustion), tobacco smoke, and oil spillage [3,4].

2-Methylnaphthalene: Synthesis of organic compounds such as insecticides, and release from gasoline due to its use as an additive [1,5].

FATE AND TRANSPORT

Naphthalene's sorption to soil ranges from low to moderate, depending upon the organic carbon content of the soil, and will leach rapidly through sandy soils. Volatilization from the uppermost soil layer will be important, but will lessen in importance with soil depth. In addition, volatilization from moisture-saturated soil is not expected to be important. Biodegradation is expected to be rapid in soils previously contacted with other polycyclic aromatic hydrocarbons (PAHs), but slow in "virgin" soils [3].

Volatilization, photolysis, sorption (to suspended solids, sediments, etc.), and biodegradation are the primary removal mechanisms for naphthalene in waters. The actual predominant mechanisms change with variations in several factors (i.e., water flow rate, level of sediments/suspended soils, water clarity, etc.) In addition, biodegradation rates of naphthalene in water vary with changes in concentration of naphthalene (higher concentrations yield higher rates), "virgin" versus oil-polluted water (quicker in oil-polluted waters), actual pollution site (more rapid biodegradation in sediments than waters), aerobic versus anaerobic conditions (no biodegradation in anaerobic conditions), and so on. Bioconcentration in aquatic organisms is expected to be moderate, except for accelerated bioconcentration in organisms lacking an aryl hydroxylase enzyme system (i.e. phytoplankton, snails, mussels). Naphthalene in the atmosphere reacts during daylight hours with hydroxyl radicals, and during nighttime hours with nitrate radicals. Photolysis is also expected in the atmosphere [3].

HUMAN TOXICITY

General. The breakdown of red blood cells is the primary health concern for humans exposed to naphthalene. Human deaths following ingestion have occurred [1]. The USEPA has placed naphthalene in weight-of-evidence Group D, indicating that it is not classifiable as to human carcinogenicity [6]. The USEPA does not currently provide any toxicity values for 2-methylnaphthalene [6,7].

Oral Exposure. Both the chronic and subchronic RfDs for naphthalene of 0.04 mg/kg/day are based on a NOEL of 50 mg/kg/day for decreased body weight observed in a subchronic oral (gavage) study in rats [7]. Clinical evidence indicates that naphthalene is absorbed by humans in significant quantities via the oral route. The oral LD₅₀ reported for naphthalene in rats ranges from 2,200 to 2,400 mg/kg in rats [1]. The oral LD₅₀ reported for 2-methylnaphthalene in rats is 1,630 mg/kg [5]. Lethal doses of naphthalene in humans have ranged from as low as 74 mg/kg to as high as 574 mg/kg [1]. Ocular damage has been documented in humans and animals following oral exposure [1]. Symptoms of intoxication include: nausea, vomiting, headache, diaphoresis, hematuria, hemolytic anemia, fever, central nervous system depression, hepatic necrosis, jaundice, convulsions, and coma [1,2,8]. Administration of 300 mg/kg/day to pregnant mice resulted in a decrease in the number of live pups per litter [1].

Inhalation Exposure. An inhalation RfC was not reported for naphthalene [6,7]. Clinical reports suggest that inhaled naphthalene may be absorbed in sufficient quantity to produce adverse health effects in humans; however, no quantitative absorption data were located for humans or animals. One study, on rats, reported a NOAEL of 78 ppm for a 4-hour exposure. Symptoms and effects of inhalation exposure in humans include: headache, nausea, vomiting, abdominal pain, malaise, confusion, anemia, jaundice, and renal disease. No information was found regarding developmental and reproductive effects [1].

Dermal Exposure. Limited evidence in human infants indicated that hemolytic anemia may have resulted from dermal exposure to an unknown quantity of naphthalene. A NOAEL of 2,500 mg/kg was reported for rats. Naphthalene is a mild dermal and ocular irritant [1].

REFERENCES

1. ATSDR, 1990. Toxicological Profile for Naphthalene and 2-Methylnaphthalene. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. December 1990.
2. Howard, P.H.; Boethling, R.S.; Jarvis, W.F.; Meylan, W.M.; and Michalenko, E.M.; 1991. Handbook of Environmental Degradation Rates. Lewis Publishers, Inc. Chelsea, MI. 725 pp.
3. Howard, P.H., 1989. Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. I: Large Production and Priority Pollutants. Lewis Publishers, Inc. Chelsea, MI. 574 pp.
4. Merck, 1989. The Merck Index. Eleventh Edition. Merck & Company, Inc. Rahway, NJ.
5. Arthur D. Little, Inc., 1989. The Installation Restoration Program Toxicology Guide. Volume 4. Cambridge, MA. July 1989.
6. USEPA, 1993a. Integrated Risk Information System (IRIS). On-line data base. July, 1993.
7. USEPA, 1993b. Health Effects Assessment Summary Tables (HEAST). Office of Emergency and Remedial Response. OHEA ECAO-CIN-909. March 1993. (Information received via contact with the Superfund Technical Support Center).
8. National Institute for Occupation Safety and Health, 1991. Registry of Toxic Effects of Chemical Substances (RTECS), Volume I-III. United States Department of Health and Human Services. Cincinnati, OH.

POLYCYCLIC AROMATIC HYDROCARBONS

GENERAL

Polycyclic aromatic hydrocarbons (PAHs) are a large group of chemicals formed during the incomplete combustion of organic materials. There are over one hundred PAHs, and they are found throughout the environment in air, water, and soil. Seven of the 15 PAHs addressed in this profile are classified as probable human carcinogens [1,2].

CAS NUMBERS

Acenaphthene	83-32-9	Chrysene	218-01-9
Acenaphthylene	208-96-8	Dibenzo(a,h)anthracene	53-70-3
Anthracene	120-12-7	Fluoranthene	206-44-0
Benzo(a)anthracene	56-55-3	Fluorene	86-73-7
Benzo(a)pyrene	50-32-8	Indeno(1,2,3-cd)pyrene	193-39-5
Benzo(b)fluoranthene	205-99-2	Phenanthrene	85-01-8
Benzo(g,h,i)perylene	191-24-2	Pyrene	129-00-00
Benzo(k)fluoranthene	207-08-9		

COMMON SYNONYMS

Polynuclear aromatic hydrocarbons, PNAs, PAHs.

ANALYTICAL CLASSIFICATION

Semivolatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: insoluble to 3.93 mg/L [1]

Vapor Pressure: negligible to very low at 25°C [1]

Henry's Law Constant: 6.95×10^{-8} to 1.45×10^{-3} atm-m³/mole [1]

Specific Gravity: approximately 0.9 to 1.4 at 0 to 27°C [1]

Organic Carbon Partition Coefficient (K_{oc}): 2.5×10^3 to 5.5×10^6 [1]

FATE DATA: HALF-LIVES

Soil: 12.3 days to 5.86 years [3]

Air: 0.191 hours to 2.8 days [3]

Surface Water: 0.37 hours to 1.78 years [3]

Groundwater: 24.6 days to 10.4 years [3]

NATURAL SOURCES

Volcanoes, forest fires, crude oil, and oil shale [1].

ARTIFICIAL SOURCES

Motor vehicles and other petroleum fuel engines, wood-burning stoves and fireplaces, furnaces, cigarette smoke, industrial smoke or soot, and charcoal-broiled foods [1].

FATE AND TRANSPORT

Because the physical and chemical properties of PAHs vary substantially depending on the specific compounds in question, the fate and transport characteristics vary. Thus, the following discussion is presented in very general terms. Some fate characteristics are roughly correlated with molecular weight; so the compounds are grouped as follows [1]:

- Low molecular weight: acenaphthene, acenaphthylene, anthracene, fluorene, and phenanthrene;
- Medium molecular weight: fluoranthene and pyrene; and
- High molecular weight: benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

PAHs are present in the atmosphere in the gaseous phase and sorbed to particulates. They may be transported great distances, and are subject to photodegradation as well as wet or dry deposition [1].

PAHs in surface water are removed by volatilization, binding to particulates and sediments, bioaccumulation, and sorption onto aquatic biota. The low molecular weight PAHs have Henry's Law constants in the range of 10^{-3} to 10^{-5} atm-m³/mole, and would therefore be expected to undergo significant volatilization; medium molecular weight PAHs have constants in the 10^{-6} range; and high molecular weight PAHs have constants in the range of 10^{-5} to 10^{-8} . Half-lives for volatilization of benzo(a)anthracene and benzo(a)pyrene from water have been estimated to be greater than 100 hours. It has been reported that lower molecular weight PAHs could be substantially removed by volatilization under conditions of high temperature, shallow depth, and high wind. For example, anthracene was found to have a half-life for volatilization of 18 hours in a stream with moderate current and wind. In an estuary, volatilization and adsorption are the primary removal mechanisms for medium and high molecular weight PAHs, whereas volatilization and biodegradation are the major mechanisms for low molecular weight compounds. PAHs can bioaccumulate in plants and animals, but are subject to extensive metabolism by high-trophic-level consumers, indicating that biomagnification is not significant [1].

Potential mobility in soil is related to the organic carbon partition coefficient (K_{oc}). The low molecular weight PAHs have K_{oc} values in the range of 10^3 to 10^4 , which indicates a moderate potential to be adsorbed to organic material. Medium molecular weight compounds have values on the order of 10^4 , while high molecular weight compounds have values in the 10^5 to 10^6 range. The latter compounds, then, have a much greater tendency to adsorb and resist movement through soil. Volatilization of the lower molecular weight compounds from soil may be substantial. However, some

portion of PAHs in soil may be transported to groundwater, and then move laterally in the aquifer, depending on soil/water conditions [1].

HUMAN TOXICITY

General. Ingestion of, inhalation of, or dermal contact with PAHs by laboratory animals has been shown to produce tumors. Reports in humans show that individuals exposed by inhalation or dermal contact for long periods of time to mixtures of PAHs and other compounds can also develop cancer. However, the relationship of exposure to any individual PAH with the onset of cancer in humans is not clear [1]. The available RfDs and weight-of-evidence groups for the PAHs addressed in this profile are presented in Table 1. The available slope factors are presented below. No other toxicity values were available [2,4].

Oral Exposure. Indirect evidence suggests that benzo(a)pyrene may not be readily absorbed following oral exposure in humans. On the other hand, absorption in rats appears to be rapid and efficient. Whether or not there is actually a significant difference between humans and rats in the capacity to absorb benzo(a)pyrene is questionable. It should be noted that the degree of uptake is highly dependent on the vehicle of administration. A NOAEL of 150 mg/kg-day was determined for gastrointestinal, hepatic, and renal effects in rats following acute oral exposure to benzo(a)pyrene or benzo(a)anthracene. LOAELs in the range of 40 to 160 mg/kg-day were determined for developmental and reproductive effects in mice following acute oral exposure to benzo(a)pyrene [1]. An oral slope factor of $7.3 \text{ (mg/kg-day)}^{-1}$ for benzo(a)pyrene is based on tumors detected in the forestomachs of rats and mice in various diet studies [2].

Inhalation Exposure. The USEPA does not currently provide inhalation RfCs for any of the PAHs [2,4]. Pure PAH aerosols appear to be well absorbed from the lungs of animals. However, PAHs adsorbed to various particles appear to be poorly absorbed, if at all. The latter are most likely to be removed from the lungs by mucociliary clearance and subsequent ingestion. Lung cancer in humans has been strongly associated with long-term inhalation of coke-oven emissions, roofing-tar emissions, and cigarette smoke, all of which contain mixtures of carcinogenic PAHs. It has been estimated that the 8-hour time-weighted average exposure to PAHs in older coke plants was approximately 22 to 33 $\mu\text{g}/\text{m}^3$ [1]. An inhalation slope factor of $6.1 \text{ (mg/kg-day)}^{-1}$ for benzo(a)pyrene is based on tumors detected in the respiratory tracts of hamsters in a chronic intermittent inhalation study [4].

Dermal Exposure. Limited *in-vivo* evidence exists that PAHs are at least partially absorbed by human skin. An *in-vitro* study with human skin indicated that 3% of an applied dose of benzo(a)pyrene was absorbed after 24 hours. Studies in mice indicated that at least 40% of an applied dose of benzo(a)pyrene was absorbed after 24 hours. The carcinogenic PAHs as a group cause various noncancerous skin disorders in humans and animals. Substances containing mixtures of PAHs have been linked to skin cancers in humans. Studies in laboratory animals have demonstrated the ability of benz(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene to induce skin tumors [1].

TABLE 1
SELECTED TOXICITY DATA FOR PAHSA/

Compound	CAG Group ^{b/}	Oral RfD (mg/kg-day)	Species	Critical Effect	Experimental Doses (mg/kg-day)	Study Type ^{c/}
Acenaphthene	NR	0.06	Mouse	Hepatotoxicity	NOAEL: 175 LOAEL: 350	SC
Acenaphthylene	D	UR				
Anthracene	D	0.3	Mouse	None observed	NOEL: 1,000	SC
Benzo(a)anthracene	B2	0.3				
Benzo(a)pyrene	B2	NR				
Benzo(b)fluoranthene	B2	NR				
Benzo(g,h,i)perylene	D	NR				
Benzo(k)fluoranthene	B2	NR				
Chrysene	B2	NR				
Dibenzo(a,h)anthracene	B2	NR				
Fluoranthene	D	0.04	Mouse	Nephropathy, increased liver wt, hematol alter	NOAEL: 125 LOAEL: 250	SC
Fluorene	D	0.04	Mouse	Decreased RBC, packed cell vol, and hemoglobin	NOAEL: 125 LOAEL: 250	SC
Indeno(1,2,3-cd)pyrene	B2	NR				
Phenanthrene	D	NR				
Pyrene	D	0.03	Mouse	Renal tubular pathology, decreased kidney weights	NOAEL: 75 LOAEL: 125	SC

a/ From IRIS [2]. When IRIS values were unavailable, HEAST [4] values were used. RfD = reference dose, NR = not reported.

b/ CAG = USEPA Carcinogen Assessment Group. B2 = probable human carcinogen; D = not classifiable as to human carcinogenicity.

c/ SC = subchronic.

REFERENCES

1. ATSDR, 1990. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. Agency for Toxic Substances and Disease Registry. USPHS/USEPA. NTIS No. PB91-181537. December 1990.
2. USEPA, 1994. Integrated Risk Information System (IRIS). Online. Database.
3. Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko, 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.
4. USEPA, 1993. Health Effects Assessment Summary Tables (HEAST). Office of Emergency and Remedial Response. OHEA ECAO-CIN-821. March 1994.

1,2,4-TRIMETHYLBENZENE

CAS NUMBER

95-63-6

COMMON SYNONYMS

Pseudocumene.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: Insoluble

Vapor Pressure: NA

Henry's Law Constant: 5×10^{-3} atm-m³/mole [1]

Specific Gravity: 0.8761 at 20°C [1]

Organic Carbon Partition Coefficient: 2150 [1]

FATE DATA: HALF-LIVES

Soil: NA

Air: NA

Surface Water: NA

Groundwater: NA

NATURAL SOURCES

Naturally occurring in coal tar and petroleum products [1].

ARTIFICIAL SOURCES

Used in the manufacture of dyes, perfumes, and resins; used as a solvent and paint thinner [1].

FATE AND TRANSPORT

No information was found regarding the fate and transport of 1,2,4-trimethylbenzene (1,2,4-TMB).

HUMAN TOXICITY

General. The relevant routes of exposure to 1,2,4-TMB are via inhalation and potentially dermal contact. The CNS, respiratory system, and the liver are the primary targets of 1,2,4-TMB toxicity [1].

Oral Exposure. A chronic RfD for 1,2,4-TMB is currently not available from the USEPA [1]. Information regarding toxic effects in humans or animals following oral exposure to 1,2,4-TMB are not available [1].

Inhalation Exposure. A chronic inhalation RfC for 1,2,4-TMB is currently not available from the USEPA [1]. Information regarding toxic effects in humans or animals following inhalation exposure to 1,2,4-TMB are not available [1].

Dermal Exposure. 1,2,4-TMB is a known skin irritant [1]. No other information was located regarding dermal exposure to 1,2,4-TMB in humans or animals [1].

REFERENCES

1. USEPA, 1996. Hazardous Substance Data Base (HSDB). Online. Database.

1,3,5-TRIMETHYLBENZENE

CAS NUMBER

108-67-8

COMMON SYNONYMS

Mesitylene.

ANALYTICAL CLASSIFICATION

Volatile organic.

PHYSICAL AND CHEMICAL DATA

Water Solubility: Insoluble

Vapor Pressure: 1.86 mm Hg at 20°C [1]

Henry's Law Constant: 5×10^{-3} atm-m³/mole [1]

Specific Gravity: 0.8637 at 20°C [1]

Organic Carbon Partition Coefficient: 2150 [1]

FATE DATA: HALF-LIVES

Soil: NA

Air: NA

Surface Water: NA

Groundwater: NA

NATURAL SOURCES

Naturally occurring in coal tar and petroleum crudes [1].

ARTIFICIAL SOURCES

Used as a dyestuff intermediate, solvent, and paint thinner [1].

FATE AND TRANSPORT

No information was found regarding the fate and transport of 1,3,5-trimethylbenzene (1,3,5-TMB).

HUMAN TOXICITY

General. The relevant routes of exposure to 1,3,5-TMB are via inhalation and potentially dermal contact. The skin and lungs are the primary targets of 1,3,5-TMB toxicity [1].

Oral Exposure. A chronic RfD for 1,3,5-TMB is currently not available from the USEPA [1]. Information regarding toxic effects in humans and animals following oral exposure to 1,3,5-TMB are not available [1].

Inhalation Exposure. A chronic RfC for 1,3,5-TMB is currently not available from the USEPA [1]. Information regarding toxic effects in humans or animals following inhalation exposure to 1,3,5-TMB are not available [1].

Dermal Exposure. 1,3,5-TMB is a known skin irritant [1]. No other information was located regarding dermal exposure to 1,3,5-TMB in humans or animals [1].

REFERENCES

1. USEPA, 1996. Hazardous Substance Data Base (HSDB). Online. Database.