Remedial Action Plan for the Risk-Based Remediation of the KC-135 Crash Site

Wurtsmith Air Force Base
Michigan

Prepared For

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

and

Air Force Base Conversion Agency
Wurtsmith Air Force Base, Michigan

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DECISION DOCUMENT TO SUPPORT NATURAL ATTENUATION AS THE REMEDY FOR THE KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

SITE NAME AND LOCATION

Installation Restoration Program Site
KC-135 Aircraft Crash Site, RI designated site as SS-51
Wurtsmith Air Force Base
Oscoda, Michigan

STATEMENT OF PURPOSE AND BASIS

The purpose of the attached document is to recommend a preferred alternative for remedial action at the KC-135 Crash Site. This decision is based on the results of the Installation Restoration Program (IRP), including remedial investigations conducted in 1992 and 1994, and this remedial action plan (RAP) which supports the use of natural attenuation to reduce long-term risks at the site.

DESCRIPTION OF THE SELECTED REMEDY

Based on current conditions at the KC-135 Crash Site on Wurtsmith AFB, it has been determined that existing site conditions do not pose unacceptable to risks human health and the environment, and the preferred alternative will maintain this condition until natural attenuation mechanisms reduce contaminant concentration to levels below Michigan Department of Environmental Quality (MDEQ) Generic Industrial Cleanup Criteria.

DECLARATION

This attached RAP describes the selected remedial action for the KC-135 Crash Site and was prepared in accordance with the Installation Restoration Program (IRP) Handbook and the laws and regulations of the State of Michigan. It has been determined that the remedy, natural attenuation, will be protective of human health and the environment and meets applicable Federal and State requirements for site remediation. The protection of this remedy will be verified by long-term monitoring.

_____ _____

Paul Rekowski, U.S. Air Force Operating Location-T, Environmental Coordinator — *Date*

_____ _____

Diana Mally, USEPA BCT Member — *Date*

_____ _____

Bob Delaney, State of Michigan, BCT Member — *Date*

FINAL

REMEDIAL ACTION PLAN FOR THE RISK-BASED REMEDIATION OF THE KC-135 CRASH SITE

WURTSMITH AIR FORCE BASE

MICHIGAN

Prepared for

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

and

Wurtsmith Air Force Base
Michigan

December 1996

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SECTION 1

INTRODUCTION

1.1 PURPOSE AND BASIS

Parsons Engineering Science, Inc. (Parsons ES) was retained by the United States Air Force Center for Environmental Excellence (AFCEE) to prepare this Remedial Action Plan (RAP) for soil and groundwater contaminated with JP-4 fuel hydrocarbons at the KC-135 Crash Site at Wurtsmith Air Force Base (AFB), Oscoda, Michigan (the base). By virtue of its waiver of sovereign immunity, Congress has determined that the Air Force, as a department of the federal government, must comply with all cleanup obligations imposed by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA; 42, United States Code [USC] §9601). In addition, in the Defense Environmental Restoration Program (DERP) legislation (10 USC §2701), Congress created an independent obligation for facilities in the Department of Defense to clean up "hazardous substances, pollutants, and contaminants" and to do so consistent with CERCLA Section 120 (42 UCS §9620), "Federal Facilities." CERCLA requires "the President" to respond to releases of hazardous substances into the environment (42 USC §9604). In this case, the contaminants at the KC-135 Crash Site consists of petroleum products, a category excluded from the term "hazardous substance." The Air Force Installation Restoration Program (IRP) covers cleanups of contaminants not covered by the definition of "hazardous substance" in CERCLA. Thus, the KC-135 Crash Site, while not a CERCLA site, does come within the Air Force authority for cleanup under the IRP and DERP. Consequently, the purpose of this RAP is to develop and describe a recommended remedial action to be implemented at the KC-135 Crash Site which meets the substantive requirements of the IRP and DERP and the procedural and documentations requirements of Part 201 of Michigan's Natural Resources and Environmental Protection Act, 1994, Public Act 451 as amended in 1995 by House Bill 4596 [formerly the Michigan Environmental Response Act (MERA), 1982 Public Act 307].

The intent of the Air Force is to pursue a site-specific, risk-based remediation of the KC-135 Crash Site through the AFCEE-sponsored Risk-Based Approach Initiative. The Risk-Based Approach is the Air Force's strategy to combine the natural attenuation process with low cost source remediation technologies to minimize the migration of BTEX and potential risk. Other components of the Air Force's strategy are:

- Following well defined sampling objectives to support Intrinsic Remediation;
- Preferably evaluate only potentially complete pathways;

- Select clean-up goals that are established to achieve the desired risk reduction;
- Perform source reduction only if the site specific risk dictates; and
- Once any risk driven source reduction has been completed, recommend natural attenuation closure with l ng term monitoring.

The Air Force's strategy for developing and implementing cleanups at petroleum release sites is risk-based; that is, the remedy is to be designed to prevent unacceptable exposure of current and hypothetical future receptors to chemical contamination at and migrating from the release site. One major element of the risk-based strategy is to assess the potential for natural chemical attenuation processes to reduce contaminant mass, concentration, mobility, and toxicity. These natural chemical attenuation processes may effectively interrupt potential exposure pathways (e.g., by limiting migration), and may even be sufficient to reduce contaminant concentrations to appropriate health-protective cleanup levels. As part of the risk-based strategy, the Air Force can supplement, as necessary, the effects of natural chemical attenuation processes with other actions, such as low-cost source reduction and/or exposure controls. The Air Force's risk-based strategy is compatible with the purpose and basis of the IRP and DERP and applicable federal and state environmental statutes.

This RAP is prepared as part of a multi-site initiative sponsored by AFCEE to develop a standardized approach regarding how risk information and quantitative fate and transport calculations based on site-specific data can be integrated to determine the type and magnitude of remedial action required at fuel contaminated sites. The KC-135 Crash Site RAP is based on the generic industrial approach defined by the Michigan Department of Environmental Quality (MDEQ). This RAP documents that the exposure assumptions used to develop the generic industrial cleanup criteria are representative of, or exceed, the expected exposure at the site. The RAP also includes an assessment of the potential for off-site receptors to be exposed to site-related contamination.

Several remedial approaches that relied on both natural processes and engineered solutions were evaluated for the site. An exposure pathways analysis was completed for the KC-135 Crash Site to ensure that existing and predicted future concentrations of petroleum substances would not pose a threat to current and foreseeable future onsite and offsite receptors. This analysis demonstrates that no exposure pathway would be complete for onsite workers given current and future land and groundwater uses, and site-related contamination will not migrate beyond the current airfield boundaries at concentrations in excess of generic (i.e., not site-specific) residential cleanup criteria. This RAP documents that the recommended remedial approach would reduce petroleum constituent concentrations in groundwater to levels equal to or below MDEQ-defined generic industrial cleanup criteria within 8 years. Measured soil concentrations are already below MDEQ generic residential criteria.

The recommended remedy provides for the removal of petroleum constituents from the groundwater through the use of both natural biological and chemical processes (which are documented in accordance with applicable Michigan law and guidance [i.e., Natural Resources and Environmental Protection Act]). No engineered source

reduction is recommended to attain industrial cleanup criteria. This RAP has been submitted for review and approval consistent with Part 201 of the Natural Resources and Environmental Protection Act.

The activities conducted pursuant to the preparation of this RAP included focused site investigation activities and data analysis to characterize:

- The nature and extent of fuel hydrocarbon contamination at the site;
- The local geology, hydrogeology, and hydrology that may affect contaminant transport;
- The current and potential future uses of groundwater and exposure of receptors to other potentially impacted environmental media;
- The proximity of the site to drinking water aquifers, surface water, and other sensitive environmental resources;
- The expected persistence, mobility, chemical form, and fate of petroleum constituents in groundwater under the influence of natural physical, chemical, and biological processes; and
- The treatability of residual and dissolved fuel contamination using low-cost source reduction technologies such as bioventing and biosparging.

It is the intent of the Air Force to pursue a site-specific risk-based remediation of the KC-135 Crash Site. Even though petroleum constituents are currently present in groundwater at concentrations above generic industrial cleanup criteria, a site-specific exposure assessment demonstrates that existing concentrations do not pose a risk to current or future onsite workers because no actual exposure pathway is complete. This analysis also shows that no exposure pathway to offsite receptors has been or will be complete. A quantitative assessment of the expected performance of the recommended remedial action suggests that generic industrial cleanup criteria can be achieved at the site within 8 years.

1.1.1 Overview of MDEQ-Defined Types of Remedial Actions

Three levels of generic cleanup criteria, which are based on current and foreseeable land use, have been defined by MDEQ. These generic cleanup criteria are used to define the type of risk reduction activities or remedial actions that may be necessary at a site, given its long-term beneficial use. Generic residential cleanup criteria were developed using algorithms designed to be protective of human health within a residential setting and are the most protective generic cleanup criteria. Generic industrial cleanup criteria were developed to be protective of human health at an industrial site where the primary activities are of an industrial nature and access to the property is restricted. Generic commercial cleanup criteria have been developed to be protective of human health within a diverse range of exposure scenarios that could be encountered within commercial businesses.

A remedial action developed to be protective within a residential land use scenario is designed to provide a level of remediation at a site such that contaminant concentrations do not pose an unacceptable risk to human health and the environment on the basis of standardized exposure assumptions and acceptable risk levels for unrestricted-use sites. The exposure assumptions and target risk levels for these generic cleanup criteria are described in the provisions of Part 201 of Michigan's Natural Resources and Environmental Protection Act and illustrated in MDEQ (1996) Operational Memorandum #4, Revision 1. Health-based generic residential cleanup criteria were developed by MDEQ to protect against carcinogenic and noncarcinogenic human health effects as a result of exposure to contaminated soil and groundwater. Health-based cleanup criteria for carcinogens are calculated to be the concentration representing an increased cancer risk of one in one hundred thousand (10^{-5}). The increased cancer risk of one in one hundred thousand replaces the former target risk level of one in one million (10^{-6}). This change applies to all three generic cleanup criteria. Health-based cleanup criteria for noncarcinogens are calculated to be the concentration representing no adverse effects to humans, using the algorithms developed by the MDEQ. Health-based residential criteria for soil are calculated to protect against unacceptable risks from direct human contact with contaminants in soil and incidental ingestion of contaminated soil particulates. Potential risks through inhalation of volatilizing contaminants must be addressed separately. The inhalation Risk Based Screening Levels (RBSLs) are currently under development by MDEQ. Health-based residential criteria for groundwater are calculated to protect against unacceptable risks due to human ingestion.

Generic residential cleanup criteria also have been developed to minimize or eliminate adverse impacts to the environment or aesthetic qualities of natural resources. Generic residential cleanup criteria for soils were developed by MDEQ to assure that contamination in soils does not leach into and impact aquifer water quality (hereinafter referred to as residential leaching criteria). Generic residential cleanup criteria for groundwater also were developed by MDEQ to protect against adverse taste and odor effects (hereinafter referred to as the residential aesthetic criteria). MDEQ requires that the more restrictive of the health-based and aesthetic criteria that are applicable to a site be the preferred cleanup criteria for a residential remedy (MDEQ, 1996).

A generic industrial remedial action provides for a level of cleanup such that site-related contaminant concentrations do not pose an unacceptable risk on the basis of standardized exposure assumptions and acceptable risk levels for industrial sites, as provided for in Part 201 of the Natural Resources and Environmental Protection Act and MDEQ (1995a) Operational Memorandum #14, Revision 2. Generic industrial cleanup criteria are similar to residential criteria, except the types of receptors and intensity and frequency of exposure incorporated into the generic algorithms are different. Generic industrial criteria are calculated to protect site workers engaged in different types of activities. Generic industrial criteria are less stringent than generic residential criteria, because site workers will not be exposed to site-related contamination as much, as often, or in the same way that humans with unrestricted access to the site.MDEQ requires that the more restrictive of the health-based and aesthetic criteria be used as cleanup criteria for the industrial remedy (MDEQ, 1996).

1.1.2 Summary of Proposed Type of Cleanup

The site characterization data presented in this RAP show that existing site-related contaminant concentrations in soil are equal to or less than generic residential cleanup criteria. However, existing site-related contaminant concentrations in groundwater are greater than generic industrial cleanup criteria. The analysis conducted during this effort and included in this RAP indicates that concentrations of site-related fuel hydrocarbon compounds in groundwater at the KC-135 Crash Site does not pose an unacceptable risk to human health because no complete exposure pathway exists. Regardless of the lack of current health risk, the Air Force will pursue compliance with generic heath-based industrial cleanup criteria to ensure that no potential risk would exist under planned future industrial land use.

A quantitative fate and transport model simulation (using the Bioplume II code) developed specifically for the KC-135 Crash Site indicates that dissolved fuel hydrocarbon contaminants will not migrate beyond the southeastern edge of the runway, which is approximately 2,600 feet upgradient from the nearest Base property boundary. An assessment of the effects of natural physical, chemical, and biological processes operating at the site suggests that, without engineered activities, these processes will be sufficient to attain a industrial cleanup criteria for the entire site in approximately 8 years. Supplementing these natural processes with limited pumping or biosparging in the source area are options that were evaluated in this study and are discussed in Sections 7 and 8. Long-term compliance monitoring is proposed to confirm the effectiveness of the natural chemical attenuation processes at reducing contaminant mass and minimizing contaminant transport. Long-term compliance monitoring is necessary to confirm that the desired degree of remediation is being attained.

1.2 REPORT ORGANIZATION

This RAP consists of 10 sections, including this introduction, and 8 appendices. The remaining discussion in Section 1 is an overview of site background information. Section 2 summarizes the site characterization activities performed by Parsons ES in support of this RAP. Physical characteristics of the KC-135 Crash Site and the nature and extent of soil and groundwater contamination are described in Sections 3 and 4, respectively. Section 5 presents the proposed cleanup objectives and requirements for the site. Section 6 documents the effects of natural physical, chemical, and biological processes on site-related contaminants, and summarizes how these processes will affect groundwater contamination over time. Section 7 presents contaminant treatability pilot test results and evaluates source reduction technologies. Section 8 presents a comparative analysis of three candidate remedial alternatives. Section 9 is a more detailed implementation plan for the recommended remedial alternative, and a detailed long-term monitoring plan is presented in Section 10.

Appendix A contains the boring logs, well construction diagrams, and well development data for sampling activities completed in 1994. Appendix B presents soil gas, soil, and groundwater analytical results collected at the site (1992-1996). The aquifer test data and analyses are presented in Appendix C. Appendix D contains the quantitative calculations and fate and transport model results relevant to documenting

the effectiveness of natural physical, chemical, and biological processes on reducing the mass, mobility, and toxicity of site-related contaminants. Appendix E contains source reduction feasibility testing data and calculations. Chemical profiles for each contaminant evaluated as part of this RAP are included in Appendix F. Appendix G summarizes the screening and development of remedial alternatives considered in detail within this RAP. Appendix H presents a site-specific sampling and analysis plan (SAP) for use during long-term monitoring at the site.

1.3 SITE BACKGROUND

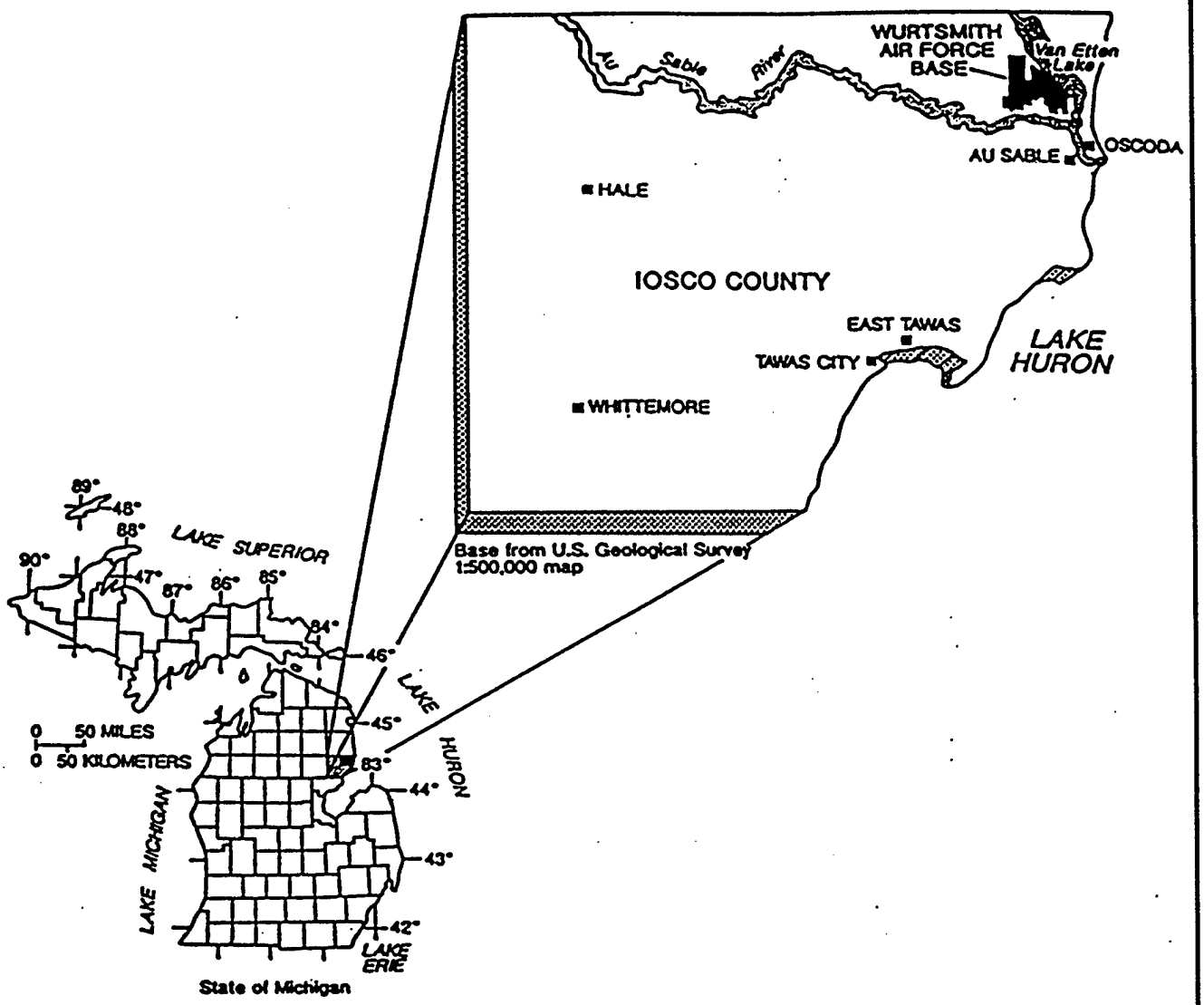
Wurtsmith AFB is located approximately 2 miles west of Oscoda, Michigan, within Iosco County (Figure 1.1). The Base is bounded on the north by Van Etten Lake, on the south by the Au Sable River and the Huron National Forest, on the east and the southeast by the cities of Oscoda and Au Sable, respectively, 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 man-made 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, Inc., 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

The KC-135 Crash Site is located in the western portion of the Base, approximately 600 feet north of the former Air Combat Command (ACC) instrument runway and 8,900 feet from the north end of the runway (Figure 1.2). A KC-135 aircraft crashed at the site during an attempted landing in October 1988. Approximately 3,000 gallons of JP-4 jet fuel were in the fuel tanks at the time of the crash. An unknown amount of fuel was consumed in the ensuing fire, and the remainder percolated into the ground.

1.3.2 Previous Remedial Investigations

The US Geological Survey (USGS) conducted an initial site investigation during March 1989. The study included a soil gas survey, which included 48 discrete sampling locations, and the installation of two groundwater monitoring wells (USGS-4 and USGS-7). Figure 1.3 shows the locations of monitoring wells used to characterize the site under previous investigations. The results of the soil gas survey indicated that JP-4 contamination in soil and groundwater was confined to an elongated area surrounding the crash location (USGS, 1989). The soil gas survey indicated that soil and groundwater immediately adjacent to and downgradient from the crash site were contaminated with fuel hydrocarbons. Light nonaquous phase liquid (LNAPL) was measured in both of the newly-installed monitoring wells between April 1989 and June 1991. From 1989 to 1991, LNAPL thickness ranged from a thin sheen to 1.58 feet in monitoring well USGS-4 and from a thin sheen to 1.31 feet in monitoring well USGS-7. No LNAPL was measured in these wells or in newly-installed monitoring wells during later site investigations.



Source: USGS, 1990.

FIGURE 1.1

REGIONAL MAP
KC-135 CRASH

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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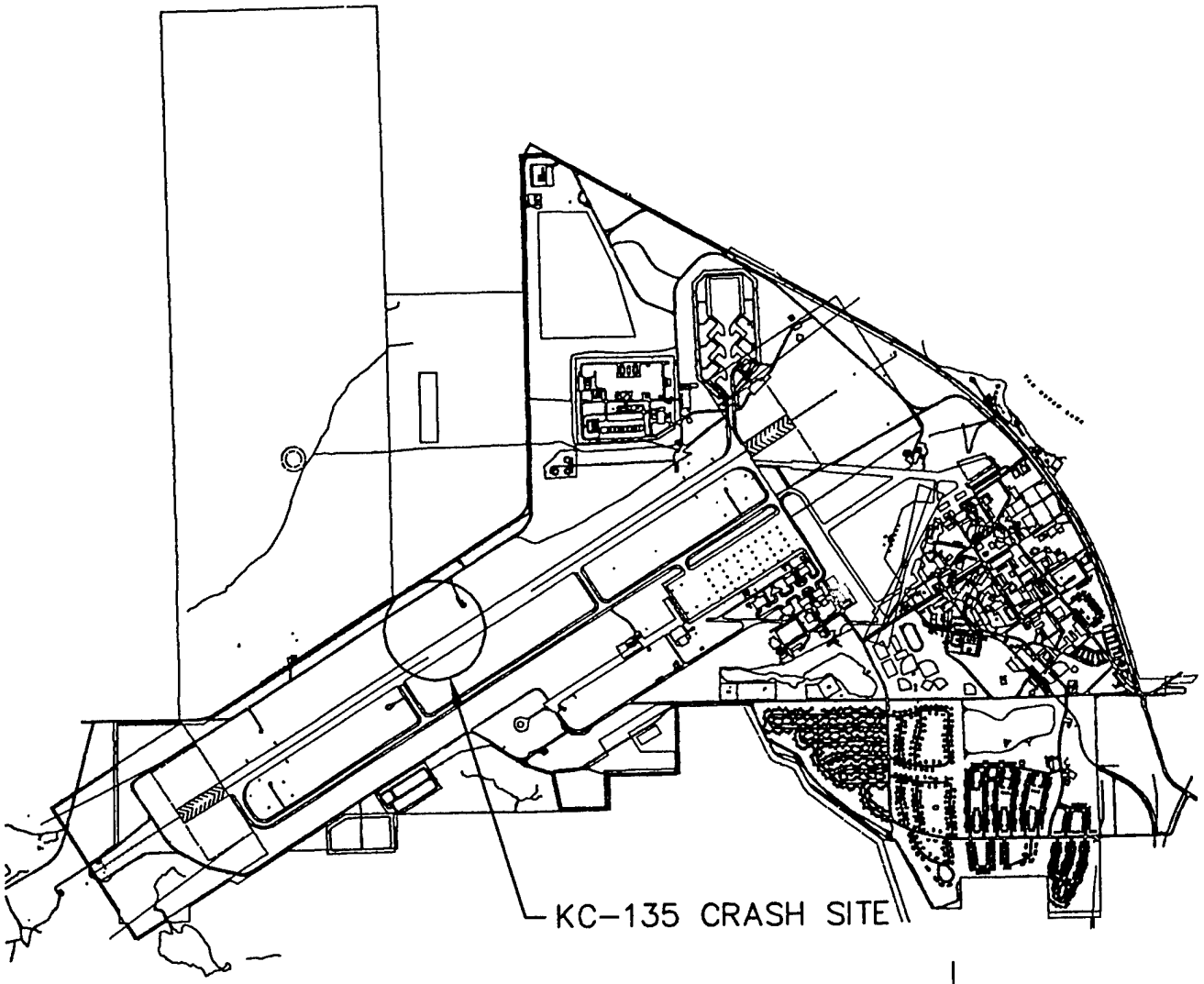

Not to Scale

FIGURE 1.2

LOCATION OF KC-135 CRASH SITE WITHIN WURTSMITH AFB

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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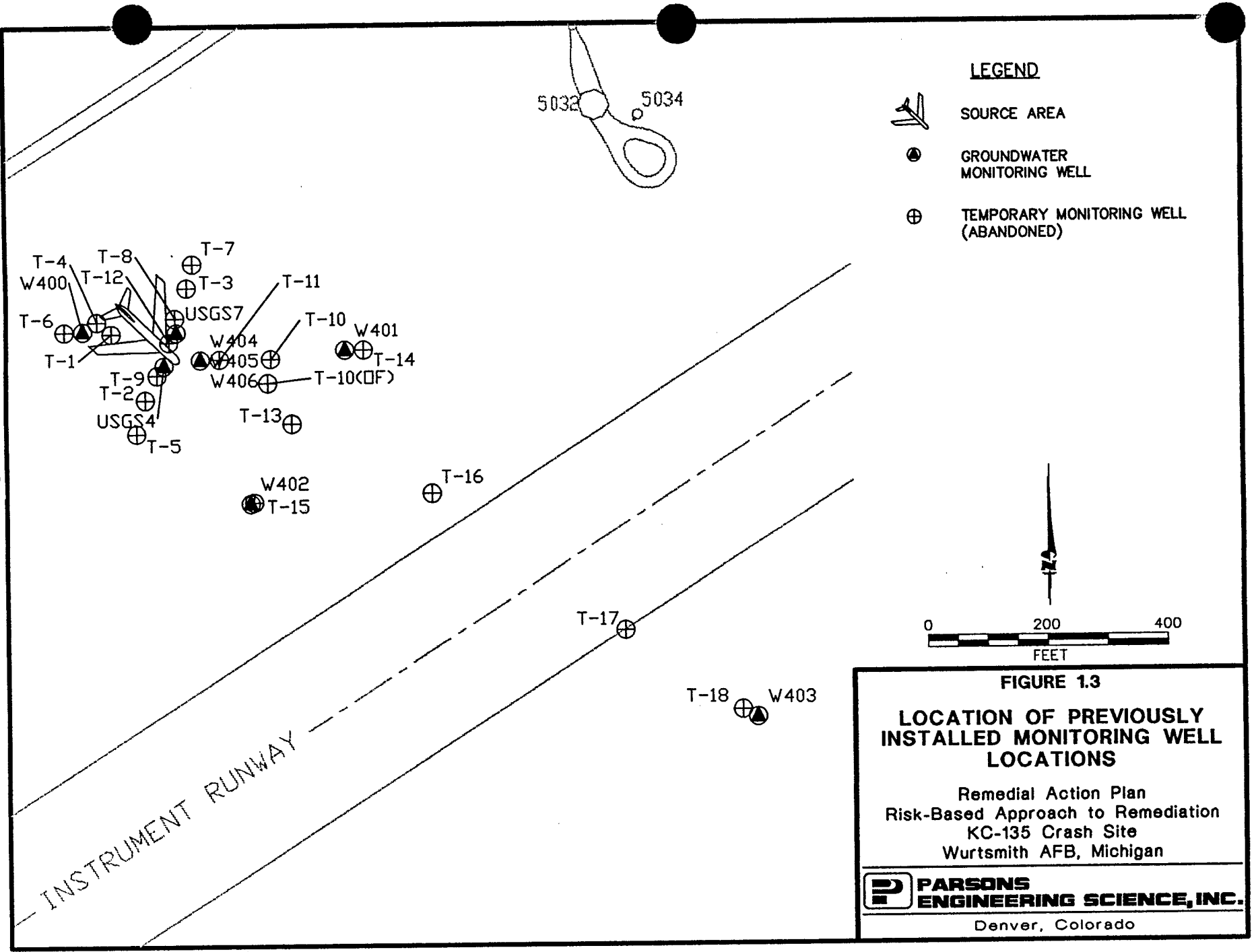

FIGURE 1.3

LOCATION OF PREVIOUSLY INSTALLED MONITORING WELL LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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A remedial investigation (RI) was conducted at the site from December 1992 through April 1993 to determine the vertical and horizontal extent of soil and groundwater contamination in support of developing a RAP for the site (WW Engineering & Science, 1993). Eighteen soil boreholes were drilled from the ground surface to the groundwater table and sampled for chemical analysis at 2.5-foot intervals. Temporary groundwater monitoring wells, which were screened across the groundwater surface, were installed in each of the eighteen soil boreholes and sampled for chemical analysis (wells T-1 through T-18). Additionally, seven permanent groundwater monitoring wells (five shallow wells and two deep wells) were installed and sampled (wells W400 through W406D). These data were collected to supplement the USGS investigation results.

Only one of the soil samples collected during the 1992 RI sampling event contained detectable concentrations of any of the target compounds. The soil sample collected from a depth of 5 to 7 feet below ground surface (bgs) at well T-1 was contaminated with 37 micrograms per kilogram (µg/kg) of total xylenes. This concentration is below the generic residential leaching criteria for soils of 5,600 µg/kg (MDEQ, 1995a). Benzene, toluene, and ethylbenzene were not detected in this or any other soil sample collected at the site during the RI. No polynuclear aromatic hydrocarbons (PAHs) were measured in any soil samples at concentrations above the reported method detection limit (WW Engineering & Science, 1993).

However, analytical results for groundwater samples indicated that dissolved benzene, toluene, ethylbenzene, and total xylenes (BTEX) had migrated at detectable concentrations to temporary monitoring well T-16, about 500 feet downgradient from the crash site. The maximum lateral extent of detected concentrations of BTEX compounds was determined to be about 100 feet. No BTEX or PAH compounds were detected in groundwater samples from well T-17, which is located approximately 400 feet downgradient from well T-16 and 900 feet downgradient from the crash site. Naphthalene was the only PAH compound detected in any groundwater samples collected and analyzed during the RI.

The maximum concentration of total BTEX measured in groundwater at the site was 16,300 micrograms per liter (µg/L) in a sample collected from well USGS-4 in early 1993. Benzene was detected at a concentration of about 500 µg/L at USGS-4 and at a concentration of 280 µg/L at well T-13, both of which are near the crash site. The concentration of benzene decreased to 26 µg/L at temporary well T-16, the furthest sampling point downgradient from the source area with detected concentrations of any BTEX compounds. All detected concentrations of benzene in groundwater at the site were above the residential health based/aesthetic drinking water criteria of 5 µg/L (i.e., benzene concentrations exceeded residential cleanup criteria at 7 of the 27 groundwater sampling locations). Toluene, ethylbenzene, and total xylenes also were measured at concentrations above their respective residential groundwater criteria at up to 4 of the 27 sampling locations.

Naphthalene was detected in groundwater samples in early 1993. The maximum measured concentration of naphthalene was 120 µg/L at USGS-4, which is below the health based/aesthetic drinking water residential cleanup criteria of 260 µg/L (MDEQ,

1996). Naphthalene also was detected at wells T-11, T-12, and W404S at concentrations of 20 µg/L, 5 µg/L, and 21 µg/L, respectively.

The RI report compared measured concentrations of the BTEX compounds and naphthalene in soils and groundwater to MDEQ-defined generic cleanup criteria. Based on this comparison, the RI report concluded that site-related contamination did not present a risk to human health through the air inhalation pathway or as a result of direct contact with contaminated soils. Potential adverse impacts from contaminants leaching from soils into groundwater and from groundwater migrating to and discharging into surface water bodies also were determined to be negligible. The RI report recommended that a feasibility study be conducted to evaluate potential remedial options for achieving remediation of groundwater at the KC-135 Crash Site.

Consequently, the focused site investigation and remedial alternatives analysis described in this RAP were designed to evaluate and recommend the type and magnitude of remedial action necessary to protect human health, safety, and welfare, as well as the environment and natural resources at and downgradient from the KC-135 Crash Site. This RAP specifically documents the effects of natural physical, chemical, and biological processes and low-cost source reduction technologies on contaminant persistence, mobility, mass, and toxicity over time at the site.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

To fully define the downgradient extent of JP-4 fuel hydrocarbons in groundwater and collect site-specific data documenting the effects of natural contaminant attenuation processes, a field investigation was conducted by Parsons ES at the KC-135 Crash Site in September through November 1994. Sufficient data were collected to conduct a quantitative fate and transport analysis, perform an exposure pathway analysis, and evaluate the potential treatability of contaminated media using low-cost remedial technologies and approaches. Emphasis was placed on filling data gaps identified during previous remedial investigations and on collecting data relevant to documenting the natural attenuation, specifically the bioattenuation, of JP-4 fuel hydrocarbons in soil and groundwater. In addition to the 1994 sampling event, analytical data for fuel hydrocarbon compounds in groundwater were conducted in December 1995 by the National Center for Integrated Bioremediation Research and Development (NCIBRD). Samples were collected at the KC-135 Crash Site from multi-level wells installed by NCIBRD. Although details of this sampling event are not provided herein, the analytical results are used in later sections of the RAP to verify trends in contaminant natural attenuation over time. These 1995 data are further supplemented by groundwater data collected in October 1996 at several permanent monitoring wells by Parsons ES.

2.1 SCOPE OF DATA COLLECTION ACTIVITIES

The 1994 field investigation focused on collecting data on the specific chemical constituents that may drive potential risks and impact the final remedial design for the KC-135 Crash Site. The chemicals of potential concern (COPC) for the KC-135 Crash Site were identified based on the RI results and the chemical composition of the known source, which is a release of JP-4 jet fuel to soils and groundwater resulting from an aircraft crash. JP-4 is an aircraft fuel consisting predominantly of C_5 through C_{14} hydrocarbons. The major hydrocarbon component categories (and their percentages by weight) in JP-4 are n-alkanes (32 percent), branched alkanes (31 percent), cycloalkanes (16 percent), benzenes and alkylbenzenes (18 percent), and naphthalenes (3 percent).

On the basis of the environmental behavior of each group of specific hydrocarbons and the results of previous site characterization activities at the KC-135 Crash Site, the COPCs identified and addressed as part of this study included the BTEX compounds and naphthalene. Analytical data on other PAH compounds also were collected to confirm the absence of these compounds in soils and groundwater at the site. All analytical data collected for these COPCs were obtained using fixed-base analytical methods. Analytical results for COPCs 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 reduction technologies also were collected.

The investigation activities completed at the KC-135 Crash Site during the risk-based remediation field test were 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 KC-135 Crash Site* (Parsons ES, 1994) (hereinafter referred to as the work plan). The following planned sampling and testing activities were performed by Parsons ES at the KC-135 Crash Site as part of this field test:

- Collection of soil gas samples at three locations;
- Drilling and installation of nine new permanent groundwater monitoring wells, one permanent nested groundwater monitoring well pair, and one soil borehole;
- Collection of 12 subsurface soil samples from 7 new soil boreholes for fixed-base analytical evaluation;
- Collection of 48 subsurface soil samples from 11 new soil boreholes for field screening; and
- Collection of 20 groundwater samples from different sampling locations for field and/or fixed-base analytical evaluation.

Figure 2.1 shows the soil gas sampling locations. Figure 2.2 shows the location of groundwater monitoring wells that were sampled and/or used for testing purposes during the 1994 and 1996 sampling events. Figure 2.3 shows the location of the multi-level wells installed and sampled by NCIBRD in December 1995. A descriptive summary of all of the field and fixed-base analytical methods used at the KC-135 Crash Site in 1994 and 1996 is presented in Table 2.1.

Pursuant to Michigan's Natural Resources and Environmental Protection Act and MDEQ supplemental guidance, analytical method detection limits (MDL) were considered before site characterization work was initiated under this risk-based remediation field test. Suitable analytical methods were selected and presented in the work plan (Parsons ES, 1994) to ensure that analytical results collected under this program could be compared to background levels and generic residential cleanup criteria. Fixed-base analytical methods used as part of this project were similar or identical to those used during the RI at the KC-135 Crash Site (WW Engineering & Science, 1993).

Table 2.1 identifies the analytical methods used for the different types of environmental samples collected under this program (i.e., 1994 and 1996). All fixed-base analytical methods used during this effort are identical to those recommended by MDEQ (1994c) in Operational Memorandum #6, Revision 3. This table also lists the laboratory-specified method detection limits (MDLs) and practical quantitation limits (PQLs) for each analytical method by analyte and environmental medium. The MDL is the lowest concentration at which a chemical can be measured and distinguished with

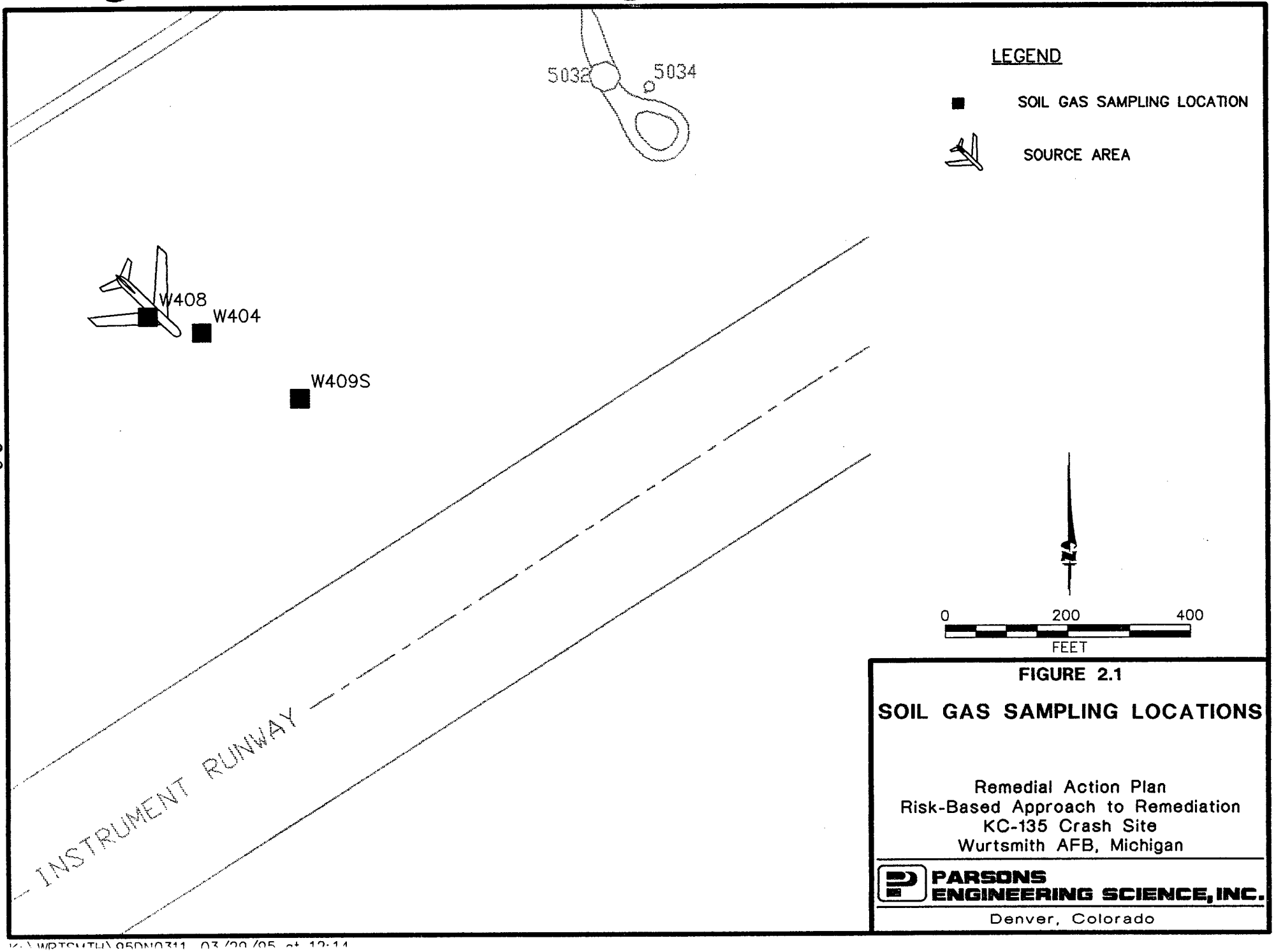

FIGURE 2.1

SOIL GAS SAMPLING LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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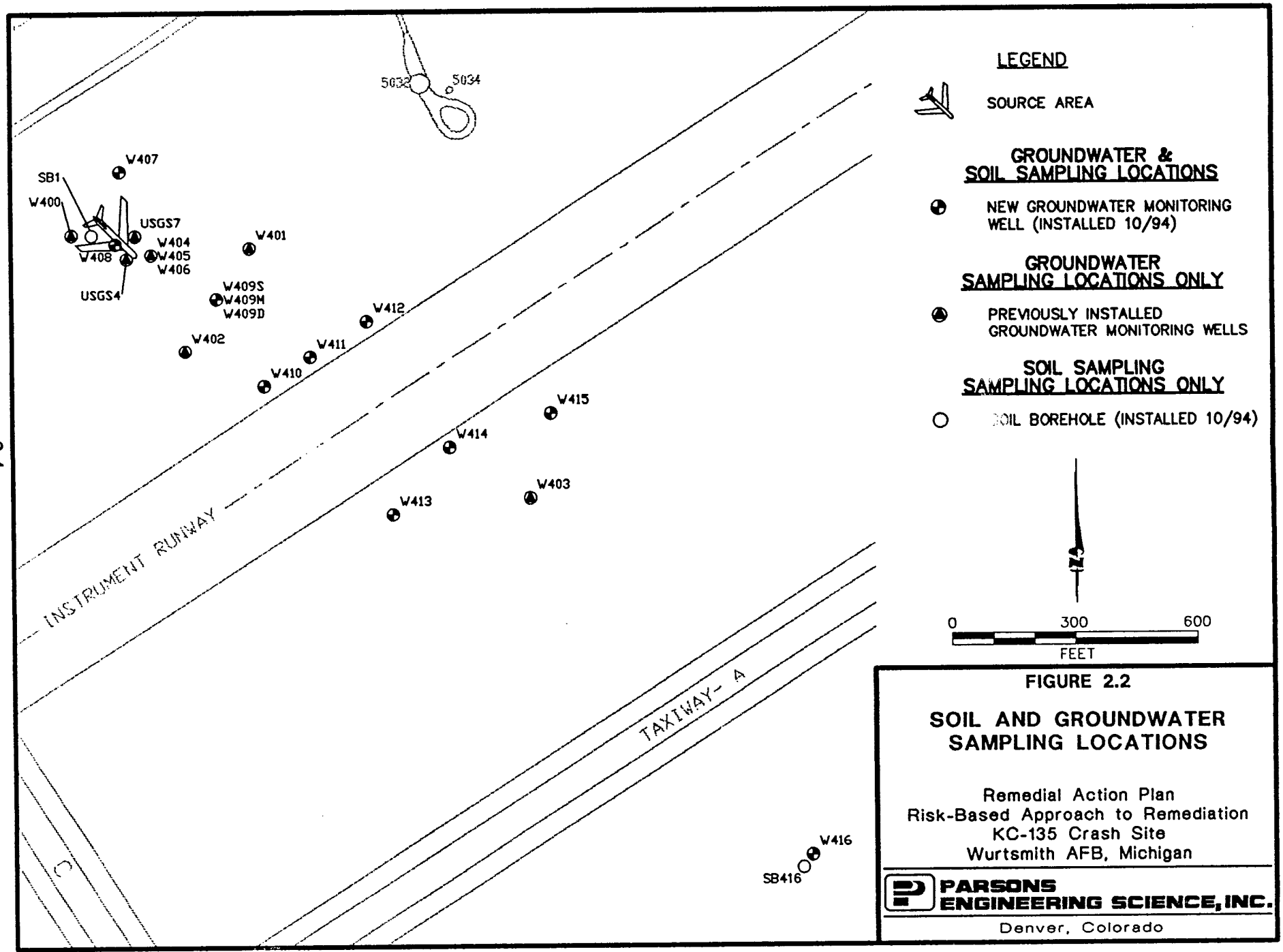

FIGURE 2.2

SOIL AND GROUNDWATER SAMPLING LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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TABLE 2.1
ANALYTE REPORTING LIMITS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	MDNR Soil Required MDL [a]	Soil Reporting Limit [b]	Soil Units	Site-Specific Water MDL	MDNR Water Required MDL [a]	Water Reporting Limit [b]	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 (TEH)	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			0.400	10.000		µg/kg	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
Benzo(a)anthracene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.350	5.000	10.000	µg/L
Benzo(a)pyrene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.370	5.000	10.000	µg/L
Benzo(b)fluoranthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.440	5.000	10.000	µg/L
Benzo(g,h,i)perylene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.200	5.000	10.000	µg/L
Benzo(k)fluoranthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.510	5.000	10.000	µg/L
Chrysene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.330	5.000	10.000	µg/L
Dibenz(a,h)anthracene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.680	5.000	10.000	µg/L
Dibenzofuran	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.010	5.000	10.000	µg/L
Fluoranthene	SW8270	Fixed-Base			10.000	330.000	330.000	µg/kg	0.410	5.000	10.000	µg/L
Fluorene	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

TABLE 2.1 (Continued)
ANALYTE REPORTING LIMITS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE , WURTSMITH AFB, MICHIGAN

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Michigan Soil Required MDL [1]	Soil Reporting Limit [2]	Soil Units	Site-Specific Water MDL	Michigan Water Required MDL [1]	Water Reporting Limit [2]	Water Units
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
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
Electrical Conductivity	FCOND	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									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-O2	Fixed-Base							4.000		5.000	mg/L
Methane	RSK175	Fixed-Base							0.004		0.004	mg/L

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

[2] Most of these reporting limits are equal to the practical quantitation limit (PQL); in some cases, the reporting limit is equal to the reliable detection limit (RDL).

99-percent confidence from the normal "noise" of an analytical instrument or method. In contrast, the PQL is the lowest level at which a chemical can be accurately and reproducibly quantitated. The analytical methods and target MDLs used during this project were equal to or better than MDEQ's recommendations for environmental contamination response activities.

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 MEASUREMENTS

The purpose of soil gas sampling was to confirm the 1989 soil gas survey results that showed a limited extent of subsurface soil contamination and to determine the potential for lateral and upward diffusion of contaminated soil gas at the site. 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 existing monitoring well W404 and from newly-installed monitoring wells W408 and W409S. Each of these wells had screened intervals above the water table, which allowed soil gas to be collected from the capillary fringe. All soil gas samples were screened for fuel hydrocarbons, oxygen, and carbon dioxide using the test equipment and methods specified for field 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 Environmental Protection Agency (EPA) Method TO-3 for specific volatile COPCs (i.e., the BTEX compounds) and total volatile hydrocarbons (TVH). Table 2.2 identifies both field and fixed-base analytical data collected at each soil gas sampling location. One field duplicate 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, 1994). Analytical results for soil gas samples are summarized in Section 4 and presented in tabular form in Appendix B.

2.3 SUBSURFACE SOIL SAMPLING

Subsurface soil samples were collected at the KC-135 Crash Site to further delineate the nature and extent of saturated and unsaturated soil contamination at the site. New soil boreholes were drilled with the goals of expanding the existing groundwater monitoring well network and collecting additional contaminant data. The specific rationale for collecting each soil sample is presented in the work plan (Parsons ES, 1994). 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 following the procedures described in the work plan (Parsons ES, 1994). These procedures are in accordance with the general

TABLE 2.2
SAMPLE ANALYSIS BY SAMPLING LOCATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

SAMPLING LOCATION	NORTHING	EASTING	SCREEN INTERVAL (ft. bgs)	SAMPLE MATRIX	SAMPLE DEPTH (ft. bgs)	ANALYTES											
						BTEX	PNA	TVH/ TEH	ELECTRON ACCEPTORS	PHOS	ALK	CO_2	CH_4	NITROGEN	IRON	SOIL pH	SOIL TOC
SB-416	NS [a]	NS	NA	Soil	10-12					X	X			X	X	X	X
SB-1	NS	NS	NA	Soil	8-10	1 [b]	X										
USGS-4	415134.57	2244021.04	NR [c]	Groundwater	NA	1	X	X	X								
W400	415193.12	2243885.29	5.2-15.5	Groundwater	NA	1			X								
W401	415159.26	2244324.52	7.1-17.4	Groundwater	NA	1	X		X								
W402	414905.47	2244164.4	5.5-16	Groundwater	NA	1	X		X								
W403	414545.85	2245013.97	8-18.5	Groundwater	NA	1			X								
W404	415148.51	2244075.91	7.3-17.6	Groundwater	NA	1			X								
W405	415143.9	2244081.79	25.4-30.6	Groundwater	NA	1			X								
W406	415142.15	2244084.23	40.2-45.2	Groundwater	NA	1			X								
W407	415346.70	2244004.82	5-15	Soil	5-7	1	X			X	X			X	X	X	
					9-11	1											X
				Groundwater	NA	1	X	X	X			X	X				
W408	415171.17	2243993.22	5-15	Soil	8-10	1	X										
					10-12	1	X										
				Groundwater	5-10	2 [d]	X										
				Groundwater	NA	2	X	X	X			X	X				
W409S	415031.87	2244235.72	5-15	Soil Gas	5-10	1											
				Groundwater	NA	2	X	X	X			X	X				
W409M	415033.94	2244242.58	35-40	Groundwater	NA	1	X	X	X			X	X				
W409D	415036.69	2244249.07	64-69	Soil	13-15	1	X										X
					38-40												X
					62-64												X
				Groundwater	NA	1	X	X	X			X	X				
W410	414819.14	2244358.81	5-15	Groundwater	NA	1			X								
W411	414890.18	2244471.94	5-15	Groundwater	NA	1	X		X			X	X				
W412	414977.63	2244611.92	5-15	Groundwater	NA	1			X								
W413	414506.60	2244673.58	5-15	Groundwater	NA	1			X								
W414	414669.07	2244815.06	6-16	Groundwater	NA	1	X	X	X			X	X				
W415	414750.13	2245065.91	5-15	Soil	11-13												X
				Groundwater	NA	1			X								
W416	413668.30	2245706.28	8-18	Soil	12-14	1	X										
					14-16	1											X
				Groundwater	NA	1	X	X	X			X	X				

[a] NS = Not surveyed.
[b] 1 = SW8020: Purgeable Aromatics.
[c] NR = Not reported in available review material.
[d] 2 = TO3: Determination of Volatile Organic Compounds in Ambient Air.

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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 during soil sampling at the KC-135 Crash Site.

Seven subsurface samples were collected from 5 of the 11 new soil boreholes. Figure 2.2 shows the location of each of these subsurface soil sampling locations. Table 2.2 presents the coordinates and sample interval for each of the subsurface soil sampling locations sampled as part of the 1994 sampling event at the KC-135 Crash Site. This table also lists the field and fixed-base analytical methods used to evaluate each of the soil samples. Ten of the 11 new soil boreholes were completed as permanent 2-inch-diameter groundwater monitoring wells (W407 through W416). One of the new soil boreholes was not completed as a well because it was located close to existing well W400. Borehole logs, well completion diagrams, well development records, and survey data 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 characterize the nature and extent of soil contamination at the site.

2.4 1994 GROUNDWATER INVESTIGATIONS

Groundwater samples were collected in 1994 from new wells and previously installed wells to define the nature and extent of source area and dissolved contamination. Geochemical data relevant to documenting the potential for biodegradation of dissolved COPCs and quantitatively investigating environmental fate and transport also were collected in 1994. Groundwater samples were collected using the procedures described in the work plan (Parsons ES, 1994). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). Three field duplicates, one equipment rinseate blank, and two trip blanks were collected during the 1994 groundwater sampling event at the KC-135 Crash Site.

Groundwater samples were collected 1994 from the 20 different sampling locations listed in Table 2.2 and shown on Figure 2.2. Both field and fixed-base analytical data were collected at each groundwater sampling location, as summarized in Table 2.2. All groundwater samples, 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 and laboratory analytical data were collected to evaluate natural attenuation processes in accordance with the AFCEE document *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater,* which was prepared by Parsons ES and the EPA's Robert S. Kerr Research Laboratory (Wiedemeier *et al.,* 1995). Table 2.1 summarizes the types of field measurements completed at the KC-135 Crash Site as part of this field test. Hydrogeological data are presented in Section 3 to characterize the physical setting of the site. Field and fixed-base analytical results for groundwater are used in Section 4 to characterize the nature and extent of groundwater contamination at the site. These analytical results also are used in Section 6 to assess the potential effects of natural physical, chemical, and biological processes on contaminant concentration, mass, form, persistence, and mobility.

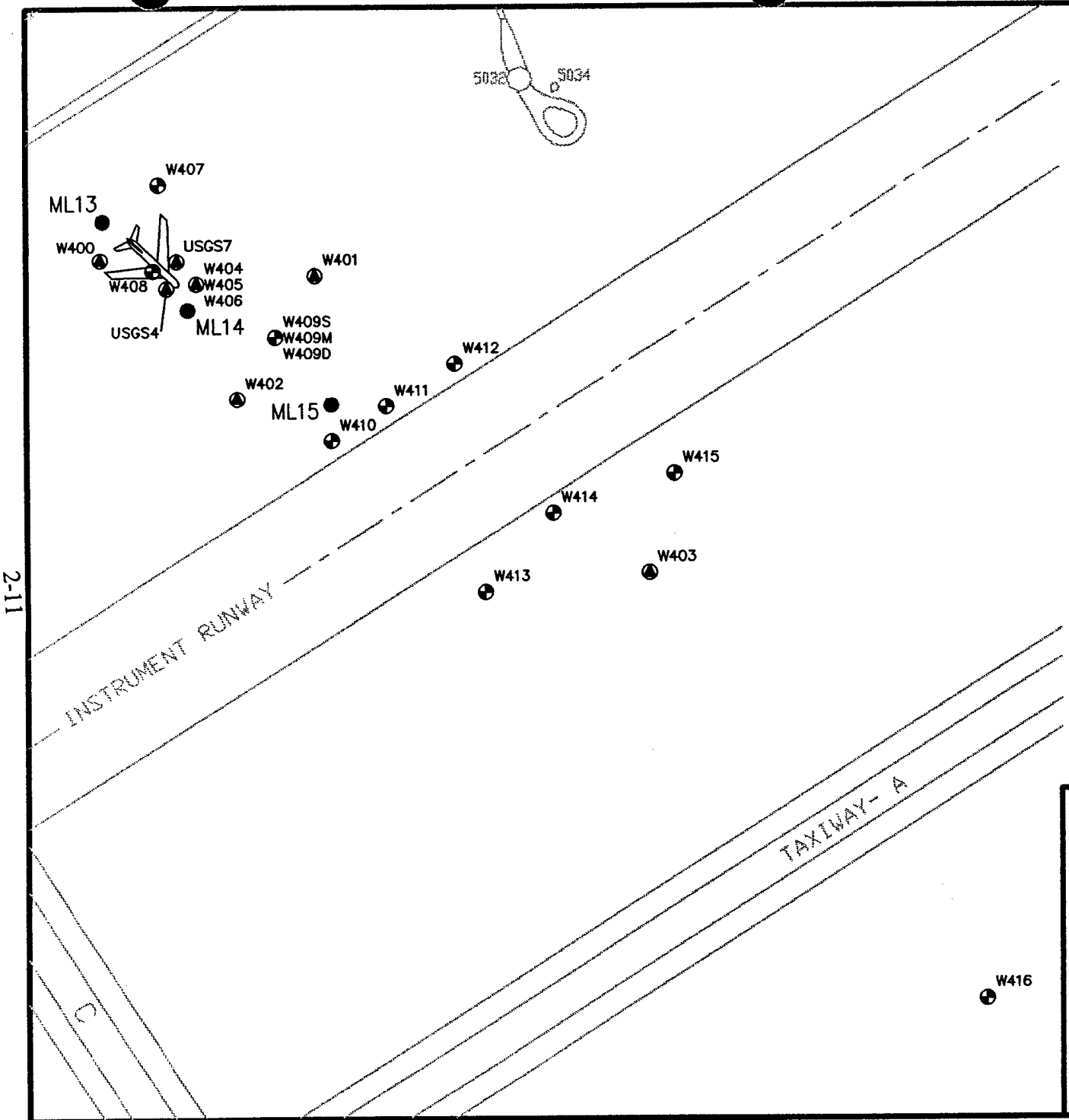
2.5 1995 AND 1996 GROUNDWATER INVESTIGATIONS

Following the 1994 risk-based sampling event, groundwater samples were collected in both December 1995 and October 1996 to further characterize the extent of dissolved contamination and to assess potential trends in contaminant distributions over time at the KC-135 Crash Site. In December 1995, the NCIBRD installed three multi-level monitoring wells at the KC-135 Crash Site (Figure 2.3). These multi-level wells were installed upgradient from the crash site (ML13), downgradient from the most contaminated well (i.e., ML14 downgradient from USGS-4), and at the leading edge of the dissolved plume (ML15). A total of 23 groundwater samples were collected at the multi-level wells and analyzed for each of the BTEX compounds. These data are presented in Section 4 to characterize the vertical distribution of contamination and in comparison to 1994 groundwater data.

As part of the AFCEE-sponsored risk-based project at the KC-135 Crash Site, Parsons ES collected a total of 11 groundwater samples at 10 permanent wells (one of which is a nested shallow and deep well). Wells sampled included W401, W402, W404, W407, W409S, W409D, W410, W411, W412, W414, W420, and USGS-4. These data were collected to verify trends in dissolved contaminant natural attenuation over time. All collected groundwater samples were analyzed for both BTEX and target PAH compounds. The 1996 groundwater data are presented in Section 4 in concert with the 1995 NCIBRD data to assess changes in contaminant mass, concentration, mobility, and toxicity over time.

2.6 SOURCE REDUCTION FEASIBILITY TESTING

No source reduction technologies were tested onsite as part of the 1994 investigation activities. However, bioventing and biosparging were investigated at site OT45 at Wurtsmith AFB. Biosparging involves the injection of air into saturated soils with the purpose of increasing dissolved oxygen (DO) concentrations to enhance biodegradation and volatilization of COPCs. A single biosparging test well was constructed at Site OT45 as part of the risk-based field test program at Wurtsmith AFB. The goal of the biosparging test was to measure the increase in the DO concentrations created by sparging and to determine the flow rates required for a full-scale biosparging system in the event that this type of remediation is warranted. A bioventing test also was completed at Site OT45 to determine the ability of injected air to supply oxygen for biological degradation of fuel residuals. Due to significant hydrogeological similarities between Site OT45 and the KC-135 Crash Site, these test results should be useful in predicting the effectiveness of bioventing and biosparging on soil and groundwater contamination at the KC-135 Crash Site. Consequently, the Site OT45 biosparging and bioventing feasibility test results are summarized in Section 7. Field test data and analyses are presented in Appendix E.



LEGEND

SOURCE AREA

GROUNDWATER & SOIL SAMPLING LOCATIONS

GROUNDWATER MONITORING WELL (INSTALLED 10/94)

GROUNDWATER SAMPLING LOCATIONS ONLY

EXISTING GROUNDWATER MONITORING WELLS

MULTILEVEL SAMPLING WELLS (INSTALLED 12/95)

N

0 300 600

FEET

FIGURE 2.3

MULTILEVEL WELL SAMPLING LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

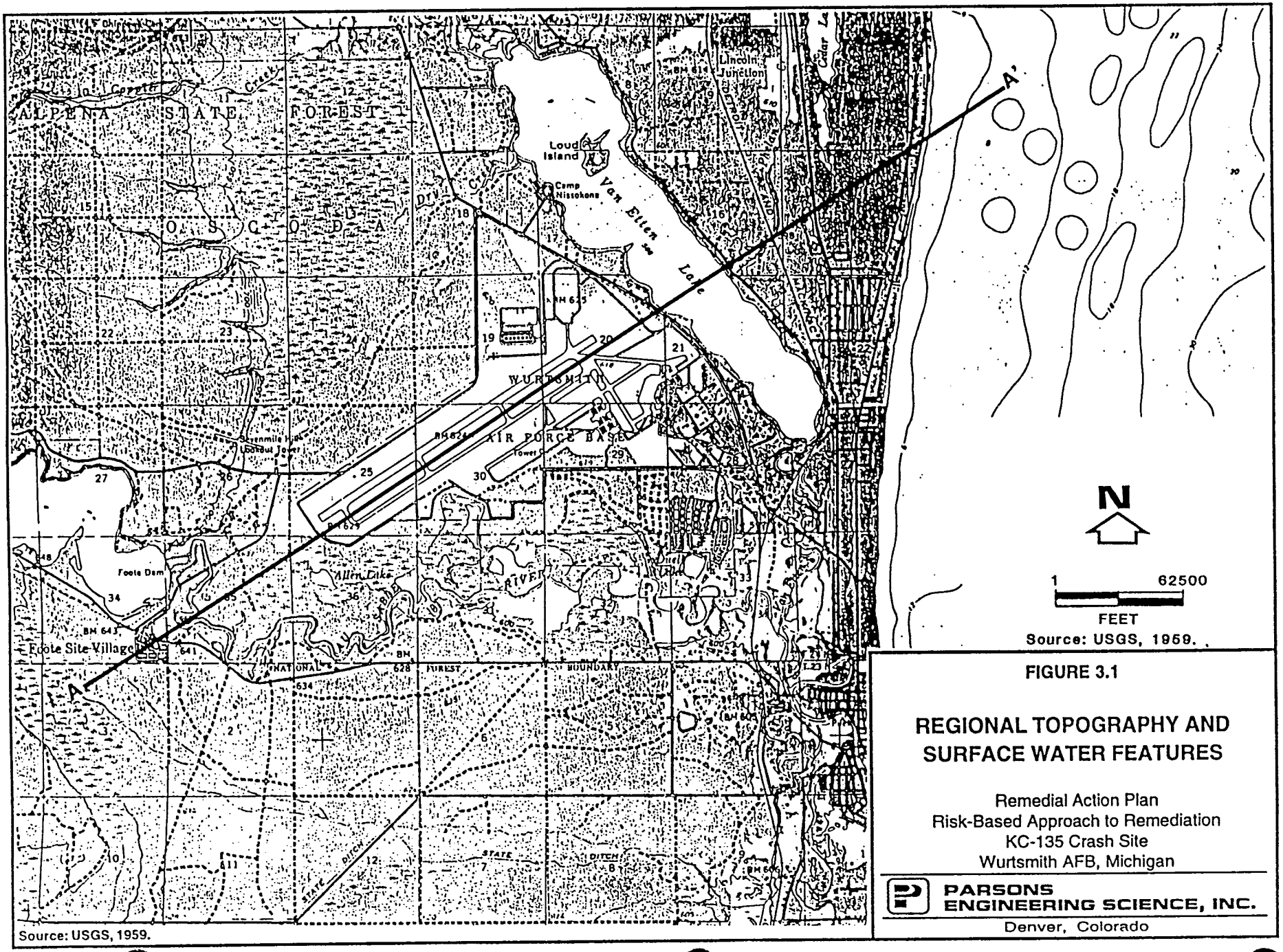
This section describes the physical characteristics of the KC-135 Crash Site, as determined from data collected during previous site investigations and from data collected by Parsons ES in September and November 1994 as part of the risk-based remediation field test. Data incorporated into this section from previous investigations were taken from the RI report (WW Engineering & Science, 1993) for the KC-135 Crash Site. 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 physiographical district, near the eastern shore of Michigan (USGS, 1990). This plain extends approximately 5 miles from the shore of Lake Huron to a line of 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 has relatively flat topography, with the western portion of the base (including the KC-135 Crash Site), sloping very gently to the southeast. Surface elevations in the vicinity of the KC-135 Crash Site range from approximately 630 feet above msl at the runway near the KC-135 Crash Site to 588 feet above msl at Van Etten Lake. The topography and major surface water features of the area 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, the Au Sable River, and wetlands in the northwest and southwest regions of the base. Dry Creek drains a swampy area located west of the AFB and flows into Van Etten Lake, which is also fed from the north by the Pine River. The lake discharges into Van Etten Creek, which is located at the southeast 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.

Because the topography is relatively flat and the soils are very sandy beneath the base, most precipitation infiltrates into the groundwater system. Runoff from paved areas is treated at the Wurtsmith AFB sewage treatment plant and discharged into settling ponds located near the southern base boundary (ICF, Inc., 1994). Limited amounts of surface water runoff drain northeast into Van Etten Lake and south into the Au Sable River.



Source: USGS, 1959.

FIGURE 3.1

REGIONAL TOPOGRAPHY AND SURFACE WATER FEATURES

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Risk-Based Approach to Remediation
KC-135 Crash Site
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 over 250 feet of unconsolidated glacial, deltaic, and lacustrine deposits overlying the Mississippian-aged Marshall Formation sandstone and Coldwater Shale bedrock (Rama Rao, 1992). A generalized geologic cross section of the base and adjacent area is presented in Figure 3.2. The location of the cross section is shown on Figure 3.1. The glacially eroded bedrock surface dips gently from west to east, toward Lake Huron. The Pleistocene- and Holocene-aged 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 lake sediments ranging from approximately 95 to over 200 feet thick. This silty clay layer forms the lower confining layer for the regional shallow 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 aeolian deposits forms the regional shallow aquifer, and is the interval of primary interest to this study.

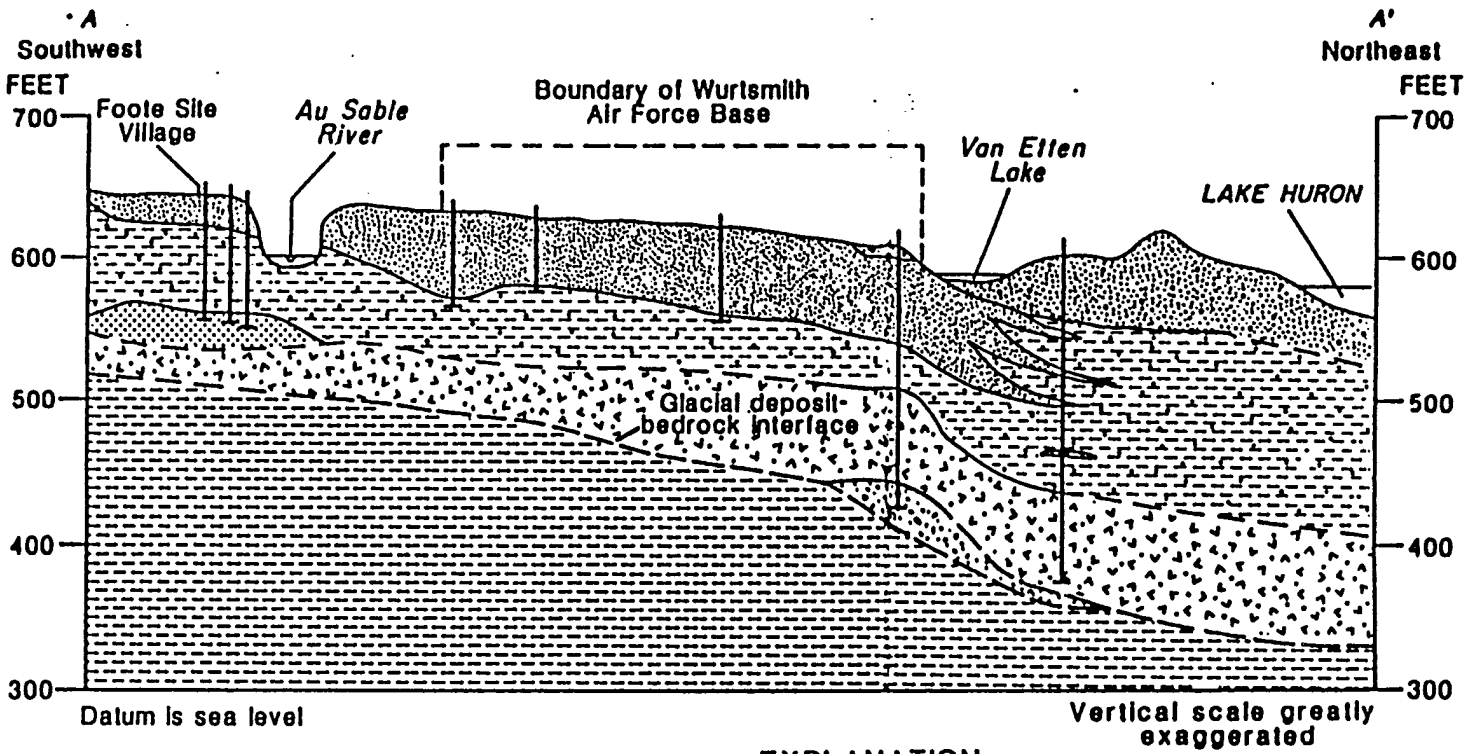
The U.S. Soils Conservation Service has identified the Grayling sand as the primary surficial soil association at Wurtsmith AFB. The Grayling series consist of excessively drained soils formed in sandy glaciofluvial sediments, with slopes ranging from 0 to 6 percent.

3.2.2 Hydrogeology

The two major aquifers at Wurtsmith AFB are the shallow sands and deeper glacial till deposits, which are 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, Inc., 1994).

The surficial sand and gravel deposits are the principal aquifer in the vicinity of Wurtsmith AFB. Groundwater is present at depths ranging from less than 10 feet bgs at places along the western part of the base to 25 feet bgs near Van Etten Lake. Groundwater levels fluctuate 1 to 3 feet annually, and the aquifer is unconfined. Most groundwater beneath Wurtsmith AFB flows to the northeast, toward Van Etten Lake; a smaller amount, from beneath the southern portion of the base (including the KC-135 Crash Site), flows to the south toward the Au Sable River

Studies performed by the USGS (1990) in 1979-81 and 1982-85 indicated that average advective 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.



0 1 2 MILES

0 1 2 KILOMETERS

EXPLANATION

DESCRIPTION OF UNITS

- Alluvial deposits
- Beach and eolian sand deposits
- Deltaic sand deposits
- Lacustrine silt and clay
- Sand and gravel
- Till
- Marshall Formation
- Coldwater Shale

⊥ WELL

FIGURE 3.2

GEOLOGIC
CROSS-SECTION A-A'

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Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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3.3 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

The KC-135 Crash Site and the surrounding area is generally flat, with a surface elevation of about 625 feet above msl. The site is a gently sloping, grassy area bound by a gravel perimeter road to the northwest and a large 300-foot-wide aircraft runway to the southeast. The area between the crash site and the runway has been graded to create a broad, shallow swale parallel to the runway.

Because of the flat topography and well-drained, sandy soils, most precipitation infiltrates the sandy soils. Any surface water runoff from the site would flow into the swale along the runway and run northeast to one of two catch basins located in the swale. Water collected in the catch basins is conveyed to the southeast by 30-inch-diameter storm drains and discharge into the low-lying marshlands adjacent to the Au Sable River. The nearest downgradient catch basin is located approximately 2,400 feet northeast of the crash site. The closest body of surface water is a marshlands area approximately 4,500 feet south of the KC-135 Crash Site. These marshlands are not directly downgradient from the site. The closest body of surface water directly downgradient from the site is the Au Sable River and its surrounding marsh area, which are approximately 4,500 feet southeast of the crash site.

3.4 SITE GEOLOGY AND HYDROGEOLOGY

The vadose zone and shallow aquifer system at the KC-135 Crash Site was characterized by Parsons ES in September through November 1994. Data collected as part of this field test were used to supplement geologic and hydrogeologic data collected during the RI by WW Engineering & Science (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 of about 32 feet of gravelly sand overlying about 38 feet of medium- to very coarse-grained sand, which in turn overlies a slightly silty clay. Figure 3.3 shows the location of cross section B-B' (Figure 3.4), which is oriented through the center of the source area and parallel to the direction of groundwater flow. The sand and gravel deposits are the Pleistocene and Holocene beach, aeolian, and alluvial deposits previously discussed. The sand deposits are a light to medium yellow color and are poorly to moderately sorted, with thin gravelly layers in the upper interval. Minor iron staining was observed near the water table surface, at depths between 9 and 11 feet bgs.

The clay layer was encountered at a depth of 70 feet bgs in the borehole for well W409D. This clay layer was interpreted to be the top surface of the regionally continuous lacustrine clay layer that overlies the glacial till. No soil boreholes were drilled into the clay layer. The clay layer is a gray, very stiff to hard, silty clay. The hard texture and high clay content of this unit indicates a very low permeability.

3.4.2 Site Hydrogeology

The water table was approximately 10 feet bgs at the time of well installation. Groundwater elevation data collected in October 1994 were used to construct a map of

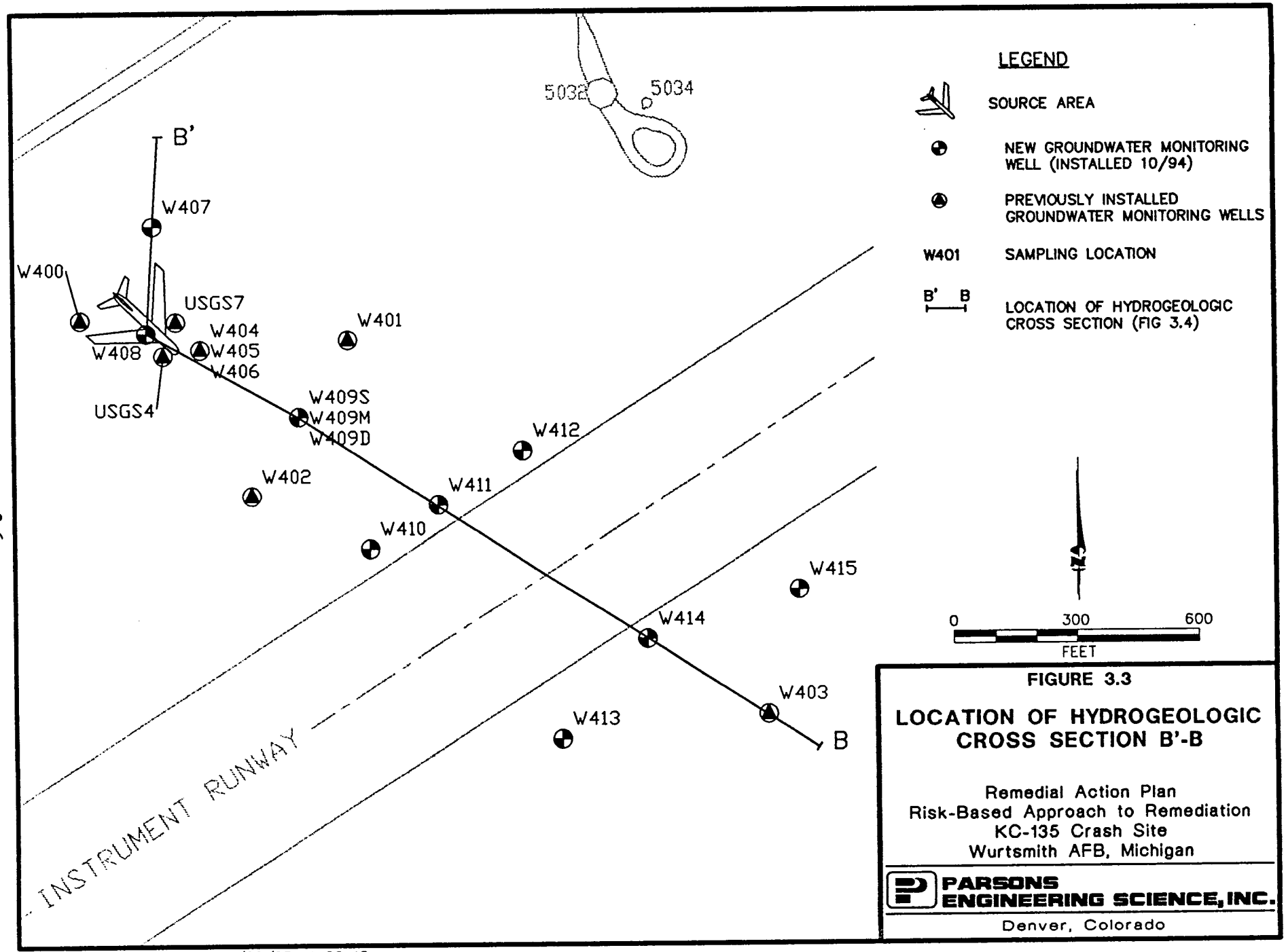

FIGURE 3.3

LOCATION OF HYDROGEOLOGIC CROSS SECTION B'-B

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KC-135 Crash Site
Wurtsmith AFB, Michigan

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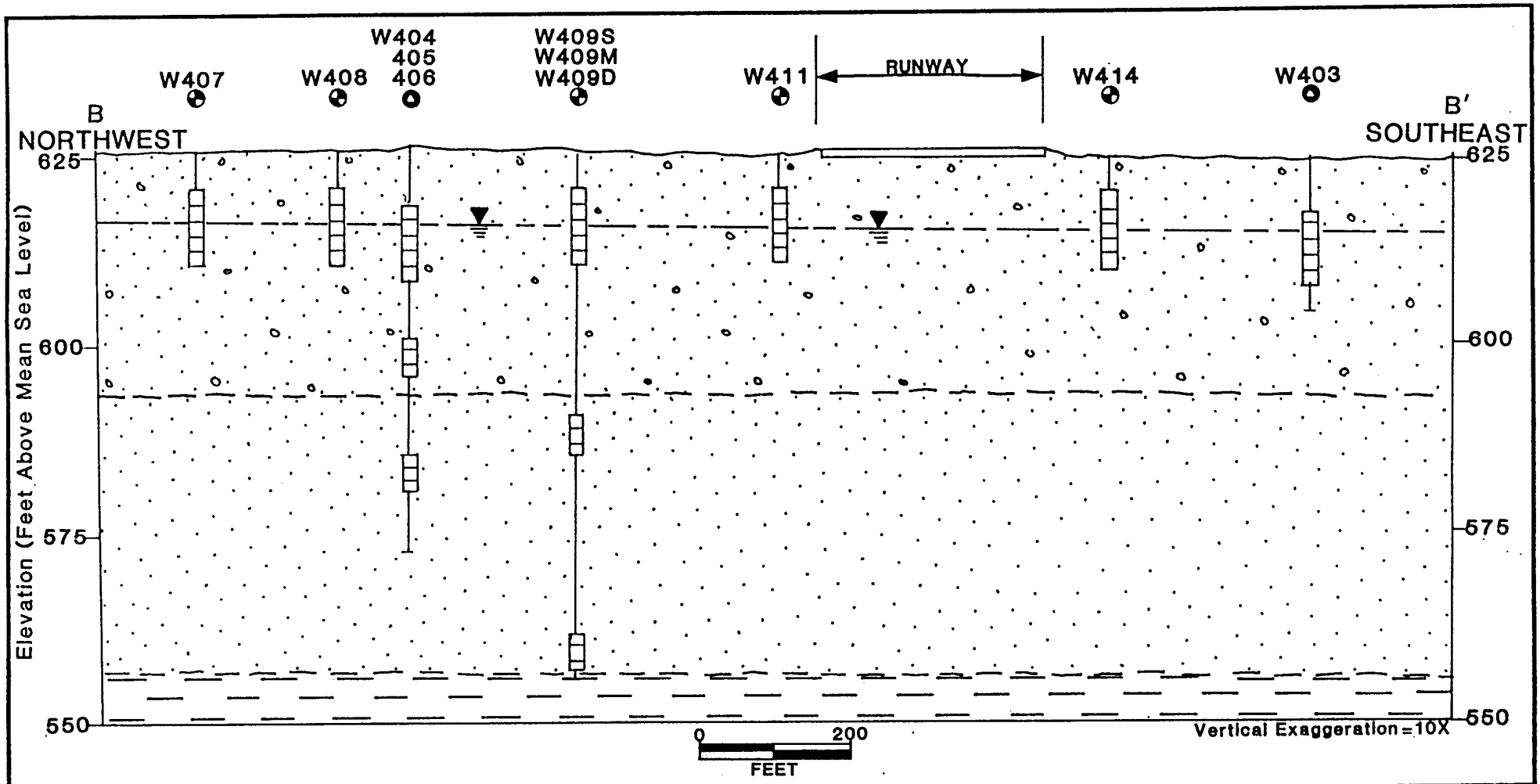

LITHOLOGIC DESCRIPTION

GRAVELLY SAND | SAND | CLAY

LEGEND

W407 NEW MONITORING WELL

W403 PREVIOUSLY INSTALLED WELL

GROUNDWATER SURFACE

APPROXIMATE GEOLOGIC CONTACT, DASHED WHERE INFERRED

SCREENED INTERVAL
BOREHOLE TOTAL DEPTH

FIGURE 3.4

HYDROGEOLOGIC CROSS-SECTION B-B'

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KC-135 Crash Site
Wurtsmith AFB, Michigan

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the approximate groundwater surface at the KC-135 Crash Site (Figure 3.5). According to historic groundwater elevation data, water table elevations fluctuate between 8.79 and 13.44 feet bgs at the site (WW Engineering & Science, 1993).

Groundwater levels measured in the new and previously installed wells on October 18, 1995 indicate that shallow groundwater flow is generally to the southeast, toward the Au Sable River, with a hydraulic gradient of 0.0024 foot per foot (ft/ft). The gradient appears to be uniform across the site with no significant discontinuities. The observed flow direction is consistent with the regional groundwater flow direction (USGS, 1990).

Slug tests were conducted at seven monitoring wells (W400 through W406D) during the RI to estimate the horizontal hydraulic conductivity of the saturated soils (WW Engineering & Science, 1993). From these data, the average hydraulic conductivity of the upper portion of the shallow aquifer was determined to be 68.7 ft/day. The average linear groundwater velocity in the shallow portion of the aquifer was calculated to be approximately 0.56 ft/day based on an average hydraulic conductivity of 68.7 ft/day, a gradient of 0.0024 ft/ft, and an assumed effective porosity of 0.3.

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) in January. The prevailing wind is from the west/southwest.

3.6 LAND USE

3.6.1 Site Access

The KC-135 Crash Site is located near the center of the base in a controlled-access area adjacent to the runway. The site can only be reached by way of the perimeter road. The site also is within the boundaries of Wurtsmith AFB, which is completely enclosed by an 8-foot-high 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 a day, 7 days a week.

3.6.2 Current Land Use

The KC-135 Crash Site has been maintained as an airfield since the crash occurred in October 1988. The current land use at the KC-135 Crash Site is classified as airfield (US Air Force, 1993). The KC-135 Crash Site is located approximately 660 feet north of the runway and 8,900 feet from the north end of the runway.

The airfield area is surrounded on all sides by the Huron National Forest, which is owned and maintained by the US government. These parcels are zoned as forestry

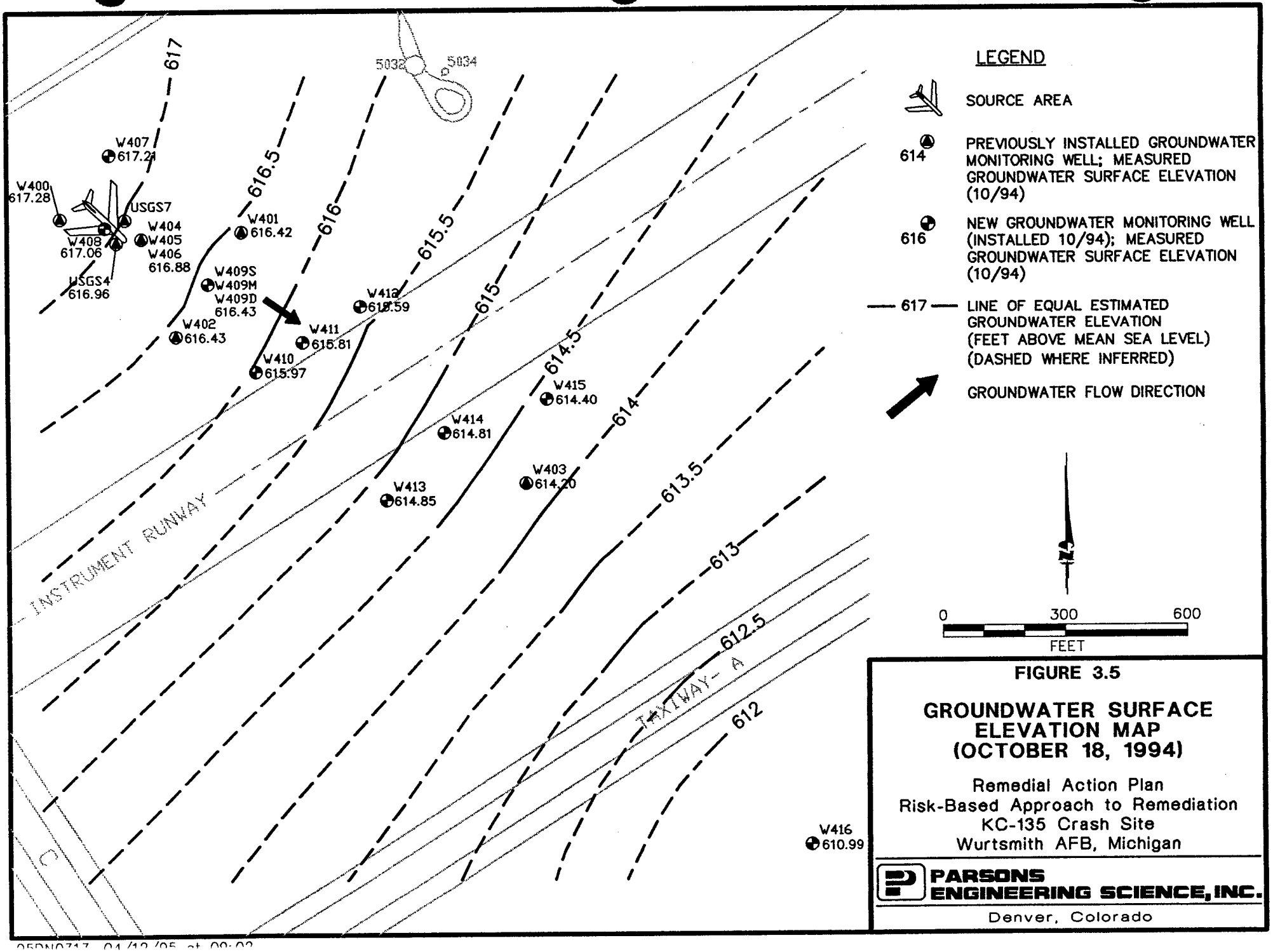

FIGURE 3.5

GROUNDWATER SURFACE ELEVATION MAP (OCTOBER 18, 1994)

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Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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land, and are currently used as public facilities and/or recreation areas. There are no occupied buildings in the vicinity of the crash site. There are no permanent human populations between the KC-135 Crash Site and the Au Sable River, which is downgradient from the site with respect to groundwater flow.

3.6.3 Proposed Land Use

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

The 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 Authority (AFBCA), which acts as the holding agency for receipt, maintenance, and disposition of base property. WAEAC and the Oscoda Township Board of Trustees selected The Pathfinders, Inc. to develop a final land reuse plan for Wurtsmith AFB property. The *Preliminary Final Environmental Impact Statement: Disposal and Reuse of Wurtsmith Air Force Base, Michigan* (US Air Force, 1993) was approved by the Oscoda Township Board of Trustees in December 1992.

Based on the approved final land reuse plan (US Air Force, 1993), the KC-135 Crash Site is proposed to be maintained as an airfield. The planned use of this site will result in continued restrictions on public access. No human occupancy of this area is expected. Property immediately to the north, south, east, and west are proposed to be maintained as either industrial properties, specifically light industrial, warehousing, and light manufacturing, or aviation support areas. Site workers in these areas 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 current and proposed land use for the KC-135 Crash Site and adjacent environs as described in the final reuse plan

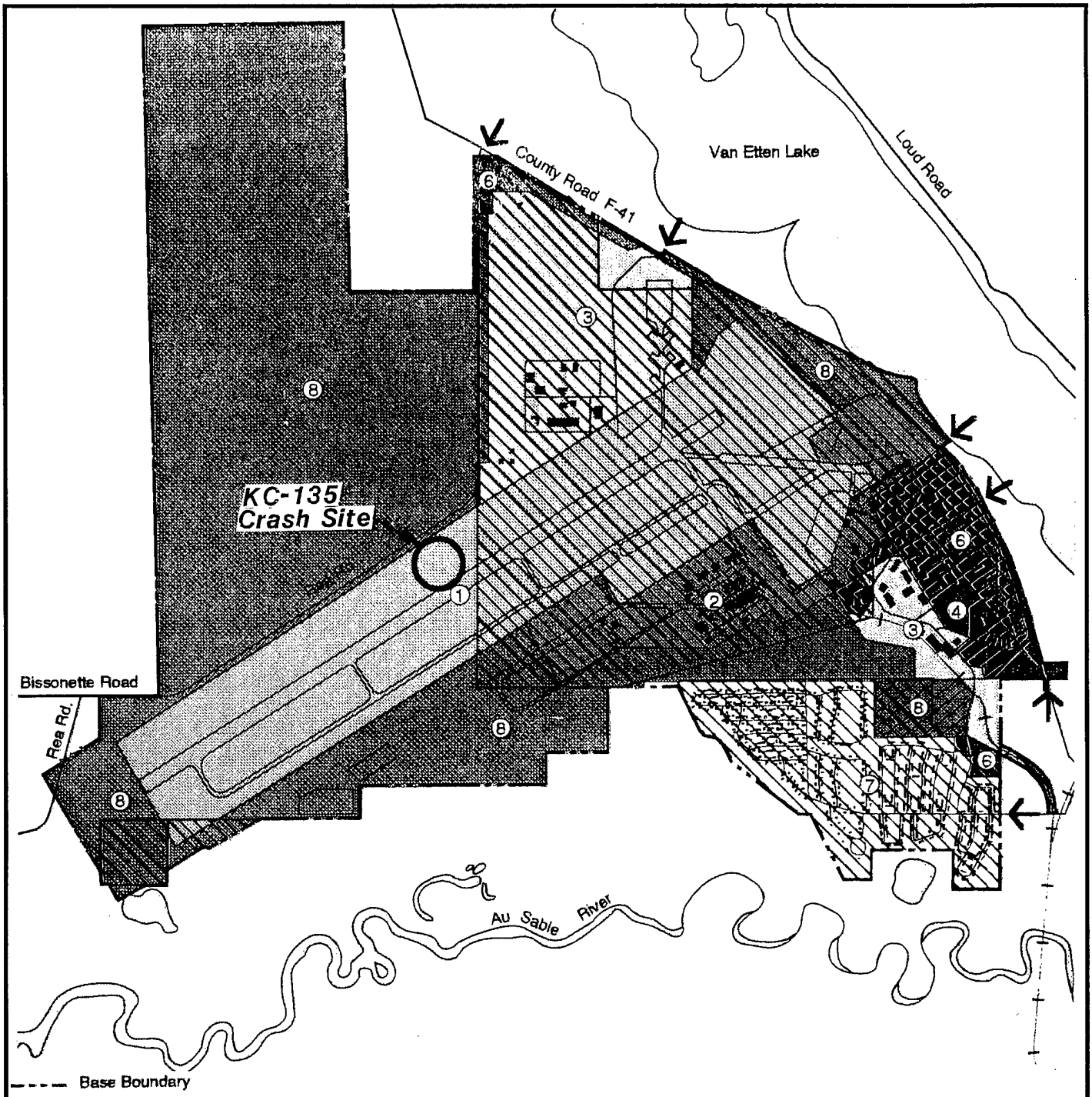

FIGURE 3.6

CURRENT AND FUTURE LAND USE ON WURTSMITH AFB

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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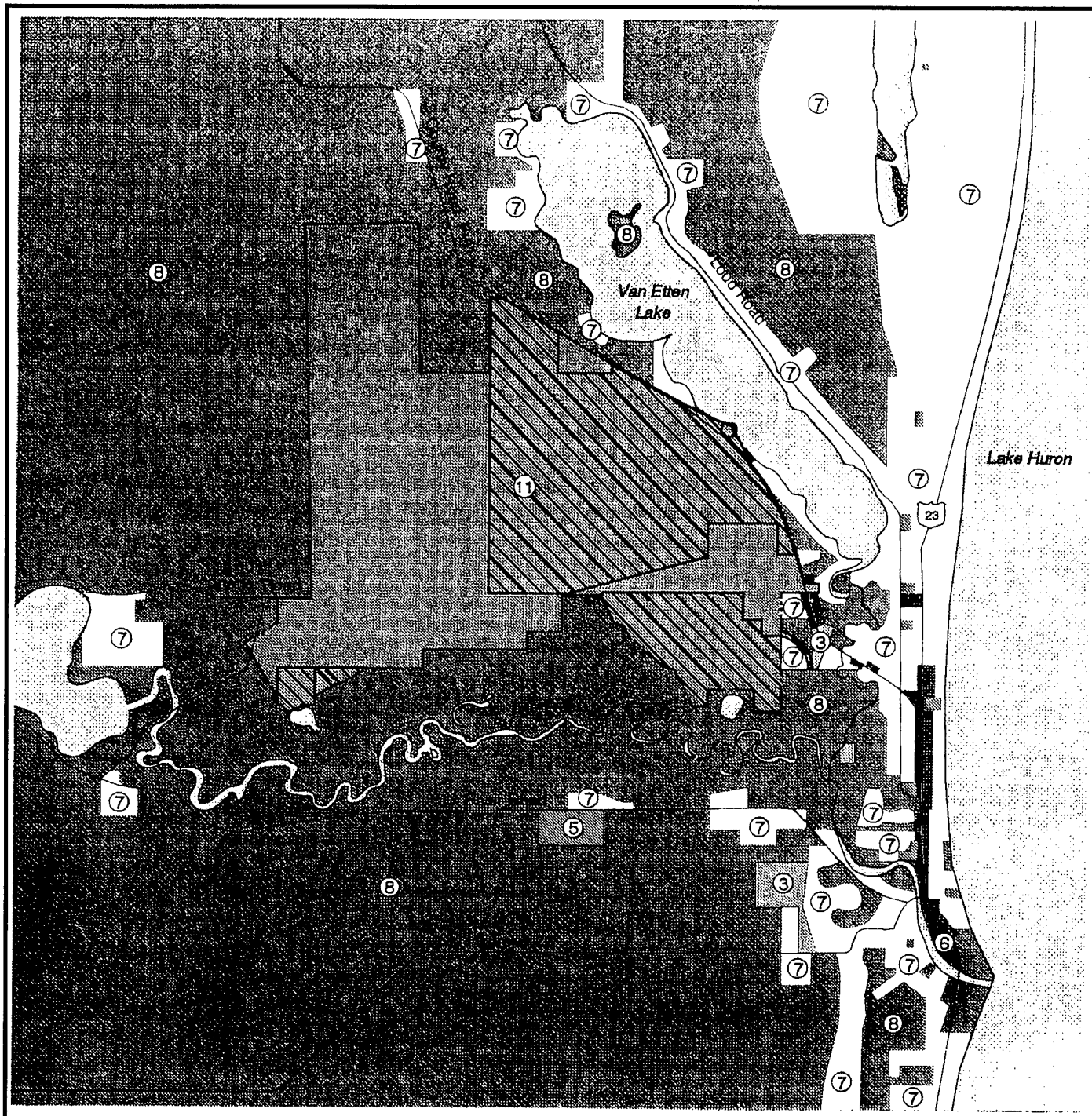

EXPLANATION

- 1 Airfield*
- 2 Aviation Support*
- 3 Industrial
- 4 Institutional (Medical)*
- 5 Institutional (Education)
- 6 Commercial
- 7 Residential
- 8 Public Facilities/ Recreation
- 9 Agriculture *
- 10 Vacant Land *
- 11 Base Property
- Air Force Fee-Owned
- Base Boundary

0 1375 2750 5500 Feet

* Not Applicable

Sources: US Air Force, 1993.

FIGURE 3.7

CURRENT LAND USE SURROUNDING WURTSMITH AFB

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Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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for the base. Section 9 of this RAP specifies that any Air Force transfer of the airfield will contain restrictive convenants to prevent non-industrial land use until remediation is complete.

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 undesirable as a 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 seven on-base groundwater wells drilled and installed within the shallow aquifer. The pumping capacity of these wells has been reported to be 2.2 million gallons per day (US Air Force, 1993). Groundwater use restrictions have been imposed on areas where shallow groundwater contamination exists or is suspected to exist. Extracted groundwater is treated only with chlorine before it is routed to the Base water distribution system.

The proposed land reuse plan includes replacing the on-base water supply system with local water supply systems. This means that there is no need (or plan) to extract groundwater from the shallow aquifer at the KC-135 Crash Site (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). No wells have been installed within or downgradient from the KC-135 Crash Site that could be used to meet potable or nonpotable water demands.

SECTION 4

NATURE AND EXTENT OF CONTAMINATION

4.1 OVERVIEW

This section summarizes the nature and extent of soil and groundwater contamination at the KC-135 Crash Site based on the findings of site characterization activities conducted under the RI in 1992, the 1994 risk-based remediation field test, and 1995 and 1996 sampling events. MDLs and MDEQ generic residential cleanup criteria are used to define the nature and extent of contamination in soil and groundwater that will be considered when evaluating remedial requirements to protect human health, welfare, and safety, as well as the environment and natural resources.

4.2 SOURCES OF CONTAMINATION

Contamination at the KC-135 Crash Site was the result of a KC-135 aircraft crash during an attempted landing in October 1988. The aircraft contained approximately 3,000 gallons of JP-4 jet fuel at the time of the crash. An unknown amount of fuel was consumed in the ensuing fire, and the remainder percolated into the ground. Based on the very limited soil contamination found on this site, the spilled fuel must have percolated through the sandy soil in a narrow column directly to the water table. Although significant amounts of LNAPL were measured in wells USGS-4 and USGS-7 from 1989 to 1991, LNAPL thicknesses decreased over time. Recoverable quantities of LNAPL were not found at any well during any of the sampling events after 1991. Table 4.1 presents historical measurements of free product taken from April 1989 to March 1992. Measurable LNAPL was last observed in groundwater monitoring wells in June 1991. Previous site characterization efforts conducted at the site indicated that soil was contaminated with ethylbenzene and total xylenes. However, the RI report concluded that remaining ethylbenzene and total xylenes contamination detected in soils at the KC-135 Crash Site will not act as a significant source of groundwater contamination because maximum concentrations did not exceed the MDEQ residential groundwater leaching criterion (WW Engineering & Science, 1993). The RI report concluded that groundwater at the KC-135 Crash Site had elevated concentrations of the BTEX compounds and naphthalene (WW Engineering & Science, 1993).

4.3 CHEMICALS OF POTENTIAL CONCERN

According to the final land use plan for Wurtsmith AFB (US Air Force, 1993), which has been approved by the Oscoda Township Board of Trustees, the expected

TABLE 4.1
DEPTH TO WATER AND ACCUMULATIONS OF FREE-PHASE HYDROCARBONS IN WELLS KC-135 CRASH SITE WURTSMITH AIR FORCE BASE
OSCODA, MICHIGAN

(measurements in feet)

	USGS-4		USGS-7	
Date	* Depth to Water	Hydrocarbon Thickness	* Depth to Water	Hydrocarbon Thickness
04/07/93	11.93	1.20	11.80	0.00
05/25/89	11.76	1.06	11.67	0.00
06/12/89	11.82	1.10	11.73	0.00
07/27/89	12.23	0.97	12.10	0.00
09/09/89	12.66	1.35	12.55	0.00
10/12/89	12.94	1.58	13.01	1.28
11/21/89	12.92	dry	12.89	1.31
01/03/90	13.23	0.00	13.44	1.01
01/24/90	13.37	1.05	13.32	0.98
03/08/90	13.35	0.92	13.45	0.89
04/09/90	12.28	0.26	12.22	0.39
05/16/90	11.77	0.36	11.70	0.41
06/22/90	11.77	0.48	11.69	0.42
08/02/90	12.10	0.61	12.03	0.44
09/17/90	11.96	0.25	11.92	0.41
11/08/90	10.71	0.10	10.65	0.02
12/18/90	10.29	0.15	10.22	0.11
01/25/91	10.41	0.27	10.34	0.09
03/14/91	10.39	0.22	10.30	0.08
06/03/91	8.87	trace	8.79	trace
11/22/91	10.39	0.00	10.33	0.00
02/04/92	10.55	0.00	10.50	0.00
03/30/92	10.38	0.00	10.32	0.00

Note: Data obtained via Department of Air Force letter dated May 7,1992.
* = Measurement taken from Top of Casing.

future use of the KC-135 Crash Site will be as an airfield. As described in Section 3.6.2, the site is currently maintained as an airfield with limited access. The administrative rules for Michigan's Natural Resources and Environmental Protection Act specify that industrial cleanups will generally apply at sites where the uses of the property are expected to be limited at the completion of the remedial action (MDEQ, 1995a). Industrial cleanup criteria are appropriate for sites where the current and/or planned activities to be conducted onsite can be described as industrial or commercial in nature. The exposure potential at these sites will be less than the exposure potential at sites that have been or are planned to be opened for unrestricted (e.g., residential) use. For example, the amount of time that an onsite worker engaged in industrial work such as warehousing would be exposed to contaminated media is much less than the amount of time that an onsite resident would be exposed. Consequently, the degree of cleanup required to provide the same level of health protection for onsite workers is different than that required for sites that may be planned for residential development or other similar uses.

Section 5 explains in more detail why a generic industrial cleanup approach is proposed for the KC-135 Crash Site. The most stringent cleanup criteria that could ever be applied at the KC-135 Crash Site are MDEQ generic residential cleanup criteria. Thus, generic residential cleanup criteria for soil and groundwater were used as screening criteria to define the maximum nature and extent of contamination. Generic residential cleanup criteria are used only as a means of identifying the maximum extent of contamination at the site that may warrant remediation. The current and planned future uses of the site are consistent with the objectives and requirements of an industrial cleanup. It is the intention of the Air Force to obtain approval for a generic industrial remedial action for the KC-135 Crash Site.

Residential cleanup criteria developed in MDEQ (1996) Operational Memorandum #4, Revision 1 were used to identify the maximum extent of chemical contamination in soil and groundwater at the KC-135 Crash Site. In the cases where residential cleanup criteria are more stringent than MDLs, MDLs were used as the comparison criteria.

Table 4.2 compares the 1992, 1994, 1995, and 1996 maximum and minimum analytical concentrations for each compound measured at the KC-135 Crash Site to the residential cleanup criteria. Maximum BTEX concentrations were consistently measured in or near well USGS-4. Health-based, aesthetic, and groundwater/surface water interface (GSI) residential groundwater criteria, and residential soil cleanup criteria that are protective of human health (i.e., related to direct contact and incidental ingestion), and the environment (i.e., related to leaching to groundwater and surface water) are included in this table.

All analytical results measured below the MDL were identified as not detected (U qualified) and reported at the PQL. This is consistent with EPA (1989) guidance on how to use not-detected values in quantitative risk assessments. All analytical results measured above the MDL but below the PQL were identified as estimated but useable data (J qualified). All analytical results measured above the PQL were identified as detected concentrations and not qualified. The 1994 and 1996 data collected by Parsons ES also were subject to a usability/acceptability review that included (1) a review of chain-of-custody records, reported holding times, status of instrument calibration, and reported recoveries for laboratory control samples and matrix

TABLE 4.2
IDENTIFICATION OF RESIDENTIAL SOIL AND GROUND WATER CLEANUP CRITERIA EXCEEDANCES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Compound (units)	Frequency of Detection Oct-94	Maximum Concentration Oct-94	Minimum Concentration Oct-94	Maximum Concentration Dec-92/Jan-93	Minimum Concentration Dec-92/Jan-93	GENERIC RESIDENTIAL CRITERIA	
						Ground Water Leaching Value	Direct Contact
Soil							
1,2,3-trimethylbenzene (µg/kg)	1/7	62J	62J	NA	NA	ID	ID
1,2,4-trimethylbenzene (µg/kg)	3/7	120J	0.6J	NA	NA	6.00E+02	4.50E+05
1,3,5-trimethylbenzene (µg/kg)	3/7	91J	0.6J	NA	NA	4.60E+02	3.40E+05
2-methylnapthalene (µg/kg)	1/6	200J	200J	NA	NA	ID	ID
Acenaphthene (µg/kg)	0/6	360U	390U	1,700U	330U	300,000 D	7.60E+07
Acenaphthylene (µg/kg)	0/6	360U	390U	1,700U	330U	5.20E+02	1.50E+06
Anthracene (µg/kg)	0/6	360U	390U	1,700U	330U	6,900,000 D	4.20E+08
Benzene (µg/kg)	0/7	0.44U	0.48U	10U	10U	1.00E+02	88,000
Benzo(a)anthracene (µg/kg)	0/6	360U	390U	1,700U	330U	A	14,000
Benzo(a)pyrene (µg/kg)	0/6	360U	390U	1,700U	330U	A	1,400
Benzo(b)fluoranthene (mg/kg)	0/6	360U	390U	1,700U	330U	A	14,000
Benzo(g,h,i)perylene (µg/kg)	0/6	360U	390U	1,700U	330U	A	1.50E+06
Benzo(k)fluoranthene (µg/kg)	0/6	360U	390U	1,700U	330U	A	1.40E+05
Butyl Carbitol	0/0	NA	NA	5,000U	25,000U	ID	ID
Chrysene (µg/kg)	0/6	360U	390U	1,700U	330U	A	1.40E+06
Dibenzo(a,h)anthracene (µg/kg)	0/6	360U	390U	1,700U	330U	A	1400
Dibenzofuran (µg/kg)	0/6	360U	390U	NA	NA	ID	ID
Ethylbenzene (µg/kg)	1/7	21	21	10U	10U	1.50E+03	$>C_{sat}$
Fluoranthene (µg/kg)	0/6	360U	390U	1,700U	330U	3,000,000 D	5.10E+07
Fluorene (µg/kg)	0/6	360U	390U	1,700U	330U	390,000 D	5.10E+07
Indeno(1,2,3-cd)pyrene (µg/kg)	0/6	360U	390U	1,700U	330U	A	14,000
Naphthalene (µg/kg)	1/6	360U	390U	1,700U	330U	17,000 D	1.50E+07
Phenanthrene (µg/kg)	0/6	360U	390U	1,700U	330U	12,000 D	1.50E+06
Pyrene (µg/kg)	0/6	360U	390U	1,700U	330U	1,800,000 D	3.20E+07
Toluene (µg/kg)	0/7	4.4U	4.8U	10U	10U	1.60E+04	$>C_{sat}$
Total xylenes (µg/kg)	1/7	95	95	37	37	5.60E+03	$>C_{sat}$

TABLE 4.2 (Continued)
IDENTIFICATION OF RESIDENTIAL SOIL AND GROUNDWATER CLEANUP CRITERIA EXCEEDANCES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Compound (units)	Maximum Concentration Oct-96	Minimum Concentration Oct-96	Maximum Concentration Dec-95	Minimum Concentration Dec-95	Frequency of Detection Oct-94	Maximum Concentration Oct-94	Minimum Concentration Oct-94	Maximum Concentration Nov-92	Minimum Concentration Nov-92	GENERIC RESIDENTIAL CRITERIA	
										Health-Based / Aesthetic Drinking Water	GSI Criterion
Groundwater											
1,2,3-trimethylbenzene (µg/L)	190	0.4U	NA	NA	4/20	84	14	NA	NA	ID	ID
1,2,4-trimethylbenzene (µg/L)	630	0.4U	NA	NA	4/20	580	62	NA	NA	30	22
1,3,5-trimethylbenzene (µg/L)	210	0.4U	NA	NA	5/20	100	0.8J	NA	NA	23	26
2-methylnapthalene (µg/L)	NA	NA	NA	NA	1/11	32	23	NA	NA	ID	B
Acenaphthene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	1,300	3.8
Acenaphthylene (µg/L)	NA	NA	NA	NA	0/9	10 U	10 U	5U	5U	26	B
Anthracene (µg/L)	NA	NA	NA	NA	3/9	5 J	1 J	5U	5U	7,300	1.10E+05
Benzene (µg/L)	3.8	0.4U	0.4U	0.4U	4/20	89	1J	280	1.5	5 (C)	53
Benzo(a)anthracene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	1.2	0.31
Benzo(a)pyrene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	0.2 (C)	0.31
Benzo(b)fluoranthene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	1.2	0.31
Benzo(g,h,i)perylene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	26	B
Benzo(k)fluoranthene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	12	0.31
Butyl Carbitol	NA	NA	NA	NA	0/0	NA	NA	50U	50U	ID	ID
Chrysene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	120	0.31
Dibenzo(a,h)anthracene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	0.12	0.31
Dibenzofuran (µg/L)	NA	NA	NA	NA	0/11	10U	10U	NA	NA	ID	B
Ethylbenzene (µg/L)	570	0.4U	330	0.4U	4/20	520	15	2,400	53	74	31
Fluoranthene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	880	370
Fluorene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	880	14,000
Indeno(1,2,3-cd)pyrene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	1.2	0.31
Naphthalene (µg/L)	NA	NA	NA	NA	3/11	100	2J	120	5	260	54
Phenanthrene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	26	B
Pyrene (µg/L)	NA	NA	NA	NA	0/11	10U	10U	5U	5U	550	11,000
Toluene (µg/L)	1100	8U	6300	8U	6/20	2,100	0.4 J	3,700	1.9	790	110
Total xylenes (µg/L)	2600	0.4U	3300	0.4U	4/20	2,500	58	9,700	17	280	59

A = Chemical, due to its physiochemical properties, is not expected to leach through soils to groundwater under most conditions (MDEQ, 1995a).

B = Chemical has either not been evaluated or an inadequate data base precludes the development of a GSI value (MDEQ, 1995a).

C = State of Michigan Drinking Water Standard established pursuant to section 5 of the Safe Drinking Water Act, Act No. 399 of the Public Acts of 1976 used as the default.

D =A linear equilibrium soil/water partition equation (SWP) was substituted for the 20X groundwater value where the SWP value was higher. The SWP predicts the contaminant release from soil into soil leachate by relating the concentration of contaminants absorbed to soil organic carbon to the concentration in the soil water and air pore space. The method also accounts for contamination transport by applying a generic dilution attenuation factor (DAF) to represent the dilution in soil leachate concentrations that result from contaminants mixing in an aquifer. The DAF is defined as the ratio of the soil leachate concentration to the acceptable groundwater concentration. A DAF of 16 was agreed upon by technical staff within the DEQ. The equation can be found in EPA's Soil Screening Guidance, published by the Office of Solid Waste and Emergency Response, Washington, D.C., EPA/540/R95/128 1996.

$>C_{sat}$ = Concentration exceeds saturation concentration.

J = Estimated concentration of analyte

U = Analyte concentration below method detection limit

ID = Inadequate data to develop criterion

NA = Not analyzed.

NOTE: Shading indicates concentration exceeds generic residential criterion. Both concentration and appropriate criterion are shaded.

spike/matrix spike duplicates; (2) analyzing and using laboratory and field blanks to qualify reported sample concentrations; and (3) measuring the reproducibility of sampling techniques and laboratory analytical precision using blind field duplicates/replicates. Appendix B presents the analytical results for all samples collected under this project, organized by environmental medium, and a summary of the data evaluation methodology and results.

All nondetect analytical results obtained during the 1994 and 1996 sampling events are reported on Table 4.2 at the PQL and U qualified. Nondetect analytical results obtained during the other sampling events included on this table are reported at the reporting limit. All analytical results obtained during the 1994 and 1996 sampling events measured between the MDL and the PQL have been J qualified. All MDLs achieved for these sampling events are consistent with the MDEQ recommendations for analytical sensitivity and are below the most stringent residential cleanup criteria (see Table 2.1).

The most restrictive residential cleanup criteria were used in this comparison pursuant to Michigan guidance (MDEQ, 1995a and 1996). The stringent residential GSI criteria also were used to identify COPCs pursuant to direction from MDEQ and Michigan's Natural Resources and Environmental Protection Act. The residential GSI values were calculated to be protective of surface water receiving groundwater discharge. However, the GSI values are not appropriate cleanup objectives or criteria for the KC-135 Crash Site because no surface water bodies are located on or within 10,400 feet downgradient from the site. The Au Sable River and its surrounding marshy regions are the nearest surface water bodies downgradient from the site Therefore, risk reduction requirements implied in residential GSI criteria are not necessary to protect human health, safety, and welfare, and the environment and natural resources. Any chemical that is targeted for remediation solely because measured concentrations exceed residential GSI cleanup criteria will be re-evaluated with respect to the required risk reduction needs for the site.

Table 4.3 lists the specific chemicals that were measured during any of the 1992-1996 sampling events at concentrations that exceeded any of the generic residential cleanup criteria. On the basis of these exceedances, there are no COPCs for soil at the KC-135 Crash Site. The COPCs for groundwater are benzene, ethylbenzene, naphthalene, toluene, total xylenes, and trimethylbenzene isomers. All of these compounds have been conservatively included as groundwater COPCs based on data collected since 1991.

These compounds are considered in detail in subsequent sections. Compounds measured at the site at concentrations that did not exceed the most restrictive generic residential criteria have not been carried forward in this analysis. Emphasis has been given to defining the nature and extent of contamination that must be addressed to protect human health, safety, and welfare and the environment and natural resources in accordance with the intent of MDEQ risk reduction rules and guidance. Only compounds that may pose a health threat (i.e., a carcinogenic and/or noncarcinogenic risk) to potential receptors or are relevant to conducting remedial technology assessments have been considered as part of this risk-based approach to remediation. For example, although total petroleum hydrocarbon (TPH) contamination may be

TABLE 4.3
LIST OF CHEMICALS OF POTENTIAL CONCERN
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Chemical of Potential Concern	Rationale
	Groundwater
Benzene	1992 and 1994 maximum concentrations > generic residential health-based value for ingestion 1992 and 1994 maximum concentrations > generic residential GSI value
Ethylbenzene	1992 and 1994 maximum and 1992 minimum concentrations > generic residential GSI value 1992 and 1994 maximum concentrations > generic residential aesthetic value 1992 maximum concentration >residential heath-based value for ingestion.
Toluene	1992 and 1994 maximum concentrations > residential health-based value for ingestion, generic residential aesthetic value, and generic residential GSI value
Total Xylenes	1992 and 1994 maximum concentrations > generic residential aesthetic value, and generic residential GSI value
Naphthalene	1992 and 1994 maximum concentrations > residential GSI value
1,3,5 Trimethylbenzenes	1994, 1996 maximum concentrations > generic residential health-based value, residential GSI value.
1,2,4 Trimethylbenzenes	1994, 1996 maximum concentrations > generic residential health-based value, residential GSI value.

useful as a gross indicator of JP-4 fuel contamination, toxicity data adequate for use in risk assessment are not available.

4.4 SOIL CHEMISTRY

Soil samples collected from seven different depth intervals within five new soil boreholes were analyzed for BTEX and PAH compounds. Contamination was detected only in well W408, where low concentrations of ethylbenzene, total xylenes, naphthalene and 2-methylnaphthalene were measured in samples gathered from 10-12 feet bgs. None of the detected contaminant concentrations exceeded residential soil cleanup criteria. All of the analytical soil sampling results from 1994 for BTEX and PAHs are presented in Appendix B.

4.5 SOIL GAS SAMPLING RESULTS

Soil gas samples collected at the KC-135 Crash Site during the 1994 field effort were analyzed for BTEX compounds and TVH. Soil gas samples can be used for secondary confirmation of the nature and extent of soil contamination at a site. Soil gas samples can be used to obtain a better qualitative representation of soil contamination than discrete soil samples from a splitspoon because the sample is extracted from a larger volume of soil. Discrete soil samples are usually nonhomogeneous and analytical results can vary greatly from sampling location to sampling location. Thus, soil gas samples provide a valuable indication of the type of volatile organic contamination in the soil.

Soil gas samples were collected from W404, W408, and W409S in October 1994. Benzene and toluene were 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 of the soil gas samples collected at the KC-135 Crash Site. The maximum ethylbenzene concentration of 36 milligrams per cubic meter (mg/m^3) was detected in the soil gas sample collected at W408; the minimum concentration of 1.8 mg/m^3 was measured at W409S. The maximum total xylenes concentration of 43 mg/m^3 was measured at W408; the minimum of 1.5 mg/m^3 was measured at W409S.

These soil gas results correlate well with 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) (435 mg/m^3 for both ethylbenzene and total xylenes), and are below concentrations that would be in violation of the provisions of Act No. 348 of the Public Acts of 1965, as amended. 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 risk to potential human receptors. All analytical results for soil gas samples collected during the 1994 field effort are presented in Appendix B.

4.6 GROUNDWATER CHEMISTRY

The following sections describe the results of groundwater sampling events conducted during the 1992 RI, the 1994 focused field investigation, the 1995 NCIBRD sampling event, and the 1996 sampling event in support of a risk-based remediation of the KC-135 Crash Site. Only groundwater COPCs are described in detail. No free product (LNAPL) was observed at the site during any sampling event conducted after 1991. Current groundwater contamination is limited to dissolved constituents.

Most permanent groundwater monitoring wells at the site are screened across the upper 10 feet of the aquifer. Two nested well clusters (i.e., W404, W405, and W406 and W409S, W409M, and W409D) are screened at multiple depths to assess the vertical distribution of chemical contamination in groundwater at the site. The upper screens within these nested wells are set across the upper 10 feet of the aquifer, while the lower screens are 5 feet long and set at specific lower depths within the shallow aquifer. Additionally, three multi-level wells were installed at the site in 1995 by NCIBRD. ML14 (source area) is screened at 11.5 feet bgs, 13.5 feet bgs, 14.9 feet bgs, 16.8 feet bgs, 18.8 feet bgs, 20.8 feet bgs, 22.7 feet bgs, and 24.7 feet bgs. ML13 (upgradient, background) is screened at 11.6 feet bgs, 13.4 feet bgs, 15.5 feet bgs, 17.4 feet bgs, 19.2 feet bgs, 21.4 feet bgs, and 23.4 feet bgs. ML15 (downgradient, leading edge) is screened at 9.8 feet bgs, 11.0 feet bgs, 12.9 feet bgs, 14.8 feet bgs, 16.8 feet bgs, 18.6 feet bgs, 20.6 feet bgs, and 22.8 feet bgs. Background permanent groundwater wells W400 and ML13 are upgradient from and outside of the zone of contaminant influence.

4.6.1 1992/1994 Groundwater BTEX Contamination

Groundwater samples were collected and analyzed for the BTEX compounds as part of the 1992 RI field effort. During the 1992 RI elevated concentrations of BTEX compounds were measured in samples collected from wells T-10-OF, T-11, T-12, T-13, T-16, W404, USGS-7, and USGS-4. Table 4.4 presents the measured concentrations of each of the BTEX compounds at 1992 RI sampling locations that exceed one or more of the generic residential cleanup criteria for each of these compounds. No other BTEX concentrations reported as part of the 1992 RI exceeded MDEQ-defined residential cleanup criteria.

Groundwater samples collected at the KC-135 Crash Site in 1994 also were analyzed for the BTEX compounds. During the 1994 focused field investigation in support of risk-based remediation, samples collected from wells USGS-4, W404, W408, and W409S contained BTEX concentrations that exceeded one or more of the generic residential criteria. Table 4.4 presents analytical results for each of the BTEX compounds that exceed one or more of the generic residential cleanup criteria. Table 4.2 identifies all three major types of generic residential cleanup criteria. Measured concentrations for each of the BTEX compounds at each sampling location are shown in Figure 4.1. The isoconcentration lines estimate concentrations of contaminants within the upper 20 feet of the aquifer. Analytical results from deeper wells are shown but not incorporated into the isoconcentration contours.

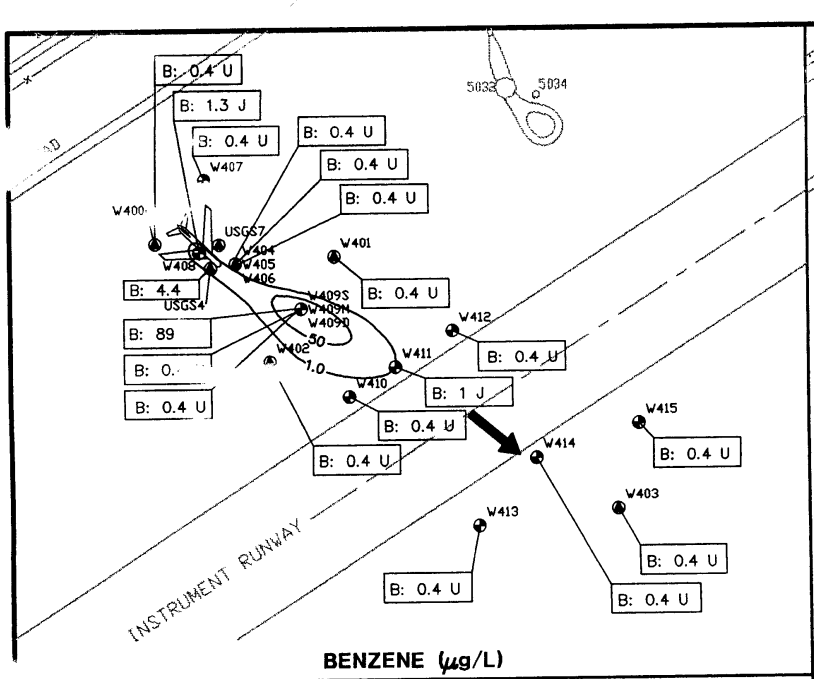
TABLE 4.4
SUMMARY OF CONTAMINANT CONCENTRATIONS IN GROUNDWATER
EXCEEDING GENERIC RESIDENTIAL CLEANUP CRITERIA
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

RESULTS FROM 1992 RI							
Well	Benzene (µg/L)	Ethylbenzene (µg/L)	Toluene (µg/L)	Total Xylenes (µg/L)	Naphthalene (µg/L)	1,3,5 Trimethylbenzene (µg/L)	1,2,4 Trimethylbenzene (µg/L)
T-10-OF	2.2	60	NE[a/]	92	NE	NA	NA
T-11	NE	180	790	940	NE	NA	NA
T-12	NE	53	NE	270	NE	NA	NA
T-13	280	56	640	360	NE	NA	NA
T-16	28	NE	NE	NE	NE	NA	NA
W404	NE	130	420	700	NE	NA	NA
USGS-7	1.5	NE	NE	NE	NE	NA	NA
USGS-4	NE	2400	3700	9700	120	NA	NA

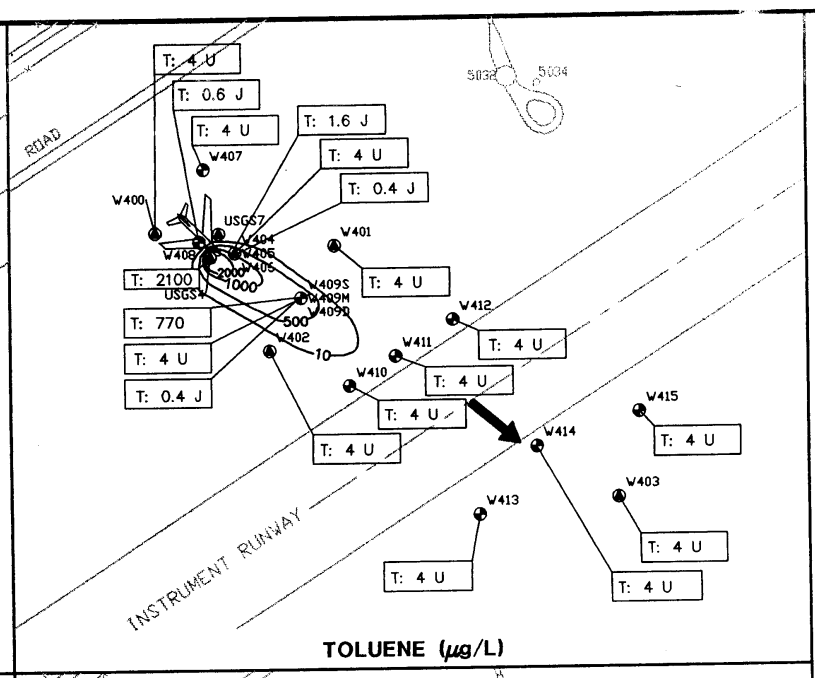
RESULTS FROM 1994 RISK-BASED INVESTIGATION							
Well	Benzene (µg/L)	Ethylbenzene (µg/L)	Toluene (µg/L)	Total Xylenes (µg/L)	Naphthalene (µg/L)	1,3,5 Trimethylbenzene (µg/L)	1,2,4 Trimethylbenzene (µg/L)
W404	NE	54	NE	66	NE	34	62
W408	NE	NE	NE	NE	NE	93	220
W409S	89	140	770	370	NE	49	130
USGS-4	4.4	520	2100	2500	100	100	580

NA: Not Analyzed

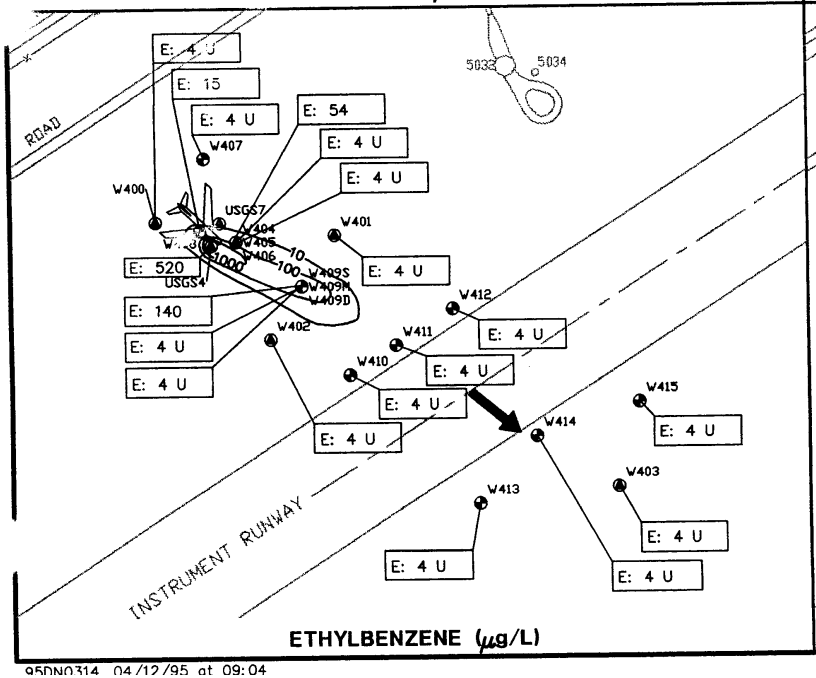
NE: Generic residential cleanup criteria not exceeded.



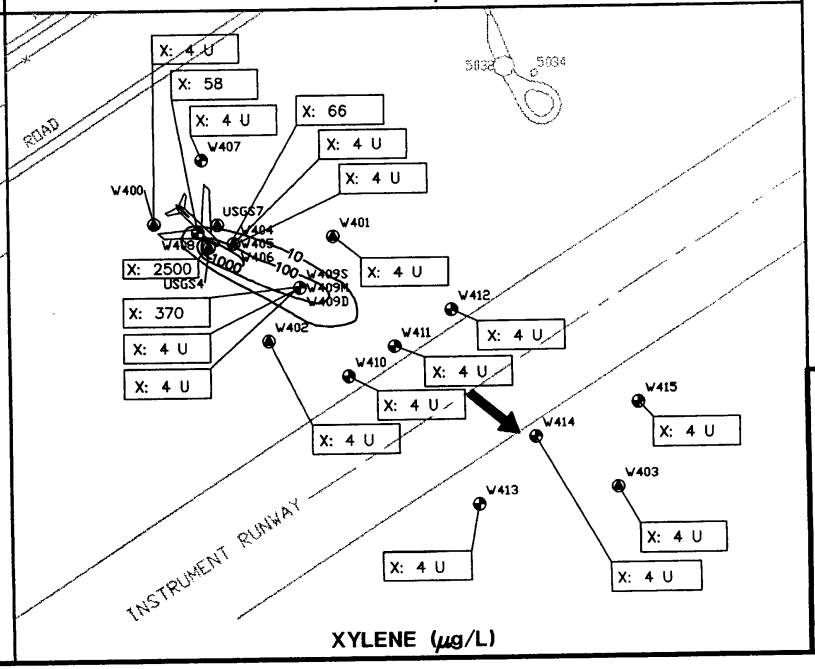
BENZENE (µg/L)



TOLUENE (µg/L)



ETHYLBENZENE (µg/L)



XYLENE (µg/L)

LEGEND

- SOURCE AREA
- EXISTING GROUNDWATER MONITORING WELL
- GROUNDWATER MONITORING WELL (INSTALLED 10/94)
- W400 SAMPLING LOCATION
- 10 ESTIMATED LINE OF EQUAL CHEMICAL CONCENTRATION (µg/L) (DASHED WHERE INFERRED)
- B: BENZENE (µg/L)
- T: TOLUENE (µg/L)
- E: ETHYLBENZENE (µg/L)
- X: XYLENE (µg/L)
- U ANALYTE CONCENTRATION BELOW DETECTION LIMIT
- J ESTIMATED VALUE
- GROUNDWATER FLOW DIRECTION

N

0 300 600
FEET

FIGURE 4.1

EXTENT OF BTEX CONTAMINATION IN GROUNDWATER

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

95DN0314 04/12/95 at 09:04

Analytical results from the 1992 and 1994 multilevel sampling efforts indicate that dissolved BTEX contamination is generally limited to the upper 20 feet of the shallow aquifer. Toluene was detected at concentrations equal to the detection limit in groundwater samples collected from the deep wells W409D and W406. However, toluene did not appear at intermediate-depth sampling locations within these well clusters. There were no other detections of BTEX compounds in the samples collected from the intermediate-depth or deep sampling locations. The lack of substantial concentrations of BTEX compounds in groundwater samples collected from deeper parts of the aquifer indicates that these compounds have not migrated vertically. The toluene detected in the deep well may indicate minor cross-contamination in the sampling equipment because none of the BTEX compounds were found at the intermediate-depth wells. All BTEX analytical results for groundwater samples collected during the 1994 field effort are presented in Appendix B.

4.6.2 1995/1996 Groundwater BTEX Contamination

Additional groundwater quality samples were collected in December 1995 and October 1996 to track trends in contaminant distributions over time at the KC-135 Crash Site. Table 4.5 presents the groundwater samples collected in December 1995 by NCIBRD. No benzene was detected in any of the multi-level wells sampled in December 1995. The maximum BTEX concentration detected during this sampling event was 9,230 µg/L at ML14 at a depth of 13.5 feet bgs. ML14 is located approximately 50 feet downgradient from USGS-4, where 5,125 µg/L BTEX was measured in 1994. Low concentrations of BTEX (i.e., < 60 µg/L) were detected in the multi-level well ML14 screened at 24.7 feet bgs. However, only toluene at ML14 at 13.5 feet bgs exceeded the MDEQ generic health-based residential criterion (see Table 4.2).

Groundwater samples were collected at several permanent monitoring wells in October 1996 by Parsons ES. The wells sampled in October 1996 include W401, W402, W404, W407, W409S, W409D, W410, W411, W412, W414, W420, and USGS-4. Figure 4.2 presents the 1996 analytical results for each of the individual BTEX compounds, including the trimethylbenzene isomers, by sampling location. Based on these sampling results, the dissolved BTEX plume appears stable, with concentrations decreasing at some locations. The maximum BTEX concentration detected during this sampling event was 4,270 µg/L at USGS-4. This BTEX concentration represents an almost 17 percent reduction from the measured 1994 BTEX concentration. No benzene was detected in groundwater in 1996 at concentrations above the MDEQ generic health-based residential cleanup criterion.

4.6.3 Groundwater PAH Contamination

Naphthalene was the only PAH compound detected in groundwater at concentrations above the generic residential cleanup criteria in November 1992 and October 1994. The maximum concentration of naphthalene detected in groundwater in 1992 at the KC-135 Crash Site was 120 µg/L at USGS-4. This concentration is below the health-based residential criterion but above the generic residential GSI cleanup criterion. Additionally, naphthalene was detected at concentrations of 20 µg/L, 5 µg/L, and 21 µg/L in wells T-11, T-12, and W404, respectively. However, these concentrations do

TABLE 4.5
SUMMARY OF CONTAMINANT CONCENTRATIONS IN GROUNDWATER
COLLECTED IN DECEMBER 1995
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

RESULTS FROM 1995 NCIBRD SAMPLING				
Well	Benzene (µg/L)	Ethylbenzene (µg/L)	Toluene (µg/L)	Total Xylenes (µg/L)
ML13-11.6	ND	ND	ND	ND
ML13-13.4	ND	ND	ND	ND
ML13-15.5	ND	ND	ND	ND
ML13-17.4	ND	ND	ND	ND
ML13-19.2	ND	ND	ND	ND
ML13-21.4	ND	ND	ND	ND
ML13-23.4	ND	ND	ND	ND
ML14-11.5	ND	850	ND	3300
ML14-13.5	ND	6300	330	2600
ML14-14.9	ND	530	300	980
ML14-16.8	ND	ND	ND	ND
ML14-18.8	ND	39	4	25
ML14-20.8	ND	14	7	42
ML14-22.7	ND	38	10	46
ML14-24.7	ND	19	9	31
ML15-9.8	ND	ND	ND	ND
ML15-11.0	ND	ND	ND	ND
ML15-12.9	ND	ND	ND	ND
ML15-14.8	ND	ND	ND	ND
ML15-16.8	ND	ND	ND	ND
ML15-18.6	ND	ND	ND	ND
ML15-20.6	ND	ND	ND	ND
ML15-22.8	ND	ND	ND	ND

ND: Not Detected

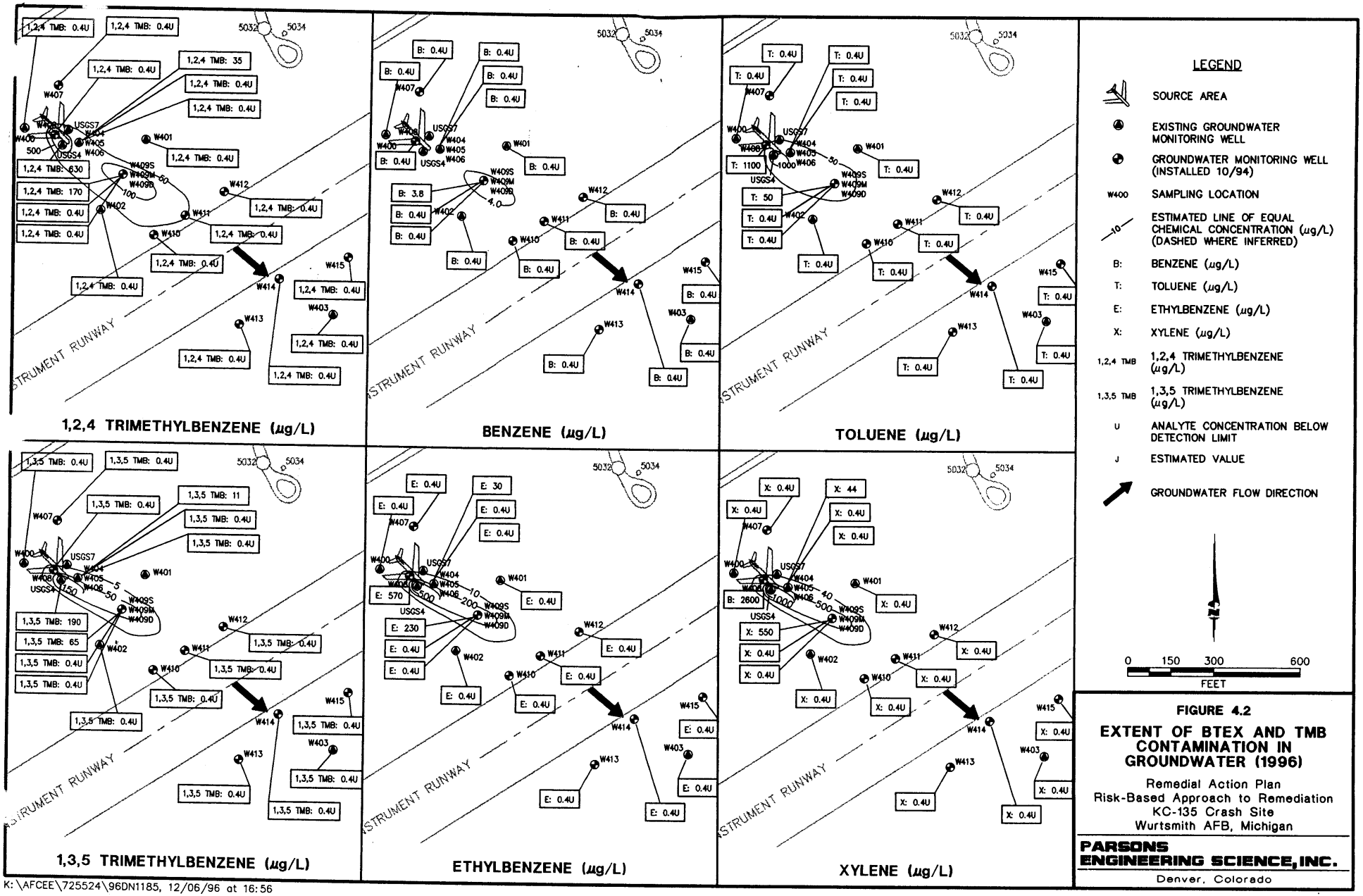


FIGURE 4.2

EXTENT OF BTEX AND TMB CONTAMINATION IN GROUNDWATER (1996)

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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not exceed the generic residential cleanup criteria. There were no other reported detections of naphthalene in groundwater during the 1992 RI. Lower concentrations of naphthalene were measured in groundwater samples collected during the 1994 field effort. The maximum measured concentration of naphthalene was 100 µg/L at USGS-4, which exceeds the residential GSI cleanup criterion. No other detected concentration of naphthalene in groundwater was above the generic residential cleanup criteria at the KC-135 Crash Site in 1994. Naphthalene was detected at low concentrations, 16 µg/L and 2 µg/L, in groundwater samples collected from W409S and W408. Naphthalene was not detected in groundwater samples from any other location during the 1994 field effort. Figure 4.3 shows the concentrations of naphthalene measured in groundwater during the 1994 sampling event.

Naphthalene was not analyzed for in groundwater samples collected in 1995. Naphthalene was detected at well W404 (3J µg/L), well W409S (16 µg/L), and USGS-4 (140 µg/L) in 1996. These results also are presented on Figure 4.3. Only the naphthalene concentration detected at USGS-4 exceeds the MDEQ generic GSI residential cleanup criterion.

All sampling events indicate minimal migration of naphthalene in groundwater. Naphthalene was not detected in samples collected from deeper parts of the shallow aquifer during any of the sampling events. All PAH analytical results for groundwater samples collected during the 1994 and 1996 field effort are presented in Appendix B.

4.7 SUMMARY

The KC-135 Crash Site has minimal soil contamination. Concentrations of potential contaminants in soil measured at the KC-135 Crash Site during the 1992 and 1994 investigations were below the generic residential cleanup criteria. The lack of significant concentrations of soil contaminants precludes detected contaminants from becoming COPCs for soils at the KC-135 Crash Site.

Dissolved groundwater contamination has migrated 600 feet downgradient from the source area to W411, and appears to be limited to a region extending from the source area to the northern edge of the aircraft runway. COPCs in groundwater include benzene, toluene, ethylbenzene, total xylenes, the trimethylbenzene isomers and naphthalene. Concentrations of these contaminants exceeded the MDEQ-defined residential cleanup criteria during recent sampling events. However, 1995/1996 groundwater sampling results indicate that the dissolved plume is stable and that concentrations are decreasing over time. Naphthalene is only considered a groundwater COPC because concentrations above generic residential GSI cleanup criteria were measured onsite. Naphthalene is not likely to represent an actual chemical threat since no surface water bodies will be impacted. The fate of these COPCs in groundwater based on their chemical characteristics and site-specific characteristics is examined in Section 6. Emphasis will be given to documenting the effects of natural physical, chemical, and biological processes on contaminant mass, concentration, persistence, toxicity, and mobility.

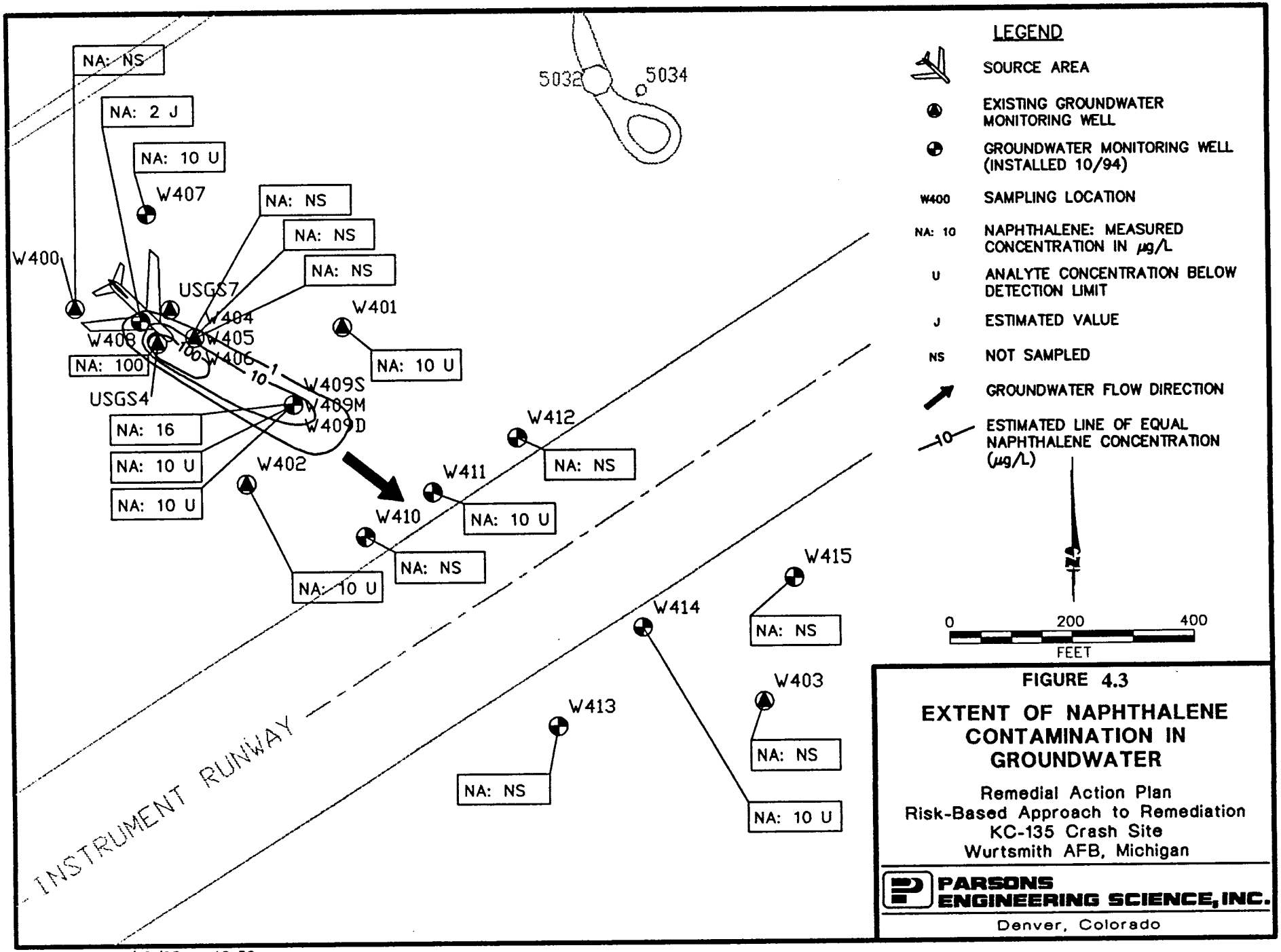

FIGURE 4.3

EXTENT OF NAPHTHALENE CONTAMINATION IN GROUNDWATER

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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SECTION 5

PROPOSED DEGREE OF CLEANUP REQUIREMENTS

Section 4 discusses the nature and extent of contamination at the KC-135 Crash Site and identifies COPCs based on screening criteria (i.e., the most stringent residential criteria). The use of residential cleanup criteria is desired at sites that are planned to be returned to unrestricted use at the completion of the remedial action. Although implementation of RAPs to attain residential cleanup criteria may be desirable and pursued to the extent possible, such cleanups are not required at sites that are not planned or expected to be available for unrestricted activities at the completion of the remedial action. An overview of MDEQ cleanup criteria was included in Section 1.1.1.

The goal of the risk-based approach to remediation is to identify and implement an appropriate remedial action for the KC-135 Crash Site which is protective of the human health, safety, and welfare, and the environment and natural resources. To clearly identify a proposed remedial action for the KC-135 Crash Site, it was necessary to assess what level of risk reduction or type of cleanup would be necessary to protect human health and the environment pursuant to Michigan's Natural Resources and Environmental Protection Act. This evaluation was based on the existing and future exposure potential at the site given the current and foreseeable uses of the site.

5.1 EXPOSURE PATHWAY ANALYSIS

An exposure pathway analysis describes the course a chemical takes from the source of contamination to a potentially exposed individual or sensitive ecological receptor (EPA, 1989). A completed exposure pathway must consist of a source, a release mechanism (e.g., leaching, volatilization), a transport medium (e.g., groundwater, air), a potential human or ecological receptor (e.g., current onsite workers, potential future onsite workers, current and future offsite receptors), a potential exposure point (i.e., locations where receptors could come into contact with site-related contamination), and potential routes of exposure (e.g., ingestion, inhalation). Each of these elements must be present if a particular exposure pathway is to be considered complete. If any one of these elements is missing, the exposure pathway is considered incomplete and there is no risk. Site-related contamination can only present a potential risk to human health, safety, and welfare, and the environment and natural resources if exposure pathways are complete.

A site-specific exposure pathway analysis was completed for the KC-135 Crash Site to determine the likelihood of human contact with site-related contamination. The first step in the exposure pathway analysis was to conduct a qualitative screening of potential pathways. The objective of this screening assessment was to determine

which, if any, exposure pathways are complete (EPA, 1989). Emphasis was given to identifying those pathways where contaminants are released and may migrate within the environment, but humans currently do not come into contact with these chemicals and are not likely to do so in the future. These incomplete exposure pathways were eliminated from further consideration. Exposure pathways that presented negligible risks also were identified. The remedial requirements for the KC-135 Crash Site were not developed to address chemical contamination that does not pose an actual risk to human health, safety, and welfare, and the environment and natural resources.

Those exposure pathways that were considered complete and significant as a result of the qualitative screening assessment were retained for quantitative evaluation. A quantitative evaluation of the type of contaminant released from a site, the impact on environmental media, and the environmental transport and transformation of contaminants following such a release was then conducted for potentially complete exposure pathways. Resultant concentrations of COPCs were then used to evaluate the likely implications to human health, safety, welfare, and the environment and natural resources. The effects of various remedial technologies on eliminating potentially complete exposure pathways, or at least minimizing exposure-point concentrations, was investigated. The remedial action recommended for implementation at the site was designed to meet the site-specific, risk-based remedial requirements.

5.1.1 Conceptual Site Model

A conceptual site model (CSM) is used to define the type of potential exposure to contaminants at and migrating from a site (i.e., used to systematically evaluate the impact of site COPCs in relevant media on potential receptors). The CSM qualitatively describes each onsite release point, the types of contaminant transport and fate mechanisms that may be involved at the site, each group of potentially exposed populations or receptors, and how each receptor group could come into contact with site-related contamination. The CSM is used to summarize existing site characterization data, including assumptions about land and groundwater use, and to complete the qualitative exposure pathway screening assessment.

5.1.1.1 Source and Release Mechanisms

The first component of the CSM is contaminant release screening. The likelihood of release from each source, the nature of the contaminants involved, and the probable magnitude of their release must all be considered (EPA, 1992). The source of chemical contamination at the site was the October 1988 KC-135 aircraft crash. Jet fuel was released to soils when fuel tanks ruptured upon impact and during subsequent emergency response and cleanup activities. Jet fuel apparently percolated through a narrow column of unsaturated soil and collected on the water table. Site characterization activities conducted by the USGS in March 1989 confirmed the presence of measurable amounts of LNAPL in newly installed groundwater monitoring wells (WW Engineering & Science, 1993). LNAPL was not detected in any monitoring wells at the site after June 1991.

Sampling and analysis completed as part of the RI in 1992 and as part of the risk-based field test in 1994 indicated only very low concentrations of fuel hydrocarbons in soil. Subsurface soil sample locations were selected in both sampling events (1992 and

1994) to target soils having the highest potential for soil contamination. It was possible to target these soils for contamination because the release area is well defined. Selecting sample locations in this fashion is more conservatively biased than statistically random strategies. A total of 45 soil samples were collected during the 1992 and 1994 site investigations according to procedures in the KC-135 Crash Site Sampling and Analysis Plan (SAP) for the 1994 focused risk-based investigation contained in the work plan (Parsons ES, 1994). Figures 1.3 and 2.2 show locations of soil samples collected during the 1992 and 1994 sampling events. Appendix B contains a complete list of soil samples and associated depth intervals collected during both sampling events.

Of the 45 soil samples collected from this site, 26 soil samples were collected from the source area, 17 soil samples were collected from downgradient locations, and two were collected from upgradient locations. Only two soil samples had detections of BTEX and PAH contaminants (T-1 from the 1992 investigation and W408 from the 1994 investigation). In 1992, total xylenes were measured at a concentration of 370 µg/kg in temporary well T-1 at a depth interval of 5-7 feet bgs. In 1994, ethylbenzene was measured at a concentration of 21 µg/kg and total xylenes at a concentration of 95 µg/kg in a soil sample from well W408 at a depth interval of 10-12 feet bgs. These are the only concentrations of soil contaminants detected at the KC-135 Crash Site. These concentrations do not approach any of the generic residential soil cleanup criteria (Table 4.2). Based on the data collected to date, it appears that soils are no longer a significant source of chemical contamination at the site, even under the more stringent residential criteria.

Possible release mechanisms from the soil include volatilization and leaching from any remaining pockets of fuel residuals. Chemicals most likely to be released via these mechanisms will be volatile and water soluble. Thus, because the BTEX compounds, the trimethylbenzene isomers, and the naphthalene isomers are volatile and highly to moderately water soluble, they are the most probable chemicals that will be released from fuel residuals. into environmental media at the site. A more detailed evaluation of the nature and magnitude of chemical releases expected at the site is presented in Section 6.

5.1.1.2 Contaminant Environmental Transport and Fate

The second component of the CSM is a screening assessment of contaminant transport, transformation, and fate in the environment following release. This screening step involves identifying each type of transport process that may govern the movement of contaminants within and among environmental media, determining the direction and general rate of contaminant movement from the site, and defining the areas to which contaminants may have been or are expected to be transported (EPA, 1992). This screening analysis is designed only to identify likely pathways of contaminant migration. An in-depth, quantitative evaluation of contaminant transport, transformation, and fate over time and distance at the KC-135 Crash Site is presented in Section 6.

Volatilization of chemicals from contaminated media into the atmosphere is a possible release/transport mechanism at the site. However, the RI report (WW Engineering & Science, 1993) concluded that air quality impacts due to chemical

volatilization was not likely to be significant at this site based on existing site characterization data. This conclusion was further supported by soil gas sampling data collected during the 1994 sampling event. Only very low concentrations of any of the volatile BTEX compounds were measured. No measured concentrations of soil gas exceeded OSHA 8-hour TWA PELs (Section 4.5). Therefore, volatilization from contaminated media and transport into the atmosphere is considered to be an insignificant exposure pathway. This pathway has been eliminated from further consideration.

No fuel hydrocarbons were detected in soil samples collected during both the 1992 and 1994 sampling events at concentrations above generic residential cleanup criteria (Table 4.2 and Sections 4.4 and 5.1.1). The RI report (WW Engineering & Science, 1993) concluded that soils do not present a risk to human health due to direct contact or incidental ingestion of contaminated particulates (i.e., no soil concentrations exceeded generic health-based residential cleanup criteria). The RI report also concluded that soils do not present a risk to the environment and natural resources (i.e., no soil concentrations exceeded generic residential leaching cleanup criteria). Soil data collected in 1994 confirmed this finding. No fuel hydrocarbon was measured in soil samples at concentrations that approached even the most stringent generic residential soil cleanup criteria (Table 4.2). Consequently, contaminant transport from soils is considered to be an insignificant exposure pathway at the KC-135 Crash Site. This pathway has been eliminated from further consideration.

Groundwater data collected as part of the 1992 RI, the 1994 field test, the 1995 NCIBRD sampling event, and the 1996 sampling event (all presented in Section 4) confirm that chemicals have been released into groundwater at the site. October 1994 groundwater elevation data indicate that groundwater flow at the site is toward the southeast (Figure 3.5). The average linear groundwater velocity for the shallow aquifer was calculated to be approximately 0.56 ft/day. Consequently, it would take a minimum of 24 years for contaminated groundwater at the KC-135 Crash Site to migrate to the nearest downgradient base boundary, which is located 4,875 feet to the southeast of the source area. If the effects of natural attenuation processes such as adsorption and biodegradation are not considered during this initial screening step, it is possible that after approximately 24 years site-specific contamination could migrate in groundwater to areas beyond base control. This is an extremely conservative exposure assumption. The actual extent of contaminant transport and the effects of natural attenuation processes on dissolved contaminant concentration, mass, mobility, persistence, and toxicity (i.e., toxicity of chemical could change as it transforms to compounds like carbon dioxide and water) have been quantitatively investigated in Section 6 using both historical monitoring data and numerical fate and transport models. For the purposes of this screening assessment, however, it has been conservatively assumed that dissolved contaminants could migrate in groundwater to areas outside the airfield. Contaminant transport in groundwater is retained as a potential pathway for contaminant movement in the environment for the KC-135 Crash Site.

No bodies of surface water are present in the immediate vicinity of the KC-135 Crash Site. The marshlands of the Au Sable River is located approximately 4,500 feet southeast (downgradient) of the site. Given the linear advective velocity of groundwater at the site (i.e., 0.56 ft/day), it would take contaminated groundwater

over 20 years to migrate to and possibly discharge into the nearest surface water body. Due to the extremely long time frame involved, contaminant transfer to surface water is considered to be an insignificant mechanism controlling contaminant environmental fate at the site. However, the potential for groundwater contaminated with fuel hydrocarbons to migrate significantly downgradient, possibly to surface water, is further investigated in Section 6.

Additionally, detected concentrations of COPCs were measured at only a few deep soil sampling locations. No fuel hydrocarbons were measured in soil at concentrations exceeding even the most stringent residential leaching criteria (Table 4.2). This means that the potential for precipitation to become contaminated due to contact with surface soils is very low. Although most precipitation infiltrates into the groundwater system (Section 3.1), any precipitation runoff is directed to the swale along the runway to two catch basins, the nearest of which is 2,400 feet northeast of the site (Section 3.3). Water from these basins eventually discharge to an area near the Au Sable River. Because surface runoff is not likely to become contaminated, the exposure pathway involving runoff to surface water and sensitive ecological receptors is incomplete. Therefore, environmental fate mechanisms involving surface water have been eliminated from further consideration.

5.1.1.3 Potentially Exposed Populations

The final major component of the CSM for the KC-135 Crash Site is the identification of potentially exposed populations. The objective of this step is to draw upon the results of the contaminant fate screening assessment to qualitatively determine the likelihood and extent of human or ecological population contact with site-related contaminants (EPA, 1992). Land use assumptions are critical to defining the types of receptors that are now present or may be present in the foreseeable future at the KC-135 Crash Site or in immediately adjacent areas and areas outside base property which could be impacted by site-related contamination.

5.1.1.3.1 Current Conditions

As described in Section 3.6.2, the site is currently zoned and maintained as an airfield. The KC-135 Crash Site is within an access-restricted area. The site is not and cannot be used by local populations. The likelihood of trespassing at the site has been severely reduced due to the perimeter fence and its proximity to the runway. Onsite workers conservatively would have very limited contact time with site environmental media. Worker activities are primarily associated with airfield support services, which may include indoor flight support services, vehicle and plane maintenance, grass mowing and runway maintenance. No groundwater is withdrawn from areas within or immediately adjacent to the KC-135 Crash Site to meet potable or nonpotable water requirements. The water supply for base facilities, including the airfield, is currently derived from seven on-base wells located in areas where groundwater contamination does not exist (Section 3.6.4). Extracted groundwater used to meet all base water requirements is chlorinated before being routed to the base water distribution system.

The contaminant release and transport screening assessments showed that groundwater is the only impacted environmental medium at the site that could possibly be involved in complete and significant exposure pathways. All potential exposure

pathways involving air, soil, and surface water have been eliminated as part of the screening assessments. This is consistent with the conclusions of the RI report (WW Engineering & Science, 1993). Therefore, current onsite worker populations could only be exposed to site-related contamination via groundwater. However, since groundwater is not extracted and used by onsite workers to meet potable or nonpotable water demands, these worker populations do not come into contact with site-related contamination. Even if these workers were to engage in runway maintenance and repair, the depth to the groundwater surface (i.e., 10 feet bgs) would make even incidental contact unlikely. Onsite workers could only be exposed to groundwater contamination as a result of highly intrusive construction/excavation activities within the area impacted by the dissolved plume at the KC-135 Crash Site. All exposure pathways to onsite receptors are incomplete under current conditions.

The airfield area is essentially surrounded by the Huron National Forest and other base industrial support areas. All areas downgradient from the airfield and beyond the base property boundaries are zoned as forestry land, and used as public facilities and/or recreation areas (Section 3.6.2 and Figures 3.6 and 3.7). No site-related contamination has migrated more than 600 feet beyond the source area (which is much less than the 4,875 feet to the nearest downgradient base property boundary), as indicated by all sampling events (1992-1996). This means that offsite and off-base populations have not come into contact with site-related contamination. All exposure pathways to offsite populations are incomplete under current conditions. The water supply for off-base populations within the Township of Oscoda consists of two well fields. The northern well field is located 0.5 mile northwest of the southern shore of Van Etten Lake, approximately 3.5 miles northwest of the KC-135 Crash Site. Water produced from this well field is treated by chlorine addition, potassium permanganate addition, aeration, and precipitate settling in retention tanks. The southern well field is located 2 miles west of downtown Oscoda, just south of River Road, approximately 2.5 miles southeast of the KC-135 Crash Site. Water from the southern well field is treated by chlorination only.

5.1.1.3.2 Future Conditions

As described in Section 3.6.3, the site is planned to be maintained as an airfield as part of the final approved land use plans for Wurtsmith AFB (US Air Force, 1993). All groups of receptors and the types of activities in which they will engage will be identical to current conditions. The final land use plan for Wurtsmith AFB also includes replacing the on-base water supply system with local water supply systems (Section 3.6.4). It is anticipated that the base water system will be deactivated in 1996. This is important because it means that all on-base workers will not use on-base groundwater to meet potable or nonpotable water demands. Future onsite worker populations will not come into contact with site-related contamination. As under current conditions, even if these workers were to engage in runway maintenance and repair, the depth to the groundwater surface (i.e., 10 feet bgs) would make even incidental contact unlikely. Future onsite workers could only be exposed to groundwater contamination as a result of deep intrusive construction/excavation activities. The extent of groundwater that may be impacted by site-related contamination in the future depends on contaminant transport, transformation, and fate mechanisms. The anticipated extent of groundwater contamination at and downgradient from the KC-135 Crash Site over time is quantitatively explored in Section 6. These

data are used to determine where future construction workers engaged in excavation activities could incidentally contact contaminated groundwater. However, for all intents and purposes, all exposure pathways to probable onsite receptors should remain incomplete under foreseeable land use conditions. Lease restrictions are currently applied to any land use within the base, and deed restrictions as part of any future land transfers will insure industrial land use (without groundwater pumping) continues.

If site-related contaminants were to be transported with and at the same linear velocity as groundwater (assuming no attenuation), groundwater contamination could migrate beyond the southeast base property boundary within 24 years (Section 5.1.1.2). As discussed previously, all areas downgradient from the KC-135 Crash Site and beyond the base property boundaries are zoned as forestry land, and used as public facilities and/or recreation areas (Section 3.6.2 and Figures 3.6 and 3.7). Although future potential receptors visiting and using these public facilities are not expected to come into contact with groundwater, this potential exposure pathway was investigated in more detail. The objective of this evaluation was to determine the nature and magnitude of remediation activities that may be warranted at the site to eliminate this potential future exposure pathway. This quantitative assessment is presented in Section 6.

5.1.2 Summary of Potentially Completed Exposure Pathways

Table 5.1 summarizes the results of the site-specific exposure pathway screening assessment. The only exposure pathway that may be complete at this site would involve potential future off-base receptor exposure to contaminated groundwater. This exposure pathway was retained based on an extremely conservative, qualitative evaluation of contaminant transport in groundwater. Section 6 presents a quantitative fate and transport analysis using monitoring data and the numerical groundwater flow and contaminant transport model Bioplume II. The effects of transformation processes and other contaminant characteristics that influence contaminant concentration, mass, mobility, persistence, and toxicity are factored into this thorough analysis.

The conclusions of this site-specific exposure pathways analysis are important for several reasons. First, the screening assessment demonstrates that, even under extremely conservative assumptions, current concentrations of fuel hydrocarbons in groundwater at concentrations above generic residential criteria do not pose a risk to human health, safety, and welfare, and the environment and natural resources because no potential exposure pathway is complete. This is important because it shows that active remediation is not necessary to minimize or eliminate any imminent risks. Second, the screening assessment shows that groundwater contamination will take more than 20 years to migrate to the base property boundary or the nearest surface water. This gross estimate of contaminant travel time assumes that all contaminants migrate as fast as groundwater and are not subject to the natural chemical attenuation processes described in Section 6. This is important because it shows that onsite groundwater contamination does not pose an immediate threat to downgradient media or receptors. Third, the screening assessment confirms that only future exposure pathways involving groundwater may be complete and significant for the KC-135 Crash Site. This information helps to focus the range of remedial objectives and requirements.

TABLE 5.1
SUMMARY OF EXPOSURE PATHWAY ANALYSIS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Exposure Medium and Route	Current Conditions		Future Conditions	
	Onsite	Off-Base	Onsite	Off-Base
Soil				
Ingestion of soil	NC[a/]	NC	NC	NC
Dermal contact	NC	NC	NC	NC
Wildlife ingestion	NC	NC	NC	NC
Air				
Inhalation of emissions	NC	NC	NC	NC
Groundwater				
Ingestion	NC	NC	NC	X[b/]
Incidental contact	NC	NC	X	X
Surface Water				
Human ingestion	NC	NC	NC	NC
Wildlife ingestion	NC	NC	NC	NC

[a/] Indicates exposure pathway not complete.

[b/] Indicates exposure pathway has been retained for quantitative evaluation and is used to define site-specific remediation goals.

5.2 PROPOSED TYPE OF CLEANUP

The Air Force intends to implement a remedial action at the KC-135 Crash Site to attain contaminant concentrations that are below generic industrial cleanup criteria, as defined by MDEO (1996). The proposed remedial action also eventually will be sufficient to reduce site concentrations to below generic residential cleanup criteria. However, cleanup to residential standards is neither a requirement or goal of this RAP.

5.2.1 Justification

On the basis of the exposure pathway analysis summarized in Table 5.1, site-related contamination does not pose a risk to human health, safety, and welfare, and the environment and natural resources at this time. However, given the current and planned uses, zoning, and access restrictions enforced at the site, it would be reasonable to pursue implementation of remedial actions that will achieve concentrations equal to or below generic industrial cleanup criteria. This level of cleanup will be more than sufficient to protect onsite workers involved in flight operations support and future construction or remediation workers that could come into incidental contact with groundwater during excavation activities.

The Air Force proposes using MDEQ's generic (Tier 1) industrial groundwater cleanup criteria developed for industrial sites as risk-based target remedial goals for the source area and contaminated groundwater at and downgradient from the KC-135 Crash Site. These criteria were developed to protect onsite workers who may regularly come into direct contact with contaminated groundwater during a normal 8-hour workday (MDEQ, 1996). Although no use of onsite groundwater is planned to meet potable or nonpotable applications, the generic industrial cleanup criteria should be more than sufficient to protect against future risks due to incidental contact with contaminated groundwater.

Generic residential cleanup criteria for groundwater are proposed as the target risk-based cleanup criteria for the downgradient property boundary to protect potential offsite receptors. In many cases, the generic industrial criteria is equivalent to the generic residential criteria (e.g., 5µg/L for benzene). Implementation of a remedial action that will attain residential cleanup criteria in the spill area is neither a requirement or goal of this RAP. However, at the request of MDEQ, the effectiveness of different remedial technologies and approaches to achieve a residential cleanup criteria at the property boundary (and over time for the entire site) will be qualitatively considered when developing an appropriate remedial action for the site to minimize or eliminate potential risks to offsite receptors. The benefits of attaining a residential cleanup criteria at the site may include providing the Air Force long-term flexibility in managing or leasing of the site for unrestricted use and minimizing long-term land use control and monitoring requirements. A comparison of residential and industrial cleanup criteria for each of the groundwater COPCs is shown in Table 5.2.

5.2.2 Risk-Based Cleanup Criteria

The algorithms used to derive generic industrial cleanup criteria are predicated on exposure of workers who spend a significant percentage of their work time outdoors. The current use, including restricted access, of the KC-135 Crash Site is fully

TABLE 5.2
SUMMARY OF CHEMICAL-SPECIFIC CLEANUP CRITERIA
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Compound	Current/Future Onsite Workers: Generic Industrial Cleanup Criteria Groundwater		Current/Future Off-Site Receptors (Applies at Property Boundaries) Generic Residential Cleanup Criteria Groundwater		Chemical-Specific Promulgated ARARs[c] Groundwater	
	Aesthetic[a] (µg/L)	Health-Based[b] (µg/L)	Aesthetic[a] (µg/L)	Health-Based[b] (µg/L)	MCL (µg/L)	MCLG (µg/L)
Benzene	–	119.9	–	29.37	5	0
Toluene	790	4,171	790	1,460	1,000	1,000
Ethylbenzene	74	2,086	74	730	700	700
Total xylenes	280	41,714	280	14,600	10,000	10,000
Naphthalene	–	750	–	260	–	–

Note: Health-based Type C groundwater cleanup criteria for industrial exposure settings were calculated using the algorithms provided by MDNR in Operational Memorandum #14.

Sources: MDNR Interoffice Communication, MERA Operational Memorandum #6, Revision 3, Analytical Detection Level Guidance for Response Activities under Act 307 Rules (dated February 4, 1994); MDNR Interoffice Communication, MERA Operational Memorandum #8, Revision 4, Residential Criteria (dated June 5, 1995); MDNR Interoffice Communication, MERA Operational Memorandum #14, Revision 2, Industrial Cleanup Criteria (dated June 6, 1995);

[a] Aesthetic cleanup criteria designed to eliminate any adverse taste, odor, appearance, or other aesthetic impacts.
[b] Health-based cleanup criteria for groundwater calculated to protect against human health risks due to ingestion of contaminated groundwater used as a drinking water source.
[c] Chemical-specific promulgated ARARs are not defined on the basis of the need to protect human health and the environment.

compatible with the exposure assumptions used to derive generic reasonable maximum exposure (RME) criteria for industrial workers (MDEQ, 1996). No change in the groups of onsite receptors and the types of activities in which they engage are expected in the future because the site will be maintained and operated as an airfield in accordance with the final, approved land use plans for the base (US Air Force, 1993). This means that the future use of the site also is compatible with the RME exposure assumptions used to calculate generic industrial cleanup criteria.

MDEQ (1996) has identified the state of Michigan Drinking Water Standards, established pursuant to Section 5 of the Safe Drinking Water Act (SDWA), as the generic health-based/aesthetic industrial cleanup criteria for groundwater for benzene. The generic industrial cleanup criteria for groundwater for ethylbenzene, toluene, and xylenes has been defined as the aesthetic criteria, which are designed to prevent adverse odor and taste impacts (assuming ingestion as a potable source). As with benzene, the generic aesthetic industrial criteria for these chemicals are equivalent to the most stringent generic residential cleanup criteria. In comparison, MDEQ has established exposure algorithms to be used to derive the health-based industrial criteria for some chemicals (e.g., naphthalene and trimethylbenzene isomers), assuming that groundwater extracted from onsite resources will be used as a source of drinking water (MDEQ, 1996). No shallow groundwater is currently extracted for potable or nonpotable applications from the site or immediately downgradient of the plume. Future land use plans include obtaining potable water for site activities from the Oscoda Township water supply system, which uses groundwater drawn from the shallow aquifer at a well field located on the south side of the Au Sable River, which is south of the base. Although shallow groundwater will not be extracted to meet potable or nonpotable water demands during future airfield-related repair or construction efforts, workers could inadvertently contact contaminated groundwater during excavation activities. Health-based cleanup criteria calculated to be protective of risks due to regular ingestion of contaminated groundwater should be more than sufficient to protect workers from risks due to incidental dermal contact with contaminated groundwater.

Therefore, the conservative generic industrial criteria will be more than sufficient to protect both current and foreseeable future onsite human receptors. Implementation of a remedial action designed to be protective of onsite industrial workers will be sufficient to protect the health of workers that may engage in onsite excavation activities. Although Section 5.1 illustrates that no exposure pathway to onsite workers has been or will likely be complete, the degree of remediation implied by the generic industrial cleanup criteria will ensure that, even in the event that an exposure pathway were to be completed, the site would not pose a risk to human health, safety, and welfare, and the environment and natural resources.

Off-base property is located 4,875 feet to the south and southeast (downgradient) of the airfield. Land uses in these areas have been conservatively assumed to be unrestricted and beyond the scope of the exposure controls that could be established on base-controlled property. Residential cleanup criteria will be achieved for media affected by KC-135 contamination at all downgradient property boundaries to ensure protection of potential current and future offsite receptors.

5.3 REMEDIATION REQUIREMENTS

Table 5.2 summarizes the relevant risk-based cleanup criteria developed by the MDEQ for each of the COPCs in groundwater at the KC-135 Crash Site. Health-based industrial criteria which are the most appropriate cleanup levels to provide the desired level of risk reduction for onsite workers under the current and foreseeable future land use, zoning, and access conditions, for each of the groundwater COPCs are presented for comparison. Health-based values were developed using MDEQ-defined exposure algorithms and available toxicity data (Micromedex, 1996). However, in accordance with MDEQ guidance, Drinking Water Standards or aesthetic criteria could have primacy over health-based criteria. The degree of cleanup implied by drinking water or aesthetic standards is more than is necessary to protect human health, safety, and welfare and the environment and natural resources given current and foreseeable exposure potential at the KC-135 Crash Site. The Air Force notes that imposing compliance with these types of standards for groundwater at this site is not consistent with with a "risk-based" approach to remediation. The Air Force is concerned that MDEQ has, by identifying standards more stringent than health-based criteria developed from industrial exposure algorithms, prescribed a level of cleanup that is not tied to risk reduction. The current level of contamination at the site does not pose a risk to onsite or off-base receptors. Compliance with generic industrial cleanup criteria is being pursued as a means to reduce the types of restrictions on groundwater use that would be necessary. When generic industrial cleanup criteria can be achieved at all points at the site, the groundwater could be used to meet industrial applications, if desired.

No site-related contaminants exceeding generic residential cleanup criteria will be allowed to migrate beyond the site boundaries. Because of this requirement, this RAP must demonstrate that current concentrations of COPCs will not migrate to the base boundaries at levels above generic residential criteria. The RAP also must demonstrate that a industrial remedy will be protective of off-base receptors and resources. This quantitative evaluation is completed in Section 6.

Table 5.3 identifies, by environmental medium, the KC-135 Crash Site COPCs that were measured during the 1992, 1994, 1995, or 1996 sampling events at concentrations in excess of generic industrial cleanup criteria. Benzene was measured in groundwater in both 1992 and 1994 at concentrations above the generic industrial cleanup criterion of 5µg/L. However, benzene was measured at all sampling locations in 1995 and 1996 below the generic industrial cleanup criterion of 5µg/L.

Toluene was measured during all sampling events at concentrations above the generic industrial (aesthetic) cleanup criteria. However, it is important to note that toluene was not measured in site groundwater at concentrations near or above its calculated industrial health-based cleanup criteria. Ethylbenzene also was measured in groundwater during each of the sampling events at concentrations above the generic industrial (aesthetic) cleanup criteria. Ethylbenzene was not measured in groundwater at concentrations above the industrial health-based criterion. Similarly, total xylenes were measured during all sampling events at concentrations above the generic industrial (aesthetic) cleanup criteria only. No concentration of total xylenes in groundwater exceeded the industrial health-based cleanup criteria. Compliance with the aesthetic industrial cleanup criteria is not strictly required for groundwater at this site due to the

TABLE 5.3
COMPARISION OF GROUNDWATER COPC CONCENTRATIONS TO CHEMICAL-SPECIFIC STATE CLEANUP CRITERIA
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

	Industrial Cleanup Criteria (ug/L)		Maximum Sampling Data, by Year			
	Generic[a/]	Health-Based [b/]	1992	1994	1995	1996
Benzene	5	120	280	89	0.4 U	3.8
Toluene	790	4171	3700	2100	6300	1100
Ethylbenzene	74	2086	2400	520	330	570
Xylenes	280	41714	9700	2500	3300	2600
Naphthalene	750	750	120	100	--	--
1,2,4-Trimethylbenzene	86	86	--	580	--	630
1.3.5-Trimethylbenzene	65	65	--	100	--	210

a/ MCL, aesthetic, or health-based, whichever is more stringent as per MDEQ.

b/ Heath-based cleanup criteria for groundwater calculated to protect against human health risks due to worker ingestion of contaminated groundwater used as a drinking water source.

current and proposed future restrictions on groundwater use. Prevention of adverse taste, odor, and other aesthetic impacts should only be strictly required for groundwater to be used as a potable source of water. Health-based industrial cleanup criteria are more than sufficient to protect onsite workers from risks due to incidental dermal contact with contaminated groundwater.

Although measured above the generic GSI residential criterion, naphthalene has not been measured in site groundwater above its generic industrial criterion of 750µg/L. This means that no further action is warranted for naphthalene in groundwater as long as this compound is not expected to migrate to downgradient surface water at concentrations above the generic GSI value of 29µg/L. However, both isomers of trimethylbenzene (i.e., 1, 2, 4-TMB and 1, 3, 5-TMB) were measured in 1994 and 1996 above their generic industrial cleanup criteria.

5.4 Summary

Based on a comparison of available groundwater sampling data to MDEQ (1996) generic industrial cleanup criteria, the site-specific remediation target chemicals or chemicals of concern (COCs) that need to be addressed during the remedial action include toluene, ethylbenzene, xylenes, 1, 2, 4-TMB, and 1, 3, 5-TMB. Benzene and naphthalene strictly do not qualify as COCs for groundwater at the site because none of these chemicals were measured at concentrations above generic industrial cleanup criteria during the most recent sampling events. However, to verify that no site-related contamination will migrate to the downgradient base boundaries at concentrations above generic residential cleanup criteria, all BTEX compounds, naphthalene, and the trimethylbenzene isomers were considered in the quantitative chemical fate analysis in Section 6.

SECTION 6

CHEMICAL FATE AND TRANSPORT ASSESSMENT

6.1 INTRODUCTION

Section 3 of this RAP is devoted to describing the physical site conditions. Section 4 summarizes the nature and extent of site-related contamination. Section 5 of the RAP describes the proposed degree of cleanup required to protect human health, welfare, and safety, and the environment and natural resources. Section 5 also identifies the COCs for the site that must be addressed by remedial activities to assure that generic industrial cleanup criteria can be achieved at the site.

This section provides estimates of the effect natural attenuation processes have had and will have on the extent of migration, mass, persistence, and toxicity of each of the groundwater/COCs. Although benzene and naphthalene were not measured during recent sampling events at concentrations exceeding generic industrial cleanup criteria (Section 5.3), the environmental fate of each of the COPCs will be quantitatively investigated in this section. This approach is appropriate for two reasons. First, this analysis is necessary to determine if site-related contamination will migrate to and beyond the nearest base boundary at concentrations exceeding generic residential cleanup criteria. All of the COPCs were detected in groundwater at concentrations above at least one of the generic residential cleanup criteria (Table 4.2). Consequently, this analysis explores whether existing groundwater concentrations of each of the COPCs will be sufficient to protect potential off-base receptors. Second, the degree to which COCs such as xylenes and 1, 3, 5-TMB can be biodegraded in groundwater can be positively and negatively affected by the presence of other hydrocarbons. Therefore, this section of the RAP considers the impact of different natural chemical attenuation processes, especially biodegradation, on all COPCs as well as on individual chemical species.

As discussed in Section 1, one of the objectives of this RAP is to evaluate the effectiveness of remedial options that could be implemented at the KC-135 Crash Site to protect human health, safety, and welfare, the environment, and natural resources. As noted in the screening exposure assessment in Section 5, the only exposure pathway that could be completed in the future involves exposure of off-base receptors to contaminated groundwater that migrates to and beyond the base property boundary. This exposure pathway was retained on the basis of several very conservative assumptions about contaminant transport. It is very likely that this exposure pathway will never be complete because site-related contaminants will be effectively attenuated in groundwater by natural processes before appreciable downgradient migration can occur. Thus, the persistence, mobility, and ultimate environmental fate of each of the groundwater COPCs must be described and evaluated when determining what type of

remedial action may be warranted to attain the desired degree of cleanup. This section summarizes and interprets site characterization data used to document the effectiveness of natural chemical, physical, and biological processes which are minimizing COPC migration and reducing mass over time and distance.

6.2 OPERATIVE MECHANISMS OF CONTAMINANT ATTENUATION

Understanding the fate of each of the COPCs in environmental media is critical to evaluating and predicting contaminant distribution patterns. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater. The following paragraphs present a brief overview of the major chemical characteristics that define the fate of JP-4 jet fuel in groundwater at the KC-135 Crash Site. These chemical characteristics ultimately determine if the mass of fuel hydrocarbon compounds in the environment can be eliminated or rendered immobile by natural processes. The positive effects of these natural processes on reducing the actual mass of COPCs and/or minimizing the extent of COPCs migration in groundwater has been termed natural chemical attenuation.

6.2.1 Chemical Characteristics and Mass Transport Mechanisms

6.2.1.1 Solubility

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. The BTEX compounds are more highly water soluble than the PAHs or trimethylbenzne isomers, which have a fairly limited water solubility. For example, the water solubilities of benzene, toluene, ethylbenzene, and the various xylene isomers are above 1,700 mg/L, 500 mg/L, about 160 mg/L, and about 145 to 175 mg/L, respectively (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Verschueren, 1983; Isnard and Lambert, 1988; Howard, 1990). Consequently, even though the BTEX compounds may make up a low mass fraction of the initial source of contamination, these compounds preferentially leach from residual source contamination into groundwater and migrate as dissolved contamination (Lyman *et al.*, 1992).

In contrast, other hydrocarbons commonly found in JP-4 jet fuel are much less soluble than the BTEX compounds. For example, the water solubility of naphthalene is about 30 mg/L. The water solubility of the trimethylbenzene isomers range from 4 to 90 mg/L. The differences in solubility between the BTEX and these other compounds is the cause of the disproportionate effect that the BTEX compounds can have on groundwater quality in comparison to other hydrocarbons commonly found in JP-4 jet fuel. Although JP-4 jet fuel can be comprised of about 4 percent of BTEX compounds by weight, the BTEX compounds can account for at least 80 percent of the total hydrocarbons dissolved in groundwater (ES, 1993a). Although the higher molecular weight aromatic compounds (such as PAH compounds) usually make up a greater percentage of the initial source of hydrocarbon contamination, they represent only a small fraction of the contaminant mass that can dissolve into groundwater. Usually these heavier compounds become adsorbed or occluded in the soils.

6.2.1.2 Sorption

Another chemical characteristic that can govern how a compound is attenuated in soil and groundwater is its sorptive properties. 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. The BTEX compounds are less sorptive than other petroleum hydrocarbons. Benzene does not sorb readily to soil and is considered the most mobile of the BTEX compounds. Toluene sorbs more readily to soil than benzene, but is still very mobile. Ethylbenzene sorbs more strongly to soil than benzene but less strongly than toluene. Of all the BTEX compounds, xylenes sorb most strongly to soil, but can still leach from unsaturated soil and dissolve into and migrate slowly in groundwater (Abdul *et al.*, 1987). In comparison, heavier hydrocarbons such as naphthalene or the trimethylbenzene isomers sorb more strongly to the soil matrix and migration is limited in both soil and groundwater (Verschueren, 1983).

The organic carbon content of both unsaturated and saturated soils was measured during the 1994 soil sampling event. The total organic carbon content ranged from less than 0.05 percent to 0.09 percent (Appendix B). The measured background concentration of total organic carbon in soils was determined to be less than 0.05 percent at W407. Organic compounds sorb to that portion of the soil matrix that is composed of organic carbon and to fine clay particles. Thus, less than 0.0005 kg of organic carbon per kg of soil is available to sorb contaminants. This level of organic carbon is not likely to significantly retard chemical migration in groundwater. For soils containing less than 0.1 percent organic carbon, the silt and clay fraction of the soil may dominate the sorption process (Mehran, *et al.*, 1987). The relatively uniform, medium-grained sands found at this site contain a very small silt/clay fraction which should also minimize contaminant sorption. The effect of sorption on contaminant velocity in groundwater is described in subsequent sections.

6.2.1.3 Volatility

The volatility of each of the COPCs also can affect how it behaves in the environment. All of the BTEX compounds are classified as volatile chemicals because they have vapor pressures in excess of 0.1 millimeter of mercury (mm Hg). Benzene is the most volatile of the BTEX compounds, with a vapor pressure of about 95 mm Hg, and xylenes are the least volatile with vapor pressures between 6 and 9 mm Hg. The PAH compound naphthalene is not considered a volatile chemical. Naphthalene has a vapor pressure below 0.1 mm Hg. Similarly, the trimethylbenzene isomers are not considered volatile with vapor pressures ranging from 2 to 2.4 mm Hg.

Volatilization was not directly investigated as a mass transport mechanism at the KC-135 Crash Site. However, as described in Section 4, no significant soil gas concentration of any of the volatile COPCs was measured at the site. The lack of soil contamination, the isolated nature of any possible remaining pockets of fuel residuals, and the low concentrations of dissolved contamination in groundwater have apparently minimized the importance of this process at the site. This is why the volatilization pathway was not identified as a major risk element at the site (Section 5.1).

6.2.1.4 Discussion

Solubility and sorptive characteristics are important chemical characteristics to consider when assessing whether hydrocarbon contamination in groundwater at the KC-135 Crash Site may present an unacceptable risk to human health and the environment. Chemicals characterized by high water solubility and low sorptive properties, such as the BTEX compounds, can be rapidly introduced into and transported with groundwater. Consequently, because the BTEX compounds are more mobile, they may drive the type and magnitude of remediation necessary to the isolate the contamination and protect downgradient receptors from potential risks due to exposure to these chemicals. Less soluble chemicals that also are effectively sorbed to the soil matrix such as naphthalene and the trimethylbenzene isomers are not as mobile and are more likely to be isolated in and near the initial source of contamination.

The nature and extent of contamination at the KC-135 Crash Site as defined to date can be explained in part based on the solubility and sorptive properties of each of the COPCs. The BTEX compounds are highly water soluble and do not sorb strongly onto soil. Therefore, these chemicals should preferentially partition from fuel residuals and dissolve into and migrate with groundwater. Figure 4.1 illustrates the extent of benzene, toluene, ethylbenzene, and total xylene contamination (by individual chemical species) in groundwater in 1994. Figure 4.2 illustrates the nature and extent of these same compounds in 1996. Benzene, which is the least sorptive (i.e., most mobile) of the BTEX compounds, has migrated further downgradient from the spill area than any of the other compounds. Elevated concentrations of toluene, which sorbs less readily than benzene but more readily than ethylbenzene or xylenes, were measured at sampling locations about 300 feet downgradient from the source. In comparison, elevated concentrations of ethylbenzene and xylenes of the same magnitude as toluene were measured only at sampling locations about 150 feet downgradient from the source area. This spatial differentiation of each of the BTEX compounds in groundwater is consistent with their sorptive properties. Benzene travels farther because it sorbs less than the other compounds; ethylbenzene and xylenes are effectively attenuated near the source because these compounds sorb more strongly to the aquifer matrix.

6.2.2 Biodegradation of Fuel Hydrocarbon Compounds in Groundwater

The relative solubility and sorptive nature of a chemical can govern the effectiveness of nondestructive attenuation processes at the KC-135 Crash Site. Nondestructive attenuation processes can be described as those physical and chemical processes that may prohibit 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. These processes must be evaluated when determining whether a compound poses an actual risk to human health and the environment. If the contaminant is not likely to reach a potential receptor, the contaminant poses no risk to that receptor.

Destructive attenuation processes result in the permanent removal of contaminant mass from the environment. Documenting and distinguishing the effects of destructive attenuation processes, such as biodegradation, from nondestructive attenuation processes is critical to evaluating the potential for these processes 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 how amenable the chemical is to biodegradation and whether the site is characterized by physical, chemical, and biological conditions favorable to such processes.

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of JP-4 jet fuel, including the BTEX compounds and the PAHs, under both aerobic and anaerobic conditions (e.g., Jobson *et al.*, 1972; Perry, 1977; Atlas, 1981, 1984, 1988; Gibson, 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, 1994; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Bauman, 1991; Borden, 1991; Brown and McFarland, 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; ES, 1994a Parsons ES, 1994b, 1994c, 1995). 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 hydrocarbons generally contain microbial populations competent to facilitate biodegradation reactions (Zobell, 1946; Litchfield and Clark, 1973; Borden, 1994; Seech *et al.*, 1994; Simpkin and Giesbrecht, 1994). The chemical basis for the biodegradation of the fuel COPCs is described in more detail in Section 6.4, where geochemical data relevant to documenting biodegradation at the field scale at the KC-135 Crash Site are presented.

6.3 EVIDENCE OF CONTAMINANT BIODEGRADATION OVER TIME AND DISTANCE

The first step in determining whether site data indicate that COPCs are biodegrading in groundwater at the KC-135 Crash Site was to compare analytical data on the nature and extent of site contamination collected in December 1992, January 1993, October 1994, December 1995, and October 1996. The purpose of this comparison was to assess the evidence of field-scale contaminant mass loss. Changes in the nature and extent of contamination at a site over time that cannot be explained by physical processes (e.g., transport in groundwater) may be an indication that contaminants are biodegrading at the site.

6.3.1 Observed Contaminant Loss from Groundwater

The concentrations of each of the COPCs measured in groundwater at several sampling locations during recent sampling events were substantially less than those measured at the same sampling locations during earlier sampling events completed as part of the RI. For example, the maximum concentration of benzene measured at USGS-4 in 1993 was less than 500 µg/L [note: the analytical data reported for this sample suggests that the reporting limit for benzene was 500 µg/L after dilution] (WW Engineering & Science, 1993; Appendix B). Benzene was detected at 4.4 µg/L at the same sampling location in 1994 (Figure 4.1; Appendix B). Benzene was further reduced to below detection by October 1996 at ML14 near USGS-4. The maximum concentration of benzene measured at the site in December 1992 was 280 µg/L at

temporary sampling location T-13. Benzene was detected at W409S, which is adjacent to temporary sampling location T-13, at a concentration of 89 µg/L in October 1994. This was the maximum concentration of benzene measured at the site during the 1994 investigation. The maximum concentration of benzene detected in October 1996 was 3.8µg/L at W409S. An overall decreasing trend in benzene concentrations was observed at the leading edge of the plume, also. In 1994, W411 was installed near the former location of the 1992 temporary well T-16. Temporary well T-16 was located near the leading edge of the BTEX plume in 1992. Benzene was detected in temporary well T-16, at 28 µg/L, in 1992. In 1994 benzene was detected at 1 µg/L in well W411. In 1996, benzene was not detected at well W411.

The maximum concentration of toluene measured at USGS-4 in 1993 was 3,700 µg/L (WW Engineering & Science, 1993; Appendix B). Toluene was detected at 2,100 µg/L at the same sampling location in 1994 (Figure 4.1; Appendix B). Toulene was detected at 1,100µg/L at this sampling location in October 1996 (Figure 4.2; Appendix B). The analytical results for USGS-4 for toluene represent the maximum concentrations of toluene measured at the site during all sampling events (Table 4.2). Toluene also decreased from a concentration of 420 µg/L at W404S (near the spill area) in January 1993 to a concentration of 1.6 J µg/L in October 1994.Toulene was not detected at W404S in October 1996. Toluene also was not detected at the leading edge of the BTEX plume in either temporary well T-16 or W411 during the 1992, 1994, or 1996 sampling events.

The maximum concentration of ethylbenzene measured at USGS-4 in 1993 was 2,400 µg/L (WW Engineering & Science, 1993; Appendix B). Ethylbenzene was detected at 520 µg/L at the same sampling location in 1994 (Figure 4.1; Appendix B). Ethylbenzene was measured at this sampling location at 570µg/L in October 1996. The analytical results for USGS-4 for ethylbenzene represent the maximum concentrations of ethylbenzene measured at the site during all sampling events described herein (Table 4.2). Ethylbenzene also decreased from a concentration of 130 µg/L at W404S (near the spill area) in January 1993 to a concentration of 54 µg/L in October 1994. By 1996, the concentration of ethylbenzene had been further reduced to 30µg/L at W404S Ethylbenzene was not detected at the leading edge of the BTEX plume during any of the 1992-1996 sampling events.

The maximum concentration of total xylenes measured at USGS-4 in 1993 was 9,700 µg/L (WW Engineering & Science, 1993; Appendix B). Total xylenes were measured at 2,500 µg/L at the same sampling location in 1994 (Figure 4.1; Appendix B). By 1996, total xylenes were measured at a concentration of 2,600µg/L at USGS-4. As with all the other BTEX compounds, the analytical results for USGS-4 for total xylenes represent the maximum concentration of total xylenes measured at the site during each of the sampling events (Table 4.2). Total xylenes also decreased from a concentration of 700 µg/L at W404S (near the spill area) in January 1993 to a concentration of 66 µg/L in October 1994. By 1996, the concentration of xylenes at W404S was 44µg/l. As was the case for toluene and ethylbenzene, total xylenes were not detected at the leading edge of the plume in 1992, 1994, or 1996.

6.3.2 Discussion of Field-Scale Contaminant Mass Losses

The first line of evidence for natural attenuation of contaminants at the KC-135 Crash Site is the decreasing concentrations of each COPC measured at the same groundwater sampling locations over time. Comparison of available groundwater quality data indicate that the dissolved fuel hydrocarbon compounds are being attenuated. Benzene concentrations decreased throughout the plume by almost 98 percent in approximately 22 months (i.e., 1992-1994, about 660 days). From 1994 to 1996, benzene concentrations were reduced an additional 96 percent. Toluene concentrations decreased by 43 percent in the source area between January 1993 and October 1994. Between October 1996, toulene concentrations further decreased by 48 percent. Ethylbenzene concentrations decreased by 78 percent in the source area between 1993 and 1994. Additionally, total xylenes concentrations decreased by 74 percent in the source area between 1993 and 1994. The difference in the amount of chemical mass being removed from groundwater underlying the source area and from groundwater downgradient from the crash site is significant because it suggests that the dissolved plume may be shrinking in size. Decreases in contaminant concentrations in the groundwater at the KC-135 Crash Site are likely due to a combination of dilution during contaminant transport and destruction via aerobic and anaerobic biodegradation.

The second line of evidence of natural attenuation of contaminants is the lack of significant plume migration over time. Table 6.1 summarizes how far each of the COPCs should have migrated downgradient from the source area between January 1993 and October 1994 and between January 1993 and October 1996 based on the linear advective groundwater velocity and their sorptive characteristics. Field data on groundwater velocity and total organic carbon content was combined with chemical-specific octanol-carbon partition coefficients (K_{oc}) to estimate contaminant velocities and expected travel distances. The BTEX compounds should have migrated approximately 300 to 340 feet downgradient between 1993 and 1994 and an additional 350 feet by 1996. However, no detected concentrations of any of the chemicals were measured at sampling location W414, which is about 300 feet downgradient from T-13 and W411 (Figures 4.1 and 4.2). The areal extent of the dissolved fuel hydrocarbon plume does not appear to be expanding (Figure 6.1). Because no substantial contaminant migration was observed at the site, the dissolved plume appears to be effectively attenuated and may actually be shrinking. This observation is further supported by the reduction in concentration of COPCs in the source area.

The lack of observed contaminant migration suggests that mass removal processes such as biodegradation are operating at the site. In fact, the dissolved plume could not remain constant in areal extent over time in the absence of contaminant mass removal processes.

6.3.3 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 the KC-135 Crash Site. Comparison of December 1992/January 1993 to October 1994 and October 1996 data suggest that the COPCs are being removed from saturated soils and groundwater by mechanisms other than dispersion,

TABLE 6.1
OBSERVED VS. EXPECTED CONTAMINANT TRAVEL DISTANCES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Compound	Advective Groundwater Velocity (ft/day)	Partition Coefficient (L/kg)[a/]	Contaminant Velocity (ft/day)[b/]	Expected Travel Distance (1/93-10/94) (ft)	Expected Travel Distance (1/93-10/96) (ft)	Observed Travel Distance (1/93-10/96) (ft)
Benzene	0.56	0.02	0.52	341	718	Shrinking Plume
Toluene	0.56	0.06	0.47	308	650	Shrinking Plume
Ethylbenzene	0.56	0.05	0.48	317	668	Shrinking Plume
Total xylenes	0.56	0.06	0.46	302	637	Shrinking Plume
Naphthalene	0.56	0.27	0.29	190	399	Shrinking Plume
TMB Isomers	0.56	0.32	0.27	177	373	Shrinking Plume

[a/] Partition coefficient based on fractional organic carbon content of = 0.0005 and octonal-carbon partition coefficient (K_{oc}) values in Montgomery, 1996.

[b/] Calculated using relationship: velocity of groundwater/retardation coefficient. The retardation coefficient is defined as [1+(((1-n)/n)*density soil*partition coefficient)], where n is the porosity of the medium.

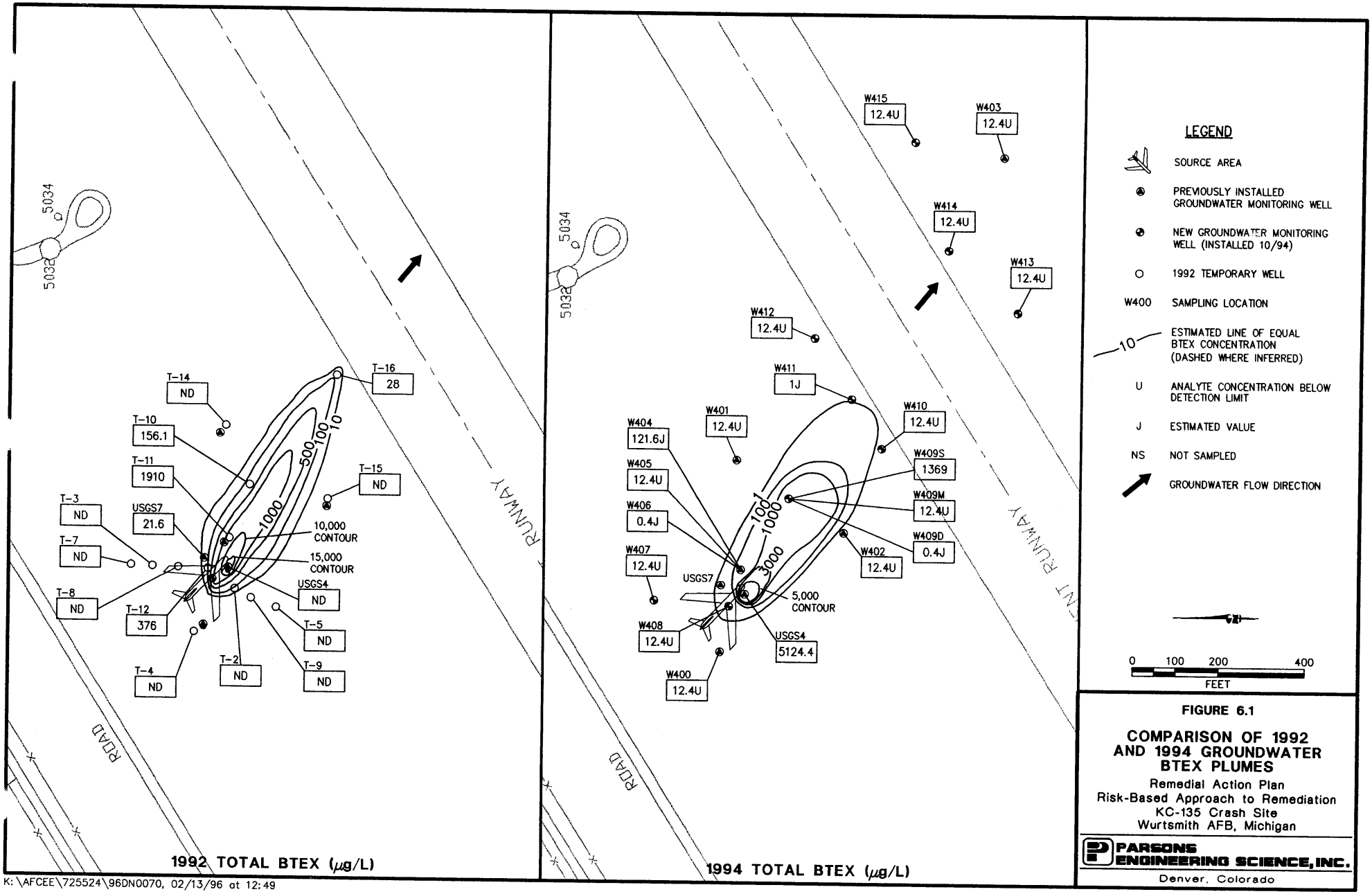

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FIGURE 6.1

COMPARISON OF 1992 AND 1994 GROUNDWATER BTEX PLUMES

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

advection, and sorption. To quantify these effects, a spatial regression technique (Buscheck and Alcantar, 1995) was used to estimate the site-specific biodegradation rates of each of the COPCs in saturated soil and groundwater based on analytical data.

It is commonly assumed that biodegradation rates for fuel hydrocarbon compounds in saturated media can be approximated by a first-order decay constant. The rates of biodegradation of COPCs can be calculated and compared in this manner because the biodegradation processes for each is similar (Chapelle, 1993). A spatial regression analysis of contaminant concentration data is presented in Appendix D. The slope of the best fit regression line through measured concentrations versus distance is used to estimate the amount of distance that each of the compounds was attenuated that cannot be explained by advection, dispersion, and sorption (Buscheck and Alcantar, 1995). This spatial regression technique is more clearly described in Appendix D.

Table 6.2 summarizes the calculated biodegradation rates for total BTEX, benzene, toluene, ethylbenzene, total xylenes, naphthalene, 1,2,4-TMB, and 1,3,5-TMB based on analytical data collected at the KC-135 Crash Site. These rates express how much of the contaminant mass is currently being removed from the saturated media that cannot be explained by nondestructive attenuation processes such as dispersion and adsorption. The effects of both aerobic and anaerobic destructive attenuation processes are included in these site-specific biodegradation rate constant estimates. It is important to point out that these rates may change over time and can be recalculated after each long-term monitoring event.

The calculated biodegradation rate for total BTEX compounds in saturated soil and groundwater at the KC-135 Crash Site was 0.0071 day^{-1} based on 1992/1993 RI data, which compares favorably to the saturated soil and groundwater degradation rates for benzene, toluene, ethylbenzene, and total xylenes found in the technical literature. This rate apparently has increased to 0.009 day^{-1} based on the October 1996 sampling data. The 1992/1993 biodegradation rate of benzene was calculated to be 0.003 day^{-1}, slightly less than that of total BTEX. No biodegradation rate for benzene could be estimated from 1996 data since benzene was not detected except in one well. The reported biodegradation rates of benzene in saturated soils and groundwater range from 0.0009 day^{-1} to 0.069 day^{-1} (Howard *et al.*, 1991). Biodegradation rates for toluene can be faster than benzene, ranging from 0.025 day^{-1} to 0.098 day^{-1} (Howard *et al.*, 1991). The site-specific degradation rate of toluene in groundwater at the KC-135 Crash Site, based on 1992/1993 data, was estimated to be 0.008 day^{-1}, which is faster than the site-specific biodegradation rate for benzene. This rate increased to 0.0095 day^{-1} as of October 1996.

The biodegradation rates of ethylbenzene in saturated soils and groundwater can be slower or similar to toluene, with rates reported from 0.003 day^{-1} to 0.1 day^{-1} (Howard *et al.*, 1991). The site-specific biodegradation rate of ethylbenzene in groundwater at the KC-135 Crash Site in 1992/1993 was estimated to be 0.008 day^{-1}, which is identical to the calculated biodegradation rate of toluene in groundwater at the KC-135 Crash Site. Similar biodegradation rates for ethylbenzene were estimated from October 1996 sampling data. The reported biodegradation rates of total xylenes in saturated media range from 0.002 day^{-1} to 0.05 day^{-1} (Howard *et al.*, 1991). The site-specific 1992/1993 and 1996 biodegradation rate for total xylenes in groundwater was

TABLE 6.2
COMPOUND-SPECIFIC BIODEGRADATION RATES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Compound	Contaminant Velocity (ft/day)	Site-specific Biodegradation Rate - 1993 (1/day)[a/]	Site-specific Biodegradation Rate - 1996 (1/day)[a/]	Literature-reported Biodegradation Rates (1/day)[b/]
Total BTEX	0.43	0.007	0.009	0.0009 - 0.23
Benzene	0.52	0.003	Not available	0.0009 - 0.069
Toluene	0.47	0.008	0.0095	0.025 - 0.098
Ethylbenzene	0.48	0.008	0.008	0.003 - 0.1
Total xylenes	0.46	0.010	0.010	0.002 - 0.05
Naphthalene	0.29	Not available	0.018	0.002 - 0.3
1,2,4-trimethylbenzene	0.27	Not available	0.0048	Not available
1,3,5-trimethylbenzene	0.27	Not available	0.004	Not available

[a/] Rate calculated using methods described in Appendix D.

[b/] Based on biodegradation rates reported in Howard *et al.*, 1991

calculated to be 0.01 day^{-1}. Based on these calculations, total xylenes are biodegrading faster than any of the other BTEX compounds at the KC-135 Crash Site. Site-specific calculations are presented in Appendix D. Based on these data, the site-specific half-lives of benzene, toluene, ethylbenzene, and total xylenes in saturated soil and groundwater at the KC-135 Crash Site in 1992/1993 were 230 days, 87 days, 87 days, and 69 days, respectively. In 1996, the half-lives for toulene, ethylbenzene, and xylenes was 72 days, 82 days, and 69 days, respectively.

October 1996 data were used to estimate site-specific biodegradation rates for the other COPCs (i.e., naphthalene, 1,2,4-TMB, and 1,3,5-TMB). Analytical data from the 1992/1993 R1 sampling event were either insufficient or not available to estimate biodegradation rates for these compounds. As Table 6.2 shows the biodegradation rates for these 3 COPCs are slightly slower than for the BTEX compounds. The estimated half-lives for naphthalene, 1,2,4-TMB, and 1,3,5-TMB are 383 days, 145 days, and 173 days, respectively. The biodegradation rates for the trimethylbenzene isomers are expected to increase as the groundwater becomes more aerobic as fuel hydrocarbon mass decreases. These compounds can be rapidly biodegradable under oxic conditions.

6.4 EVIDENCE OF CONTAMINANT BIODEGRADATION VIA MICROBIALLY CATALYZED REDOX REACTIONS

Available site data suggest that the COPCs are biodegrading in saturated soils and groundwater at the KC-135 Crash Site. There were measurable decreases in the concentrations of each compound in groundwater between the December 1992/January 1993 RI sampling event the October 1994 sampling event, and the October 1996 sampling event. Spatial regression techniques were applied to calculate site-specific biodegradation rates for each compound. On the basis of this evaluation, it can be inferred that the fuel hydrocarbon compounds are biodegrading at the KC-135 Crash Site at rates consistent with those reported in the technical literature.

There is a third line of evidence that can be used to show that these contaminants are biodegrading in saturated soil and groundwater at the KC-135 Crash Site. Analytical data on potential electron acceptors can be used as geochemical indicators of biodegradation (Salanitro, 1993; McCallister and Chiang, 1994; Wiedemeier *et al.*, 1995; Borden *et al.*, 1995). Reductions in the concentrations of oxidized chemical species that are used by microorganisms to facilitate the oxidation of fuel hydrocarbon compounds within contaminated media is another indication that contaminants are biodegrading. The amount of potential electron acceptors available to participate in contaminant biodegradation reactions can be used to estimate the total contaminant mass that can be biodegraded over time at this site. Coupled with the biodegradation rates described earlier, this information can be used to predict how much and how quickly fuel hydrocarbon compounds can be permanently removed from saturated soils and groundwater at the KC-135 Crash Site by natural processes.

6.4.1 Relevance of Redox Couples in Biodegradation

Microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of the fuel hydrocarbon compounds is the

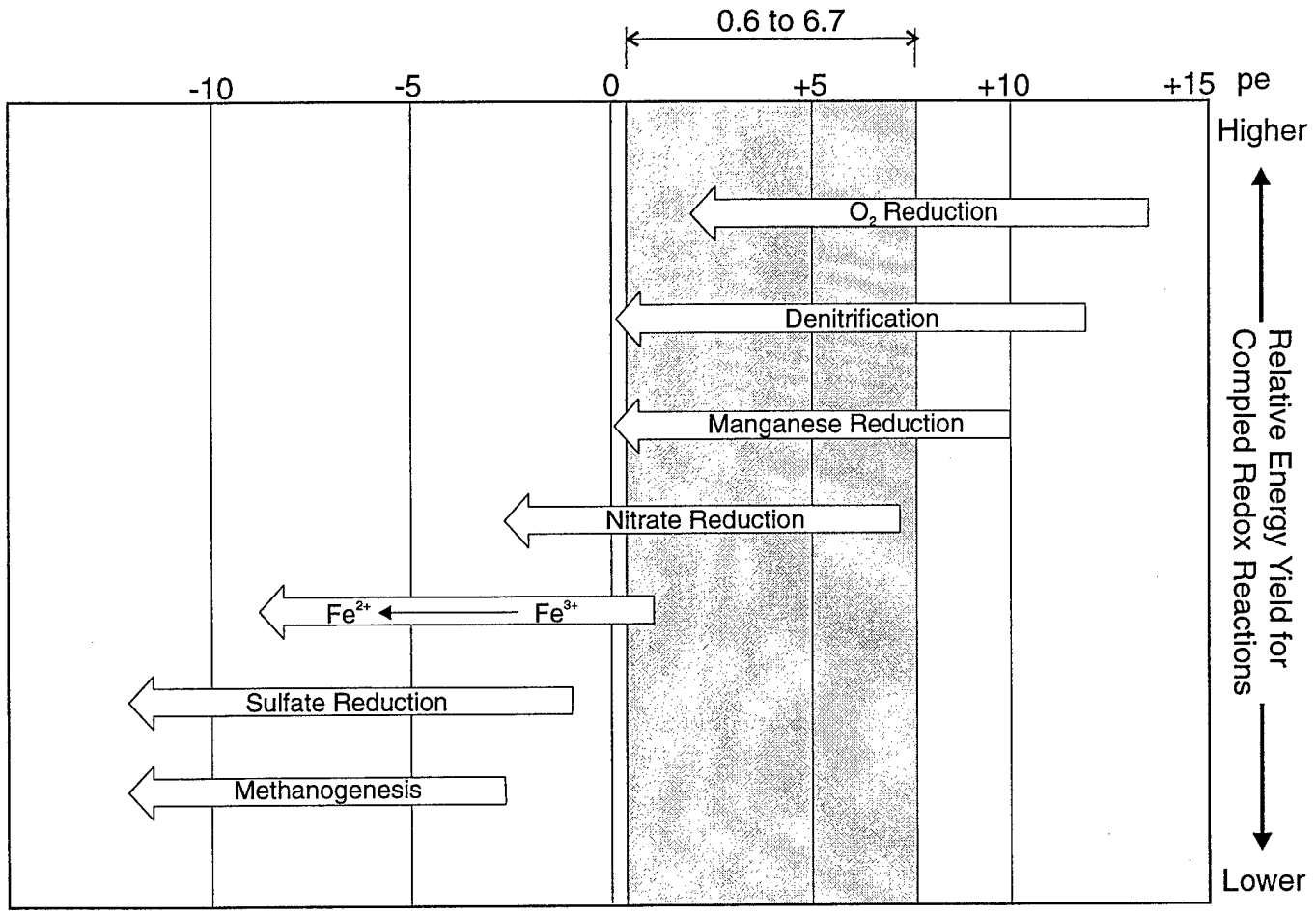
result of a series of reduction-oxidation (redox) reactions which maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of the fuel hydrocarbon compounds by transferring electrons from the contaminant (electron donor) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and can participate in redox reactions involving the fuel hydrocarbon compounds. Electron acceptors that may be present in saturated soil and groundwater at the KC-135 Crash Site are oxygen, nitrate, manganese, sulfate, ferric iron, and carbon dioxide.

Microorganisms facilitate biodegradation 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 yield 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 requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide), which yield energy, the overall reaction will yield energy. Detailed information on the redox reactions required to biodegrade each of the COPCs is included in Appendix D. The reader is encouraged to review this information to more fully understand the chemical basis of biodegradation.

Figure 6.2 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). As Figure 6.2 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. Appendix D includes tables that show that redox couples including nitrate, oxygen, manganese, ferric iron, sulfate, and carbon dioxide all have higher



Notes

Range of Eh (expressed as pe) measured at the KC-135 Crash Site

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 COC oxidation.

4. Redox sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 6.2

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

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KC-135 Crash site
Wurtsmith, AFB, Michigan

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oxidizing potentials than the redox couples including the COPCs. This is why these electron acceptors can be used to oxidize the fuel hydrocarbon compounds. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 6.2, 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 as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

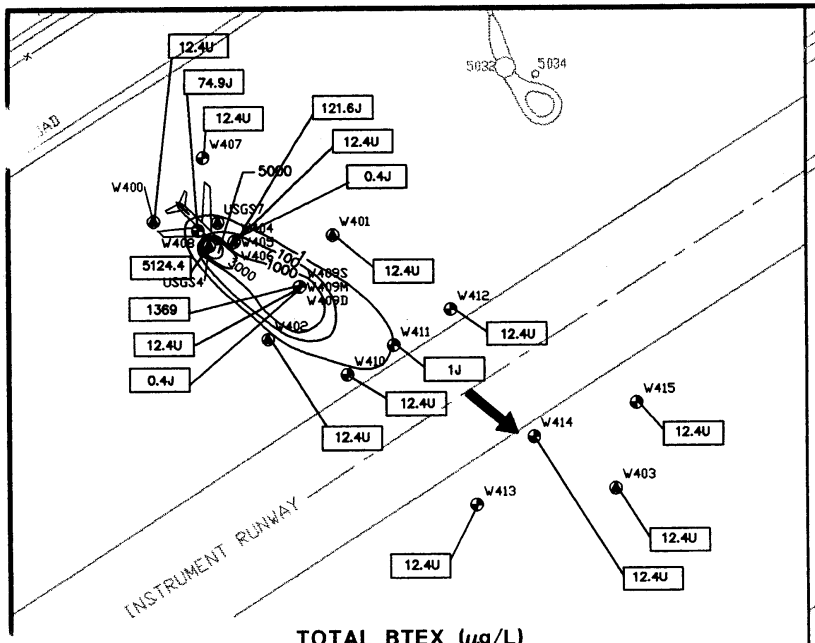
Figure 6.2 shows the range of pe measured in the groundwater in 1994 at the KC-135 Crash Site, based on Eh measurements. These data imply that oxygen, nitrate, manganese, and ferric iron may be used to biodegrade contaminants at the KC-135 Crash Site.

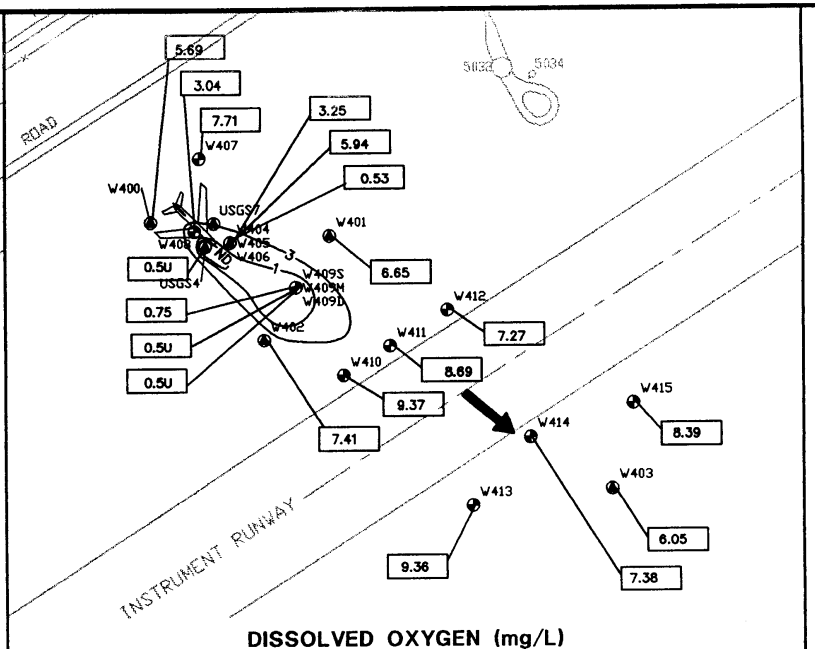
Analytical data on oxidized and reduced species are presented in the next sections to verify which electron acceptors are actually being used to biodegrade the COPCs in saturated soil and groundwater at the KC-135 Crash Site.

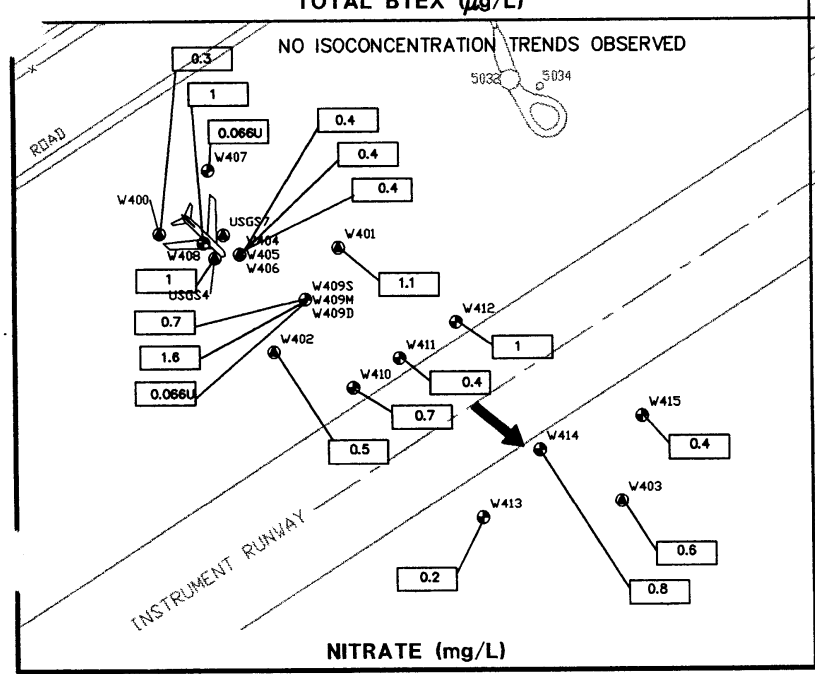
6.4.2 Dissolved Oxygen Concentrations

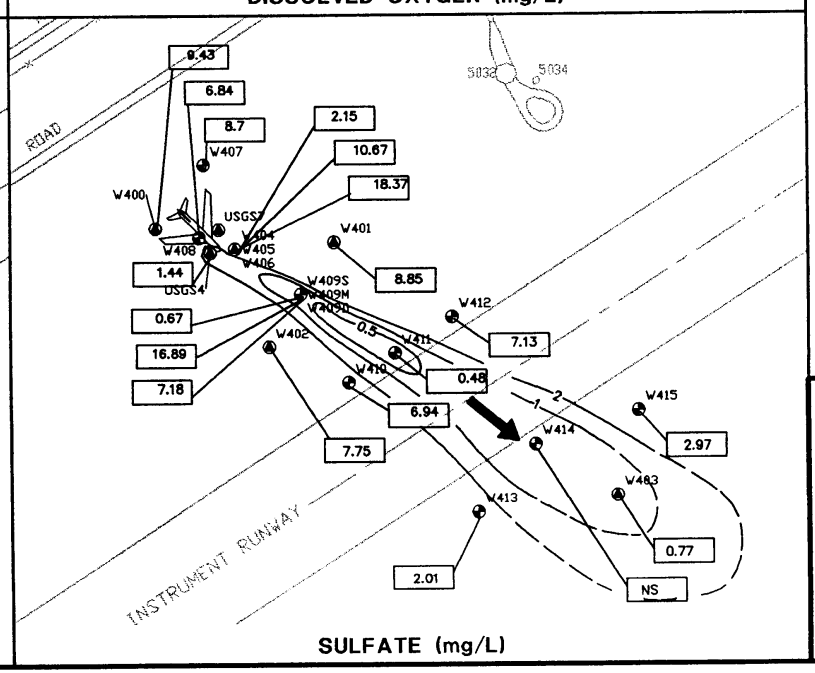
Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a cosubstrate during the initial stages of metabolism, and as a terminal electron acceptor 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 the fuel hydrocarbon compounds yields a significant amount of free energy to the system that the microorganisms could utilize.

DO concentrations were measured at groundwater monitoring wells in October 1994. Figure 6.3 presents analytical results for DO by sampling location. The isoconcentration contours compared in Figure 6.3 show that there is a strong correlation between areas of elevated total BTEX concentrations and areas depleted of DO relative to measured background levels. DO concentrations from sampling locations within the fuel spill area and immediately downgradient of the crash site ranged from about 3 mg/L to below 0.5 mg/L. In comparison, background concentrations of DO at this site were at least as high as 7.7 mg/L, as indicated by DO concentrations measured in W407, which is upgradient from and outside the area of fuel contamination. DO concentrations at sampling locations downgradient from and/or beyond the area of fuel contamination ranged from 6.6 mg/L (W401) to 9.4 mg/L (W413). The low concentrations of DO in contaminated groundwater indicate that oxygen is functioning as an electron acceptor during microbially mediated degradation of fuel hydrocarbons. Use of this electron acceptor during microbial degradation of the BTEX compounds (and any available fuel hydrocarbon compounds, such as naphthalene or the trimethylbenzne isomers) is consistent with the measured Eh (pe) levels at the site (Figure 6.2 and Appendix D). However, the reduction of molecular oxygen will cause anaerobic conditions, reduce the oxidizing potential of the









LEGEND

- SOURCE AREA
- PREVIOUSLY INSTALLED GROUNDWATER MONITORING WELL
- NEW GROUNDWATER MONITORING WELL (INSTALLED 10/94)
- W400 SAMPLING LOCATION
- ESTIMATED LINE OF EQUAL CHEMICAL CONCENTRATION (DASHED WHERE INFERRED)
- U ANALYTE CONCENTRATION BELOW DETECTION LIMIT
- J ESTIMATED VALUE
- NS NOT SAMPLED
- GROUNDWATER FLOW DIRECTION

0 300 600
FEET

FIGURE 6.3

EXTENT OF OXIDIZED ELECTRON ACCEPTORS (OCTOBER 1994)

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aquifer, and will bring about a change in the types of microorganisms that facilitate the degradation of the contaminants.

6.4.3 Dissolved Nitrate and Nitrite Concentrations

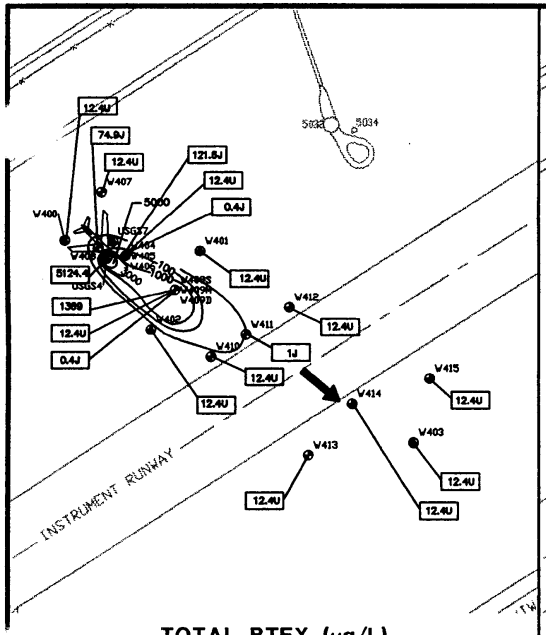
Once anaerobic conditions prevail in the groundwater, nitrate can be used as an electron acceptor by facultative anaerobic microorganisms to mineralize fuel hydrocarbon compounds (and any available PAH compounds) via either denitrification or nitrate reduction processes. Denitrification is the most energetically favorable of the redox reactions likely to be involved in the oxidation of the contaminants (Appendix D). Although the oxidation of the BTEX 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 the KC-135 Crash Site as the groundwater becomes more reducing. As conditions become more reducing, nitrate is used as an electron acceptor via nitrate reduction. However, nitrate can only function as an electron acceptor in microbially facilitated fuel hydrocarbon degradation reactions if the groundwater system has been depleted of oxygen (i.e., the groundwater must be functionally anaerobic). Oxygen is toxic to the enzyme systems used for electron transfer and energy production of nitrate-reducing microorganisms (McCarty, 1972).

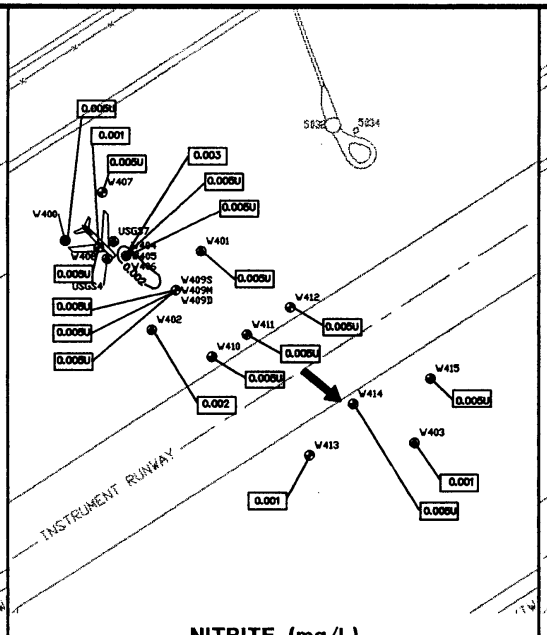
Concentrations of both nitrate and nitrite were measured at groundwater monitoring wells in October 1994. Figures 6.3 and 6.4 present the analytical data for the oxidized nitrate and reduced nitrite, respectively. Figure 6.3 shows that there is no depletion of nitrate near or downgradient from the crash site relative to measured background concentrations. Figure 6.4 shows that detected concentrations of nitrite, which is produced as nitrate is reduced during the oxidation of BTEX compounds, was only measured at one sampling location at the site near the source area. Although measured Eh (pe) levels at the site suggest that the oxidizing potential of the groundwater has been reduced sufficiently so that denitrification and nitrate reduction can occur (Figure 6.2), analytical data imply that insufficient nitrate is available in the groundwater at the KC-135 Crash Site to be used by microorganisms to support fuel hydrocarbon oxidation. Thus, these data demonstrate that nitrate is not being used as a potential electron acceptor during the oxidation of the COPCs at this site.

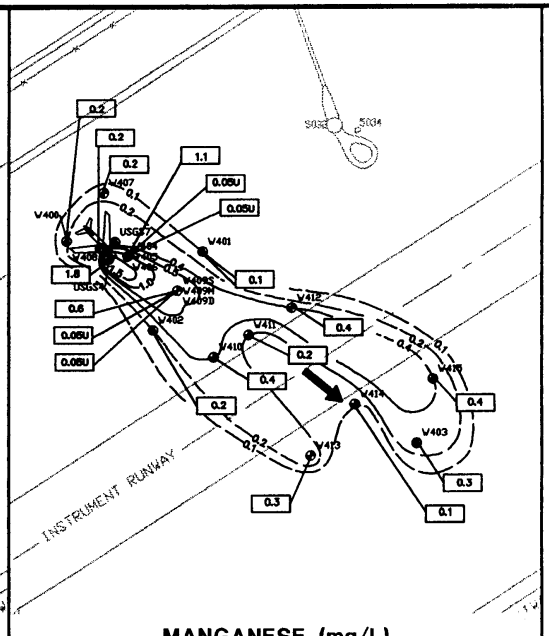
6.4.4 Dissolved Manganese Concentration

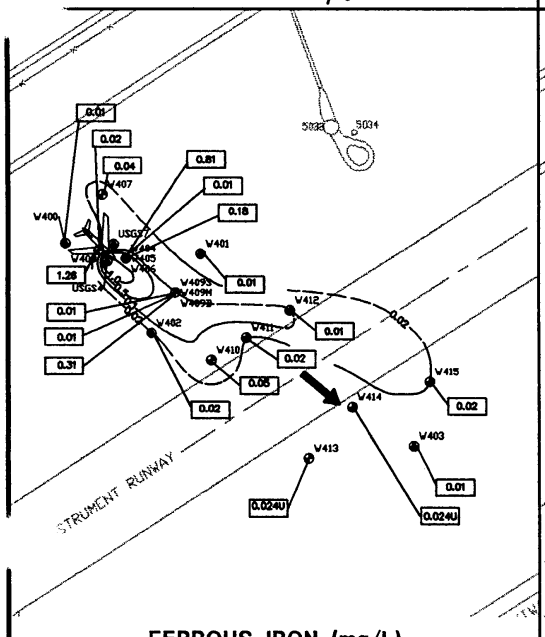
Manganese also can be used as an electron acceptor to facilitate the oxidation of fuel hydrocarbon compounds under anaerobic and slightly reducing conditions. In fact, as Figure 6.2 shows, manganese reduction can be microbially facilitated in groundwater conditions similar to those required to support denitrification. The reduction of manganese to oxidize fuel hydrocarbon compounds yields essentially as much free energy to the system as aerobic respiration. Under anaerobic and slightly reducing conditions, manganese reduction is the second most energetically favorable redox reaction that can be used to biodegrade fuel hydrocarbon compounds.

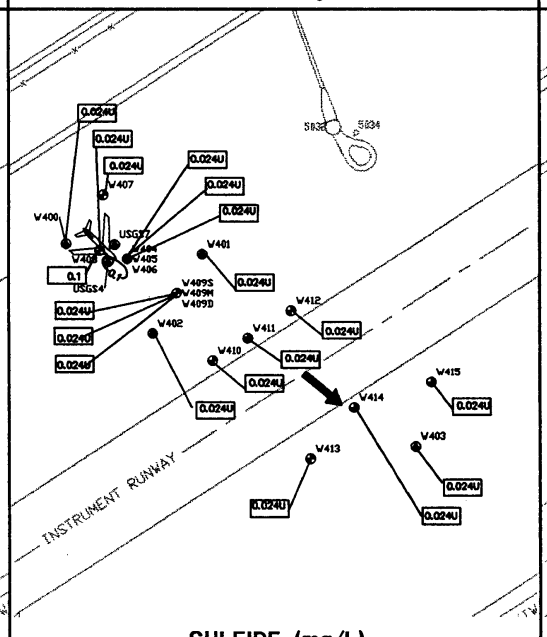
Reduced forms of manganese were measured at groundwater monitoring wells in October 1994. Figure 6.4 show the analytical results for reduced manganese found in groundwater by sampling location. Because manganese (Mn^{3+}) is used as an electron

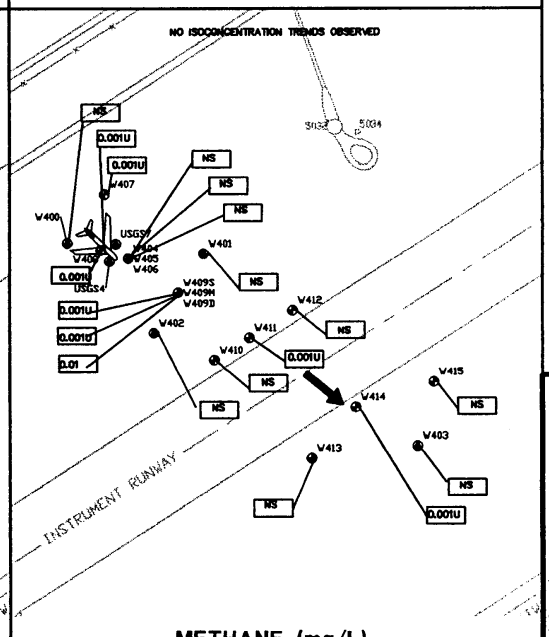












LEGEND

- SOURCE AREA
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- U ANALYTE CONCENTRATION BELOW DETECTION LIMIT
- J ESTIMATED VALUE
- NS NOT SAMPLED
- GROUNDWATER FLOW DIRECTION

N

0 300 600
FEET

FIGURE 6.4

EXTENT OF BYPRODUCTS OF ELECTRON ACCEPTOR REDUCTION (OCTOBER 1994)

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acceptor in the oxidation of fuel hydrocarbon compounds, an increase in the total concentration of dissolved reduced manganese (Mn^{2+}) is a good geochemical indicator that these contaminants are being biodegraded via manganese reduction. Elevated concentrations of reduced forms of manganese relative to measured background concentrations correlate well with areas of elevated concentrations of BTEX in groundwater at the KC-135 Crash Site. Concentrations of reduced forms of manganese ranged from a low of 0.2 mg/L at background sampling location W407 to a high of 1.8 mg/L at USGS-4, the most contaminated groundwater well at the site. Thus, the spatial distribution of reduced forms of manganese at the KC-135 Crash Site indicate that manganese is being used as an electron acceptor in biodegradation reactions.

6.4.5 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). Elevated concentrations of ferrous iron (Fe^{2+}) are often found in anaerobic groundwater systems. Concentrations of dissolved ferrous iron once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX and the PAH compounds. However, recent evidence suggests that the reduction of ferric iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires mediation by microorganisms with the appropriate enzymatic capabilities. The reduction of ferric iron results in the formation of ferrous iron.

To determine if ferric iron is being used as an electron acceptor at the KC-135 Crash Site, ferrous iron concentrations were measured at groundwater monitoring wells in October 1994. Figure 6.4 presents the analytical results for ferrous iron in groundwater at the site. As with manganese, areas characterized by elevated concentrations of fuel hydrocarbons correspond well with areas of elevated concentrations of ferrous iron relative to measured background concentrations. Ferrous iron was measured at or below the detection limit in background wells and most wells located outside the area affected by fuel contamination. However, the concentrations of ferrous iron in groundwater monitoring wells where elevated concentrations of BTEX were measured ranged from 0.05 mg/L to 1.26 mg/L.

The correlation between elevated dissolved hydrocarbon concentrations and elevated ferrous iron concentrations suggests that the iron-reducing microorganisms are using ferric iron to oxidize the contaminants. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in contaminated groundwater at the KC-135 Crash Site are strong indicators of microbial activity. These geochemical data suggest that iron-reducing microorganisms are present in the groundwater at the site, and that these microorganisms are using ferric iron to energize COPC metabolism. Measured Eh

levels at the site also indicate that the groundwater at the site may be sufficiently reducing for iron reduction to occur (Figure 6.2).

6.4.6 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. Sulfate is reduced to sulfide during the oxidation of fuel hydrocarbon compounds. The presence of decreased concentrations of sulfate in the source area relative to background concentrations indicates that sulfate may be participating in redox reactions at the site. To investigate the potential for sulfate reduction at the KC-135 Crash Site, total sulfate and sulfide concentrations were measured at groundwater monitoring wells in October 1994.

Figure 6.3 shows the analytical results for sulfate in groundwater. In general, areas characterized by elevated concentrations of total BTEX are depleted in sulfate concentrations relative to measured background concentrations. Background concentrations of sulfate at this site ranged from 8.7 mg/L at W407 to 9.43 mg/L at W400. Sulfate concentrations measured in groundwater wells with elevated BTEX compound concentrations ranged from 0.48 mg/L at the leading edge of the dissolved plume to 1.44 mg/L at USGS-4 near the spill area. This depletion of sulfate within the contaminated area suggests that this compound is acting as an electron acceptor. Figure 6.4 shows that elevated concentrations of sulfide, which are produced when sulfate is reduced during oxidation, were measured near the fuel spill area.

The measured Eh of the groundwater at the KC-135 Crash Site does not correlate with the analytical data on sulfate. Sulfate reduction can only be mediated in reducing conditions (low pe). Measured Eh levels at the KC-135 Crash Site are not sufficiently negative to suggest that sulfate reduction could occur at the site. This is characteristic of the problems associated with measuring oxidizing potential using field instruments. It is quite likely that the platinum electrode probes are not sensitive to the sulfate/sulfide redox couple. Many authors have noted that measured Eh data cannot be used alone to reliably predict the electron acceptors that may be operating at a site (e.g., Stumm and Morgan, 1991; Godsey, 1994; Lovley *et al.*, 1994). However, integrating Eh measurements with analytical data on reduced and oxidized chemical species allows a more thorough and reasonable interpretation of which electron acceptors are being used to biodegrade site contaminants.

6.4.7 Methane and Carbon Dioxide Concentrations

On the basis of free energy yield and the oxidizing potential of the site groundwater, the carbon dioxide-methane (CO_2-CH_4) redox couple also could 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 6.2 and Appendix D). The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

Carbon dioxide and methane concentrations were measured at groundwater monitoring wells in October 1994. Figure 6.4 presents the analytical data for methane by sampling location. Carbon dioxide data are included in Appendix B. These data were not used to estimate the reservoir of available electron acceptors for the KC-135 Crash Site. Methane was detected at only one groundwater sampling location near the detection limit (W409D). This well is screened more than 50 feet bgs (Section 2 and Appendix A). Although toluene was measured in a groundwater sample taken from this depth, the presence of this contaminant at this depth is more likely attributable to sampling cross-contamination than natural vertical migration. No BTEX or PAH compounds were detected in the intermediate-depth well in 1994 in this well cluster (W409M). No methane was detected in groundwater samples taken from the shallow portions of the aquifer from within or immediately downgradient from the crash site. The absence of methane in groundwater at the KC-135 Crash Site indicates that biodegradation processes are not occurring via methanogenesis. This is likely due to the relatively low concentrations of contaminants at the site and the abundance of other electron acceptors. 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 THEORETICAL ASSIMILATIVE CAPACITY ESTIMATES

The preceding discussions have been devoted to determining if the COPCs are biodegrading at the KC-135 Crash Site. Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of fuel hydrocarbons, including the BTEX compounds, naphthalene, and the trimethylbenzene isomers, 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 remediation by natural processes.

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 the KC-135 Crash Site 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 6.2), will provide the basis for determining the potential for continued natural remediation of groundwater contamination at the site.

Appendix D presents the coupled redox reactions that represent the biodegradation of each of the COPCs. These tables also present the stoichiometric mass ratio of electron acceptors needed to oxidize each of the COPCs. These stoichiometric mass ratios can be used to estimate the assimilative capacity of the groundwater at the KC-135 Crash Site. This is accomplished by first determining the initial mass of each electron acceptor available in the groundwater. Data on these chemical species were collected at sample locations upgradient of the site (i.e., sampling locations W400 and W407). As groundwater migrates downgradient into the source area, electron acceptors are brought into contact with hydrocarbon-degrading microorganisms and site

contamination. This influent mass is divided by the mass of electron acceptors required to mineralize each of the fuel hydrocarbon compounds to estimate the intrinsic capacity of the groundwater to biodegrade each of the compounds.

Conservative estimates of the background concentrations of all of the electron acceptors that appear to be operating at the site to biodegrade the COPCs are listed in Table 6.3. These concentrations are used to calculate the available or expressed assimilative capacity of each electron acceptor for total BTEX based on the mass stoichiometric relationships presented in detail in Appendix D. Table 6.3 also presents the highest concentration of ferrous iron measured at the site. This concentration is used to "back-calculate" the expressed assimilative capacity that is attributable to ferric iron reduction. On the basis of these calculations, the groundwater at the KC-135 Crash Site has the intrinsic capacity to oxidize a concentration of approximately 3,900 µg/L of total BTEX.

The maximum measured BTEX concentrations in both January 1993 and October 1994 exceeded the theoretical assimilative capacity of the groundwater at the KC-135 Crash Site. This is why contaminant mass remains in the groundwater at this site. It is important to note that the expressed assimilative capacity estimate derived in Table 6.3 is an upper-bound estimate of the assimilative capacity because it assumes perfect mixing of the COPCs and available electron acceptors, instantaneous reaction rates, and complete mineralization. Actually, the total reservoir of electron acceptors will not be available to the microorganisms because of mass transfer, kinetic, and other biological and chemical limitations.

6.6 PREDICTING THE COMBINED EFFECTS OF CONTAMINANT MIGRATION AND BIODEGRADATION OVER TIME

Understanding the effects of natural physical, chemical, and biological processes on chemicals is an important step in determining potential long-term risks associated with chemical migration in the environment. The behavior of fuel hydrocarbon compounds under the influence of these processes must be quantified to estimate the likelihood and nature of a future release, to predict the extent that any chemical could migrate, and to assess the effects on chemical persistence, mass, concentration, and toxicity over time at the site. If destructive and nondestructive attenuation processes can minimize or eliminate the concentration of contaminants to which a receptor could be exposed, remedial action may not be warranted because no reasonable exposure pathway exists or the exposure pathway would result in insignificant risks. The focus of this final section is to predict how the most mobile of the COPCs, the BTEX compounds, will be transported and transformed over time in groundwater based on site data and a site-specific transport and fate model. These COPCs were selected from quantitative evaluation to investigate the maximum downgradient migration potential.

6.6.1 Bioplume II Model Overview

A numerical modeling approach was selected to investigate the transport and fate of the mobile COPCs, the BTEX compounds, in groundwater at the KC-135 Crash Site. The mathematical model Bioplume II was used to simulate the behavior of total BTEX in groundwater at the site over time. The two primary objectives of this modeling effort were to determine the maximum extent of contaminant migration toward the nearest downgradient base property boundary and to characterize the anticipated

TABLE 6.3
ESTIMATE OF ASSIMILATIVE CAPACITY OF SATURATED SOIL AND GROUNDWATER REMEDIAL ACTION PLAN RISK-BASED APPROACH TO REMEDIATION KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Electron Acceptor	Background Concentration (Measured W400) (ug/L)	Initial BTEX Assimilative Capacity[a] (ug/L)
Oxygen	5690	1853.4
Manganese[b]	200	18.9
Ferric iron[b]	10	0.5
Sulfate	9430	2045.6
	Total	3918.4
	1993 Maximum	16300
	1994 Maximum	5124.4
	Observed Mass Loss	11175.6
	Calculated % Utilized[c]	2.5

[a] Calculated based on the ratio of the total mass of electron acceptor required to oxidize a given mass of total BTEX (Appendix D).

[b] This represents the reduced form of the electron acceptor. Assimilative capacity is expressed only as an estimate. Does not represent actual total reservoir of electron acceptor to be exhausted.

[c] Percent of total assimilative capacity utilized per liter of groundwater to reduce 1992 concentrations to observed 1994 concentrations. Based on volume of groundwater flushing through source area from January 1993 until October 1994 (Appendix D).

concentration of total BTEX in groundwater as a function of distance and time at the site. The mathematical model developed for this effort accounts for the natural physical, chemical, and biological processes documented to be occurring at the KC-135 Crash Site. This type of model is useful in defining and understanding the various factors that may contribute most to potential future exposure to site-related contamination (EPA, 1992).

The Bioplume II model code incorporates advection, dispersion, adsorption, and biodegradation to simulate BTEX plume migration and degradation. The computer code used to simulate these processes is based upon the US Geological Survey Method of Characteristics (USGS MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The USGS MOC model accounts for advective, dispersive, and adsorptive mechanisms only. The model was modified by researchers at Rice University to include a biodegradation component based on the work of Borden and Bedient (1986). The model assumes an instantaneous reaction between DO and total BTEX to model contaminant biodegradation. The amount of BTEX lost versus the amount of oxygen supplied to the aquifer can be calculated based on the simple mass stoichiometry (described in Appendix D) which assumes complete mineralization of each of the BTEX compounds to carbon dioxide and water. Another way to incorporate the loss of BTEX from groundwater in this model is to use a first-order degradation or decay coefficient. A more complete description of the Bioplume II model is included in Appendix D.

The Bioplume II model developed for the KC-135 Crash Site used site-specific data and conservative assumptions about governing physical, chemical, and biological processes. The use of a two-dimensional model is appropriate at the KC-135 Crash Site because the saturated interval appears to be generally homogeneous. Groundwater contamination was conservatively assumed to be limited to the upper 28 feet of the aquifer for modeling purposes. This assumption was made because, although the true depth of the aquifer is approximately 50 feet, no dissolved BTEX compounds were detected in 1994 in groundwater samples collected below 28 feet bgs (Section 4).

Prior to developing the groundwater flow and contaminant transport model, existing data was summarized to provide a reasonable estimate of the aquifer hydraulic and geochemical conditions. The most important assumption made as part of the Bioplume II model development for this site involved the use of site-specific biodegradation rate constants to simulate a combination of aerobic and anaerobic biodegradation mechanisms. The site-specific biodegradation rate constant for total BTEX described in Section 6.3.3 (0.0071 day^{-1}) was used as the model degradation coefficient to simulate the effects of biological processes on contaminant fate over time.

Other model assumptions focused on defining the effects of remaining fuel residuals on groundwater quality over time at the site. As described in Section 4, LNAPL was measured at the site at groundwater wells USGS-4 and USGS-7 from 1989 until 1991. No LNAPL was found at the site during the RI or subsequent sampling events. To be conservative, the Bioplume II model was constructed to incorporate a transient source of BTEX in the form of residual and mobile LNAPL. The source was conceptualized to reside on top of the groundwater table in the area surrounding monitoring wells

USGS-4 and USGS-7. Detailed discussions on model setup and assumptions are presented in Appendix D.

6.6.2 Model Calibration

Part of the modeling strategy for this site was to identify and develop a groundwater flow and contaminant model that can be used to reasonably simulate observed site conditions. The ideal situation would be to have a limitless supply of site data to use in the creation of a groundwater model that would then generate output that was absolutely representative of site conditions. However, the economics and logistics of collecting enough site data to satisfy each model input parameters would be enormous. Sites with limited data are usually modeled by performing a model calibration rather than returning to the field for additional data to check model predictions. Model calibration is the process of systematically adjusting specific model input parameters within an expected range until the resulting model output is a reasonably good match to actual field data. Model calibration is an essential step toward developing an appropriate and defensible mathematical tool to predict contaminant behavior in a complex system (Freeze and Cherry, 1979; National Research Council, 1990).

Site data collected during the RI and the 1994 sampling event were used to calibrate the Bioplume II model for the KC-135 Crash Site. Additionally, model calibration for this site was simplified because an exact time of contaminant release can be defined. Thus, three defined sets of site data were initially available to calibrate the model. The groundwater flow and contaminant transport model for the KC-135 Crash Site was calibrated by directly adjusting a select range of model parameters until good agreement between model predictions and site conditions was achieved. Very few model parameters had to be adjusted as part of the calibration of the Bioplume II model for this site. Site-specific data on the hydraulic conductivity (Section 3), the total BTEX biodegradation coefficient (Table 6.2), and total BTEX contaminant velocity (Table 6.1) were used directly and not varied during model calibration.

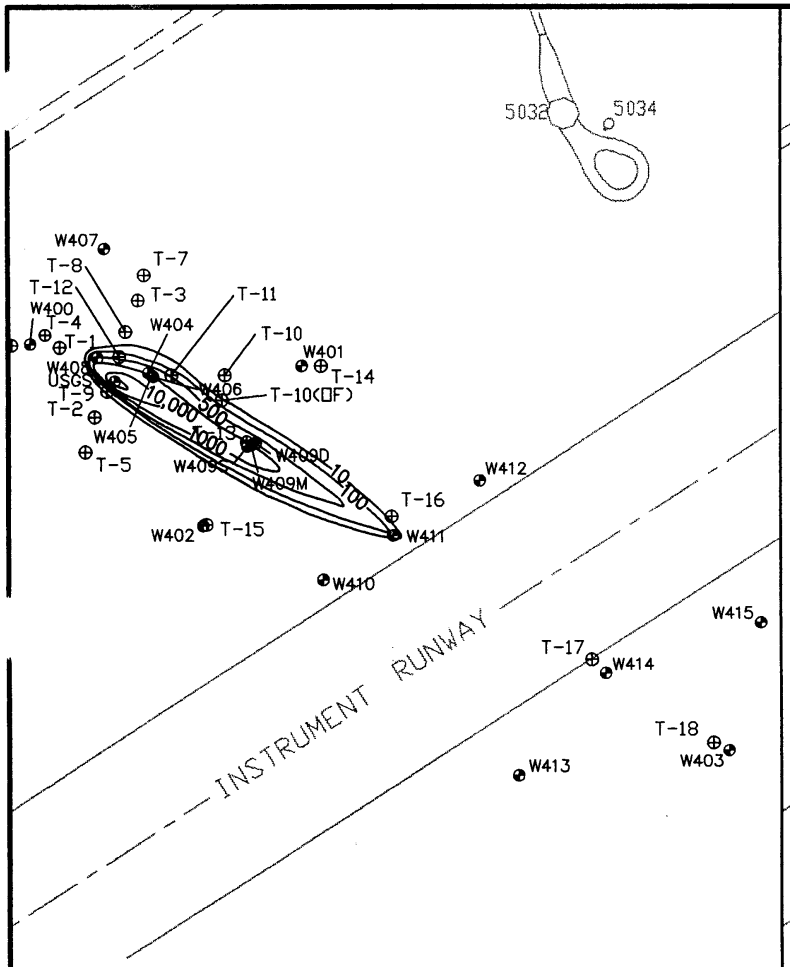
The only model parameters used to calibrate the Bioplume II model for the KC-135 Crash Site were the contaminant dispersivity and the contaminant loading rate. Contaminant dispersivity was indirectly estimated from site-specific data to aid in model calibration. As dissolved contaminants in the groundwater are convected through the aquifer, they may appear to travel slightly faster or slower than the mean linear advective velocity of groundwater. This phenomenon is known as dispersion. Dispersivity is linked to both molecular diffusion and mechanical dispersion. Molecular diffusion is a microscopic process that causes particles to spread outward from areas of high concentration to low concentration due to molecular agitation. Mechanical dispersion is a macroscopic process that describes the many different velocities that an individual contaminant may experience due to variations in soil type and porosity. Acquiring an accurate description of both these processes as a dispersivity coefficient is difficult to accomplish without significant field studies. However, a good estimate of the dispersivity coefficient can be obtained by assuming that dispersivity is equivalent to one-tenth the distance between the source of contamination and the center of mass of the contaminant plume. Using this assumption, an initial dispersivity estimate for the Bioplume II model for this site was made. It proved unnecessary to revise this estimate to obtain a good fit to observed site conditions (Appendix D).

The model parameter that was used almost exclusively to obtain calibration to the three sets of data was the contaminant loading rate. This loading rate specifies the amount of total BTEX that can partition from possible pockets of remaining fuel residuals at the site and dissolve into groundwater. Although no LNAPL was found at the site during the RI and subsequent sampling events, it was conservatively estimated that small pockets of mobile and residual LNAPL may be present to act as a continual source of total BTEX to groundwater. Without a source term, it was not possible to obtain simulate observed changes in site conditions from the time of the crash in 1988 to January 1993 or from January 1993 to October 1994. The source used to calibrate this model consisted of an initial LNAPL source at the time of the crash that spread outward from the crash site over time, and then began to diminish in terms of the mass of total BTEX that it could contribute to the groundwater over the years.

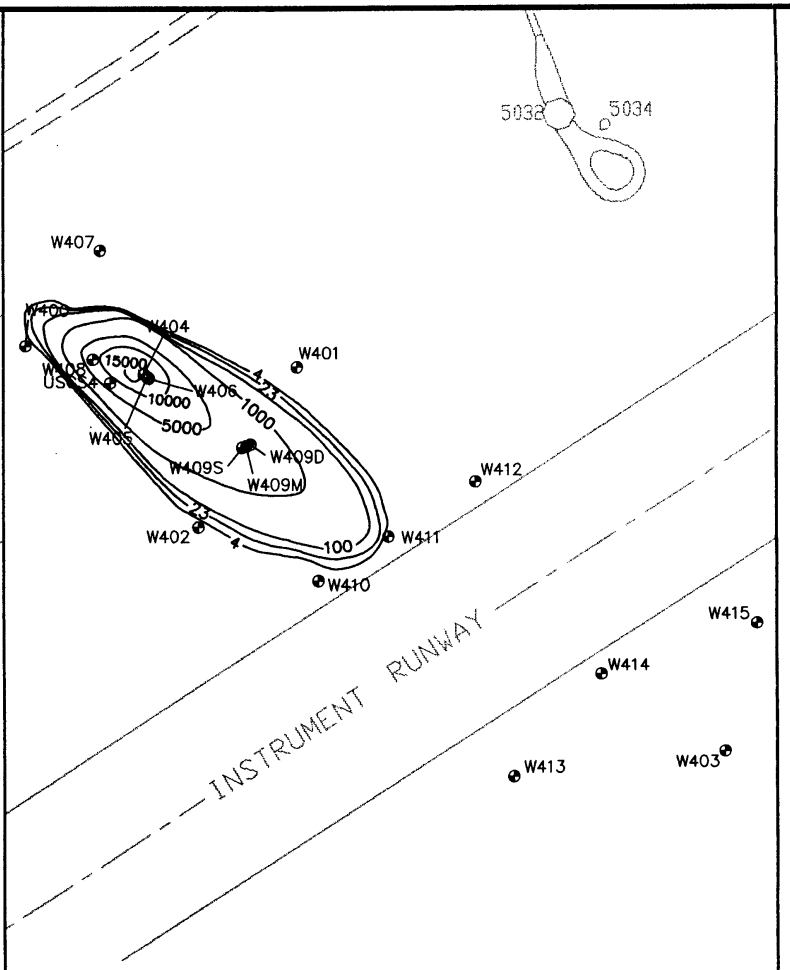
The calibration of the Bioplume II model developed for the KC-135 Crash Site can be evaluated by comparing how closely model predictions match recorded site conditions in terms of groundwater hydraulics and contaminant plume shape and migration. The final calibrated model resulted in an excellent representation of groundwater flow patterns. The root-mean-square error between actual and observed groundwater elevation heads was 0.04 feet, which translates to a model error of less than 2 percent given a total head drop of 2.7 feet over the model domain. Most groundwater models are considered good estimates of the flow system when the model error is less than 5 percent (Anderson and Woessner, 1992).

There also was good agreement between the simulated total BTEX plumes and the observed total BTEX plumes. Figure 6.5 compares the modeled total BTEX plume for 1992 (which is 4 years after the crash date) to the total BTEX plume measured during the RI. The measured maximum and minimum total BTEX concentrations in the center and leading edge of the plume, respectively, were matched closely by the model. The horizontal extent of contaminant migration simulated by the model correlates well to the horizontal extent measured in the field. The only notable difference between the simulated and observed plumes for 1992 is the lateral width of the total BTEX plume. The modeled plume reaches a maximum width of about 250 feet, whereas the total BTEX plume estimated from December 1992/January 1993 field data was much narrower (a maximum width of about 100 feet). However, the fact that the model plume is wider means the model is a conservative representation of actual field conditions.

The conservative nature of the Bioplume II model for the KC-135 Crash Site is further confirmed by comparing the simulated total BTEX plume for 1994 to the total BTEX plume observed from field data collected in October 1994. Figure 6.6 compares modeling results to actual field conditions for 1994 (which is 6 years after the crash date). Again, the modeled maximum and minimum total BTEX concentrations are in



TOTAL BTEX PLUME (μg/L)
OBSERVED IN 1992
(SOURCE: WW ENGINEERING AND SCIENCE, 1993)



CALIBRATED TOTAL BTEX PLUME (μg/L)
IN 1992
(MODELS KC1, KC2)

LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 10/94)
- TEMPORARY MONITORING WELL (ABANDONED)
- W400 SAMPLING LOCATION
- 100 ESTIMATED LINE OF EQUAL TOTAL BTEX CONCENTRATION (μg/L) CONTOUR INTERVAL=VARIABLE

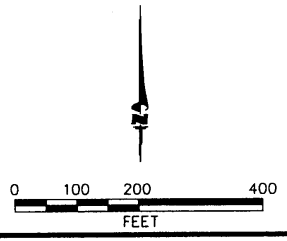


FIGURE 6.5

COMPARISON OF MODELED VS OBSERVED GROUNDWATER TOTAL BTEX PLUMES YEAR=1992

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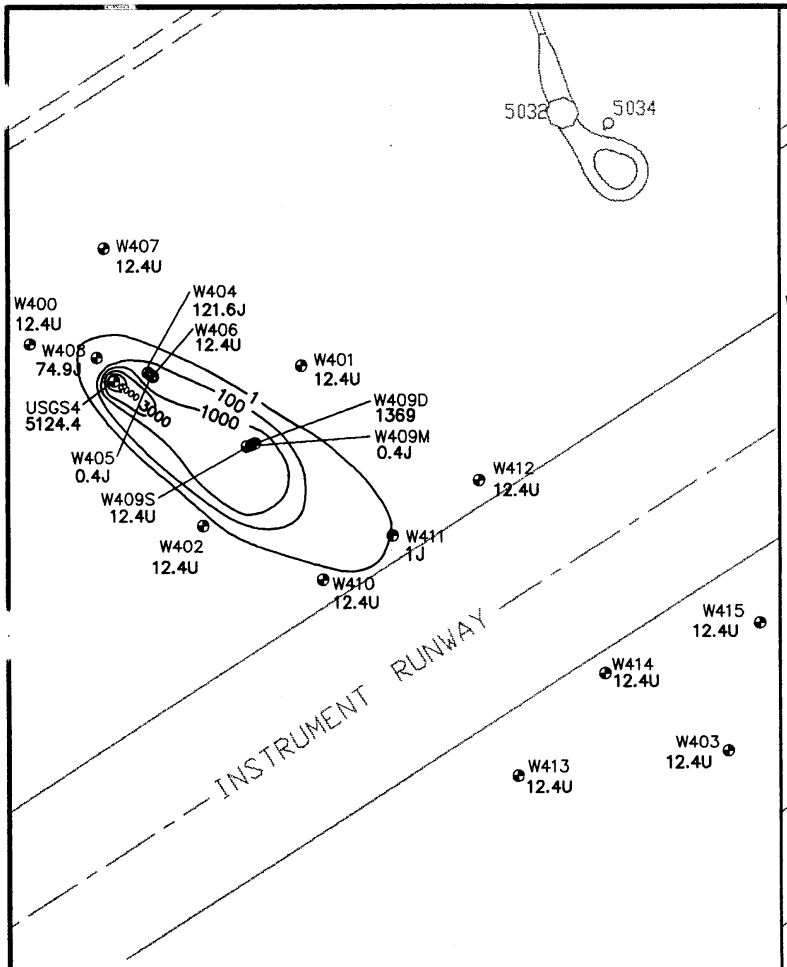
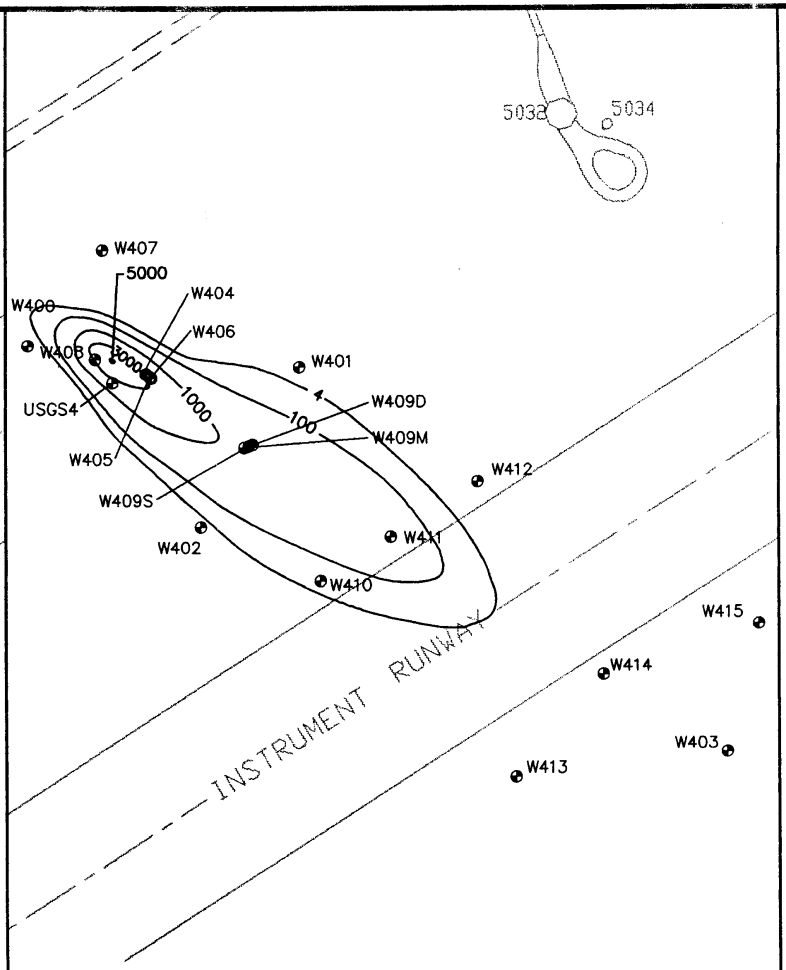


TOTAL BTEX PLUME (μg/L)
OBSERVED IN 1994



CALIBRATED TOTAL BTEX PLUME (μg/L)
IN 1994
(MODELS KC1, KC2)

LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 10/94)
- W400 SAMPLING LOCATION
- 100 ESTIMATED LINE OF EQUAL TOTAL BTEX CONCENTRATION (μg/L) CONTOUR INTERVAL=VARIABLE

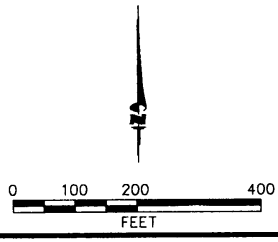


FIGURE 6.6

COMPARISON OF MODELED VS OBSERVED GROUNDWATER TOTAL BTEX PLUMES YEAR=1994

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good agreement with the maximum and minimum total BTEX concentrations measured at the site. This model simulation clearly shows that the Bioplume II is a conservative representation of field conditions because the model predicts that total BTEX would have migrated approximately 150 feet farther downgradient by the year 1994 than was actually observed. Figures 6.5 and 6.6 demonstrate that the calibrated Bioplume II model is a reasonable and conservative estimate of actual field conditions, and is sufficient to use to develop predictive chemical fate estimates.

6.6.3 Sensitivity Analysis

The Bioplume II model calibration described in Section 6.6.2 is a non-unique solution for conditions at the KC-135 Crash Site. Nearly every groundwater model can have more than one plausible solution because of the number of variable model input parameters and the complex interactions between them (Anderson and Woessner, 1992). Because a model calibration does not quantify the uncertainty or reliability of the calibrated results, a model calibration should always be followed by a sensitivity analysis. A sensitivity analysis helps quantify the uncertainty in a model calibration by observing changes in modeled output produced by specific changes in model input parameters.

Based on the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of reaeration (which was set equal to the site-specific degradation coefficient in this model to simulate biodegradation), the coefficient of anaerobic decay (which was conservatively set equal to zero), and the hydraulic conductivity of the aquifer media. The Bioplume II model is typically less sensitive to changes in the retardation factor, porosity, and dispersivity. For the sensitivity analysis for the KC-135 Crash Site model, only hydraulic conductivity (and therefore transmissivity), the coefficient of reaeration (i.e., site-specific biodegradation rate constant), the retardation factor, and the dispersivity were varied. A detailed discussion of the sensitivity values used and the sensitivity results is presented in Appendix D.

The results of the sensitivity analysis suggest that the calibrated Bioplume II model is a good representation of site conditions. With respect to contaminant migration, the reaeration rate or degradation rate constant (Section 6.3.3) is the parameter to which the model is most sensitive. Small variations in this parameter produce substantial changes in how far the total BTEX plume migrates and affects the maximum concentrations of total BTEX predicted to be present in the groundwater at the site at any time. Hydraulic conductivity is the model parameter with the next greatest influence on predicted results. The retardation coefficient and dispersivity follow hydraulic conductivity in terms of how much these input parameters can affect model results. The retardation coefficient and dispersivity had little effect on either contaminant concentrations or migration distance when specific input values were varied up to 50 percent from the calibrated input values.

6.6.4 Model Results for Natural Attenuation Scenario

On the basis of the available site data, the BTEX compounds are biodegrading in saturated soils and groundwater at the KC-135 Crash Site. Destructive contaminant

attenuation processes have minimized contaminant migration and reduced contaminant concentrations over time (Section 6.3). The assimilative capacity of the saturated soils and groundwater at the KC-135 Crash Site were shown to be sufficient to maintain reasonable biodegradation rates (Sections 6.3.3 and 6.5). Biodegradation has been proven to be a major process governing the environmental fate of contaminants in saturated soils and groundwater at the KC-135 Crash Site.

The removal of BTEX mass via destructive contaminant attenuation processes will change the concentration of the contaminant in the affected media over time and distance at the site. This is important since the conservative exposure pathway assessment completed in Section 5 concluded that the only potential receptors for site-related contamination may be future off-base receptors who could be exposed to groundwater contamination if contaminants were to migrate off-base at concentrations above target generic residential cleanup criteria. No exposure pathway involving onsite receptors is complete at this site.

Thus, the Bioplume II model developed for the KC-135 Crash Site was employed to quantitatively investigate whether existing concentrations of BTEX compounds may eventually pose a threat to off-base receptors. Model predictions also provide quantitative estimates of when generic industrial cleanup criteria can be achieved at every point in the shallow aquifer at the site. The calibrated Bioplume II model was run for a period of 20 years to predict chemical behavior in groundwater in the absence of any engineered remediation activities. The model was initiated at the time of the KC-135 aircraft crash, so no dissolved BTEX was present in groundwater at the start of the model simulation. The mass of total BTEX in the LNAPL, which was released into the soil as a result of the aircraft crash, was assumed to decrease over time as a result of volatilization, dissolution, and biodegradation at a rate of approximately 72 percent every two years after 1994. It was assumed that this decrease in mass resulted in an identical reduction in BTEX mass loading rates. This contaminant mass loading rate was estimated based on actual contaminant reductions over time and incorporated into the model calibration process summarized in Section 6.6.2 and fully described in Appendix D.

The Bioplume II model predicts that the total BTEX plume will migrate to its maximum extent by the year 1996 (Figure 6.7). Data collected in October 1996 confirm that the plume size is not expanding. The Bioplume II model predicts that detected concentrations of total BTEX (most likely benzene) will migrate to the southern edge of the runway. The concentration of total BTEX at the source area is expected to be approximately 1,500 µg/L, which is nearly one-third of the maximum dissolved total BTEX concentration measured at this location in October 1994. Measured 1996 maximum concentrations of total BTEX in the source area were slightly above this estimated value. Figure 6.8 shows the expected extent of total BTEX migration and the spatial distribution of BTEX mass and concentration in the shallow aquifer at the KC-135 Crash Site in the year 2000, which is 12 years from the time of the aircraft crash. By the year 2000 (Figure 6.8), the maximum concentration of total BTEX is expected to be about 100 µg/L. This level of contamination will be limited to a small area within the existing plume boundary. No detected concentrations of total BTEX compounds will migrate beyond the instrument runway at the site. This quantitative analysis shows that the exposure pathway to potential off-base receptors will remain incomplete.

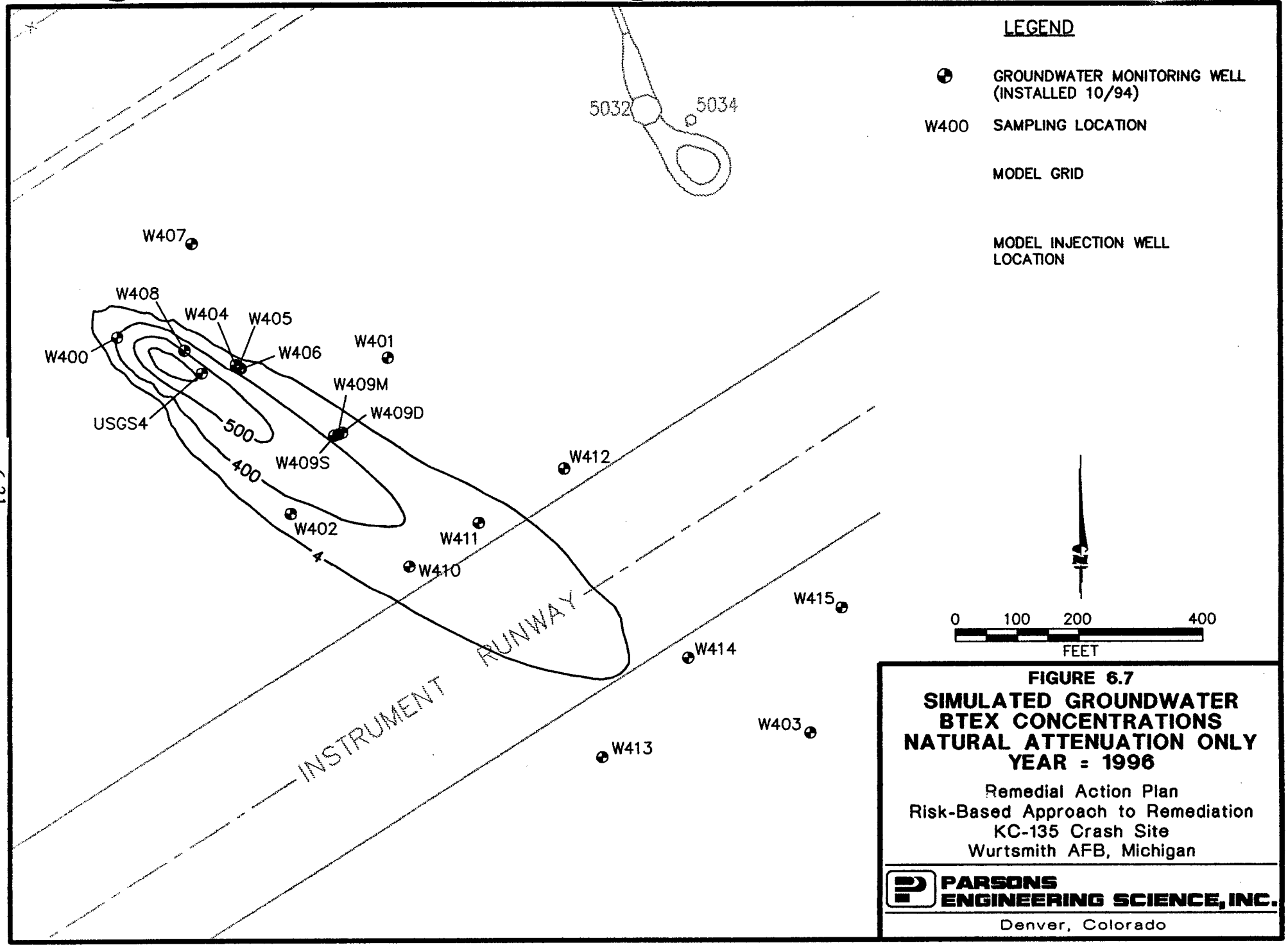

FIGURE 6.7

SIMULATED GROUNDWATER BTEX CONCENTRATIONS NATURAL ATTENUATION ONLY YEAR = 1996

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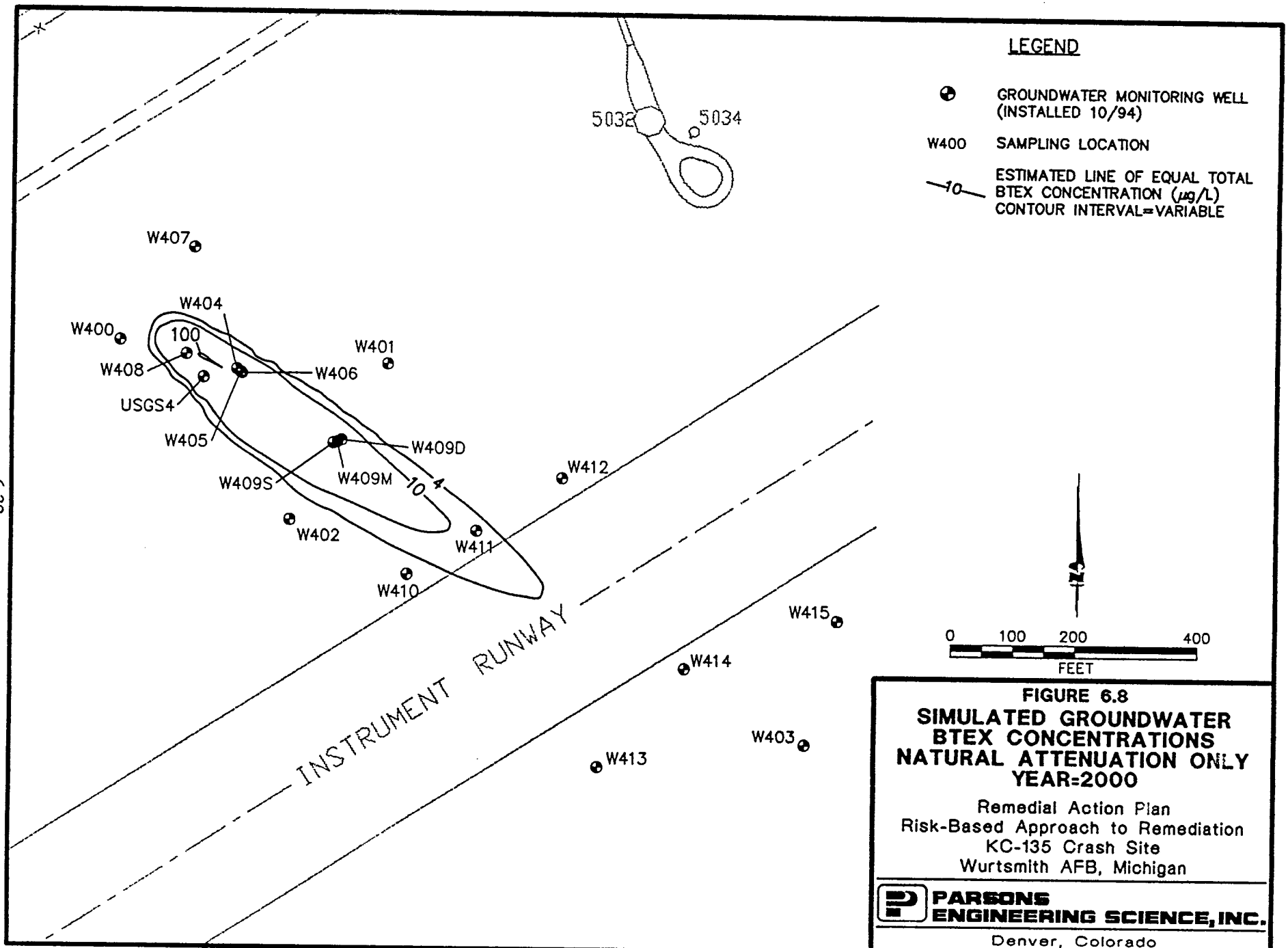

FIGURE 6.8
SIMULATED GROUNDWATER BTEX CONCENTRATIONS NATURAL ATTENUATION ONLY YEAR=2000

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Figure 6.9 shows the predicted total BTEX plume at the KC-135 Crash Site by the year 2004. The modeling results show that the dissolved BTEX plume will continue to recede and concentrations decrease over time. The maximum predicted concentration of total BTEX at the site by the year 2004 is expected to be approximately 5 µg/L. The accuracy of this model prediction depends on the accuracy of the source weathering calculation. The model simulation indicates that generic industrial cleanup criteria are expected to be achieved at every point in site groundwater within about 8 years (i.e., year 2004).

These model predictions can be used to estimate the impact of natural chemical attenuation processes on the other COPCs as well. Naphthalene has not been measured in site groundwater above its generic industrial criterion of 750 µg/L during recent sampling events. Based on a biodegradation rate of 0.0018 day^{-1} and the Bioplume II model results, naphthalene should be reduced to below the generic residential GSI criterion of 29 µg/L within 5 to 6 years. No significant downgradient migration is expected. Furthermore, as the hydrocarbon mass diminishes, groundwater conditions will be come less reducing and aerobic processes will again dominate. Although recalcitrant in anaerobic environments, the trimethylbenzene isomers are susceptible to rapid degradation under aerobic conditions. Consequently, once the dissolved plume mass is minimized (i.e., by the year 2004), the trimethylbenzene isomers should undergo rapid oxidation and be reduced below generic industrial cleanup criteria.

6.7 CONCLUSIONS

This section has focused on explaining how and why fuel hydrocarbon compounds in saturated soil and groundwater at the KC-135 Crash Site are biodegrading. The important findings of this section are summarized as follows:

- Fuel hydrocarbon compounds are biodegrading in saturated soils and groundwater at the KC-135 Crash Site via oxygen reduction, manganese reduction, ferric iron reduction, and sulfate reduction, at rates comparable to those found in the technical literature;

- Site-specific biodegradation rate estimates and site-specific theoretical assimilative capacity estimates confirm that measured concentrations of contaminants in saturated soil and groundwater can be completely biodegraded by natural processes;

- The Bioplume II model simulation predicts that no detected concentrations of any of the COPCs will migrate near or beyond the nearest base property boundary (i.e., no exposure pathway to off-base receptors will be complete); and

- The Bioplume II model predicts that chemical concentrations in groundwater should be reduced by natural processes to concentrations below the most stringent generic industrial criteria within 8 years. Once aerobic conditions are restored, (when other COC concentrations are reduced), the trimethylbenzene isomers will be rapidly biodegraded.

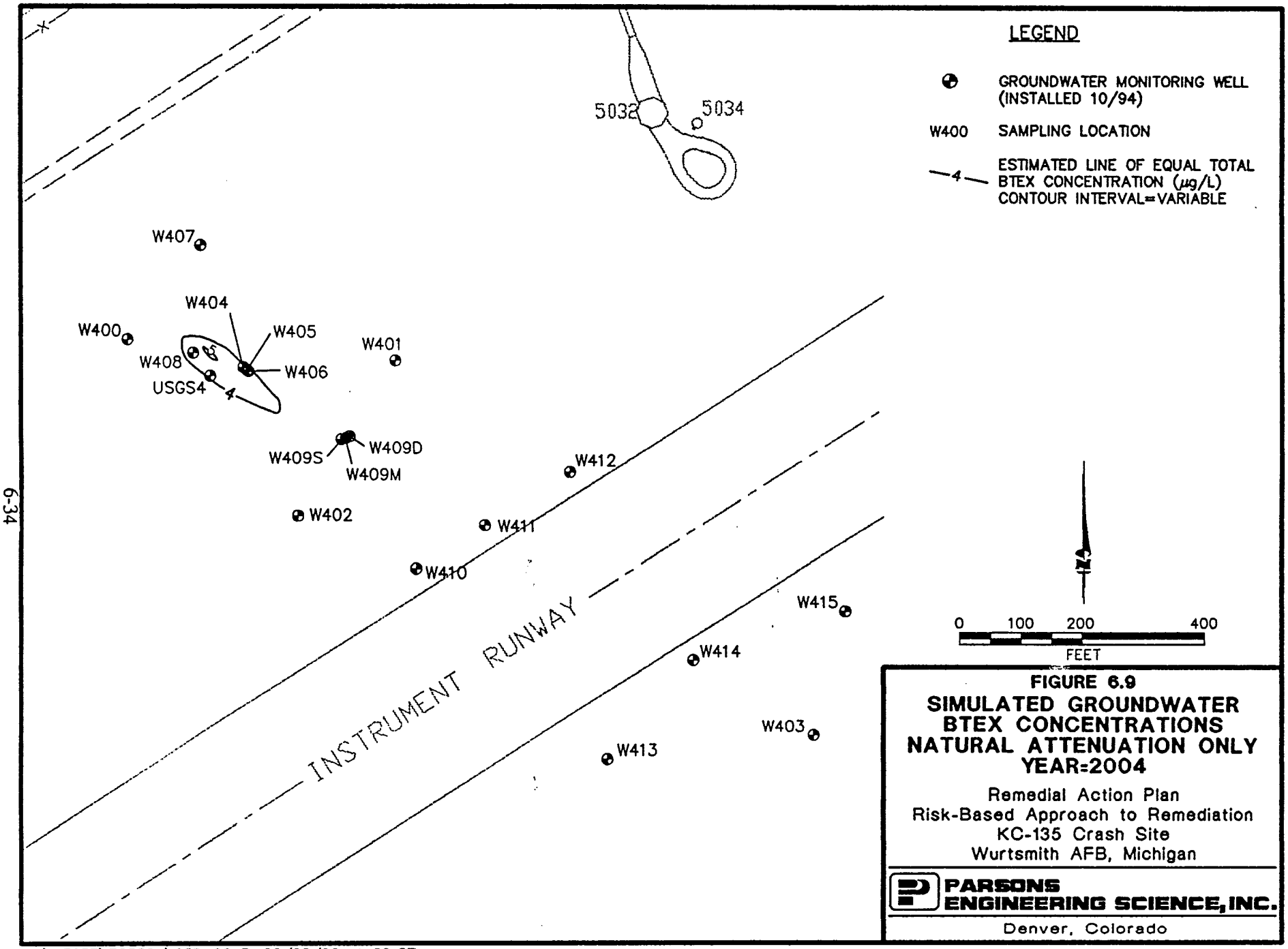

FIGURE 6.9
SIMULATED GROUNDWATER BTEX CONCENTRATIONS NATURAL ATTENUATION ONLY YEAR=2004

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SECTION 7

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 reduction technologies were evaluated at Wurtsmith AFB at Site OT45 as part of the 1994 field investigation in the event that engineered source reduction is required to protect human health and the environment or to reduce the total time and cost of remediation. Pilot tests were not conducted at the KC-135 Crash Site because of the significant hydrogeological similarities to Site OT45 and because power was not readily available at the KC-135 Crash Site. Both sites have nearly identical sandy soils with confining clay layers at 70 feet bgs. The unconfined water table at both sites is approximately 10 feet bgs. Both sites have little or no vadose zone contamination with remaining BTEX or PAH contamination present in saturated soils and groundwater. Fuel hydrocarbons, especially BTEX, are the primary groundwater contaminants at both sites. Neither site has significant vertical migration of COCs. In light of these similarities, the pilot test results for Site OT45 have been used to supplement the KC-135 Crash Site remedial evaluation.

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. At the KC-135 Crash Site, soil gas oxygen ranged from 19.2 to 20.8 percent, which is sufficient to sustain *in situ* bioremediation of remaining fuel residuals in the vadose zone. High oxygen levels are commonly found in soils where little or no hydrocarbon contamination is available to exert a biological oxygen demand. Bioventing is only appropriate for sites with anaerobic, contaminated unsaturated soils.

7.1 AIR PERMEABILITY TEST AT SITE OT45

7.1.1 Bioventing Well and Vapor Monitoring Point Installation

Bioventing well VW-1 and monitoring points MPA and MPB were installed at Site OT45 on September 28, 1994. Figure 7.1 shows the locations of VW-1, MPA, and MPB, and Figure 7.2 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 of the RAP for Site OT45 (Parsons ES, 1995).

One 4-inch-diameter PVC air-injection vent well (VW-1) was installed in contaminated source area soils with the screened interval from 5 to 15 feet bgs. The

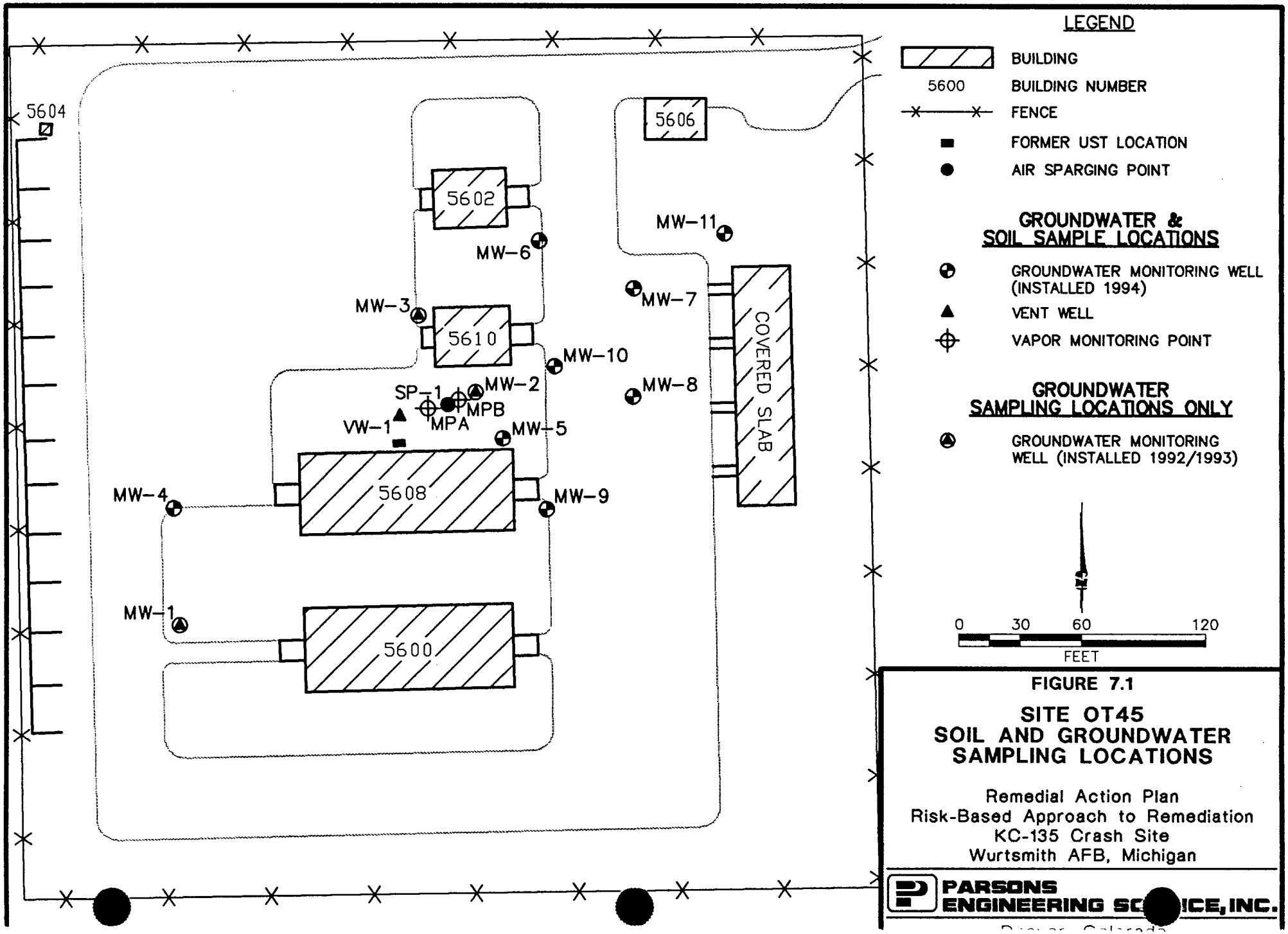

FIGURE 7.1

SITE OT45
SOIL AND GROUNDWATER SAMPLING LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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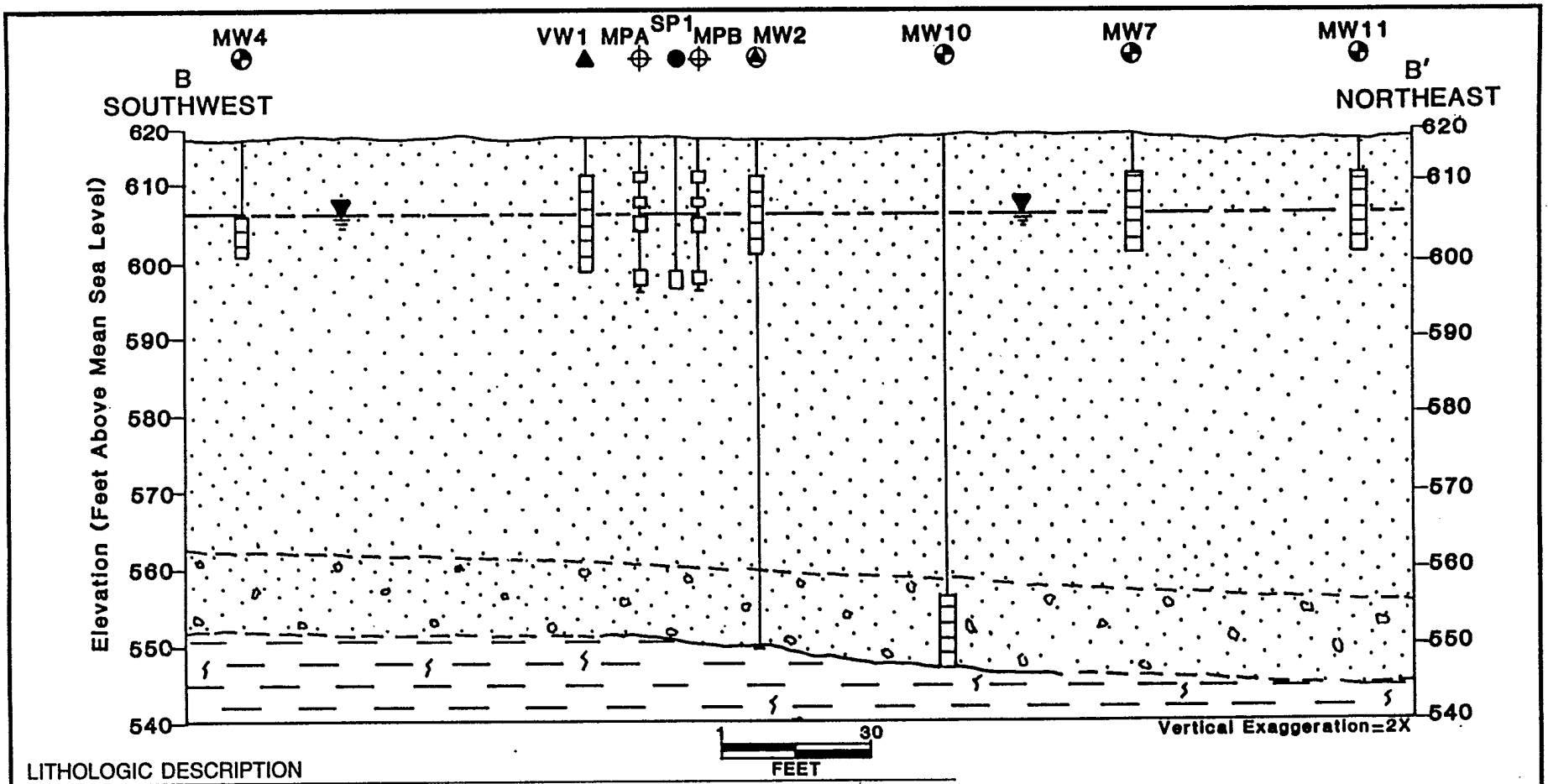

LITHOLOGIC DESCRIPTION

SAND

GRAVELLY SAND WITH CLAY SENSES

SILTY CLAY

LEGEND

MW-4 GROUNDWATER MONITORING WELL (1994)

VW-1 VENT WELL

SP1 AIR SPAGING POINT

MPA VAPOR MONITORING POINT

MW2 GROUNDWATER MONITORING WELL (1992/1993)

GROUNDWATER ELEVATION; DASHED WHERE INFERRED

GEOLOGIC CONTACT, DASHED WHERE INFERRED

SCREENED INTERVAL

FIGURE 7.2

SITE OT45
HYDROGEOLOGIC
CROSS SECTION B-B'

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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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 using 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.

7.1.2 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. Next, 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.

7.1.3 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 from this pilot test 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 air injection at VW-1. Table 7.1 presents the changes 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

TABLE 7.1
INFLUENCE OF AIR INJECTION AT VENT WELL AND BIOSPARGING POINT ON SOIL GAS OXYGEN AND TOTAL VOLATILE HYDROCARBON CONCENTRATIONS AT SITE OT45
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Location	Depth (feet bgs)	10/8/94	10/12/94		10/13/94			10/14/94			10/17/94	10/18/94	10/21/94
		12:00	15:30	19:00	08:50	12:10	14:30	10:00	15:00	17:20	09:20	17:00	08:30
Concurrent Activity ---> Activities and Comments		initial values	air permeability test (10 SCFM) --->					air sparging test (4 SCFM) --->	8 SCFM --->			5 SCFM	blower stopped
		Oxygen Concentrations (%)											
VW-1	5-15	18.3	---[a/]	—	—	—	—	—	—	—	18.5	20.0	19.8
MPA-5	4.75-5.25	16.5	16.2	16.5	20.2	20.0	20.9	20.3	17.2	18.5	20.6	21.0	20.5
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	20.6	19.2
MPB-5	4.75-5.25	17.0	17.0	16.8	16.0	16.0	16.2	16.7	19.0	20.5	20.0	21.0	20.4
MPB-9	8.75-9.25	16.0	15.5	15.5	14.5	14.0	14.4	18.0	20.2	20.6	20.9	20.8	20.0
MW-2	10-15	18.5	18.1	18.2	17.6	17.6	17.9	—	—	—	—	20.4	20.2
MW-5	6-16	—	18.8	19.0	18.7	18.6	18.6	—	—	—	—	18.6	18.5
		Total Volatile Hydrocarbons (ppmv)[b/]											
VW-1	5-15	90	—	—	—	—	—	—	—	—	130	380	230
MPA-5	4.75-5.25	105	180	180	160	120	100	100	880	540	320	430	320
MPA-9	8.75-9.25	205	300	520	790	780	480	560	670	480	660	560	480
MPB-5	4.75-5.25	96	150	190	160	160	160	170	580	600	610	260	170
MPB-9	8.75-9.25	115	200	200	190	180	190	180	620	600	340	290	230
MW-2	10-15	78	200	200	190	190	180	—	—	—	—	460	420
MW-5	6-16	—	140	140	140	130	140	—	—	—	—	220	220

a/ --- = No data Collected.
b/ ppmv = Parts per million on a volume per volume basis.

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 a single vent well should exceed 45 feet.

7.2 BIOSPARGING TEST AT SITE OT45

Biosparging was evaluated at Wurtsmith AFB as a remediation technology for removing fuel hydrocarbons from the saturated soil zone. Injecting air into the source area groundwater serves two purposes: volatilizing the more volatile compounds from the groundwater, and supplying oxygen to the groundwater to enhance biodegradation of less volatile compounds (e.g., the trimethylbenzene isomers).

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 areal 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 for the biosparging test conducted at Site OT45, and assess the applicability of this technology for source reduction at the KC-135 Crash Site.

7.2.1 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 7.1.1. 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 7.1 shows the locations of VW-1, MPA, MPB, SP-1, MW2, and MW5. Figure 7.2 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).

7.2.2 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 7.1) 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.

7.2.3 Biosparging Test Results

7.2.3.1 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 7.2.

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 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 of 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.

7.2.3.2 Soil Gas Monitoring

Soil gas oxygen and TVH concentrations were measured before and during the biosparging test. These results are summarized in Table 7.1. 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 and the KC-135 Crash Site, increased soil gas oxygen concentrations would ensure enhanced biodegradation of remaining vadose soil contamination and any fuel vapors stripped from the groundwater.

TABLE 7.2
BIOSPARGING TREATABILITY TEST RESULTS
FOR DISSOLVED OXYGEN CONCENTRATIONS AND GROUND WATER LEVELS
AT SITE OT45
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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	10:30	11:15	12:35	15:50	16:20	16:50	18:10	12:45	09:30	17:30	18:30	08:30
Concurrent Activity and Comments			Initial Values	4 CFM Flow Rate	4 CFM Flow Rate	4 CFM Flow Rate	4 CFM Flow Rate	8 CFM Flow Rate	8 CFM Flow Rate	8 CFM Flow Rate	8 CFM Flow Rate	8 CFM Flow Rate	5 CFM Flow Rate	4.6 CFM Flow Rate	Blower Off
			Dissolved Oxygen (mg/L)												
VW-1	5-15	11.5	1.6	—[a]	—	1.4	1.5	—	1.6	1.7	1.8	1.7	0.8	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	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	1.5
MPB-10	10-12.5	12.0	1.6	0.0	0.6	0.6	0.8	—	0.4	0.6	2.3	1.6	1.6	3.2	2.3
MPB-17.5	17.5-20	10.5	2.8	3.8	3.6	2.8	2.9	—	4.0	4.2	4.9	4.2	2.8	6.8	6.1
MW-4	10-15	12.0	—	9.4	—	9.5	9.5	—	—	—	9.6	9.7	9.5	10.0	9.9
MW-5	6-16	10.5	1.8	—	—	2.6	4.2	—	4.2	3.8	3.2	3.6	2.8	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
MPA-10	10-12.5		10.28	9.97	9.75	—	10.14	10.06	9.76	—	—	—	10.15	—	10.02
MPA-17.5	17.5-20		10.50	10.19	10.17	—	10.60	10.19	10.20	—	—	—	10.37	—	10.42
MPB-10	10-12.5		10.18	9.70	9.60	—	10.30	10.05	9.66	—	—	—	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
MW-4	10-15		—	10.05	10.01	—	10.02	—	—	—	—	—	9.93	—	9.98
MW-5	6-16		9.80	9.66	9.65	—	9.80	9.66	9.62	—	—	—	9.67	—	9.71

a/ — = No data collected.

7.2.3.3 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. Similar tests could be conducted at the KC-135 Crash Site if biosparging was employed for source reduction.

7.2.3.4 Technology Assessment

Air sparging was pilot tested and evaluated as a potential remediation tool at Site OT45. Based on test results and air sparging research to date, the Air Force believes 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. However, 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 the KC-135 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 both Site OT45 and the KC-135 Crash Site. A greater benefit would be realized at the KC-135 Crash Site because of the higher concentrations of BTEX in the crash site source area and the additional benefits of oxygen-enhanced biodegradation. Biosparging also could 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. The benefits of oxygen addition in the source area were simulated using the Bioplume II model described in Section 6. Details of these model simulations are presented in Section 8 as part of the remedial alternatives evaluation.

SECTION 8

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Sections 6 and 7 provided scientific documentation of natural attenuation processes and the potential benefits of biosparging and bioventing in accelerating the remediation of the source area. An initial screening of remedial approaches and technologies was completed, and several technologies identified for possible use at the KC-135 Crash Site. A complete review of the initial screening process is included in Appendix G. Three remedial alternatives were developed using various combinations of natural attenuation, land and groundwater use controls, long-term monitoring, and active source removal. The objectives of Section 8 are to summarize the alternatives developed in Appendix G, to review the primary evaluation criteria used to compare these alternatives, and to complete a more detailed comparative analysis of each alternative in an effort to identify the most logical approach for remediating the KC-135 Crash Site. Each alternative is more fully explained in terms of its effectiveness, technical and administrative implementability, and cost. Following this evaluation, an implementation plan for the recommended alternative is summarized in Section 9.

8.1 SUMMARY OF CANDIDATE REMEDIAL ALTERNATIVES

Based on the initial screening summarized in Appendix G, several remedial approaches and technologies were retained for the development of remedial alternatives. These technologies were selected to provide a range of passive to more active response actions, all of which can attain generic industrial cleanup criteria in slightly different time frames and at different costs. The following remedial approaches and technologies were retained:

- Long-term soil and groundwater monitoring;
- Land use controls;
- Groundwater use controls;
- Public education;
- Natural chemical attenuation of soil and groundwater contamination;
- Biosparging in the source area;
- Groundwater extraction in the source area with activated carbon treatment;

- Treated groundwater discharge via reinjection trench; and
- Limited bioventing in dewatered soils.

The primary objective of source reduction technologies would be to more rapidly remove COC contamination from the shallow groundwater and first two feet of saturated soils near the crash site, where the greatest concentrations of these compounds remain. Results from October 1994 soil sampling in the source area indicate that natural processes may have already reduced fuel hydrocarbon compound concentrations to levels below the most stringent residential soil cleanup criteria (Table 4.2). However, groundwater in the vicinity of monitoring well USGS-4 contained elevated COC concentrations, which will continue to generate plume concentrations in excess of generic industrial cleanup criteria for approximately 8 years.

Because natural chemical attenuation processes, and specifically biodegradation, has been effectively reducing dissolved COC compounds in the groundwater and limiting downgradient migration, this ongoing remediation process can only be enhanced through a reduction of the continuing source of contamination at the crash site. Three candidate source reduction technologies (biosparging, bioventing, and limited groundwater extraction) have been retained for additional analysis. Three candidate remedial alternatives were developed and are described in the following sections.

8.1.1 Alternative 1- Natural Chemical Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 1: Attainment of generic industrial cleanup criteria in approximately 8 years.

Section 6 presented significant evidence that groundwater COCs are being remediated by naturally occurring physical, chemical, and biological processes. On the basis of 1992 and 1994 soil sampling results presented in Section 4, soil fuel hydrocarbon concentrations may have already been reduced to below generic residential cleanup criteria as a result of natural leaching and biodegradation. Given the significant reductions in dissolved COC concentrations observed between 1992 and 1996, it appears that the soil is no longer a significant source of groundwater contamination. Groundwater data collected from 1992 to 1996 clearly indicate a decrease in BTEX concentrations over time. Section 6 provided a thorough evaluation of natural attenuation processes operating at the site, and a Bioplume II model was used to simulate the effects of these processes on contaminant mass and mobility over time. The model predicted that generic industrial cleanup criteria could be achieved by the year 2004.

Because site soil contaminants are present at concentrations below generic industrial (and residential) cleanup criteria, this site is considered suitable for its current industrial/airfield use. Limitations on groundwater use until the groundwater attains generic industrial cleanup criteria do not pose additional restrictions to current or planned future land use in this uninhabited and remote industrial area. The Oscoda Township Board of Trustees has approved the KC-135 Crash Site for continued airfield use (Section 3.6.3). Remedial actions designed to attain industrial cleanup criteria will be sufficient to protect of human health and the environment if these land reuse plans

are implemented and human ingestion of site groundwater is not required before the year 2004.

As stated in Section 5, the site's current and planned use as an airfield does not strictly require that generic industrial groundwater criteria be achieved. Although not required for this site, attainment of generic industrial groundwater criteria is desirable to implement MDEQ's low environmental impact policy. The analysis presented in Section 6 showed that no COC would migrate to or beyond the airfield boundary at concentrations above generic residential criteria. Natural processes have been removing and will continue to remove COC mass and minimize COC migration. In the event that any COC exceeds generic residential cleanup criteria in a downgradient point-of-action (POA) well, a contingency plan would be initiated (Section 9).

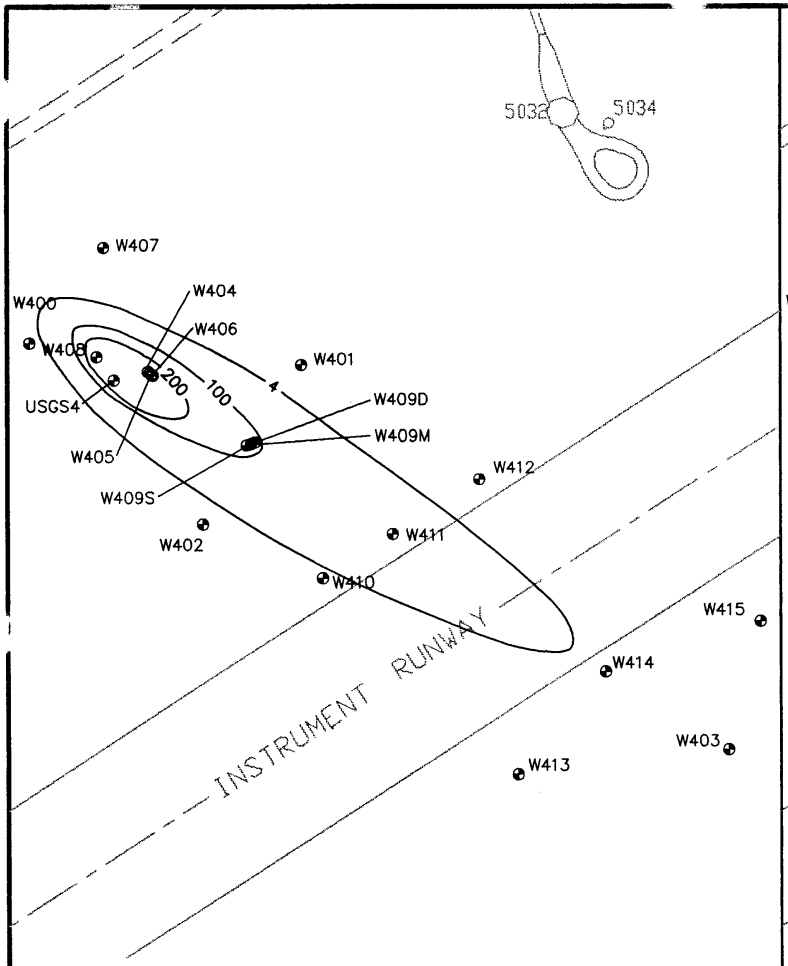
This alternative would include annual monitoring of groundwater to verify and document that natural attenuation processes alone are sufficient to reduce site concentrations to below generic industrial cleanup criteria. The progress of natural attenuation will be monitored using the existing network of monitoring wells, including sentry wells and POA wells that will be used to ensure that no groundwater exceeding generic residential cleanup criteria approaches the airfield boundary. Additional details on the frequency and types of groundwater analysis recommended to confirm the effectiveness of ongoing natural processes and to verify the completion of a cleanup appropriate for an industrial site are presented in the long-term monitoring plan included in Section 10.

8.1.2 Alternative 2 - Biosparging in Source Area, Natural Chemical Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls.

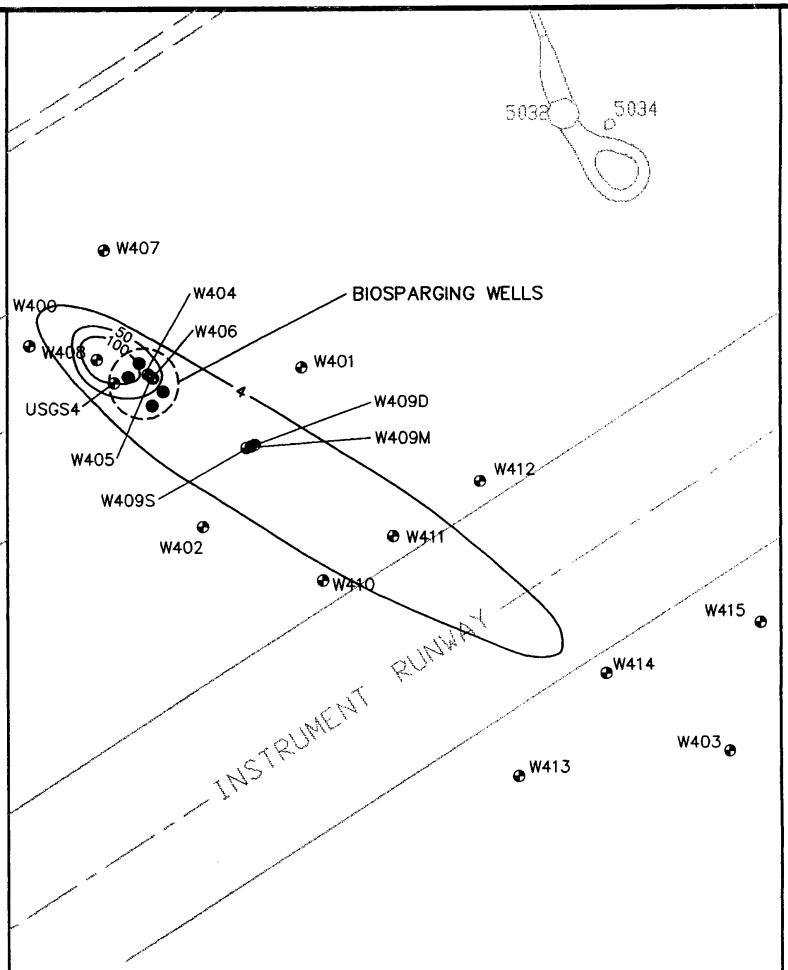
Goal of Alternative 2 - Attainment of generic industrial cleanup criteria in approximately 6 years.

Alternative 2 is similar to Alternative 1 except for the addition of several biosparging wells in the source area in the vicinity of and immediately downgradient from well USGS-4. One method of enhancing DO concentrations and promoting COC removal in the source area groundwater (particularly the TMB isomers) would be to inject air into the saturated interval using air sparging points. Pilot test results described in Section 7 show that the dissolved oxygen could be increased in the most contaminated area of the shallow aquifer. Based on the radius of oxygen influence measured during pilot testing, four sparge points injecting air at 6 scfm will provide sufficient additional oxygen to the source area. Pilot testing results also suggest that the biosparging system could enhance the physical removal of COCs from the groundwater and capillary fringe. Despite the positive pilot test results, biosparging is still considered an unproven technology by many independent researchers. These researchers cite air channeling and lack of uniform oxygen distribution as factors which may negatively impact long-term performance (Johnson, 1993).

The Bioplume II model was used to simulate the positive effects of biosparging in the source area (details are presented in Appendix D). To provide a conservative simulation, only the biological enhancement due to the addition of 1 milligram per liter of additional DO was simulated by the model. Any additional COC removal due to volatilization was not modeled. Figure 8.1 illustrates the enhanced reduction



PREDICTED TOTAL BTEX PLUME (μg/L)
NATURAL ATTENUATION ALONE
(1998)



PREDICTED TOTAL BTEX PLUME (μg/L)
AFTER THREE YEARS OF BIOSPARGING
(1998)

LEGEND

- GROUNDWATER MONITORING WELL (INSTALLED 10/94)
- W400 SAMPLING LOCATION
- 100 ESTIMATED LINE OF EQUAL TOTAL BTEX CONCENTRATION (μg/L) CONTOUR INTERVAL=VARIABLE

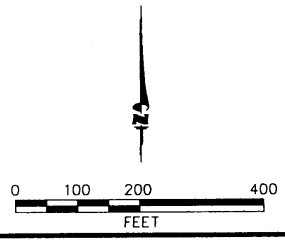


FIGURE 8.1

PREDICTED IMPACT OF THREE YEARS OF BIOSPARGING ON GROUNDWATER BTEX PLUMES

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

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for BTEX predicted after 3 years of biosparging compared to the effects natural attenuation alone. The primary benefit of the first 3 years of biosparging is the reduction of the source of COC contamination at the crash site. The model predicts a maximum total BTEX concentration of approximately 500 µg/L under the natural attenuation alternative and a 250 µg/L maximum if biosparging is used to treat the source area. Bioplume II model predicts that after approximately six years of biosparging, groundwater COC concentrations could be reduced to below generic industrial criteria. Due to the uncertainty of long-term biosparging performance, these simulations could underestimate or overestimate DO concentration increases and the time required to achieve generic industrial cleanup criteria.

Land use and groundwater use controls for Alternative 2 would be identical to Alternative 1. Additional site access would be required to maintain the biosparging system. Long-term groundwater monitoring would also be the same as Alternative 1, except that additional soil gas monitoring would be included during the first six months of biosparging to quantify the amount of COCs removed from the groundwater and to monitor the biodegradation of vapors passing through the vadose zone.

Assuming that biosparging can increase the average DO concentration in the source area to 1 milligram per liter, the estimated time required for attainment of a industrial cleanup criteria under Alternative 2 is approximately 6 years. An additional year of long-term groundwater monitoring (7 years total) has been assumed for cost estimating purposes.

8.1.3 Alternative 3 - Limited Groundwater Extraction, Air Injection Bioventing, Natural Chemical Attenuation, Long-term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 3 - Attainment of generic industrial cleanup criteria in 4 years.

This alternative combines more active groundwater extraction and bioventing activities in the source area with natural attenuation. Three 4-inch extraction wells would be installed down the centerline of the source area, extending from well USGS-4 to W409. Each well would be screened over an interval of 10 to 25 feet bgs. Both groundwater extraction and air injection would be accomplished in the same well. The objectives would be to more rapidly remove the most contaminated groundwater at the site while dewatering the contaminated soil interval and exposing the contaminated soil to injected air (oxygen) to promote *in situ* bioventing. Based on estimates of hydraulic conductivity at the KC-135 Crash Site (Section 3), each extraction well could be pumped at 14 gallons per minute (gpm) to produce a capture radius of approximately 50 feet. This pumping rate and drawdown would ensure that the most contaminated groundwater on the site would be rapidly removed and treated and that downgradient migration of COCs would be significantly reduced. The influx of oxygenated groundwater and the reinjection of treated groundwater also will enhance natural biodegradation throughout the most contaminated area of the plume. Although not a major concern at this site, the removal of contaminants in saturated soils would be enhanced if the most contaminated soil interval is dewatered and exposed to allow more rapid biodegradation via bioventing.

Groundwater treatment would be accomplished using a fabric prefilter followed by two granulated activated carbon (GAC) canisters in series to prevent contaminant breakthrough. Based on the expected total flow rate of 42 gpm and October 1994 contaminant concentrations, two 1,800-pound GAC canisters in series are recommended for use during the first 90 days of system operation. Contaminant concentrations would be expected to decrease rapidly, as would carbon replacement requirements. The canisters and prefilter would be placed in a temporary, low-profile building that would be located north of the crash site. The building would be heated to allow year-round operation. Following treatment, groundwater would be discharged into a reinjection trench, which would be constructed upgradient of the site. A reinjection permit may be required, as would monthly effluent monitoring. Intrinsic remediation would continue to be the primary removal mechanism for COCs that have migrated beyond the capture zone of the proposed extraction wells.

Land and groundwater use controls similar to Alternative 1 are recommended until groundwater COCs are reduced below generic industrial cleanup criteria. During groundwater extraction, and for at least two years following the extraction, long-term groundwater monitoring would continue in accordance with the long-term monitoring plan. Under this alternative, additional monitoring of extracted groundwater and the activated carbon effluent would be required to ensure contaminant removal prior to reinjection.

It is anticipated that once the groundwater extraction and bioventing system is operating, industrial cleanup criteria could be achieved in 3 years or less. However, design, permitting, and construction could easily require a lead time of nine months to one year. Therefore, the total estimated time for Alternative 3 to be implemented and to achieve industrial cleanup criteria is 4 years. One additional year of groundwater monitoring is recommended to confirm that concentrations of COCs have been reduced below target cleanup criteria at every point at the site.

8.2 REVIEW OF SCREENING AND EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for soil and groundwater contamination at the KC-135 Crash Site were adapted from those recommended by the EPA (1988) for selecting remedial actions for Superfund sites (OSWER Directive 9355.3-01). These criteria are consistent with those required for initial screening and detailed evaluation of remedial alternatives by the MDEQ. These criteria include (1) anticipated effectiveness in meeting target cleanup criteria, (2) technical and administrative implementability, and (3) relative cost. An initial screening of remedial technologies was conducted using the three broad evaluation criteria (Appendix G). The following sections briefly describe the scope and purpose of each criterion.

8.2.1 Effectiveness

Each remedial technology or remedial alternative (which can be a combination of remedial technologies) was evaluated to determine how effectively it can attain the desired degree of cleanup. The remedial action proposed for this site is designed to attain generic industrial cleanup criteria. Section 5 provided the rationale for why industrial cleanup criteria are appropriate for the site, given the current and planned

future land uses and the potential for exposure to site-related contamination. Remedial technologies that could not cost-effectively attain the desired level of remediation were eliminated from further consideration.

Remedial technologies retained for detailed evaluation are evaluated in more detail in terms of the expected effectiveness of each technology to attain the desired degree of risk reduction at the KC-135 Crash Site, based on site-specific data supplemented with actual treatability tests (performed at Wurtsmith AFB Site OT45). The ability to minimize potential adverse impacts to surrounding facilities and operations and other environmental resources is considered. Time to implementation and time until protection is achieved are described. Potential adverse impacts that could be realized during implementation, the cost of necessary mitigation measures, and the potential for residual risks remaining following remedial action also were qualitatively considered. Potential residual risks that may exist following remedy implementation are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, is also evaluated.

8.2.2 Implementability

The technical feasibility, applicability, and reliability of each remedial technology were initially used as broad criteria to narrow the list of potentially applicable remedial approaches for the site. Technologies retained for detailed evaluation were evaluated in terms of engineering implementation, reliability, constructability, and technical feasibility. Potential effects due to unanticipated site conditions or significant changes in site conditions were considered. The ability to monitor performance and public perception are discussed. Any prohibition of onsite activities that would be required to ensure successful implementation is described.

8.2.3 Cost

Relative cost of various remedial technologies was used as an initial screening tool (Appendix G). More detailed cost estimates were prepared for each remedial approach retained for comparative analysis. The cost includes operation and maintenance costs, distributed over the time required for implementation. Present worth cost estimates were prepared in accordance with OSWER Directive 9355.3-20.

8.3 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

In this section, each of the candidate alternatives is evaluated using the more detailed criteria described in the previous section. Each alternative is more fully described in terms of its effectiveness, technical and administrative implementability, and cost.

8.3.1 Alternative 1 - Natural Chemical Attenuation, Long-Term Monitoring and Groundwater Use Controls

8.3.1.1 Effectiveness

Natural attenuation has already been proven effective in reducing site contaminants based on historical reductions in dissolved COCs. A comparison of groundwater

contaminant concentrations measured in the source area in October 1996 to concentrations measured in January 1993 indicate that natural processes have been responsible for reducing total contaminant concentrations by more than 70 percent over the past 46 months. Definitive evidence presented in Section 6 indicates that natural biodegradation is actively removing COC compounds in the source area and in downgradient groundwaters. Based on the actual rates of biodegradation observed between January 1993 and October 1996, and on conservative modeling results, all groundwater COCs should be reduced to levels below generic industrial cleanup criteria in approximately 8 years. The Bioplume II modeling results presented in Section 6 demonstrate that even the mobile BTEX compounds will not migrate a significant distance downgradient of the present plume position. The assimilative capacity of the saturated media and the site-specific biodegradation rates will be sufficient to transform COCs into carbon dioxide and water and to limit migration of the plume. Natural chemical attenuation has proven to be an effective method of reducing both the contaminant mass and the potential toxicity of this JP-4 spill.

Groundwater use controls are an important component of this alternative. The current restrictions to site access (airfield perimeter fencing) provide an effective measure of protection against unauthorized groundwater contact. The present (uninhabited) land use and nonuse of groundwater have effectively eliminated potential exposure pathways involving groundwater at this site. The Oscoda Township Board of Trustees has approved the current airfield (including the KC-135 Crash Site) for continued industrial/airfield use. As a part of this RAP, the Air Force proposes well permit restrictions to prevent withdrawal of groundwater from the shallow aquifer for drinking water applications within 1,000 feet of the plume centerline until such time as the COCs decrease below industrial groundwater cleanup criteria. The generic industrial cleanup criteria were developed to protect onsite workers who regularly ingest contaminated groundwater during an 8-hour workday. Groundwater use restrictions should be a component of the airfield lease agreement and site operation/management (O&M) plans. This strategy will not interfere with the current and intended use of the site and affected natural resources.

Long-term groundwater monitoring is recommended under Alternative 1 as a method of measuring the effectiveness of natural attenuation and determining when generic industrial cleanup criteria have been achieved. Groundwater samples will be collected from 8 monitoring wells, including W410, W412 and W409D, which will serve as sentry wells to provide early warning if significant COC contamination migrates beyond its predicted horizontal or vertical boundaries. Well W416 will not be sampled unless COC compounds are first detected in POA well W414. Annual groundwater sampling is recommended, given the limited COC migration that was observed between 1992 and 1996. Groundwater samples will be analyzed for BTEX and trimethylbenzene using EPA Method SW8020. Analytical data on selected geochemical indicators of biodegradation such as DO and sulfate also will be collected to assess the progress of natural attenuation. Annual groundwater monitoring will continue until industrial cleanup criteria are uniformly achieved at the site. Based on conservative Bioplume model predictions, 9 years of long-term monitoring has been assumed for the Alternative 1 cost estimate.

A complete long-term monitoring plan is provided in Section 10 to assist the base in implementing this important component of Alternative 1. Every year, groundwater data should be compared to model predictions to ensure that natural attenuation processes are reducing site concentrations to levels near the generic industrial cleanup criteria. In the event that natural attenuation is not progressing and is not likely to achieve industrial cleanup criteria for groundwater, or in the event that residential cleanup criteria are exceeded at the POA well, the following contingency actions are recommended:

- All downgradient sentry and POA wells will be resampled to confirm initial results;
- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating more rapid contaminant migration due to a lack of natural attenuation;
- The risk analysis will be updated to determine if the levels of groundwater contamination present a risk given actual site and downgradient land use at the time of sampling; and
- If a significant risk exists, more active methods of remediation will be reevaluated and the most effective risk reduction method will be implemented. This could include initiation of the active remediation methods described for Alternatives 2 or 3.

8.3.1.2 Technical and Administrative Implementability

Alternative 1 is technically simple and easy to implement. No new sentry or POA well construction is required to monitor the plume. Due to the distance between the leading edge of the plume and the airfield boundary, no new point-of-compliance (POC) wells are proposed at this time. Long-term groundwater sampling is a standard procedure involving minimal worker exposure to contaminated media. Equipment reliability and maintainability are not issues under Alternative 1 because no remediation equipment will be used on the site. The reliability of natural attenuation processes to reduce COC concentrations and limit plume migration will be reevaluated every year.

Administrative implementation of this alternative will require that the AFBCA and Oscoda Township continue to communicate regarding the future use of the airfield and the KC-135 Crash Site area. Any proposed change in land use which differs from industrial/airfield or any proposed groundwater pumping within 1,000 feet of the current plume centerline should be carefully evaluated. The existing airfield perimeter fence also should be maintained to prevent unauthorized access. Any future construction or maintenance activities in this area should be planned to minimize deep excavations (i.e., greater than 8 feet deep) and should protect the network of long-term monitoring wells. Wells should remain locked and protected against tampering or vandalism.

The public perception of Alternative 1 is expected to be positive. This alternative is protective of human health and the environment and achieves COC reductions that are compatible with existing and future land use at minimum taxpayer expense. Consistent

long-term monitoring will provide verification of natural attenuation effectiveness. This remedial approach should not impose a financial burden on, or delay implementation of, Oscoda Township's land reuse plans for this area of the airfield.

8.3.1.3 Cost

The costs associated with Alternative 1 are presented in Table 8.1. Detailed cost calculations are presented in Appendix E. There are no capital costs associated with this alternative because no additional monitoring wells are needed to monitor the dissolved plume. There is no remediation equipment to be operated or maintained under this alternative. Annual costs include groundwater monitoring and site management (to be provided by AFBCA), which will include evaluation of annual monitoring data and continued liaison with Oscoda Township and participation in future land use planning. Based on the conservative assumption that 9 years of natural attenuation/long-term monitoring will be required to ensure and verify uniform attainment of generic industrial cleanup criteria, the present-worth cost of Alternative 1 is estimated to be $123,110. These costs are most sensitive to unexpected delays in attaining industrial cleanup criteria. For example, if twenty years of annual long-term monitoring was required, the present-worth cost of this alternative would increase to more than $240,000.

8.3.2 Alternative 2 - Biosparging in Source Area, Natural Chemical Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

8.3.2.1 Effectiveness

The effectiveness of Alternative 2 in reducing site contaminants to levels below industrial cleanup criteria will rely primarily on natural attenuation. Pilot testing indicates that the use of biosparging within the source area could enhance the removal of volatile COC compounds from the groundwater and saturated soils and will add additional oxygen to enhance the biodegradation of downgradient COCs. The Bioplume II model predicts that if additional oxygen can be provided to the source area the plume will more rapidly biodegrade and the time to achieve industrial cleanup criteria could be reduced (Figure 8.1). The enhanced reduction of contaminant mass and toxicity is a potential advantage of Alternative 2. The Bioplume II model for this site predicts that generic industrial groundwater criteria could be achieved in approximately 6 years. Although biosparging pilot test results for site OT45 indicated a relatively uniform increase in DO, many independent researchers have cast doubt on the long-term effectiveness of this technology. Problems such as severe channeling, short-circuiting of air flow, lateral migration of contaminants, and inaccurate monitoring methods have been cited by these researchers. Despite its current popularity, many still considered biosparging an experimental technology with relatively few documented successes. Pulsed operation of biosparging systems has been suggested as one way of improving effectiveness. However, there is little documentation on the benefits of pulsing.

The groundwater use controls for this alternative would be identical to those described for Alternative 1, except that the controls could possibly be removed in 6 years. The installation and operation of a biosparging system would require additional site access. The long-term groundwater monitoring proposed for Alternative 2 is

TABLE 8.1

COST ESTIMATE FOR ALTERNATIVE 1
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Tasks	Capital Costs
No capital costs	$0
Site Management and Monitoring Tasks	**Annual Costs**
Conduct annual groundwater sampling at 8 monitoring wells in accordance with the Long-Term Monitoring Plan (9 years)	$9,340
Site Management and Public Liaison (9 years) (assumes 160 man-hours/year)	$9,600
Present Worth of Alternative 1 [a/]	$123,110

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

nearly identical to Alternative 1, except that the biosparging system would require weekly system checks and more frequent monitoring to determine the effectiveness of oxygenation, COC removal from the groundwater and biodegradation of vapors released to the vadose zone. In recognition of the COC mass reduction that could result from three years of biosparging, the long-term monitoring requirement for Alternative 2 has been decreased from 9 years to 7 years for cost comparison purposes.

8.3.2.2 Technical and Administrative Implementability

Alternative 2 would require the construction of four biosparging wells and an air pump system to introduce approximately 6 scfm of air into each air sparging point. Six sets of discrete-interval well points would be driven in the biosparging area to monitor the distribution of DO at varying distances and depths from the air sparging points. The installation of air sparging points and discrete level monitoring points was successfully demonstrated during the Site OT45 pilot test. Installation at the KC-135 Crash Site will use similar drilling techniques. No additional drilling would be required for new downgradient monitoring wells. Technical implementation would include the installation of a 3-horsepower air pump and associated gauges and flow control valves. Power is available approximately 300 feet from the site. The air pump would be housed in a simple wooden enclosure.

The general reliability and maintainability of biosparging systems is high. These are simple mechanical systems. Motors are sealed and do not require lubrication. Air filters provide protection for the air pump and generally require replacement every 90 to 180 days. Weekly system checks are recommended, and operating data such as injection pressure and flow rate would be manually recorded. A rise in injection pressure can indicate plugging of the sparging point; however, plugging is unlikely in the sandy aquifer at this site. The possible failure of the biosparging system to provide a significant and sustained increase in DO is the greatest threat to the success of this alternative.

Administrative implementation of this alternative is similar to Alternative 1 and will require that the AFBCA and Oscoda Township continue to communicate regarding the future use of the airfield (i.e., continued industrial zoning), with appropriate lease restrictions, be upheld to prevent unnecessary exposure of humans to contaminated groundwater. Access to the site should continue to be restricted by the airfield perimeter fence. Site development plans should protect the biosparging system and the network of long-term monitoring wells. Wells should remain locked and protected against damage.

The public perception of Alternative 2 is expected to be positive. This alternative is protective of human health and the environment and could achieve COC reductions in a shorter time and at a relatively low expense. Although biosparging is expected to more rapidly reduce COC concentrations, there is no real advantage over Alternative 1 unless future land use requires that site groundwater be used as drinking water between the years 2002 and 2004. Because the site is expected to remain an uninhabited airfield this advantage may never be realized. This remedial approach should not impose a financial burden on, or delay implementation of, Oscoda Township's land reuse plans for this area of the airfield.

8.3.2.3 Cost

The costs associated with Alternative 2 are presented in Table 8.2 Detailed cost calculations are presented in Appendix E. Capital costs include the cost of design and construction of a biosparging system and six discrete-level monitoring points. Three years of biosparging operation and monitoring have been included as annual costs. Annual costs will also include groundwater monitoring and site management (provided by AFBCA), which will include public education and continued liaison with Oscoda Township and participation in future land use planning. Assuming that biosparging remains effective and that 6 years will be required to achieve industrial groundwater criteria, this cost estimate has assumed that a total of 7 years of long-term monitoring will be required to ensure uniform attainment of industrial cleanup criteria in downgradient areas. Using these assumptions, the present worth cost of Alternative 2 is $179,200. As with Alternative 1, these costs are most sensitive to unexpected delays in attaining industrial cleanup criteria. For example, if six years of biosparging and 12 years of long-term monitoring were required, the present-worth cost of this alternative would increase to more than $240,000.

8.3.3 Alternative 3 - Limited Groundwater Extraction, Bioventing in Source area, Natural Chemical Attenuation, and Land and Groundwater Use Controls

8.3.3.1 Effectiveness

The effectiveness of Alternative 3 in reducing site contaminants to levels below generic industrial cleanup criteria will depend upon a combination of intense, short-term source reduction and long-term natural attenuation. A three-well groundwater extraction system would be constructed along the plume centerline extending from well USGS-4 to well W409. This remains the most contaminated area of the site and is the primary source of COCs. Recent slug testing at the KC-135 Crash Site has confirmed the suitability of the shallow aquifer properties for extracting large volumes of groundwater for dissolved contaminant recovery. Based on the average hydraulic conductivity determined from multiple slug tests, a pumping rate of approximately 14 gpm per well could be used to create a capture radius of approximately 50 feet for each well. A screened interval of 10 to 25 feet bgs was used for pumping calculations (Appendix E). This interval was selected to minimize downward vertical migration of contamination while minimizing pumping rates and the number of extraction wells. Groundwater extraction within the source area will more rapidly remove dissolved COCs in a 100 x 300 foot area downgradient from the crash site. The influx of clean groundwater also will accelerate the partitioning of COCs from saturated soils and add additional oxygen to the aquifer to enhance biodegradation. Results of simple batch flushing calculations (provided in Appendix E) indicate that this intense pumping should reduce all COCs to concentrations below industrial cleanup criteria levels in 3 years.

Once extracted, groundwater will be treated using GAC. Carbon adsorption is a proven and cost-effective technology for removing all dissolved COCs present at the KC-135 Crash Site. Due to the relatively short time that should be required to attain generic industrial criteria, more capital-intensive technologies such as air stripping were not considered appropriate for this site. The rapid decline in extracted contaminant

TABLE 8.2

COST ESTIMATE FOR ALTERNATIVE 2
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

Tasks	Capital Costs
Design and construction of 4-well biosparging system with 6 sets of discrete monitoring points	$51,370
Site Management and Monitoring Costs	**Annual Costs**
Operation, maintenance and monitoring of biosparging system (3 years)	$9,560
Conduct annual groundwater sampling at 9 monitoring wells in (9LTM wells + W404) (7 years)	$9,440
Site Management and Public Liaison (7 years) (assumes 160 man-hours/year)	$9,600
Present Worth of Alternative 2 [a/]	$179,233

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

concentrations should result in lower carbon costs during the second and third year of pumping. Treated groundwater would be reinjected into the groundwater using a large infiltration trench located immediately upgradient from the site.

Dewatering of the source area during groundwater extraction will make it possible to introduce air via bioventing into the only remaining contaminated soils on the site (i.e., soils just below the water table). Bioventing is a proven technology for the reduction of jet fuel residuals and should provide for more rapid biodegradation of more strongly sorbed compounds such as xylenes and trimethylbenzenes. Biodegradation of these compounds will ensure that when pumping is terminated, the groundwater will not become recontaminated from capillary fringe soils. Groundwater extraction and bioventing were selected as the most aggressive approach for reducing all dissolved COCs below generic industrial cleanup criteria. Alternative 3 should rapidly remove the source and reduce the areal extent of groundwater contamination. The more rapid reduction of soil contaminants using bioventing also is an advantage of Alternative 3.

One major drawback to the effectiveness of this alternative is the expected lead time required to design, permit, and construct the much more complex groundwater extraction/carbon treatment system with an integrated bioventing system. Once operating, however, this intensive treatment system should attain industrial cleanup criteria for soil and groundwater in approximately 3 years. Unfortunately, the lead time for design, permitting, and construction is expected to be at least 9 months. This reduces the time effectiveness advantage when compared to Alternative 2.

Land and groundwater use controls for this alternative would be identical to those described for Alternative 1 and 2, except that the installation and operation of a groundwater extraction and treatment system and bioventing system would require additional site access. The groundwater treatment system would require weekly system checks, and at a minimum, monthly monitoring of groundwater influent and treated effluent groundwater. Bioventing monitoring would be limited to semiannual respiration testing to determine the effectiveness *in situ* biodegradation in the contaminated soil. In recognition of the COC mass reduction that should result from this more intensive source removal, the total long-term monitoring requirement for Alternative 3 has been estimated at 5 years.

8.3.3.2 Technical and Administrative Implementability

Alternative 3 would require construction of three, 4-inch groundwater extraction wells, and installation of three, 1/2-horsepower submersible pumps with controls, a prefilter, and the installation of two 1,800-pound GAC canisters in series. For this engineering estimate, it is assumed that this treatment system would be installed inside a prefabricated building, which would be heated during winter operations. The bioventing system for the KC-135 Crash Site would consist of a single 2.5-horsepower regenerative blower, an inlet air filter, and temperature and pressure gauges. Standard mechanical and electrical construction would be used; special construction techniques should not be necessary.

Submersible pumps and carbon treatment systems generally are highly reliable when they are properly maintained. The most frequent reliability problems occur with pump controls, which must be carefully set to minimize pump cycling. Due to the short, 3-

year pumping period, the submersible pump should operate with minimal maintenance. The most significant maintenance requirement for this system will be regular replacement of the prefilter element and monitoring of the carbon effluent to ensure that discharge standards are attained. Due to the anticipated rapid decline in extracted COC concentrations, replacement of the two 1,800-pound carbon canisters may be required only two or three times during the life of the project. Three sets of replacements have been estimated for cost purposes. The documentation associated with meeting reinjection monitoring requirements could add several hours each month to project management. Bioventing systems are very reliable and require only minimal maintenance. Air filters provide blower protection and generally require replacement every 90 to 180 days. Weekly system checks are recommended, and operating data such as injection pressure and flow rate will be manually recorded.

Administrative implementation of this alternative will require that the AFBCA and Oscoda Township continue to communicate regarding the future use of the airfield and that the approved airfield zoning be upheld, with appropriate lease restrictions to prevent potable use of site groundwater. The perimeter fence should be maintained to prevent unauthorized entrance. Future airfield development plans should protect the pumping and treatment system and network of long-term monitoring wells. Wells should remain locked and protected against tampering.

The public perception of Alternative 3 is expected to be positive. However, most experienced remediation professionals would view this level of treatment as excessive, given that the site is zoned for uninhabited airfield use and the risk of off-site migration is very low. This alternative is protective of human health and the environment and achieves COC reductions that are compatible with current industrial/airfield land use. However, any benefits of more rapid risk reduction may not be justified, given the additional costs.

8.3.3.3 Cost

The costs associated with Alternative 3 are presented in Table 8.3. Detailed cost calculations are included in Appendix E. Capital costs include the cost of design and construction of groundwater extraction, groundwater treatment, and bioventing systems. Annual costs will include the 3 years of intensive groundwater extraction/bioventing, 5 years of groundwater monitoring and site management (provided by AFBCA), which will include public education and continued liaison with Oscoda Township, and participation in future land use planning. Based on these assumptions, the present worth cost of Alternative 3 is $384,000. Alternative 3 costs are most sensitive to additional years of groundwater treatment system operation and maintenance.

8.4 RECOMMENDED ALTERNATIVE

Alternative 1 (Natural Chemical Attenuation, Long-Term Monitoring, and Groundwater Use Controls) is recommended for remediation of the KC-135 Crash Site based on its expected effectiveness in attaining a generic industrial cleanup criteria, its relative simplicity with respect to technical and administrative implementation, and its low overall cost. Table 8.4 provides a summary of the evaluation process for each alternative.

TABLE 8.3

COST ESTIMATE FOR ALTERNATIVE 3
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Tasks	Capital Cost
Design and construction of a three-well extraction system w/pumps	$49,000
Discharge Permit Preparation/Negotiation	$4,800
Design and construction of groundwater treatment system	$74,540
Design and construction of bioventing system	$19,140
Site Management and Monitoring Tasks	**Annual Costs**
Operation and Monitoring of Groundwater Treatment/Bioventing Systems (3 years)	$60,540[b/]
Conduct annual groundwater sampling at 8 wells in accordance with the LTMP (5 years)	$9,340
Site Management and Public Liaison (5 years) (assumes 160 man-hours/year)	$9,600
Present Worth of Alternative 3 [a/]	$384,00

[a/] Based on a discount rate of 7 percent.
[b/] Includes GAC supply and disposal costs.

TABLE 8.4
SUMMARY OF REMEDIAL ALTERNATIVE EVALUATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRACH SITE, WURTSMITH AFB, MICHIGAN

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			$123,100
-Natural Chemical Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Contaminant mass, volume, and toxicity will gradually be reduced by intrinsic remediation alone. Concentration of COCs will be below industrial cleanup criteria in approximately 8 years.	Technically simple and easy to implement. Long-term groundwater monitoring for 9 years is required. Current land use restrictions are in place and effective. Requires public education.	
Alternative 2			$179,233
-Biosparging in Source Area -Natural Chemical Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Similar to Alternative 1, with the addition of biosparging to increase contaminant degradation in the source area. Pilot testing produced significant DO increases. Controversial technology: may not provide effective long-term treatment.	Long-term groundwater monitoring for 7 years is predicted if biosparging can provide uniform oxygen addtion to groundwater. Biosparging system will require weekly monitoring. Current land use restrictions are in place and effective. Positive public perception.	
Alternative 3			$384,000
-Limited Groundwater Extraction -Air Injection Bioventing -Natural Chemical Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Similar to Alternative 1, with the addition of groundwater removal and treatment and air injection bioventing to treat dewatered soils. Generic industrial cleanup criteria for all COCs in groundwater will be met in approximately 3 years once system operation begins. GAC will sufficiently treat groundwater to meet generic residential aesthetic and health-based criteria. Discharge to infiltration trench is recommended.	Long-term groundwater monitoring for 5 years is required Pump and treat and bioventing systems will require weekly monitoring. A discharge permit may be required for reinjection of treated groundwater. Lengthy lead time required for design and installation of pump and treat system. Contaminated GAC will have to be disposed. Current land use restrictions are in place and effective. Positive public perception.	

Significant evidence exists that natural attenuation processes will achieve a generic industrial cleanup criteria for groundwater in approximately 8 years. Given the current and projected land use in the airfield and the conservative estimates of plume migration, no active remediation is required at this site to protect human health or the natural environment. Bioplume II modeling predicted very limited plume migration, with virtually no chance of off-base migration. Long-term groundwater monitoring will be used to verify natural attenuation and to insure that COCs do not migrate to the airfield boundary or base boundary. Limitations on groundwater pumping at this site should not impose a restriction on future airfield land use or operations.

Bioplume II modeling suggested that the addition of biosparging in the plume source area could reduce the long-term monitoring time and the time to achieve generic industrial cleanup criteria from approximately 8 to 6 years. This model assumed that long-term biosparging will uniformly increase the DO in the source area and that pilot tests are indicative of long-term performance. As discussed in Section 7, there is considerable evidence that long-term biosparging may not provide uniform DO distribution. Because of this potential overestimation of the DO supply, the Bioplume II modeling results depicted in Figure 8.1 should be considered best-case; actual treatment times could exceed predictions. Alternative 3 should provide for more rapid plume remediation, but the cost of constructing and maintaining a pump and treat system at this site is not justified given that no current risk exists, no future risk is expected, and no off base migration seems likely. Alternative 3 could be implemented if future land use required more immediate groundwater use.

On the basis of this evaluation, Alternative 1 provides the best combination of risk reduction and low cost without imposing additional land use restrictions or delays to the transfer of this property from AFBCA control to Oscoda Township. Section 9 provides additional details on the recommended implementation of this alternative.

SECTION 9

IMPLEMENTATION OF RECOMMENDED REMEDIAL ACTION

This section provides an implementation plan for the recommended remedial action Alternative 1 (Natural Chemical Attenuation, Long-Term Monitoring, and Groundwater Use Controls) at the KC-135 Crash Site. This section reviews the scope and schedule of remediation activities, discusses possible contingencies if this remedial approach does not prevent offsite migration of COCs, and summarizes costs by fiscal year.

9.1 SCOPE OF REMEDIAL ACTIVITIES

The recommended remedial action alternative will be implemented over a 9-year period to ensure uniform attainment of generic industrial cleanup criteria onsite and to verify that no COCs are migrating off the base at concentrations exceeding generic residential cleanup criteria. The following sequence of events is proposed to fully implement this remedial action.

9.1.1 Final Approval of Remedial Action Plan

Approval of this RAP is within the authority of the Base Realignment and Closure (BRAC) Cleanup Team, consisting of representatives from the AFBCA, MDEQ, and EPA Region V. This team of environmental professionals is responsible for final approval of this RAP and eventual implementation of the approved remedial actions.

9.1.2 Verification of Current and Future Land and Groundwater Use Controls

An important element of the recommended remedial action at the KC-135 Crash Site is groundwater use control. On the basis of available soil and groundwater data and the exposure pathway analysis in Section 5, the site is immediately acceptable for continued airfield use provided that future land use does not require extraction and ingestion of site groundwater. It is recommended that the current restricted access be maintained at the airfield and that any future lease of this land for airfield activities stipulate that groundwater will not be extracted within 1,000 feet of the plume centerline until COC concentrations have been reduced below the industrial cleanup criteria. Excavation in the plume area also should be limited to depths of less than 8 feet bgs. These minor restrictions will eliminate a potential exposure point to contaminated groundwater. Lease restrictions are currently applied to any change in land use within the base and deed restrictions will be implemented as a part of future land transfers

There is significant land use flexibility under the proposed land reuse scenarios for this site. The key to implementation will be open and clear communications between

the BRAC Cleanup Team and Oscoda Township on the progress of natural attenuation and notification when industrial groundwater cleanup criteria are achieved. Once industrial cleanup criteria are achieved, industrial-use groundwater use restrictions can be removed from the crash site area. Groundwater could be used to meet industrial potable and nonpotable applications when industrial cleanup criteria have been achieved at every point in the aquifer at and downgradient from this site.

9.1.3 Implementation of the Long-Term Monitoring Plan

Section 10 provides a complete long-term monitoring plan (LTMP) for the KC-135 Crash Site. Long-term groundwater monitoring is essential for verification of natural attenuation progress. Careful implementation of the LTMP is a key component of this RAP. The proposed remedial alternative at this site calls for annual groundwater sampling at a total of 8 sampling locations, including 3 sentry wells to track the horizontal and vertical motion of the plume, and a downgradient POA well (W414) to verify that COCs are not moving at a rate that could result in off-base migration. Due to the large distance which separates the plume from the base boundary (4,875 feet), a possible point-of-compliance well (W416) will not be sampled unless COCs are first detected in the POA well (W414). The plume is not expected to migrate appreciably beyond well W411. In fact, 1995 and 1996 groundwater data indicate that the plume has stabilized and may be receding.

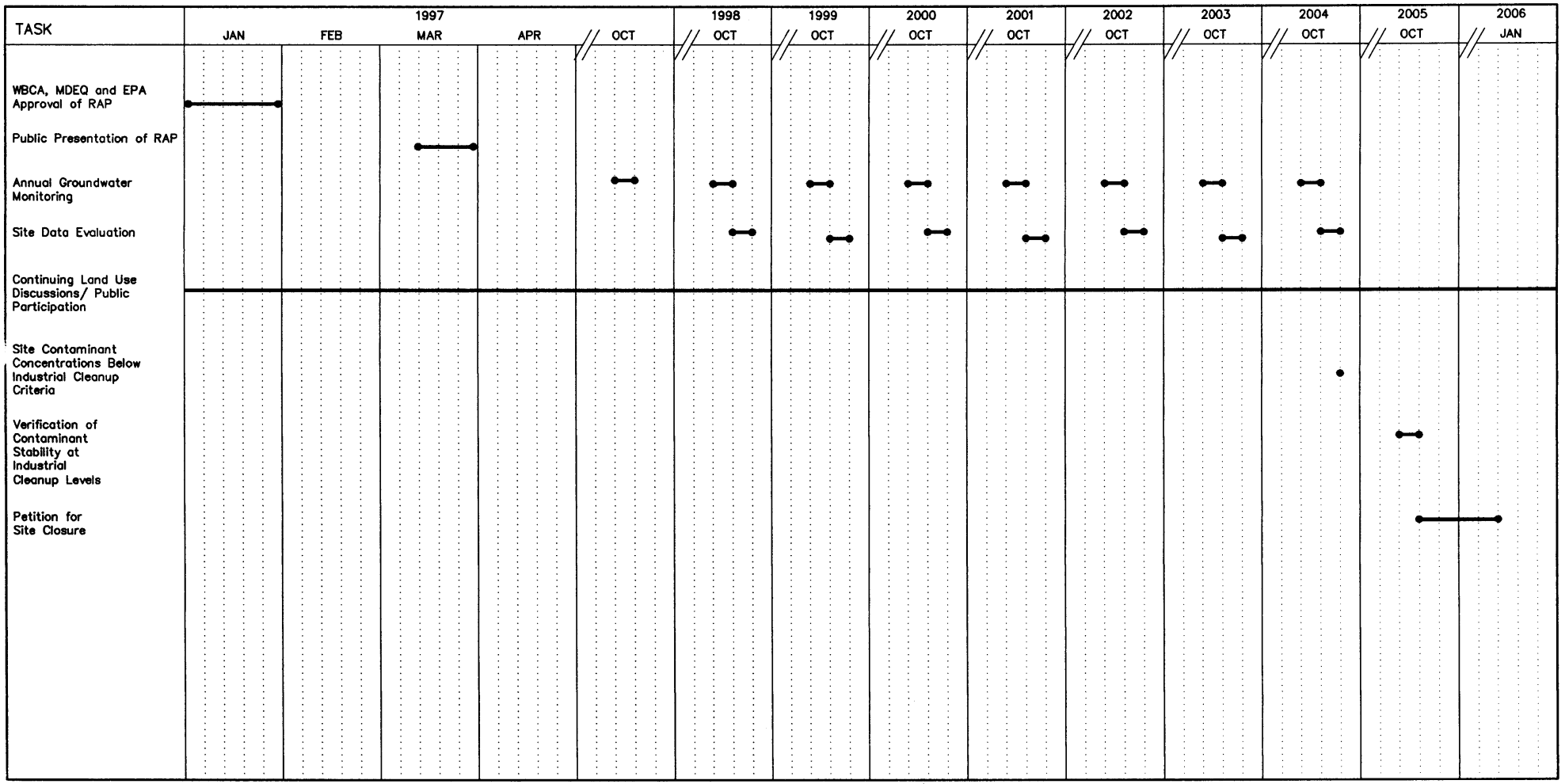
Annual groundwater sampling is recommended beginning in October 1997. Annual sampling is considered appropriate given the limited contaminant migration observed from 1992 to 1996. The actual number of years that annual sampling is required will be based on the BRAC Cleanup Team's determination of when generic industrial cleanup criteria have been uniformly attained at the site. Contaminant biodegradation and transport calculations presented in Section 6 suggest that BTEX and trimethylbenzene concentrations in groundwater should be reduced below industrial cleanup criteria in approximately 8 years. The results of groundwater sampling will be provided to the AFBCA, MDEQ, and EPA Region V to update the team on remediation progress and to provide new information for pending land use decisions.

9.2 IMPLEMENTATION SCHEDULE

Figure 9.1 is a proposed schedule for implementation of the RAP at the KC-135 Crash Site. The schedule is provided for planning purposes only, and is subject to approval of the RAP by the BRAC Cleanup Team. The schedule has significant flexibility at this point because under the current land use and proposed future land use, site contaminants pose no risk to human health or the environment. The only administrative action required in the near term is a statement in any lease agreement that restricts extraction, use of groundwater, and deep excavations in the vicinity of the spill site. The only potential schedule delay that could occur would result from a lack of funding to complete annual groundwater sampling. Any delay in the attainment of a generic industrial cleanup criteria will have minimal impact on future use of this area if it remains an uninhabited airfield.

FIGURE 9.1

IMPLEMENTATION OF REMEDIAL ACTION PLAN AND LONG-TERM MONITORING PLAN KC-135 CRASH SITE - WURTSMITH AFB, MICHIGAN



9.3 CONTINGENCY PLAN

Should natural chemical attenuation fail to achieve industrial cleanup criteria over the next 8 years, there should be no impact on the land redevelopment plans for this area. Oscoda Township has approved the site for airfield use and groundwater extraction in this area is not anticipated so long as alternate water supplies exist. In the event that shallow groundwater from this site must be extracted for potable uses, and generic industrial criteria have not yet been achieved, the following contingency actions are available:

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation processes are not proceeding at the rates predicted in Section 6.

- The risk analysis will be updated to determine if residual levels of groundwater contamination present an actual risk based on the intended use of the groundwater.

- If shallow groundwater must be used for drinking water, more active methods of remediation will be evaluated. This could include possible initiation of active remediation methods described in Alternatives 2 and 3. A more likely solution would be the installation of a point-of-use treatment system, such as GAC, which could provide the most economical treatment of dilute contaminants.

Once again, failure of natural attenuation to achieve industrial cleanup criteria will not impact the approved use of this area as an airfield, unless groundwater must be extracted for long-term potable uses.

Contingency plans also would be required if the plume continues to migrate toward the base boundary at concentrations exceeding residential cleanup criteria. Based on available sampling data, which indicates that the dissolved plume is stabilizing, and on Bioplume II predictions of plume attenuation due to natural processes, no appreciable migration is expected. If COCs are detected at concentrations significantly beyond model predictions in the POA well (W414), or if sentry well sampling indicates a significant change in the direction of plume migration, the following contingency actions are available:

- If the POA well appears to contain COC concentrations exceeding residential criteria, it will be resampled to confirm that analytical results are above generic residential cleanup criteria.

- Additional downgradient wells W403, W413, and W415 will be sampled to determine the extent of plume migration and to locate the center of highest plume concentrations.

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural attenuation is not proceeding at the rates predicted in Section 6.

- The risk analysis will be updated to determine if concentrations approaching the POC well present a risk based on the actual intended use of the groundwater.

- If significant risk exists, or if COC concentrations exceeding generic residential cleanup criteria could migrate off-Base, more active methods of remediation will be evaluated. This could include possible initiation of active remediation methods described in Alternatives 2 and 3, including a groundwater extraction system designed to contain contaminants within the Base boundary.

9.4 COST OF IMPLEMENTATION

A summary of the estimated present worth cost of implementing the recommended remedial alternative is provided in Section 8.1.3. Table 9.1 provides a cost estimate, based on expenditures in the next five fiscal years, to assist the Air Force in budgeting for KC-135 Crash Site remedial actions. As discussed in Section 8.1.3, this cost estimate is most sensitive to the number of years assumed for long-term monitoring.

TABLE 9.1

ESTIMATED COST BY FISCAL YEAR[a/]
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Task	FY98	FY99	FY00	FY01	FY02
Annual Groundwater Sampling[b/]	$9,340	$9,800	$10,300	$10,800	$11,350
Site Management (By AFBCA)[b/] (160 hours/year)	$9,600	$10,000	$10,600	$11,150	$11,700
Fiscal Year Totals	$18,940	$19,800	$20,900	$21,950	$23,050

a/ Estimates for the first 5 years of a 9-year long-term monitoring plan.
b/ Assumes a 5 percent annual inflation rate.

SECTION 10

LONG-TERM MONITORING PLAN

10.1 OVERVIEW

In keeping with the requirements of the recommended remedial action for the KC-135 Crash Site (Natural Chemical Attenuation, long-term monitoring (LTM), and land and groundwater use controls), a LTMP has been developed. This LTMP includes a proposed groundwater monitoring network, sampling and analysis strategies for groundwater, an evaluation of land use controls, and a schedule for implementation of the actions described in the plan. The purpose of LTMP is to confirm the effectiveness of naturally occurring processes at reducing contaminant concentration, mass, mobility and toxicity in affected media. This plan also will assess site conditions over time and evaluate the appropriateness of future unrestricted land uses.

As part of LTM, contaminant behavior in groundwater over time will be monitored to verify that the proposed remedial action is sufficient to protect public health, welfare, and safety, and the environment and natural resources. The horizontal and vertical extent of contamination will be monitored for any increases in COC concentrations during the course of the proposed remediation. In the event that data collected under this LTM program indicate that natural physical, chemical, and biological processes are insufficient to achieve the intended level of cleanup, contingency actions to augment the beneficial effects of the implemented remedy will be undertaken.

10.2 GROUNDWATER MONITORING NETWORKS

A total of 8 wells will be utilized to monitor contaminant removal at the site. These wells are located within, laterally, upgradient from, and at the leading edge of the dissolved fuel hydrocarbon contamination to ensure that natural attenuation processes are occurring at rates sufficient to remove COC mass and minimize contaminant transport in groundwater.

One POA groundwater monitoring well will be located approximately 1,250 feet downgradient from the leading edge of the plume (i.e., downgradient from any detected concentrations of COCs). The purpose of the POA well is to act as an indicator of when additional action may be required to ensure that no COC concentrations exceeding the most stringent residential cleanup criteria migrate beyond the base boundary. All LTM well locations are illustrated on Figure 10.1.

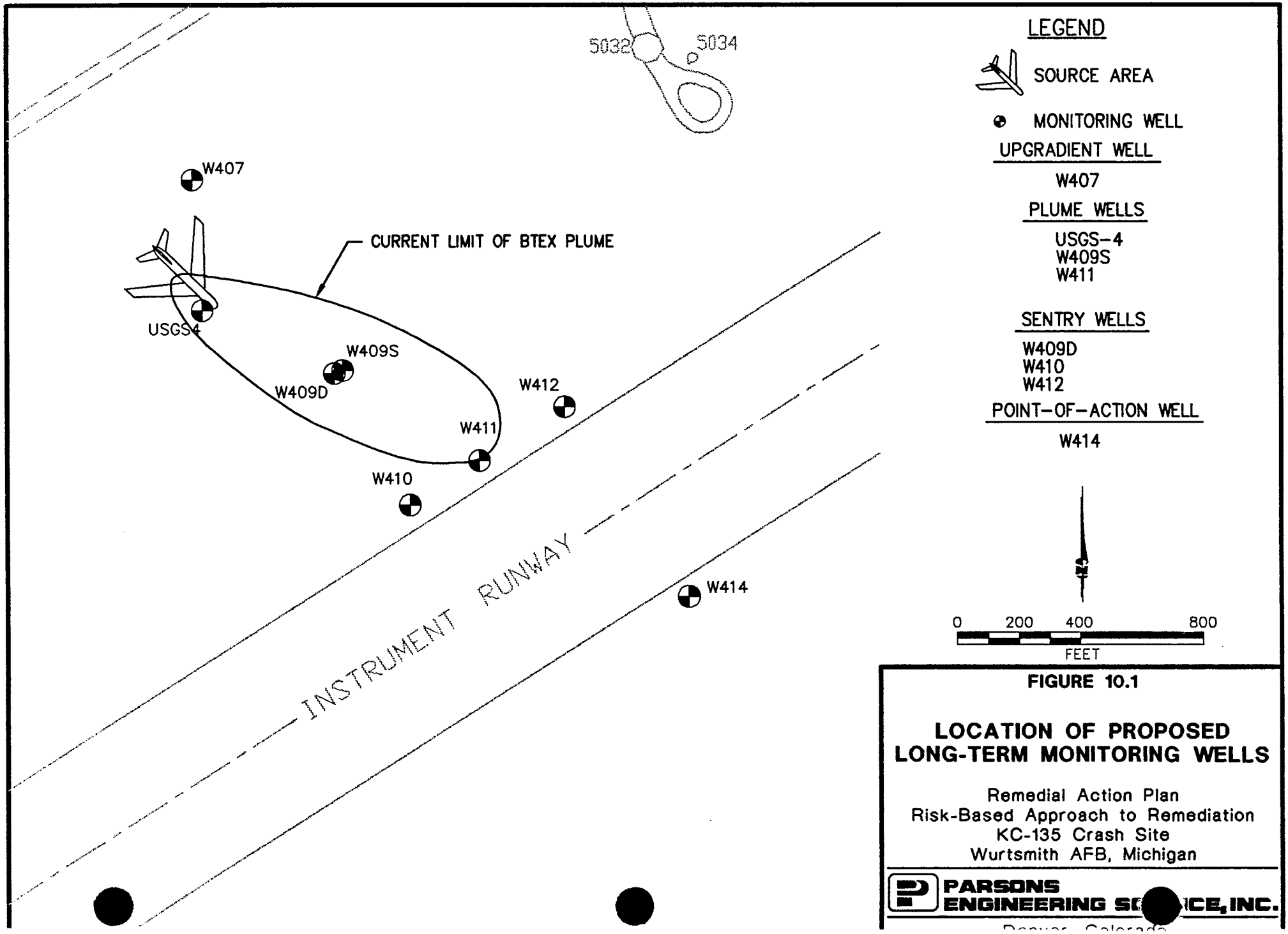


FIGURE 10.1

LOCATION OF PROPOSED LONG-TERM MONITORING WELLS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

10.2.1 Upgradient and Plume Wells

One existing well (W407) upgradient from and outside the influence of the contaminant source will be monitored to evaluate background conditions. Three additional wells located within the contaminant plume area will be monitored to evaluate the ongoing rates of natural attenuation. One of these plume wells (USGS-4) is located in the source area, and the other two plume wells (W409S and W411) are located downgradient of the source area. If concentrations of COCs significantly greater than these indicated by model predictions (Section 6) are measured at W411, additional existing wells (W413 and W415) will be monitored to evaluate the downgradient migration of the contaminant plume. Upgradient and plume wells will be sampled annually and analyzed for the parameters listed in Table 10.1 to verify the effectiveness of the proposed remedial action.

10.2.2 Sentry Wells

Three sentry wells will be used to evaluate migration of the contaminant plume. One existing well (W409D) located downgradient from the source area within the contaminant plume will be used to monitor vertical migration of the contaminant plume. W409D is screened below the existing contaminant plume. If significant contamination is ever detected in W409D, another deep well will be installed in the vicinity of W411. The other two sentry wells (W410 and W412) are located slightly downgradient and off the centerline of the plume. These wells will be used to monitor any unexpected lateral migration of the contaminant plume. All of the sentry wells will be monitored for parameters listed in Table 10.2.

10.2.3 Point-of-Action Well

One downgradient well (W414) located outside the contaminant plume will be monitored to ensure that the plume is not approaching the base boundary. The POA well will be monitored for parameters listed in Table 10.2 to evaluate the need for additional investigation and/or remedial actions. The detection of any of the site-related contaminants in samples from W414 will trigger the need to evaluate possible contingency actions. These actions could include, but should not be limited to, the following:

- Additional investigation efforts to reevaluate results obtained during initial investigation activities;
- Reevaluation of model results to determine if concentrations of contaminants above the most stringent residential cleanup criteria have the potential to migrate beyond base boundaries (approximately 4,875 ft. downgradient from the leading edge of the current plume location); and
- Additional engineering evaluations to determine if more aggressive remedial efforts are necessary.

TABLE 10.1

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR UPGRADIENT AND PLUME WELLS REMEDIAL ACTION PLAN RISK-BASED APPROACH TO REMEDIATION KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site -Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (BTEX and trimethlbenzene isomers)	SW8020 (Gas Chromatography/ Mass Spectrometry method)	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	BTEX compounds (benzene, toluene, ethylbenzene, and total xylenes) and TMBs have been identified as groundwater COCs	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	See Table 2.1	See Table 2.1	Fixed-base
Redox potential	Direct-reading meter (Orion Model 290A with Orion Combination Redox 9678BN probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions: can be used as an indicator of the terminal electron acceptor process involved in COC biodegradation	Annually	Measure directly using a flow-through cell with probe portals. Probe should be standardized against Zobel solution	NA[a/]	0.0 pe units	Field
Dissolved oxygen	Direct-reading meter (YSI Model 50B with YSI 5739 probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Reduced concentrations of dissolved oxygen indicate that microorganisms are facilitating oxygen reduction to biodegrade COCs	Annually	Measure directly using flow-through cell with probe portals. Probe should be calibrated with zero dissolved oxygen solution	NA	0.5 mg/L	Field

TABLE 10.1 (Continued)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL
FOR UPGRADIENT AND PLUME WELLS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Manganese (Mn^{+2})	Colorimetric HACH 8034	Field only	Elevated concentrations of reduced forms of manganese indicate that microorganisms are facilitating manganese reduction to biodegrade COCs	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.05 mg/L	Field
Ferrous iron (Fe^{2+})	Colorimetric HACH 8146	Field only	Elevated ferrous iron concentrations indicate that microorganisms are facilitating ferric iron reduction to biodegrade COCs	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.024 mg/L	Field
Total iron (Fe)	Colorimetric HACH 8008	Field only	Used to calculate the gross mass fraction of dissolved iron that has been reduced	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.024 mg/L	Field
Sulfate (SO_4^{2-})	Colorimetric HACH 8051	Field only	Reduced concentrations of sulfate indicate that microorganisms are facilitating sulfate reduction to biodegrade COCs	Annually	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.01 mg/L	Field
pH	Direct-reading meter (Orion Model 140)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Aerobic and anaerobic processes are pH-sensitive	Annually	Measure directly using a contained flow-through cell with probe portals. Probe should be calibrated using at least three pH standards	NA	0.00 pH units	Field
Temperature	Direct-reading meter	Field only	Metabolism rates for microorganisms depend on temperature	Annually	Measure directly using a contained flow-through cell with probe portals	NA	1.0 °C	Field

TABLE 10.1 (Continued)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR UPGRADIENT AND PLUME WELLS REMEDIAL ACTION PLAN RISK-BASED APPROACH TO REMEDIATION KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Conductivity	Direct-reading meter (Orion Model 140 with Conductivity Cell 014050)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Measure directly using a contained flow-through cell with probe portals. Probe is factory calibrated	NA	0.02 µmhos/cm	Field

[a] NA = not applicable

TABLE 10.2

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR POINT-OF-ACTION AND SENTRY GROUNDWATER REMEDIAL ACTION PLAN RISK-BASED APPROACH TO REMEDIATION KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (BTEX and triethlbenzene isomers)	SW8020 (Gas Chromatography/ Mass Spectrometry method SW8020	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	BTEX compounds (benzene, toluene, ethylbenzene, and total xylenes) and TMBs have been identified as groundwater COCs	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	See Table 2.1	See Table 2.1	Fixed-base
Redox potential	Direct-reading meter (Orion Model 290A with Orion Combination Redox 9678BN probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions: can be used as an indicator of the terminal electron acceptor process involved in COC biodegradation	Annually	Measure directly using a flow-through cell with probe portals. Probe should be standardized against Zobel solution	NA[a/]	0.0 pe units	Field
Dissolved oxygen	Direct-reading meter (YSI Model 50B with YSI 5739 probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Reduced concentrations of dissolved oxygen indicate that microorganisms are facilitating oxygen reduction to biodegrade COCs	Annually	Measure directly using flow-through cell with probe portals. Probe should be calibrated with zero dissolved oxygen solution	NA	0.5 mg/L	Field

TABLE 10.2 (Continued)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL FOR POINT-OF-ACTION AND SENTRY GROUNDWATER REMEDIAL ACTION PLAN RISK-BASED APPROACH TO REMEDIATION KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
pH	Direct-reading meter (Orion Model 140)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Aerobic and anaerobic processes are pH-sensitive	Annually	Measure directly using a contained flow-through cell with probe portals. Probe should be calibrated using at least three pH standards	NA	0.00 pH units	Field
Temperature	Direct-reading meter	Field only	Metabolism rates for microorganisms depend on temperature	Annually	Measure directly using a contained flow-through cell with probe portals	NA	1.0 °C	Field
Conductivity	Direct-reading meter (Orion Model 140 with Conductivity Cell 014050)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Measure directly using a contained flow-through cell with probe portals. Probe is factory calibrated	NA	0.02 µmhos/cm	Field

[a/] NA = not applicable

10.2.4 Point-of-Compliance Wells

Due to the extreme distance (4,250 feet) between the leading edge of the plume and the base boundary, no point-of-compliance wells have been designated for long-term monitoring at this time. Monitoring well W416 is available for potential use as a POC well, but no sampling will be considered for this well unless COCs are first detected in the POA well W414.

10.3 GROUNDWATER SAMPLING

This LTMP includes a comprehensive groundwater SAP. The LTMP, when implemented in accordance with the SAP, will ensure that COC concentrations above residential cleanup criteria are not migrating offsite. Sentry and POC wells will be sampled and analyzed annually to verify that natural processes are effectively reducing contaminant concentrations, mass, mobility, and toxicity. Reductions in COC toxicity will be implied by concentration and mass reduction (e.g., as COCs are biodegraded to less toxic compounds such as carbon dioxide and water).

10.3.1 Implementation Requirements

All LTM groundwater monitoring wells will be sampled and analyzed in accordance with Tables 10.1 and 10.2, respectively, to determine progress toward and compliance with the proposed chemical-specific cleanup criteria for the KC-135 Crash Site. All samples will be collected in accordance with the SAP presented in Appendix H.

10.3.2 Sampling Frequency

Each of the groundwater sampling points will be sampled annually for approximately 8 years. This is the amount of time conservatively estimated to be required to achieve target industrial cleanup criteria in the groundwater at every point at the KC-135 Crash Site. Once it appears that this criteria have been achieved, the groundwater will be sampled for four consecutive quarters (one full year) to verify that groundwater contaminant concentrations have stabilized at values less than generic industrial criteria. A schedule of all sampling events prescribed by the LTMP is shown on Figure 9.1. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, contingency remedial activities will be considered (Section 9.3 and 10.2.3).

10.4 SOIL SAMPLING

No active soil remediation is proposed as part of the recommended remedial action. Sample data from vadose zone soils at the KC-135 Crash Site indicate that all COC concentrations are below the most stringent generic residential cleanup criteria, and thus no remedial action is required for the vadose zone (Section 5.1.1.2).

10.5 LAND USE CONTROLS VERIFICATION

Long term site management responsibilities will include verification that planned land uses are consistent with the degree of cleanup targeted by the recommended remedial action. As part of this effort, any existing land leases or agreements will be

reviewed to confirm that the contaminant exposures that exist at the site are still representative of, or less than, the exposure assumptions used to derive cleanup objectives. The site lease or agreement should specify that the underlying groundwater should not be used as a source of potable water until such time as appropriate cleanup criteria have been attained at the site. (This restriction is necessary as a precaution only, as the industrial cleanup criteria are calculated to protect onset workers from risks through ingestion of groundwater and to prevent adverse aesthetic impacts.) The recommended remedy for site-related contamination imposes residential cleanup criteria for all media at and downgradient from the base boundary. The analytical sampling program will be used to confirm that there is no need for exposure controls at and downgradient from the property boundary. Further, any changes in physical characteristics of the site that could result in inhalation hazards will be documented. However, soil gas measurements at the site suggest that this potential exposure pathway is insignificant. As an extra precaution, this RAP has recommended that soil excavation within the source area of the KC-135 Crash Site be minimized.

In addition to lease reviews, interim confirmation of land and groundwater use controls are proposed to include documenting the land zoning, types of potential on-site receptors, and the kinds of activities in which these potential receptors may engage in at the site. This confirmation step will be formally documented when the results of annual analytical sampling events are prepared for review and assessment. Any significant changes in land use will be identified, and any modification of the recommended remedial alternative that may be required to protect public health, safety, and welfare, and the environment and natural resources will be identified and proposed for review and implementation, as necessary.

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APPENDIX A

BORING LOGS, WELL CONSTRUCTION DIAGRAMS, AND WELL DEVELOPMENT DATA

BOREHOLE LOG

SITE NAME AND LOCATION: KC-135 Crash Site (SS51)

DRILLING METHOD:

SAMPLING METHOD:

BORING NO.: SB401 SS51

SHEET: OF

DRILLING: START / FINISH

					START TIME	FINISH TIME
WATER LEVEL						
TIME					14:25	15:10
DATE					3/10/94	3/10/94
CASING DEPTH						

BTEX, PNA
abandon hole w/ grout

DATUM ELEVATION

DRILL RIG

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

DRILLING CONTR

DEPTH IN FEET (ELEVATION)	BLOWS/6" ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: RQD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2						SAND, M-gr, dk brn								
4						SAND M-gr, tan								
6	2 3 2 3					SAND M-UC gr lt brn v. moist.						5	7	6ppm
8	2 4 2 5					SAND M-C, tr-sm gravel @ 10' lt brn wet Fe stain @ 9.5		WL Drilled - 8½'			8	8	10	5ppm Lab
10											10			
12											12			
14						SAA		TD=15'			14	13	15	6ppm
16														

LOGGED BY RL

DATE CHK'D BY

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION

KC-135 Crosst Site

Collect MS/MSD samples 7-9'

Samples 10-20'

TKN at 5-7 - 0 2oz

cap. fringe 4-20' 9-11

DATUM ELEVATION

DRILLING METHOD:

SAMPLING METHOD:

WATER LEVEL				
TIME				
DATE				
CASING DEPTH				

BORING NO. W407-SS1

SHEET OF

DRILLING START TIME 13:00 DATE 10/3/94

DRILLING FINISH TIME 13:45 DATE 10/3/94

DRILL RIG

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2						SAND, M.gr, dk brn								
4						SAND M·gr, tan moisy					4			
6						SAA						5	7	<2
8						SAA v. moist @ 8' wet @ 9'		WL drilled 9'				7	9	<2
10						SAND, M-UC wet md brn to gravel @ 11'						9	11	2
12						SAA, to gravel						11	13	2
14						SAA						13	15	
16						SAA, sm gravel								
						TD Drill 15' TD Samp 17'								

DRILLING CONTR

LOGGED BY

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION

DRILLING METHOD:

SAMPLING METHOD:

BORING NO. W408

SHEET OF

DRILLING START TIME 15:50 FINISH TIME 16:15

WATER LEVEL / TIME / DATE / CASING DEPTH

DATE 10/3/94 DATE 10/3/94

BTEX, PNA
collect duplicate

DATUM ELEVATION

DRILL RIG

SURFACE CONDITIONS

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

DRILLING CONTR

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	PERMEABILITY CM./SEC.
2						SAND, m-gr, dk brn SAND		moist						
4											4			
6	3 4 3 3					SAND, m-c gr, lt brn, moist slight odor					6	5	7	7 ppm
8	3 6 7 7					SAND, m gr, lt brn SAA m-uc gr		moist slight odor wet @ ~9'			8	8	10	6ppm Lab
10											10			
12	6					SAA, fuel odor					12		(300)	Lab cuttings
14	4 6 2 16					SAA m-uc, tr gravel up to 1.25"		TD=15'			14	13	15	8ppm
16											16			

LOGGED BY RL

DATE CHK'D BY

Figure A.1
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION

Wurtsmith

5551

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD: 2-inch Split Spoon

BORING NO. 409 S

SHEET OF

					DRILLING START	DRILLING FINISH
WATER LEVEL					TIME	TIME
TIME					10'28	
DATE					DATE	DATE
CASING DEPTH					10-5-94	

ELEVATION

RIG Acker Drill Max

BEARING

HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

BLOWS/ 6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
					See 409M								

Figure A.1 - Geologic Boring Log

DRILLING CONTR

LOGGED BY

DATE

BOREHOLE LOG

NAME AND LOCATION

DRILLING METHOD:

SAMPLING METHOD:

BORING NO. 409S

SHEET 2 OF 2

DRILLING START TIME / FINISH TIME

					START TIME	FINISH TIME
WATER LEVEL						
TIME						
DATE					DATE	DATE
CASING DEPTH						

/M ELEVATION

. RIG

SURFACE CONDITIONS

.E BEARING

PLE HAMMER TORQUE FT.-LBS

DRILLING CONTR

LOGGED BY RL

DATE CHK'D BY

BLOWS/ FT. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
										13 14 15			

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: Wurtsmith SS51 (KC-135) ~~East~~

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD: 2-inch Split Spoon

BORING NO.: 409M

SHEET: 1 OF 3

					DRILLING START	DRILLING FINISH
WATER LEVEL	6ft				TIME	TIME
TIME	9:50				9:00	
DATE	90-4-94				DATE	DATE
CASING DEPTH					10-4-94	

DATUM: ELEVATION:

DRILL RIG: Acker Soil Max

SURFACE CONDITIONS: .5 - 1 ft grassy

ANGLE: 0 BEARING: 0

SAMPLE HAMMER TORQUE: FT.-LBS

DRILLING CONTR: CTI

LOGGED BY: Dick Mayer IIc Hi

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD (RQD)	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
1														
2														
3														
4														
5	6 4 6 5	1	1 6"	40	11	Sand fine - med Moist Yellowish Brown 10YR 5/6 Top 3 inches of Med Dense spoon Black topsoil								
6														
7														
8														
9	5 3 2 4	2	1 12	40 80	21	Sand med wet Yellowish Brown 10YR 5/6 Loose								
10														
11														
12														
13	12 24 22 23	3	1 24	100	53	Sand Med - Coarse Trace fine Grave wet Light Yellowish Brown 10YR 6/4 Very Dense con't on next pg								

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: Wurtsmith SS 51 (KC-135 Crashsite)

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD: 2-inch Split Spoon

BORING NO.: 404 m

SHEET: 2 OF 3

WATER LEVEL	9 ft			
TIME	9110			
DATE	10-4-94			
CASING DEPTH				

DRILLING START: TIME 9:00, DATE 10-4-94

DRILLING FINISH: TIME 1:30, DATE 10-4-94

DATUM: ELEVATION:

DRILL RIG: Acker Soil Max

DRILLING CONTR: CTI

SURFACE CONDITIONS: 1.5-1 ft grass

ANGLE: 0 BEARING: 0

SAMPLE HAMMER TORQUE: FT.-LBS

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: RQD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
15														
16														
17														
18														
19	7 10 12 17	4	1 7	30	7.0	sand fine-med wet light Yellowish Brown 10 YR 6/4 Dense								
20														
21						EOB								
22														
23														
24														
25														
26														
27														
28														

LOGGED BY N. Marchetti

DATE 10-4-94 CHK'D BY

RL

Figure A.1
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION: Wurtsmith SS 51 CKC-135 Crashsite

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD: 2-Inch Split-Spoon

BORING NO. 409 M

SHEET 3 OF 3

					DRILLING START	DRILLING FINISH
WATER LEVEL					TIME	TIME
TIME					9:00	
DATE					DATE	DATE
CASING DEPTH					10-4-94	

UM ELEVATION

RIG Acker Drill Max

LE BEARING

PLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS .5-1 Ft grassy

BLOWS/ 6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD 11-92	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
3													
13	5	1	80	8.0	Sand med coarse thin seam Fine med gravel wet								
20					Yellowish Brown Dense 10YR5/4								
8													
6	6	1	100	3.00	Same as above but No gravel								
7													
8													

28 29 30 31 32 33 34 35 36 37 38 39 40

EOB

Figure A.1
Geologic Boring Log

DRILLING CONTR

LOGGED BY N. Marcellett.

DATE

BOREHOLE LOG

NAME AND LOCATION: Wurtsmith SS51

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD: 2-inch Split Spoon

BORING NO. 409D

SHEET 1 OF 4

DRILLING START TIME 1159 DATE 10-4-94

DRILLING FINISH TIME DATE

WATER LEVEL				
TIME				
DATE				
CASING DEPTH				

/M ELEVATION

. RIG Acker Drill Max

.E BEARING

PLE HAMMER TOROUE FT.-LBS

SURFACE CONDITIONS Level

DRILLING CONTR CET

BLOWS/ 6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
5 6 6	1	1	40	7.0	Sand fine - med Moist Brownish Yellow Med Dense								
6 14 5W	2	1	30	9.0	Same as above but wet Med Dense								

Figure A.1
Geologic Boring Log

LOGGED BY Dick Macvelle III RL

DATE 10-7 CHK'D BY

BOREHOLE LOG

NAME AND LOCATION: Wurtsmith SS-1

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD: 2-Inch Split Spoon

BORING NO. 4090

SHEET 2 OF 4

	DRILLING START	DRILLING FINISH
WATER LEVEL		
TIME	1159	
DATE	10-4-94	

/M ELEVATION

. RIG Acker Soil Max

.E BEARING

PLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

BLOWS/ 6 IN ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD %	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
12 23 22 29	3	1	100	24.0	Med Coarse Sand wet trace fine gravel pale Brown Very Dense								
4 6 11 18	4	1	100	72	10 Sand fine-Med Wet ~~Same as above~~ Brown Trace fine gravel Dense								

Figure A.1
Geologic Boring Log

DRILLING CONTR

LOGGED BY

DATE

CHK'D BY

RI

BOREHOLE LOG

NAME AND LOCATION

DRILLING METHOD: Hollow Stem Auger

SAMPLING METHOD:

BORING NO. 409 D

SHEET 3 OF 4

DRILLING START TIME: | DRILLING FINISH TIME:

WATER LEVEL | TIME | DATE | CASING DEPTH

DRILLING START DATE: 10-7-74 | DRILLING FINISH DATE:

/M ELEVATION

. RIG

.E BEARING

PLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

DRILLING CONTR

LOGGED BY RL

DATE CHK'D BY

BLOWS/ 6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
7 11 29 37	7	1	100	5.8	Sand fine - med wet silt at tip gray Very Dense					49 50 51 52 53 54 55 56 57 58 59 60			

Figure A.1
Geologic Boring Log

BOREHOLE LOG

NAME AND LOCATION

DRILLING METHOD: Hollow Stem Auger

BORING NO. 409D

SHEET 4 OF 4

SAMPLING METHOD:

DRILLING START TIME / FINISH TIME

	WATER LEVEL				
	TIME				
	DATE				
	CASING DEPTH				

DRILLING START DATE / FINISH DATE

/M ELEVATION

. RIG

SURFACE CONDITIONS

.E BEARING

PLE HAMMER TORQUE FT.-LBS

BLOWS/ 6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD/Prop	SOIL DESCRIPTION / ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
18 19 22 26	8	1	100	45.0	sand fine - Med Wet ~~Light~~ Brownish Yellow 10YR 6/6 Very Dense								
33 37	9	1	100	11	Top sand same as above bottom gray silty clay moist Hard								
					EOB								

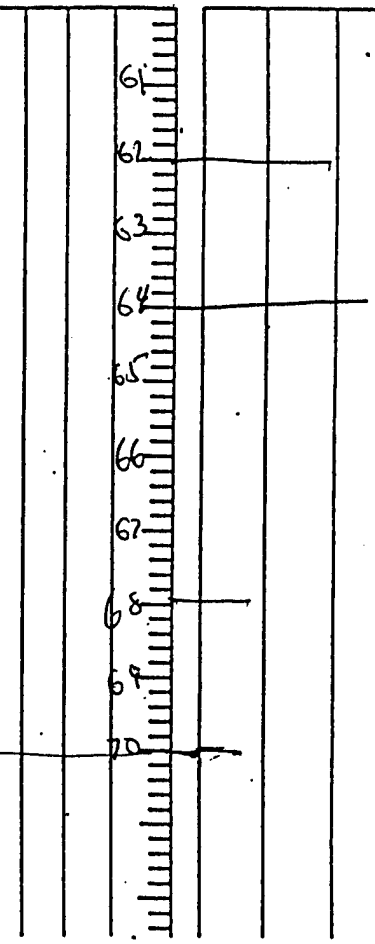


Figure A.1
Geologic Boring Log

DRILLING CONTR

LOGGED BY

DATE

BOREHOLE LOG

SITE NAME AND LOCATION: Wurtsmith AFB
KC-135

DRILLING METHOD: HSA

SAMPLING METHOD: Split Spoon

BORING NO.: W410

SHEET: 1 OF 1

					DRILLING START	DRILLING FINISH
WATER LEVEL	9					
TIME					TIME 0845	TIME 0912
DATE					DATE 10/4/94	DATE
CASING DEPTH						

DATUM ELEVATION

DRILL RIG

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

DRILLING CONTR CTI

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2											2			
4											4			
6						SAND, m-c gr. m brn, v. moist					6	5	7	Spoon
8	3 3 3 5					SAND, m. gr tan moist					8	7	9	12 ppm
10	2 3 4 6					SAND, m-vc, tr gravel wet		WL Drilled - 9'			10	9	11	2 ppm
12	5 7 9 11					SAA		TD = 15'			12	11	13	12
14											14			
16											16			

LOGGED BY JFH DATE 10/4/94 CHK'D BY

RL

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: KC135 Crash Site (SSS1) Wurtsmith AFB

DRILLING METHOD: HSA

SAMPLING METHOD: Split Spoon

BORING NO.: WL11

SHEET: OF

					DRILLING START	DRILLING FINISH
WATER LEVEL	9.5				TIME 09:50	TIME 10:20
TIME					DATE 10/4/94	DATE 10/4/94
DATE						
CASING DEPTH						

DATUM: ELEVATION:

DRILL RIG: SURFACE CONDITIONS:

ANGLE: BEARING:

SAMPLE HAMMER TORQUE: FT.-LBS

DRILLING CONTR: CTI

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2														
4														
6	3 3 5					SAND, M-UC, tr. moist		gravel, lt brn				5	7	4 ppm
8								WL Drilled 9.5'						
10	1 2 1 1					SAA, wet @ 9.5						8	10	5 ppm
12	1 2 2 1					SAA		TD=15'				10	12	3 ppm
14														
16														

LOGGED BY: JFH 10/11/94

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: KC135 Crash Site (SS51) Wurtsmith AFB

DRILLING METHOD: HSA

SAMPLING METHOD: Split Spoon

BORING NO.: W412

SHEET: 1 OF 1

					DRILLING START	DRILLING FINISH
WATER LEVEL					TIME	TIME
TIME					11:50	12:30
DATE					DATE	DATE
CASING DEPTH					10/4/94	10/4/94

DATUM ELEVATION

DRILL RIG: CTI

SURFACE CONDITIONS

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

DRILLING CONTR

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: RQD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2														
4														
6	2 3 6 8					SAND, M-VC gr tan, moist						5	7	6ppm
8	4 4 4 4					SAND, M-C, tan wet @ 9.5' ~½" silty layer @ 9.5		w.l. drilled 9.5'				8	10	10ppm
10	2 4 6 10					SAND, M-VC gr tan, wet						10	12	11ppm
12														
14								TD=15'						
16														

LOGGED BY JFH

DATE 10/4/94 CHK'D BY

RL

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: KC135 Crash Site (SS51) Wurtsmith AFB

DRILLING METHOD: HSA

SAMPLING METHOD: Split Spoon

BORING NO.: W413

SHEET: 1 OF 1

					DRILLING START	DRILLING FINISH
WATER LEVEL					TIME	TIME
TIME					13:15	13:45
DATE					DATE	DATE
CASING DEPTH					10/4/94	10/4/94

~~Coffee + TBC~~

DATUM: ELEVATION:

DRILL RIG: SURFACE CONDITIONS:

ANGLE: BEARING:

SAMPLE HAMMER TORQUE: FT.-LBS

DRILLING CONTR: CTI

DEPTH IN FEET (ELEVATION)	BLOWS/6" ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2											2			
4											4			
6	2 3 4 5					SAND, M-VC. gr. tan, moist					6	5	7	4ppm
8	4 4 4 7					SAA, wet @ 9'		W.L. drilled ~ 9.0'				8	10	10ppm
10	4 6 10					SAA, Tr-Sm gravel up to 1½"						10	12	6ppm
12	22							TD=15'						
14														
16														

LOGGED BY: JFH

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: KC135 Crash Site (SS51) Wurtsmith AFB

DRILLING METHOD: HSA

SAMPLING METHOD: Split Spoon

BORING NO.: W414

SHEET: 1 OF 1

					DRILLING START	DRILLING FINISH
WATER LEVEL	10.5					
TIME					TIME 14:15	TIME 14:40
DATE					DATE 10/4/94	DATE 10/4/94
CASING DEPTH						

DATUM ELEVATION

DRILL RIG

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

DRILLING CONTR CTI

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN. ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: RQD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	PERMEABILITY CM./SEC.
2														
4														
6	5 7 8 9					SAND, M-VC, tr gravel, tan, moist						5	7	10ppm
8	2 3 3 4					SAP, Fe stain @ 9.5'						8	10	12ppm
10	2 4 6 7					SAND, M-C gr tan wet @ 10.5		WL drilled 10.5				10	12	12ppm
12														
14								TD=16'						
16														

LOGGED BY JFL

DATE 10/4/94 CHK'D BY RL

Figure A.1
Geologic Boring Log

BOREHOLE LOG

SITE NAME AND LOCATION: KC135 Crash Site (SSS1) Wurtsmith AFB

collect TOC

DRILLING METHOD: HSA

SAMPLING METHOD: Split Spoon

BORING NO. W415

SHEET 1 OF 1

					DRILLING START	DRILLING FINISH
WATER LEVEL	9					
TIME					15:25	15:45
DATE					10/4/94	10/4/94
CASING DEPTH						

DATUM ELEVATION

DRILL RIG

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

SURFACE CONDITIONS

DRILLING CONTR CTI

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2														
4														
6	3 5 7 6					SAND, M-gr, tan moist						5	7	16 ppm
8														
10	3 3 3 5					SAND, M-VC gr, tr gravel wet @ 9.0' tr gravel		WL drilled 9'				9	11	12 ppm
12	4 4 5 7					SAA						11	13	LOD
14														10 ppm
16								TD=16'						

LOGGED BY JFH

Figure A.1
Geologic Boring Log

water blank 14ppm

BOREHOLE LOG

SITE NAME AND LOCATION: ~~ORMO~~ SS51

DRILLING METHOD: HSA

BORING NO. W416 SPLIT45

SHEET OF

SAMPLING METHOD: Spl.-t-Spoon

DRILLING: START / FINISH

Collect BTEX, PNA, TOC (4 jars)

					START TIME	FINISH TIME
WATER LEVEL	13.0				09:05	
TIME					16:45	
DATE					DATE	DATE
CASING DEPTH					10/4/94	

DATUM ELEVATION

DRILL RIG

SURFACE CONDITIONS 6

ANGLE BEARING

SAMPLE HAMMER TORQUE FT.-LBS

DRILLING CONTR CTI

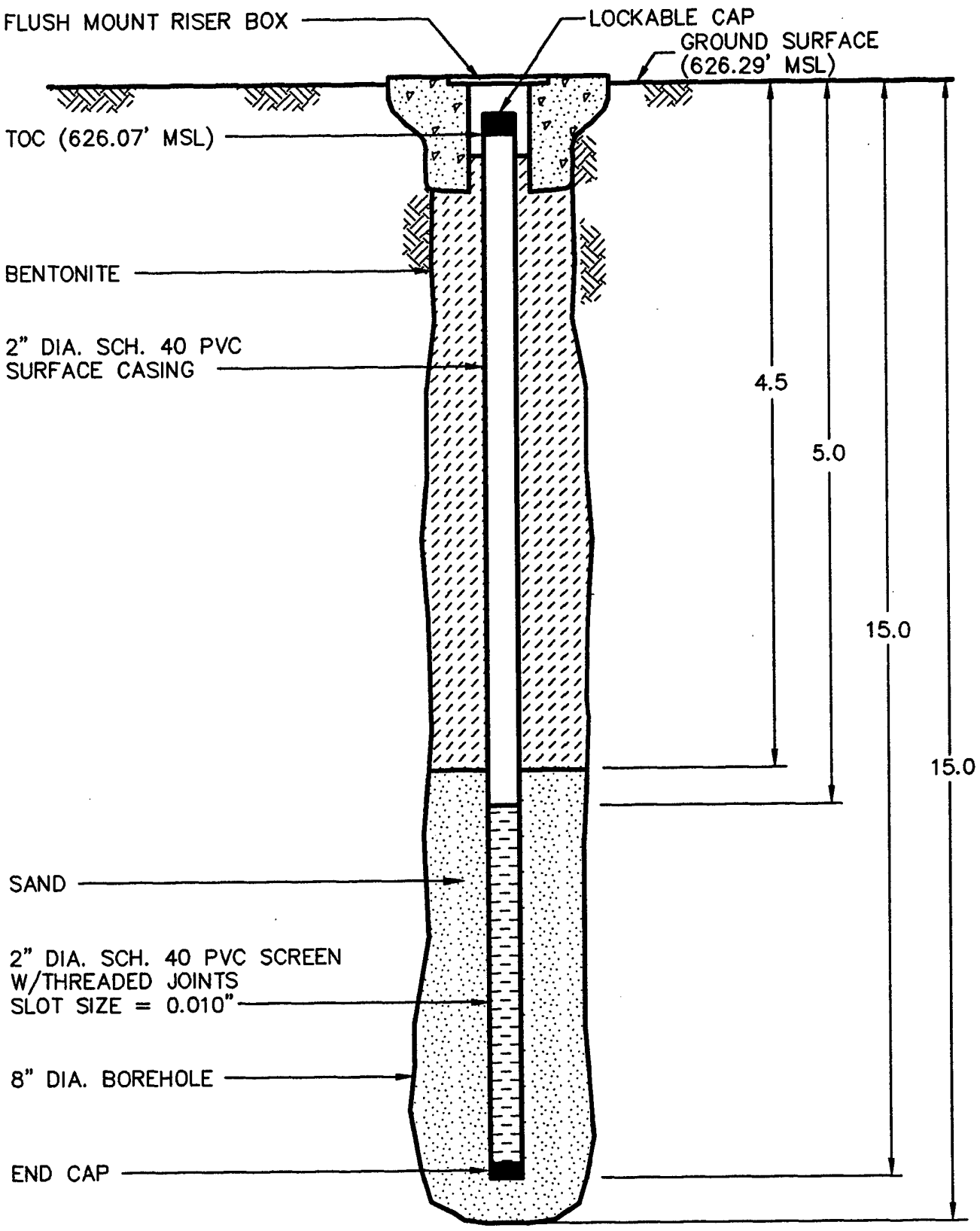
RL

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

DEPTH IN FEET (ELEVATION)	BLOWS/ 6 IN ON SAMPLER (RECOVERY)	CORES: RUN NO.	CORES: NO. AND SIZE OF CORE PIECES	CORES: % RECOVERY	CORES: ROD	SOIL DESCRIPTION OR ROCK LITHOLOGY	SYMBOL	ROCK STRUCTURE	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	TEST RESULTS: DEPTH IN FEET FROM	TEST RESULTS: DEPTH IN FEET TO	TEST RESULTS: PERMEABILITY CM./SEC.
2						SAND, M. gr, dk brn moist								
4														
6	3 2 3 6					SAND, 5-6' c-uc; moist		6-7 M. gr, lt brn				5	7	4ppm
8	3 3 3 7					SAND, c-uc, tr gravel, tan, moist		WL drilled 13'				8	16	5ppm
10	4 5 9 9					SAA, M-uc, tr gravel						10	12	5ppm
12	4 7 12 16					SAA, wet @ 13'						12	14	4ppm S1
16	4 7 19 12					SAA		TD = 18'				14	16	6ppm S2
18														
20														

water blank 5ppm

Figure A.1
Geologic Boring Log

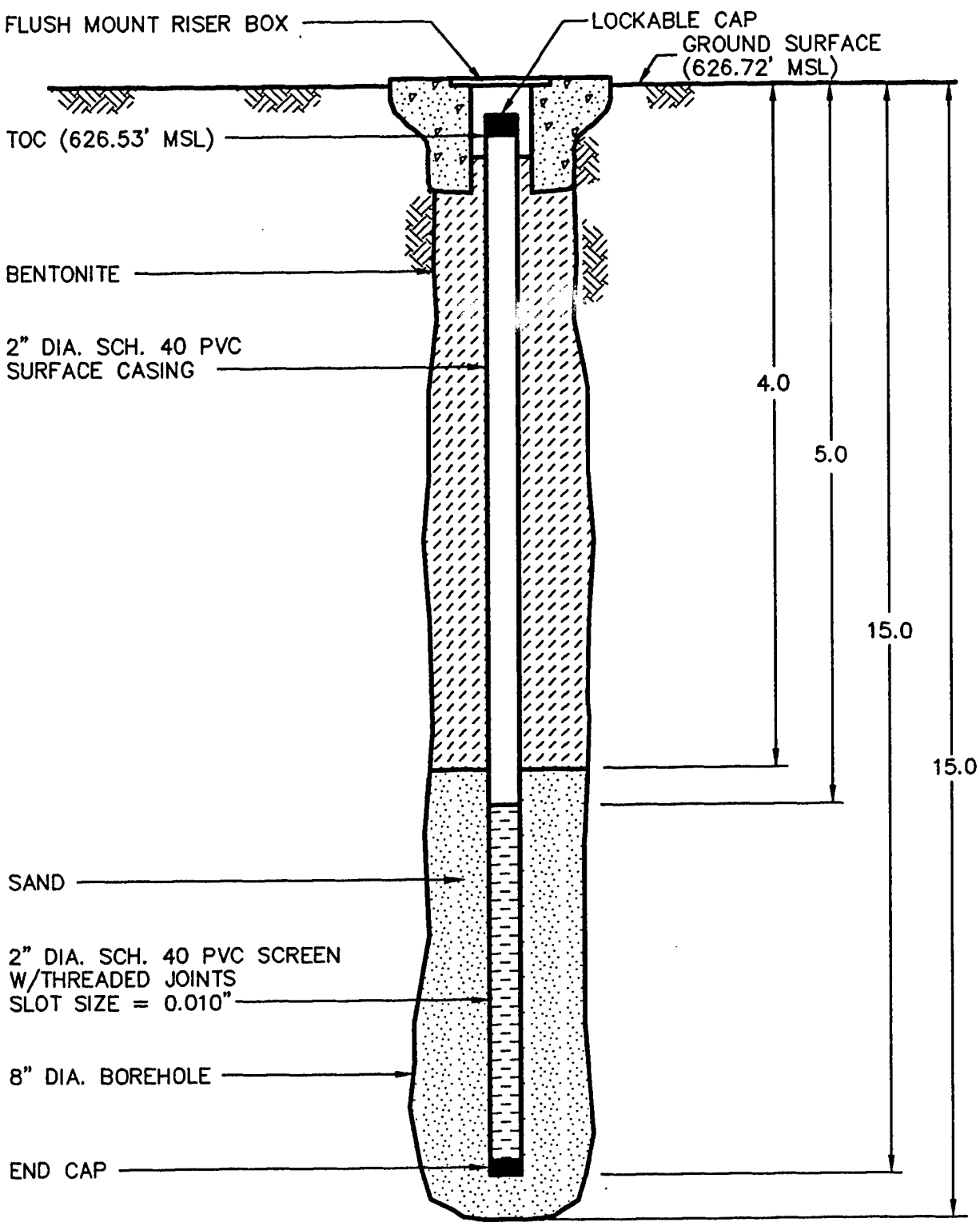


FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W407

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/03/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

K:\WRTSMTH 95DN0260 02/15/95 @ 0732



FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W408

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/03/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

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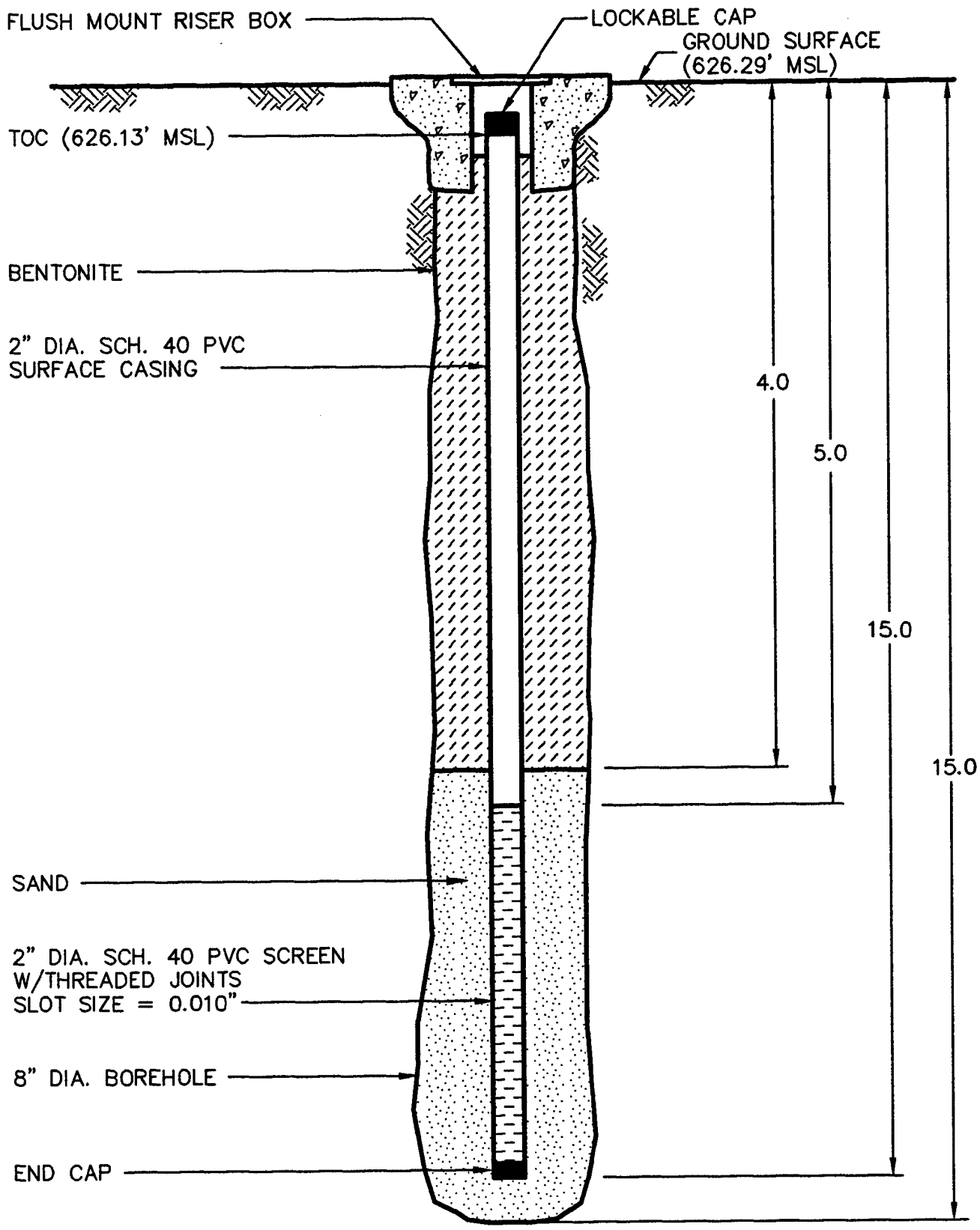

FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W409S

SITE: SS51
GEOLOGIST: NM
DATE COMPLETED: 10/05/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

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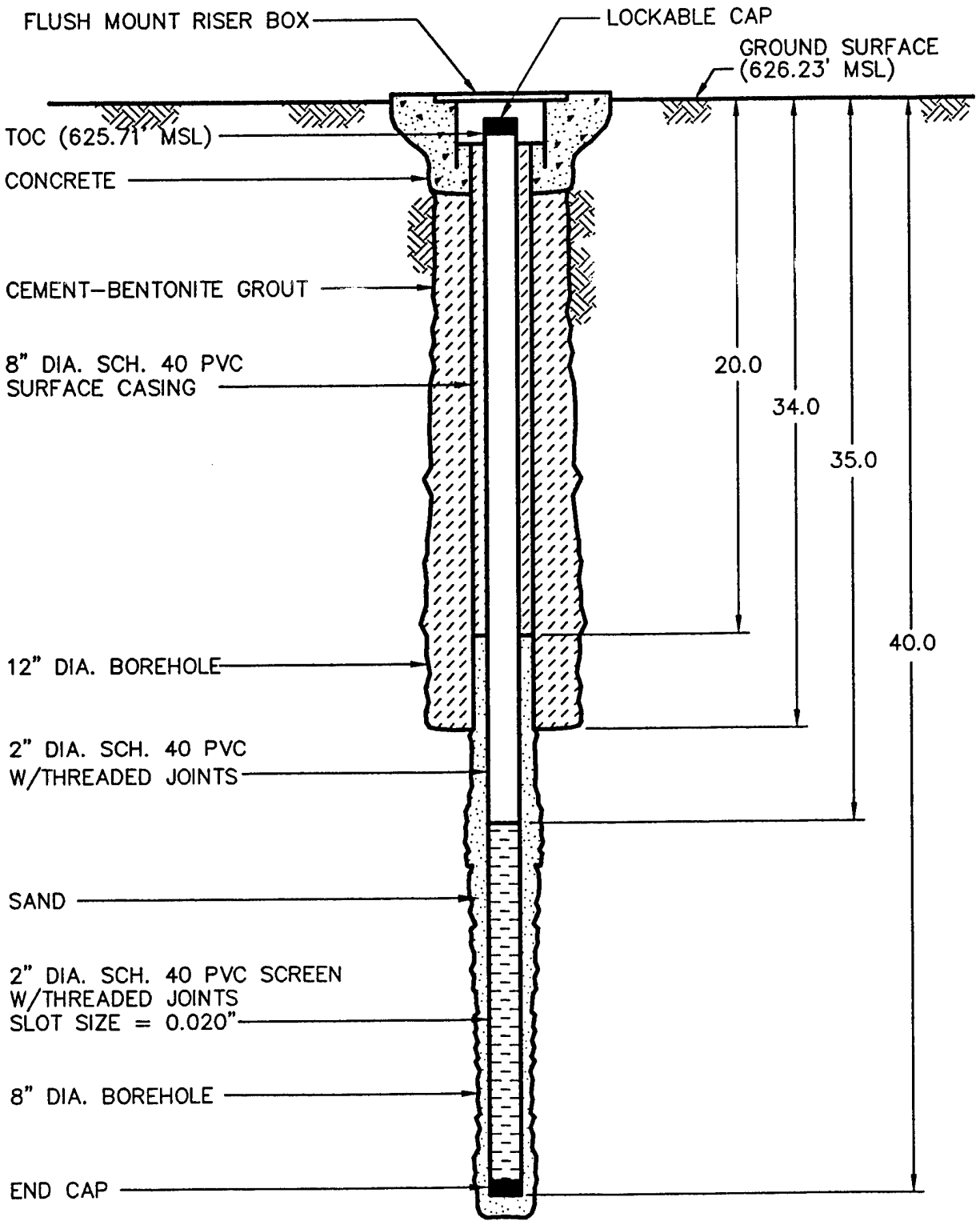
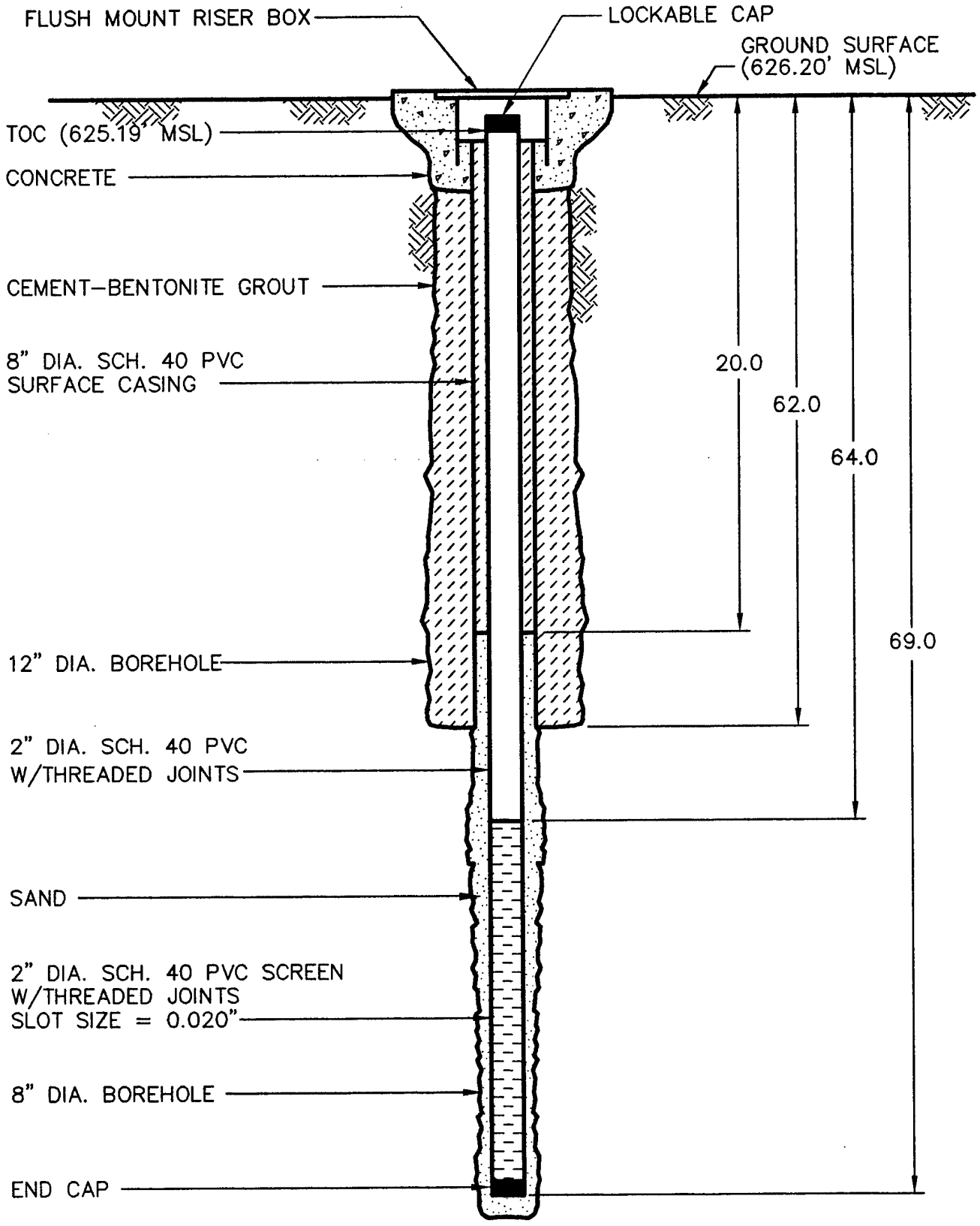


MONITORING WELL DESIGN DETAIL
WELL NO. W409M

SITE: SS51
GEOLOGIST: NM
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

K:\WRTSMTH\95DN0250, 03/28/95 at 13:22



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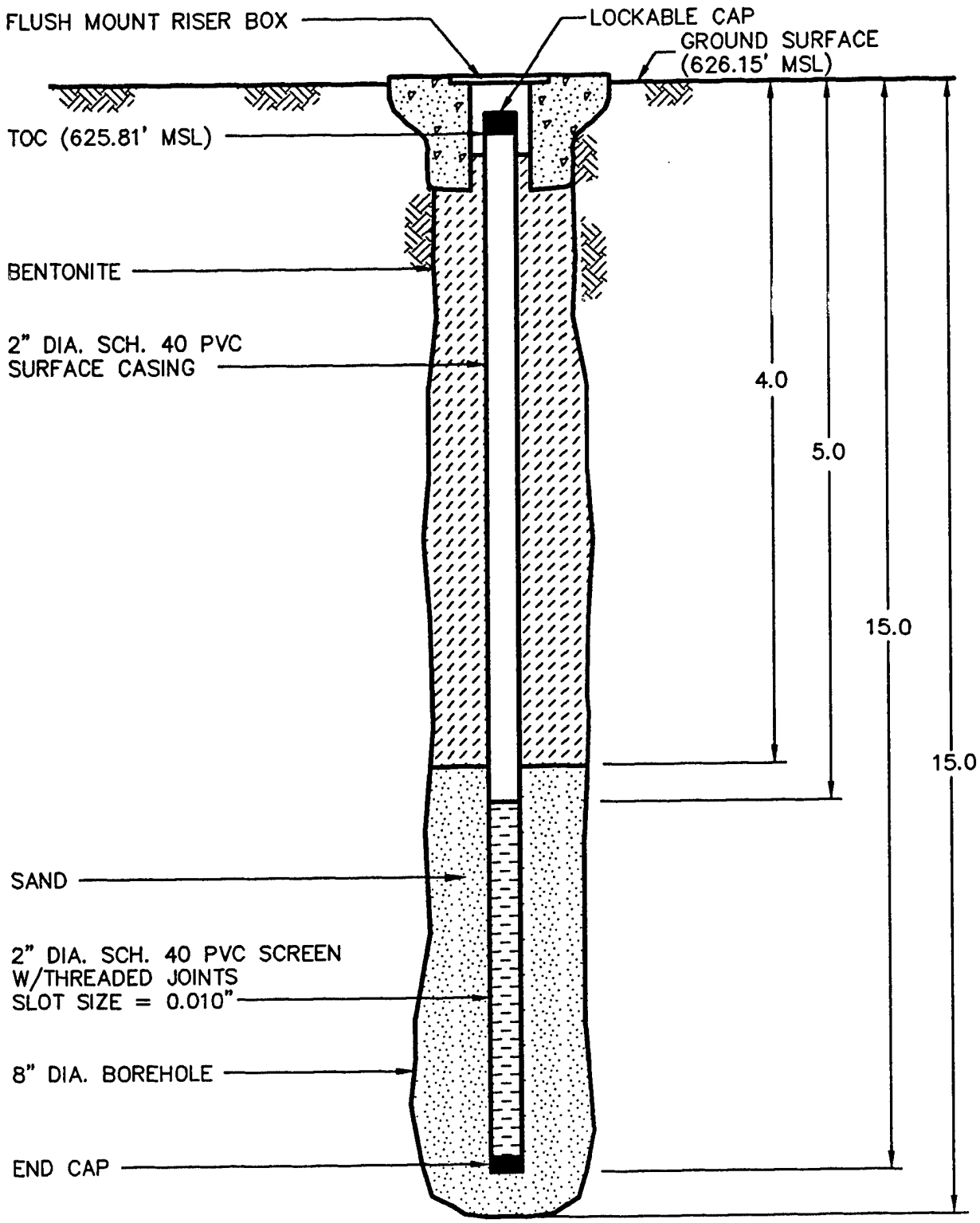
WELL NO. W409D

SITE: SS51
GEOLOGIST: NM
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

K:\WRTSMTH\95DN0251, 03/28/95 at 13:25

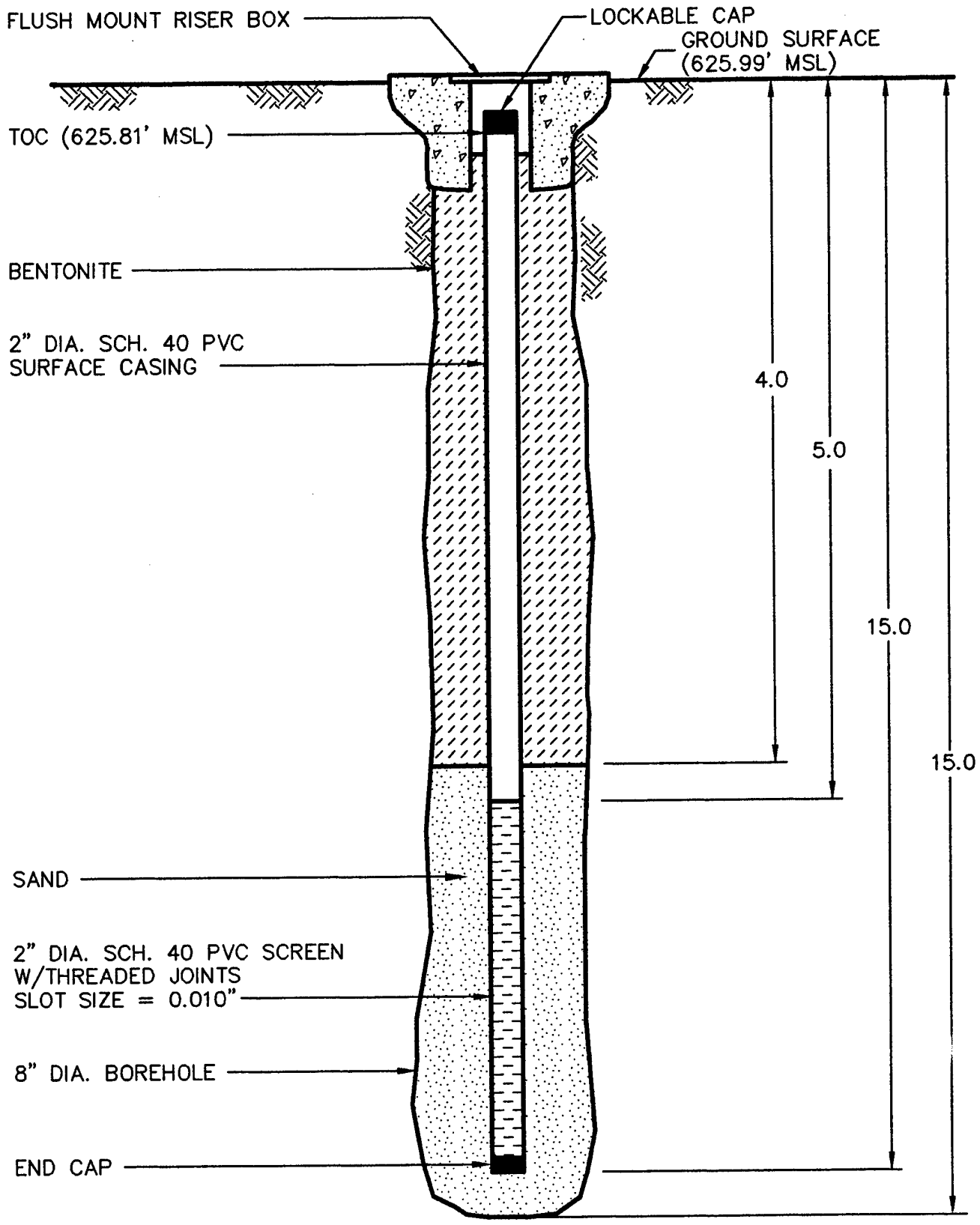


FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W410

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

K:\WRTSMTH 95DN0253 02/15/95 @ 0711



FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W411

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

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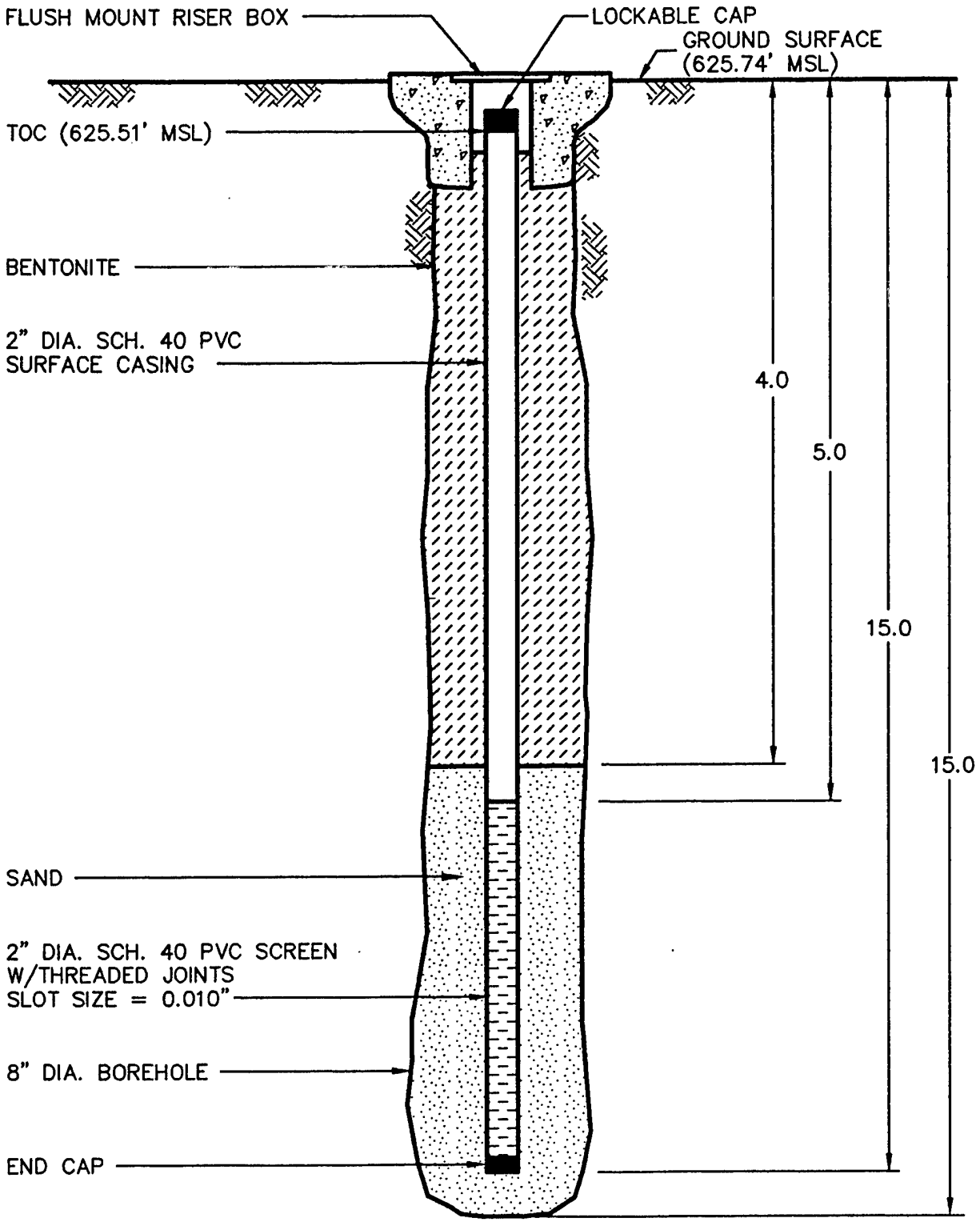
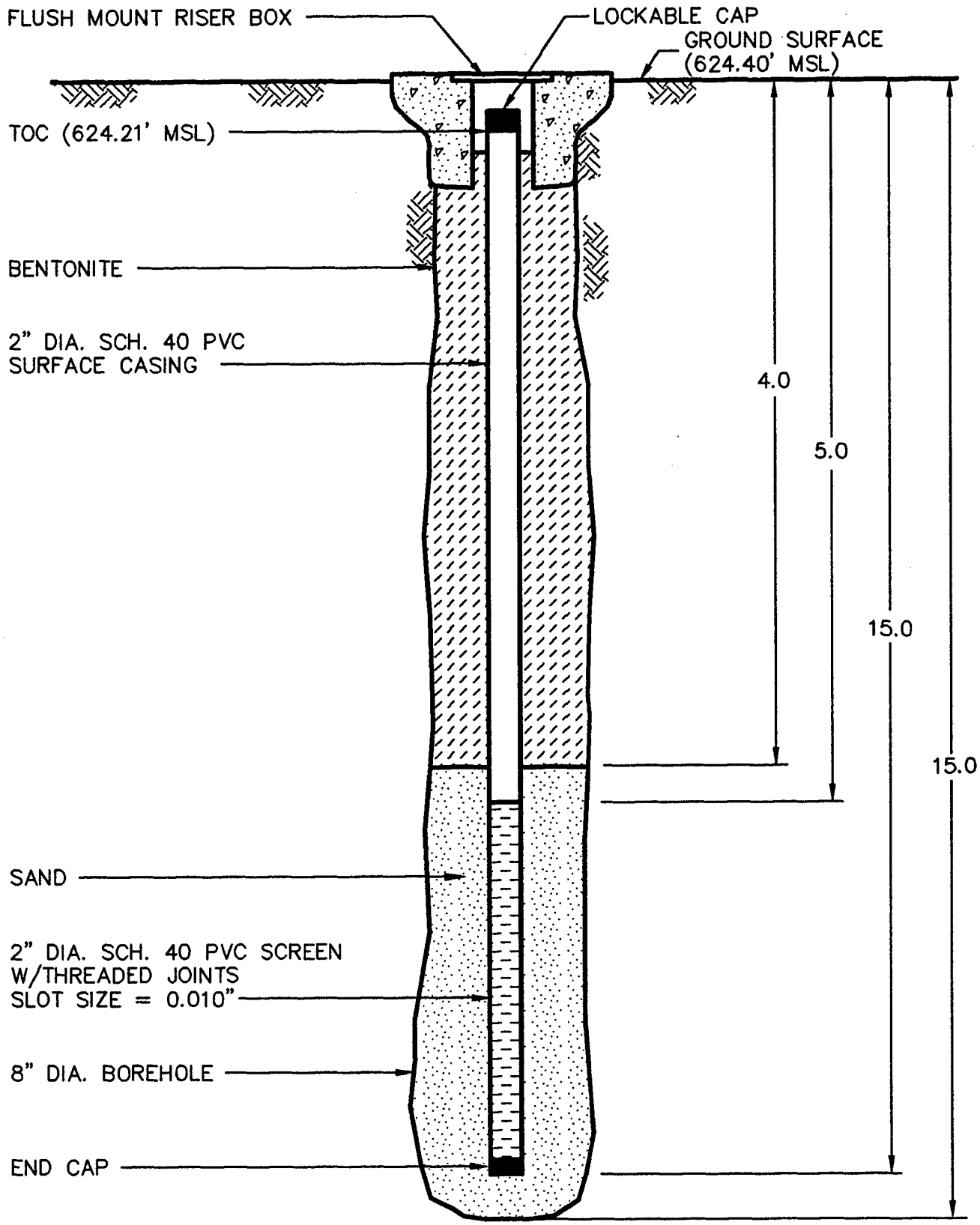


FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W412

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

K:\WRTSMTH 95DN0255 02/15/95 @ 0724

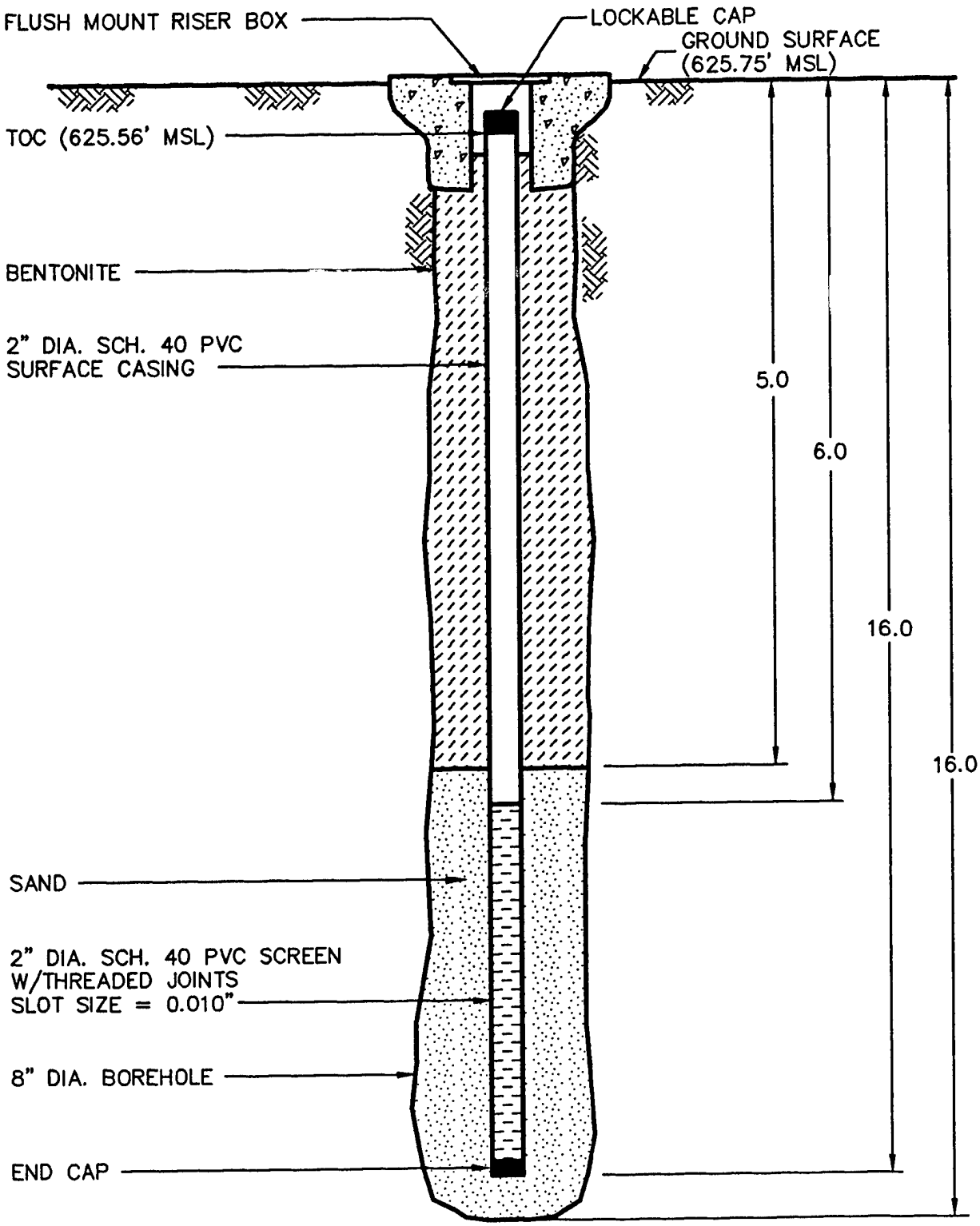


FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W413

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS
ENGINEERING SCIENCE, INC.

K:\WRTSMTH 95DN0256 02/15/95 @ 0725



FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W414

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

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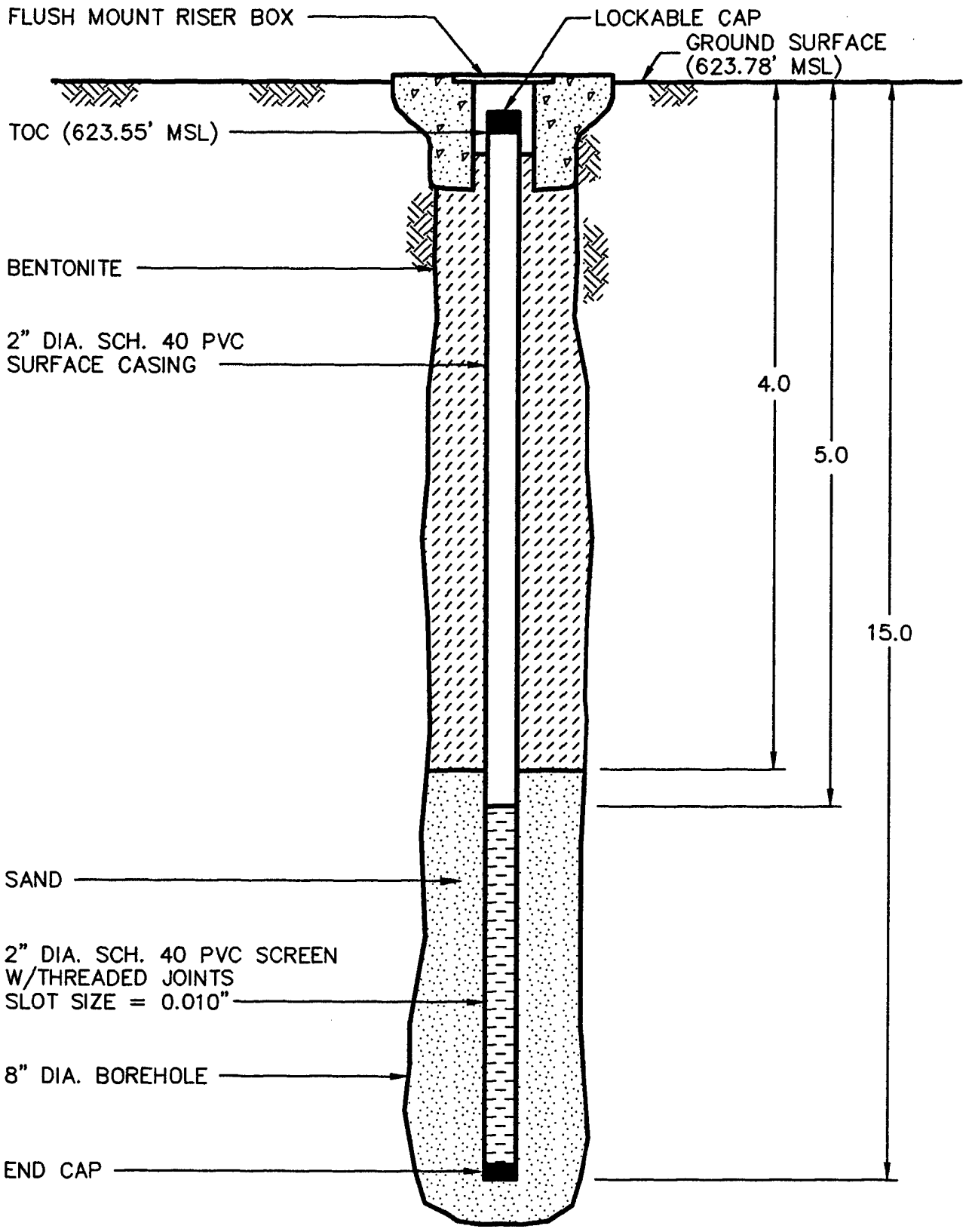
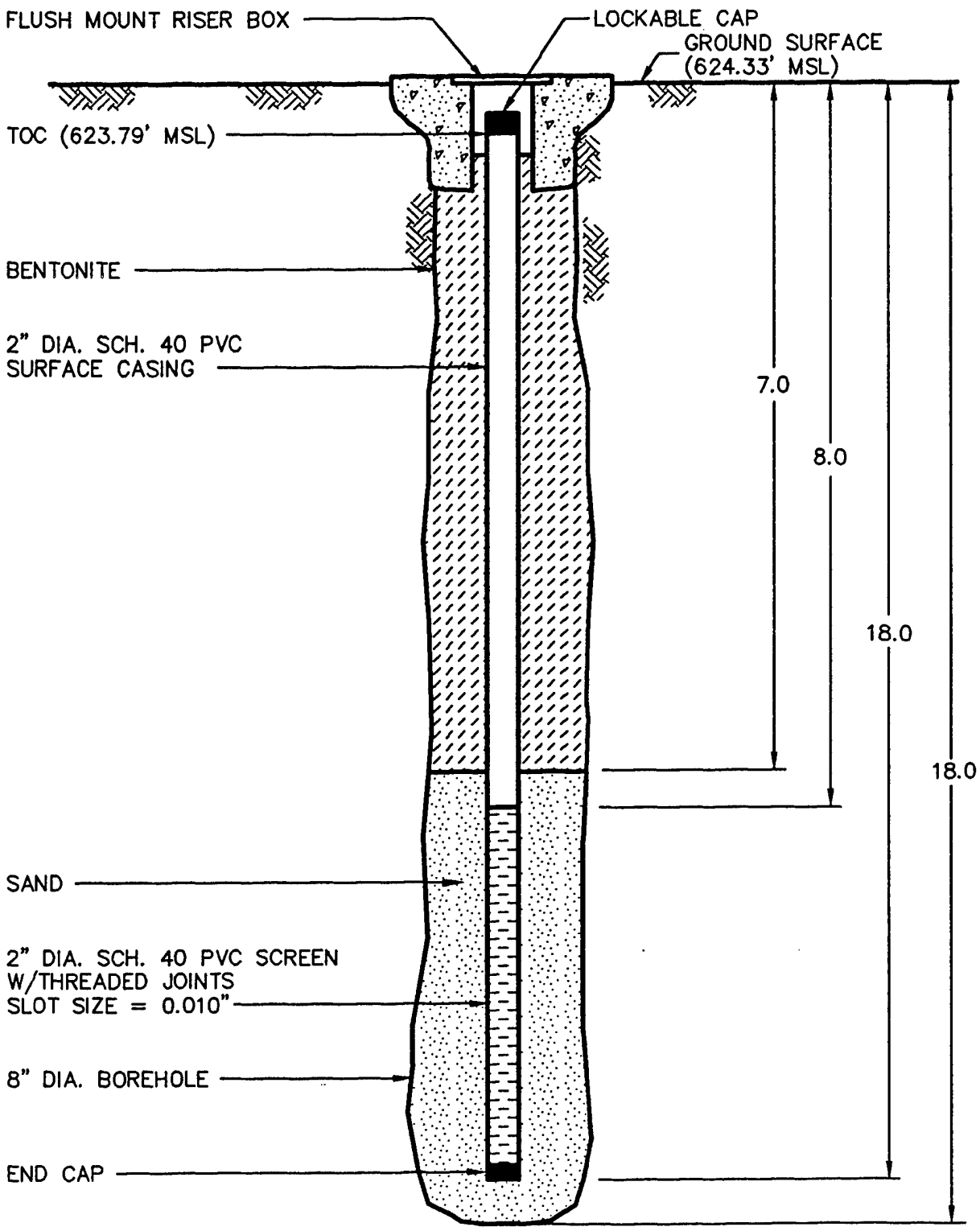


FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W415

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/04/94
WURTSMITH AFB, MI

PARSONS
ENGINEERING SCIENCE, INC.

K:\WRTSMTH 95DN0258 02/15/95 @ 0728



FLUSH-MOUNTED
MONITORING WELL DESIGN DETAIL
WELL NO. W416

SITE: SS51
GEOLOGIST: JFH
DATE COMPLETED: 10/06/94
WURTSMITH AFB, MI

PARSONS ENGINEERING SCIENCE, INC.

K:\WRTSMTH 95DN0259 02/15/95 @ 0730

Figure A.6
Well Development Record

Job Number_____ Job Name_____
Location SS51 By_____ Date 10/5/94
Well Number W410 Measurement Datum_____

Pre-Development Information

Time (Start): 13:00

Water Level: 9.77 Total Depth of Well: 14.60

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	5	20	25	35				
pH	7.5	7.20	7.88	7.96				
Temperature (°F °C)	58.9	53.4	55.0					
Specific Conductance(µS/cm)	199	159	163					

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:

Figure A.6
Well Development Record

Page__ of__

Job Number_____ Job Name_____
Location 5551 By JFH Date 10/5/94
Well Number W407 Measurement Datum TOC

Pre-Development Information

Time (Start): 14.60

Water Level: 8.78 Total Depth of Well:

Water Characteristics

Color brn 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	5	20	35		
pH	7.20	7.55	8.03		
Temperature (°F °C)	55.1	55.0	55.1		
Specific Conductance(µS/cm)	120	122	111		

Post-Development Information

Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color brn sl. cloudy Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material N/a
pH 8.03 Temperature (°F °C) 55.1
Specific Conductance(µS/cm) 111

Comments:

Figure A.6
Well Development Record

Job Number _____ Job Name _____
Location WWH 5551 By _____ Date 10/5/94
Well Number W411 Measurement Datum TOC

Pre-Development Information

Time (Start): 13:30

Water Level: 9.93 Total Depth of Well: 14.64

Water Characteristics

Color brn Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH _____ Temperature(°F °C) _____
Specific Conductance(µS/cm) _____

Interim Water Characteristics

Gallons Removed	~2	15	20		35
pH	7.13	7.66	7.15	7.75	7.84
Temperature (°F °C)	57.4	56.4	55.9	55.5	55.4
Specific Conductance(µS/cm)	189	190	167	172	173

Post-Development Information

Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color brn sl cloudy Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.84 Temperature (°F) °C) 55.4
Specific Conductance(µS/cm) 173

Comments:

Figure A.6
Well Development Record

Page__ of__

Job Number 725524
Location SS51
Well Number W408

Job Name
By Date 10/5/94
Measurement Datum

Pre-Development Information

Time (Start): 17:06

Water Level: 9.40

Total Depth of Well: 14.65

Water Characteristics

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

Interim Water Characteristics

Gallons Removed	2	8	20	30
pH	7.40	8.26	8.35	8.43
Temperature (°F °C)	55.2	55.4	55.3	54.6
Specific Conductance(µS/cm)	121	111	108	108 weak odor

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:

Figure A.6
Well Development Record

Page__ of__

Job Number_____
Location 5551
Well Number W412

Job Name_____
By_____ Date 10/5/94
Measurement Datum_____

Pre-Development Information

Time (Start): 14:00

Water Level: 9.97.

Total Depth of Well: 14.70

Water Characteristics

Color brown Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH_____ Temperature(°F °C)_____
Specific Conductance(µS/cm)_____

Interim Water Characteristics

	2	8	15	25	
Gallons Removed					
pH	7.45	7.80	7.99	8.10	8.12
Temperature (°F) °C)	56.4	55.4	55.8	54.9	55.1
Specific Conductance(µS/cm)	209	181	202	192	189

Post-Development Information

Time (Finish):

Water Level:

Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color brn, slcloudy Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material None
pH 8.12 Temperature(°F °C) 55.1
Specific Conductance(µS/cm) 189

Comments:

Figure A.6
Well Development Record

Job Number _____
Location _____
Well Number W413

Job Name _____
By JFH Date 10/5/94
Measurement Datum TOC

Pre-Development Information

Time (Start):

Water Level: 9.4

Total Depth of Well: 14.7

Water Characteristics

Color brn Clear (Cloudy)
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.19 Temperature (°F °C) 56.8
Specific Conductance(µS/cm) 159

Interim Water Characteristics

Gallons Removed	2	10	35				
pH	7.19	7.90	8.34				
Temperature (°F) °C)	56.8	56.9	57.3				
Specific Conductance(µS/cm)	159	154	155				

Post-Development Information

Time (Finish):

Water Level:

Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color Clear Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH 8.34 Temperature (°F °C) 57.3
Specific Conductance(µS/cm) _____

Comments:

Figure A.6
Well Development Record

Page__ of__

Job Number_____ Job Name_____
Location 5551 By_____ Date 10/5/94
Well Number W414 Measurement Datum_____

Pre-Development Information Time (Start):

Water Level: 9.67 Total Depth of Well: 15.45

Water Characteristics

Color brn Clear (Cloudy)
Odor: None Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.12 Temperature(°F °C) 56.7
Specific Conductance(µS/cm) 200

Interim Water Characteristics

Gallons Removed	2	15	25	35
pH	7.12	7.80	8.00	7.98
Temperature (°F °C)	56.7	56.2	55.8	56.5
Specific Conductance(µS/cm)	200	206	208	204

Post-Development Information Time (Finish):

Water Level: Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color brn, sl cloudy Clear Cloudy
Odor: (None) Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.98 Temperature(°F °C) 56.5
Specific Conductance(µS/cm) 204

Comments:

Figure A.6
Well Development Record

Page__ of__

Job Number 725524
Location W10 445 5551
Well Number W415

Job Name
By JFH Date 10/5/94
Measurement Datum

Pre-Development Information

Time (Start): 16:00

Water Level: 9.21

Total Depth of Well: 14.61

Water Characteristics

Color Brn Clear (Cloudy)
Odor: None Weak Moderate Strong
Any Films or Immiscible Material No
pH 7.15 Temperature (°F °C) 55.7
Specific Conductance(µS/cm) 147

Interim Water Characteristics

Gallons Removed	2	15	35		
pH	7.15	7.62	7.98		
Temperature (°F °C)	55.7	56.0	55.9		
Specific Conductance(µS/cm)	147	139	135		

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:

APPENDIX B

ANALYTICAL DATA AND VALIDATION RESULTS

1992 RI ANALYTICAL RESULTS

Table 5
Summary of Analytical Results for Soils
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identification:				T-1	T-1	T-1	T-2	T-2	T-3	T-3	T-4	T-4	T-5
Sample Identification:				E41159	E41160	E41161	E41162	E41163	E41164	E41165	E41166	E41167	E41641
Sample Date:				12/15/92	12/15/92	12/15/92	12/15/92	12/15/92	12/16/92	12/16/92	12/16/92	12/16/92	12/17/92
Sampled By:		Type A	Type B	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:		Soil	Soil	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Depth (feet):		Criteria	Criteria	0 - 2	5 - 7	5 - 7	0 - 2	5 - 7.5	0 - 2	7.5 - 9.5	0 - 2	5 - 7	0 - 2
Parameters	***Units***												
Benzene	mg/kg	.01	.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Ethylbenzene	mg/kg	.01	1.4	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Toluene	mg/kg	.01	16	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Xylene	mg/kg	.03	6	<.03	.037	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
Percent solids	%	-	NA	95	96	96	94	97	93	91	91	97	93
Acenaphthene	mg/kg	.33	8	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Acenaphthylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Anthracene	mg/kg	.33	40	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(a)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(b and/or k)fluoranthene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(a)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(ghi)perylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Chrysene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Dibenz(a,h)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Fluoranthene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Fluorene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Indeno(1,2,3-cd)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Naphthalene	mg/kg	.33	.6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Phenanthrene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Pyrene	mg/kg	.33	4	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Butyl Carbitol	mg/kg	-	NA	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

ID = Insufficient data to calculate Type B criteria.
NA = Not Available

Table 5
Summary of Analytical Results for Soils
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identification:				T-5	T-6	T-6	T-7	T-7	T-8	T-8	T-9	T-9	T-10-OF
Sample Identification:				E41642	E41644	E41643	E41645	E41646	E41647	E41648	E41649	E41650	E41651
Sample Date:				12/17/92	12/17/92	12/17/92	12/17/92	12/17/92	12/18/92	12/18/92	12/18/92	12/18/92	12/18/92
Sampled By:		Type A	Type B	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:		Soil	Soil	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Depth (feet):		Criteria	Criteria	7.5 - 9.5	2.5 - 4.5	5 - 7	2.5 - 4.5	5 - 7	0 - 2	7.5 - 9.5	0 - 2	7.5 - 9.5	0 - 2
Parameters	*Units*												
Benzene	mg/kg	.01	.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Ethylbenzene	mg/kg	.01	1.4	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Toluene	mg/kg	.01	16	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Xylene	mg/kg	.03	6	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
Percent solids	%	-	NA	96	96	96	97	97	94	90	94	87	88
Acenaphthene	mg/kg	.33	8	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Acenaphthylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Anthracene	mg/kg	.33	40	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Benzo(a)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Benzo(b and/or k)fluoranthene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Benzo(a)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Benzo(ghi)perylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Chrysene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Dibenz(a,h)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Fluoranthene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Fluorene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Indeno(1,2,3-cd)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Naphthalene	mg/kg	.33	.6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Phenanthrene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Pyrene	mg/kg	.33	4	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<1.7	<.33	<.33
Butyl Carbitol	mg/kg	-	NA	<5	<5	<5	<5	<5	<5	<5	<25	<5	<5

ID = Insufficient data to calculate Type B criteria.
NA = Not Available

Table 5
Summary of Analytical Results for Soils
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identification:				T-10-OF	T-11	T-11	T-12	T-12	T-13	T-13	T-13	T-14	T-14
Sample Identification:				E41652	E41653	E41654	E41655	E41656	E41659	E41657	E41658	E41660	E41661
Sample Date:				12/18/92	12/19/92	12/19/92	12/20/92	12/20/92	12/20/92	12/20/92	12/20/92	12/21/92	12/21/92
Sampled By:		Type A	Type B	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:		Soil	Soil	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Depth (feet):		Criteria	Criteria	7.5 - 9.5	0 - 2	7.5 - 8.5	0 - 2	7.5 - 8.5	0 - 2	0 - 2	5 - 7	0 - 2	7.5 - 8.5
Parameters	***Units***												
Benzene	mg/kg	.01	.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Ethylbenzene	mg/kg	.01	1.4	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Toluene	mg/kg	.01	16	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Xylene	mg/kg	.03	6	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
Percent solids	%	-	NA	93	95	93	94	96	95	94	96	94	96
Acenaphthene	mg/kg	.33	8	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Acenaphthylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Anthracene	mg/kg	.33	40	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(a)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(b and/or k)fluoranthene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(a)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(ghi)perylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Chrysene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Dibenz(a,h)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Fluoranthene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Fluorene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Indeno(1,2,3-cd)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Naphthalene	mg/kg	.33	.6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Phenanthrene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Pyrene	mg/kg	.33	4	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Butyl Carbitol	mg/kg	-	NA	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

ID = Insufficient data to calculate Type B criteria.
NA = Not Available

Table 5
Summary of Analytical Results for Soils
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identification:				T-15	T-15	T-16	T-16	T-17	T-17	T-18	T-18
Sample Identification:				E41662	E41663	E41664	E41665	E41666	E41667	E42626	E42627
Sample Date:				12/21/92	12/21/92	12/21/92	12/21/92	12/22/92	12/22/92	01/06/93	01/06/93
Sampled By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:		Type A Soil Criteria	Type B Soil Criteria	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Depth (feet):				0 - 2	5 - 7	0 - 2	7.5 - 9.5	0 - 2	7.5 - 9.5	0 - 2	7.5 - 9.5
Parameters	*Units*										
Benzene	mg/kg	.01	.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Ethylbenzene	mg/kg	.01	1.4	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Toluene	mg/kg	.01	16	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Xylene	mg/kg	.03	6	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
Percent solids	%	-	NA	95	95	94	96	93	94	96	96
Acenaphthene	mg/kg	.33	8	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Acenaphthylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Anthracene	mg/kg	.33	40	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(a)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(b and/or k)fluoranthene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(a)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Benzo(ghi)perylene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Chrysene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Dibenz(a,h)anthracene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Fluoranthene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Fluorene	mg/kg	.33	6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Indeno(1,2,3-cd)pyrene	mg/kg	.33	.2	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Naphthalene	mg/kg	.33	.6	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Phenanthrene	mg/kg	.33	ID	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Pyrene	mg/kg	.33	4	<.33	<.33	<.33	<.33	<.33	<.33	<.33	<.33
Butyl Carbitol	mg/kg	-	NA	<5	<5	<5	<5	<5	<5	<5	<5

ID = Insufficient data to calculate Type B criteria.
NA = Not Available

Table 6
Summary of Analytical Results for Ground Water
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identfication:				T-1	T-2	T-2 Dup	T-3A	T-3B	T-4	T-5	T-6	T-7	T-7A
Sample Identification:		Type A	Type B	E41151	E41152	E41153	E41673	E42815	E41154	E41156	E41155	E41671	E42816
Sample Date:		GW	GW	12/16/92	12/16/92	12/16/92	12/19/92	01/06/93	12/16/92	12/17/92	12/17/92	12/18/92	01/06/93
Sampled By:		Criteria	Criteria	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Parameters	*Units*												
Benzene	ug/L	1	1	<1	<1	<1	<1	-	<1	<1	<1	<1	-
Ethylbenzene	ug/L	1	70	15	<1	<1	<1	-	<1	<1	<1	<1	-
Toluene	ug/L	1	800	2.9	<1	<1	<1	-	<1	<1	<1	<1	-
Xylene	ug/L	3	300	180	<3	<3	<3	-	<3	<3	<3	<3	-
Acenaphthene	ug/L	5	400	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Acenaphthylene	ug/L	5	ID	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Anthracene	ug/L	5	2000	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Benzo(a)anthracene	ug/L	5	.006	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Benzo(b and/or k)fluoranthene	ug/L	5	.006	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Benzo(a)pyrene	ug/L	5	.006	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Benzo(ghi)perylene	ug/L	5	ID	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Chrysene	ug/L	5	.006	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Dibenz(a,h)anthracene	ug/L	5	.006	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Fluoranthene	ug/L	5	300	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Fluorene	ug/L	5	300	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Indeno(1,2,3-cd)pyrene	ug/L	5	.006	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Naphthalene	ug/L	5	30	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Phenanthrene	ug/L	5	ID	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Pyrene	ug/L	5	200	<5	<5	<5	-	<5	<5	<5	<5	-	<5
Butyl Carbitol	ug/L	-	NA	<50	<50	<50	-	<50	<50	<50	<50	-	<50

ID = Insufficient data to calculate Type B criteria.
NA = Not Available.
- = Not Analyzed.
BB = Bailer Blank.
EB = Equipment Blank.
TB = Trip Blank.
= Exceed Type B Criteria

Printed: 08-Jun-93

Table 6
Summary of Analytical Results for Ground Water
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identfication:				T-8	T-9	T-10-OF	T-11	T-12	T-13	T-14	T-14 Dup	T-15	T-16
Sample Identification:		Type A GW	Type B GW	E41670	E41669	E41668	E41672	E41674 E42943	E41678	E41675	E41676	E41677	E41680
Sample Date:				12/18/92	12/18/92	12/18/92	12/19/92	12/20/92	12/20/92	12/21/92	12/21/92	12/21/92	12/21/92
Sampled By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Parameters	*Units*												
Benzene	ug/L	1	1	<1	<1	2.2	<50	<1	280	<1	<1	<1	28
Ethylbenzene	ug/L	1	70	<1	<1	60	180	53	56	<1	<1	<1	<1
Toluene	ug/L	1	800	<1	<1	1.9	790	53	640	<1	<1	<1	<1
Xylene	ug/L	3	300	<3	<3	92	940	270	360	<3	<3	<3	<3
Acenaphthene	ug/L	5	400	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthylene	ug/L	5	ID	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Anthracene	ug/L	5	2000	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(a)anthracene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(b and/or k)fluoranthene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(a)pyrene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(ghi)perylene	ug/L	5	ID	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chrysene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Dibenz(a,h)anthracene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Fluoranthene	ug/L	5	300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Fluorene	ug/L	5	300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Indeno(1,2,3-cd)pyrene	ug/L	5	.006	<5	<5	<5	<20	5	<5	<5	<5	<5	<5
Naphthalene	ug/L	5	30	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Phenanthrene	ug/L	5	ID	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Pyrene	ug/L	5	200	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Butyl Carbitol	ug/L	-	NA	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50

ID = Insufficient data to calculate Type B criteria.
NA = Not Available.
- = Not Analyzed.
BB = Bailer Blank.
EB = Equipment Blank.
TB = Trip Blank.
= Exceed Type B Criteria

Table 6
Summary of Analytical Results for Ground Water
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identfication:				T-17	T-18	W-400	W-401	W-402	W-403	W-404S	W-405M	W-405M Duplicate	W-406D
Sample Identification:				E41679	E42628	E42818	E42823	E42824	E42825	E42819	E42820	E42821	E42822
Sample Date:		Type A GW	Type B GW	12/22/92	01/06/93	01/09/93	01/09/93	01/09/93	01/09/93	01/09/93	01/09/93	01/09/93	01/09/93
Sampled By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Parameters	*Units*												
Benzene	ug/L	1	1	<1	<1	<1	<1	<1	<1	<10	<1	<1	<1
Ethylbenzene	ug/L	1	70	<1	<1	<1	<1	<1	<1	130	<1	<1	<1
Toluene	ug/L	1	800	<1	<1	<1	<1	<1	<1	420	<1	<1	<1
Xylene	ug/L	3	300	<3	<3	<3	<3	<3	<3	700	<3	<3	<3
Acenaphthene	ug/L	5	400	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthylene	ug/L	5	ID	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Anthracene	ug/L	5	2000	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(a)anthracene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(b and/or k)fluoranthene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(a)pyrene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Benzo(ghi)perylene	ug/L	5	ID	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chrysene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Dibenz(a,h)anthracene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Fluoranthene	ug/L	5	300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Fluorene	ug/L	5	300	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Indeno(1,2,3-cd)pyrene	ug/L	5	.006	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Naphthalene	ug/L	5	30	<5	<5	<5	<5	<5	<5	21	<5	<5	<5
Phenanthrene	ug/L	5	ID	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Pyrene	ug/L	5	200	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Butyl Carbitol	ug/L	-	NA	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50

ID = Insufficient data to calculate Type B criteria.
NA = Not Available.
- = Not Analyzed.
BB = Bailer Blank.
EB = Equipment Blank.
TB = Trip Blank.
[redacted] = Exceed Type B Criteria

Table 6
Summary of Analytical Results for Ground Water
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identfication:				NE/USAF (USGS-7)	SW/USAF (USGS-4)	BB @W-404S	BB @SW/USAF (USGS-4)	EB@T-11	EB@T-16	TB #1	TB #2	TB #1
Sample Identification:				E42826	E42827	E42828	E42829	E41681	E41682	E41157	E41158	E41683
Sample Date:		Type A GW	Type B GW	01/09/93	01/09/93	01/09/93	01/10/93	12/19/92	12/21/92	12/16/92	12/16/92	12/17/92
Sampled By:		Criteria	Criteria	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Parameters	*Units*											
Benzene	ug/L	1	1	1.5	<500	<1	<1	<1	<1	<1	<1	<1
Ethylbenzene	ug/L	1	70	<1	2400	<1	<1	<1	<1	<1	<1	<1
Toluene	ug/L	1	800	3.1	3700	<1	<1	<1	<1	<1	<1	<1
Xylene	ug/L	3	300	17	9700	<3	<3	<3	<3	<3	<3	<3
Acenaphthene	ug/L	5	400	<5	<5	<5	<5	-	<5	-	-	-
Acenaphthylene	ug/L	5	ID	<5	<5	<5	<5	-	<5	-	-	-
Anthracene	ug/L	5	2000	<5	<5	<5	<5	-	<5	-	-	-
Benzo(a)anthracene	ug/L	5	.006	<5	<5	<5	<5	-	<5	-	-	-
Benzo(b and/or k)fluoranthene	ug/L	5	.006	<5	<5	<5	<5	-	<5	-	-	-
Benzo(a)pyrene	ug/L	5	.006	<5	<5	<5	<5	-	<5	-	-	-
Benzo(ghi)perylene	ug/L	5	ID	<5	<5	<5	<5	-	<5	-	-	-
Chrysene	ug/L	5	.006	<5	<5	<5	<5	-	<5	-	-	-
Dibenz(a,h)anthracene	ug/L	5	.006	<5	<5	<5	<5	-	<5	-	-	-
Fluoranthene	ug/L	5	300	<5	<5	<5	<5	-	<5	-	-	-
Fluorene	ug/L	5	300	<5	<5	<5	<5	-	<5	-	-	-
Indeno(1,2,3-cd)pyrene	ug/L	5	.006	<5	<5	<5	<5	-	<5	-	-	-
Naphthalene	ug/L	5	30	<5	120	<5	<5	-	<5	-	-	-
Phenanthrene	ug/L	5	ID	<5	<5	<5	<5	-	<5	-	-	-
Pyrene	ug/L	5	200	<5	<5	<5	<5	-	<5	-	-	-
Butyl Carbitol	ug/L	-	NA	<50	<50	<50	<50	-	<50	-	-	-

ID = Insufficient data to calculate Type B criteria.
NA = Not Available.
- = Not Analyzed.
BB = Bailer Blank.
EB = Equipment Blank.
TB = Trip Blank.
= Exceed Type B Criteria

GSI 04/94

Table 6
Summary of Analytical Results for Ground Water
Wurtsmith AFB, KC-135 Crash Site
Oscoda, Michigan
(Units as Given)

Site Identfication:				TB #2	TB #3	TB #4	TB #5	TB #6	TB	TB #1	TB #2	TB #3	TB #4
Sample Identification:				E41684	E41685	E41686	E41687	E41688	E42629	E42830	E42831	E42832	E42833
Sample Date:		Type A GW	Type B GW	12/17/92	12/17/92	12/17/92	12/17/92	12/17/92	01/06/93	01/09/93	01/09/93	01/09/93	01/09/93
Sampled By:		Criteria	Criteria	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Analyzed By:				WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES	WWES
Parameters	***Units***												
Benzene	ug/L	1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ethylbenzene	ug/L	1	70	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	ug/L	1	800	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Xylene	ug/L	3	300	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Acenaphthene	ug/L	5	400	-	-	-	-	-	-	-	-	-	-
Acenaphthylene	ug/L	5	ID	-	-	-	-	-	-	-	-	-	-
Anthracene	ug/L	5	2000	-	-	-	-	-	-	-	-	-	-
Benzo(a)anthracene	ug/L	5	.006	-	-	-	-	-	-	-	-	-	-
Benzo(b and/or k)fluoranthene	ug/L	5	.006	-	-	-	-	-	-	-	-	-	-
Benzo(a)pyrene	ug/L	5	.006	-	-	-	-	-	-	-	-	-	-
Benzo(ghi)perylene	ug/L	5	ID	-	-	-	-	-	-	-	-	-	-
Chrysene	ug/L	5	.006	-	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	ug/L	5	.006	-	-	-	-	-	-	-	-	-	-
Fluoranthene	ug/L	5	300	-	-	-	-	-	-	-	-	-	-
Fluorene	ug/L	5	300	-	-	-	-	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	ug/L	5	.006	-	-	-	-	-	-	-	-	-	-
Naphthalene	ug/L	5	30	-	-	-	-	-	-	-	-	-	-
Phenanthrene	ug/L	5	ID	-	-	-	-	-	-	-	-	-	-
Pyrene	ug/L	5	200	-	-	-	-	-	-	-	-	-	-
Butyl Carbitol	ug/L	-	NA	-	-	-	-	-	-	-	-	-	-

ID = Insufficient data to calculate Type B criteria.
NA = Not Available.
- = Not Analyzed.
BB = Bailer Blank.
EB = Equipment Blank.
TB = Trip Blank.
= Exceed Type B Criteria

1994 ANALYTICAL RESULTS

TABLE B.1
VALIDATED SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
SB1-SS51	3-Oct-94	8.00 - 10.00	Benzene	0.46 U [a/]	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	0.6 J [b/]	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.6 U	µg/kg	SW8020
W407-SS51	3-Oct-94	5.00 - 7.00	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
W407-SS51	3-Oct-94	9.00 - 11.00	Benzene	0.47 UJ [c/]	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	4.7 UJ	µg/kg	SW8020
			1,2,4-Trimethylbenzene	0.6 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.7 UJ	µg/kg	SW8020
W408-SS51	3-Oct-94	8.00 - 10.00	Benzene	0.44 UJ	µg/kg	SW8020
			Toluene	4.4 UJ	µg/kg	SW8020
			Ethylbenzene	4.4 UJ	µg/kg	SW8020
			Xylenes (Total)	4.4 UJ	µg/kg	SW8020
			1,3,5-Trimethylbenzene	1.7 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.4 UJ	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.4 UJ	µg/kg	SW8020
W408-SS51	3-Oct-94	10.00 - 12.00	Benzene	0.45 U	µg/kg	SW8020
			Toluene	4.5 U	µg/kg	SW8020
			Ethylbenzene	21	µg/kg	SW8020
			Xylenes (Total)	95	µg/kg	SW8020
			1,3,5-Trimethylbenzene	91 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	120 J	µg/kg	SW8020
			1,2,3-Trimethylbenzene	62 J	µg/kg	SW8020
W409D-SS51	4-Oct-94	13.00 - 15.00	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	0.6 J	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.8 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.8 U	µg/kg	SW8020
W416-SS51	6-Oct-94	12.00 - 14.00	Benzene	0.44 U	µg/kg	SW8020
			Toluene	4.4 U	µg/kg	SW8020
			Ethylbenzene	4.4 U	µg/kg	SW8020
			Xylenes (Total)	4.4 U	µg/kg	SW8020
			1,3,5-Trimethylbenzene	4.4 U	µg/kg	SW8020
			1,2,4-Trimethylbenzene	4.4 U	µg/kg	SW8020
			1,2,3-Trimethylbenzene	4.4 U	µg/kg	SW8020

[a/] U = Analyte Not Detected Above Method Detection Limit

[b/] J = Estimated Concentration of Analyte

[c/] 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 KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
SB1-SS51	3-Oct-94	8.00 - 10.00	Naphthalene	380 U [a]	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
			[illegible]ene	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
W407-SS51	3-Oct-94	5.00 - 7.00	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
W408-SS51	3-Oct-94	8.00 - 10.00	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
W408-SS51	3-Oct-94	10.00 - 12.00	Naphthalene	23 J [b]	µg/kg	SW8270
			2-Methylnaphthalene	200 J	µg/kg	SW8270
			Acenaphthylene	370 U	µg/kg	SW8270
			Acenaphthene	370 U	µg/kg	SW8270

TABLE B.2
VALIDATED SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
W408-SS51	3-Oct-94	10.00 - 12.00	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
W409D-SS51	4-Oct-94	13.00-15.00	Naphthalene	390 U	µg/kg	SW8270
			2-Methylnaphthalene	390 U	µg/kg	SW8270
			Acenaphthylene	390 U	µg/kg	SW8270
			Acenaphthene	390 U	µg/kg	SW8270
			Dibenzofuran	390 U	µg/kg	SW8270
			Fluorene	390 U	µg/kg	SW8270
			Phenanthrene	390 U	µg/kg	SW8270
			Anthracene	390 U	µg/kg	SW8270
			Fluoranthene	390 U	µg/kg	SW8270
			Pyrene	390 U	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
W416-SS51	6-Oct-94	12.00 - 14.00	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

[a] U = Analyte Not Detected Above Method Detection Limit
[b] J = Estimated Concentration of Analyte

TABLE B.3
VALIDATED SOIL DATA FOR OTHER ANALYSIS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
SB-416	11-Oct-94	10.00 - 12.00	Phosphorus, Total Orthophosphate	12.7	mg/kg	E300.0
			Nitrogen, Total Kjeldahl	5.22 U [a]	mg/kg	E351.3
			Iron	2200	mg/kg	SW6010
			pH	7.71	pH units	SW9045
			Total Organic Carbon	0.05 U	%	SW9060
			Alkalinity, Carbonate	26.2 U	mg/kg	E310.1
W407-SS51	3-Oct-94	9.00 - 11.00	Total Organic Carbon	0.05 U	%	SW9060
W407-SS51	7-Oct-94	5.00 - 7.00	Phosphorus, Total Orthophosphate	4.29	mg/kg	E300.0
			Nitrogen, Total Kjeldahl	5.13 U	mg/kg	E351.3
			Iron	1600	mg/kg	SW6010
			pH	7.8	pH units	SW9045
			Alkalinity, Carbonate	37.9	mg/kg	E310.1
W409D-SS51	4-Oct-94	13.00 - 15.00	Total Organic Carbon	0.7	%	SW9060
W409D-SS51	7-Oct-94	38.00 - 40.00	Total Organic Carbon	0.04 J [b]	%	SW9060
W409D-SS51	7-Oct-94	62.00 - 64.00	Total Organic Carbon	0.03 J	%	SW9060
W415-SS51	4-Oct-94	11.00 - 13.00	Total Organic Carbon	0.05 U	%	SW9060
W416-SS51	6-Oct-94	14.00 - 16.00	Total Organic Carbon	0.09	%	SW9060

[a] U = Analyte Not Detected Above Method Detection Limit
[b] J = Estimated Concentration of Analyte

TABLE B.4
VALIDATED SOIL GAS DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs: begining-ending)	Analyte	Result	Units	Analytical Method
W404-SS51	19-Oct-94	5.00 - 10.00	Benzene	0.007 U [a]	µg/L	TO3
			Toluene	0.008 U	µg/L	TO3
			Ethylbenzene	4.8	µg/L	TO3
			Xylenes (Total)	5.3	µg/L	TO3
			Petroleum Hydrocarbons	780	µg/L	TO3
W408-SS51	19-Oct-94	5.00 - 10.00	Benzene	0.068 U	µg/L	TO3
			Toluene	0.08 U	µg/L	TO3
			Ethylbenzene	36	µg/L	TO3
			Xylenes (Total)	43	µg/L	TO3
			Petroleum Hydrocarbons	7800	µg/L	TO3
W409S-SS51	19-Oct-94	5.00 - 10.00	Benzene	0.006 U	µg/L	TO3
			Toluene	0.008 U	µg/L	TO3
			Ethylbenzene	1.8	µg/L	TO3
			Xylenes (Total)	1.5	µg/L	TO3
			Petroleum Hydrocarbons	160	µg/L	TO3

[a] U = Analyte Not Detected Above Method Detection Limit

TABLE B.5
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
USGS4-SS51	14-Oct-94	Total Extractable Hydrocarbons	2.9 J [a/]	mg/L	M8015
		Total Volatile Hydrocarbons	5.6	mg/L	M8015
		Benzene	4.4	µg/L	SW8020
		Toluene	2100	µg/L	SW8020
		Ethylbenzene	520	µg/L	SW8020
		Xylenes (Total)	2500	µg/L	SW8020
		1,3,5-Trimethylbenzene	100	µg/L	SW8020
		1,2,4-Trimethylbenzene	580	µg/L	SW8020
		1,2,3-Trimethylbenzene	84	µg/L	SW8020
W400-SS51	17-Oct-94	Benzene	0.4 U [b/]	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	0.8 J	µg/L	SW8020
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
W401-SS51	17-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
W402-SS51	18-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
W403-SS51	18-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
W404-SS51	17-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	1.6 J	µg/L	SW8020
		Ethylbenzene	54	µg/L	SW8020
		Xylenes (Total)	66	µg/L	SW8020
		1,3,5-Trimethylbenzene	34	µg/L	SW8020
		1,2,4-Trimethylbenzene	62	µg/L	SW8020
		1,2,3-Trimethylbenzene	14	µg/L	SW8020
W405-SS51	17-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
W406-SS51	17-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	0.4 J	µg/L	SW8020

TABLE B.5
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W406-SS51	17-Oct-94	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
W407-SS51	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
W408-SS51	14-Oct-94	Total Extractable Hydrocarbons	0.8 J	mg/L	M8015
		Total Volatile Hydrocarbons	2.6	mg/L	M8015
		Benzene	1.3 J	µg/L	SW8020
		Toluene	0.6 J	µg/L	SW8020
		Ethylbenzene	15	µg/L	SW8020
		Xylenes (Total)	58	µg/L	SW8020
		1,3,5-Trimethylbenzene	93	µg/L	SW8020
		1,2,4-Trimethylbenzene	220	µg/L	SW8020
		1,2,3-Trimethylbenzene	42	µg/L	SW8020
W409D-SS51	11-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	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
		1,2,4-Trimethylbenzene	4 U	µg/L	SW8020
		1,2,3-Trimethylbenzene	4 U	µg/L	SW8020
W409M-SS51	7-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
	11-Oct-94	Total Extractable Hydrocarbons	5 U	mg/L	M8015
		Total Volatile Hydrocarbons	0.1 J	mg/L	M8015
W409S-SS51	17-Oct-94	Total Extractable Hydrocarbons	0.6 J	mg/L	M8015
		Total Volatile Hydrocarbons	3.6	mg/L	M8015
		Benzene	89	µg/L	SW8020
		Toluene	770	µg/L	SW8020
		Ethylbenzene	140	µg/L	SW8020
		Xylenes (Total)	370	µg/L	SW8020
		1,3,5-Trimethylbenzene	49	µg/L	SW8020
		1,2,4-Trimethylbenzene	130	µg/L	SW8020
		1,2,3-Trimethylbenzene	58	µg/L	SW8020
W410-SS51	14-Oct-94	Benzene	0.4 U	µg/L	SW8020
		Toluene	4 U	µg/L	SW8020
		Ethylbenzene	4 U	µg/L	SW8020

TABLE B.5
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W410-SS51	14-Oct-94	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
W411-SS51	14-Oct-94	Benzene	1 J	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
W412-SS51	14-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
W413-SS51	18-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
W414-SS51	18-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
W415-SS51	18-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
W416-SS51	18-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

[a/] J = Estimated Concentration of Analyte

[b/] U = Analyte Not Detected Above Method Detection Limit

TABLE B.6
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
USGS4-SS51	14-Oct-94	Naphthalene	100	µg/L	SW8270
		2-Methylnaphthalene	32	µg/L	SW8270
		Acenaphthylene	10 U [a/]	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
W401-SS51	17-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
W402-SS51	18-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

TABLE B.6
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W402-SS51	18-Oct-94	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
W407-SS51	17-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
W408-SS51	14-Oct-94	Naphthalene	2 J [b/]	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
W409D-SS51	11-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

TABLE B.6
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W409D-SS51	11-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
W409M-SS51	7-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
W409S-SS51	17-Oct-94	Naphthalene	16	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
W411-SS51	14-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

TABLE B.6
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W411-SS51	14-Oct-94	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 [illegible]	10 U	µg/L	SW8270
		Dibenz(a,h) [illegible] ne	10 U	µg/L	SW8270
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270
W414-SS51	18-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
W416-SS51	18-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

[a/] U = Analyte Not Detected Above Method Detection Limit

[b/] J = Estimated Concentration of Analyte

TABLE B.7
VALIDATED GROUND WATER DATA FOR OTHER RELAVENT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
USGS4-SS51	14-Oct-94	Carbon Dioxide	147	mg/L	COU-O2
		Dissolved Oxygen	0.5 U [a]	mg/L	FDO
		Iron	1.3	mg/L	H8008
		Nitrate	1	mg/L	H8039
		Sulfate	1.44	mg/L	H8051
		Hydrogen Sulfide	0.1	mg/L	H8131
		Iron, Ferrous	1.26	mg/L	H8146
		Carbon Dioxide	23.75	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	1.8	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W400-SS51	17-Oct-94	Dissolved Oxygen	5.69	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	0.3	mg/L	H8039
		Sulfate	9.43	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.01	mg/L	H8146
		Carbon Dioxide	6.25	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
W401-SS51	17-Oct-94	Dissolved Oxygen	6.65	mg/L	FDO
		Iron	0.02	mg/L	H8008
		Nitrate	1.1	mg/L	H8039
		Sulfate	8.85	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.01	mg/L	H8146
		Carbon Dioxide	7.5	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.1	mg/L	HMANG
W402-SS51	18-Oct-94	Dissolved Oxygen	7.41	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	0.5	mg/L	H8039
		Sulfate	7.75	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.02	mg/L	H8146
		Carbon Dioxide	6.25	mg/L	H8223
		Nitrite	0.002	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
W403-SS51	18-Oct-94	Dissolved Oxygen	6.05	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	0.6	mg/L	H8039
		Sulfate	0.77	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.01	mg/L	H8146
		Carbon Dioxide	10	mg/L	H8223

TABLE B.7
VALIDATED GROUND WATER DATA FOR OTHER RELAVENT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W403-SS51	18-Oct-94	Nitrite	0.001	mg/L	H8507
		Manganese	0.3	mg/L	HMANG
W404-SS51	17-Oct-94	Dissolved Oxygen	3.25	mg/L	FDO
		Iron	0.9	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	2.15	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.81	mg/L	H8146
		Carbon Dioxide	10	mg/L	H8223
		Nitrite	0.003	mg/L	H8507
		Manganese	1.1	mg/L	HMANG
W405-SS51	11-Oct-94	Dissolved Oxygen	5.94	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	10.67	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	0.005 U	mg/L	H8507
		Manganese	0.05 U	mg/L	HMANG
W406-SS51	17-Oct-94	Dissolved Oxygen	0.53	mg/L	FDO
		Iron	0.31	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	18.37	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.18	mg/L	H8146
		Carbon Dioxide	10	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.05 U	mg/L	HMANG
W407-SS51	13-Oct-94	Carbon Dioxide	59	mg/L	COU-O2
		Dissolved Oxygen	7.71	mg/L	FDO
		Iron	0.03	mg/L	H8008
		Nitrate	0.066 U	mg/L	H8039
		Sulfate	8.7	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.04	mg/L	H8146
		Carbon Dioxide	6.25	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W408-SS51	14-Oct-94	Carbon Dioxide	55	mg/L	COU-O2
		Dissolved Oxygen	3.04	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	1	mg/L	H8039
		Sulfate	6.84	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131

TABLE B.7
VALIDATED GROUND WATER DATA FOR OTHER RELAVENT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W408-SS51	14-Oct-94	Iron, Ferrous	0.02	mg/L	H8146
		Carbon Dioxide	6.25	mg/L	H8223
		Nitrite	0.001	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W409D-SS51	11-Oct-94	Carbon Dioxide	140	mg/L	COU-O2
		Dissolved Oxygen	0.5 U	mg/L	FDO
		Iron	0.37	mg/L	H8008
		Nitrate	0.066 U	mg/L	H8039
		Sulfate	7.18	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.31	mg/L	H8146
		Carbon Dioxide	13.75	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.05 U	mg/L	HMANG
		Methane	0.01	mg/L	METHAN
W409M-SS51	11-Oct-94	Carbon Dioxide	5 U	mg/L	COU-O2
		Dissolved Oxygen	0.5 U	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	1.6	mg/L	H8039
		Sulfate	16.89	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.01	mg/L	H8146
		Carbon Dioxide	1.25 U	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.05 U	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W409S-SS51	17-Oct-94	Carbon Dioxide	114	mg/L	COU-O2
		Dissolved Oxygen	0.75	mg/L	FDO
		Iron	0.12	mg/L	H8008
		Nitrate	0.7	mg/L	H8039
		Sulfate	0.67	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.1	mg/L	H8146
		Carbon Dioxide	8.75	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.6	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W410-SS51	14-Oct-94	Dissolved Oxygen	9.37	mg/L	FDO
		Iron	0.25	mg/L	H8008
		Nitrate	0.7	mg/L	H8039
		Sulfate	6.94	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	0.005 U	mg/L	H8507

TABLE B.7
VALIDATED GROUND WATER DATA FOR OTHER RELAVENT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W410-SS51	14-Oct-94	Manganese	0.4	mg/L	HMANG
W411-SS51	14-Oct-94	Carbon Dioxide	106	mg/L	COU-O2
		Dissolved Oxygen	8.69	mg/L	FDO
		Iron	0.01	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	0.48	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.02	mg/L	H8146
		Carbon Dioxide	11.25	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.2	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W412-SS51	14-Oct-94	Dissolved Oxygen	7.27	mg/L	FDO
		Iron	0.25	mg/L	H8008
		Nitrate	1	mg/L	H8039
		Sulfate	7.13	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.1	mg/L	H8146
		Carbon Dioxide	11.25	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.4	mg/L	HMANG
W413-SS51	18-Oct-94	Dissolved Oxygen	9.36	mg/L	FDO
		Iron	0.024 U	mg/L	H8008
		Nitrate	0.2	mg/L	H8039
		Sulfate	2.01	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.024 U	mg/L	H8146
		Carbon Dioxide	13.75	mg/L	H8223
		Nitrite	0.001	mg/L	H8507
		Manganese	0.3	mg/L	HMANG
W414-SS51	18-Oct-94	Carbon Dioxide	114	mg/L	COU-O2
		Dissolved Oxygen	7.38	mg/L	FDO
		Iron	0.02	mg/L	H8008
		Nitrate	0.8	mg/L	H8039
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.024 U	mg/L	H8146
		Carbon Dioxide	15	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.1	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN
W415-SS51	18-Oct-94	Dissolved Oxygen	8.04	mg/L	FDO
		Iron	0.02	mg/L	H8008
		Nitrate	0.4	mg/L	H8039
		Sulfate	2.97	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.02	mg/L	H8146

TABLE B.7
VALIDATED GROUND WATER DATA FOR OTHER RELAVENT ANALYSES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W415-SS51	18-Oct-94	Carbon Dioxide	11.25	mg/L	H8223
		Nitrite	0.005 U	mg/L	H8507
		Manganese	0.4	mg/L	HMANG
W416-SS51	18-Oct-94	Carbon Dioxide	103	mg/L	COU-O2
		Dissolved Oxygen	8.43	mg/L	FDO
		Iron	0.01	mg/L	H8008
		Nitrate	1	mg/L	H8039
		Sulfate	2.68	mg/L	H8051
		Hydrogen Sulfide	0.024 U	mg/L	H8131
		Iron, Ferrous	0.024 U	mg/L	H8146
		Carbon Dioxide	11.25	mg/L	H8223
		Nitrite	0.004	mg/L	H8507
		Manganese	0.3	mg/L	HMANG
		Methane	0.001 U	mg/L	METHAN

[a/] U = Analyte Not Detected Above Method Detection Limit

TABLE B.8
GEOLOGICAL PARAMETERS MEASURED IN THE FIELD
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
USGS4-SS51	14-Oct-94	Electrical Conductivity	0.266 J [b/]	mmhos/cm	FCOND
		pH	7.2 J	pH units	FPH
		Redox Potential	0.59838 J	pE units	FREDOX
		Temperature	13.3 J	°C	FTEMP
		Alkalinity, Carbonate	140 J	mg/L	H8221
W400-SS51	17-Oct-94	Electrical Conductivity	0.1595 J	mmhos/cm	FCOND
		pH	8.09 J	pH units	FPH
		Redox Potential	4.03482 J	pE units	FREDOX
		Temperature	13.2 J	°C	FTEMP
		Alkalinity, Carbonate	100 J	mg/L	H8221
W401-SS51	17-Oct-94	Electrical Conductivity	0.1355 J	mmhos/cm	FCOND
		pH	8.13 J	pH units	FPH
		Redox Potential	5.69473 J	pE units	FREDOX
		Temperature	12.5 J	°C	FTEMP
		Alkalinity, Carbonate	80 J	mg/L	H8221
W402-SS51	18-Oct-94	Electrical Conductivity	0.1558 J	mmhos/cm	FCOND
		pH	8.24 J	pH units	FPH
		Redox Potential	3.23529 J	pE units	FREDOX
		Temperature	12.7 J	°C	FTEMP
		Alkalinity, Carbonate	100 J	mg/L	H8221
W403-SS51	18-Oct-94	Electrical Conductivity	0.1849 J	mmhos/cm	FCOND
		pH	8.1 J	pH units	FPH
		Redox Potential	3.14909 J	pE units	FREDOX
		Temperature	13.7 J	°C	FTEMP
		Alkalinity, Carbonate	120 J	mg/L	H8221
W404-SS51	17-Oct-94	Electrical Conductivity	0.1585 J	mmhos/cm	FCOND
		pH	7.25 J	pH units	FPH
		Redox Potential	3.35869 J	pE units	FREDOX
		Temperature	13.3 J	°C	FTEMP
		Alkalinity, Carbonate	100 J	mg/L	H8221
W405-SS51	11-Oct-94	Electrical Conductivity	0.1574 J	mmhos/cm	FCOND
		pH	8.48 J	pH units	FPH
		Redox Potential	4.1954 J	pE units	FREDOX
		Temperature	12.9 J	°C	FTEMP
		Alkalinity, Carbonate	100 J	mg/L	H8221
W406-SS51	17-Oct-94	Electrical Conductivity	0.208 J	mmhos/cm	FCOND
		pH	8.05 J	pH units	FPH
		Redox Potential	1.58384 J	pE units	FREDOX
		Temperature	11.2 J	°C	FTEMP
		Alkalinity, Carbonate	120 J	mg/L	H8221
W407-SS51	13-Oct-94	Electrical Conductivity	0.1373 J	mmhos/cm	FCOND
		pH	8.37 J	pH units	FPH
		Redox Potential	1.88303 J	pE units	FREDOX
		Temperature	13 J	°C	FTEMP
		Alkalinity, Carbonate	80 J	mg/L	H8221
W408-SS51	14-Oct-94	Electrical Conductivity	0.1313 J	mmhos/cm	FCOND

TABLE B.8
GEOLOGICAL PARAMETERS MEASURED IN THE FIELD
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W408-SS51	14-Oct-94	pH	7.92 J	pH units	FPH
		Redox Potential	1.89655 J	pE units	FREDOX
		Temperature	13.4 J	°C	FTEMP
		Alkalinity, Carbonate	80 J	mg/L	H8221
W409D-SS51	11-Oct-94	Electrical Conductivity	0.281 J	mmhos/cm	FCOND
		pH	8.15 J	pH units	FPH
		Redox Potential	6.74949 J	pE units	FREDOX
		Temperature	9.8 J	°C	FTEMP
		Alkalinity, Carbonate	180 J	mg/L	H8221
W409M-SS51	7-Oct-94	Electrical Conductivity	0.342 J	mmhos/cm	FCOND
		pH	11.42 J	pH units	FPH
		Redox Potential	3.81677 J	pE units	FREDOX
		Temperature	10.5 J	°C	FTEMP
	11-Oct-94	Alkalinity, Carbonate	140 J	mg/L	H8221
W409S-SS51	17-Oct-94	Electrical Conductivity	0.215 J	mmhos/cm	FCOND
		pH	7.6 J	pH units	FPH
		Redox Potential	4.24104 J	pE units	FREDOX
		Temperature	12.2 J	°C	FTEMP
		Alkalinity, Carbonate	140 J	mg/L	H8221
W410-SS51	14-Oct-94	Electrical Conductivity	0.1883 J	mmhos/cm	FCOND
		pH	7.93 J	pH units	FPH
		Redox Potential	2.12306 J	pE units	FREDOX
		Temperature	13.5 J	°C	FTEMP
		Alkalinity, Carbonate	100 J	mg/L	H8221
W411-SS51	14-Oct-94	Electrical Conductivity	0.216 J	mmhos/cm	FCOND
		pH	7.77 J	pH units	FPH
		Redox Potential	2.1332 J	pE units	FREDOX
		Temperature	12.9 J	°C	FTEMP
		Alkalinity, Carbonate	120 J	mg/L	H8221
W412-SS51	14-Oct-94	Electrical Conductivity	0.234 J	mmhos/cm	FCOND
		pH	7.61 J	pH units	FPH
		Redox Potential	2.30561 J	pE units	FREDOX
		Temperature	13.2 J	°C	FTEMP
		Alkalinity, Carbonate	140 J	mg/L	H8221
W413-SS51	18-Oct-94	Electrical Conductivity	0.1863 J	mmhos/cm	FCOND
		pH	7.84 J	pH units	FPH
		Redox Potential	3.48715 J	pE units	FREDOX
		Temperature	14.6 J	°C	FTEMP
		Alkalinity, Carbonate	140 J	mg/L	H8221
W414-SS51	18-Oct-94	Electrical Conductivity	0.235 J	mmhos/cm	FCOND
		pH	7.58 J	pH units	FPH
		Redox Potential	3.35193 J	pE units	FREDOX
		Temperature	14.9 J	°C	FTEMP
		Alkalinity, Carbonate	140 J	mg/L	H8221
W415-SS51	18-Oct-94	Electrical Conductivity	0.1841 J	mmhos/cm	FCOND
		pH	8.39 J	pH units	FPH

TABLE B.8
GEOLOGICAL PARAMETERS MEASURED IN THE FIELD
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W415-SS51	18-Oct-94	Redox Potential	3.16261 J	pE units	FREDOX
		Temperature	14.3 J	°C	FTEMP
		Alkalinity, Carbonate	120 J	mg/L	H8221
W416-SS51	18-Oct-94	Electrical Conductivity	0.217 J	mmhos/cm	FCOND
		pH	7.85 J	pH units	FPH
		Redox Potential	3.37897 J	pE units	FREDOX
		Temperature	13 J	°C	FTEMP
		Alkalinity, Carbonate	120 J	mg/L	H8221

[b/] J = Estimated Concentration of Analyte

TABLE B.9
QA/QC WATER BLANKS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Sample Type	Sample Date	Matrix
Equipment Blank	06-Oct-94	Water
Equipment Blank	18-Oct-94	Water
Field Blank	14-Oct-94	Water
Field Blank	18-Oct-94	Water
Trip Blank	06-Oct-94	Water
Trip Blank	14-Oct-94	Water
Trip Blank	03-Oct-94	Water
Trip Blank	18-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.10
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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
SB1-SS51	03-Oct-94	1,2,4-Trimethylbenzene	Soil	SW8020	=			J	J
		Toluene	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	=		U	J	U
W407-SS51	03-Oct-94	Toluene	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	=		U	J	U
		1,2,3-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		1,2,4-Trimethylbenzene	Soil	SW8020	=	J		J	J
		1,3,5-Trimethylbenzene	Soil	SW8020	ND	J			UJ
		Benzene	Soil	SW8020	ND	J			UJ
		Ethylbenzene	Soil	SW8020	ND	J			UJ
		Toluene	Soil	SW8020	ND	J	U	J	UJ
		Xylenes (Total)	Soil	SW8020	ND	J	U	J	UJ
W408-SS51	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	=			J	J
		1,3,5-Trimethylbenzene	Soil	SW8020	=	J		J	J
		Benzene	Soil	SW8020	ND	J			UJ
		Ethylbenzene	Soil	SW8020	ND	J			UJ
		Toluene	Soil	SW8020	=		U	J	U
		Toluene	Soil	SW8020	=	J	U	J	UJ
		Xylenes (Total)	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	=	J	U	J	UJ
		1,2,3-Trimethylbenzene	Soil	SW8020	=	J			J
		1,2,4-Trimethylbenzene	Soil	SW8020	=	J			J
		1,3,5-Trimethylbenzene	Soil	SW8020	=	J			J
		Toluene	Soil	SW8020	=		U		U

TABLE B.10
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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
W408-SS51	03-Oct-94	2-Methylnaphthalene	Soil	SW8270	=			J	J
		Naphthalene	Soil	SW8270	=			J	J
W409D-SS51	04-Oct-94	1,3,5-Trimethylbenzene	Soil	SW8020	=			J	J
		Toluene	Soil	SW8020	=		U	J	U
		Xylenes (Total)	Soil	SW8020	=		U	J	U
	07-Oct-94	Total Organic Carbon	Soil	SW9060	=			J	J
		Total Organic Carbon	Soil	SW9060	=			J	J
USGS4-SS51	14-Oct-94	Total Extractable Hydrocarbons	Water	M8015	=			J	J
W400-SS51	17-Oct-94	1,3,5-Trimethylbenzene	Water	SW8020	=			J	J
		Toluene	Water	SW8020	=		U	J	U
		Xylenes (Total)	Water	SW8020	=		U	J	U
W401-SS51	17-Oct-94	Toluene	Water	SW8020	=		U	J	U
		Xylenes (Total)	Water	SW8020	=		U	J	U
W405-SS51	17-Oct-94	Toluene	Water	SW8020	=		U	J	U
		Xylenes (Total)	Water	SW8020	=		U	J	U
W406-SS51	17-Oct-94	1,2,3-Trimethylbenzene	Water	SW8020	=		U	J	U
W406-SS51	17-Oct-94	Toluene	Water	SW8020	=			J	J
W407-SS51	13-Oct-94	Xylenes (Total)	Water	SW8020	=		U	J	U
W408-SS51	14-Oct-94	Total Extractable Hydrocarbons	Water	M8015	=			J	J
		Benzene	Water	SW8020	=			J	J
		Toluene	Water	SW8020	=			J	J
		Naphthalene	Water	SW8270	=			J	J
W409D-SS51	11-Oct-94	Toluene	Water	SW8020	=			J	J
W409M-SS51	07-Oct-94	Xylenes (Total)	Water	SW8020	=		U	J	U
		Total Volatile Hydrocarbons	Water	M8015	=			J	J
W409S-SS51	17-Oct-94	Total Extractable Hydrocarbons	Water	M8015	=			J	J

TABLE B.10
DATA VALIDATION QUALIFIER APPLICATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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
W411-SS51	14-Oct-94	Benzene	Water	SW8020	=			J	J
W413-SS51	18-Oct-94	Xylenes (Total)	Water	SW8020	=		U	J	U
W414-SS51	18-Oct-94	Iron	Water	H8008	=			J	J
W415-SS51	18-Oct-94	Xylenes (Total)	Water	SW8020	=		U	J	U
W416-SS51	18-Oct-94	Xylenes (Total)	Water	SW8020	=		U	J	U
W508-SS51	14-Oct-94	Ethylbenzene	Water	SW8020	=			J	J
W509-SS51	17-Oct-94	Total Extractable Hydrocarbons	Water	M8015	=			J	J

[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.11
DUPLICATE AND REPLICATE SAMPLE RESULTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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/]
W408-SS51	03-Oct-94	Soil	SW8020	8 - 10	Benzene	0.44 UJ	0.44 U	µg/kg	
			SW8020	8 - 10	Toluene	4.4 UJ	4.4 U	µg/kg	
			SW8020	8 - 10	Ethylbenzene	4.4 UJ	4.4 U	µg/kg	
			SW8020	8 - 10	1,2,3-Trimethylbenzene	4.4 UJ	4.4 U	µg/kg	
			SW8020	8 - 10	1,2,4-Trimethylbenzene	4.4 UJ	4.4 U	µg/kg	
			SW8020	8 - 10	1,3,5-Trimethylbenzene	1.7 J	1.7 J	µg/kg	0.00
			SW8020	8 - 10	Xylenes (Total)	4.4 UJ	4.4 U	µg/kg	
			SW8270	8 - 10	Acenaphthene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Acenaphthylene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Anthracene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Benzo(a)anthracene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Benzo(a)pyrene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Benzo(b)fluoranthene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Benzo(g,h,i)perylene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Benzo(k)fluoranthene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Chrysene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Dibenz(a,h)anthracene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Dibenzofuran	370 U	370 U	µg/kg	
			SW8270	8 - 10	Fluorene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Fluoranthene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Indeno(1,2,3-cd)pyrene	370 U	370 U	µg/kg	
			SW8270	8 - 10	2-Methylnaphthalene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Naphthalene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Phenanthrene	370 U	370 U	µg/kg	
			SW8270	8 - 10	Pyrene	370 U	370 U	µg/kg	
W408-SS51	14-Oct-94	Water	H8008		Iron	0.024 UJ	0.024 UJ	µg/L	
			H8039		Nitrate	1 J	1 J	µg/L	0.00
			H8051		Sulfate	6.84 J	4.45 J	µg/L	26.37

TABLE B.11
DUPLICATE AND REPLICATE SAMPLE RESULTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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/]
W408-SS51	14-Oct-94	Water	H8146		Iron, Ferrous	0.02 J	0.01 J	µg/L	40.00
			H8221		Alkalinity, Carbonate	80 J	80 J	µg/L	0.00
			H8223		Carbon Dioxide	6.25 J	6.25 J	µg/L	0.00
			H8507		Nitrite	0.001 J	0.005 UJ	µg/L	0.00
			HMANG		Manganese	0.2 J	0.1 J	µg/L	40.00
			SW8020		Benzene	1.3 J	0.4 U	µg/L	0.00
			SW8020		Toluene	0.6 J	7.4	µg/L	158.14
			SW8020		Ethylbenzene	15	2.8 J	µg/L	74.39
			SW8020		1,2,3-Trimethylbenzene	42	4.1	µg/L	86.04
			SW8020		1,2,4-Trimethylbenzene	220	11	µg/L	92.68
			SW8020		1,3,5-Trimethylbenzene	93	7.7	µg/L	88.07
			SW8020		Xylenes (Total)	58	12	µg/L	71.88
			SW8270		Acenaphthene	10 U	50 U	µg/L	
			SW8270		Acenaphthylene	10 U	50 U	µg/L	
			SW8270		Anthracene	10 U	50 U	µg/L	
			SW8270		Benzo(a)anthracene	10 U	50 U	µg/L	
			SW8270		Benzo(a)pyrene	10 U	50 U	µg/L	
			SW8270		Benzo(b)fluoranthene	10 U	50 U	µg/L	
			SW8270		Benzo(g,h,i)perylene	10 U	50 U	µg/L	
			SW8270		Benzo(k)fluoranthene	10 U	50 U	µg/L	
			SW8270		Chrysene	10 U	50 U	µg/L	
			SW8270		Dibenz(a,h)anthracene	10 U	50 U	µg/L	
			SW8270		Dibenzofuran	10 U	50 U	µg/L	
			SW8270		Fluorene	10 U	50 U	µg/L	
			SW8270		Fluoranthene	10 U	50 U	µg/L	
			SW8270		Indeno(1,2,3-cd)pyrene	10 U	50 U	µg/L	
			SW8270		2-Methylnaphthalene	10 U	50 U	µg/L	
			SW8270		Naphthalene	2 J	50 U	µg/L	0.00

TABLE B.11
DUPLICATE AND REPLICATE SAMPLE RESULTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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/]
W408-SS51	14-Oct-94	Water	SW8270		Phenanthrene	10 U	50 U	µg/L	
			SW8270		Pyrene	10 U	50 U	µg/L	
W409S-SS51	17-Oct-94	Water	H8008		Iron	0.12 J	0.11 J	µg/L	5.71
			H8039		Nitrate	0.7 J	0.7 J	µg/L	0.00
			H8051		Sulfate	0.67 J	0.53 J	µg/L	14.97
			H8131		Hydrogen Sulfide	0.024 UJ	0.024 UJ	µg/L	
			H8146		Iron, Ferrous	0.1 J	0.1 J	µg/L	0.00
			H8221		Alkalinity, Carbonate	140 J	140 J	µg/L	0.00
			H8223		Carbon Dioxide	8.75 J	8.75 J	µg/L	0.00
			H8507		Nitrite	0.005 UJ	0.005 UJ	µg/L	
			HMANG		Manganese	0.6 J	0.6 J	µg/L	0.00
			M8015		Total Extractable Hydrocarbo	0.6 J	0.7 J	µg/L	10.53
			M8015		Total Volatile Hydrocarbons	3.6	3.2	µg/L	7.69
W411-SS51	14-Oct-94	Water	SW8020		Benzene	1 J	0.4 U	µg/L	0.00
			SW8020		Toluene	4 U	4 U	µg/L	
			SW8020		Ethylbenzene	4 U	4 U	µg/L	
			SW8020		1,2,3-Trimethylbenzene	4 U	4 U	µg/L	
			SW8020		1,2,4-Trimethylbenzene	4 U	4 U	µg/L	
			SW8020		1,3,5-Trimethylbenzene	4 U	4 U	µg/L	
			SW8020		Xylenes (Total)	4 U	4 U	µg/L	
			SW8270		Acenaphthene	10 U	10 U	µg/L	
			SW8270		Acenaphthylene	10 U	10 U	µg/L	
			SW8270		Anthracene	10 U	10 U	µg/L	
			SW8270		Benzo(a)anthracene	10 U	10 U	µg/L	
			SW8270		Benzo(a)pyrene	10 U	10 U	µg/L	
			SW8270		Benzo(b)fluoranthene	10 U	10 U	µg/L	
			SW8270		Benzo(g,h,i)perylene	10 U	10 U	µg/L	
			SW8270		Benzo(k)fluoranthene	10 U	10 U	µg/L	

TABLE B.11
DUPLICATE AND REPLICATE SAMPLE RESULTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, 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/]
W411-SS51	14-Oct-94	Water	SW8270		Chrysene	10 U	10 U	µg/L	
			SW8270		Dibenz(a,h)anthracene	10 U	10 U	µg/L	
			SW8270		Dibenzofuran	10 U	10 U	µg/L	
			SW8270		Fluorene	10 U	10 U	µg/L	
			SW8270		Fluoranthene	10 U	10 U	µg/L	
			SW8270		Indeno(1,2,3-cd)pyrene	10 U	10 U	µg/L	
			SW8270		2-Methylnaphthalene	10 U	10 U	µg/L	
			SW8270		Naphthalene	10 U	10 U	µg/L	
			SW8270		Phenanthrene	10 U	10 U	µg/L	
			SW8270		Pyrene	10 U	10 U	µg/L	
W414-SS51	18-Oct-94	Water	M8015		Total Extractable Hydrocarbo	5 U	5 U	µg/L	
			M8015		Total Volatile Hydrocarbons	1 U	1 U	µg/L	
W409S-SS51	19-Oct-94	Soil Gas	TO3	5 - 10	Benzene	0.006 U	0.007 U	µg/L	
			TO3	5 - 10	Toluene	0.008 U	0.008 U	µg/L	
			TO3	5 - 10	Ethylbenzene	1.8	2.5	µg/L	22.95
			TO3	5 - 10	Petroleum Hydrocarbons	160	360	µg/L	58.82
			TO3	5 - 10	Xylenes (Total)	1.5	2.6	µg/L	39.29

[a/] RPD = relative percent difference between real and duplicate sample.

1994 VALIDATION RESULTS

MS/MSD SAMPLES &
GC/MS CONFIRMATION SAMPLES

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

GCMS CONFIRMATION

Client Sample Number	: W-411	Client I.D.	: 725520.500/ WURTSMITH
Lab Sample Number	: X05425		
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.	: >V6325
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	U	10
Styrene	100-42-5	U	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	99%	(83-112)
Toluene-d8	100%	(93-104)
Bromofluorobenzene	89%	(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

Analyst

Approved

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

Method 602 Data Report

Client Sample Number	: W-411	Client Project No.	: 725520.500 Wurtsmith
Lab Sample Number	: X05425	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.	: BX2041213
		Method Blank No.	: MB041295

Compound Name	Cas Number	Sample Concentration ug/L		RL ug/L
Benzene	71-43-2	0.7		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
1,3,5-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		U	0.4
Surrogate Recovery (α,α,α-Trifluorotoluene):		83%		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.

K. Cone
Analyst

P McClellan
Approved

BTX1136.XLS

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

GCMS CONFIRMATION

Client Sample Number	: W-411	Client I.D.	: 725520.500/ WURTSMITH
Lab Sample Number	: X05425		
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.	: >V6325
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	U	10
Styrene	100-42-5	U	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	99%	(83-112)
Toluene-d8	100%	(93-104)
Bromofluorobenzene	89%	(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

Analyst

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BTEX Data Report

		Client Project No.	: 725524.03000 Wurtsmith AFB
Client Sample Number	: W408-SS51W		
Lab Sample Number	: X96767	Lab Project No.	: 94-4003
Date Sampled	: 10/14/94	Dilution Factor	: 1.00
Date Received	: 10/18/94	Method	: 602
Date Extracted/Prepared	: 10/22/94	Matrix	: Water
Date Analyzed	: 10/22/94	Lab File No.	: BX1102214
		d Blank No.	: MB102294

Compound Name	Cas Number	Sample Concentration ug/L		MDL ug/L
Benzene	71-43-2	1.3		0.4
Toluene	108-88-3	0.6		0.4
Ethyl Benzene	100-41-4	15		0.4
Total Xylene (m/p + o)	1330-20-7	58		0.4
Chlorobenzene	108-90-7		U	0.4
1,3,5-trimethylbenzene	108-67-8	93		0.4
1,2,4-trimethylbenzene	95-63-6	220		0.4
1,2,3-trimethylbenzene	526-73-8	42		0.4

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

Surrogate Recovery:
a,a,a,-Trifluorotoluene : 100%
QC Reporting Limits : 77%-116%

QUALIFIERS:
E = Extrapolated value
U = Compound analyzed for, but not detected.
B = Compound found in blank and sample. Compare blank and sample data.
MDL = Method Detection Limit.
NA = Not available.

Analyst

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BTEX Data Report

Client Sample Number	: W508-SS51W	Client Project No.	: 725524.03000 Wurtsmith AFB
Lab Sample Number	: X96769	Lab Project No.	: 94-4003
Date Sampled	: 10/14/94	Dilution Factor	: 1.00
Date Received	: 10/18/94	Method	: 602
Date Extracted/Prepared	: 10/22/94	Matrix	: Water
Date Analyzed	: 10/22/94	Lab File No.	: BX1102216
		Method Blank No.	: MB102294

Compound Name	Cas Number	Sample Concentration ug/L		MDL ug/L
Benzene	71-43-2		U	0.4
Toluene	108-88-3	7.4		0.4
Ethyl Benzene	100-41-4	2.8		0.4
Total Xylene (m/p + o)	1330-20-7	12		0.4
Chlorobenzene	108-90-7		U	0.4
1,3,5-trimethylbenzene	108-67-8	7.7		0.4
1,2,4-trimethylbenzene	95-63-6	11		0.4
1,2,3-trimethylbenzene	526-73-8	4.1		0.4

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

Surrogate Recovery:
a,a,a,-Trifluorotoluene : 88%
QC Reporting Limits : 77%-116%

QUALIFIERS:
E = Extrapolated value
U = Compound analyzed for, but not detected.
B = Compound found in blank and sample. Compare blank and sample data.
MDL = Method Detection Limit.
NA = Not available.

Analyst

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EVERGREEN ANALYTICAL, INC.
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(303)425-6021

GCMS CONFIRMATION

Client Sample Number	: W408-SS51W	Client I.D.	: 725524.03000 WURTSMITH AFB
Lab Sample Number	: X96767		
Date Sampled	: 10/14/94	Lab Project No.	: 94-4003
Date Received	: 10/18/94	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/26/94	Method	: 8240(8260)
Date Analyzed	: 10/26/94	Matrix	: WATER
Methanol Extract?	: N	Lab File No.	: >L9487
Percent Loss on Drying	: NA	Method Blank No.	: RB102694A

Compound Name	Number	Conc. ug/L		PQL* ug/L
Benzene	71-43-2		U	5
Toluene	108-88-3	0.2	J	5
Ethyl Benzene	100-41-4	0.7	J	5
Total Xylenes	1330-20-7	4.0	J	5
Chlorobenzene	108-90-7		U	5
1,2,4-Trimethylbenzene	95-63-6	9	X	5
1,2,3-Trimethylbenzene	526-73-8	4	JX	5
1,3,5-Trimethylbenzene (Mesitylene)	108-67-8	10	X	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	99%	(83-112)
Toluene-d8	100%	(93-104)
Bromofluorobenzene	95%	(87-105)

Qualifiers:
X = Concentration estimated. No daily calibration.
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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BTEX Data Report

		Client Project No.	: 725524.03000 Wurtsmith
Client Sample Number	: W403-SS51W		
Lab Sample Number	: X96870	Lab Project No.	: 94-4041
Date Sampled	: 10/18/94	Dilution Factor	: 1.00
Date Received	: 10/20/94	Method	: 602
Date Extracted/Prepared	: 10/28/94	Matrix	: Water
Date Analyzed	: 10/28/94	Lab File No.	: BX2102815
		Method Blank No.	: MB102894

Compound Name	Cas Number	Sample Concentration ug/L	MDL ug/L
Benzene	71-43-2	U	0.4
Toluene	108-88-3	U	0.4
Ethyl Benzene	100-41-4	U	0.4
Total Xylene (m/p + o)	1330-20-7	U	0.4
Chlorobenzene	108-90-7	U	0.4
1,3,5-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

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

Surrogate Recovery:
a,a,a,-Trifluorotoluene : 77%
QC Reporting Limits : 77%-116%

QUALIFIERS:
E = Extrapolated value
U = Compound analyzed for, but not detected.
B = Compound found in blank and sample. Compare blank and sample data.
MDL = Method Detection Limit.
NA = Not available.

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GCMS CONFIRMATION

Client Sample Number	: W403-SS51W	Client I.D.	: 725524.03000 WURTSMITH AFB
Lab Sample Number	: X96870		
Date Sampled	: 10/18/94	Lab Project No.	: 94-4041
Date Received	: 10/20/94	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/26/94	Method	: 8240(8260)
Date Analyzed	: 10/26/94	Matrix	: WATER
Methanol Extract?	: N	Lab File No.	: >L9488
Percent Loss on Drying	: NA	Method Blank No.	: RB102694A

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	UX	5
1,2,3-Trimethylbenzene	526-73-8	UX	5
1,3,5-Trimethylbenzene (Mesitylene)	108-67-8	UX	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	105%	(83-112)
Toluene-d8	101%	(93-104)
Bromofluorobenzene	98%	(87-105)

Qualifiers:
X = Concentration estimated. No daily calibration.
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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BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

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

3C

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.

Lab Project No.: 94-3869 | Client I.D. : 725524.03

Lab Sample No. : X95962 | Client Sample No. : W409M-SS51W

Lab File Ids. : >26850,1 | 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	QC LIMITS %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.

Evergreen Analytical, Inc.
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(303) 425-6021

BTEX Water Matrix Spike/Matrix Spike Duplicate Data Report

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

3C

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC. Client I.D. : 725524.03000-WURTSMITH AFB
Lab Project No.: 94-4017
Lab Sample No. : X96822 Client Sample No. : W409S-SS51W
Lab File Ids. : >27014,5 Date Extracted : 10/20/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	16.32	100.18	84	NA
1,4-Dichlorobenzene	100	0.00	70.79	71	36-97
N-Nitrosodipropylamine	100	0.00	104.50	105	41-116
1,2,4-Trichlorobenzene	100	0.00	62.15	62	39-98
Acenaphthene	100	0.00	78.67	79	46-118
2,4-Dinitrotoluene	100	0.00	77.95	78	24-96
Pyrene	100	0.00	87.80	88	26-127

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	QC LIMITS %REC
Naphthalene	100	94.56	78	6.9	NA	NA
1,4-Dichlorobenzene	100	64.68	65	9	28	36-97
N-Nitrosodipropylamine	100	99.27	99	5.1	38	41-116
1,2,4-Trichlorobenzene	100	56.16	56	10	28	39-98
Acenaphthene	100	72.29	72	8.5	31	46-118
2,4-Dinitrotoluene	100	41.19	41	62 *	38	24-96
Pyrene	100	78.81	79	11	31	26-127

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

* Values outside of QC limits

RPD: 1 out of 7 outside limits.

Spike Recovery: 0 out of 14 outside limits.

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

3C

WATER SEMIVOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.
Lab Project No.: 94-4041
Lab Sample No. : X96871
Lab File Ids. : >27053,4

Client I.D. : 725524-03000 WURTSMITH AFB
Client Sample No. : W414-SS51W
Date Extracted : 10/20/94

COMPOUND	SPIKE ADDED (mg/ml)	SAMPLE CONCENTRATION (mg/ml)	MS CONCENTRATION (mg/ml)	MS % REC #	QC LIMITS %REC
Naphthalene	100	0.00	84.55	85	NA
1,4-Dichlorobenzene	100	0.00	60.81	61	36-97
N-Nitrosodipropylamine	100	0.00	95.63	96	41-116
1,2,4-Trichlorobenzene	100	0.00	55.09	55	39-98
Acenaphthene	100	0.00	68.14	68	46-118
2,4-Dinitrotoluene	100	0.00	67.02	67	24-96
Pyrene	100	0.00	72.67	73	26-127

COMPOUND	SPIKE ADDED (mg/ml)	MSD CONCENTRATION (mg/ml)	MSD % REC #	RPD #	QC LIMITS RPD	QC LIMITS %REC
Naphthalene	100	101.58	102	18	NA	NA
1,4-Dichlorobenzene	100	62.29	62	2.4	28	36-97
N-Nitrosodipropylamine	100	101.46	101	5.9	38	41-116
1,2,4-Trichlorobenzene	100	65.16	65	17	28	39-98
Acenaphthene	100	71.38	71	4.6	31	46-118
2,4-Dinitrotoluene	100	72.24	72	7.5	38	24-96
Pyrene	100	75.59	76	3.9	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.

1995 ANALYTICAL RESULTS

TABLE B.12
VALIDATED SOIL GAS DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs)	Analyte	Result	Units
ML14-SS51	12/95	16.8	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML14-SS51	12/95	18.8	Benzene	ND	µg/L
			Toluene	39	µg/L
			Ethylbenzene	4	µg/L
			Xylenes (Total)	25	µg/L
ML14-SS51	12/95	13.5	Benzene	ND	µg/L
			Toluene	6300	µg/L
			Ethylbenzene	330	µg/L
			Xylenes (Total)	2600	µg/L
ML14-SS51	12/95	22.7	Benzene	ND	µg/L
			Toluene	38	µg/L
			Ethylbenzene	10	µg/L
			Xylenes (Total)	46	µg/L
ML14-SS51	12/95	24.7	Benzene	ND	µg/L
			Toluene	19	µg/L
			Ethylbenzene	9	µg/L
			Xylenes (Total)	31	µg/L
ML13-SS51	12/95	23.4	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML13-SS51	12/95	13.4	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML13-SS51	12/95	19.2	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	14.8	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	16.8	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	11.0	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	20.6	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	22.8	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L

TABLE B.12 (Continued)
VALIDATED SOIL GAS DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Sample Interval (ft bgs)	Analyte	Result	Units
ML15-SS51	12/95	12.9	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	[illegible]	Benzene	ND	µg/L
			[illegible]	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L
ML15-SS51	12/95	9.8	Benzene	ND	µg/L
			Toluene	ND	µg/L
			Ethylbenzene	ND	µg/L
			Xylenes (Total)	ND	µg/L

a/ U = Analyte Not Detected Above Method Detection Limit

1995 ANALYTICAL DATA

National Center for Integrated Bioremediation R and D
4140 E. California St. Oscoda, MI 48750 (517)739-0185

Sample Name / ft BLS:	ML14-16.8'	ML14-16.8' Dup.	ML14-18.8'	ML14-18.8' Dup.	ML14-13.5'	ML14-13.5' Dup.	ML14-22.7'	ML14-22.7' Dup.	ML14-24.7'	ML14-24.7' Dup.
TGI's Sample ID:	TA21533	TA21533B	TA21534	TA21534B	TA21535	TA21535B	TA21536	TA21536B	TA21537	TA21537B
Compounds (ug/l) Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	ND	ND	39	3	6300	5300	38	36	19	14
Ethylbenzene	ND	ND	4	ND	330	300	10	10	9	4
Xylenes	ND	ND	25	3	2600	2200	46	42	31	17

Sample Name / ft BLS:	ML14-14.9'	ML14-14.9' Dup.	ML14-20.8'	ML14-20.8' Dup.	ML14-11.5'	ML14-11.5' Dup.	ML13-15.5'	ML13-17.4	ML13-11.6'	ML13-21.4'
TGI's Sample ID:	TA21538	TA21538B	TA21539	TA21539B	TA21540	TA21540B	TA21542	TA21543	TA21544	TA21545
Compounds (ug/l) Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	530	540	14	9	850	550	ND	ND	ND	ND
Ethylbenzene	300	210	7	6	ND	ND	ND	ND	ND	ND
Xylenes	980	1000	42	22	3300	2800	ND	ND	ND	ND

Sample Name / ft BLS:	ML13-23.4'	ML13-13.4'	ML13-19.2'	ML15-14.8'	ML15-16.8'	ML15-11.0'	ML15-20.6'	ML15-22.8'	ML15-12.9'	ML15-18.6'
TGI's Sample ID:	TA21546	TA21547	TA21548	TA21550	TA21551	TA21552	TA21553	TA21554	TA21555	TA21556
Compounds (ug/l) Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylenes	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Sample Name / ft BLS:	ML15-9.8'
TGI's Sample ID:	TA21557
Compounds (ug/l) Matrix:	Water
Benzene	ND
Toluene	ND
Ethylbenzene	ND
Xylenes	ND

1996 ANALYTICAL RESULTS

TABLE B.13
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result		Units	Analytical Method
W401-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W402-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W404-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	30		µg/L	SW8020
		Xylenes (Total)	44		µg/L	SW8020
		1,3,5-Trimethylbenzene	13		µg/L	SW8020
		1,2,4-Trimethylbenzene	35		µg/L	SW8020
		1,2,3-Trimethylbenzene	11		µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	8.5		µg/L	SW8020
W407-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W409S-SS51	4 Oct 96	Benzene	3.8		µg/L	SW8020
		Toluene	50		µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	230		µg/L	SW8020
		Xylenes (Total)	550		µg/L	SW8020
		1,3,5-Trimethylbenzene	61		µg/L	SW8020
		1,2,4-Trimethylbenzene	170		µg/L	SW8020
		1,2,3-Trimethylbenzene	73		µg/L	SW8020
		1,2,3,4-Tetramethylbenzene	31		µg/L	SW8020
W409D-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020

TABLE B.13 (Continued)
VALIDATED GROUNDWATER DATA FOR VOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result		Units	Analytical Method
W410-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W411-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W412-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW802
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W414-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
W420-SS51	4 Oct 96	Benzene	0.4	U	µg/L	SW8020
		Toluene	0.4	U	µg/L	SW8020
		Chlorobenzene	0.4	U	µg/L	SW8020
		Ethylbenzene	0.4	U	µg/L	SW8020
		Xylenes (Total)	0.4	U	µg/L	SW8020
		1,3,5-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,4-Trimethylbenzene	0.4	U	µg/L	SW8020
		1,2,3-Trimethylbenzene	0.4	U	µg/L	SW8020
USGS4-SS51	4 Oct 96	Benzene	8.0	U	µg/L	SW8020
		Toluene	1100		µg/L	SW8020
		Chlorobenzene	8.0	U	µg/L	SW8020
		Ethylbenzene	570		µg/L	SW8020
		Xylenes (Total)	2600		µg/L	SW8020
		1,3,5-Trimethylbenzene	210		µg/L	SW8020
		1,2,4-Trimethylbenzene	630		µg/L	SW8020
		1,2,3-Trimethylbenzene	190		µg/L	SW802
		1,2,3,4-Tetramethylbenzene	280		µg/L	SW8020

[a] J = Estimated Concentration of Analyte

[b] U = Analyte Not Detected Above Method Detection Limit

TABLE B.14
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W401-SS51	4 Oct 96	Naphthalene	10 U [a/]	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W402-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W404-SS51	4 Oct 96	Naphthalene	3 J [b/]	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B

TABLE B.14 (Continued)
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W404-SS51 (Cont)		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W407-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W409S-SS51	4 Oct 96	Naphthalene	16	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B

TABLE B.14 (Continued)
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W409S-SS51 (Cont)		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W409D-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W4010-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W411-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B

TABLE B.14 (Continued)
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W411-SS51 (Cont)		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W412-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W414-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B

TABLE B.14 (Continued)
VALIDATED GROUNDWATER DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE KC-135
WURTSMITH AFB, MICHIGAN

Sample Location	Sample Date	Analyte	Result	Units	Analytical Method
W414-SS51 (Cont)		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B
W420-SS51	4 Oct 96	Naphthalene	10 U	µg/L	SW8270B
		2-Methylnaphthalene	10 U	µg/L	SW8270B
		Acenaphthylene	10 U	µg/L	SW8270B
		Acenaphthene	10 U	µg/L	SW8270B
		Dibenzofuran	10 U	µg/L	SW8270B
		Fluorene	10 U	µg/L	SW8270B
		Phenanthrene	10 U	µg/L	SW8270B
		Anthracene	10 U	µg/L	SW8270B
		Fluoranthene	10 U	µg/L	SW8270B
		Pyrene	10 U	µg/L	SW8270B
		Benzo(a)anthracene	10 U	µg/L	SW8270B
		Chrysene	10 U	µg/L	SW8270B
		Benzo(b)fluoranthene	10 U	µg/L	SW8270B
		Benzo(k)fluoranthene	10 U	µg/L	SW8270B
		Benzo(a)pyrene	10 U	µg/L	SW8270B
		Indeno(1,2,3-cd)pyrene	10 U	µg/L	SW8270B
		Dibenz(a,h)anthracene	10 U	µg/L	SW8270B
		Benzo(g,h,i)perylene	10 U	µg/L	SW8270B

[a] U = Analyte Not Detected Above Method Detection Limit

[b] J = Estimated Concentration of Analyte

1996 VALIDATION AND ANALYTICAL DATA

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

Methods 602/8020 and 5030/8015 Modified Data Report
Method Blank Report

Method Blank Number	: MB2100796	Client Project Number	: 725524.06000
Date Prepared	: 10/7/96	Lab Work Order	: 96-3528
Dilution Factor	: 1.0	Matrix	: WATER
		Lab File Number	: TVB21007003

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/7/96	U	0.4	ug/L
Toluene	108-88-3	10/7/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/7/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/7/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/7/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/7/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/7/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/7/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/7/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		99%		70%-128%	(Limits)

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

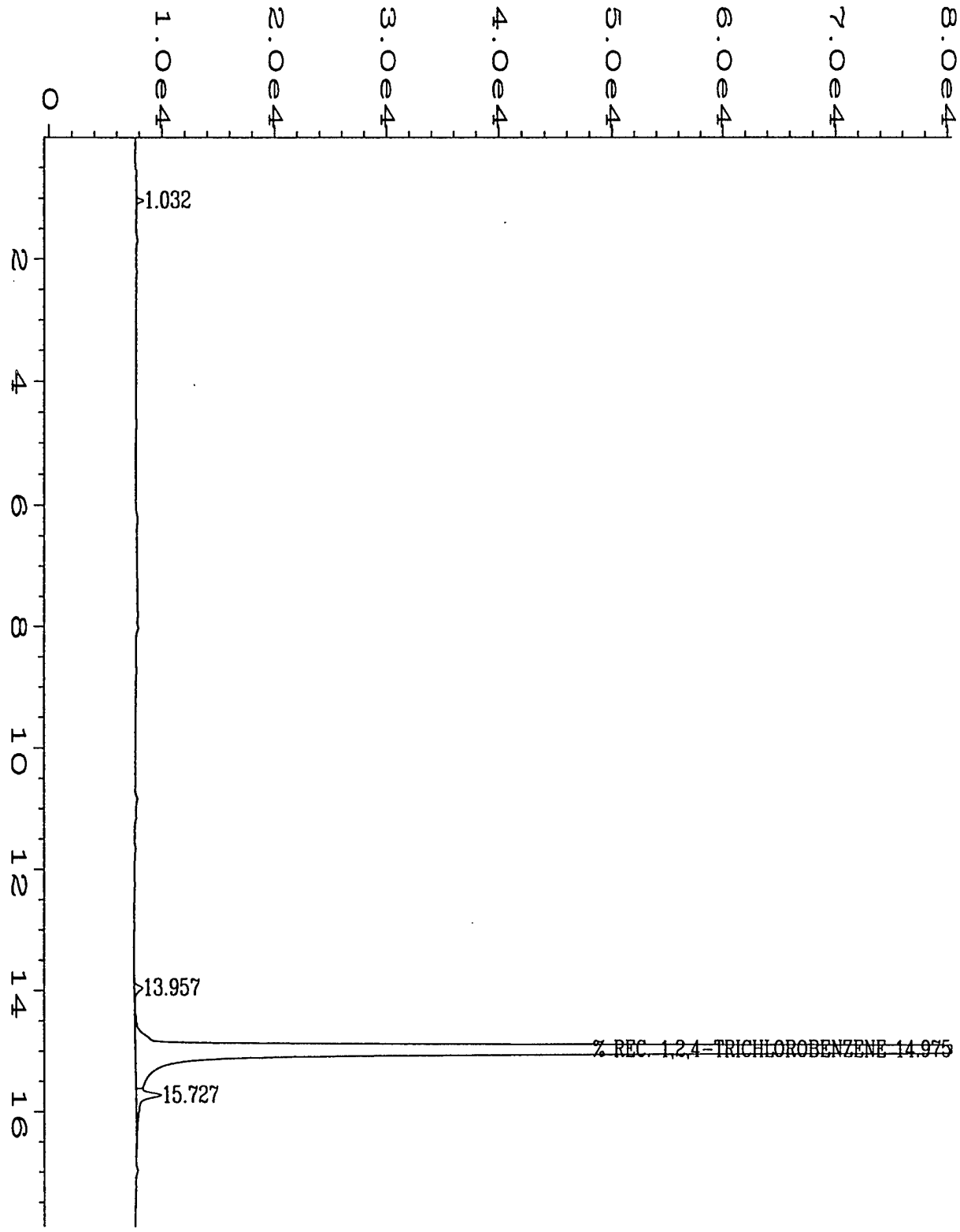
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\003R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 3
Sample Name	: MB2100796;1	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 07 Oct 96 11:52 AM	Instrument Method	: TVW20919.[illegible]
Report Created on	: 07 Oct 96 12:11 PM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: WATER BLANK		

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

Methods 602/8020 and 5030/8015 Modified Data Report
Method Blank Report

Method Blank Number	: MB2100896	Client Project Number	: 725524.06000
Date Prepared	: 10/8/96	Lab Work Order	: 96-3528
Dilution Factor	: 1.0	Matrix	: WATER
		Lab File Number	: TVB21007028

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
PID Surrogate Recovery:		NA		70%-130%	(Limits)
FID Surrogate Recovery:		98%		70%-128%	(Limits)

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

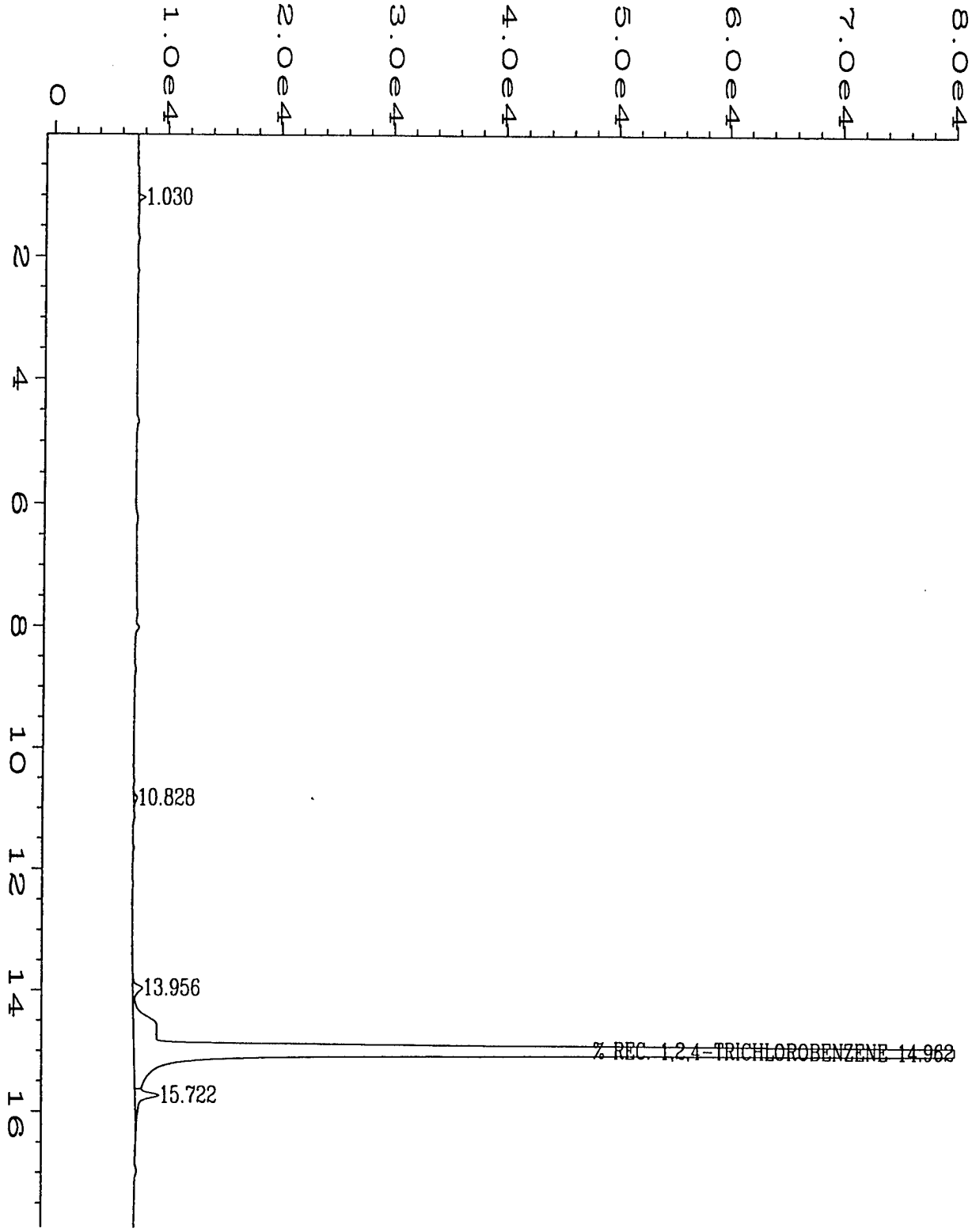
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\028R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 28
Sample Name	: MB2100896;1	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 11:03 AM	Instrument Method	: TVW20919.M
Report Created on	: 08 Oct 96 11:22 AM	Analysis Method	: BXW20919.M
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: WATER BLANK		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W401	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-01	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007022
Date Prepared	: 10/7/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/7/96	U	0.4	ug/L
Toluene	108-88-3	10/7/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/7/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/7/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/7/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/7/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/7/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/7/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/7/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		98%		70%-128%	(Limits)

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

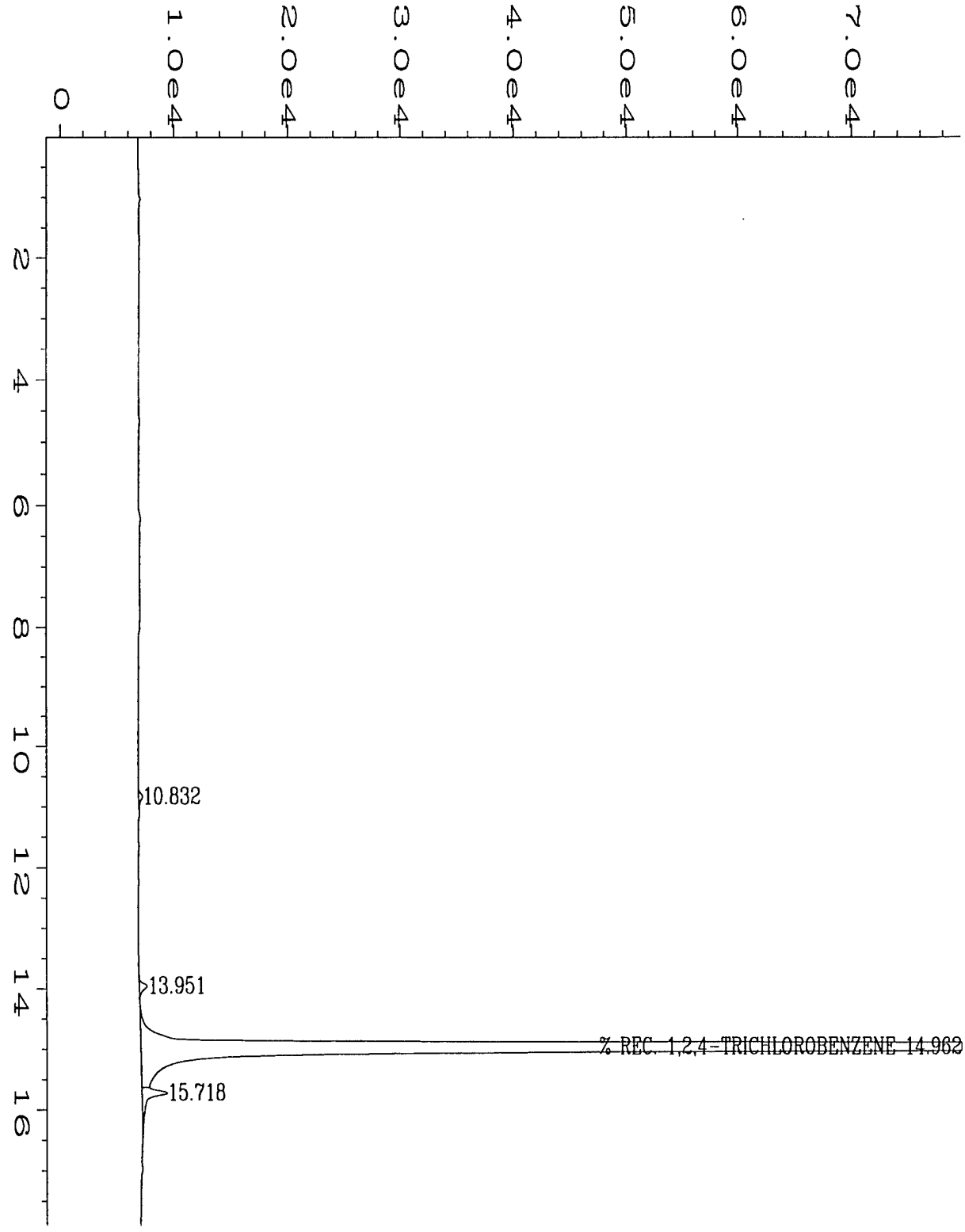
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hallman
Analyst

Approved



Data File Name : C:\HPCHEM\2\DATA\TVB21007\022R0101.D
Operator : K. S. HOLLMAN
Instrument : TVHBTEX2
Sample Name : 96-3528-01A;1
Run Time Bar Code:
Acquired on : 07 Oct 96 11:04 PM
Report Created on: 07 Oct 96 11:22 PM
Last Recalib on : 20 SEP 96 10:41 AM
Multiplier : 1
Sample Info : W401; WATER SAMPLE

Page Number : 1
Vial Number : 22
Injection Number : 1
Sequence Line : 1
Instrument Method: TVW20919
Analysis Method : BXW20919.MT
Sample Amount : 0
ISTD Amount :

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W402	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-02	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007018
Date Prepared	: 10/7/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/7/96	U	0.4	ug/L
Toluene	108-88-3	10/7/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/7/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/7/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/7/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/7/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/7/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/7/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/7/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		99%		70%-128%	(Limits)

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

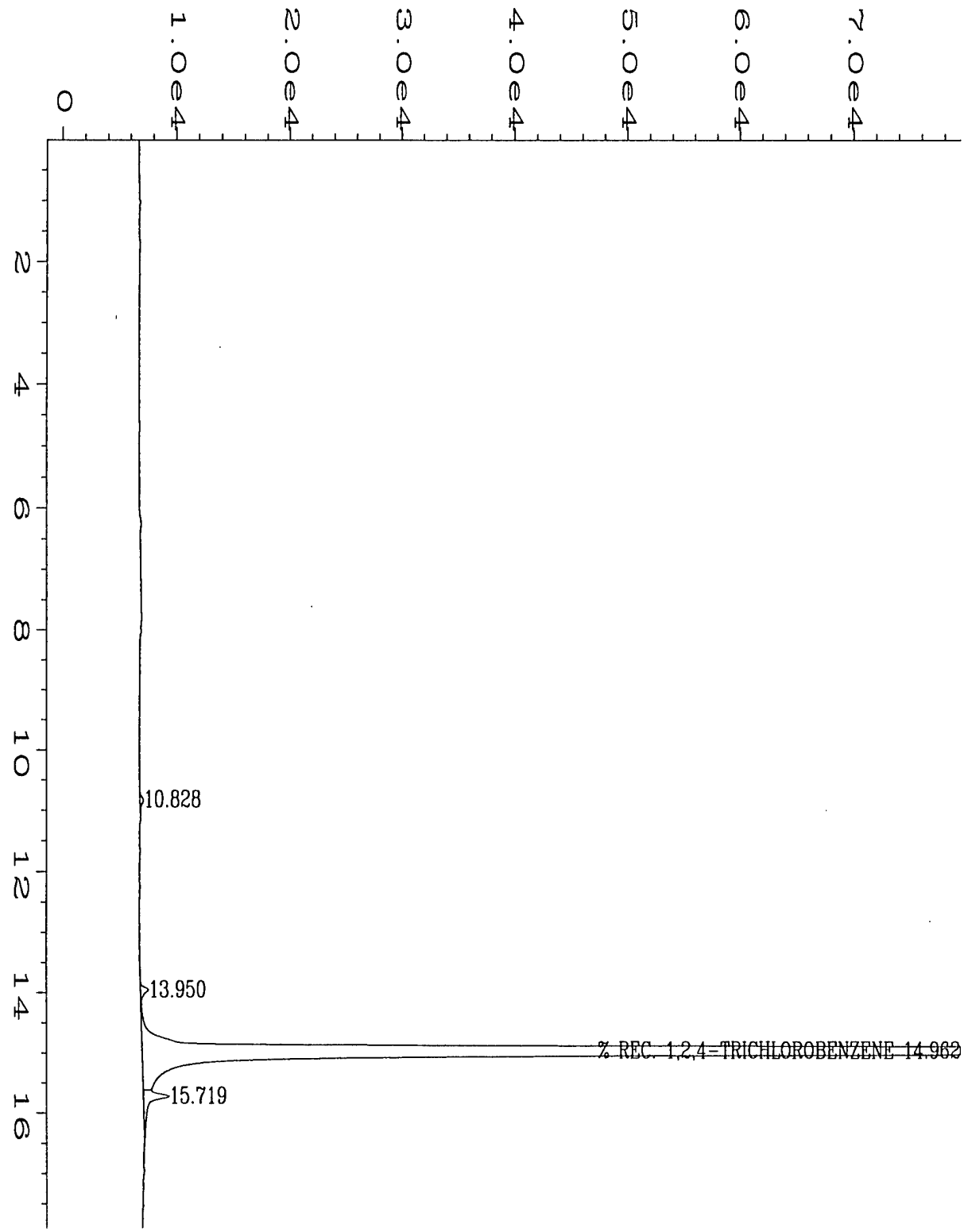
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hallman
Analyst

Approved



Data File Name : C:\HPCHEM\2\DATA\TVB21007\018R0101.D

Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 18
Sample Name	: 96-3528-02A;1	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 07 Oct 96 08:56 PM	Instrument Method	: TVW20919
Report Created on	: 07 Oct 96 09:14 PM	Analysis Method	: BXW20919.MT
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W402; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W404	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-03	Lab Work Order	: 96-3528
Date Sampled	: 10/3/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007031
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	30	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	44	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	13	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	35	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	11	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	8.5	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		97%		70%-128%	(Limits)

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

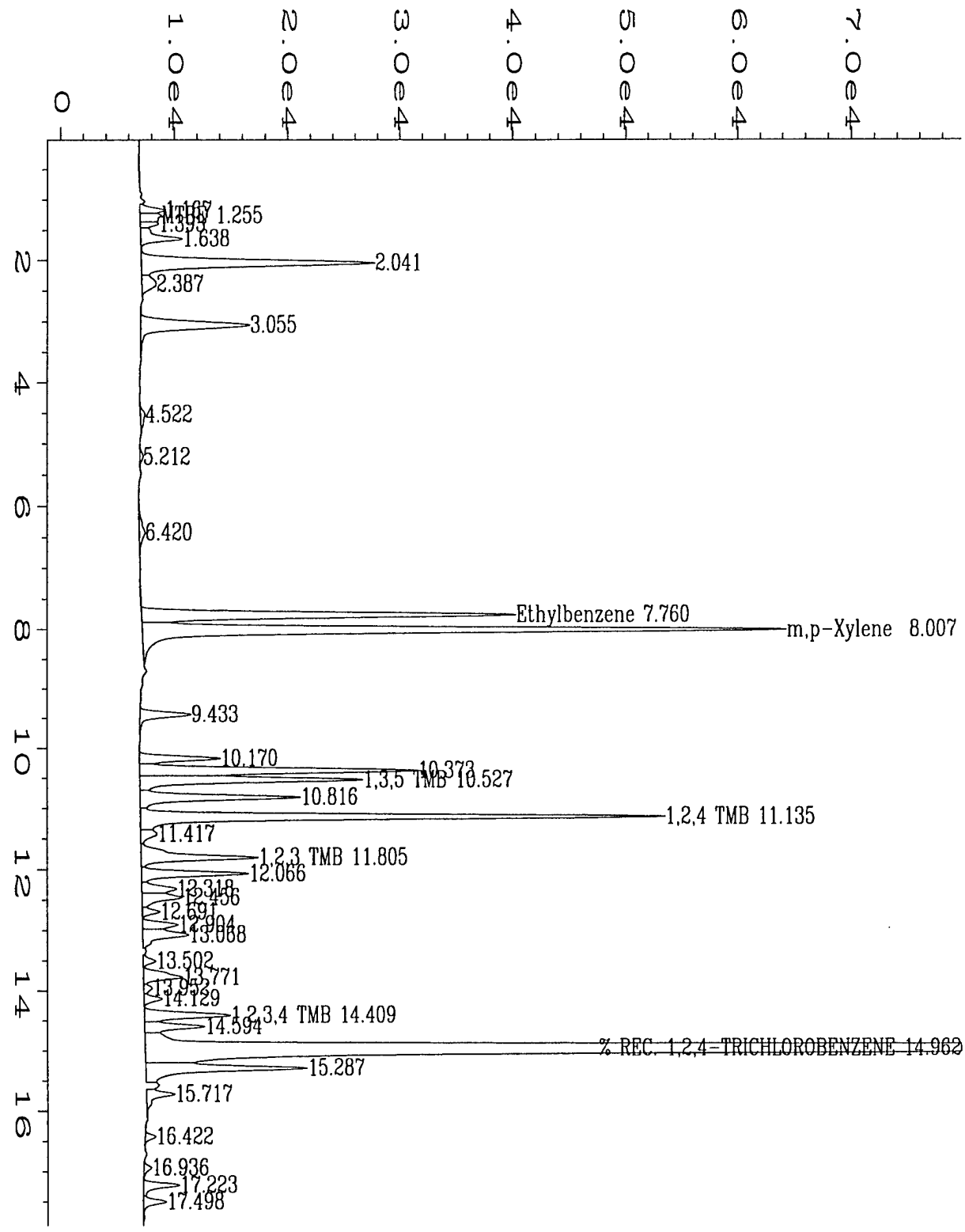
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hallman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\031R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 31
Sample Name	: 96-3528-03B;1	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 12:39 PM	Instrument Method	: TVW20919.MT
Report Created on	: 08 Oct 96 12:57 PM	Analysis Method	: BXW20919
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W404; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W407	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-04	Lab Work Order	: 96-3528
Date Sampled	: 10/3/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007023
Date Prepared	: 10/7/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/7/96	U	0.4	ug/L
Toluene	108-88-3	10/7/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/7/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/7/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/7/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/7/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/7/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/7/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/7/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		98%		70%-128%	(Limits)

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

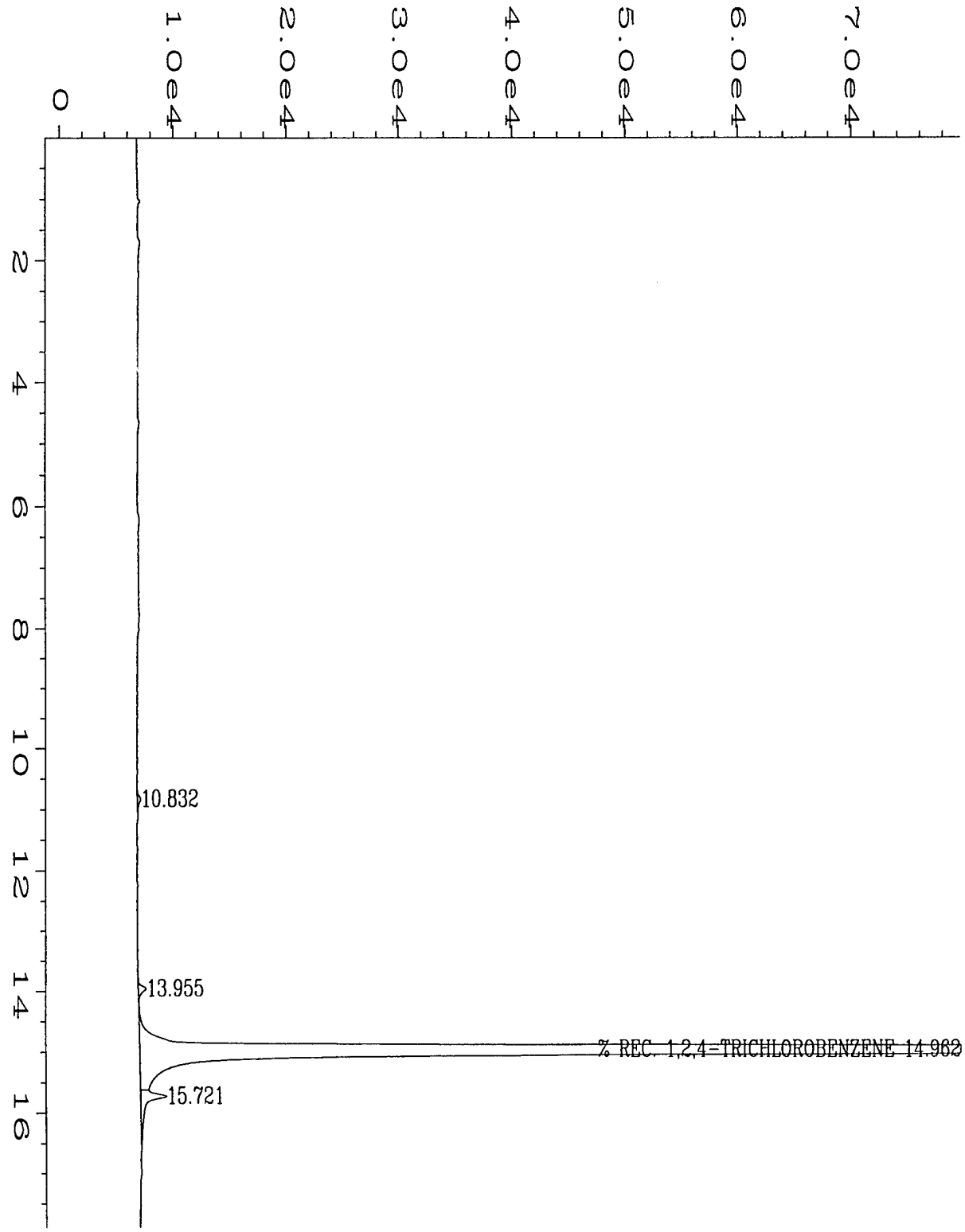
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name : C:\HPCHEM\2\DATA\TVB21007\023R0101.D
Operator : K. S. HOLLMAN
Instrument : TVHBTEX2
Sample Name : 96-3528-04A;1
Run Time Bar Code:
Acquired on : 07 Oct 96 11:36 PM
Report Created on: 07 Oct 96 11:54 PM
Last Recalib on : 20 SEP 96 10:41 AM
Multiplier : 1
Sample Info : W407; WATER SAMPLE

Page Number : 1
Vial Number : 23
Injection Number : 1
Sequence Line : 1
Instrument Method: TVW20919
Analysis Method : BXW20919.MT
Sample Amount : 0
ISTD Amount :

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W409S	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-05	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007024,43
Date Prepared	: 10/7,8/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		MB2100896
PID Dilution Factor	: 1.0; 10		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	3.8	0.4	ug/L
Toluene	108-88-3	10/8/96	50	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	230	4.0	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	550	4.0	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	61	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	170	4.0	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	73	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	31	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		97%; 97%		70%-128%	(Limits)

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

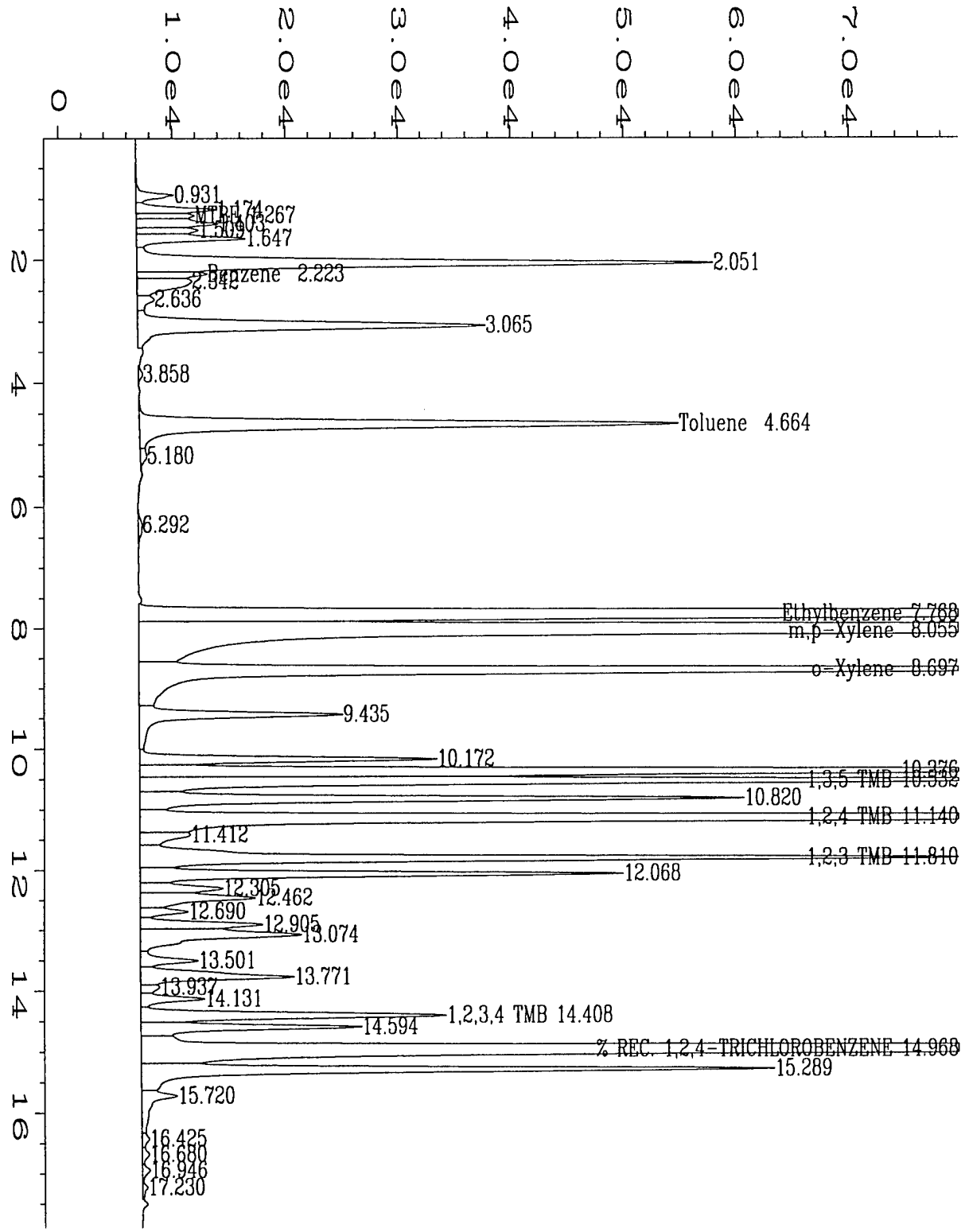
Comments:

QUALIFIERS and DEFINITIONS:

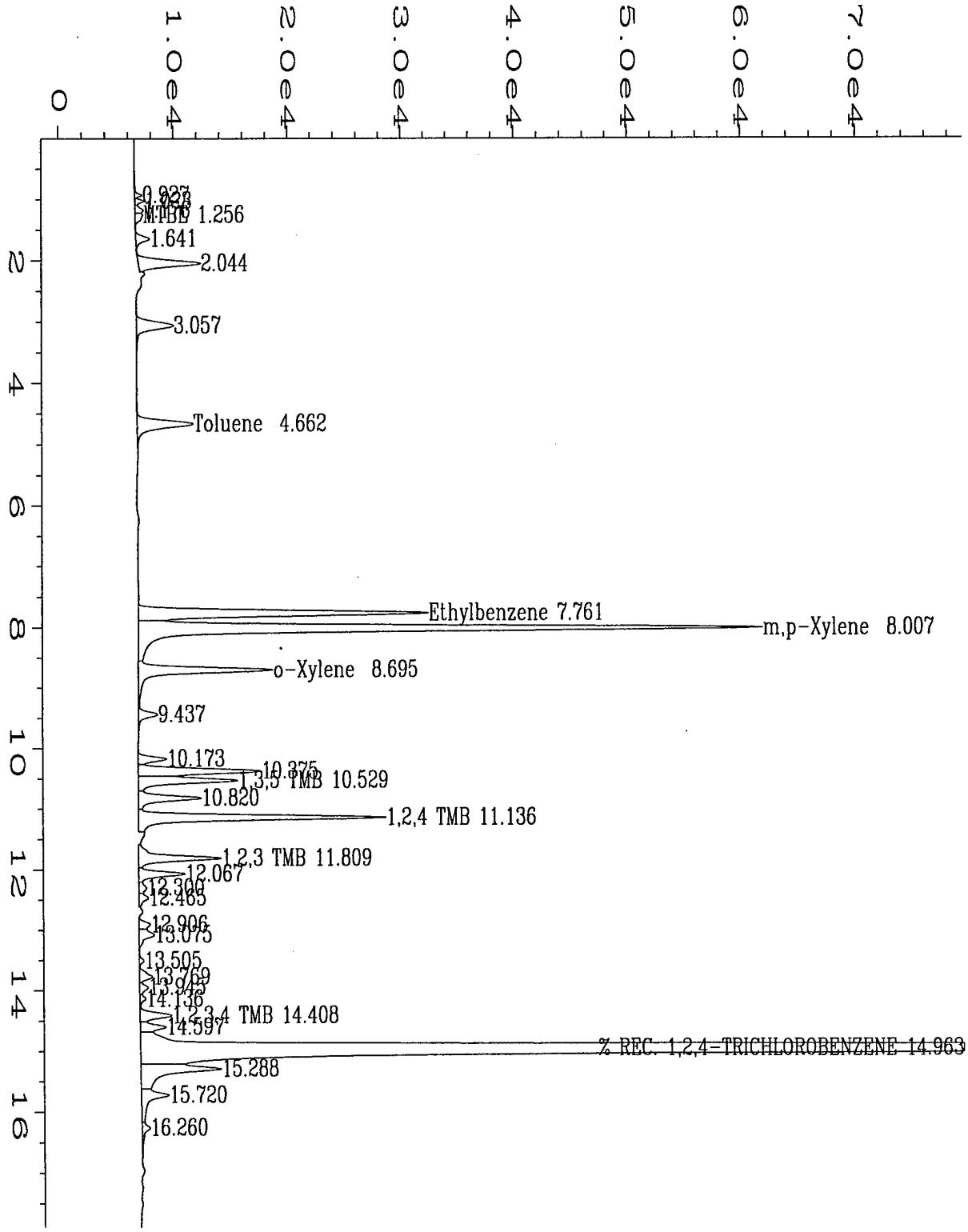
E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\024R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 24
Sample Name	: 96-3528-05A;1	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 00:08 AM	Instrument Method	: TVW20919
Report Created on	: 08 Oct 96 00:26 AM	Analysis Method	: BXW20919.MT
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W409S; WATER SAMPLE		



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\043R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 43
Sample Name	: 96-3528-05B;10	Injection Number	: 1
Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 07:31 PM	Instrument Method	: TVW20919.MTH
Report Created on	: 09 Oct 96 09:50 AM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 10	ISTD Amount	:
Sample Info	: W409S; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W409D	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-06	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007025
Date Prepared	: 10/7/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Lim
PID Surrogate Recovery:		99%		70%-128%	(Limits)

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

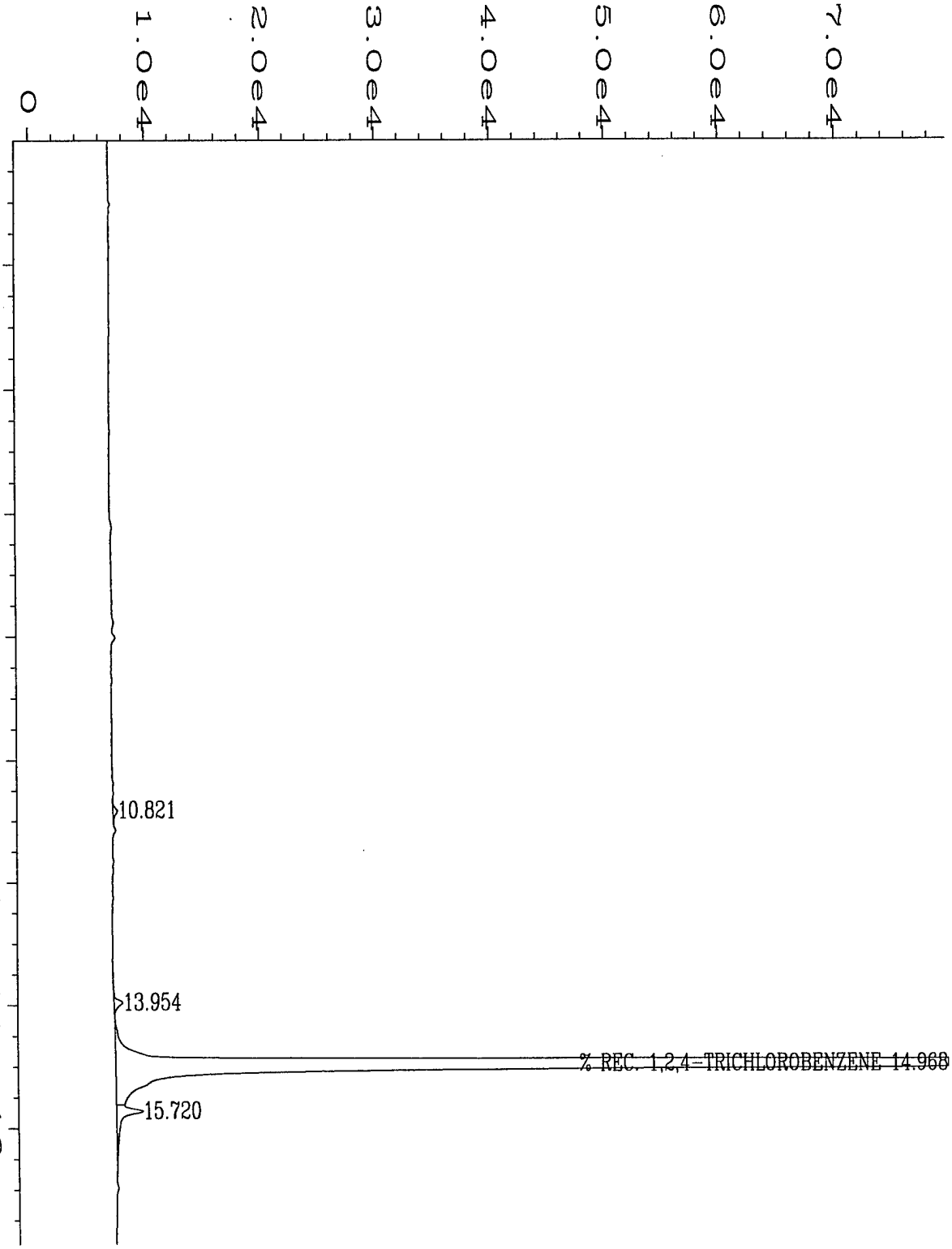
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K Hollman
Analyst

Approved



Data File Name : C:\HPCHEM\2\DATA\TVB21007\025R0101.D
Operator : K. S. HOLLMAN
Instrument : TVHBTEX2
Sample Name : 96-3528-06A;1
Run Time Bar Code:
Acquired on : 08 Oct 96 00:40 AM
Report Created on: 08 Oct 96 00:58 AM
Last Recalib on : 20 SEP 96 10:41 AM
Multiplier : 1
Sample Info : W409D; WATER SAMPLE

Page Number : 1
Vial Number : 25
Injection Number : 1
Sequence Line : 1
Instrument Method: TVW20919.MTH
Analysis Method : BXW20919.MTH
Sample Amount : 0
ISTD Amount :

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W410	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-07	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007026
Date Prepared	: 10/7/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:	NA			70%-130%	(Lin
PID Surrogate Recovery:		98%		70%-128%	(Limits)

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

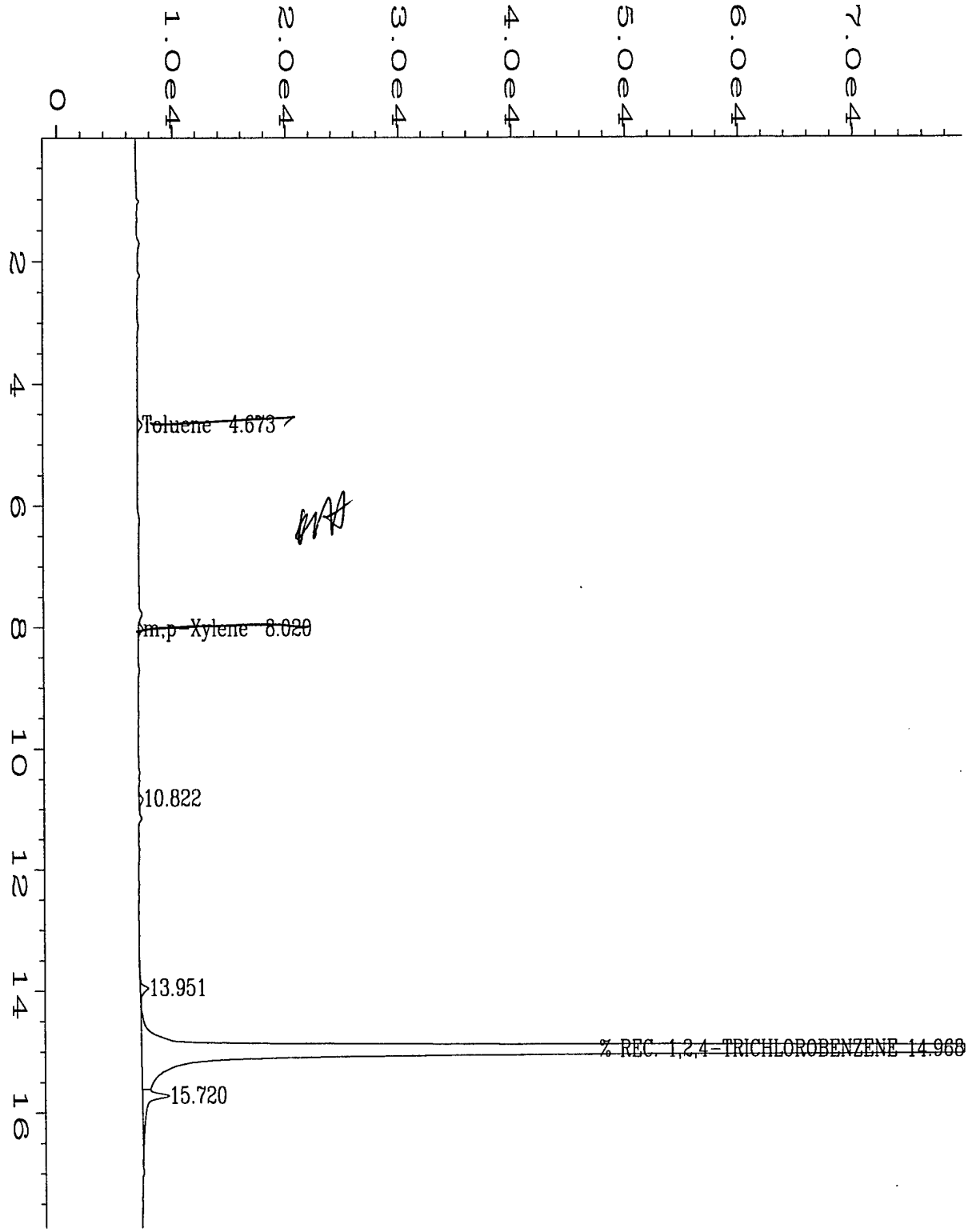
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\026R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 26
Sample Name	: 96-3528-07A;1	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 01:12 AM	Instrument Method	: TVW20919.MTH
Report Created on	: 08 Oct 96 09:51 AM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W410; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W411	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-08	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007032
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Lim
PID Surrogate Recovery:		98%		70%-128%	(Limits)

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

Comments:

QUALIFIERS and DEFINITIONS:

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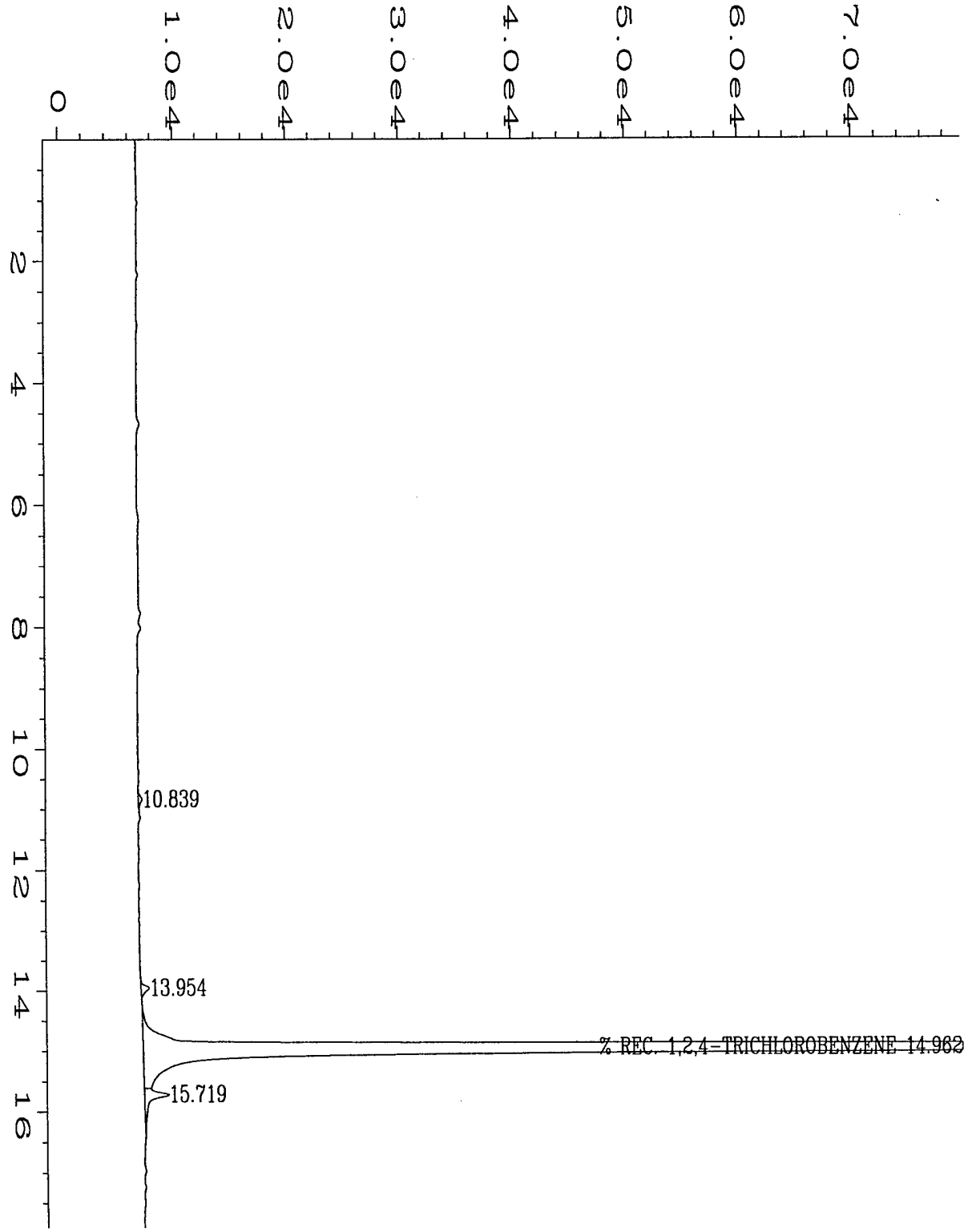
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hoffman
Analyst

Approved



Data File Name : C:\HPCHEM\2\DATA\TVB21007\032R0101.D
Operator : K. S. HOLLMAN
Instrument : TVHBTEX2
Sample Name : 96-3528-08B;1
Time Bar Code:
Acquired on : 08 Oct 96 01:12 PM
Report Created on: 08 Oct 96 01:30 PM
Last Recalib on : 20 SEP 96 10:41 AM
Multiplier : 1
Sample Info : W411; WATER SAMPLE

Page Number : 1
Vial Number : 32
Injection Number : 1
Sequence Line : 1
Instrument Method: TVW20919.MTH
Analysis Method : BXW20919.MTH
Sample Amount : 0
ISTD Amount :

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W412	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-09	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007033
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		99%		70%-128%	(Limits)

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

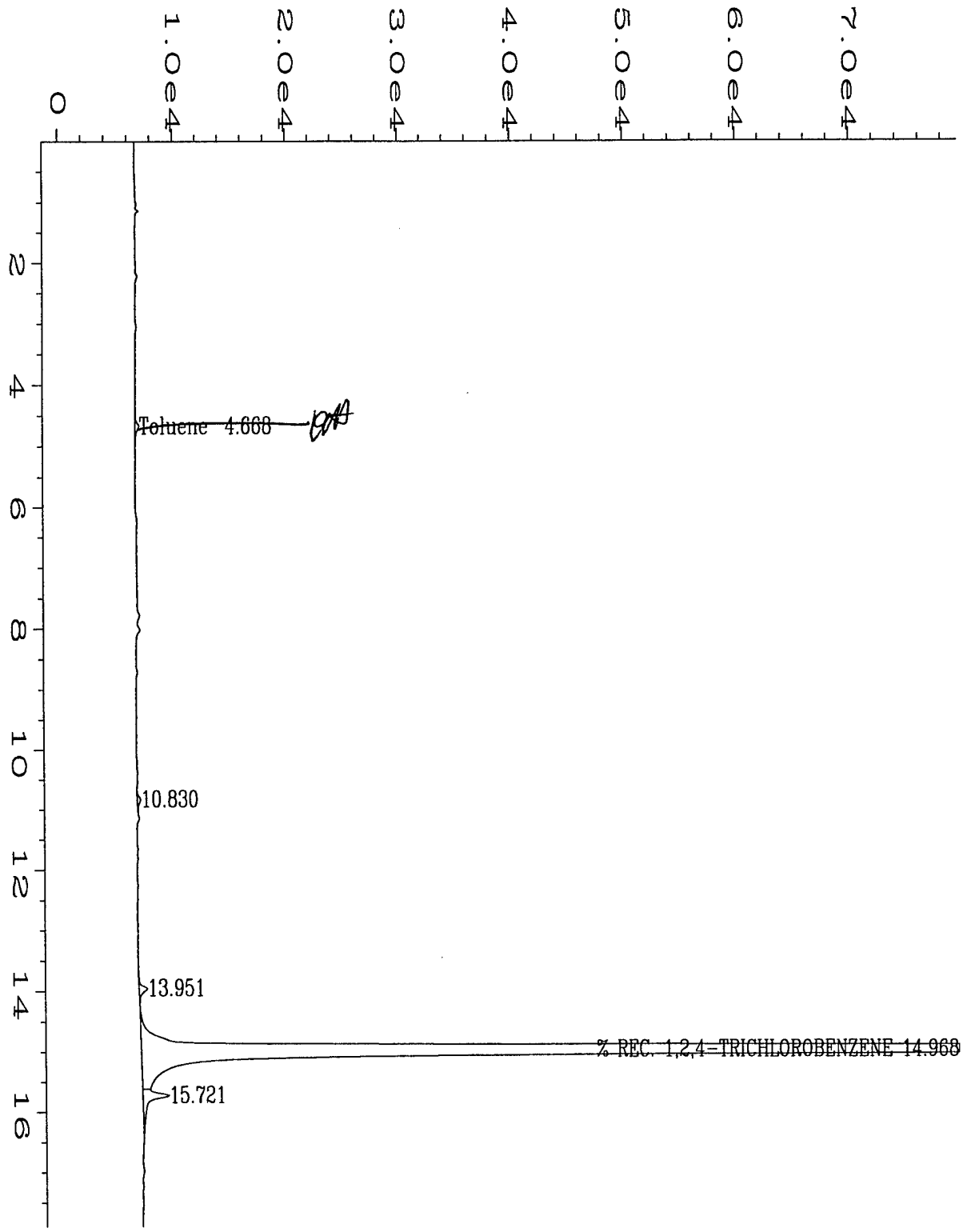
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hallman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\033R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 33
Sample Name	: 96-3528-09B;1	Injection Number	: 1
Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 01:44 PM	Instrument Method	: TVW20919.MTH
Report Created on	: 08 Oct 96 02:02 PM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W412; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W414	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-10	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007035
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Lim
PID Surrogate Recovery:		99%		70%-128%	(Limits)

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

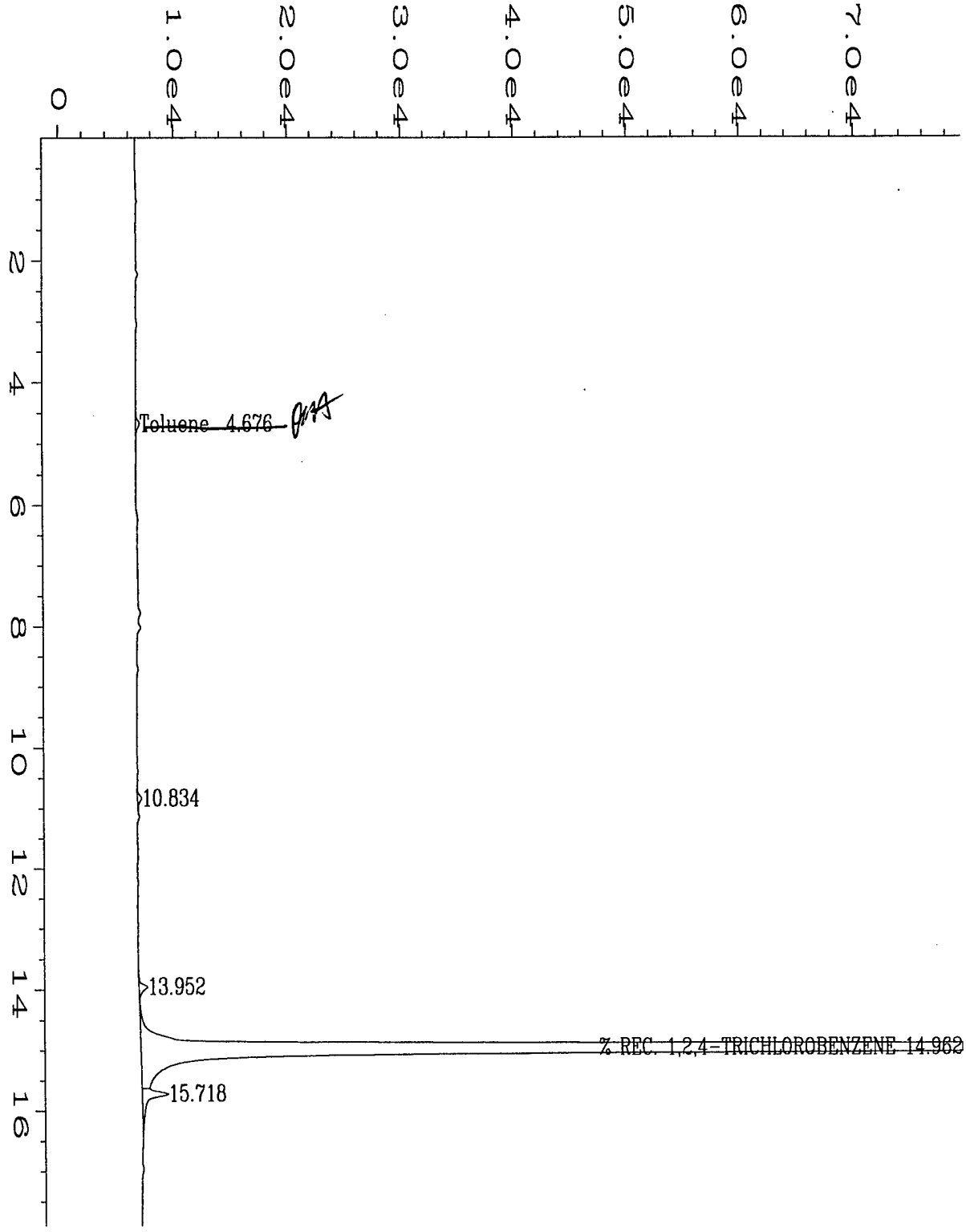
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hallman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\035R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 35
Sample Name	: 96-3528-10B;1	Injection Number	: 1
Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 02:48 PM	Instrument Method	: TVW20919.MTH
Report Created on	: 08 Oct 96 03:06 PM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W414; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: W420	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-11	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007036
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Limits)
PID Surrogate Recovery:		101%		70%-128%	(Limits)

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

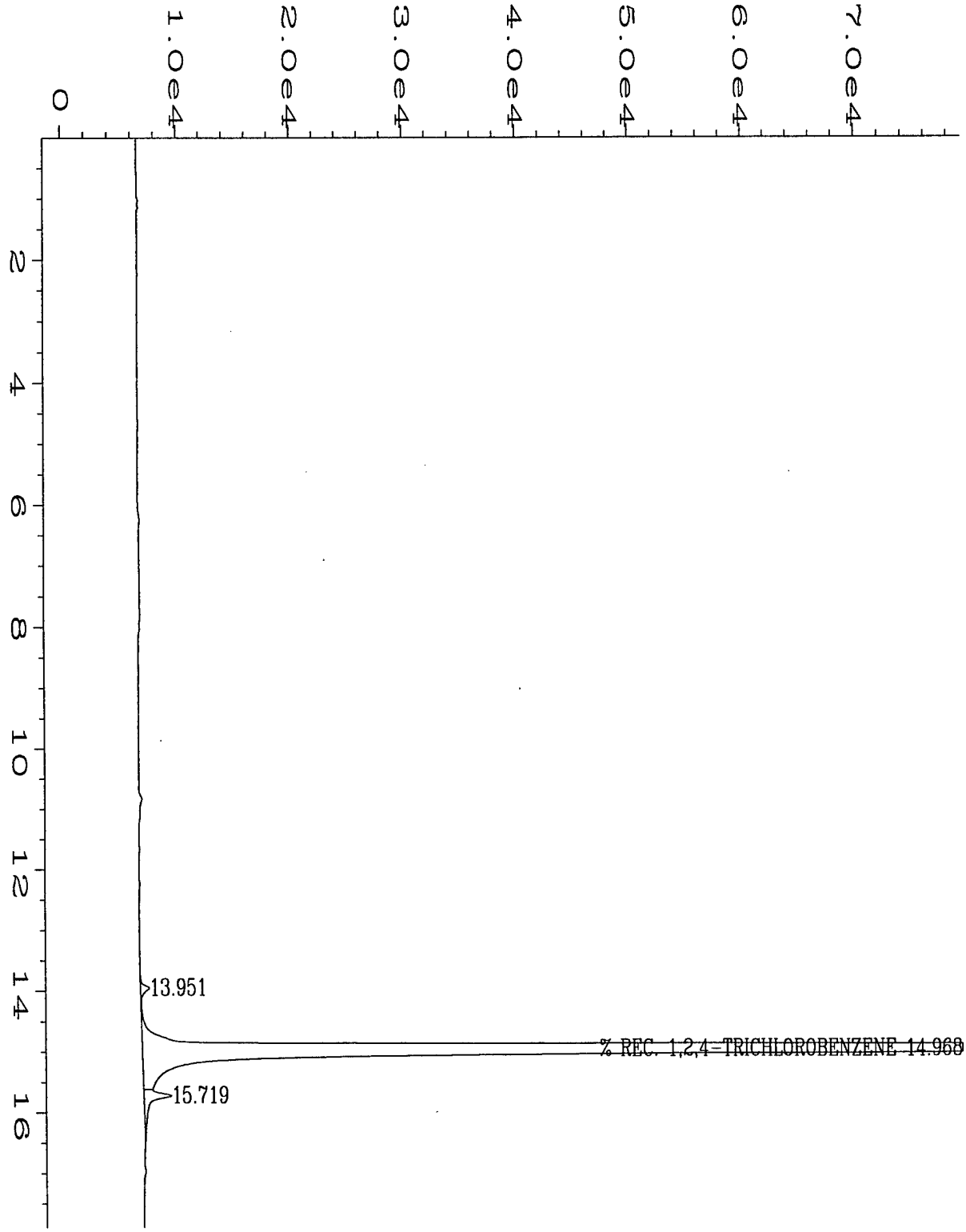
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\036R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 36
Sample Name	: 96-3528-11B;1	Injection Number	: 1
Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 03:20 PM	Instrument Method	: TVW20919.MTH
Report Created on	: 08 Oct 96 03:38 PM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: W420; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: USGS4	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-12	Lab Work Order	: 96-3528
Date Sampled	: 10/3/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007042
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 20		
PID Dilution Factor	: 20		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	8.0	ug/L
Toluene	108-88-3	10/8/96	1100	8.0	ug/L
Chlorobenzene	108-90-7	10/8/96	U	8.0	ug/L
Ethyl Benzene	100-41-4	10/8/96	570	8.0	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	2600	8.0	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	210	8.0	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	630	8.0	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	190	8.0	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	280	10	ug/L
FID Surrogate Recovery:	NA			70%-130%	(Lim
PID Surrogate Recovery:		97%		70%-128%	(Limits)

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

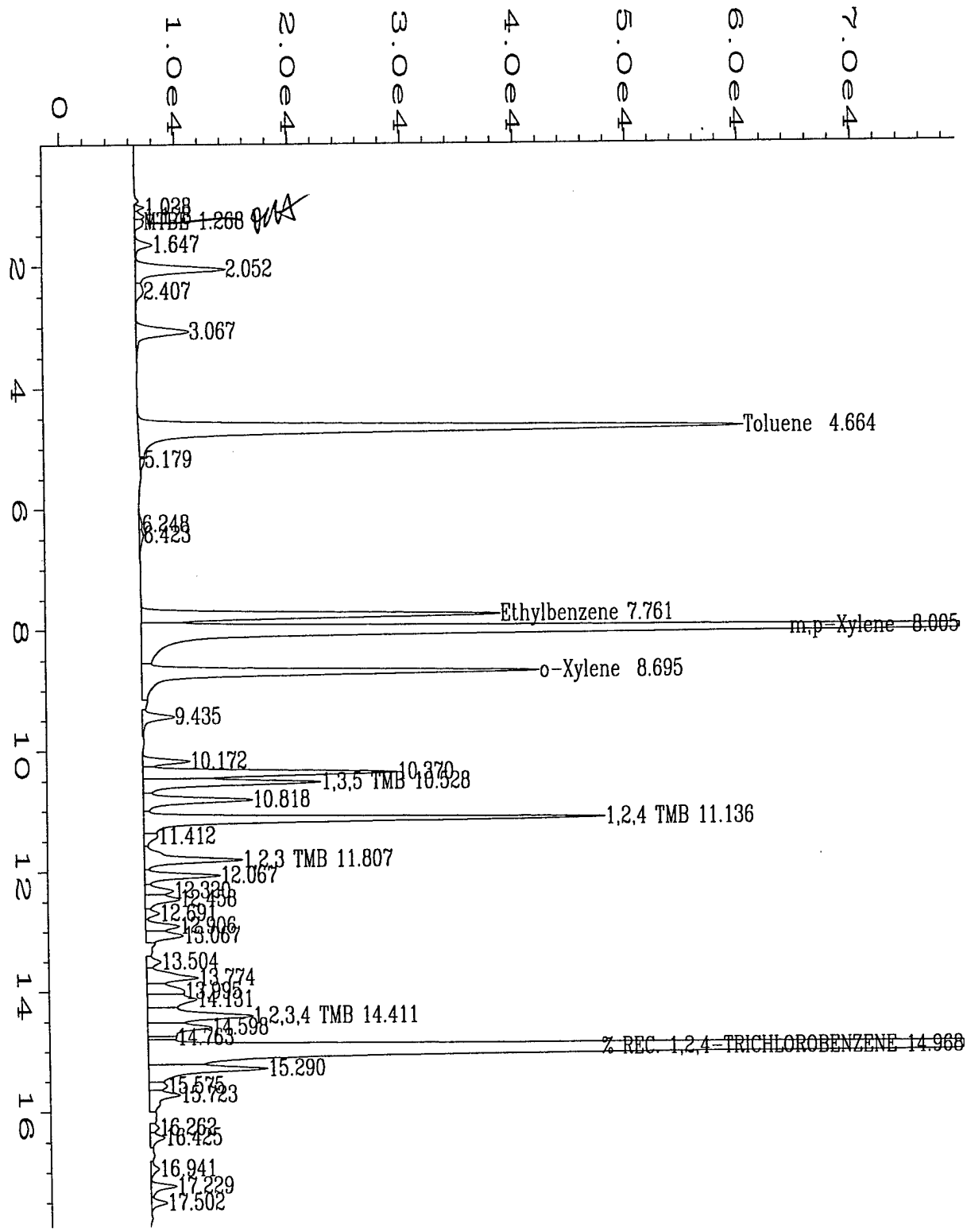
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\042R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 42
Sample Name	: 96-3528-12C;20	Injection Number	: 1
[illegible] Time Bar Code:		Sequence Line	: 1
[illegible]quired on	: 08 Oct 96 06:59 PM	Instrument Method	: TVW20919.MTH
Report Created on	: 09 Oct 96 10:22 AM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 20	ISTD Amount	:
Sample Info	: USGS4; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: R1	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-13	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007041
Date Prepared	: 10/8/96	Method Blank	: MB2100896
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/8/96	U	0.4	ug/L
Toluene	108-88-3	10/8/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/8/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/8/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/8/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/8/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/8/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/8/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/8/96	U	0.5	ug/L
FID Surrogate Recovery:	NA			70%-130%	(Lim
PID Surrogate Recovery:		97%		70%-128%	(Limits)

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

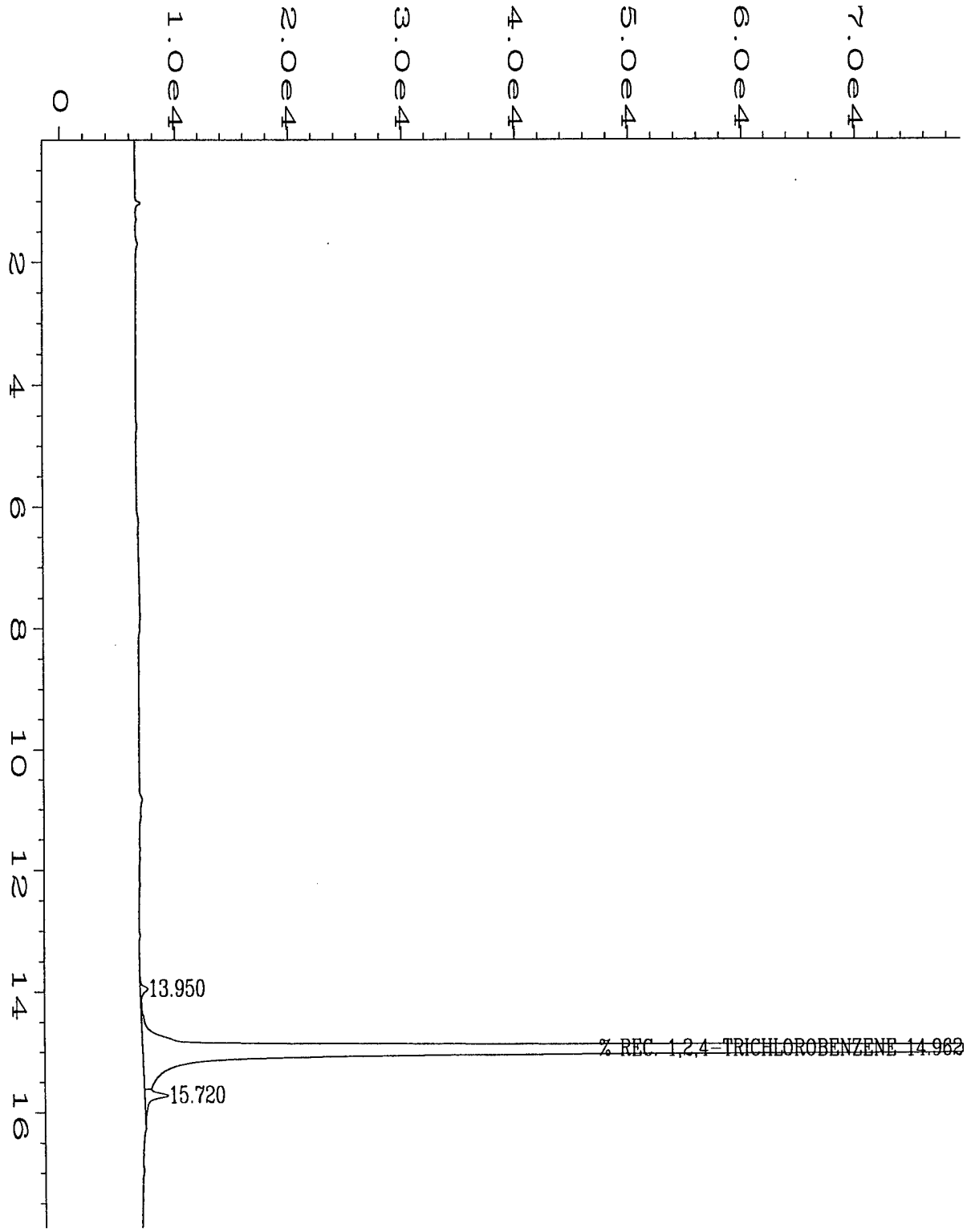
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hollman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\041R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 41
Sample Name	: 96-3528-13B;1	Injection Number	: 1
Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 06:01 PM	Instrument Method:	TVW20919.MTH
Report Created on:	08 Oct 96 06:19 PM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: R1; WATER SAMPLE		

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

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: TRIP BLANK	Client Project Number	: 725524.06000
Lab Sample Number	: 96-3528-14	Lab Work Order	: 96-3528
Date Sampled	: NA	Matrix	: WATER
Date Received	: 10/4/96	Lab File Number(s)	: TVB21007017
Date Prepared	: 10/7/96	Method Blank	: MB2100796
FID Dilution Factor	: 1.0		
PID Dilution Factor	: 1.0		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	NA	NA	NA	NA
Benzene	71-43-2	10/7/96	U	0.4	ug/L
Toluene	108-88-3	10/7/96	U	0.4	ug/L
Chlorobenzene	108-90-7	10/7/96	U	0.4	ug/L
Ethyl Benzene	100-41-4	10/7/96	U	0.4	ug/L
Total Xylenes (m,p,o)	1330-20-7	10/7/96	U	0.4	ug/L
1,3,5-Trimethylbenzene	108-67-8	10/7/96	U	0.4	ug/L
1,2,4-Trimethylbenzene	95-63-6	10/7/96	U	0.4	ug/L
1,2,3-Trimethylbenzene	526-73-8	10/7/96	U	0.4	ug/L
1,2,3,4-Tetramethylbenzene	488-23-3	10/7/96	U	0.5	ug/L
FID Surrogate Recovery:		NA		70%-130%	(Lim
PID Surrogate Recovery:		99%		70%-128%	(Limits)

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

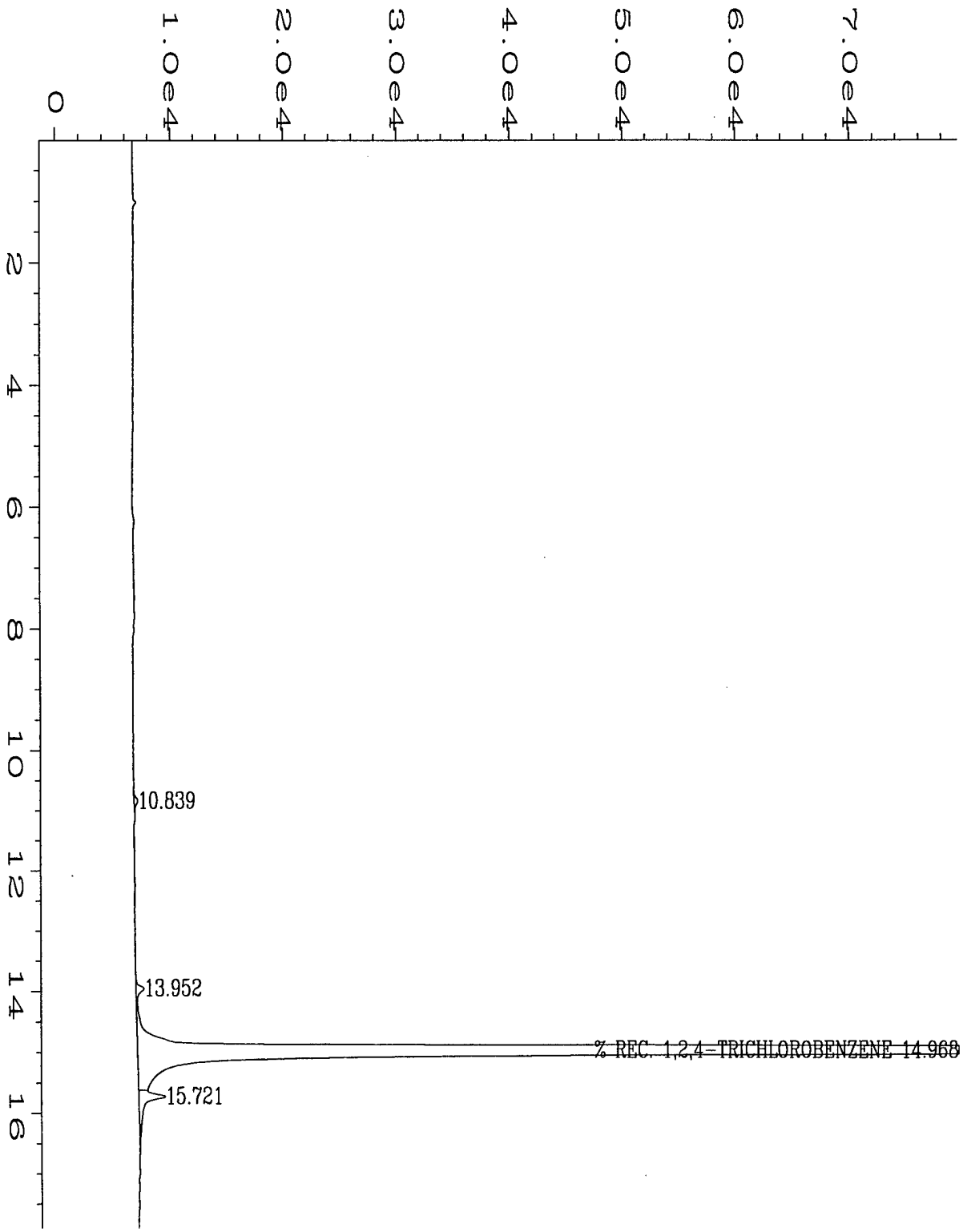
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

K. Hallman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\017R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 17
Sample Name	: 96-3528-14A;1	Injection Number	: 1
n Time Bar Code:		Sequence Line	: 1
quired on	: 07 Oct 96 08:24 PM	Instrument Method	: TVW20919.MTH
Report Created on	: 07 Oct 96 08:42 PM	Analysis Method	: BXW20919.MTH
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: TRIP BLANK; WATER SAMPLE		

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

EPA 602/8020 Matrix Spike/Matrix Spike Duplicate Data Report

Client Sample No.	: W402	Client Project No.	: 725524.06000
Lab Sample No.	: 96-3528-02	Lab Work Order	: 96-3528
Date Sampled	: 10/2/96	EPA Method No.	: 602/8020
Date Received	: 10/4/96	Matrix	: WATER
Date Prepared	: 10/8/96	Lab File Number(s)	: TVB21007039,40
Date Analyzed	: 10/8/96	Method Blank	: MB2100896
Instrument Name	: TVHBTEX2	Dilution Factor	: 1.0

Compound	Spike Added (ug/L)	Sample Conc. (ug/L)	Concentration (ug/L) MS	Concentration (ug/L) MSD	Comments
Benzene	20.0	0.0	21.5	22.1	
Toluene	20.0	0.0	20.9	21.5	
Chlorobenzene	20.0	0.0	20.9	21.4	
Ethylbenzene	20.0	0.0	21.1	21.6	
m,p-Xylene	20.0	0.0	21.3	21.9	
o-Xylene	20.0	0.0	21.0	21.6	
1,3,5-TMB	20.0	0.0	19.6	19.2	
1,2,4-TMB	20.0	0.0	21.1	21.8	
1,2,3-TMB	20.0	0.0	21.1	21.7	
1,2,3,4-TeMB	20.0	0.0	20.8	21.2	
Surrogate	100.0	99%	100%	100%	% RECOVERY

Compound		MS % RECOVERY	MSD % RECOVERY	RPD	QC# Limits RPD	QC# Limits %REC
Benzene		107.5	110.5	2.8	18	61 - 126
Toluene		104.5	107.5	2.8	19	61 - 125
Chlorobenzene		104.5	107.0	2.4	16	68 - 120
Ethylbenzene		105.5	108.0	2.3	19	63 - 123
m,p-Xylene		106.5	109.5	2.8	19	59 - 128
o-Xylene		105.0	108.0	2.8	19	61 - 126
1,3,5-TMB		98.0	96.0	2.1	19	70 - 113
1,2,4-TMB		105.5	109.0	3.3	24	70 - 115
1,2,3-TMB		105.5	108.5	2.8	17	72 - 114
1,2,3,4-TeMB		104.0	106.0	1.9	29	66 - 124
Surrogate		100.0	100.0	NA	NA	70 - 128

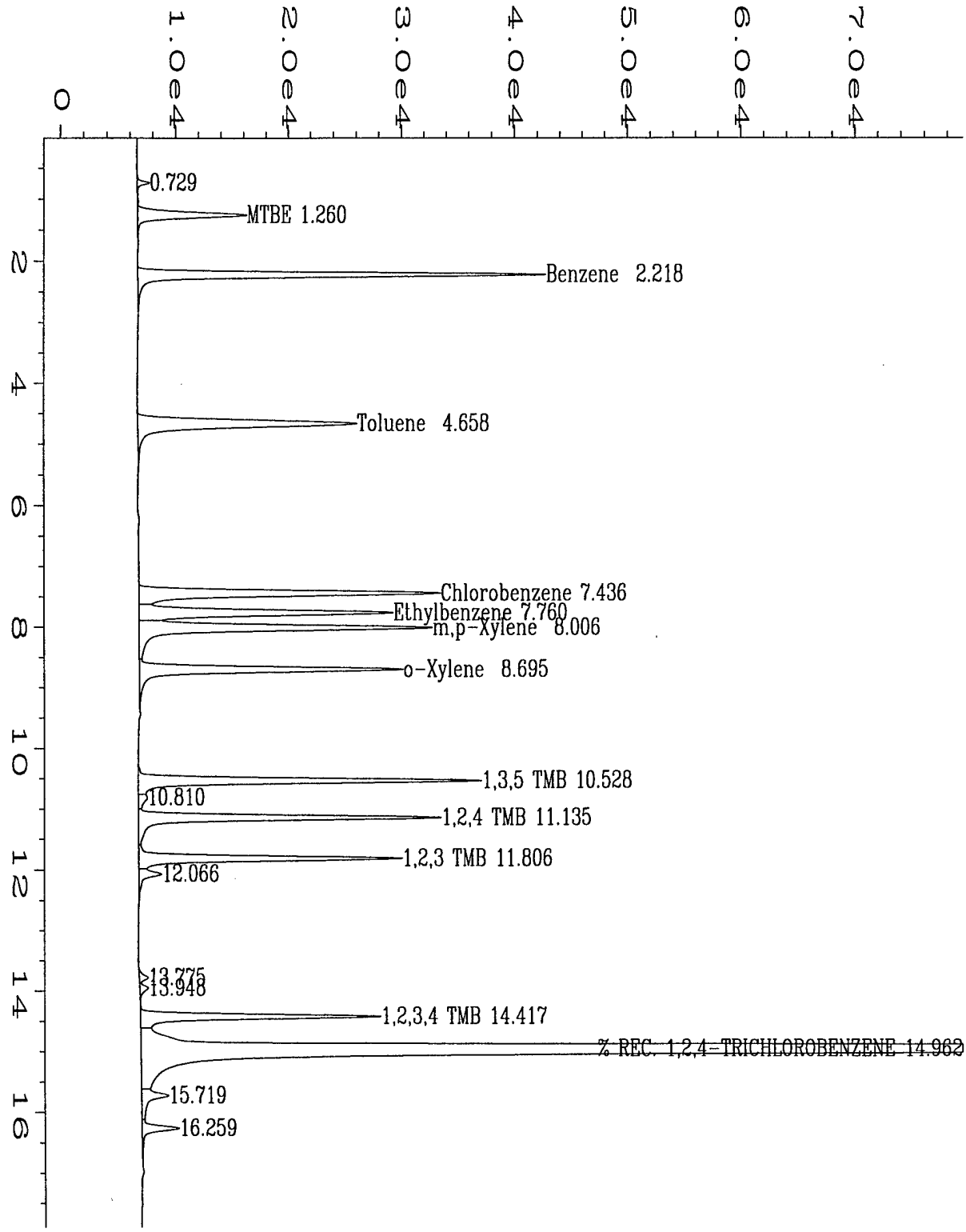
= Limits established 10/2/96, MAB
* = Values outside of QC limits.

RPD: 0 out of (10) outside limits.
Spike Recovery: 0 out of (20) outside limits.

Comments:

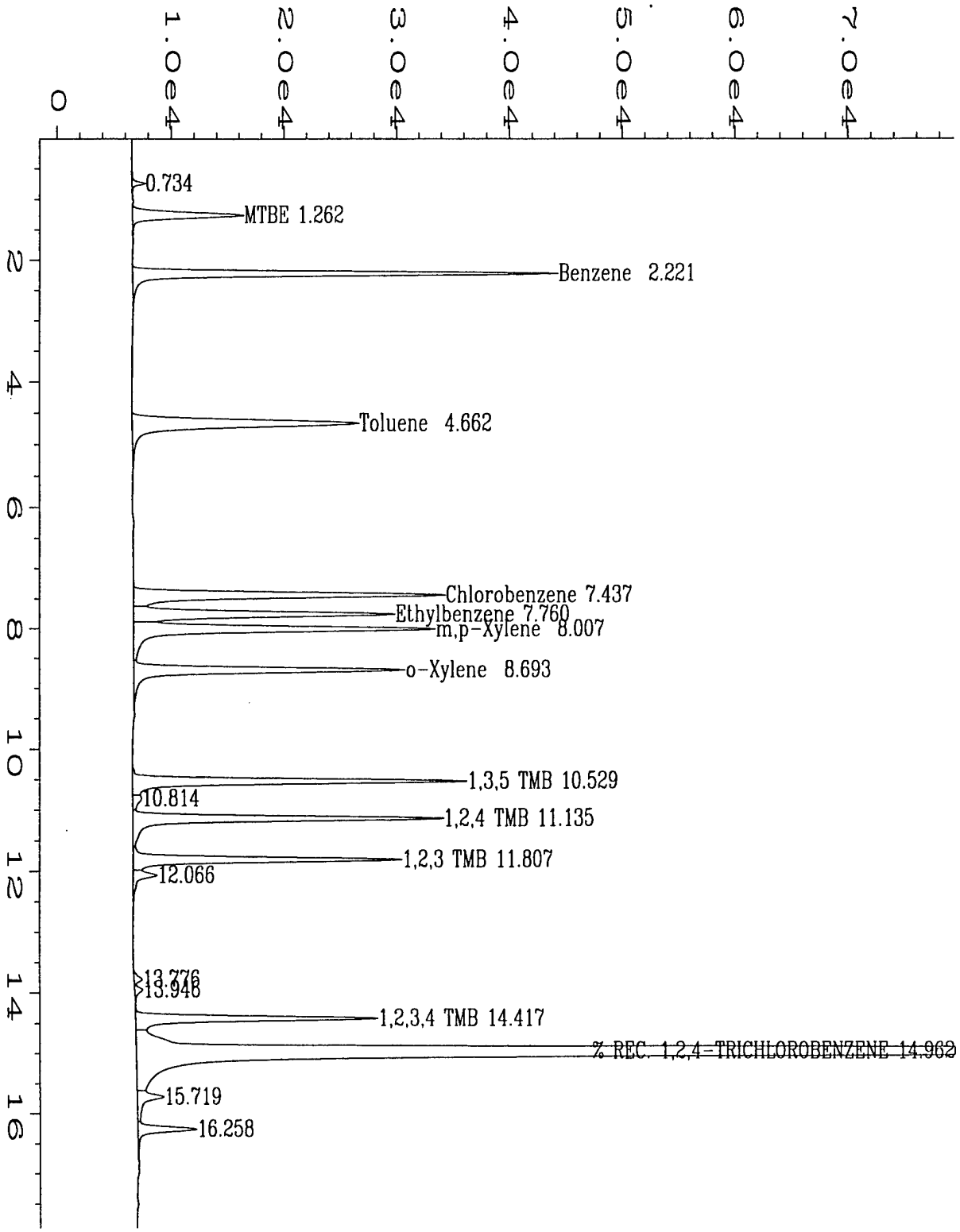
K. Holman
Analyst

Approved



Data File Name : C:\HPCHEM\2\DATA\TVB21007\039R0101.D
Operator : K. S. HOLLMAN
Instrument : TVHBTEX2
Sample Name : 96-3528-02B-MS;1
Run Time Bar Code:
Acquired on : 08 Oct 96 04:57 PM
Report Created on: 08 Oct 96 05:15 PM
Last Recalib on : 20 SEP 96 10:41 AM
Multiplier : 1
Sample Info : W402; WATER SAMPLE; PLUS 20.0 PPB BTEX SPIKE #1903.

Page Number : 1
Vial Number : 39
Injection Number : 1
Sequence Line : 1
Instrument Method: TVW20919.MTH
Analysis Method : BXW20919.MTH
Sample Amount : 0
ISTD Amount :



Data File Name : C:\HPCHEM\2\DATA\TVB21007\040R0101.D
Operator : K. S. HOLLMAN
Instrument : TVHBTEX2
Sample Name : 96-3528-02CMSD;1
Run Time Bar Code:
Acquired on : 08 Oct 96 05:29 PM
Report Created on: 08 Oct 96 05:47 PM
Last Recalib on : 20 SEP 96 10:41 AM
Multiplier : 1
Sample Info : W402; WATER SAMPLE; PLUS 20.0 PPB BTEX SPIKE #1903.

Page Number : 1
Vial Number : 40
Injection Number : 1
Sequence Line : 1
Instrument Method: TVW20919
Analysis Method : BXW20919.MT
Sample Amount : 0
ISTD Amount :

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

EPA 602/8020 Data Report
Laboratory Control Sample (LCS)

LCS Number :	LCS2100896-BTEX	Dilution Factor :	1.00
Date Extracted/Prepared :	10/8/96	Method :	602/8020
Date Analyzed :	10/8/96	Matrix :	Water
Spike Amount (ug/L) :	20.0	Lab File No. :	TVB21007029

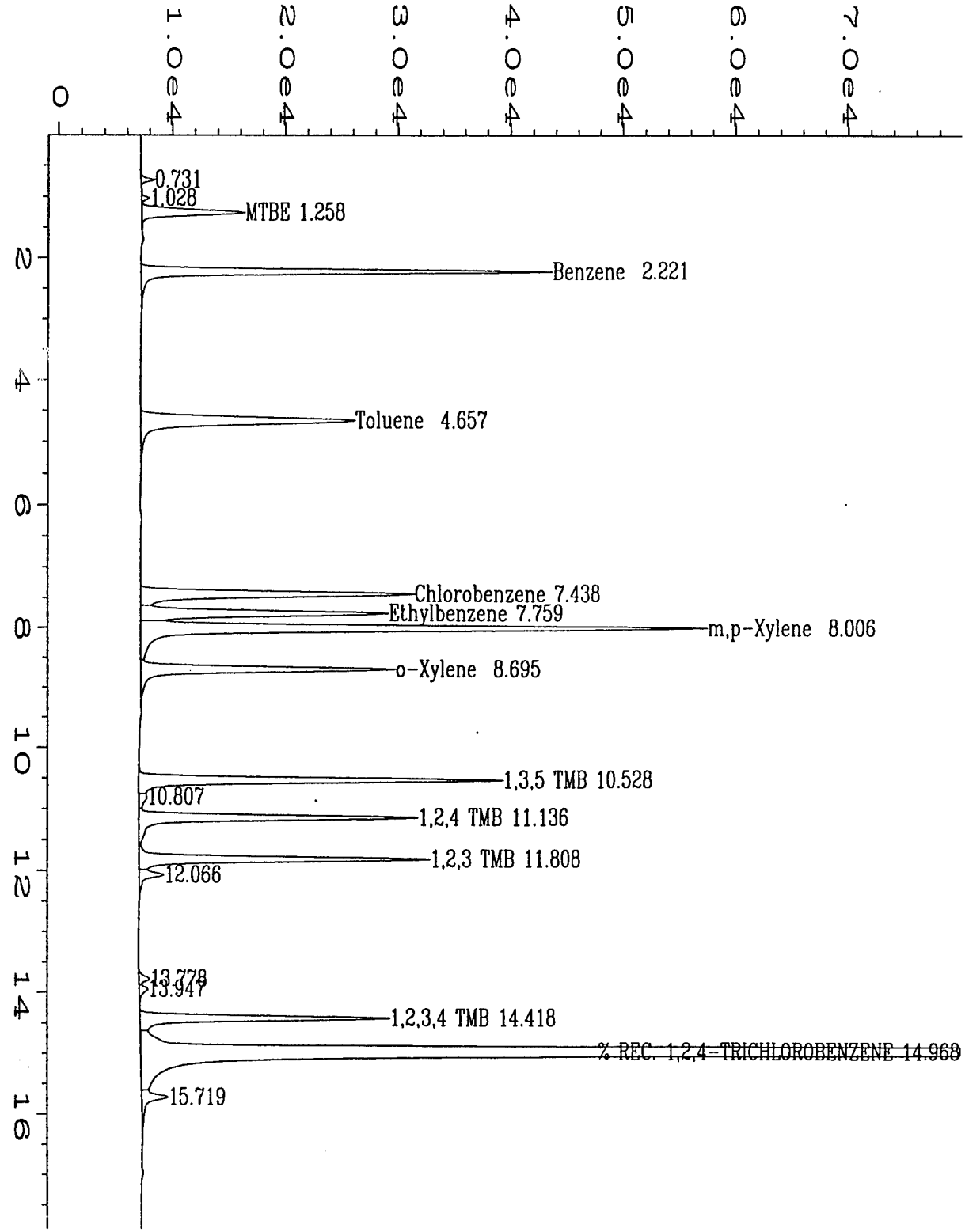
Compound Name	Cas Number	LCS Concentration (ug/L)	LCS % Recovery	QC Limit** % Recovery
Benzene	71-43-2	21.2	106.0	75 - 116
Toluene	108-88-3	20.4	102.0	75 - 118
Chlorobenzene	108-90-7	18.7	93.5	73 - 115
Ethyl Benzene	100-41-4	20.2	101.0	80 - 122
m,p-Xylene	108-38-3	39.1	97.8	76 - 120
[illegible]ylene	106-42-3 95-47-6	20.3	101.5	76 - 118
MTBE	1634-04-4	20.3	101.5	75 - 115
1,3,5-Trimethylbenzene	108-67-8	20.6	103.0	64 - 118
1,2,4-Trimethylbenzene	95-63-6	19.3	96.5	75 - 111
1,2,3-Trimethylbenzene	526-73-8	23.4	117.0	82 - 127
1,2,3,4-Tetramethylbenzene	488-23-3	21.4	107.0	72 - 131
Surrogate Recovery:		100%		70 - 128

NOTES: m,p-xylene = 40.0 ppb spike.

QUALIFIERS:
E = Extrapolated value. Value exceeds that of the calibration range.
U = Compound analyzed for, but not detected.
B = Compound found in blank and sample. Compare blank and sample data.
NA = Not available/Not analyzed.
** = Limits established 10/1/96 for TVHBTEX2. MAB

K Hellman
Analyst

Approved



Data File Name	: C:\HPCHEM\2\DATA\TVB21007\029R0101.D		
Operator	: K. S. HOLLMAN	Page Number	: 1
Instrument	: TVHBTEX2	Vial Number	: 29
Sample Name	: LCS2100896-BTEX	Injection Number	: 1
Run Time Bar Code:		Sequence Line	: 1
Acquired on	: 08 Oct 96 11:35 AM	Instrument Method	: TVW20919
Report Created on	: 08 Oct 96 11:53 AM	Analysis Method	: BXW20919.MT
Last Recalib on	: 20 SEP 96 10:41 AM	Sample Amount	: 0
Multiplier	: 1	ISTD Amount	:
Sample Info	: 20.0 PPB BTEX SPIKE #1930.		

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

POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT
Method Blank Report

Method Blank Number	: WB100796	Client I.D.	: 725524.06000
Date Extracted/Prepared	: 10/07/96	Lab Project No.	: 96-3528
Date Analyzed	: 10/16/96	Effective Dilution	: 1.00
		Method	: 8270B
		Matrix	: WATER
		Lab File No.	: >32175

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L		87%	(35-113)
2-Fluorobiphenyl	100 ug/L		96%	(45-116)
Terphenyl-d14	100 ug/L		76%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W401		
Lab Sample Number	: 96-3528-01	Client I.D.	: 725524.060
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/15/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32155
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	85%		(35-113)
2-Fluorobiphenyl	100 ug/L	90%		(45-116)
Terphenyl-d14	100 ug/L	26%	X	(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32155::Q2
Data File: >32155::B2
Name: 96-3528-01;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

Quant Rev: 7 Quant Time: 961015 18:50
Injected at: 961015 18:05
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#56

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	35694	40.00	UG/ML	96
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.94	136.0	117557	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.88	82.0	115003	84.66	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	53524	40.00	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	140977	90.31	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.61	188.0	68011	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.57	240.0	37493	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.51	244.0	20918	25.79	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.54	264.0	35954	40.00	UG/ML	100

* Compound is ISTD

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W402		
Lab Sample Number	: 96-3528-02	Client I.D.	: 725524.060
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/15/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32156
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

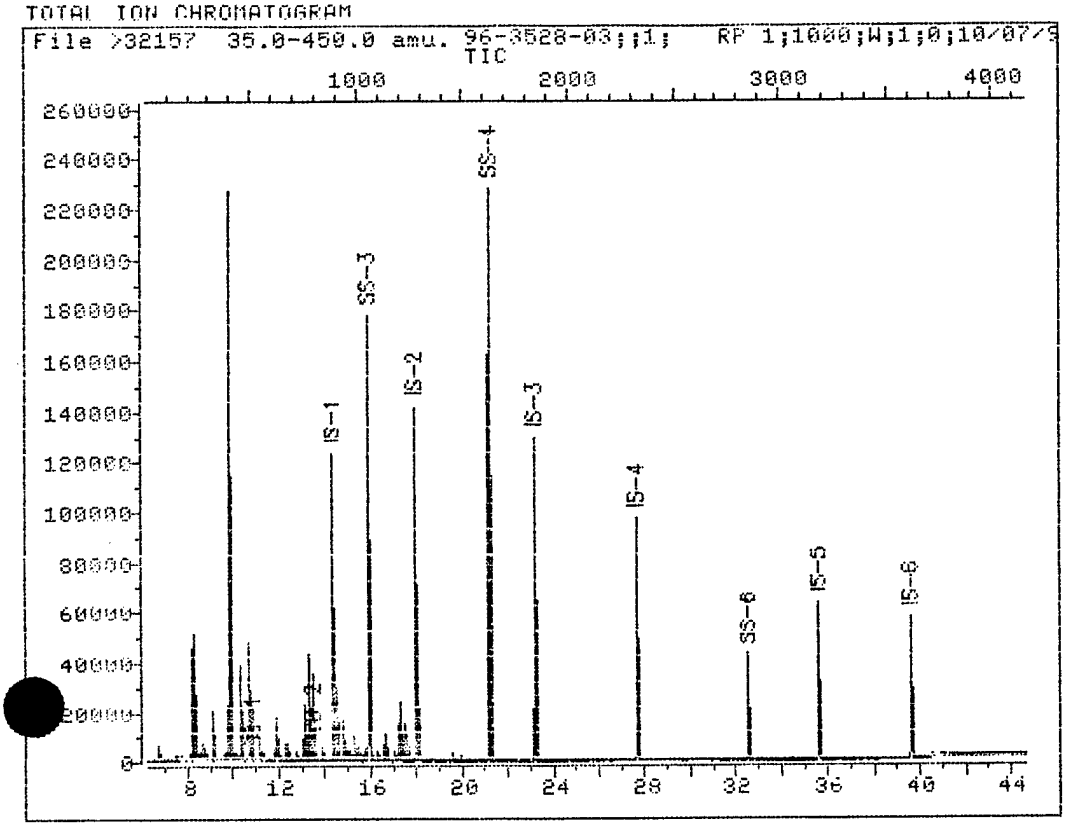
Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100	ug/L	77%	(35-113)
2-Fluorobiphenyl	100	ug/L	86%	(45-116)
Terphenyl-d14	100	ug/L	43%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >32157::B2 Quant Output File: ^32157::Q2
Name: 96-3528-03;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#58

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BUB
Quant Time : 961015 20:38
Injected at: 961015 19:52

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W407		
Lab Sample Number	: 96-3528-04	Client I.D.	: 725524.060
Date Sampled	: 10/03/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/15/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32158
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100	ug/L	90%	(35-113)
2-Fluorobiphenyl	100	ug/L	95%	(45-116)
Terphenyl-d14	100	ug/L	67%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32156::Q2
Data File: >32156::B2
Name: 96-3528-02;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

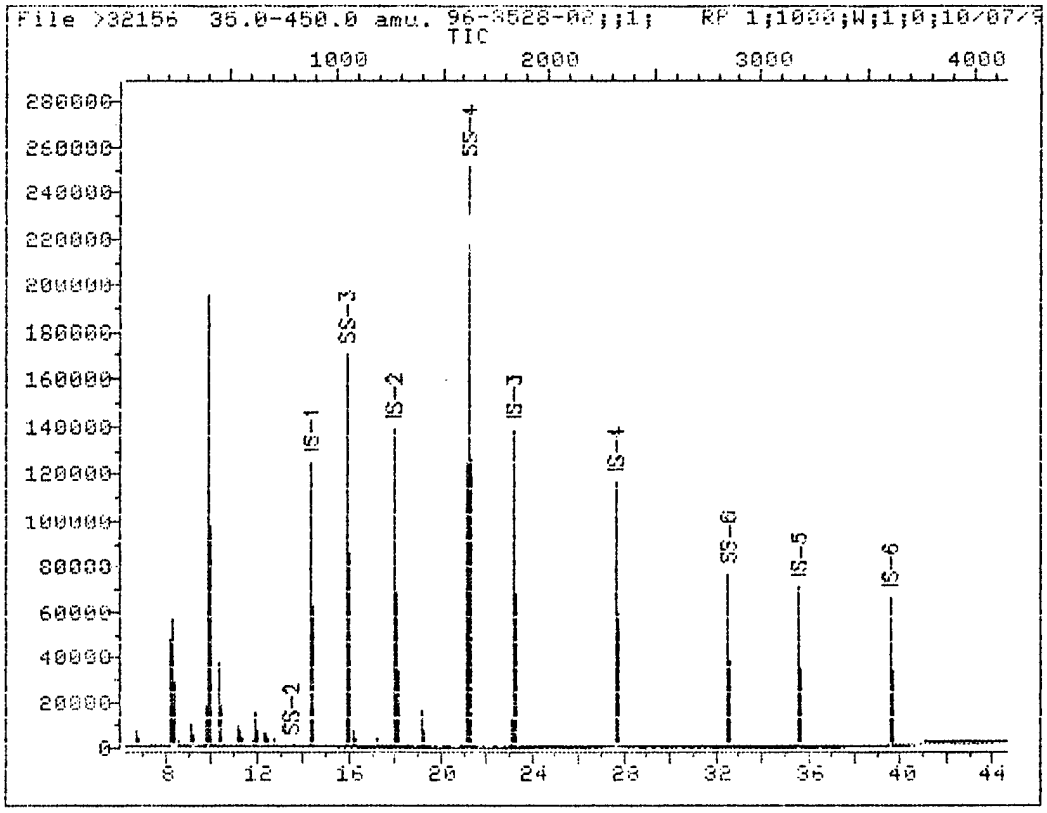
Quant Rev: 7 Quant Time: 961015 19:44
Injected at: 961015 18:58
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#5/

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	37306	40.00	UG/ML	97
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.93	136.0	130074	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.98	82.0	116466	77.49	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	64582	40.00	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	161950	85.98	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.62	188.0	91578	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.57	240.0	53902	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.51	244.0	50171	43.02	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.54	264.0	53164	40.00	UG/ML	100

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32156::B2 Quant Output File: ^32156::Q2
Name: 96-3528-02;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#57

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961015 19:44
Injected at: 961015 18:58

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W404		
Lab Sample Number	: 96-3528-03	Client I.D.	: 725524.06000
Date Sampled	: 10/03/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/15/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32157
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Naphthalene	91-20-3	3	J	10
2-Methylnaphthalene	91-57-6		U	10
Acenaphthylene	208-96-8		U	10
Acenaphthene	83-32-9		U	10
Dibenzofuran	132-64-9		U	10
Fluorene	86-73-7		U	10
Phenanthrene	85-01-8		U	10
Anthracene	120-12-7		U	10
Fluoranthene	206-44-0		U	10
Pyrene	129-00-0		U	10
Benzo(a)Anthracene	56-55-3		U	10
Chrysene	218-01-9		U	10
Benzo(b)Fluoranthene	205-99-2		U	10
Benzo(k)Fluoranthene	207-08-9		U	10
Benzo(a)Pyrene	50-32-8		U	10
Indeno(1,2,3-cd)Pyrene	193-39-5		U	10
Dibenz(a,h)Anthracene	53-70-3		U	10
Benzo(g,h,i)Perylene	191-24-2		U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	81%		(35-113)
2-Fluorobiphenyl	100 ug/L	90%		(45-116)
Terphenyl-d14	100 ug/L	29%	X	(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32157::Q2
Data File: >32157::B2
Name: 96-3528-03;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

Quant Rev: 7 Quant Time: 961015 20:38
Injected at: 961015 19:52
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#58

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14.56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	S
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	38932	40.00	UG/ML	9
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.94	136.0	127682	40.00	UG/ML	10
20)	NITROBENZENE-D5(SURROGATE ST)	15.99	82.0	120103	81.41	UG/ML	10
29)	NAPHTHALENE	18.00	128.0	7457	2.58	UG/ML	10
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	59106	40.00	UG/ML	10
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	154531	89.65	UG/ML	10
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.61	188.0	76018	40.00	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.57	240.0	44518	40.00	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.50	244.0	27609	28.67	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.54	264.0	45890	40.00	UG/ML	10

* Compound is ISTD

Operator ID: BOB
Output File: ^32158::Q2
Data File: >32158::B2
Name: 96-3528-04;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

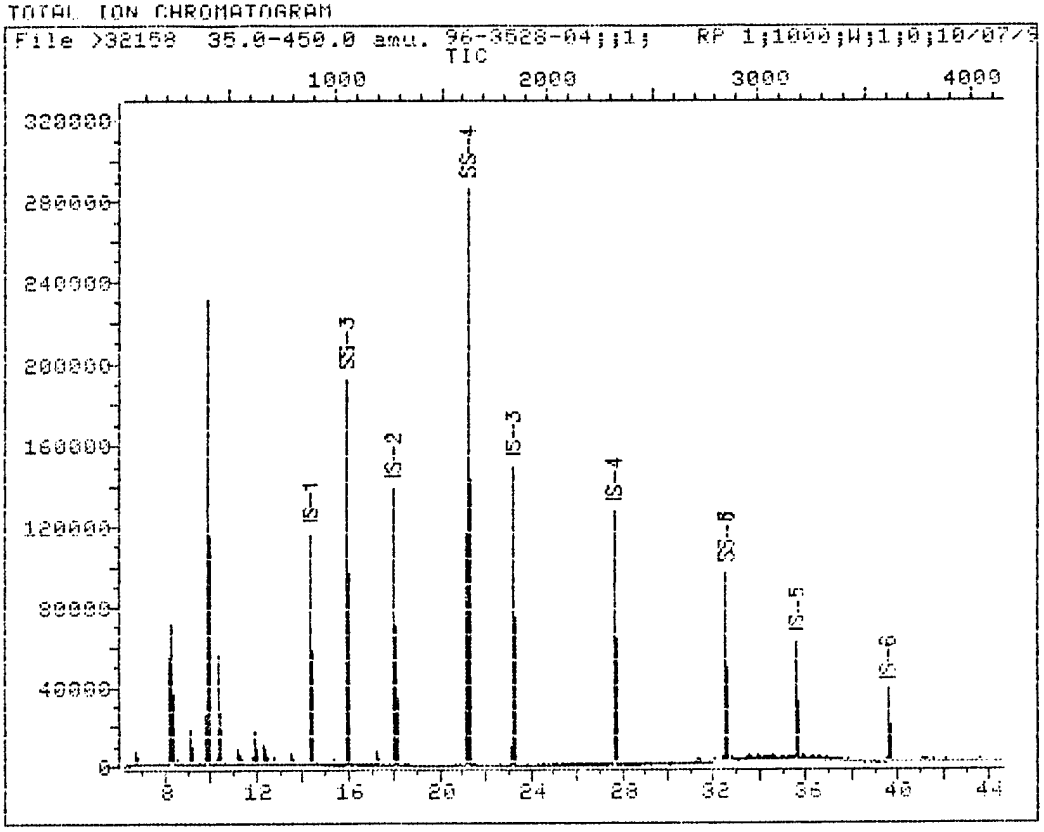
Quant Rev: 7 Quant Time: 961015 21:32
Injected at: 961015 20:46
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#59

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	35452	40.00	UG/ML	94
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.94	136.0	127692	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.89	82.0	132525	89.82	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	67356	40.00	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	186316	94.85	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.62	188.0	98949	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.57	240.0	41037	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.51	244.0	59905	67.47	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.53	264.0	29875	40.00	UG/ML	100

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32158::B2 Quant Output File: ^32158::Q2
Name: 96-3528-04;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BIL#59

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961015 21:32
Injected at: 961015 20:46

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

POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W409S		
Lab Sample Number	: 96-3528-05	Client I.D.	: 725524.06000
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/15/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32159
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Naphthalene	91-20-3	16		10
2-Methylnaphthalene	91-57-6		U	10
Acenaphthylene	208-96-8		U	10
Acenaphthene	83-32-9		U	10
Dibenzofuran	132-64-9		U	10
Fluorene	86-73-7		U	10
Phenanthrene	85-01-8		U	10
Anthracene	120-12-7		U	10
Fluoranthene	206-44-0		U	10
Pyrene	129-00-0		U	10
Benzo(a)Anthracene	56-55-3		U	10
Chrysene	218-01-9		U	10
Benzo(b)Fluoranthene	205-99-2		U	10
Benzo(k)Fluoranthene	207-08-9		U	10
Benzo(a)Pyrene	50-32-8		U	10
Indeno(1,2,3-cd)Pyrene	193-39-5		U	10
Dibenz(a,h)Anthracene	53-70-3		U	10
Benzo(g,h,i)Perylene	191-24-2		U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100	ug/L	75%	(35-113)
2-Fluorobiphenyl	100	ug/L	83%	(45-116)
Terphenyl-d14	100	ug/L	20%X	(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32159::Q2
Data File: >32159::B2
Name: 96-3528-05;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

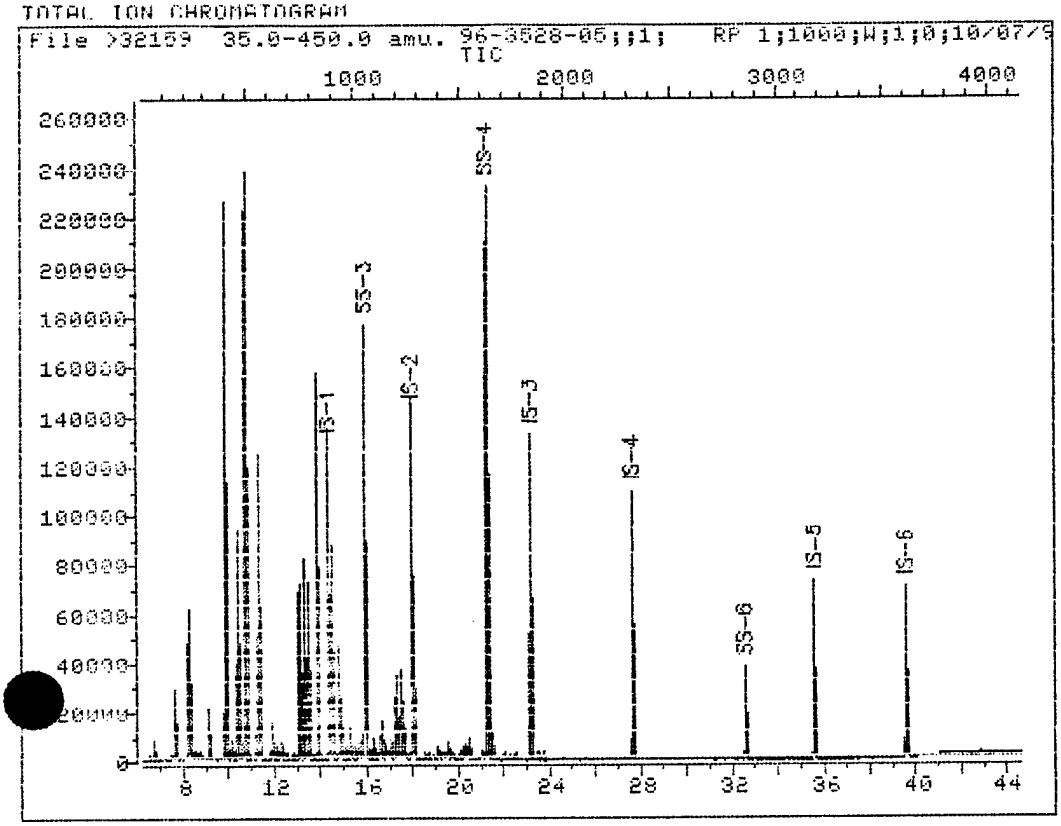
Quant Rev: 7 Quant Time: 961015 22:2
Injected at: 961015 21:39
Dilution Factor: 1.0000
Instrument ID: BNA 1
BTL#6

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	S
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	42181	40.00	UG/ML	9
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.93	136.0	140140	40.00	UG/ML	10
20)	NITROBENZENE-D5(SURROGATE ST)	15.89	82.0	121764	75.20	UG/ML	10
29)	NAPHTHALENE	18.00	128.0	49370	15.59	UG/ML	10
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.15	164.0	63392	40.00	UG/ML	10
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	153303	82.92	UG/ML	10
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.61	188.0	85984	40.00	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.57	240.0	54562	40.00	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.50	244.0	23729	20.14	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.54	264.0	56350	40.00	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32159::B2 Quant Output File: ^32159::Q2
Name: 96-3528-05;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#60

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Qcant Time : 961015 22:25
Injected at: 961015 21:39

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W409D		
Lab Sample Number	: 96-3528-06	Client I.D.	: 725524.0600
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32167
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	98%	(35-113)
2-Fluorobiphenyl	100 ug/L	94%	(45-116)
Terphenyl-d14	100 ug/L	37%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

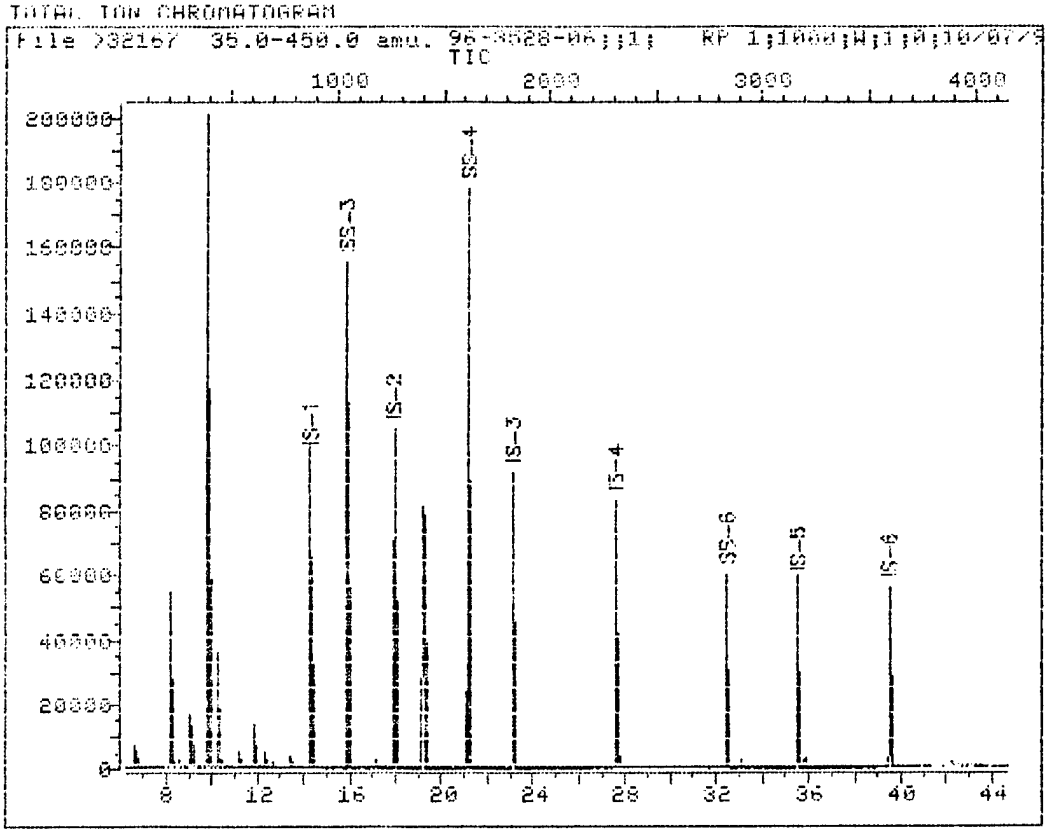
Operator ID: BOB Quant Rev: 7 Quant Time: 961016 14:3?
Output File: ^32167::Q2 Injected at: 961016 13:46
Data File: >32167::B2 Dilution Factor: 1.00000
Name: 96-3528-06;;1; RF Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BIL#53

ID File: ID_827::QI
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.26	152.0	29207	40.00	UG/ML	96
19)	*NAPHTHALENE-D8(INTERNAL STD)	12.89	136.0	97440	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.84	82.0	109875	92.59	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.11	164.0	45678	40.00	UG/ML	100
39)	2-FLUORUBIPHENYL(SURROGATE ST)	21.15	172.0	124987	93.82	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.57	188.0	72486	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.51	240.0	50528	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.46	244.0	40908	37.42	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.49	264.0	51942	40.00	UG/ML	100

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32167::B2 Quant Output File: ^32167::Q2
Name: 96-3528-06;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#53

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Ucal Time: <none>

Operator ID: BCU
Quant Time : 961016 14:31
Injected at: 961016 13:45

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W410		
Lab Sample Number	: 96-3528-07	Client I.D.	: 725524.06000
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/15/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32161
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L		80%	(35-113)
2-Fluorobiphenyl	100 ug/L		90%	(45-116)
Terphenyl-d14	100 ug/L		40%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32161::Q2
Data File: >32161::B2
Name: 96-3528-07;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

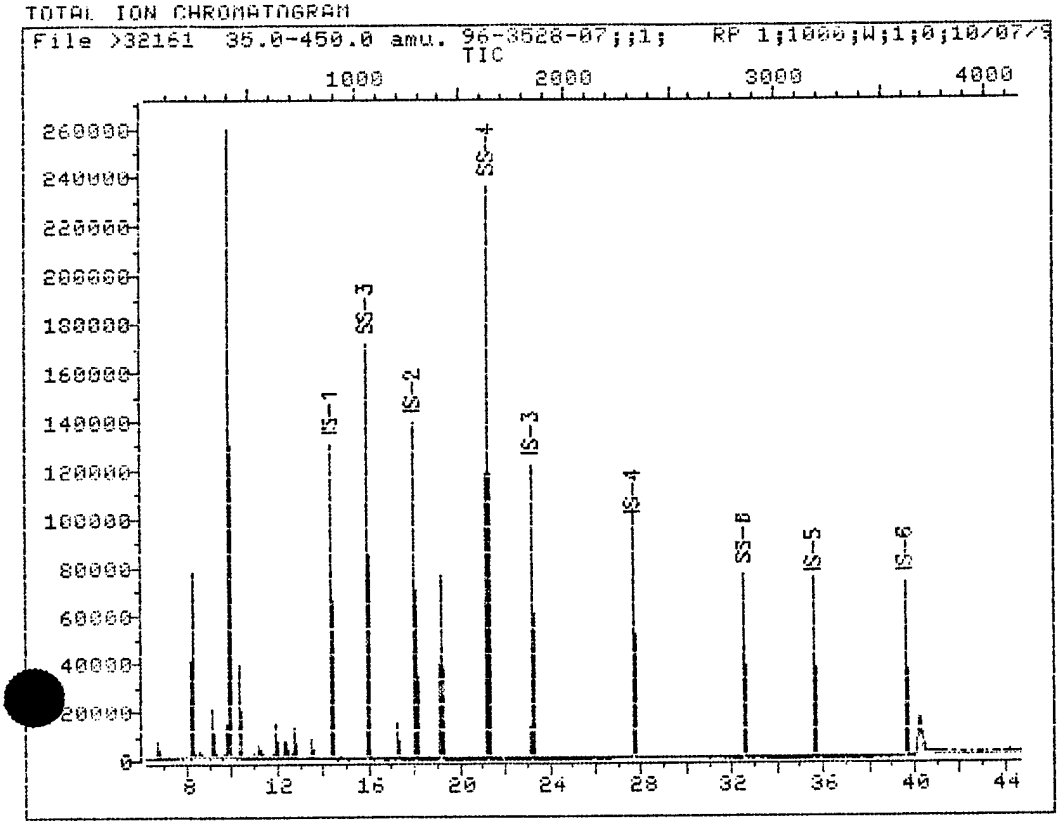
Quant Rev: 7 Quant Time: 961016 00:1[illegible]
Injected at: 961015 23:27
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#62

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	39172	40.00	UG/ML	9
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.94	136.0	128955	40.00	UG/ML	10
20)	NITROBENZENE-D5(SURROGATE ST)	15.98	82.0	119161	79.97	UG/ML	10
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	57498	40.00	UG/ML	10
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	151229	90.18	UG/ML	10
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.61	188.0	81527	40.00	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.57	240.0	55653	40.00	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.51	244.0	48410	40.21	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.54	264.0	54729	40.00	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32161::B2 Quant Output File: ^32161::Q2
Name: 96-3528-07;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#62

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961016 00:12
Injected at: 961015 23:27

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W411		
Lab Sample Number	: 96-3528-08	Client I.D.	: 725524.0600
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32162
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Naphthalene	91-20-3	U		10
2-Methylnaphthalene	91-57-6	U		10
Acenaphthylene	208-96-8	U		10
Acenaphthene	83-32-9	U		10
Dibenzofuran	132-64-9	U		10
Fluorene	86-73-7	U		10
Phenanthrene	85-01-8	U		10
Anthracene	120-12-7	U		10
Fluoranthene	206-44-0	U		10
Pyrene	129-00-0	U		10
Benzo(a)Anthracene	56-55-3	U		10
Chrysene	218-01-9	U		10
Benzo(b)Fluoranthene	205-99-2	U		10
Benzo(k)Fluoranthene	207-08-9	U		10
Benzo(a)Pyrene	50-32-8	U		10
Indeno(1,2,3-cd)Pyrene	193-39-5	U		10
Dibenz(a,h)Anthracene	53-70-3	U		10
Benzo(g,h,i)Perylene	191-24-2	U		10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	84%		(35-113)
2-Fluorobiphenyl	100 ug/L	91%		(45-116)
Terphenyl-d14	100 ug/L	38%		(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32162::Q2
Data File: >32162::82
Name: 96-3528-08;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

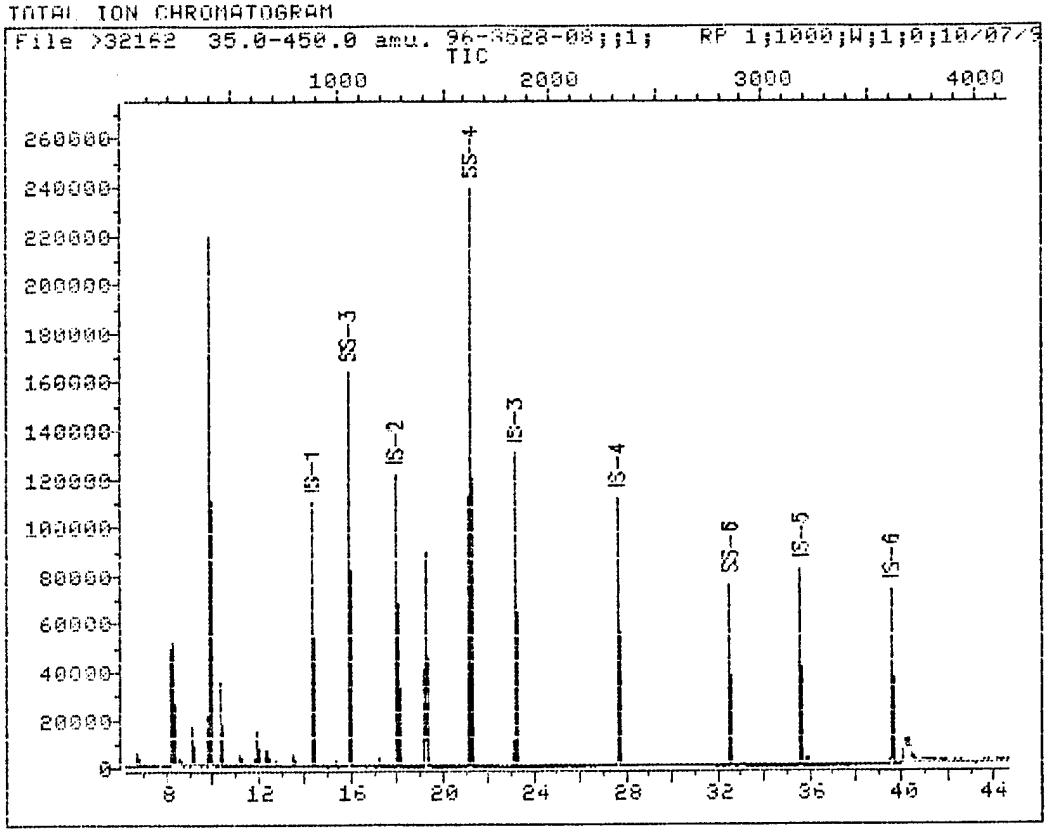
Quant Rev: 7 Quant Time: 961016 01:06
Injected at: 961016 00:20
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#63

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	Q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	33361	40.00	UG/ML	97
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.93	136.0	119823	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.88	82.0	113041	84.47	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	59446	40.00	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	157717	90.97	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.62	188.0	89928	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.58	240.0	61741	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.51	244.0	51150	38.29	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.54	264.0	61232	40.00	UG/ML	100

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32162::B2 Quant Output File: ^32162::Q2
Name: 96-3528-08;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BIL#63

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
QCant Time : 961016 01:0<
Injected at: 961016 00:20

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

POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W412		
Lab Sample Number	: 96-3528-09	Client I.D.	: 725524.06000
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32163
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100	ug/L	82%	(35-113)
2-Fluorobiphenyl	100	ug/L	86%	(45-116)
Terphenyl-d14	100	ug/L	32%X	(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BUB
Output File: ^32163::Q2
Data File: >32163::B2
Name: 96-3528-09;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

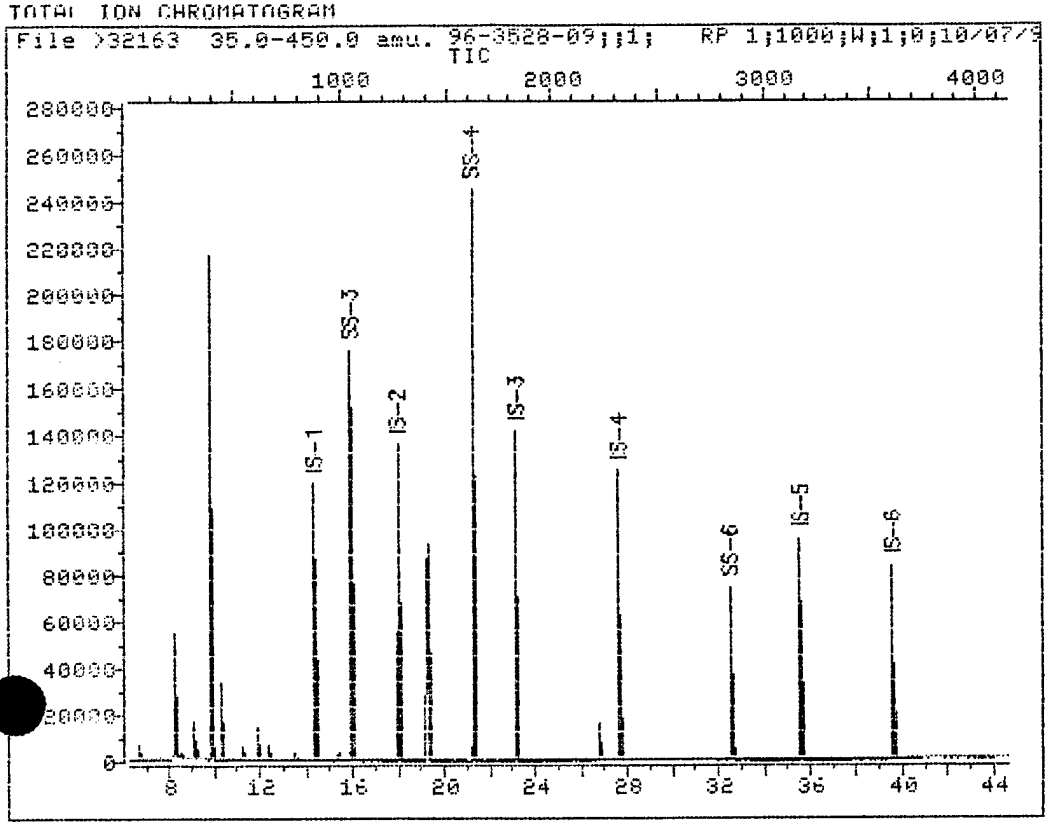
Quant Rev: 7 Quant Time: 961016 02:09
Injected at: 961016 01:14
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#64

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT [illegible]FICATION
Last Calibration: 961007 14:56 Last Ocal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	%
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.31	152.0	36167	40.00	UG/ML	9
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.94	136.0	127670	40.00	UG/ML	10
20)	NITROBENZENE-D5(SURROGATE ST)	15.88	82.0	120347	81.58	UG/ML	10
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.16	164.0	69882	40.00	UG/ML	10
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.20	172.0	165064	85.91	UG/ML	10
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.62	188.0	101000	40.00	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.58	240.0	67188M	40.00	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.51	244.0	47011M	32.34	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.55	264.0	66798	40.00	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32163::B2 Quant Output File: ^32163::Q2
Name: 96-3528-09;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#64

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961016 02:00
Injected at: 961016 01:14

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W414		
Lab Sample Number	: 96-3528-10	Client I.D.	: 725524.0600
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32168
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-2 -3	U	10
2-Methylnaphthalene	91-5 6	U	10
Acenaphthylene	208-96 8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	92%		(35-113)
2-Fluorobiphenyl	100 ug/L	97%		(45-116)
Terphenyl-d14	100 ug/L	43%		(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BUB
Output File: ^32168::Q2
Data File: >32168::B2
Name: 96-3528-10;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

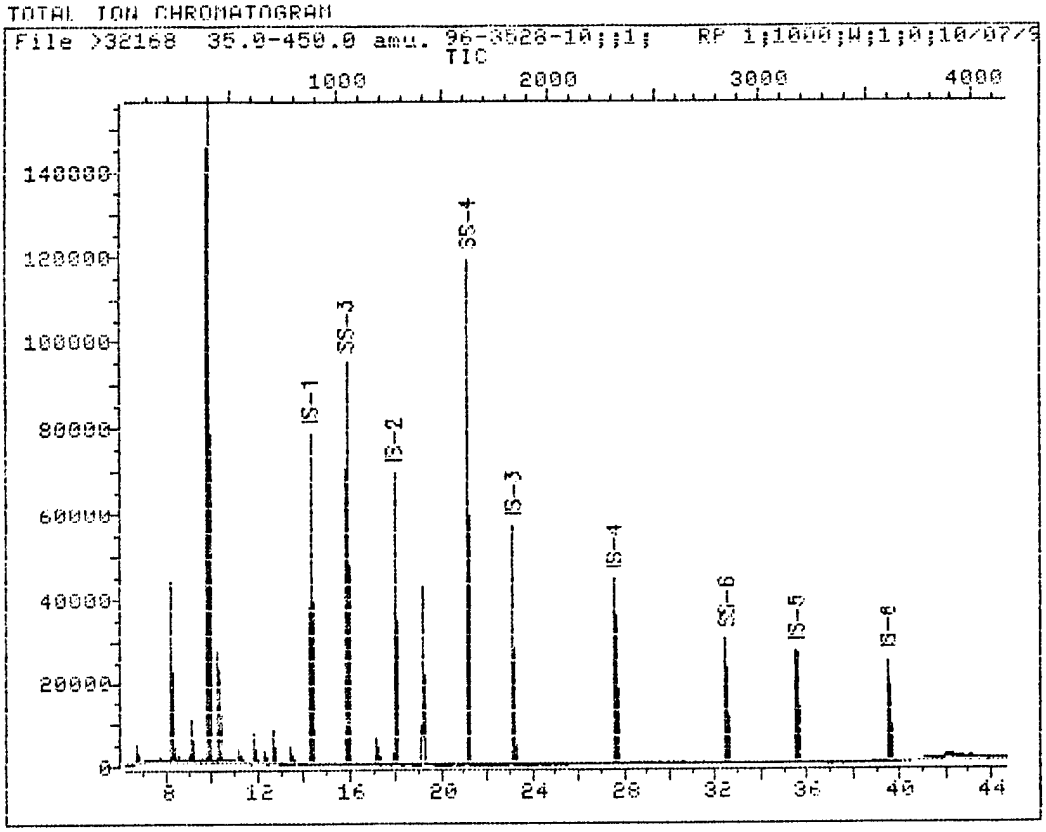
Quant Rev: 7 Quant Time: 961016 15:25
Injected at: 961016 14:39
Dilution Factor: 1.00000
Instrument ID: BNA 1
BIL#54

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.26	152.0	21308	40.00	UG/ML	90
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.89	136.0	57710	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.83	82.0	61533	92.28	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.10	164.0	24379	40.00	UG/ML	100
39)	2-FLUORUBIPHENYL(SURROGATE ST)	21.15	172.0	69095	97.18	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.56	188.0	33263	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.51	240.0	19333	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.46	244.0	17790	42.53	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.49	264.0	19398	40.00	UG/ML	100

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32168::B2 Quant Output File: ^32168::Q2
Name: 96-3528-10;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BIL#54

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961016 15:2?
Injected at: 961016 14:39

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W420		
Lab Sample Number	: 96-3528-11	Client I.D.	: 725524.06000
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32169
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100	ug/L	94%	(35-113)
2-Fluorobiphenyl	100	ug/L	98%	(45-116)
Terphenyl-d14	100	ug/L	34%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32169::Q2
Data File: >32169::B2
Name: 96-3528-11;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

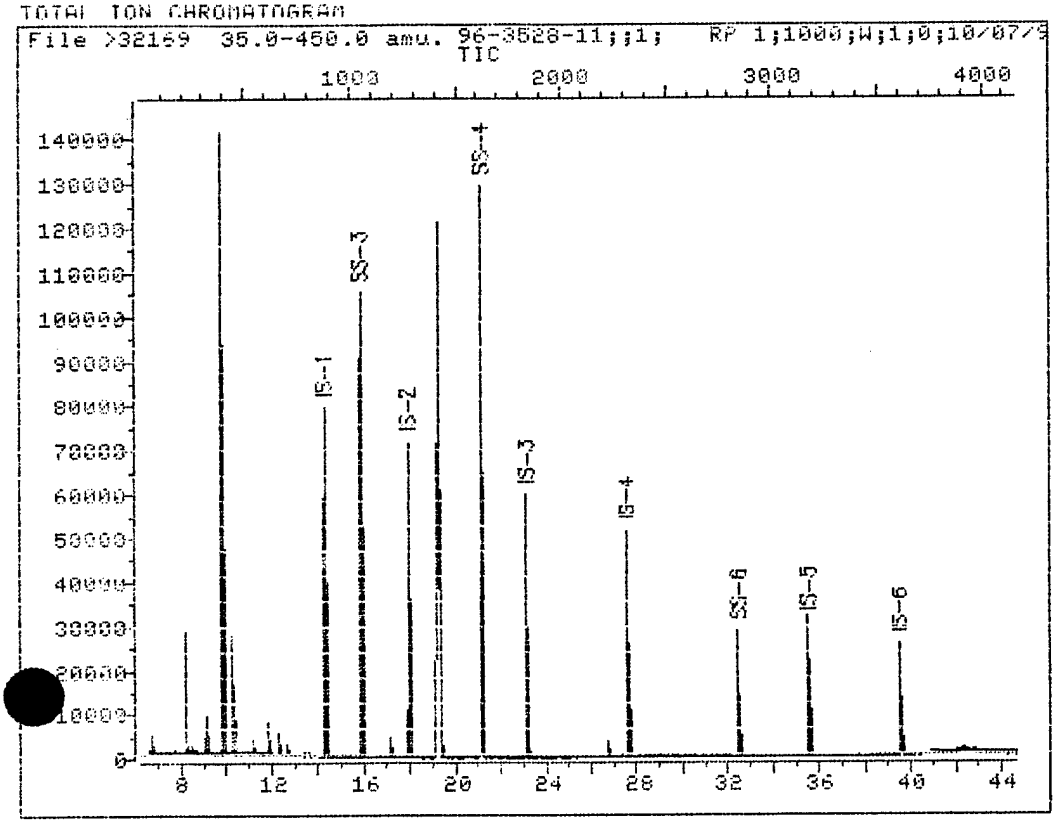
Quant Rev: 7 Quant Time: 961016 16:19
Injected at: 961016 15:33
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#59

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 96100/ 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.26	152.0	22302	40.00	UG/ML	9
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.89	136.0	61488	40.00	UG/ML	10
20)	NITROBENZENE-D5(SURROGATE ST)	15.84	82.0	66529	93.64	UG/ML	10
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.10	164.0	26905	40.00	UG/ML	10
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.15	172.0	77239	98.44	UG/ML	10
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.56	188.0	38475	40.00	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.51	240.0	23381	40.00	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.46	244.0	17219	34.04	UG/ML	10
72)	*PERYLENE-D12(INTERNAL STD)	39.48	264.0	21795	40.00	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32169::B2 Quant Output File: ^32169::Q2
Name: 96-3528-11;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BIL#55

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BUB
Quant Time : 961016 16:19
Injected at: 961016 15:33

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: USGS4		
Lab Sample Number	: 96-3528-12	Client I.D.	: 725524.0600
Date Sampled	: 10/03/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32170
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Naphthalene	91-20-3	140		10
2-Methylnaphthalene	91-57-6	88		10
Acenaphthylene	208-96-8		U	10
Acenaphthene	83-32-9		U	10
Dibenzofuran	132-64-9		U	10
Fluorene	86-73-7		U	10
Phenanthrene	85-01-8		U	10
Anthracene	120-12-7		U	10
Fluoranthene	206-44-0		U	10
Pyrene	129-00-0		U	10
Benzo(a)Anthracene	56-55-3		U	10
Chrysene	218-01-9		U	10
Benzo(b)Fluoranthene	205-99-2		U	10
Benzo(k)Fluoranthene	207-08-9		U	10
Benzo(a)Pyrene	50-32-8		U	10
Indeno(1,2,3-cd)Pyrene	193-39-5		U	10
Dibenz(a,h)Anthracene	53-70-3		U	10
Benzo(g,h,i)Perylene	191-24-2		U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	97%		(35-113)
2-Fluorobiphenyl	100 ug/L	68%		(45-116)
Terphenyl-d14	100 ug/L	19%	X	(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

QUANT REPORT Page 1

Operator ID: BOB
Output File: ^32170::Q2
Data File: >32170::B2
Name: 96-3528-12;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

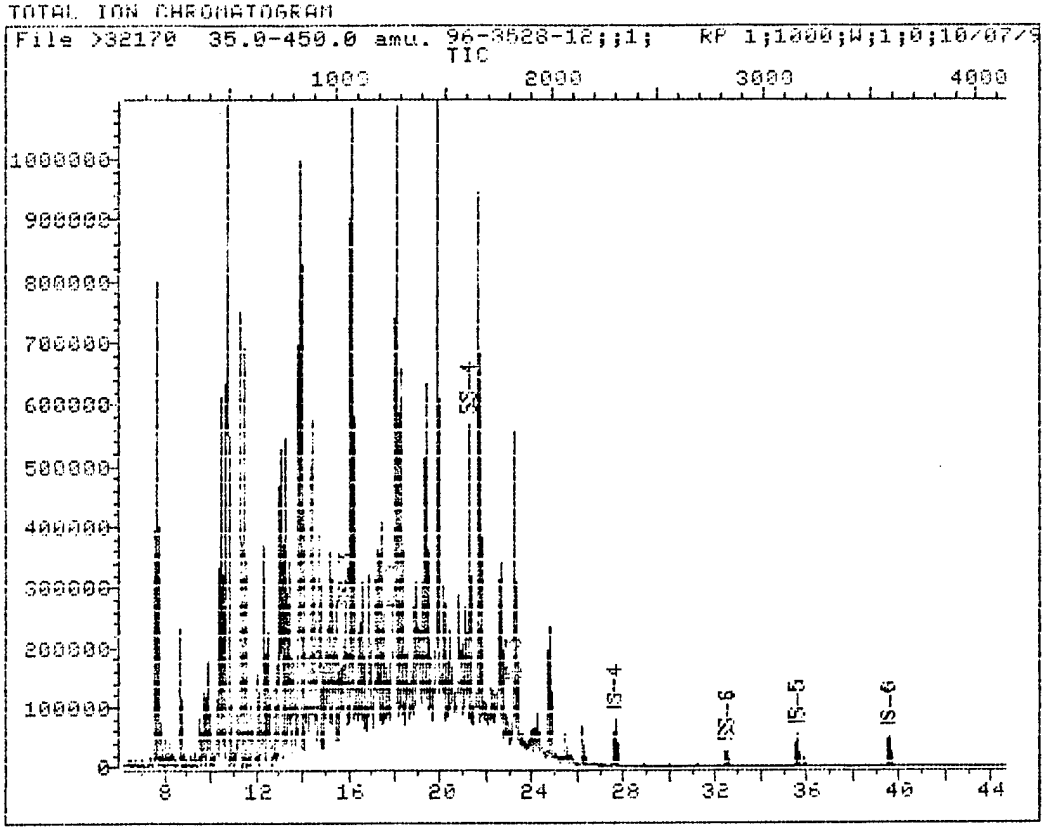
Quant Rev: 7 Quant Time: 961016 17:13
Injected at: 961016 16:27
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#56

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.28	152.0	25424	40.00	UG/ML	96
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.91	136.0	71906	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.86	82.0	80346M	96.70	UG/ML	100
29)	NAPHTHALENE	17.98	128.0	229365	141.17	UG/ML	100
33)	2-METHYLNAPHTHALENE	20.04	142.0	82153	87.51	UG/ML	100
34)	1-METHYLNAPHTHALENE	20.32	142.0	59436M	63.31	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.12	164.0	34722	40.00	UG/ML	100
39)	2-FLUORUBIPHENYL(SURROGATE ST)	21.16	172.0	68788	67.93	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.56	188.0	56667	40.00	UG/ML	100
68)	*CHRYSENE-D12(INTERNAL STD)	35.51	240.0	41147	40.00	UG/ML	100
71)	TERPHENYL-D14(SURROGATE STD)	32.45	244.0	17002	19.10	UG/ML	100
77)	*PERYLENE-D12(INTERNAL STD)	39.49	264.0	43146	40.00	UG/ML	100

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32170::B2 Quant Output File: ^32170::Q2
Name: 96-3528-12;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BIL#56

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BUB
Quant Time : 961016 17:13
Injected at: 961016 16:27

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: R1		
Lab Sample Number	: 96-3528-13	Client I.D.	: 725524.06000
Date Sampled	: 10/02/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32171
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Naphthalene	91-20-3	U	10
2-Methylnaphthalene	91-57-6	U	10
Acenaphthylene	208-96-8	U	10
Acenaphthene	83-32-9	U	10
Dibenzofuran	132-64-9	U	10
Fluorene	86-73-7	U	10
Phenanthrene	85-01-8	U	10
Anthracene	120-12-7	U	10
Fluoranthene	206-44-0	U	10
Pyrene	129-00-0	U	10
Benzo(a)Anthracene	56-55-3	U	10
Chrysene	218-01-9	U	10
Benzo(b)Fluoranthene	205-99-2	U	10
Benzo(k)Fluoranthene	207-08-9	U	10
Benzo(a)Pyrene	50-32-8	U	10
Indeno(1,2,3-cd)Pyrene	193-39-5	U	10
Dibenz(a,h)Anthracene	53-70-3	U	10
Benzo(g,h,i)Perylene	191-24-2	U	10

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100	ug/L	84%	(35-113)
2-Fluorobiphenyl	100	ug/L	95%	(45-116)
Terphenyl-d14	100	ug/L	91%	(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than the numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32171::Q2
Data File: >32171::B2
Name: 96-3528-13;;1; RP
Misc: 1;1000;W;1;0;10/07/96;W;1

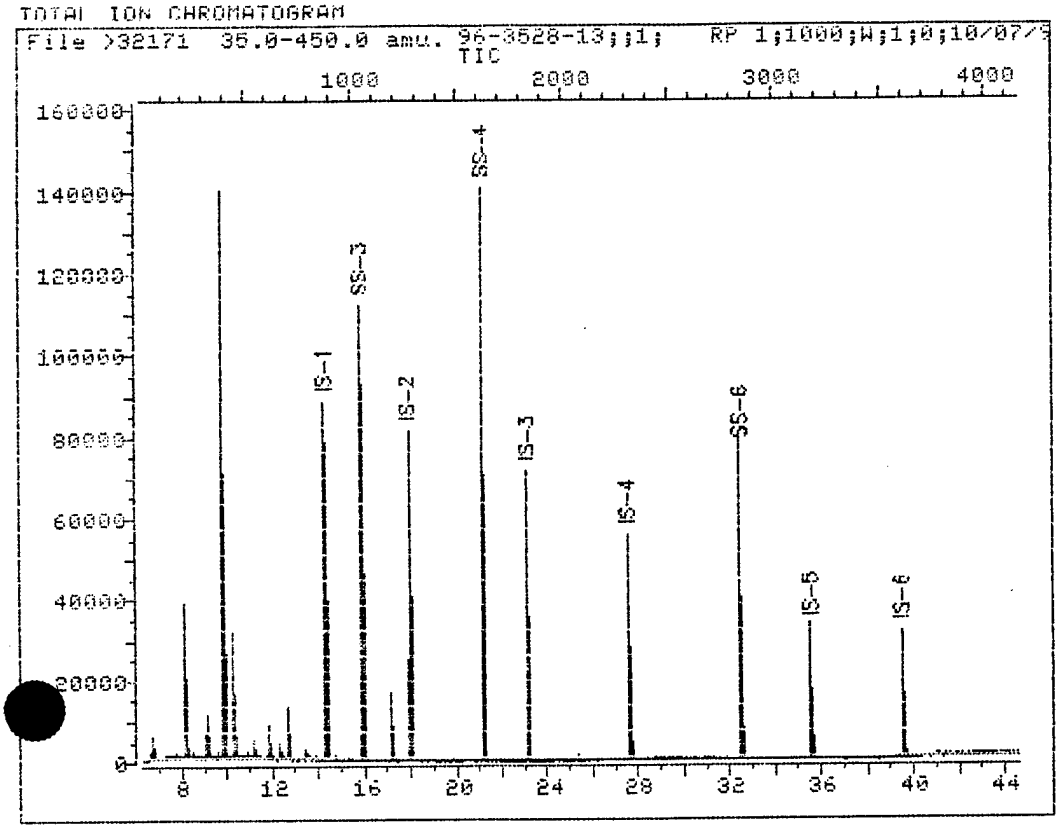
Quant Rev: 7 Quant Time: 961016 18:06
Injected at: 961016 17:20
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#5

ID File: ID_827::QI
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Q ion	Area	Conc	Units	q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.26	152.0	24990	40.00	UG/ML	9
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.89	136.0	69345	40.00	UG/ML	10
20)	NITROBENZENE-D5(SURROGATE ST)	15.83	82.0	67229	83.90	UG/ML	10
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.11	164.0	29370	40.00	UG/ML	10
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.15	172.0	81029	94.60	UG/ML	10
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.56	188.0	41563	40.00	UG/ML	10
69)	*CHRYSENE-D12(INTERNAL STD)	35.51	240.0	24712	40.00	UG/ML	10
21)	TERPHENYL-D14(SURROGATE STD)	32.46	244.0	48846	91.36	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.48	264.0	24642	40.00	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32171::B2 Quant Output File: ^32171::Q2
Name: 96-3528-13;;1; RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#57

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961016 18:06
Injected at: 961016 17:20

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W404MS		
Lab Sample Number	: 96-3528-03MS	Client I.D.	: 725524.0600
Date Sampled	: 10/03/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32172
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	% REC
Naphthalene	91-20-3	79	77%
2-Methylnaphthalene	91-57-6	120	120%
Acenaphthylene	208-96-8	76	76%
Acenaphthene	83-32-9	76	76%
Dibenzofuran	132-64-9	110	110%
Fluorene	86-73-7	73	73%
Phenanthrene	85-01-8	73	73%
Anthracene	120-12-7	67	67%
Fluoranthene	206-44-0	58	58%
Pyrene	129-00-0	65	65%
Benzo(a)Anthracene	56-55-3	54	54%
Chrysene	218-01-9	45	45%
Benzo(b)Fluoranthene	205-99-2	50	50%
Benzo(k)Fluoranthene	207-08-9	53	53%
Benzo(a)Pyrene	50-32-8	49	49%
Indeno(1,2,3-cd)Pyrene	193-39-5	51	51%
Dibenz(a,h)Anthracene	53-70-3	56	56%
Benzo(g,h,i)Perylene	191-24-2	60	60%

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	87%		(35-113)
2-Fluorobiphenyl	100 ug/L	83%		(45-116)
Terphenyl-d14	100 ug/L	27%X		(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

Operator ID: BOB
Output File: ^32172::Q2
Data File: >32172::B2
Name: 96-3528-03MS;;1; R
Misc: 1;1000;W;1;0;10/07/96;W;1

Quant Rev: 7 Quant Time: 961016 19:00
Injected at: 961016 18:14
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#58

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Scan#	Area	Conc	Units	Q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.27	872	39499	40.00	UG/ML	98
2)	N-NITROSODIMETHYLAMINE	6.72	56	70250	63.97	UG/ML	100
3)	PYRIDINE	6.70	54	145898	100.51	UG/ML	100
8)	BIS(2-CHLOROETHYL)ETHER	13.60	800	112846	65.82	UG/ML	100
10)	1,3-DICHLOROBENZENE	14.10	854	92088	70.46	UG/ML	100
11)	1,4-DICHLOROBENZENE	14.32	877	94392	70.98	UG/ML	100
13)	1,2-DICHLOROBENZENE	14.72	921	85271	69.84	UG/ML	100
15)	BIS(2-CHLOROISOPROPYL)ETHER	15.08	960	165165	93.83	UG/ML	100
17)	N-NITROSO-DI-N-PROPYLAMINE	15.48	1003	97049	91.74	UG/ML	100
18)	HEXACHLOROETHANE	15.67	1023	44964	70.02	UG/ML	100
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.90	1264	130239	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.85	1043	131539	87.41	UG/ML	100
21)	NITROBENZENE	15.91	1049	131942	83.46	UG/ML	100
22)	ISOPHORONE	16.61	1125	236566	84.22	UG/ML	100
25)	BIS(2-CHLOROETHOXY)METHANE	17.30	1199	141726	82.91	UG/ML	100
28)	1,2,4-TRICHLOROBENZENE	17.75	1248	76702	79.07	UG/ML	100
29)	NAPHTHALENE	17.97	1271	233743	79.43	UG/ML	100
30)	4-CHLOROANILINE	18.17	1293	87880	72.97	UG/ML	100
31)	HEXACHLOROBUTADIENE	18.35	1313	38763	75.21	UG/ML	100
33)	2-METHYLNAPHTHALENE	20.03	1494	198426	116.70	UG/ML	100
34)	1-METHYLNAPHTHALENE	20.03	1494	198426	116.70	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.12	1828	63637	40.00	UG/ML	100
36)	HEXACHLOROCYCLOPENTADIENE	20.48	1543	18534	51.95	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.16	1616	153607	82.77	UG/ML	100
40)	2-CHLORONAPHTHALENE	21.46	1649	130723	73.80	UG/ML	100
41)	2-NITROANILINE	21.84	1689	108406	110.31	UG/ML	100
42)	DIMETHYLPHTHALATE	22.43	1753	13830	6.48	UG/ML	100
43)	2,6-DINITROTOLUENE	22.58	1770	39495	73.87	UG/ML	100
44)	ACENAPHTHYLENE	22.70	1782	202129	75.68	UG/ML	100
45)	3-NITROANILINE	23.08	1823	89361	80.89	UG/ML	100
46)	ACENAPHTHENE	23.22	1839	125515	76.38	UG/ML	100
49)	DIBENZOFURAN	23.75	1896	238669	108.32	UG/ML	100
50)	2,4-DINITROTOLUENE	23.77	1898	44701	65.73	UG/ML	100
51)	DIETHYL PHTHALATE	24.57	1984	54741	25.87	UG/ML	100
52)	4-CHLOROPHENYL-PHENYL-ETHER	24.84	2013	59481	74.04	UG/ML	100
53)	FLUORENE	24.77	2006	123282	73.19	UG/ML	100
54)	4-NITROANILINE	24.92	2022	92456	110.55	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.57	2308	85990	40.00	UG/ML	100
58)	N-NITROSODIPHENYLAMINE	25.21	2053	88187	83.53	UG/ML	100
59)	AZOBENZENE	25.31	2064	212937	80.80	UG/ML	100

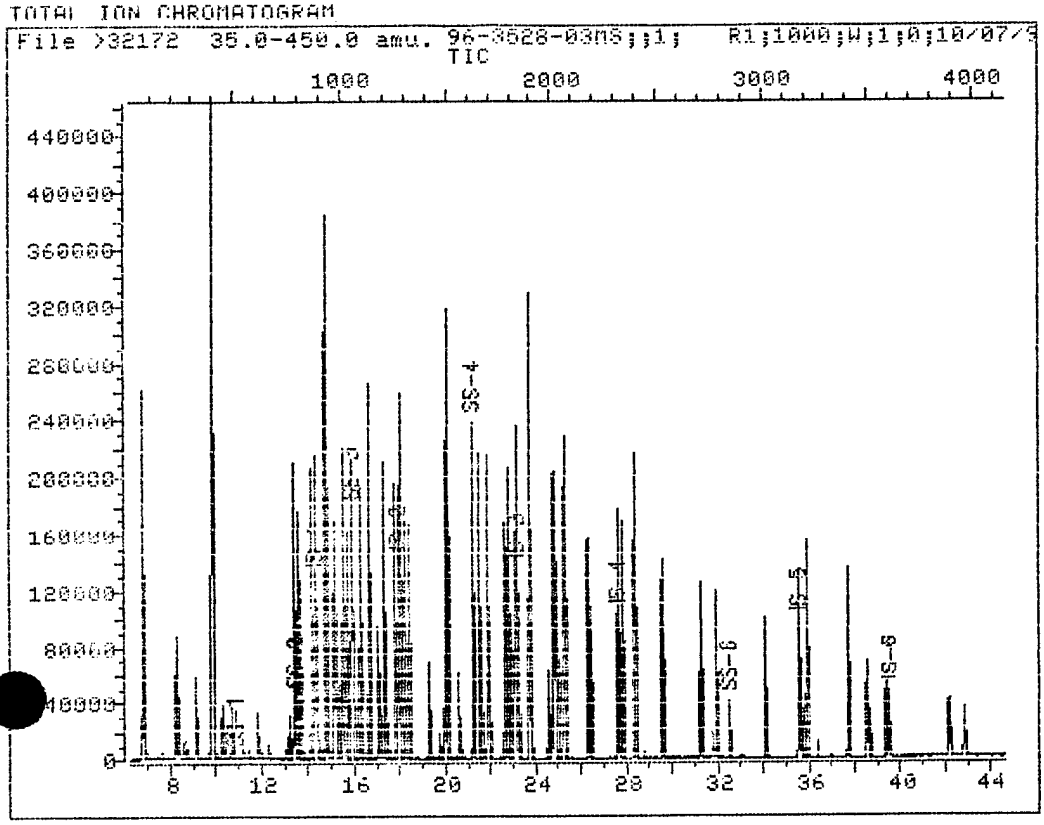
Operator ID: B08 Quant Rev: 7 Quant Time: 961016 19:00
Output File: ^32172::Q2 Injected at: 961016 18:14
Data File: >32172::B2 Dilution Factor: 1.00000
Name: 96-3528-03MS;;1; R Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#58

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:5[illegible] Last Qcal Time: <none>

	Compound	R.T.	Scan#	Area	Conc	Units	q
60)	4-BROMOPHENYL-PHENYL-ETHER	26.29	2170	31909	78.31	UG/ML	10
61)	HEXACHLOROBENZENE	26.39	2181	31969	62.83	UG/ML	10
63)	PHENANTHRENE	27.64	2316	148011	72.52	UG/ML	10
64)	ANTHRACENE	27.80	2333	137699	67.27	UG/ML	10
65)	CARBAZOLE	28.34	2392	202537	101.81	UG/ML	10
66)	DI-N-BUTYLPHTHALATE	29.54	2521	137967	45.20	UG/ML	10
67)	FLUORANTHENE	31.21	2702	110811	57.65	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.92	3168	43144	40.00	UG/ML	10
69)	PYRENE	31.88	2774	107440	65.11	UG/ML	10
70)	BENZIDINE	32.45	2836	410	29.72	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.45	2836	24883	26.66	UG/ML	10
72)	BUTYL-BENZYLPHTHALATE	34.03	3007	46136	42.63	UG/ML	10
73)	3,3'-DICHLOROBENZIDINE	35.50	3166	21291	53.82	UG/ML	10
74)	BENZO(A)ANTHRACENE	35.49	3165	65208	53.82	UG/ML	10
75)	BIS(2-ETHYLHEXYL)PHTHALATE	37.70	3404	109325	46.18	UG/ML	10
76)	CHRYSENE	35.60	3176	54005	44.76	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.48	3596	40132	40.00	UG/ML	10
78)	DI-N-OCTYLPHTHALATE	37.70	3404	109325	43.88	UG/ML	10
79)	BENZO(B)FLUORANTHENE	39.51	3491	56726	50.45	UG/ML	10
80)	BENZO(K)FLUORANTHENE	38.58	3499	56876	53.39	UG/ML	10
81)	BENZO(A)PYRENE	39.34	3591	47640	48.65	UG/ML	10
82)	INDENO(1,2,3-CD)PYRENE	42.10	3879	44247	50.88	UG/ML	10
83)	DIBENZ(A,H)ANTHRACENE	42.17	3887	43712	55.72	UG/ML	10
84)	BENZO(G,H,I)PERYLENE	42.81	3956	45504	60.07	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32172::B2 Quant Output File: ^32172::Q2
Name: 96-3528-03MS;;1; R Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#58

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961016 19:00
Injected at: 961016 18:14

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: W404MSD		
Lab Sample Number	: 96-3528-03MSD	Client I.D.	: 725524.060
Date Sampled	: 10/03/96	Lab Project No.	: 96-3528
Date Received	: 10/04/96	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32173
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	% REC
Naphthalene	91-20-3	67	64%
2-Methylnaphthalene	91-57-6	97	97%
Acenaphthylene	208-96-8	64	64%
Acenaphthene	83-32-9	63	63%
Dibenzofuran	132-64-9	91	91%
Fluorene	86-73-7	60	60%
Phenanthrene	85-01-8	56	56%
Anthracene	120-12-7	52	52%
Fluoranthene	206-44-0	45	45%
Pyrene	129-00-0	47	47%
Benzo(a)Anthracene	56-55-3	40	40%
Chrysene	218-01-9	34	34%
Benzo(b)Fluoranthene	205-99-2	37	37%
Benzo(k)Fluoranthene	207-08-9	41	41%
Benzo(a)Pyrene	50-32-8	37	37%
Indeno(1,2,3-cd)Pyrene	193-39-5	35	35%
Dibenz(a,h)Anthracene	53-70-3	37	37%
Benzo(g,h,i)Perylene	191-24-2	38	38%

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	74%		(35-113)
2-Fluorobiphenyl	100 ug/L	68%		(45-116)
Terphenyl-d14	100 ug/L	22%	X	(33- 95)

QUALIFIERS:
X = **Poor surrogate recovery exhibited in duplicate indicating matrix effect.**
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

Operator ID: BUB
Output File: ^32173::Q2
Data File: >32173::B2
Name: 96-3528-03MSD;;1;RP
Misc: 1;1000;W;1;0;10/07/96;W;1

Quant Rev: 7 Quant Time: 961016 19:53
Injected at: 961016 19:07
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#59

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Scan#	Area	Conc	Units	Q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.26	871	31663	40.00	UG/ML	94
2)	N-NITROSODIMETHYLAMINE	6.68	52	46407	52.71	UG/ML	100
3)	PYRIDINE	6.68	52	102923	88.45	UG/ML	100
8)	BIS(2-CHLOROETHYL)ETHER	13.59	799	75445	54.90	UG/ML	100
10)	1,3-DICHLOROBENZENE	14.09	853	61520	58.72	UG/ML	100
11)	1,4-DICHLOROBENZENE	14.32	877	63939	59.98	UG/ML	100
13)	1,2-DICHLOROBENZENE	14.71	920	57650	58.90	UG/ML	100
15)	BIS(2-CHLOROISOPROPYL)ETHER	15.09	961	106521	75.49	UG/ML	100
17)	N-NITROSO-DI-N-PROPYLAMINE	15.46	1001	62400	73.58	UG/ML	100
18)	HEXACHLOROETHANE	15.67	1023	29159	56.64	UG/ML	100
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.89	1263	102689	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.84	1042	88325	74.44	UG/ML	100
21)	NITROBENZENE	15.90	1048	87665	70.33	UG/ML	100
22)	ISOPHORONE	16.59	1123	154776	69.89	UG/ML	100
25)	BIS(2-CHLOROETHOXY)METHANE	17.29	1198	92636	68.73	UG/ML	100
28)	1,2,4-TRICHLOROBENZENE	17.74	1247	50148	65.56	UG/ML	100
29)	NAPHTHALENE	17.95	1270	154413	66.55	UG/ML	100
30)	4-CHLOROANILINE	18.17	1293	75428	79.44	UG/ML	100
31)	HEXACHLOROBUTADIENE	18.35	1313	24275	59.73	UG/ML	100
33)	2-METHYLNAPHTHALENE	20.02	1493	130061	97.01	UG/ML	100
34)	1-METHYLNAPHTHALENE	20.02	1493	130061	97.01	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.11	1827	49465	40.00	UG/ML	100
36)	HEXACHLOROCYCLOPENTADIENE	20.48	1543	10151	36.60	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.16	1616	98358	68.18	UG/ML	100
40)	2-CHLORONAPHTHALENE	21.45	1648	83999	61.01	UG/ML	100
41)	2-NITROANILINE	21.82	1688	73875	96.71	UG/ML	100
42)	DIMETHYLPHTHALATE	22.41	1752	16255	9.80	UG/ML	100
43)	2,6-DINITROTOLUENE	22.57	1769	26477	63.71	UG/ML	100
44)	ACENAPHTHYLENE	22.68	1781	132311	63.73	UG/ML	100
45)	3-NITROANILINE	23.06	1822	68686	83.73	UG/ML	100
46)	ACENAPHTHENE	23.21	1838	81049	63.45	UG/ML	100
49)	DIBENZOFURAN	23.74	1895	156516	91.39	UG/ML	100
50)	2,4-DINITROTOLUENE	23.77	1898	30200	57.13	UG/ML	100
51)	DIETHYL PHTHALATE	24.56	1984	49916	30.35	UG/ML	100
52)	4-CHLOROPHENYL-PHENYL-ETHER	24.82	2012	36810	58.95	UG/ML	100
53)	FLUORENE	24.77	2006	78595	60.03	UG/ML	100
54)	4-NITROANILINE	24.90	2020	62713	96.47	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.56	2308	68796	40.00	UG/ML	100
58)	N-NITROSODIPHENYLAMINE	25.19	2052	57001	67.48	UG/ML	100
59)	AZOBENZENE	25.29	2063	135469	64.29	UG/ML	100

Operator ID: BCB
Output File: ^32123::02
Data File: >32123::B2
Name: 96-3528-03MSD;;1;RP
Misc: 1;1000;W;1;0;10/07/96;W;1

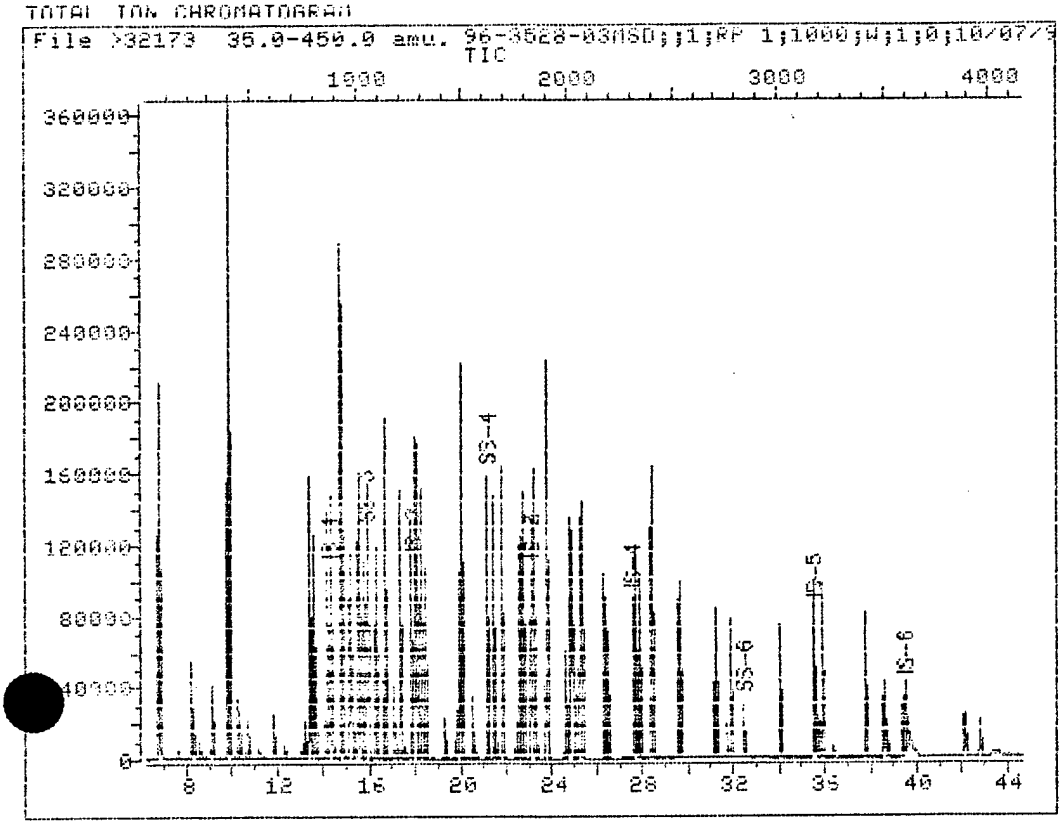
Quant Rev: 7 Quant Time: 961016 19:53
Injected at: 961016 19:0?
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#59

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Scan#	Area	Conc	Units	S
60)	4-BROMOPHENYL-PHENYL-ETHER	26.28	2170	19236	59.01	UG/ML	10
61)	HEXACHLOROBENZENE	26.39	2181	19121	46.97	UG/ML	10
63)	PHENANTHRENE	27.63	2316	91833	56.24	UG/ML	10
64)	ANTHRACENE	27.78	2332	85297	52.08	UG/ML	10
65)	CARBAZOLE	28.33	2391	139710	87.78	UG/ML	10
66)	DI-N-BUTYLPHTHALATE	29.53	2521	94417	38.66	UG/ML	10
67)	FLUORANTHENE	31.21	2702	68761	44.71	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.52	3168	37901	40.00	UG/ML	10
69)	PYRENE	31.87	2774	67587	46.63	UG/ML	10
70)	BENZIDINE	32.45	2837	241	19.89	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.45	2837	18299	22.31	UG/ML	10
72)	BUTYL-BENZYLPHTHALATE	34.04	3008	32972	34.68	UG/ML	10
73)	3,3'-DICHLOROBENZIDINE	35.50	3166	15847	49.68	UG/ML	
74)	BENZO(A)ANTHRACENE	35.49	3165	42759	40.17	UG/ML	
75)	BIS(2-ETHYLHEXYL)PHTHALATE	32.70	3404	69697	33.51	UG/ML	
76)	CHRYSENE	35.59	3176	36270	34.22	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.42	3596	33175	40.00	UG/ML	10
78)	DI-N-OCTYLPHTHALATE	32.70	3404	69697	33.84	UG/ML	10
79)	BENZO(B)FLUORANTHENE	38.50	3491	34625	37.25	UG/ML	10
80)	BENZO(K)FLUORANTHENE	38.58	3499	35888	40.75	UG/ML	10
81)	BENZO(A)PYRENE	39.34	3581	30183	37.28	UG/ML	10
82)	INDENO(1,2,3-CD)PYRENE	42.08	3878	25199	35.04	UG/ML	10
83)	DIBENZ(A,H)ANTHRACENE	42.16	3886	24229	32.47	UG/ML	10
84)	BENZO(G,H,I)PERYLENE	42.80	3959	2368?1	37.83	UG/ML	10

* Compound is IS!D

TOTAL ION CHROMATOGRAM



Data File: >32173::02 Quant Output File: ^32173::Q2
Name: 96-3528-03MSD;;1;RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#59

Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BDB
Quant Time : 961016 19:51
Injected at: 961016 19:07

EVERGREEN ANALYTICAL, INC.
4036 Youngfied Wheat Ridge CO 80033
(303)425-6021
POLYNUCLEAR AROMATICS ANALYSIS DATA REPORT

Client Sample Number	: LCS100796		
Lab Sample Number	: LCS100796	Client I.D.	: 725524.0600
Date Sampled	: NA	Lab Project No.	: 96-3528
Date Received	: NA	Effective Dilution	: 1.00
Date Extracted/Prepared	: 10/07/96	Method	: 8270B
Date Analyzed	: 10/16/96	Matrix	: WATER
Percent Loss on Drying	: NA	Lab File No.	: >32174
		Method Blank No.	: WB100796

BASE/NEUTRALS

Compound Name	Cas Number	Conc. ug/L	% REC
Naphthalene	91-20-3	84	84%
2-Methylnaphthalene	91-57-6	130	130%
Acenaphthylene	208-96-8	86	86%
Acenaphthene	83-32-9	88	88%
Dibenzofuran	132-64-9	130	130%
Fluorene	86-73-7	87	87%
Phenanthrene	85-01-8	89	89%
Anthracene	120-12-7	88	88%
Fluoranthene	206-44-0	79	79%
Pyrene	129-00-0	93	93%
Benzo(a)Anthracene	56-55-3	85	85%
Chrysene	218-01-9	71	71%
Benzo(b)Fluoranthene	205-99-2	83	83%
Benzo(k)Fluoranthene	207-08-9	86	86%
Benzo(a)Pyrene	50-32-8	80	80%
Indeno(1,2,3-cd)Pyrene	193-39-5	80	80%
Dibenz(a,h)Anthracene	53-70-3	89	89%
Benzo(g,h,i)Perylene	191-24-2	96	96%

Expected Surrogate Recoveries:		Actual Recoveries:		QC Limits
Nitrobenzene-d5	100 ug/L	96%		(35-113)
2-Fluorobiphenyl	100 ug/L	99%		(45-116)
Terphenyl-d14	100 ug/L	101%		(33- 95)

QUALIFIERS:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent wat
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits listed in EPA SW846, Vol. 1B, Part II, pa. 8270B-8. The minimum instrument detection limits are less than th numbers shown in this column.

Analyst

Approved

QUANT REPORT Page 1

Operator ID: BOB Quant Rev: 7 Quant Time: 961016 20:47
Output File: ^32174::Q2 Injected at: 961016 20:01
Data File: >32174::B2 Dilution Factor: 1.00000
Name: LCS100796;;1;RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#60

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

	Compound	R.T.	Scan#	Area	Conc	Units	Q
1)	*1,4-DICHLOROBENZENE-D4(INT ST)	14.26	871	36147	40.00	UG/ML	91
2)	N-NITROSODIMETHYLAMINE	6.72	56	70505	70.15	UG/ML	100
3)	PYRIDINE	6.70	54	149688	112.68	UG/ML	100
8)	BIS(2-CHLOROETHYL)ETHER	13.59	799	111456	71.04	UG/ML	100
10)	1,3-DICHLOROBENZENE	14.09	853	85546	71.52	UG/ML	100
11)	1,4-DICHLOROBENZENE	14.31	876	87771	72.12	UG/ML	100
13)	1,2-DICHLOROBENZENE	14.72	921	79966	71.57	UG/ML	100
15)	BIS(2-CHLOROISOPROPYL)ETHER	15.10	962	163849	101.72	UG/ML	100
17)	N-NITROSO-DI-N-PROPYLAMINE	15.48	1003	97218	100.42	UG/ML	100
18)	HEXACHLOROETHANE	15.67	1023	40108	68.25	UG/ML	100
19)	*NAPHTHALENE-D8(INTERNAL STD)	17.90	1264	119872	40.00	UG/ML	100
20)	NITROBENZENE-D5(SURROGATE ST)	15.85	1043	133465	96.36	UG/ML	100
21)	NITROBENZENE	15.91	1049	128193	88.10	UG/ML	100
22)	ISOPHORONE	16.60	1124	233689	90.39	UG/ML	100
25)	BIS(2-CHLOROETHOXY)METHANE	17.30	1199	138344	87.93	UG/ML	100
28)	1,2,4-TRICHLOROBENZENE	17.74	1247	77184	86.45	UG/ML	100
29)	NAPHTHALENE	17.96	1271	226467	83.61	UG/ML	100
30)	4-CHLOROANILINE	18.16	1292	54234	49.38	UG/ML	100
31)	HEXACHLOROBUTADIENE	18.35	1313	42942	90.52	UG/ML	100
33)	2-METHYLNAPHTHALENE	20.03	1494	205819	131.52	UG/ML	100
34)	1-METHYLNAPHTHALENE	20.03	1494	205819	131.52	UG/ML	100
35)	*ACENAPHTHENE-D10(INTERNAL STD)	23.11	1827	57961	40.00	UG/ML	100
36)	HEXACHLOROCYCLOPENTADIENE	20.48	1543	28176	86.71	UG/ML	100
39)	2-FLUOROBIPHENYL(SURROGATE ST)	21.16	1616	167870	99.31	UG/ML	100
40)	2-CHLORONAPHTHALENE	21.45	1648	136501	84.61	UG/ML	100
41)	2-NITROANILINE	21.83	1688	103430	115.56	UG/ML	100
42)	DIMETHYLPHTHALATE	22.43	1753	18452	9.50	UG/ML	100
43)	2,6-DINITROTOLUENE	22.58	1770	39605	81.33	UG/ML	100
44)	ACENAPHTHYLENE	22.69	1781	209813	86.24	UG/ML	100
46)	ACENAPHTHENE	23.21	1838	132021	88.21	UG/ML	100
49)	DIBENZOFURAN	23.75	1896	254391	126.77	UG/ML	100
50)	2,4-DINITROTOLUENE	23.77	1898	44618	72.03	UG/ML	100
51)	DIETHYL PHTHALATE	24.57	1984	84943	44.08	UG/ML	100
52)	4-CHLOROPHENYL-PHENYL-ETHER	24.83	2012	68490	93.60	UG/ML	100
53)	FLUORENE	24.77	2006	133381	86.93	UG/ML	100
54)	4-NITROANILINE	24.91	2021	91160	119.68	UG/ML	100
56)	*PHENANTHRENE-D8(INTERNAL STD)	27.56	2308	79296	40.00	UG/ML	100
58)	N-NITROSODIPHENYLAMINE	25.21	2053	91794	94.28	UG/ML	100
59)	AZOBENZENE	25.31	2064	223323	91.90	UG/ML	100
60)	4-BROMOPHENYL-PHENYL-ETHER	26.29	2170	37634	100.16	UG/ML	100

Operator ID: BOB
Output File: ^32174::Q2
Data File: >32174::B2
Name: LCS100796;;1;RP
Misc: 1;1000;W;1;0;10/07/96;W;1

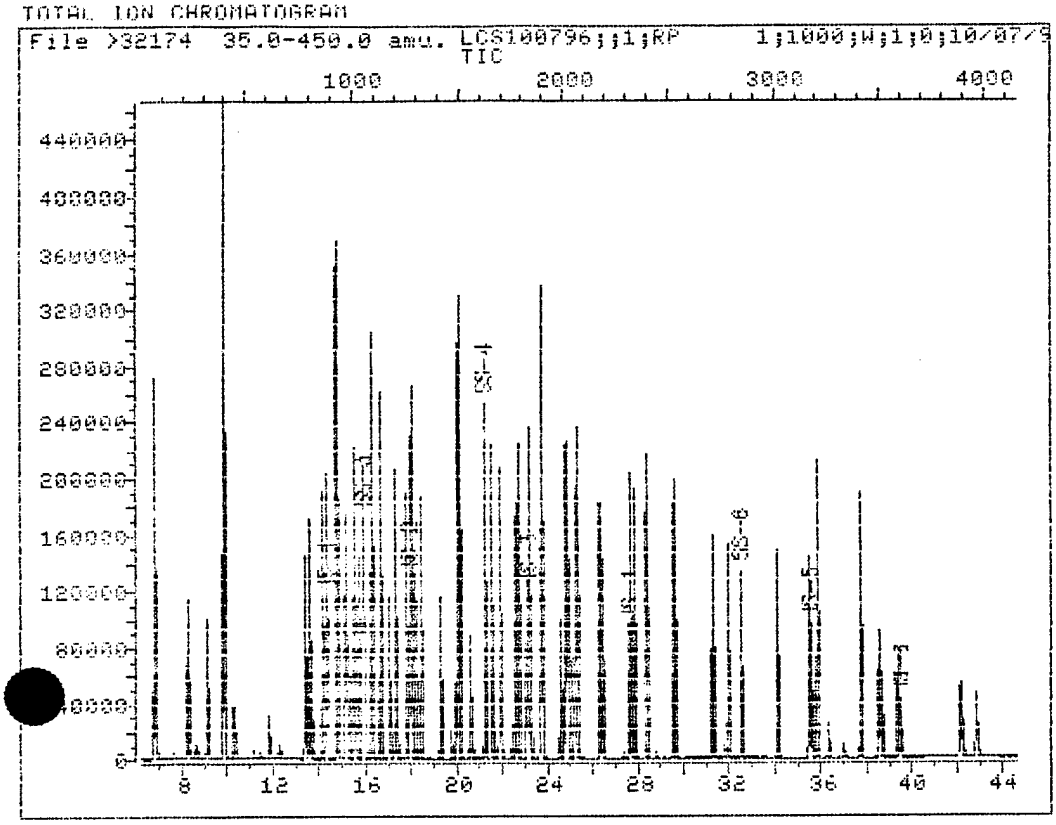
Quant Rev: 7 Quant Time: 961016 20:47
Injected at: 961016 20:01
Dilution Factor: 1.00000
Instrument ID: BNA 1
BTL#60

ID File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Local Time : <none>

	Compound	R.T.	Scan#	Area	Conc	Units	q
61)	HEXACHLOROBENZENE	26.39	2181	44161	94.12	UG/ML	10
63)	PHENANTHRENE	27.64	2316	167264	88.87	UG/ML	10
64)	ANTHRACENE	27.80	2333	166919	88.43	UG/ML	10
65)	CARBAZOLE	28.33	2391	206345	112.48	UG/ML	10
66)	DI-N-BUTYLPHTHALATE	29.54	2521	203941	72.45	UG/ML	10
67)	FLUORANTHENE	31.21	2702	140782	79.43	UG/ML	10
68)	*CHRYSENE-D12(INTERNAL STD)	35.52	3168	39233	40.00	UG/ML	10
69)	PYRENE	31.88	2774	139695	93.10	UG/ML	10
70)	BENZIDINE	32.47	2838	1331	106.12	UG/ML	10
71)	TERPHENYL-D14(SURROGATE STD)	32.46	2837	86109	101.45	UG/ML	10
72)	BUTYL-BENZYLPHTHALATE	34.04	3008	68646	69.76	UG/ML	10
73)	3,3'-DICHLOROBENZIDINE	35.49	3165	14231	39.56	UG/ML	10
74)	BENZO(A)ANTHRACENE	35.50	3166	93661	85.01	UG/ML	10
75)	BIS(2-ETHYLHEXYL)PHTHALATE	37.70	3404	159803	74.23	UG/ML	10
76)	CHRYSENE	35.59	3176	77578	70.71	UG/ML	10
77)	*PERYLENE-D12(INTERNAL STD)	39.48	3596	34356	40.00	UG/ML	10
78)	DI-N-OCTYLPHTHALATE	37.70	3404	159803	74.93	UG/ML	10
79)	BENZO(B)FLOURANTHENE	38.51	3491	80081	83.19	UG/ML	10
80)	BENZO(K)FLUORANTHENE	38.59	3500	78495	86.07	UG/ML	10
81)	BENZO(A)PYRENE	39.34	3581	67455	80.46	UG/ML	10
82)	INDENO(1,2,3-CD)PYRENE	42.10	3829	59601	80.05	UG/ML	10
83)	DIBENZ(A,H)ANTHRACENE	42.17	3837	59391	88.52	UG/ML	10
84)	BENZO(G,H,I)PERYLENE	42.82	3897	62264	96.02	UG/ML	10

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File: >32174::B2 Quant Output File: ^32174::Q2
Name: LCS100796;;1;RP Instrument ID: BNA 1
Misc: 1;1000;W;1;0;10/07/96;W;1 BTL#60

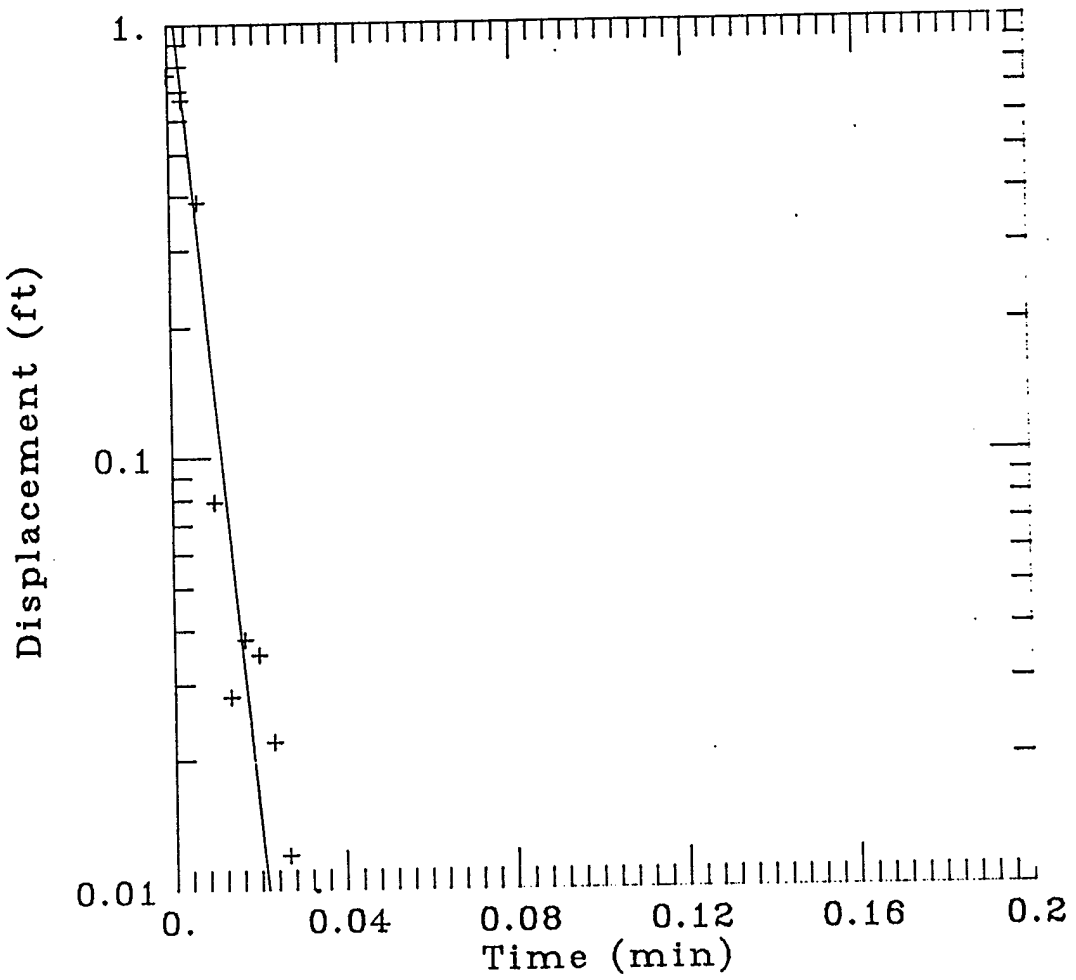
Id File: ID_827::QT
Title: SEMIVOLATILE PRIORITY POLLUTANT IDENTIFICATION
Last Calibration: 961007 14:56 Last Qcal Time: <none>

Operator ID: BOB
Quant Time : 961016 20:47
Injected at: 961016 20:01

APPENDIX C
AQUIFER TEST DATA AND ANALYSES (FROM 1992 RI)

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC – 135 (SS–51) W – 400



DATA SET:
W-400.DS
01/25/93

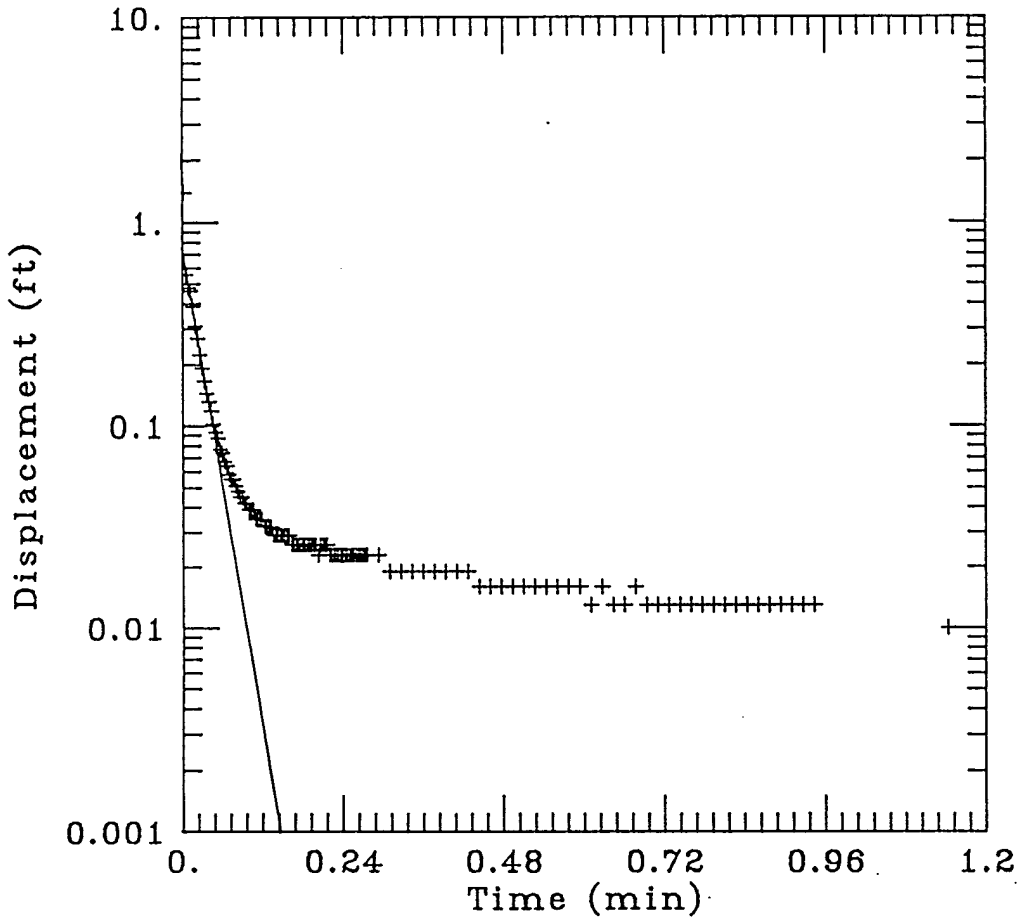
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
January 9, 10 1993
OBS. WELL:
W - 400

ESTIMATED PARAMETERS:
K = 0.216 ft/min
y0 = 1.471 ft

TEST DATA:
H0 = 0.762 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 7.38 ft
b = 12.5 ft
H = 7.38 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 401



DATA SET:
W-401.DS
01/20/93

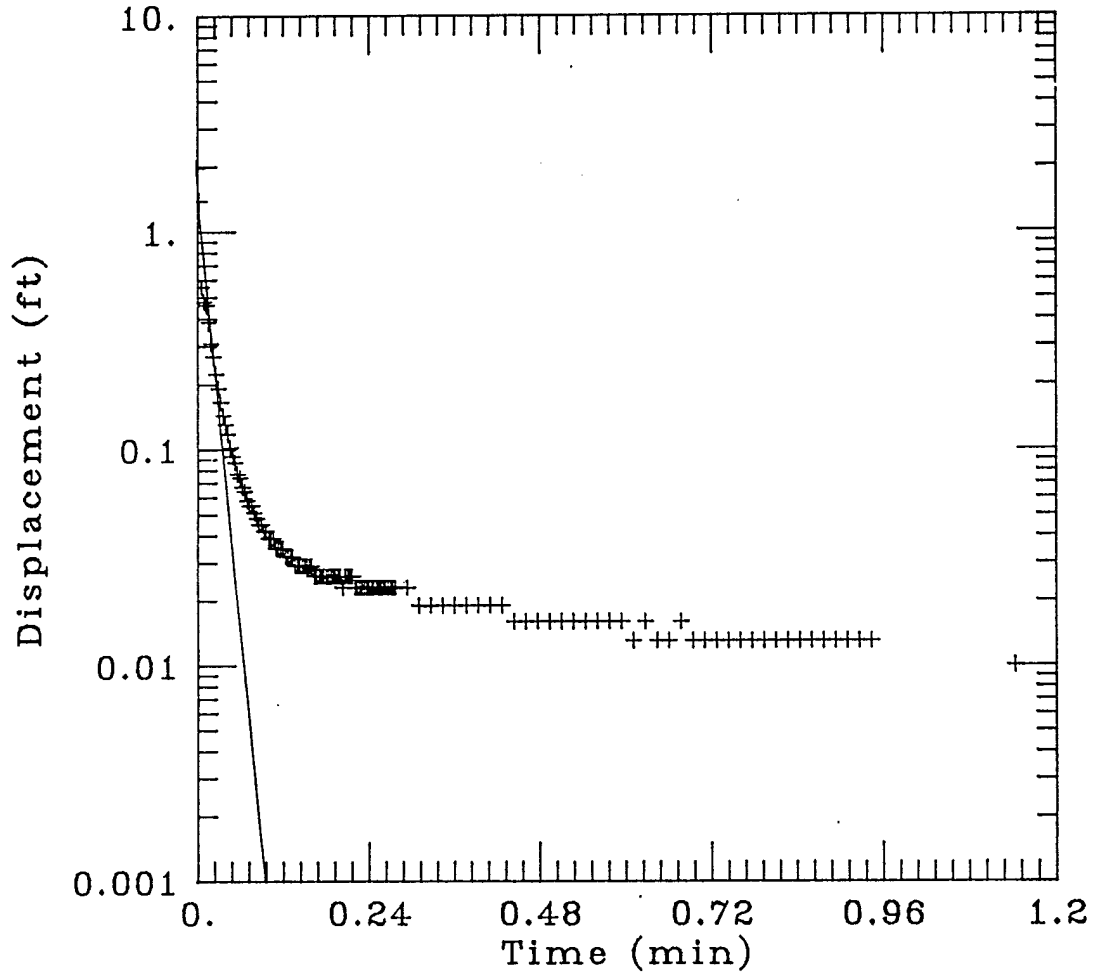
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
January 9, 10 1993
OBS. WELL:
W - 401

ESTIMATED PARAMETERS:
K = 0.03986 ft/min
y0 = 0.7427 ft

TEST DATA:
H0 = 1.979 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 8.17 ft
b = 13.5 ft
H = 8.17 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 401



DATA SET:
W-401.DS
01/20/93

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
January 9, 10 1993

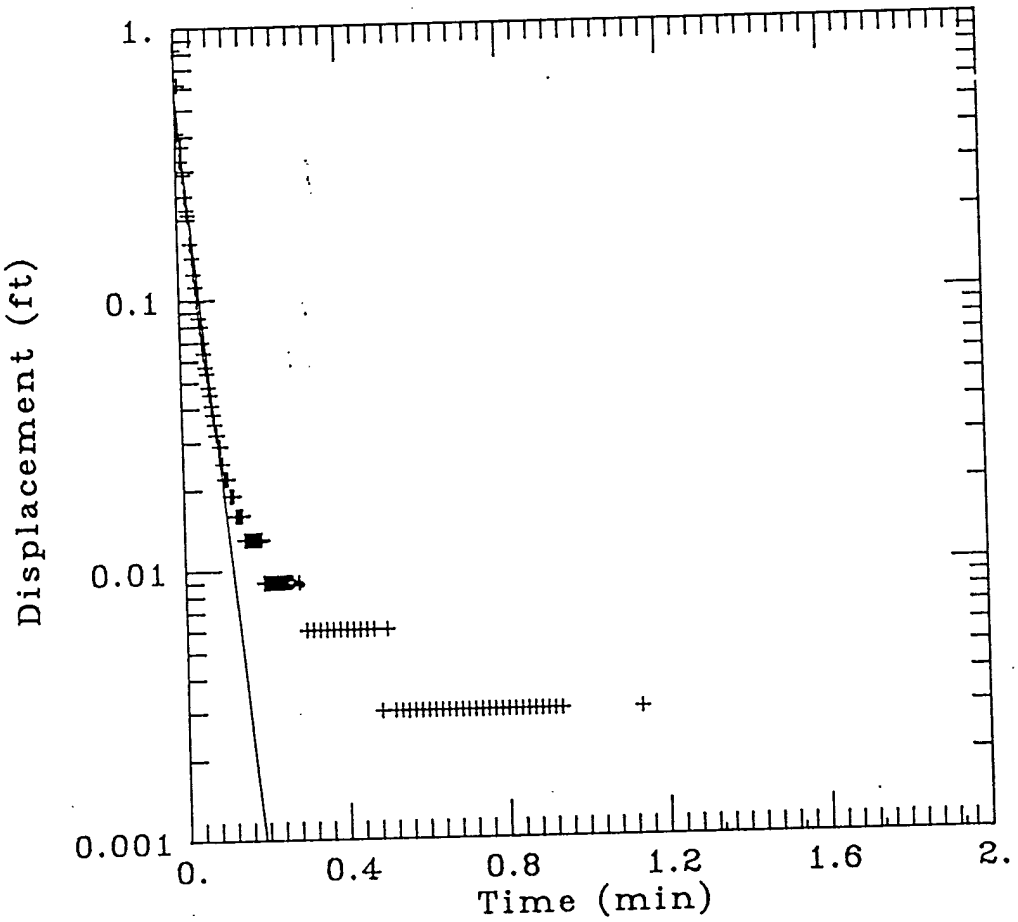
OBS. WELL:
W - 401

ESTIMATED PARAMETERS:
K = 0.06798 ft/min
y0 = 1.419 ft

TEST DATA:
H0 = 1.979 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 8.17 ft
b = 13.5 ft
H = 8.17 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 402



DATA SET:
\HERMIT\WAFB\W-402.DS
01/25/93

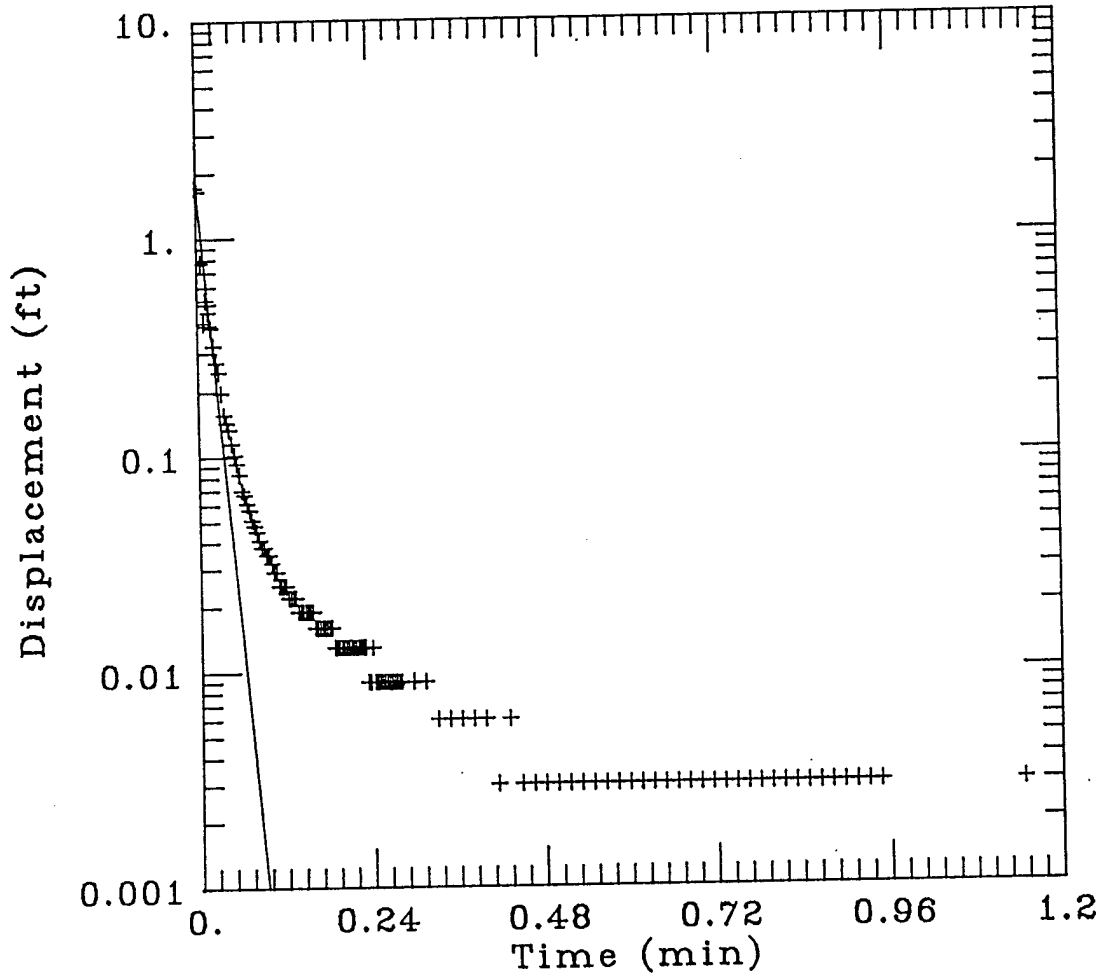
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
January 10 1993
OBS. WELL:
W - 402

ESTIMATED PARAMETERS:
K = 0.02755 ft/min
y0 = 0.5626 ft

TEST DATA:
H0 = 0.828 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 9.3 ft
b = 14.3 ft
H = 9.3 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 403



DATA SET:
W-403.DS
01/20/93

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
January 9, 10 1993

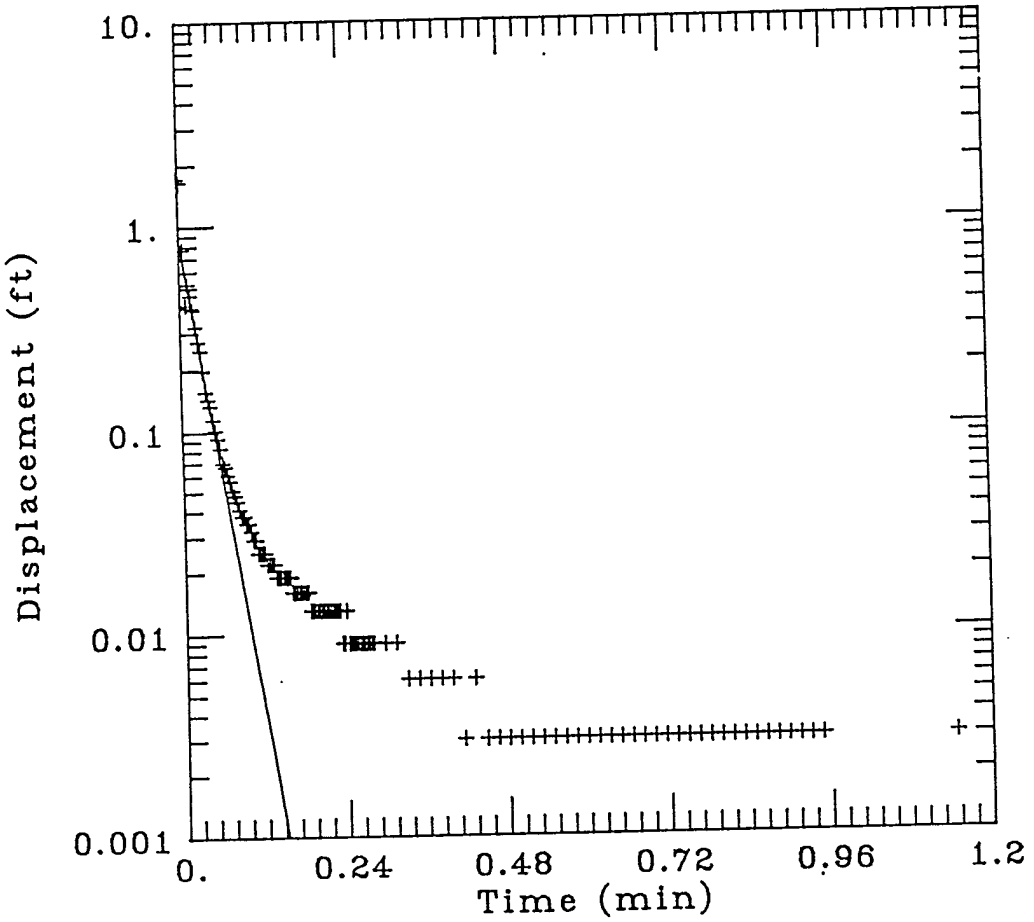
OBS. WELL:
W - 403

ESTIMATED PARAMETERS:
K = 0.07241 ft/min
y0 = 1.754 ft

TEST DATA:
H0 = 1.711 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 8.3 ft
b = 13.5 ft
H = 8.3 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 403



DATA SET:
W-403.DS
01/20/93

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATE:
January 9, 10 1993

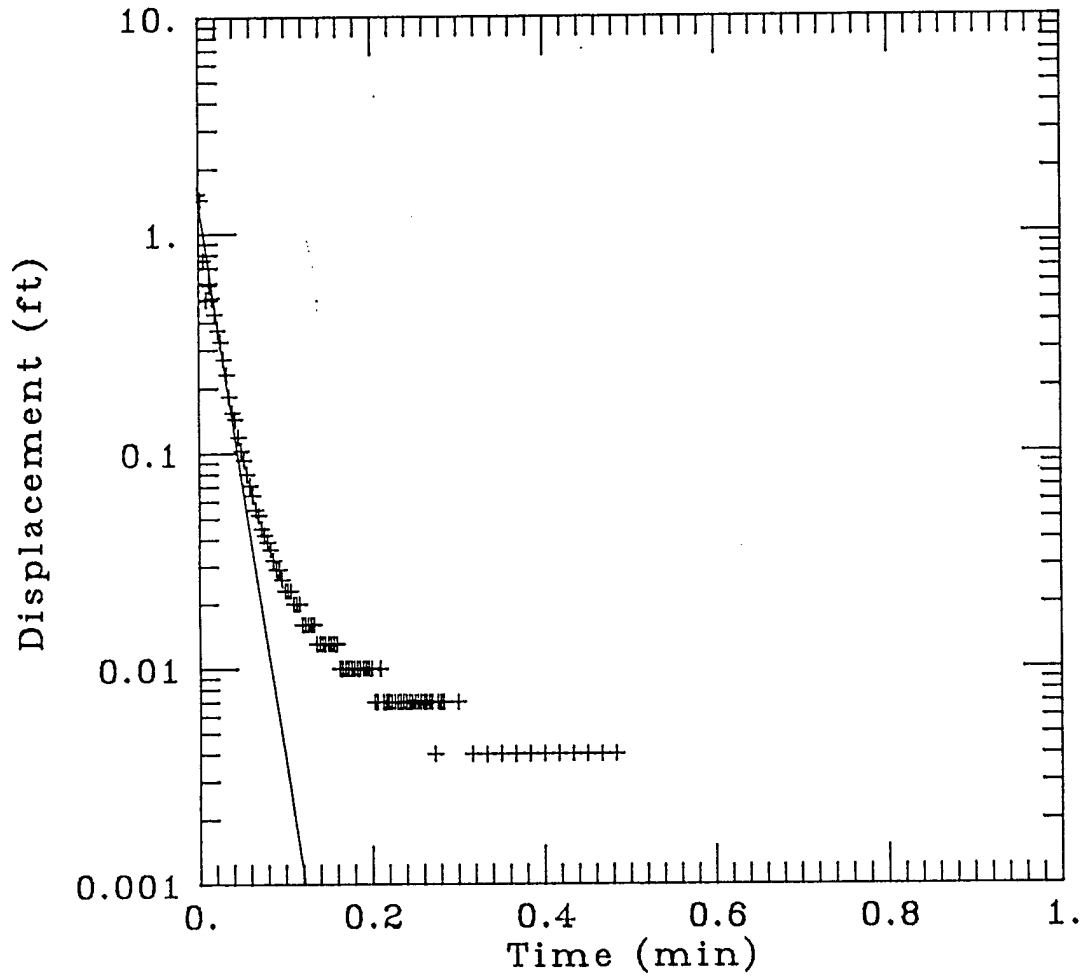
OBS. WELL:
W - 403

ESTIMATED PARAMETERS:
K = 0.04006 ft/min
y0 = 0.871 ft

TEST DATA:
H0 = 1.711 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 8.3 ft
b = 13.5 ft
H = 8.3 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC-135 (SS-51) W - 404



DATA SET:
w-404.ds
01/20/93

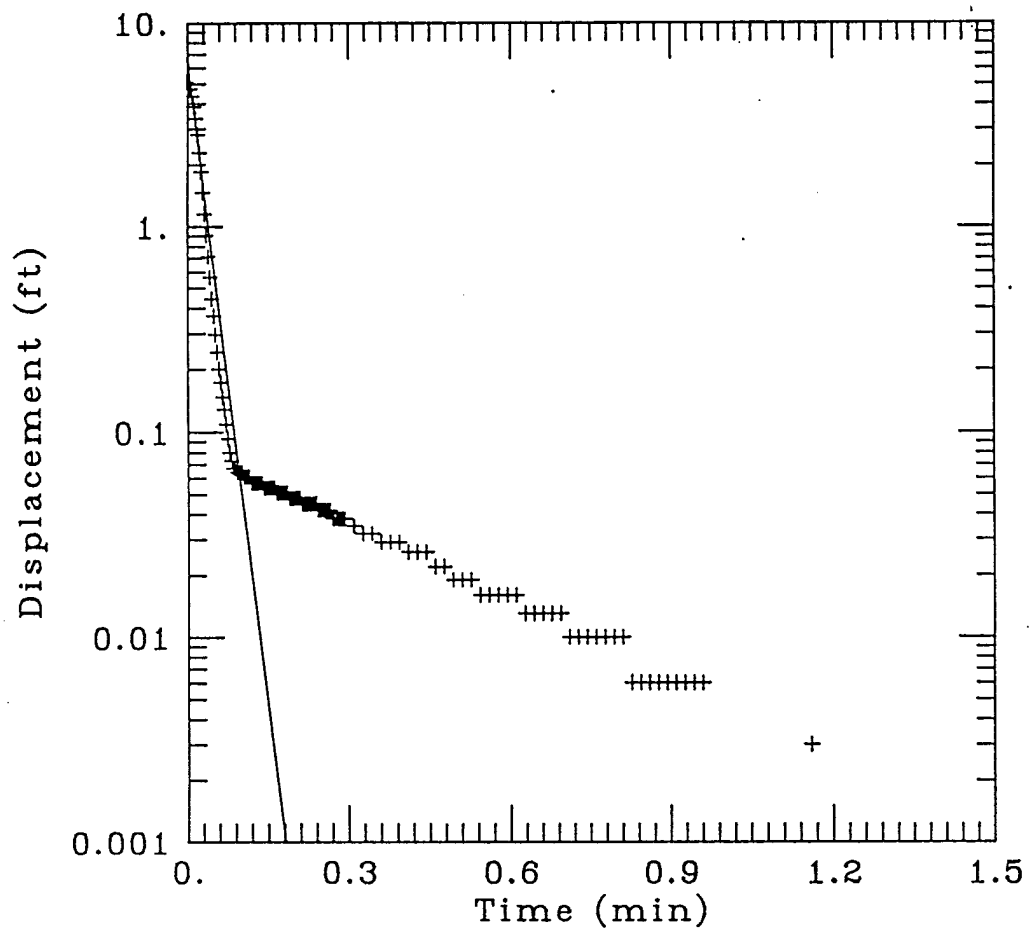
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
January 9, 10 1993
OBS. WELL:
W - 404

ESTIMATED PARAMETERS:
K = 0.05115 ft/min
y0 = 1.391 ft

TEST DATA:
H0 = 1.523 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 8.5 ft
b = 13.5 ft
H = 8.5 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 405



DATA SET:
w-405.ds
01/20/93

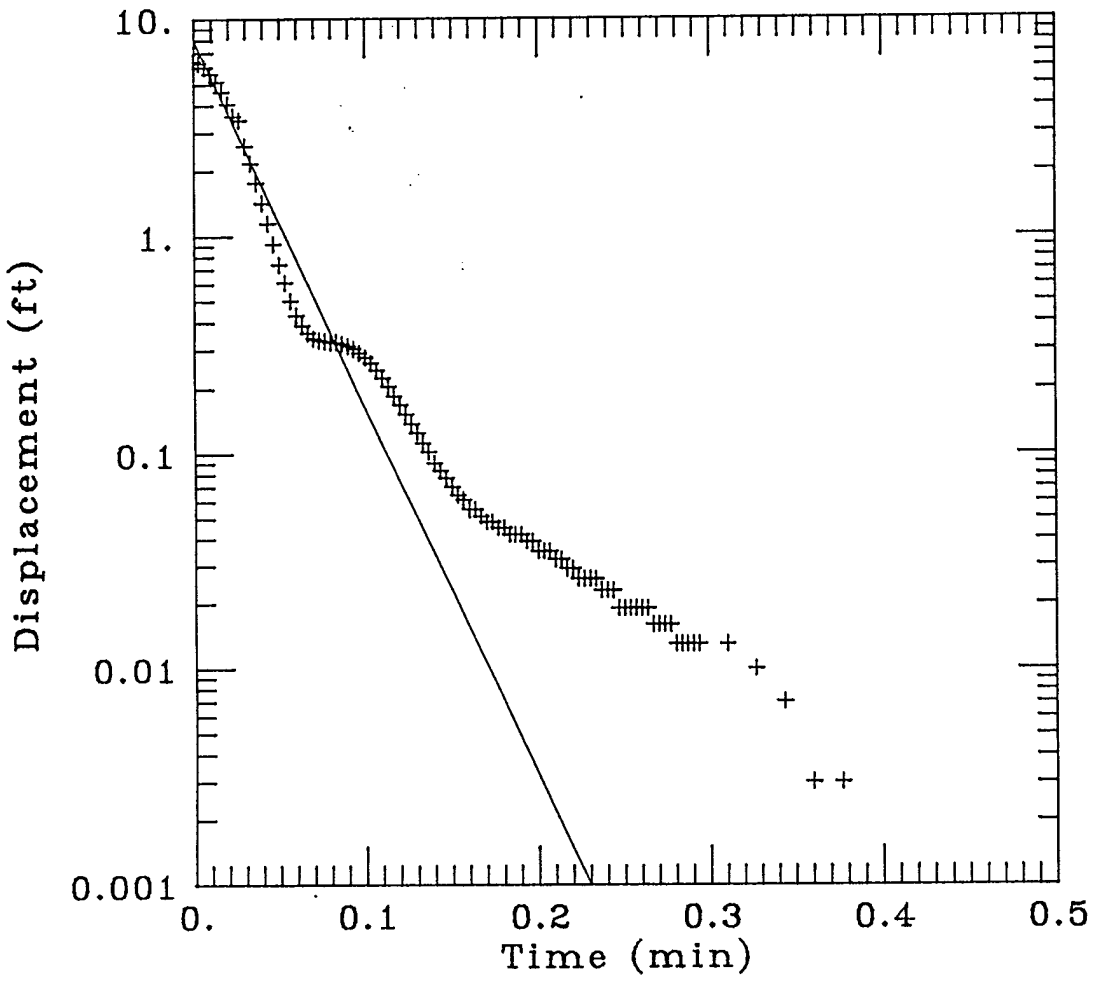
AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer Rice
TEST DATE:
January 9, 10 1993
OBS. WELL:
W - 405

ESTIMATED PARAMETERS:
K = 0.05536 ft/min
y0 = 6.561 ft

TEST DATA:
H0 = 5.115 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 8.2 ft
b = 40.[illegible] ft
H = 35.69 ft

WW ENGINEERING & SCIENCE	Client: USAF
Project No.: 22425.02	Location: WURTSMITH AFB, MI

WURTSMITH KC - 135 (SS-51) W - 406



DATA SET:
\HERMIT\WAFB\W-406.DS
01/20/93

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice
TEST DATE:
January 9, 10 1993
OBS. WELL:
W - 406

ESTIMATED PARAMETERS:
K = 0.04363 ft/min
y0 = 7.977 ft

TEST DATA:
H0 = 6.404 ft
rc = 0.08333 ft
rw = 0.345 ft
L = 7.6 ft
b = 26. ft
H = 21.06 ft

APPENDIX D
QUANTITATIVE FATE AND TRANSPORT DATA

REDOX INFORMATION

Table B.3.3

Electron Donor and Electron Acceptor Half Cell Reactions

HALF-CELL REACTIONS	$\Delta G°_r$ (kcal/equiv)*	$\Delta G°_r$ (kJ/equiv)*	E° (V)	Eh (V)	pe	Conditions for Eh and pe §
ELECTRON-ACCEPTOR (REDUCTION) HALF CELL REACTIONS						
$5e^- + 6H^+ + NO_3^- \Rightarrow 0.5N_2 + 3H_2O$ *Denitrification*	-28.7	-120.	+1.24	+0.708	+12.0	pH = 7 $\Sigma[N]=10^{-3}$
$4e^- + 4H^+ + O_2 \Rightarrow 2H_2O$ *Aerobic Respiration*	-28.3	-119.	+1.23	+0.805	+13.6	pH = 7 P_{O_2}=0.21 atm
$2e^- + 4H^+ + \underline{MnO_2} \Rightarrow Mn^{2+} + 2H_2O$ *Pyrolusite Dissolution/Reduction*	-28.3	-119	+1.23	+1.169	+19.8	pH = 7 $\Sigma[Mn]=10^{-5}$
$CO_2 + e^- + H^+ + \underline{MnOOH} \Rightarrow MnCO_3 + H_2O$ *Manganite Carbonation/Reduction*	-23.1	-96.8	+1.00	+0.408	+6.90	pH = 8 $P_{CO_2}=10^{-2}$
$e^- + H^+ + MnO_2 \Rightarrow \underline{MnOOH}$ *Pyrolusite Hydrolysis/Reduction*	-22.1	-92.5	+0.959	+0.545	+9.21	pH = 7
$e^- + 3H^+ + \underline{Fe(OH)_{3,amph.}} \Rightarrow Fe^{2+} + 3H_2O$ *Amorphous "Goethite" Dissolution/Reduction*	-21.5	-89.9	+0.932	+0.163	+2.75	pH = 6 $\Sigma[Fe]=10^{-5}$
$8e^- + 10H^+ + NO^-_3 \Rightarrow NH^+_4 + 3H_2O$ *Nitrate Reduction*	-20.3	-84.9	+0.879	+0.362	+6.12	pH = 7
$2e^- + 2H^+ + NO^-_3 \Rightarrow NO^-_2 + H_2O$ *Nitrate Reduction*	-18.9	-78.9	+0.819	+0.404	+6.82	pH = 7
$e^- + 3H^+ + \underline{FeOOH} \Rightarrow Fe^{2+} + 2H_2O$ *"Ferric oxyhydroxide" Dissolution/Reduction*	-15.0	-62.9	+0.652	-0.118	-1.99	pH = 6 Σ [Fe]=10^{-5}
$e^- + 3H^+ + \underline{Fe(OH)_{3,xline.}} \Rightarrow Fe^{2+} + 3H_2O$ *Crystallized "Goethite" Dissolution/Reduction*	-11.8	-49.2	+0.510	-0.259	-4.38	pH = 6 Σ [Fe]=10^{-5}
$e^- + H^+ + CO_{2,g} + \underline{Fe(OH)_{3,amph.}} \Rightarrow \underline{FeCO_3} + 2H_2O$ *Amorphous "Goethite" Carbonation/Reduction*	-11.0	-46.2	+0.479	-0.113	-1.90	pH = 8 $P_{CO_2}=10^{-2}$ atm
$8e^- + 9H^+ + SO^{2-}_4 \Rightarrow HS^- + 4H_2O$ *Sulfate Reduction*	-5.74	-24.0	+0.249	-0.278	-4.70	pH = 8
$8e^- + 10H^+ + SO^{2-}_4 \Rightarrow H_2S^0 + 4H_2O$ *Sulfate Reduction*	-6.93	-28.9	+0.301	-0.143	-2.42	pH = 6
$8e^- + 8H^+ + CO_{2,g} \Rightarrow CH_{4,g} + 2H_2O$ *Methanogenesis*	-3.91	-16.4	+0.169	-0.259	-4.39	pH = 7 $P_{CO_2}=10^{-2}$ $P_{CH_4}=10^{0}$
$C_2Cl_4 + H^+ + 2e^- \Rightarrow C_2HCl_3 + Cl^-$ *PCE Reductive Dechlorination*	-14.79	-61.8	+0.641	+0.552	+9.33	pH = 7 $[Cl^-]=10^{-4}$
$C_2HCl_3 + H^+ + 2e^- \Rightarrow C_2H_2Cl_2 + Cl^-$ *TCE Reductive Dechlorination*	-14.50	-60.6	+0.628	+0.539	+9.12	pH = 7 $[Cl^-]=10^{-4}$
$C_2H_2Cl_2 + H^+ + 2e^- \Rightarrow C_2H_3Cl + Cl^-$ *c-DCE Reductive Dechlorination*	-12.12	-50.7	+0.525	+0.436	+7.38	pH = 7 $[Cl^-]=10^{-4}$
$C_2H_3Cl + H^+ + 2e^- \Rightarrow C_2H_4 + Cl^-$ *VC Reductive Dechlorination*	-13.75	-57.5	+0.596	+0.507	+8.57	pH = 7 $[Cl^-]=10^{-4}$
$C_2H_2Cl_4 + H^+ + 2e^- \Rightarrow C_2H_3Cl_3 + Cl^-$ *PCA Reductive Dechlorination*	-13.59	-56.8	+0.589	+0.500	+8.45	pH = 7 $[Cl^-]=10^{-4}$
$C_2H_3Cl_3 + H^+ + 2e^- \Rightarrow C_2H_4Cl_2 + Cl^-$ *TCA Reductive Dechlorination*	-15.26	-63.8	+0.661	+0.572	+9.67	pH = 7 $[Cl^-]=10^{-4}$
$C_2H_4Cl_2 + H^+ + 2e^- \Rightarrow C_2H_5Cl + Cl^-$ *DCA Reductive Dechlorination*	-14.08	-58.9	+0.610	+0.521	+8.81	pH = 7 $[Cl^-]=10^{-4}$
$C_6Cl_6 + H^+ + 2e^- \Rightarrow C_6HCl_5 + Cl^-$ *Hexachlorobenzene Reductive Dechlorination*	-14.36	-60.0	+0.622	+0.533	+9.01	pH = 7 $[Cl^-]=10^{-4}$
$C_6HCl_5 + H^+ + 2e^- \Rightarrow C_6H_2Cl_4 + Cl^-$ *Pentachlorobenzene Reductive Dechlorination*	-14.64	-61.2	+0.634	+0.545	+9.22	pH = 7 $[Cl^-]=10^{-4}$
$C_6H_2Cl_4 + H^+ + 2e^- \Rightarrow C_6H_3Cl_3 + Cl^-$ *Tetrachlorobenzene Reductive Dechlorination*	-13.66	-57.1	+0.592	+0.503	+8.50	pH = 7 $[Cl^-]=10^{-4}$
$C_6H_3Cl_3 + H^+ + 2e^- \Rightarrow C_6H_4Cl_2 + Cl^-$ *Trichlorobenzene Reductive Dechlorination*	-13.20	-55.2	+0.572	+0.483	+8.17	pH = 7 $[Cl^-]=10^{-4}$

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 $P_{CO_2}=10^{-2}$
$16H_2O + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42H^+ + 42e^-$ *m-Xylene Oxidation*	+3.03	+12.7	-0.132	+0.303	+5.12	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 $P_{CO_2}=10^{-2}$
$4H_2O + C_2H_2Cl_2 \Rightarrow 2CO_2 + 10H^+ + 8e^- + 2Cl^-$ *DCE Oxidation*	-3.88	-16.2	+0.168	-0.131	-2.21	pH = 7 $P_{CO_2}=10^{-2}$
$4H_2O + C_2H_3Cl \Rightarrow 2CO_2 + 11H^+ + 10e^- + Cl^-$ *Vinyl Chloride Oxidation*	-0.55	-2.31	+0.024[a]	-0.006	-0.10	pH = 7 $P_{CO_2}=10^{-2}$
$12H_2O + C_6H_2Cl_4 \Rightarrow 6CO_2 + 26H^+ + 22e^- + 4Cl$ *Tetrachlorobenzene Oxidation*	-0.64	-2.68	+0.028	+0. 016	+0.27	pH = 7 $P_{CO_2}=10^{-2}$
$12H_2O + C_6H_3Cl_3 \Rightarrow 6CO_2 + 27H^+ + 24e^- + 3Cl$ *Trichlorobenzene Oxidation*	+0.42	+1.77	-0.018	-0.030	-0.50	pH = 7 $P_{CO_2}=10^{-2}$
$12H_2O + C_6H_4Cl_2 \Rightarrow 6CO_2 + 28H^+ + 26e^- + 2Cl$ *Dichlorobenzene Oxidation*	+1.40	+5.84	-0.060	-0.071	-1.21	pH = 7 $P_{CO_2}=10^{-2}$
$12H_2O + C_6H_5Cl \Rightarrow 6CO_2 + 29H^+ + 28e^- + Cl$ *Chlorobenzene Oxidation*	+2.22	+9.26	-0.096[a]	-0.107	-1.80	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) * 1.0365×10^{-5} (VF/J) from Stumm and Morgan, 1981

Table B.3.4

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

Species	State	$\Delta G^{\circ}_{f,298.15}$ (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)
$C_2H_2Cl_2$ 1,1-dichloroethene	l	+5.85	Dean (1972)
$C_2H_2Cl_2$ cis-1,2-dichloroethene	l	5.27	CRC Handbook (1990)
$C_2H_2Cl_2$ trans-1,2-dichloroethene	l	+6.52	CRC Handbook (1990)
C_2H_4 Ethene	g aq, m=1	+16.28 +19.43	CRC Handbook (1990)
C_2H_6 Ethane	g aq, m=1	-7.68 -4.09	CRC Handbook (1990)
HCl hydrochloric acid	aq, m=1	-31.372	CRC Handbook (1990)a
$C_2H_2Cl_4$, 1,1,2,2-PCA	l	-22.73	Dean (1972)
$C_2H_3Cl_3$, 1,1,2-TCA	g	-18.54	Dean (1972)
$C_2H_4Cl_2$, 1,2-DCA	g	-17.68	Dean (1972)
$C_2H_5Cl_1$, Chloroethane	g	-14.47	Dean (1972)
$C_{10}H_8$, 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_6Cl_6, Hexachlorobenzene	l	+0.502	Dolfing (1992)
$C_6H_1Cl_5$, Pentachlorobenzene	l	+3.16	Dolfing (1992)
$C_6H_2Cl_4$, 1,2,4,5-Tetrachlorobenzene	l	+5.26	Dolfing (1992)
$C_6H_3Cl_3$, 1,2,4-Trichlorobenzene	l	+9.31	Dolfing (1992)
$C_6H_4Cl_2$, 1,4-Dichlorobenzene	l	+14.28	Dolfing (1992)
C_6H_5Cl, chlorobenzene	l	+21.32	Dean (1972)
$C_{14}H_{10}$, phenanthrene	l	+64.12	Dean (1972)

Table B.3.4 - Con't

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

Species	State	$\Delta G^{\circ}_{f,298.15}$ (kcal/mole)	Source
Nitrogen Species			
NO_3^-	l	-26.61	Dean (1972)
N_2	g	0	std
NO_2^-	l	-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 *et al.* (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 l = liquid g = gaseous aq = undissociated aqueous species

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

p = freshly precipitated solid

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

std = accepted by convention

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

Table B.3.5

Coupled Oxidation-Reduction Reactions

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1	0.326:1
$6NO_3^- + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1	0.210:1
$30H^+ + 15\underline{MnO_2} + C_6H_6 \Rightarrow 6CO_{2,g} + 15Mn^{2+} + 18H_2O$ *Benzene oxidation / manganese reduction*	-765.45	-3202	10.56:1	0.095:1
$3.75\ NO_3^- + C_6H_6 + 7.5\ H^+ + 0.75\ H_2O \Rightarrow 6\ CO_2 + 3.75\ NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1	0.336:1
$60H^+ + 30\underline{Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1	0.047:1
$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S^o + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1	0.22:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1	1.30:1
$15\ C_2H_2Cl_4 + C_6H_6 + 12\ H_2O \Rightarrow 6\ CO_2 + 15\ C_2H_3Cl_3 + 15\ H^+ + 15\ Cl^-$ *Benzene oxidation / PCA reduction*	-322.7	-1349	32.2:1	0.03:1
$15\ C_2H_3Cl_3 + C_6H_6 + 12\ H_2O\ 6 \Rightarrow CO_2 + 15\ C_2H_4Cl_2 + 15\ H^+ + 15\ Cl^-$ *Benzene oxidation / TCA reduction*	-372.65	-1558	25.6:1	0.04:1
$15\ C_2H_4Cl_2 + C_6H_6 + 12\ H_2O \Rightarrow 6\ CO_2 + 15\ C_2H_5Cl + 15\ H^+ + 15\ Cl^-$ *Benzene oxidation / DCA reduction*	-337.40	-1410	19.0:1	0.05:1
$15C_2Cl_4 + 12H_2O + C_6H_6 \Rightarrow 15C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-358.55	-1499	31.8:1	0.03:1
$15C_2HCl_3 + 12H_2O + C_6H_6 \Rightarrow 15C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Trichloroethylene reductive dehalogenation*	-331.25	-1385	25.2:1	0.04:1
$15C_2H_2Cl_2 + 12H_2O + C_6H_6 \Rightarrow 15C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-297.35	-1243	18.6:1	0.05:1
$15C_2H_3Cl + 12H_2O + C_6H_6 \Rightarrow 15C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Vinyl chloride reductive dehalogenation*	-327.35	-1368	12.0:1	0.08:1
$15C_6Cl_6 + 12H_2O + C_6H_6 \Rightarrow 15C_6H_1Cl_5 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Hexachlorobenzene reductive dehalogenation*	-345.68	-1445	54.7:1	0.02:1
$15C_6H_1Cl_5 + 12H_2O + C_6H_6 \Rightarrow 15C_6H_2Cl_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Pentachlorobenzene reductive dehalogenation*	-354.05	-1480	48.1:1	0.02:1
$15C_6H_2Cl_4 + 12H_2O + C_6H_6 \Rightarrow 15C_6H_3Cl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Tetrachlorobenzene reductive dehalogenation*	-324.80	-1358	41.5:1	0.02:1
$15C_6H_3Cl_3 + 12H_2O + C_6H_6 \Rightarrow 15C_6H_4Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Trichlorobenzene reductive dehalogenation*	-311.0	-1300	34.8:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$9O_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4H_2O$ *Toluene oxidation /aerobic respiration*	-913.76	-3823	3.13:1	0.32:1
$7.2NO_3^- + 7.2H^+ + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 7.6H_2O + 3.6N_2$ *Toluene oxidation / denitrification*	-926.31	-3875	4.85:1	0.21:1
$36H^+ + 18MnO_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 18Mn^{2+} + 22H_2O$ *Toluene oxidation / manganese reduction*	-913.89	-3824	10.74:1	0.09:1
$72H^+ + 36Fe(OH)_{3,a} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ *Toluene oxidation / iron reduction*	-667.21	-2792	21.86:1	0.05:1
$9H^+ + 4.5SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4.5H_2S^o + 4H_2O$ *Toluene oxidation / sulfate reduction*	-142.86	-597.7	4.7:1	0.21:1
$5H_2O + C_6H_5CH_3 \Rightarrow 2.5CO_{2,g} + 4.5CH_4$ *Toluene oxidation / methanogenesis*	-34.08	-142.6	0.78:1	1.28:1
$18\,C_2H_2Cl_4 + C_6H_5CH_3 + 14\,H_2O \Rightarrow 7\,CO_2 + 18\,C_2H_3Cl_3 + 18H^+ + 18Cl^-$ *Toluene oxidation / PCA reduction*	-382.6	-1599	32.8:1	0.03:1
$18\,C_2H_3Cl_3 + C_6H_5CH_3 + 14\,H_2O \Rightarrow 7\,CO_2 + 18\,C_2H_4Cl_2 + 18H^+ + 18Cl^-$ *Toluene oxidation / TCA reduction*	-442.5	-1850	26.1:1	0.04:1
$18\,C_2H_4Cl_2 + C_6H_5CH_3 + 14\,H_2O \Rightarrow 7\,CO_2 + 18\,C_2H_5Cl + 18\,H^+ + 18\,Cl^-$ *Toluene oxidation / DCA reduction*	-400.2	-1673	19.3:1	0.05:1
$18C_2Cl_4 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2HCl_3 + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ Tetrachloroethylene reductive dehalogenation*	-425.6	-1779	32.4:1	0.03:1
$18C_2HCl_3 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2H_2Cl_2 + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ Trichloroethylene reductive dehalogenation*	-404.9	-1693	25.7:1	0.04:1
$18C_2H_2Cl_2 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2H_3Cl + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-340.1	-1422	18.9:1	0.05:1
$18C_2H_3Cl + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2H_4 + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ Vinyl chloride reductive dehalogenation*	-331.5	-1386	12.2:1	0.08:1
$18C_6Cl_6 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_6H_1Cl_5 + 7CO_2 + 18H^+ + 18Cl$ *Toluene oxidation/ Hexachlorobenzene reductive dehalogenation*	-410.3	-1715	55.6:1	0.02:1
$18C_6H_1Cl_5 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_6H_2Cl_4 + 7CO_2 + 18H^+ + 18Cl$ *Toluene oxidation/ Pentachlorobenzene reductive dehalogenation*	-420.3	-1757	48.9:1	0.02:1
$18C_6H_2Cl_4 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_6H_3Cl_3 + 7CO_2 + 18H^+ + 18Cl$ *Toluene oxidation/ Tetrachlorobenzene reductive dehalogenation*	-385.2	-1610	42.2:1	0.02:1
$18C_6H_3Cl_3 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_6H_4Cl_2 + 7CO_2 + 18H^+ + 18Cl$ *Toluene oxidation/ Trichlorobenzene reductive dehalogenation*	-368.6	-1541	35.4:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Ethylbenzene Oxidation reactions	ΔG°_r kcal/ mole	ΔG°_r kJ/ mole	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$10.5O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5H_2O$ *Ethylbenzene oxidation /aerobic respiration*	-1066.13	-4461	3.17:1	0.32:1
$8.4NO_3^- + 8.4H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *Ethylbenzene oxidation / denitrification*	-1080.76	-4522	4.92:1	0.20:1
$46H^+ + 22\underline{MnO_2} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 22Mn^{2+} + 28H_2O$ *Ethylbenzene oxidation / manganese reduction*	-1066.27	-4461	11.39:1	0.09:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *Ethylbenzene oxidation / iron reduction*	-778.48	-3257	22.0:1	0.05:1
$10.5H^+ + 5.25SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5.25H_2S^\circ + 5H_2O$ *Ethylbenzene oxidation / sulfate reduction*	-166.75	-697.7	4.75:1	0.21:1
$5.5H_2O + C_6H_5C_2H_5 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *Ethylbenzene oxidation / methanogenesis*	-39.83	-166.7	0.79:1	1.27:1
$21C_2H_2Cl_4 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_3Cl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ PCA reductive dehalogenation*	-446.43	-1866	32.8:1	0.03:1
$21C_2H_3Cl_3 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_4Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ TCA reductive dehalogenation*	-516.36	-2158	26.1:1	0.04:1
$21C_2H_4Cl_2 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_5Cl + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ DCA reductive dehalogenation*	-467.01	-1952	19.4:1	0.05:1
$21C_2Cl_4 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2HCl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-496.67	-2078	32.8:1	0.03:1
$21C_2HCl_3 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_2Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Trichloroethylene reductive dehalogenation*	-484.70	-2028	26.0:1	0.04:1
$21C_2H_2Cl_2 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_3Cl + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-384.74	-1610	19.2:1	0.05:1
$21C_2H_3Cl + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_4 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Vinyl chloride reductive dehalogenation*	-368.79	-1617	12.3:1	0.08:1
$21C_6Cl_6 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_6H_1Cl_5 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Hexachlorobenzene reductive dehalogenation*	-478.7	-2001	55.6:1	0.02:1
$21C_6H_1Cl_5 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_6H_2Cl_4 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Pentachlorobenzene reductive dehalogenation*	-490.4	-2050	48.9:1	0.02:1
$21C_6H_2Cl_4 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_6H_3Cl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Tetrachlorobenzene reductive dehalogenation*	-449.4	-1878	42.2:1	0.02:1
$21C_6H_3Cl_3 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_6H_4Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Trichlorobenzene reductive dehalogenation*	-430.1	-1794	35.5:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled m-Xylene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$10.5\ O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 5\ H_2O$ *m-Xylene oxidation / aerobic respiration*	-1063.25	-4448	3.17:1	0.32:1
$8.4\ H^+ + 8.4NO_3^- + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 4.2\ N_2 + 9.2\ H_2O$ *m-Xylene oxidation / denitrification*	-1077.81	-4509	4.92:1	0.20:1
$46\ H^+ + 22MnO_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 22\ Mn^{2+} + 28\ H_2O$ *m-Xylene oxidation / manganese reduction*	-1063.39	-4449	11.39:1	0.09:1
$84\ H^+ + 42Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42\ Fe^{2+} + 110\ H_2O$ *m-Xylene oxidation / iron reduction*	-775.61	-3245	22:1	0.05:1
$10.5H^+ + 5.25SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 5.25\ H_2S^o + 5\ H_2O$ *m-Xylene oxidation / sulfate reduction*	-163.87	-685.6	4.75:1	0.21:1
$5.5H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75CO_2 + 5.25CH_4$ *m-Xylene oxidation / methanogenesis*	-36.95	-154.6	0.79:1 [2]	1.27:1
$21C_2H_2Cl_4 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_3Cl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ PCA reductive dehalogenation*	-445.70	-1863	32.7:1	0.03:1
$21C_2H_3Cl_3 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_4Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ TCA reductive dehalogenation*	-513.48	-2146	26.0:1	0.04:1
$21C_2H_4Cl_2 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_5Cl + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ DCA reductive dehalogenation*	-464.13	-1940	19.3:	0.05:1
$21C_2Cl_4 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2HCl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Tetrachloroethylene reductive dehalogenation*	-493.79	-2066	32.8:1	0.03:1
$21C_2HCl_3 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_2Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Trichloroethylene reductive dehalogenation*	-469.59	-1963	26.0:1	0.04:1
$21C_2H_2Cl_2 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_3Cl + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-393.99	-1647	19.2:1	0.05:1
$21C_2H_3Cl + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_4 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Vinyl chloride reductive dehalogenation*	-383.91	-1605	12.3:1	0.08:1
$21C_6Cl_6 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_6H_1Cl_5 + 8CO_2 + 21H^+ + 21Cl$ *m-Xylene oxidation/ Hexachlorobenzene reductive dehalogenation*	-475.9	-1989	55.6:1	0.02:1
$21C_6H_1Cl_5 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_6H_2Cl_4 + 8CO_2 + 21H^+ + 21Cl$ *m-Xylene oxidation/ Pentachlorobenzene reductive dehalogenation*	-487.5	-2038	48.9:1	0.02:1
$21C_6H_2Cl_4 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_6H_3Cl_3 + 8CO_2 + 21H^+ + 21Cl$ *m-Xylene oxidation/ Tetrachlorobenzene reductive dehalogenation*	-446.6	-1867	42.2:1	0.02:1
$21C_6H_3Cl_3 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_6H_4Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Trichlorobenzene reductive dehalogenation*	-426.9	-1784	35.5:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Naphthalene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$12O_2 + C_{10}H_8 \Rightarrow 10CO_2 + 4H_2O$ *Naphthalene oxidation /aerobic respiration*	-1217.40	-5094	3.00:1	0.33:1
$9.6NO_3^- + 9.6H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 8.8H_2O + 4.8N_{2,g}$ *Naphthalene oxidation / denitrification*	-1234.04	-5163	4.65:1	0.22:1
$24MnO_2 + 48H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 24Mn^{2+} + 28H_2O$ *Naphthalene oxidation / manganese reduction*	-1217.57	-5094	16.31:1	0.06:1
$48Fe(OH)_{3,a} + 96H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 48Fe^{2+} + 124H_2O$ *Naphthalene oxidation / iron reduction*	-932.64	-3902	40.13:1	0.02:1
$6SO_4^{2-} + 12H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 6H_2S^\circ + 4H_2O$ *Naphthalene oxidation / sulfate reduction*	-196.98	-824.2	4.50:1	0.22:1
$8H_2O + C_{10}H_8 \Rightarrow 4CO_2 + 6CH_4$ *Naphthalene oxidation / methanogenesis*	-44.49	-186.1	1.13:1	0.88:1
$24C_2H_2Cl_4 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_3Cl_3 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ PCA reductive dehalogenation*	-511.68	-2139	31.1:1	0.03:1
$24C_2H_3Cl_3 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_4Cl_2 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ TCA reductive dehalogenation*	-589.09	-2462	24.8:1	0.04:1
$24C_2H_4Cl_2 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_5Cl + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ DCA reductive dehalogenation*	-532.69	-2227	18.4:1	0.05:1
$24C_2Cl_4 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2HCl_3 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Tetrachloroethylene reductive dehalogenation*	-566.59	-2371	31.1:1	0.03:1
$24C_2HCl_3 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_2Cl_2 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Trichloroethylene reductive dehalogenation*	-552.91	-2313	24.6:1	0.04:1
$24C_2H_2Cl_2 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_3Cl + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/cis-Dichloroethylene reductive dehalogenation*	-438.67	-1835	18.2:1	0.05:1
$24C_2H_3Cl + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_4 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Vinyl chloride reductive dehalogenation*	-441.01	-1843	11.6:1	0.09:1
$24C_6Cl_6 + 20H_2O + C_{10}H_8 \Rightarrow 24C_6H_1Cl_5 + 10CO_2 + 24H^+ + 24Cl$ *Naphthalene oxidation/ Hexachlorobenzene reductive dehalogenation*	-545.94	-2282	52.9:1	0.02:1
$24C_6H_1Cl_5 + 20H_2O + C_{10}H_8 \Rightarrow 24C_6H_2Cl_4 + 10CO_2 + 24H^+ + 24Cl$ *Naphthalene oxidation/Pentachlorobenzene reductive dehalogenation*	-559.33	-2338	46.5:1	0.02:1
$24C_6H_2Cl_4 + 20H_2O + C_{10}H_8 \Rightarrow 24C_6H_3Cl_3 + 10CO_2 + 24H^+ + 24Cl$ *Naphthalene oxidation/ Tetrachlorobenzene reductive dehalogenation*	-512.53	-2142	40.1:1	0.02:1
$24C_6H_3Cl_3 + 20H_2O + C_{10}H_8 \Rightarrow 24C_6H_4Cl_2 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Trichlorobenzene reductive dehalogenation*	-490.45	-2050	33.8:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled 1,3,5-Trimethylbenzene (1,3,5-TMB) Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$12O_2 + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O$ *1,3,5-TMB oxidation /aerobic respiration*	-1213.29	-5076	3.20:1	0.31:1
$9.6NO_3^- + 9.6H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 10.8H_2O + 4.8N_{2,g}$ *1,3,5-TMB oxidation / denitrification*	-1229.93	-5146	4.96:1	0.20:1
$24MnO_2 + 48H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 30H_2O + 24Mn^{2+}$ *1,3,5-TMB oxidation / manganese reduction*	-1213.46	-5077	17.40:1	0.06:1
$48Fe(OH)_{3,a} + 96H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48Fe^{2+} + 126H_2O$ *1,3,5-TMB oxidation / iron reduction*	-928.53	-3885	42.80:1	0.02:1
$6SO_4^{2-} + 12H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O + 6H_2S^o$ *1,3,5-TMB oxidation / sulfate reduction*	-192.87	-807.0	4.80:1	0.21:1
$6H_2O + C_6H_3(CH_3)_3 \Rightarrow 3CO_2 + 6CH_4$ *1,3,5-TMB oxidation / methanogenesis*	-40.39	-169.0	0.90:1	1.11:1
$24\ C_2H_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ PCA reductive dehalogenation*	-507.36	-2121	33.2:1	0.03:1
$24C_2H_3Cl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ TCA reductive dehalogenation*	-584.99	-2445	26.4:1	0.04:1
$24C_2H_4Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_5Cl + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ DCA reductive dehalogenation*	-528.59	-2210	19.6:1	0.05:1
$24C_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2HCl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Tetrachloroethene reductive dehalogenation*	-562.48	-2353	33.2:1	0.03:1
$24C_2HCl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_2Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Trichloroethene reductive dehalogenation*	-548.80	-2296	26.3:1	0.04:1
$24C_2H_2Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ cis-Dichloroethene reductive dehalogenation*	-434.56	-1818	19.4:1	0.05:1
$24C_2H_3Cl + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Vinyl chloride reductive dehalogenation*	-436.91	-1826	12.4:1	0.08:1
$24C_6Cl_6 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_1Cl_5 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Hexachlorobenzene reductive dehalogenation*	-541.84	-2265	56.4:1	0.02:1
$24C_6H_1Cl_5 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_2Cl_4 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Pentachlorobenzene reductive dehalogenation*	-555.23	-2321	49.6:1	0.02:1
$24C_6H_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_3Cl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Tetrachlorobenzene reductive dehalogenation*	-508.43	-2125	42.8:1	0.02:1
$24C_6H_3Cl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_4Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-TMB oxidation/ Trichlorobenzene reductive dehalogenation*	-486.35	-2033	36.0:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled 1,2,4-Trimethylbenzene (1,2,4-TMB) Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$12O_2 + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O$ *1,2,4-TMB oxidation /aerobic respiration*	-1212.92	-5075	3.20:1	0.31:1
$9.6NO_3^- + 9.6H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 10.8H_2O + 4.8N_{2,g}$ *1,2,4-TMB oxidation / denitrification*	-1229.56	-5144	4.96:1	0.20:1
$24\underline{MnO_2} + 48H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 30H_2O + 24Mn^{2+}$ *1,2,4-TMB oxidation / manganese reduction*	-1213.09	-5076	17.4:1	0.06:1
$48\underline{Fe(OH)}_{3,a} + 96H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48Fe^{2+} + 126H_2O$ *1,2,4-TMB oxidation / iron reduction*	-928.16	-3883	42.8:1	0.02:1
$6SO_4^{2-} + 12H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O + 6H_2S^o$ *1,2,4-TMB oxidation / sulfate reduction*	-192.50	-805.4	4.80:1	0.21:1
$6H_2O + C_6H_3(CH_3)_3 \Rightarrow 3CO_2 + 6CH_4$ *1,2,4-TMB oxidation / methanogenesis*	-40.02	-167.4	0.90:1	1.11:1
$24C_2H_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ PCA reductive dehalogenation*	-507.36	-2121	33.2:1	0.03:1
$24C_2H_3Cl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ TCA reductive dehalogenation*	-584.62	-2444	26.4:1	0.04:1
$24C_2H_4Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_5Cl + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ DCA reductive dehalogenation*	-528.22	-2208	19.6:1	0.05:1
$24C_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2HCl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ PCE reductive dehalogenation*	-562.11	-2352	33.2:1	0.03:1
$24C_2HCl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_2Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ TCE reductive dehalogenation*	-548.43	-2295	26.3:1	0.04:1
$24C_2H_2Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ cis-DCE reductive dehalogenation*	-434.19	-1817	19.4:1	0.05:1
$24C_2H_3Cl + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ Vinyl chloride reductive dehalogenation*	-436.54	-1825	12.4:1	0.08:1
$24C_6Cl_6 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_1Cl_5 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ Hexachlorobenzene reductive dehalogenation*	-541.47	-2263	56.4:1	0.02:1
$24C_6H_1Cl_5 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_2Cl_4 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ Pentachlorobenzene reductive dehalogenation*	-554.86	-2319	49.6:1	0.02:1
$24C_6H_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_3Cl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ Tetrachlorobenzene reductive dehalogenation*	-508.06	-2124	42.8:1	0.02:1
$24C_6H_3Cl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_6H_4Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-TMB oxidation/ Trichlorobenzene reductive dehalogenation*	-485.98	-2031	36.0:1	0.03:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Vinyl Chloride Oxidation Reactions	$\Delta G°_r$ (kcal/ mole)	$\Delta G°_r$ (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$2.5O_2 + C_2H_3Cl \Rightarrow 2CO_2 + H_2O + H^+ + Cl^-$ *Vinyl Chloride oxidation /aerobic respiration*	-288.98	-1209	1.29:1	0.78:1
$2NO_3^- + H^+ C_2H_3Cl \Rightarrow 2CO_2 + 2H_2O + Cl^- + N_{2,g}$ *Vinyl Chloride oxidation / denitrification*	-292.44	-1224	2.00:1	0.50:1
$5\underline{MnO_2} + 9H^+ + C_2H_3Cl \Rightarrow 2CO_2 + 6H_2O + 5Mn^{2+} + Cl^-$ *Vinyl Chloride oxidation / manganese reduction*	-289.01	-1209	7.02:1	0.14:1
$10\underline{Fe(OH)_{3,a}} + 19H^+ + C_6H_3(CH_3)_3 \Rightarrow 2CO_2 + 10Fe^{2+} + 26H_2O + Cl^-$ *Vinyl Chloride oxidation / iron reduction*	-229.65	-960.9	17.3:1	0.06:1
$1.25SO_4^{2-} + 1.5H^+ + C_2H_3Cl \Rightarrow 2CO_2 + H_2O + 1.25H_2S^o + Cl^-$ *Vinyl Chloride oxidation / sulfate reduction*	-76.40	-319.7	1.94:1	0.52:1
$1.5H_2O + C_2H_3Cl \Rightarrow .75CO_2 + 1.25CH_4 + H^+ + Cl^-$ *Vinyl Chloride oxidation / methanogenesis*	-44.62	-186.7	0.44:1	2.27:1
$5C_2H_2Cl_4 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_3Cl_3 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ PCA reductive dehalogenation*	-141.90	-593.1	13.4:1	0.07:1
$5C_2H_3Cl_3 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_4Cl_2 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ TCA reductive dehalogenation*	-158.08	-661	10.7:1	0.09:1
$5C_2H_4Cl_2 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_5Cl + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ DCA reductive dehalogenation*	-146.33	-612	7.92:1	0.13:1
$5C_2Cl_4 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2HCl_3 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ DCE reductive dehalogenation*	-153.39	-641.8	13.4:1	0.07:1
$5C_2HCl_3 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_2Cl_2 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ TCE reductive dehalogenation*	-150.54	-629.9	10.6:1	0.09:1
$5C_2H_2Cl_2 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_3Cl + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ cis-DCE reductive dehalogenation*	-126.74	-530.3	7.82:1	0.13:1
$5C_6Cl_6 + 4H_2O + C_2H_3Cl \Rightarrow 5C_6H_1Cl_5 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ Hexachlorobenzene reductive dehalogenation*	-144.60	-604.4	22.8:1	0.04:1
$5C_6H_1Cl_5 + 4H_2O + C_2H_3Cl \Rightarrow 5C_6H_2Cl_4 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ Pentachlorobenzene reductive dehalogenation*	-138.59	-579.3	20.0:1	0.05:1
$5C_6H_2Cl_4 + 4H_2O + C_2H_3Cl \Rightarrow 5C_6H_3Cl_3 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ Tetrachlorobenzene reductive dehalogenation*	-142.13	-594.1	17.3:1	0.06:1
$5C_6H_3Cl_3 + 4H_2O + C_2H_3Cl \Rightarrow 5C_6H_4Cl_2 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ Trichlorobenzene reductive dehalogenation*	-137.53	-574.9	14.5:1	0.07:1

Coupled cis-Dichloroethene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$2O_2 + C_2H_2Cl_2 \Rightarrow 2CO_2 + 2H^+ + 2Cl^-$ *DCE oxidation /aerobic respiration*	-256.53	-1072	1.31:1	0.76:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Chlorobenzene Oxidation Reactions	$\Delta G°_r$ (kcal/ mole)	$\Delta G°_r$ (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$7O_2 + C_6H_4Cl \Rightarrow 6CO_2 + H^+ + 2H_2O + Cl^-$ *Chlorobenzene oxidation /aerobic respiration*	-731.62	-3061	2.00:1	0.50:1
$5.6NO_3^- + 4.6H^+ + C_6H_4Cl \Rightarrow 6CO_2 + 4.8H_2O + 2.8N_{2,g} + 2Cl^-$ *Chlorobenzene oxidation / denitrification*	-741.33	-3102	3.10:1	0.32:1
$14\underline{MnO_2} + 27H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 16H_2O + 14Mn^{2+} + Cl^-$ *Chlorobenzene oxidation / manganese reduction*	-731.72	-3062	10.9:1	0.09:1
$28\underline{Fe(OH)_{3,a}} + 55H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 72H_2O + 28Fe^{2+} + Cl^-$ *Chlorobenzene oxidation / iron reduction*	-565.51	-2366	26.8:1	0.04:1
$3.5SO_4^{2-} + 6H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 2H_2O + 3.5H_2S^o + Cl^-$ *Chlorobenzene oxidation / sulfate reduction*	-136.38	-570.6	3.00:1	0.33:1
$5H_2O + C_6H_5Cl \Rightarrow 2.5CO_2 + 3.5CH_4 + H^+ + Cl^-$ *Chlorobenzene oxidation / methanogenesis*	-47.43	-198.4	0.80:1	1.25:1
$14C_2H_2Cl_4 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_3Cl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ PCA reductive dehalogenation*	-320.04	-1338	20.8:1	0.05:1
$14C_2H_3Cl_3 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_4Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ TCA reductive dehalogenation*	-365.11	-1526	16.5:1	0.06:1
$14C_2H_4Cl_2 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_5Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ DCA reductive dehalogenation*	-332.21	-1389	12.3:1	0.08:1
$14C_2Cl_4 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ PCE reductive dehalogenation*	-351.99	-1473	20.7:1	0.05:1
$14C_2HCl_3 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ TCE reductive dehalogenation*	-344.01	-1439	16.4:1	0.06:1
$14C_2H_2Cl_2 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ cis-DCE reductive dehalogenation*	-277.37	-1161	12.1:1	0.08:1
$14C_2H_3Cl + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ Vinyl chloride reductive dehalogenation*	-278.73	-1165	7.75:1	0.13:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Dichlorobenzene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$6.5O_2 + C_6H_4Cl_2 \Rightarrow 6CO_2 + 2H^+ + H_2O + 2Cl^-$ *Dichlorobenzene oxidation /aerobic respiration*	-698.36	-2919	1.42:1	0.70:1
$5.2NO_3^- + 3.2H^+ + C_6H_4Cl_2 \Rightarrow 6CO_2 + 3.6H_2O + 2.6N_{2,g} + 2Cl^-$ *Dichlorobenzene oxidation / denitrification*	-708.76	-2963	1.64:1	0.61:1
$13\underline{MnO_2} + 24H^+ + C_6H_4Cl_2 \Rightarrow 6CO_2 + 14H_2O + 13Mn^{2+} + 2Cl^-$ *Dichlorobenzene oxidation / manganese reduction*	-698.36	-2919	7.75:1	0.13:1
$26\underline{Fe(OH)_{3,a}} + 50H^+ + C_6H_4Cl_2 \Rightarrow 6CO_2 + 66H_2O + 26Fe^{2+} + 2Cl^-$ *Dichlorobenzene oxidation / iron reduction*	-521.56	-2180	19.05:1	0.05:1
$3.25SO_4^{2-} + 4.5H^+ + C_6H_4Cl_2 \Rightarrow 6CO_2 + H_2O + 3.25H_2S^o + 2Cl^-$ *Dichlorobenzene oxidation / sulfate reduction*	-142.74	-596.7	2.14:1	0.47:1
$5.5H_2O + C_6H_4Cl_2 \Rightarrow 2.75CO_2 + 3.25CH_4 + 2H^+ + 2Cl^-$ *Dichlorobenzene oxidation / methanogenesis*	-64.22	-268.4	0.33:1	2.99:1
$13C_2H_2Cl_4 + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2H_3Cl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ PCA reductive dehalogenation*	-317.20	-1326	14.8:1	0.07:1
$13C_2H_3Cl_3 + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2H_4Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ TCA reductive dehalogenation*	-358.93	-1500	11.8:1	0.09:1
$13C_2H_4Cl_2 + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2H_5Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ DCA reductive dehalogenation*	-328.38	-1373	8.73:1	0.11:1
$13C_2Cl_4 + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ PCE reductive dehalogenation*	-347.10	-1450	14.6:1	0.07:1
$13C_2HCl_3 + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ TCE reductive dehalogenation*	-339.56	-1419	11.6:1	0.09:1
$13C_2H_2Cl_2 + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ cis-DCE reductive dehalogenation*	-277.68	-1161	8.55:1	0.12:1
$13C_2H_3Cl + 12H_2O + C_6H_4Cl_2 \Rightarrow 13C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Dichlorobenzene oxidation/ Vinyl chloride reductive dehalogenation*	-278.72	-1165	5.52:1	0.18:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Trichlorobenzene Oxidation Reactions	ΔG°_r (kcal/ mole)	ΔG°_r (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$6O_2 + C_6H_3Cl_3 \Rightarrow 6CO_2 + 3H^+ + 3Cl^-$ *Trichlorobenzene oxidation /aerobic respiration*	-668.16	-2793	1.07:1	0.94:1
$4.8NO_3^- + 1.8H^+ + C_6H_3Cl_3 \Rightarrow 6CO_2 + 2.4H_2O + 2.4$ *Trichlorobenzene oxidation / denitrification*	-677.16	-2833	1.65:1	0.60:1
$12\underline{MnO_2} + 21H^+ + C_6H_3Cl_3 \Rightarrow 6CO_2 + 12H_2O + 12Mn^{2+} + 3Cl^-$ *Trichlorobenzene oxidation / manganese reduction*	-688.16	-2793	5.80:1	0.17:1
$24\underline{Fe(OH)_3}_{,a} + 45H^+ + C_6H_3Cl_3 \Rightarrow 6CO_2 + 60H_2O + 24Fe^{2+} + 3Cl^-$ *Trichlorobenzene oxidation / iron reduction*	-504.96	-2111	14.3:1	0.07:1
$3SO_4^{2-} + 3H^+ + C_6H_3Cl_3 \Rightarrow 6CO_2 + 3H_2S^o + 3Cl^-$ *Trichlorobenzene oxidation / sulfate reduction*	-155.28	-649.1	1.60:1	0.63:1
$6H_2O + C_6H_3Cl_3 \Rightarrow 3CO_2 + 3CH_4 + 3H^+ + 3Cl^-$ *Trichlorobenzene oxidation / methanogenesis*	-82.80	-346.1	0.25:1	4.00:1
$12C_2H_2Cl_4 + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2H_3Cl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ PCA reductive dehalogenation*	-316.32	-1322	11.1:1	0.09:1
$12C_2H_3Cl_3 + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2H_4Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ TCA reductive dehalogenation*	-354.82	-1483	8.8:1	0.11:1
$12C_2H_4Cl_2 + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2H_5Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ DCA reductive dehalogenation*	-326.62	-1365	6.53:1	0.15:1
$12C_2Cl_4 + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ PCE reductive dehalogenation*	-343.92	-1438	10.9:1	0.09:1
$12C_2HCl_3 + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ TCE reductive dehalogenation*	-336.96	-1408	8.67:1	0.12:1
$12C_2H_2Cl_2 + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ cis-DCE reductive dehalogenation*	-279.58	-1169	6.40:1	0.16:1
$12C_2H_3Cl + 12H_2O + C_6H_3Cl_3 \Rightarrow 12C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Trichlorobenzene oxidation/ Vinyl chloride reductive dehalogenation*	-280.78	-1174	4.13:1	0.24:1

Table B.3.5 - Con't

Coupled Oxidation-Reduction Reactions

Coupled Tetrachlorobenzene Oxidation Reactions	$\Delta G°_r$ (kcal/ mole)	$\Delta G°_r$ (kJ/ mole)	Stoichiometric Mass Ratio of Electron Acceptor or Metabolic Byproduct to Primary Substrate	Mass of Primary Substrate Utilized per mass of Electron Acceptor Utilized or Metabolic Byproduct Produced
$5.5O_2 + H_2O + C_6H_2Cl_4 \Rightarrow 6CO_2 + 4H^+ + 4Cl^-$ *Tetrachlorobenzene oxidation /aerobic respiration*	-639.10	-2671	0.82:1	1.22:1
$4.4NO_3^- + 0.4\,H^+ + C_6H_2Cl_4 \Rightarrow 6CO_2 + 1.2H_2O + 2.2N_{2,g} + 4Cl^-$ *Tetrachlorobenzen oxidation / denitrification*	-647.90	-2708	1.27:	0.78:1
$11\underline{MnO_2} + 18H^+ + C_6H_2Cl_4 \Rightarrow 6CO_2 + 10H_2O + 11Mn^{2+} + 4Cl^-$ *Tetrachlorobenzenoxidation / manganese reduction*	-639.10	-2671	4.47:1	0.22:1
$22\underline{Fe(OH)_{3,a}} + 40H^+ + C_6H_2Cl_4 \Rightarrow 6CO_2 + 54H_2O + 22Fe^{2+} + 4Cl^-$ *Tetrachlorobenzen oxidation / iron reduction*	-489.50	-2046	11.0:1	0.09:1
$2.75SO_4^{2-} + 1.75H^+ + H_2O + C_6H_2Cl_4 \Rightarrow 6CO_2 + 2.75H_2S^o + 4Cl^-$ *Tetrachlorobenzen oxidation / sulfate reduction*	-168.96	-706.3	1.23:1	0.81:1
$6.5H_2O + C_6H_2Cl_4 \Rightarrow 3.25CO_2 + 2.75CH_4 + 4H^+ + 4Cl^-$ *Tetrachlorobenzen oxidation / methanogenesis*	-102.52	-428.5	0.19:1	5.19:1
$11C_2H_2Cl_4 + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2H_3Cl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ PCA reductive dehalogenation*	-287.01	-1200	8.53:1	0.12:1
$11C_2H_3Cl_3 + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2H_4Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ TCA reductive dehalogenation*	-323.64	-1353	6.79:1	0.15:1
$11C_2H_4Cl_2 + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2H_5Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ DCA reductive dehalogenation*	-297.79	-1392	5.04:1	0.20:1
$11C_2Cl_4 + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ PCE reductive dehalogenation*	-313.3	-1310	8.43:1	0.12:1
$11C_2HCl_3 + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ TCE reductive dehalogenation*	-307.03	-1283	6.68:1	0.15:1
$11C_2H_2Cl_2 + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ cis-DCE reductive dehalogenation*	-254.67	-1065	4.93:1	0.20:1
$11C_2H_3Cl + 12H_2O + C_6H_2Cl_4 \Rightarrow 11C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Tetrachlorobenzen oxidation/ Vinyl chloride reductive dehalogenation*	-255.77	-1069	3.19:1	0.31:1

BIODEGRADATION RATE ESTIMATES

In press: Proceedings of the Battelle In Situ and On-Site Bioreclamation Symposium, April 24-27, 1995, San Diego, CA.

REGRESSION TECHNIQUES AND ANALYTICAL SOLUTIONS TO DEMONSTRATE INTRINSIC BIOREMEDIATION

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ABSTRACT

It is now generally recognized that a major factor responsible for the attenuation and mass reduction of benzene, toluene, ethylbenzene, and xylenes (BTEX) in groundwater plumes is hydrocarbon biodegradation by indigenous microorganisms in aquifer material. Our objective is to apply well-known regression techniques and analytical solutions to estimate the contribution of advection, dispersion, sorption, and biodecay to the overall attenuation of petroleum hydrocarbons. These calculations yield an apparent biodecay rate based on field data. This biodecay rate is a significant portion of the overall attenuation in stable, dissolved hydrocarbon plumes.

INTRODUCTION

"Intrinsic bioremediation" is the degradation of organic compounds by indigenous microbes without artificial enhancement. Advection, dispersion, sorption, and decay each contribute to the overall attenuation of a dissolved hydrocarbon plume. The effect of advection is to transport dissolved contaminants at the same rate as the groundwater velocity. The effect of dispersion is to spread contaminant mass beyond the volume it would occupy due to advection alone, and reduce contaminant concentrations. The effect of sorption is to retard contaminant migration. These factors affect the configuration of dissolved hydrocarbon plumes. Overall attenuation can cause a plume to shrink over time, create a stable plume, or reduce the rate of plume migration. Two of the conditions for which intrinsic bioremediation is likely to contribute to the configuration of a contaminant plume are a shrinking plume and a stable plume. The configuration of a migrating plume can also be affected by intrinsic bioremediation. Under the conditions of a shrinking plume, degradation mechanisms are necessarily present. Intrinsic bioremediation also is likely to contribute to a stable plume, particularly if the source persists in residually contaminated soils at the water table. In this paper we couple the regression of concentration versus distance for stable plumes to an analytical solution for one-dimensional, steady-state, contaminant transport. The analytical solution includes advection, dispersion, sorption, and decay.

Biological transformation is the process that likely contributes most to the decay of compounds such as BTEX. Several studies suggest the concurrent loss of electron acceptors from groundwater as an indicator of biodegradation (McAllister and Chiang 1994, Salanitro 1993). The mechanism of biodegradation is complex, and the rate is most likely controlled by the mixing of the contaminant and electron acceptors in a three-dimensional, heterogeneous aquifer. The assumption of a first-order decay is a useful approximation of this complex phenomenon. Evaluation of site data suggests apparent first-order attenuation rates occur in the range of 0.1 to 1.0 % per day (Buscheck et al. 1993).

The objective of this paper is to provide tools to assist in documenting the loss of contaminants. The regression techniques and analytical solution described are intended to distinguish those mechanisms that contribute to contaminant loss.

PLUME CHARACTERISTICS

Shrinking Plume

Dissolved hydrocarbon plumes may decrease in size, as observed by declining contaminant concentrations in monitoring wells. Exponential regression methods can be used to evaluate whether concentration versus time data fit a first-order decay observed for petroleum hydrocarbons under certain conditions. The solution to the first-order decay is:

$$C(t) = C_i e^{-(kt)} \quad (1)$$

Where C(t) (M/L^3) is concentration as a function of time, t (T), C_i is the initial concentration at t = 0, and k is the first-order attenuation rate, T^{-1}. Equation (1) may be used to evaluate contaminant concentration versus time data for individual monitoring wells.

Stable Plume

A stable plume is characterized by dissolved contaminant concentrations remaining constant over time in individual monitoring wells. Short-term variations in monitoring well concentrations due to water table fluctuation, variability in groundwater flow direction, sampling variability, and analytical uncertainty should be distinguished from statistically significant concentration changes. In order for a plume to reach stable conditions, the rate of natural attenuation must be equal to the rate of contaminant addition to the aquifer from the source (McAllister and Chiang 1994). The contaminant source or influx rate is limited by the compound's effective solubility and the flow rate of water through the source area (infiltration, fluctuating water table, etc.).

Kemblowski et al. (1987) recast equation (1) for concentration as a function of distance:

$$C(x) = C_o e^{-(k\frac{x}{v_x})} \quad (2)$$

Where C_o (M/L^3) is the concentration at the source. The transformation of the exponential terms in equations (1) and (2) is achieved by substituting time, t, with distance traveled, x (L) divided by the linear groundwater velocity, v_x (L/T). The term "x/v_x" is the residence time for pore water to move some distance, x, from the source. The concentration versus distance regression is based on equation (2). The groundwater flow direction is defined based on multiple monitoring events covering the hydrologic cycle. Six monitoring wells were selected along the groundwater flow path (see inset of Figure 1). A minimum of three monitoring wells are required for this analysis. In this case, contaminant concentrations declined with downgradient distance. Figure 1 plots benzene concentration versus distance for a terminal in Fairfax, Virginia. From the exponent of equation (2), the slope of the line in Figure 1 is k/v_x (L^{-1}), the reciprocal of the attenuation distance. If this slope is multiplied by groundwater velocity (L/T), we obtain

k (T^{-1}). In the absence of a reliable estimate of groundwater velocity, the k/v_x term is useful, particularly for estimating the downgradient extent of contaminant migration and selecting downgradient monitoring well locations.

ANALYTICAL SOLUTION FOR A STABLE PLUME

The general one-dimensional transport equation, with first-order decay of the contaminant, is given by the following equation:

$$\frac{\delta C}{\delta t} = \frac{1}{R_f} \left[D_x \frac{\delta^2 C}{\delta x^2} - v_x \frac{\delta C}{\delta x} \right] - \lambda C \qquad (3)$$

Where D_x (L^2/T) is the dispersion coefficient, v_x (L/T) is the linear groundwater velocity, R_f (-) is the retardation coefficient, and λ (T^{-1}) is the total decay rate. The form of equation (3) assumes D_x is constant and independent of distance, x. While the terms in brackets describe the mass transport by dispersion and advection, respectively, the retardation coefficient characterizes the contribution of sorption. The form of this equation assumes degradation occurs in the aqueous and sorbed phases at the same rate. If biological transformation of BTEX compounds occurs primarily in the aqueous phase, the term "λC" would appear inside the brackets.

Dispersion and advection are related by the longitudinal dispersivity, α_x (L), which has been described by empirical expressions (Fetter 1993).

$$D_x = \alpha_x v_x \qquad (4)$$

The retardation coefficient (R_f) accounts for contaminant partitioning between the solid and aqueous phases. R_f describes the relationship between the linear groundwater velocity, and contaminant velocity, v_c (L/T):

$$R_f = \frac{v_x}{v_c} \qquad (5)$$

Chiang et al. (1989) demonstrated that the contribution of volatilization to the dissolved contaminant attenuation was only 5% at one site. Except in the case of very shallow groundwater, volatilization is not expected to contribute significantly to the overall attenuation. Therefore, volatilization is neglected and the decay rate is assumed to be a measure of biodegradation of BTEX compounds.

Bear (1979) solved equation (3) for concentration. The steady-state solution is given as:

$$C(x) = C_o \exp\left[\left(\frac{x}{2\alpha_x}\right) \left[1 - \left(1 + \frac{4\lambda\alpha_x}{v_c}\right)^{\frac{1}{2}}\right]\right] \qquad (6)$$

For the case in which decay occurs only in the aqueous phase, the contaminant velocity, v_c, is replaced by the linear groundwater velocity, v_x, in equation (6). As the decay rate (λ) increases with respect to the other transport mechanisms, the concentration away from the source ($x > 0$), approaches zero because the material is decaying at a greater rate than it is being transported through the medium. Similarly, as the contaminant velocity increases, the decay becomes less effective in reducing concentrations as a function

of distance. Retarded contaminants therefore have a greater opportunity to decay because retarded transport velocities favor biodegradation kinetics over transport (Domenico and Schwartz 1990).

The exponential regression for concentration versus distance yields the reciprocal of the attenuation distance, k/v_x (L^{-1}), previously shown in equation (2). Equations (2) and (6) are of the same form:

$$C(x) = C_o \exp(mx) \tag{7}$$

The slope of the log-linear data is given by m. The one-dimensional, steady-state transport solution also describes the slope, m, of the log-linear data:

$$m = \left(\frac{1}{2\alpha_x}\right) \left[1-\left(1+\frac{4\lambda\alpha_x}{v_c}\right)^{\frac{1}{2}}\right] \tag{8}$$

Therefore, the term k/v_x and equation (8) both describe the slope of the log-linear data and can be equated to solve for the total decay rate, λ, a measure of intrinsic bioremediation. Dispersivity (α), contaminant velocity (v_c), and k/v_x are input to the following equation to calculate the decay rate.

$$\lambda = \left(\frac{v_c}{4\alpha_x}\right) \left(\left[1+2\alpha_x\left(\frac{k}{v_x}\right)\right]^2 - 1\right) \tag{9}$$

For the case in which decay occurs only in the aqueous phase, v_c is replaced by v_x in equation (9).

RESULTS

The results of equating the spatial regression with the steady-state analytical solution for the Fairfax Terminal are presented in Table 1. The values for source concentration (C_o) and k/v_x were regressed using the data plotted in Figure 1. Table 1 includes k and the ratio, λ/k, the contribution of biodecay to the overall attenuation rate (expressed as %). In Case 1, groundwater velocity was 0.06 m/day, based on aquifer pump tests. Retardation was estimated as 2 and dispersivity was estimated as 7.5 m, approximately 5% of the flow field (distance separating the two furthest wells). In Case 1, λ = 0.30%/day (0.0030 $days^{-1}$); λ is 75% of k for this case. The next four cases were performed to evaluate the sensitivity of changing various input parameters. In each of these cases C_o and k/v_x remain constant. In Case 2, the groundwater velocity is reduced by a factor of two (v = 0.03 m/day), which reduces the decay rate by the same factor (λ = 0.15%/day). In this case, only half the decay rate is required to maintain the Case 1 concentration decline with distance; as in Case 1, λ is 75% of k in Case 2. In Case 3, the dispersivity is increased by a factor of two (α = 15 m) and λ = 0.40%/day. More decay is required with a larger dispersivity because more spreading of the contaminant occurs in the direction of groundwater flow; λ is equivalent to k in Case 3.

Cases 4 and 5 were performed to calculate λ assuming biodecay occurs only in the aqueous phase. This is accomplished by replacing v_c with v_x in equation (9) for λ (R = 1 in Table 1 for Cases 4 and 5). Given this revised formulation, the decay rate, λ, is independent of retardation. By limiting decay to the aqueous phase in Case 4, λ = 0.60%/day, twice the decay rate in Case 1. In Case 4, λ is 150% of k. Case 5 is similar to Case 4, but dispersivity is reduced to 0.3 m. In Case 5, λ = 0.40%/day. Less decay is required with a smaller dispersivity because less spreading of the contaminant plume occurs in the

direction of groundwater flow; λ and k are identical in Case 5.

SUMMARY

Contaminant decay is the primary process contributing to a stable configuration of a dissolved contaminant plume. Given a constant source, sorption and dispersion alone are not likely to account for a stable plume. Sorption only retards contaminant velocity, whereas dispersion results in further spreading of the contaminant, reducing concentrations. Decay (biodegradation of BTEX compounds) is the most significant mechanism that accounts for mass loss in a dissolved contaminant plume. The analytical solution for steady-state contaminant transport can be equated to a regression of concentration versus distance (expressed as k/v_x) to solve for the decay rate, λ. The decay rate is a measure of intrinsic bioremediation of petroleum hydrocarbons and can be used in more sophisticated models.

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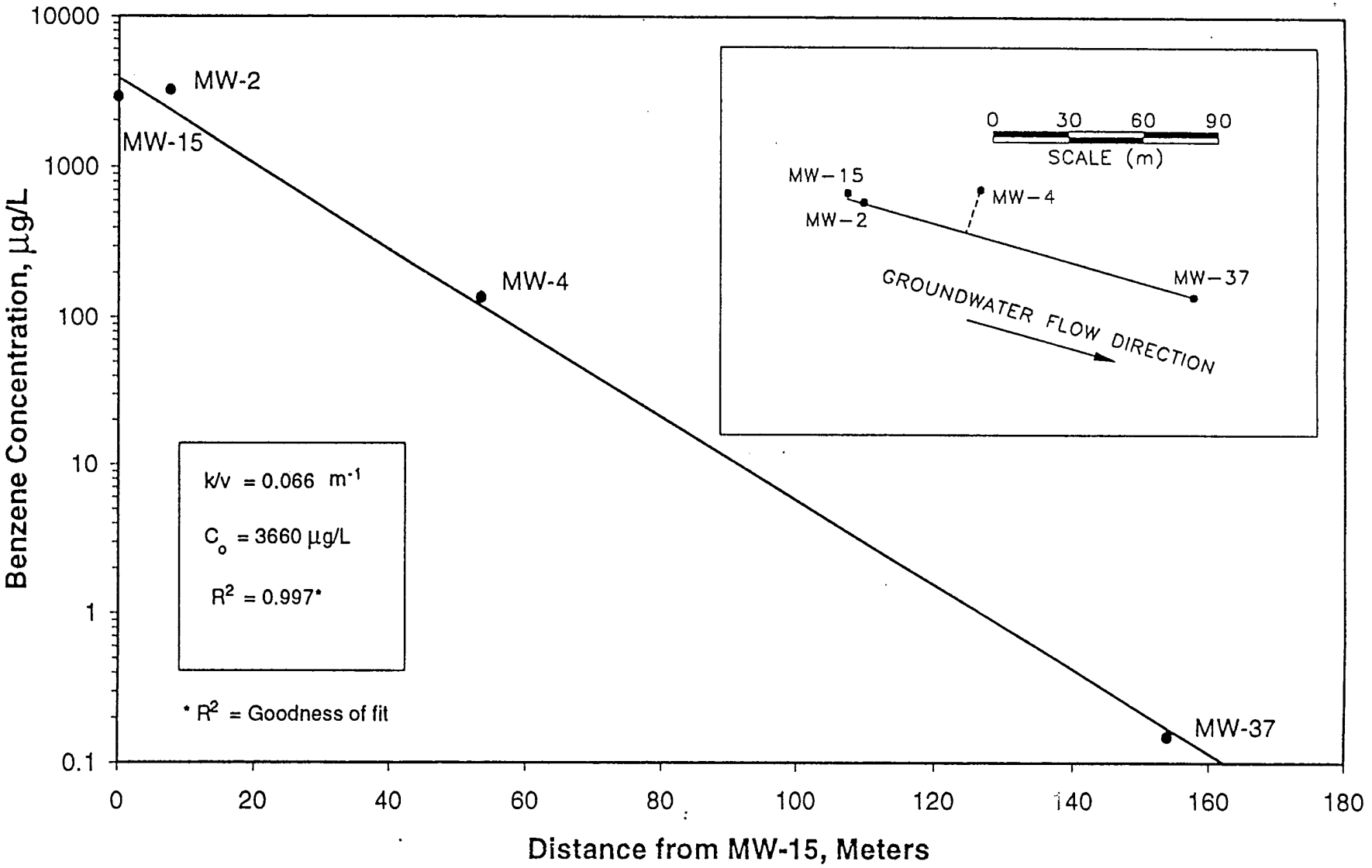

FIGURE 1. Exponential regression of concentration versus distance for Fairfax Terminal.

TABLE 1. Decay rates based on steady-state analytical solution, C_o = 3,660 µg/L, $k/v_x = 0.066\ m^{-1}$. (sensitivity on bold input values)

Case	groundwater velocity, v_x (m/day)	retardation coefficient, R_f	contaminant velocity, v_c (m/day)	dispersivity, α (m)	attenuation rate, k (%/day)	decay rate, λ (%/day)	λ/k (%)
Case 1	0.06	2	0.03	7.5	0.40	0.30	75
Case 2	**0.03**	2	0.015	7.5	0.20	0.15	75
Case 3	0.06	2	0.03	**15**	0.40	0.40	100
Case 4	0.06	**1**(1)	0.06	7.5	0.40	0.60	150
Case 5	0.06	**1**(1)	0.06	**0.3**	0.40	0.40	100

Note: (1) Calculation of λ independent of v_c.

FIRST-ORDER RATE CONSTANT CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR
KC 135 CRASH SITE
RISK-BASED APPROACH TO REMEDIATION
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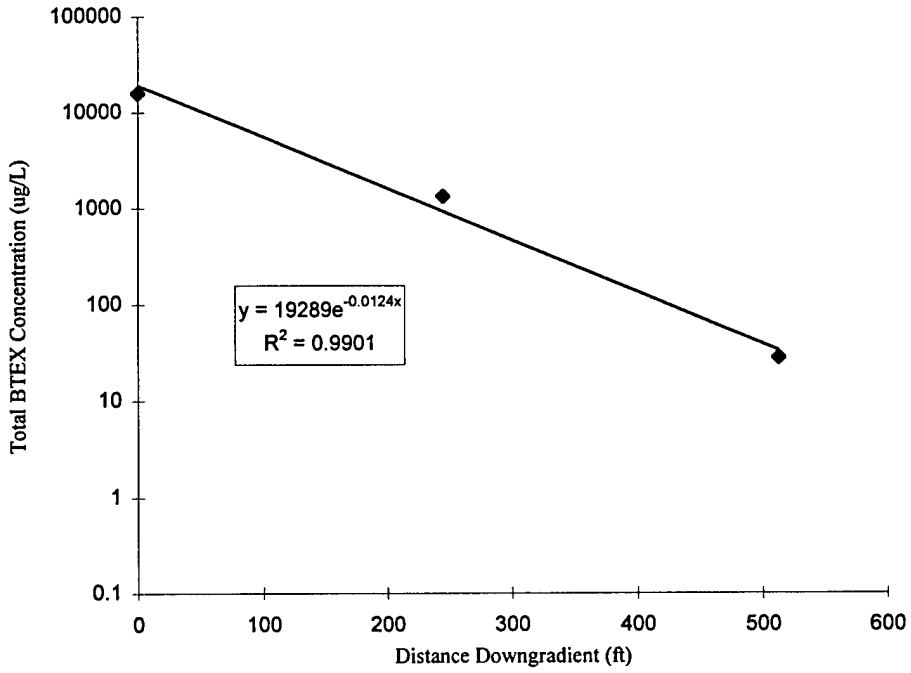
Point	Distance Downgradient	Total BTEX (µg/L) Jan-93
USGS-4	0	15920
T-13	[illegible]	1336
T-16	[illegible]	28

PLOT OF TOTAL BTEX CONCENTRATION VERSUS DISTANCE



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

where	v_c =	0.43	ft/day
	α_x =	10.94	ft
	k/v =	0.0124	percent/foot
therefore	λ =	0.00606	percent/day

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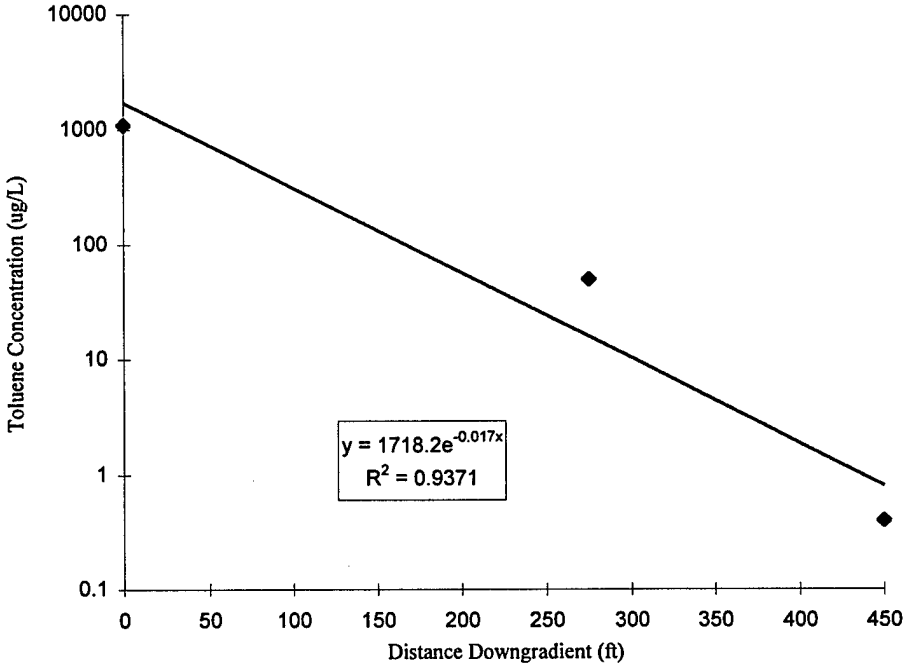
Point	Distance Downgradient	Toluene (µg/L) Oct-96
USGS-4	0	1100
W409	275	50
W411	450	0.4

PLOT OF TOLUENE CONCENTRATION VERSUS DISTANCE



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

where $v_c = 0.47$ ft/day
$\alpha_x = 10.94$ ft
$k/v = 0.017$ percent/foot

therefore $\lambda = 0.00948$ percent/day

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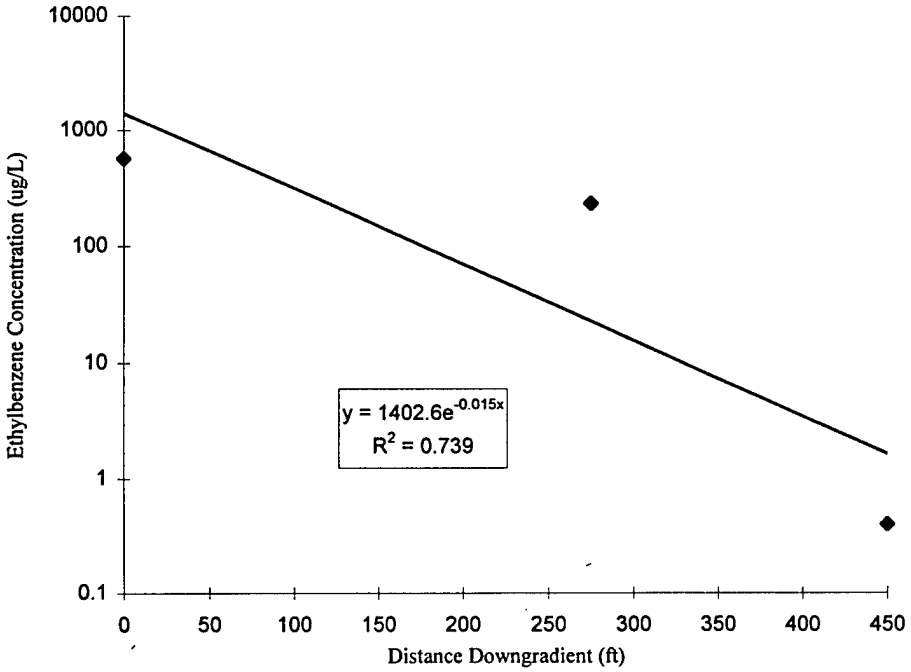
Point	Distance Downgradient	Ethylbenzene (µg/L) Oct-96
USGS-4	0	570
W409	275	230
W411	450	0.4

PLOT OF ETHYLBENZENE CONCENTRATION VERSUS DISTANCE



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

where	v_c = 0.48	ft/day
	α_x = 10.94	ft
	k/v = 0.015	percent/foot
therefore	λ = 0.00838	percent/day

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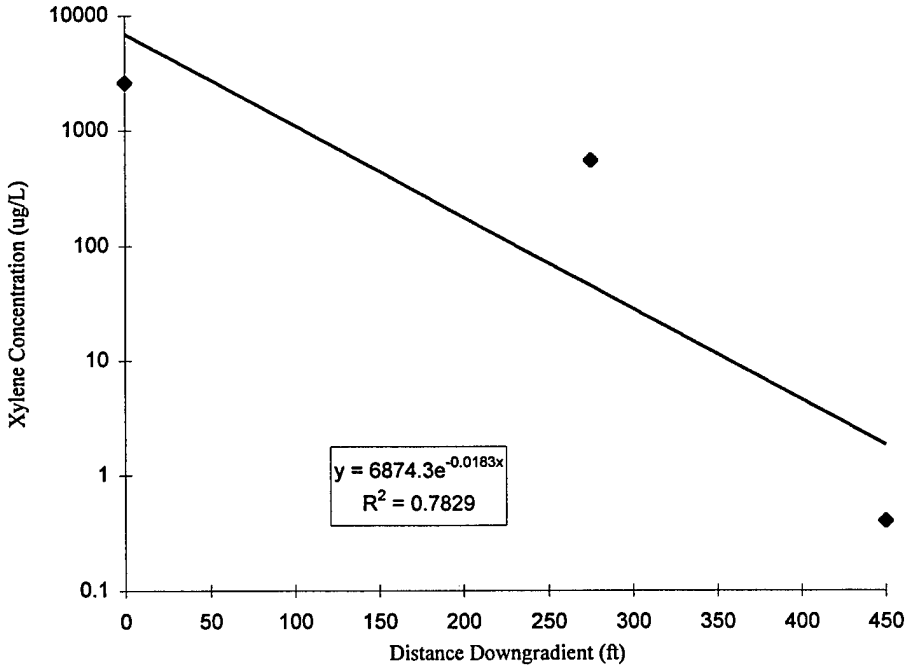
Point	Distance Downgradient	Xylenes (µg/L) Oct-96
USGS-4	0	2600
W409	275	550
W411	450	0.4

PLOT OF XYLENES CONCENTRATION VERSUS DISTANCE



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

where	v_c = 0.46	ft/day
	α_x = 10.94	ft
	k/v = 0.0183	percent/foot
therefore	λ = 0.01010	percent/day

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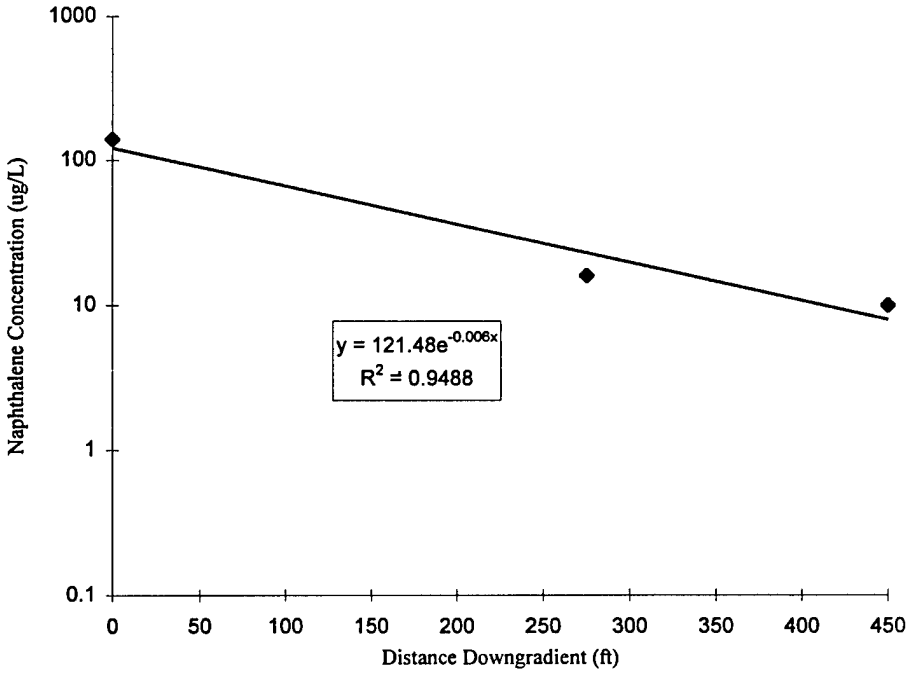
Point	Distance Downgradient	Naphthalene (µg/L) Oct-96
USGS-4	0	140
W409	275	16
W411	450	10

PLOT OF NAPHTHALENE CONCENTRATION VERSUS DISTANCE



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

where $v_c = 0.29$ ft/day
$\alpha_x = 10.94$ ft
$k/v = 0.006$ percent/foot

therefore $\lambda = 0.00185$ percent/day

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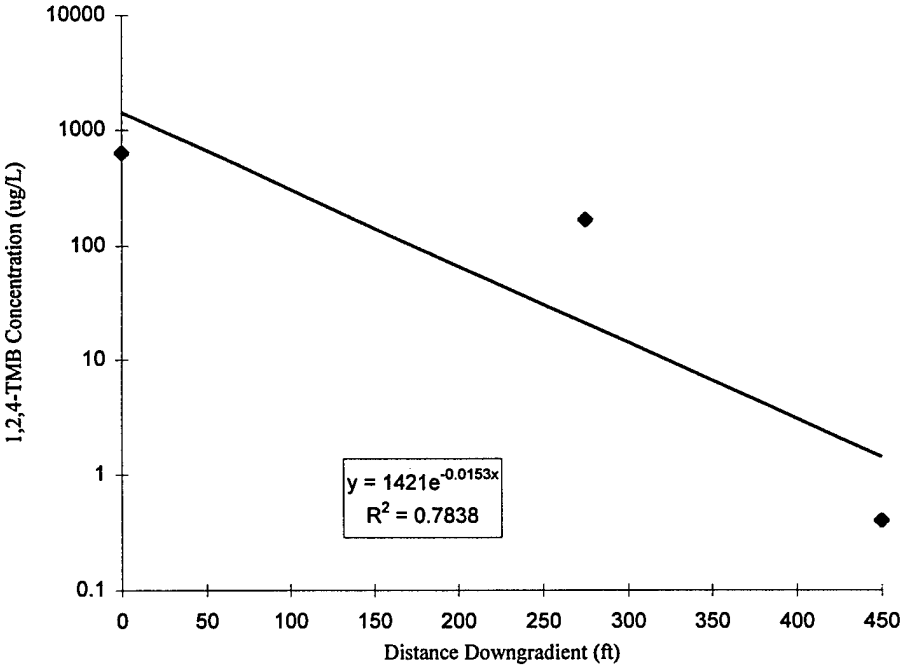
Point	Distance Downgradient	1,2,4-TMB (µg/L) Oct-96
USGS-4	0	630
W409	275	170
W411	450	0.4

PLOT OF 1,2,4-TMB CONCENTRATION VERSUS DISTANCE



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

where $v_c = 0.27$ ft/day
$\alpha_x = 10.94$ ft
$k/v = 0.0153$ percent/foot

therefore $\lambda = 0.00482$ percent/day

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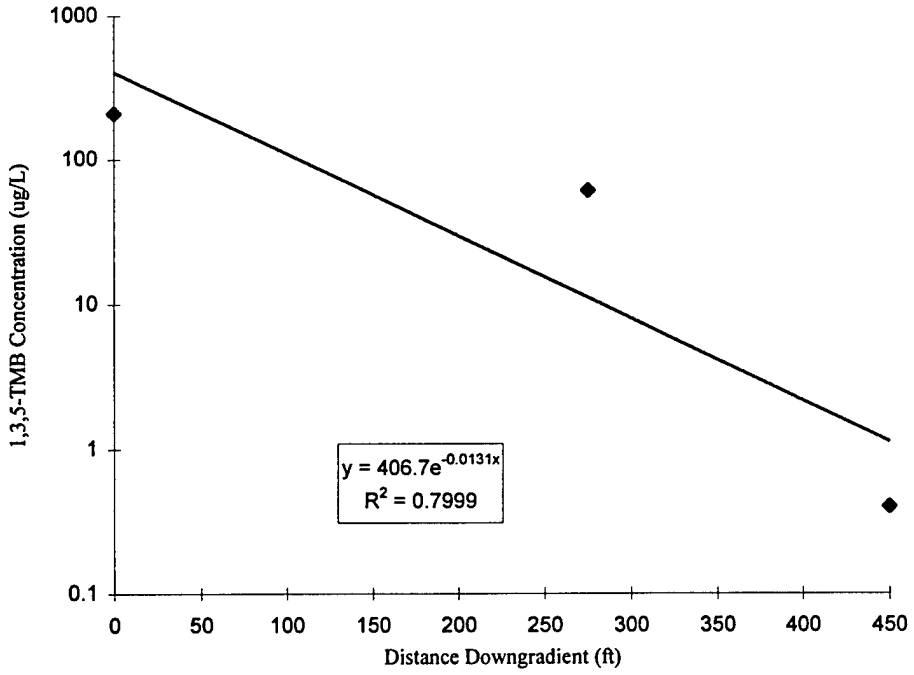
Point	Distance Downgradient	1,3,5-TMB (µg/L) Oct-96
USGS-4	0	210
W409	275	61
W411	450	0.4

PLOT OF 1,3,5-TMB CONCENTRATION VERSUS DISTANCE



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

where $v_c = 0.27$ ft/day
$\alpha_x = 10.94$ ft
$k/v = 0.0131$ percent/foot

therefore $\lambda = 0.00404$ percent/day

BIOPLUME II MODEL DEVELOPMENT AND RESULTS

BIOPLUME MODEL SETUP AND RESULTS

GENERAL OVERVIEW AND MODEL DESCRIPTION

To help estimate degradation rates for dissolved BTEX compounds at the KC-135 Crash Site and to help predict the future migration of these compounds, Parsons ES modeled the transport and fate of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess potential completion of exposure pathways involving groundwater; and 3) to provide technical support for using natural attenuation as part of the risk-based approach to remediation at the site. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from natural attenuation processes expected to exceed model predictions.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by natural mechanisms operating at the KC-135 Crash Site. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. Based on the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous, biologically-mediated, reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic′-Galic′, 1990; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic′-Galic′, 1992; Grbic′-Galic′ and Vogel, 1987; Lovley *et al.*, 1989; Hutchins, 1991). Geochemical evidence suggests that anaerobic biodegradation of BTEX compounds is occurring at the KC-135 Crash Site, specifically in the area between USGS-4 and W409 (Section 6). It is also possible to simulate biodegradation processes in Bioplume II using a site-specific decay constant. This way both aerobic and anaerobic decay processes can be simulated. Additionally, the site-specific mass transfer, mixing, and kinetic limitations can be incorporated into the model. The following subsections discuss in detail the input parameters, the model assumptions, the model calibration, and the simulation results.

CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. Data and information presented in Section 6 suggest that oxygen, manganese, sulfate, and iron hydroxide are being used as electron acceptors for aerobic and anaerobic biodegradation. The combined effect of these processes is incorporated into the model through use of a site-specific decay constant.

Based on the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a shallow unconfined aquifer composed of medium- to coarse-grained sand (Figure 3.4). The saturated thickness of the aquifer is estimated at approximately 60 feet in the vicinity of the crash site. Aquifer discharge is to the Au Sable River, more than 10,000 feet to the southeast. The use of a 2-D model is appropriate at the KC-135 Crash Site because the saturated interval is very homogenous, and the local flow system, as defined by groundwater elevation data and the deep, underlying lacustrine clay layer (60 to 70 feet bgs), will likely prevent significant downward vertical migration of dissolved BTEX contamination. The source of JP-4 contamination at the site is clearly identified, and emanates from the crash area near USGS-4. Contaminated soils at the site have not been remediated, and pockets of mobile- and residual-phase JP-4 contamination may still exist. As a result, a continuing source factor has been incorporated to account for additional dissolution of BTEX into groundwater over time.

INITIAL MODEL SETUP

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

Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 30-cell grid was used to model the KC-135 Crash Site. Each grid cell was 40 feet long by 40 feet wide. The grid was oriented so that the longest dimension was parallel to the overall direction of groundwater flow. The grid encompasses the existing BTEX plume with sufficient space between all model boundaries to avoid significant numerical errors caused by contact between the boundary and the BTEX plume. The model grid covers an area of 960,000 square feet, or approximately 22 acres. The full extent of the model grid is indicated on Figure D.1.

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

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

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

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

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

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

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

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

Where:
H = Head in the zone being modeled (generally the zone containing the contaminant plume)
H_0 = Head in external zone (separated from plume by semipermeable layer)
K' = Hydraulic conductivity of semipermeable layer
B' = Thickness of semipermeable layer.

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

Specified-head boundaries for the model were set on the northwest and southeast perimeter of the model grid to simulate groundwater flow to the southeast as observed at the site. The head of the northwest model boundary (240 feet northwest of the source) was estimated to be between 617.2 to 617.4 feet above msl. The southeast model (960 feet southeast of the source) was estimated to be 614.7 to 614.8 feet above msl.

The northeast and southwest model boundaries were configured as no-flow (specified-flux) boundaries. In this case, the flux through these boundaries is assumed to be zero because flow is generally parallel to these boundaries. The base or lower boundary of the model is also assumed to be no-flow, and is typically defined by the upper surface of the lower confining layer. On the basis of aquifer thickness and BTEX data (Sections 3 and 4), the saturated thickness of the aquifer was assumed to be 27.5 feet, instead of 60 to 70 feet for the full saturated thickness to the confining layer. The estimated saturated thickness of 27.5 feet is the split thickness from the surface of the water table to the center of screened intervals for monitoring wells W409S and W409M. This estimated saturated thickness is representative of contaminant hydrogeology at the site because contamination was not detected in W409M, suggesting that BTEX contamination had not migrated deeper in the aquifer. On the basis of this observation, the majority of contamination is likely stratified near the top of the aquifer, thereby making the estimated saturated thickness a better conceptualization of contaminant hydrology to use for modeling purposes. The upper model boundary is defined by the simulated water table surface.

Groundwater Elevation and Gradient

The water table elevation map presented in Figure 3.5 was used to define the starting heads input into the Bioplume II model. Groundwater flow in the vicinity of the KC-135 Crash Site is to the southeast with a gradient in the modeled area of approximately 0.0024 ft/ft. Gradients appear uniform over the site.

Limited data exist to document if seasonal precipitation rates significantly vary groundwater flow direction. Considering the homogeneity of sands and the constant relative thickness of the aquifer at the site, it was assumed that the observed water levels were representative of steady-state conditions. As described in later sections, the model was calibrated to the observed water table.

BTEX Concentrations

The total dissolved BTEX concentrations obtained from laboratory analytical results for each well location were used for model development. Data from December 1992/ January 1993 and October 1994 were used to calibrate the model to BTEX concentrations from two time periods. At nested well locations, BTEX concentrations were only detected in the shallowest wells. Appendix B presents dissolved BTEX concentration data. Figure 6.4 shows the aerial distribution of dissolved BTEX compounds in the aquifer in December 1992/ January 1993. Figure 6.5 shows the aerial distribution of dissolved BTEX compounds in the aquifer in October 1994. As described in Section 6 and this appendix, the simulated BTEX plume was calibrated to match the observed BTEX plumes in December 1992 and October 1994/ January 1993.

Contaminant Decay Coefficient

As discussed previously, the Bioplume II model assumes an instantaneous reaction between the BTEX plume and the DO plume. The discussion presented in Section 6 suggests that oxygen, manganese, sulfate and ferric iron are being used as electron acceptors for BTEX biodegradation at the KC-135 Crash Site. The site was modeled assuming that DO was the only electron acceptor initially present in the aquifer. The DO concentrations were assumed to be utilized for the biodegradation of BTEX compounds at a rate that is instantaneous relative to the advective groundwater flow velocity. Groundwater samples collected from contaminated and uncontaminated portions of the aquifer suggest that DO concentrations at the site range from 0.1 to 9.4 mg/L. A background oxygen concentration recorded upgradient of soil contamination was 7.7 mg/L at W407. A DO concentration of 8.0 mg/L was assumed as the ambient starting concentration over the model grid.

The upgradient specified-head cells in the Bioplume II model require that a background DO concentration be input as a constant concentrations to account for potential replenishment of electron acceptors from upgradient sources. However, the option in Bioplume II to add electron acceptors to the model grid from upgradient sources was not used because contaminant biodegradation was instead simulated with a contaminant decay coefficient. This is discussed in greater detail later.

MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by altering transport parameters in a trial-and-error fashion until the

simulated BTEX plume approximated observed field values. Table D.1 lists input parameters used for the modeling effort.

Water Table Calibration

The shallow water table at the KC-135 Crash Site was assumed to only be influenced by continuous recharge and discharge at the constant-head cells established at the upgradient and downgradient model boundaries. No surface water bodies exist in the immediate area that may affect the flow direction of the groundwater. The initial water levels at the constant-head cells were varied to calibrate the water table surface. Transmissivities were not varied in the model because of both the homogeneity of sands at the site and the availability of hydraulic conductivity estimates derived from slug test data. Recharge from annual precipitation was omitted as a conservative model estimate because of low predicted recharge rates. The model was calibrated under steady-state conditions.

Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. According to the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume that degrades at a slower rate because few electron acceptors are available

for biodegradation at the contaminant source. Higher values of hydraulic conductivity result in a faster-moving plume that degrades faster because more electron acceptors are available for biodegradation at the contaminant source.

Estimated saturated thickness data were used in conjunction with estimates of the hydraulic conductivity to create an initial transmissivity grid for the entire model. Figure D.2 shows the calibrated water table. Calibrated model hydraulic conductivities ranged from 4.49×10^{-4} foot per second (ft/sec) to 1.0×10^{-3} ft/sec (2.8×10^{-2} ft/min to 1.6×10^{-2} ft/min), which are estimated values of hydraulic conductivity for the site (WW Engineering & Science, 1993).

Water level elevation data from cells associated with 12 monitoring well locations were used to compare measured and simulated heads for calibration. The 12 selected cell locations each contained one of the following wells: W400, W401, W402, W404, W407, W408, W-409S, W410, W411, W412, W413, and USGS-4.

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

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

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

h_m = measured head value

h_s = simulated head value.

The RMS error between observed and calibrated values at the 12 comparison points was 0.04 foot, which corresponds to a calibration error of 1.6 percent (water levels dropped approximately 2.6 feet over the length of the model grid). RMS error calculations are summarized at the end of this appendix. A plot of measured vs. calibrated heads shows a random distribution of points around a straight line, as shown at the end of this appendix. Deviation of points from a straight line should be randomly distributed in such a plot of results from computer simulations (Anderson and Woessner, 1992).

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. The hydraulic mass balance for the calibrated model was good, with 99 percent of the water flux into and out of the system being numerically accounted for (i.e., a 1-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable.

BTEX Plume Calibration

Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations from groundwater samples taken in December 1992/ January 1993 and

October 1994. To do this, model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants.

Because pockets of residual and mobile JP-4 were assumed to be the main contaminant source at the site (mobile JP-4 was detected for three years in monitoring wells USGS-4 and USGS-7), it was necessary to include model injection wells to simulate partitioning of BTEX compounds from the JP-4 source into the groundwater. Available soil data suggest that residual JP-4 contamination is now insignificant at the site because of historically low concentrations of BTEX and TPH detected in the vadose zone (Section 4). The transport pathway from JP-4 to groundwater is through transfer at the groundwater/JP-4 interface or through percolating precipitation that carries BTEX constituents from the mobile JP-4 into the aquifer. The locations of the injection wells are shown on Figure D.3. Five injection wells were placed in the estimated mobile JP-4 source area to reproduce the observed BTEX plume shape in 1992 and 1994.

While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was set at 1.1×10^{-5} cubic foot per second (ft^3/sec), a value low enough that the flow calibration and water balance was not affected. Relatively high BTEX concentrations were needed in injection wells because of the low volumetric injection rates.

On the basis of available mobile JP-4 data, JP-4 levels were first measured at the site at monitoring well USGS-4 in April 1989, approximately 6 months after the KC-135 crash. JP-4 persisted at USGS-4 until it was not measured in November 1991. Floating JP-4 was also detected at USGS-7 (approximately 70 feet northwest of USGS-4) from October 1989 to November 1991. No measurable levels of JP-4 existed in any of the site monitoring wells by November 1992, suggesting that the majority of JP-4 contamination had disappeared through weathering or sorption. The BTEX plume calibration was achieved by adjusting injection well BTEX concentrations in a pattern closely resembling the observed spreading and disappearance of JP-4 over the site. Only two of five injection wells (centered around USGS-4) were used to simulate groundwater contamination from JP-4 for the first model year (October 1988 to October 1989) because JP-4 contamination had not spread to the vicinity of USGS-7 until October 1988 (approximately 1 year after the KC-135 crash). All five injection wells were used from October 1989 through October 1992 to simulate the maximum predicted extent of JP-4 near USGS-4 and USGS-7. All five injection wells were used for one year past the observed disappearance of JP-4 in November 1991 (October 1991 to October 1992) to help maintain observed plume shapes in 1992 and 1994. Only two injection wells near USGS-4 were needed after October 1992 to simulate observed BTEX concentrations in 1994 and beyond, apparently a result of diminishing JP-4 contamination at the site. The calibrated plume configuration (model KC1) for 1992 and 1994 are shown in Section 6.

The close resemblance of the modeled and observed plume shapes help describe the pattern of mobile JP-4 spreading and disappearance at the site. Modeling data and mobile JP-4 data both support that JP-4 originated from the crash near USGS-4 and spread toward USGS-7 to cover a maximum area of approximately 6,400 square feet. By 1992, the source of mobile JP-4 contamination appeared to have receded to soils near USGS-4 only. On the basis of observed BTEX plumes in 1992 and 1994, the mass of JP-4 (and

BTEX constituents) in the soil continued to weather. The mass of BTEX in the aquifer in 1994 was 72 percent less than in 1992. To simulate the BTEX concentrations in groundwater past 1994, it was assumed that BTEX contamination would continue weathering at 72 percent every two years. Therefore, calibrated injection well concentrations were reduced by 72 percent every two years in the model. This process of reducing injection well concentrations by 72 percent was continued until simulated BTEX concentrations were below MDLs. Natural attenuation is predicted to achieve total BTEX concentrations of below 1 µg/L around the year 2007 (Section 6).

Although the overall area and concentration of the modeled plume slightly exceed observed conditions, visual inspection of the calibrated model plume shows that it matches well with actual field conditions. The objective of the calibration was to achieve a modeled plume that equaled or exceeded the existing plume in terms of concentration and extent. The downgradient extent of the observed 1992 plume very closely matched the modeled plume extent as indicated by the close proximity of the simulated 28 µg/L isopleth line to temporary sampling location T-16 (which had a recorded 28 µg/L of benzene in 1992). The maximum calibrated 1992 BTEX concentration was 16,000 µg/L near USGS-4, which was higher than observed 1992 concentration of about 15,800 µg/L. (Note: the observed 1992 maximum may have been 16,300 µg/L, except the reporting limit for benzene was 500 µg/L as a result of dilution.) The modeled downgradient BTEX concentrations of the 1994 plume exceeded the observed 1994 BTEX concentrations by approximately 200 µg/L. Furthermore, the modeled 1994 BTEX plume extended farther downgradient than did the observed 1994 BTEX plume by 200 feet. However, the maximum calibrated 1994 BTEX concentration was 5,000 µg/L, which was below the observed total 1994 BTEX concentration of 5,128 µg/L. Overall, the calibrated model conservatively represented the observed BTEX contamination with either higher predicted BTEX concentrations or longer BTEX plumes. Variations in shape between the model and the observed plume are a result of subsurface heterogeneities between modeled and actual hydraulic conductivity, contaminant decay coefficient, dispersivity, and retardation coefficient that are extremely difficult to reproduce in a discretized model domain.

Discussion of Important Plume Calibration Parameters

Few transport parameters were varied during plume calibration because of the sufficient amount of available data. Hence, it was not necessary to vary the modeling parameters of dispersivity, retardation, and contaminant decay to achieve a model calibration. Only injection well BTEX concentrations and nodal boundary conditions were varied to achieve the model calibration. However, the impact on the size and shape of the simulated plume and the estimation method used for the model parameters dispersivity, retardation, and contaminant decay rate is discussed below.

Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for sediments similar to those found at the site range from 0.1 to 200

feet (Walton, 1988). Longitudinal dispersivity was estimated as 10.94 feet, using one-tenth (0.1) of the distance between the estimated spill source of the 1992 BTEX plume and the longitudinal centroid of the 1992 BTEX plume. Dispersivity estimation calculations are included at the end of this appendix. Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was maintained at 10.94 feet. This value was low compared to possible values that could have been used, but was justified by an estimate of dispersivity included at the end of this appendix. The use of a moderate dispersivity value of 10.94 feet was a good estimate for the medium- to course-grained sandy soils at the site. Similarly, the ratio of transverse dispersivity to longitudinal dispersivity was maintained at 0.1 to help reproduce the plume width observed at the site.

Coefficient of Retardation

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation for the BTEX compounds were calculated based on measured TOC concentrations in the soils in and near the saturated zone at the site (Section 3), an assumed bulk density of 1.6 grams/cubic centimeter (Freeze and Cherry, 1979), and published values of the soil sorption coefficient (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table D.2. A final value of 1.21 for the retardation coefficient was used for the BTEX compounds, which is conservative because this value is reflective of the minimum estimated retardation coefficient for benzene, which is the least sorptive BTEX compound. As with dispersivity and the reaeration coefficient, this variable was not adjusted in the model calibration.

Contaminant Decay Coefficient

The contaminant decay coefficient (or reaeration coefficient) is a first-order rate constant that can be used in Bioplume II to simulate aerobic and anaerobic contaminant removal.

The contaminant decay coefficient (or biodegradation coefficient) is estimated with an analytical solution of the general one-dimensional transport equation modified by Buscheck and Alcantar (1995). The assumptions necessary to use the Buscheck and Alcantar method are a steady-state plume and first-order BTEX biodegradation rates. Calculations of the contaminant decay coefficient using the Buscheck and Alcantar method are included at the end of this appendix. A contaminant decay coefficient of 0.0071 day^{-1} is derived by the above method. As with dispersivity and retardation, this value is not varied in the model calibration process.

The Buscheck and Alcantar method corrects for dispersion and retardation of the contaminant. A final decay rate is representative of the combined processes of aerobic and anaerobic biodegradation (because the method is based on observed hydrocarbon losses, regardless of the biodegradation processes involved). On the basis of electron acceptor data presented in Section 6, oxygen is the dominant electron acceptor at the site.

Hence, the coefficient expresses an aerobic biodegradation rate overall. However, the estimated reaeration coefficient also includes components of anaerobic biodegradation.

The appearance and disappearance of JP-4 in monitoring wells and the diminishment of groundwater BTEX plumes over time suggests that BTEX contamination is transient. Although the Buscheck and Alcantar method assumes a steady-state source, the contaminant decay coefficient is estimated from the largest observed BTEX plume (1992) to calculate the lowest decay rate. The progressive loss of BTEX (from mobile JP-4 weathering in the soil and natural attenuation in the groundwater) allows more DO from upgradient sources and precipitation to biodegrade the remaining BTEX compounds. As a result, the reaeration coefficient is anticipated to increase with time, based on increases of the DO to BTEX ratio, thereby making the estimated value of 0.0071 day^{-1} increasingly conservative over time.

SENSITIVITY ANALYSIS

The purpose of the sensitivity analyses is to determine the effect of varying model input parameters on model output. Based on the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the contaminant decay coefficient, the coefficient of anaerobic decay, and the hydraulic conductivity of the media, and is less sensitive to changes in the retardation factor, porosity, and dispersivity. A coefficient of anaerobic decay was not applied for KC-135 Crash Site modeling. The effect of anaerobic processes on BTEX mass are included in the overall contaminant decay coefficient. Because the porosity was not varied and the dispersivity was not significantly changed, the sensitivity analysis was conducted by varying the transmissivity, the contaminant decay coefficient, the coefficient of retardation, and the dispersivity coefficient.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually, and then comparing the new model runs to the original calibrated model. The sensitivity models were run for a 6-year period so that the independent effect of each variable could be assessed at predicted 1994 concentrations. As a result, eight sensitivity runs of the calibrated model were made, with the following variations:

1) Transmissivity uniformly increased by a factor of 5;
2) Transmissivity uniformly decreased by a factor of 5;
3) Coefficient of contaminant decay increased by 25 percent;
4) Coefficient of contaminant decay decreased by 25 percent;
5) Coefficient of retardation increased by 15 percent;
6) Coefficient of retardation decreased by 15 percent;
7) Dispersivity increased by 50 percent; and,
8) Dispersivity decreased by 50 percent.

The results of the sensitivity analyses are shown graphically in Figures D.4, D.5, D.6, and D.7. These figures display the modeled BTEX concentrations versus distance along the centerline of the plume (11th model grid column). This manner of displaying data is useful because BTEX concentrations are highest in the 11th column, and the plume extends the farthest downgradient from the source of contamination. Furthermore, the

plume generally migrates in a direction parallel to the model grid, and the figures allow easy visualization of the changes in BTEX concentration caused by varying model input parameters.

The effects of varying transmissivity are shown by Figure D.4. Uniformly increasing the transmissivity by a factor of five altered the plume shape such that the maximum observed concentrations in the source cell area were 1,800 µg/L, compared to the calibrated maximum of 5,000 µg/L. In this case, the BTEX plume extended farther downgradient and off the model grid. Lower BTEX concentrations in the center of the plume are a result of an increased advective velocity that reduced the residence time of groundwater below the source area. Thus, less BTEX contamination was able to dissolve into the groundwater from floating JP-4. Increased groundwater velocity also caused BTEX contamination to migrate farther downgradient before being biodegraded. In contrast, decreasing the transmissivity by a factor of five slowed overall plume migration, which shortened the plume by approximately 300 feet and in turn caused an increase in maximum BTEX levels. Increased BTEX concentrations in the plume area are caused by a reduction in the plume travel rate, thereby allowing greater BTEX concentrations to dissolve into groundwater in the source area before being biodegraded downgradient.

The effects of varying the contaminant decay coefficient (input as the reaeration coefficient) are illustrated by Figure D.5. Increasing this parameter by 25 percent results in a reduction of the maximum BTEX concentrations by 400 µg/L. In addition, the front of the plume recedes approximately 50 feet, though this is not apparent from the chart. This is a result of increased biodegradation. Conversely, decreasing this coefficient by 25 percent decreases biodegradation and increases the length of the plume by approximately 100 feet. The corresponding increase in the computed maximum BTEX concentrations in the plume center was 500 µg/L.

The effects of varying the coefficient of retardation (R) are shown on Figure D.6. Increasing R by 15 percent decreased the maximum BTEX source concentration by approximately 600 µg/L and shortened the plume by approximately 50 feet (relative to the calibrated model). The decrease in plume extent and source concentration resulted from a slowing of BTEX migration from increased contaminant sorption, which then increased the removal of BTEX mass before further migration. Decreasing R by 15 percent slightly accelerated plume migration because less contaminants were sorbed to soil particles. This reduced sorption created a faster moving BTEX plume (approximately 75 feet longer than calibrated). Less BTEX mass was removed before the plume migrating downgradient (source concentration was increased by approximately 300 µg/L). Because the retardation factor used for the model is low relative to other possible retardation factors (Table D.2), the R used for the calibrated simulation is conservative relative to the combined sorption potential of all the BTEX compounds.

The coefficient of dispersivity is considered one of the least sensitive model parameters (Rifai *et al.*, 1988). However, the dispersivity parameter in the Bioplume II model was varied because of the medium- to coarse-grained sands in the aquifer that could potentially increase the effect of mechanical dispersion at the site. The dispersivity factor was increased by 50 percent above the calibrated model, which caused a minor decrease in the contaminant source concentration of approximately 500 µg/L and no

noticeable decrease in downgradient plume extent. Decreasing the dispersivity factor by 50 percent increased the contaminant source concentrations by approximately 500 µg/L with no noticeable increase in the downgradient plume extent. The increase or decrease in source concentrations were a result of increasing or decreasing the residence time of the groundwater contamination in the vicinity of the source area. Increased residence time (decreased dispersivity) caused more BTEX contamination to dissolved into the groundwater before contaminant migration. Similarly, decreasing residence time (increased dispersivity) caused less BTEX contamination to dissolved into groundwater before contaminant migration.

The results of the sensitivity analyses suggest that the calibrated model parameters used for this Bioplume II model match observed conditions well (see, for example, Figures 6.4 and 6.5). The calibrated model is sensitive to all the parameters varied, and especially sensitive to transmissivity and the contaminant decay coefficient. Increasing transmissivities, the retardation factor, the decay coefficient, or the dispersivity factor reduced the predicted BTEX concentrations and/or reduced the predicted plume length. Lowering transmissivity increased source concentrations and reduced plume length. Lowering the reaeration coefficient, the coefficient of retardation, and the dispersivity factor tended to lengthen the plume beyond reasonable distances based on 1994 BTEX data.

SIMULATING BIOSPARGING

The effect of oxygen addition in the shallow aquifer through biosparging was evaluated with the Bioplume II model (Alternative 2). Conceptually, biosparging units are placed at the source of contamination to maximize both oxygen delivery and volatilization in zones of highest BTEX contamination. Oxygen delivery in the source area enhances aerobic biodegradation BTEX contaminants in zones of low DO. As a conservative assumption, the effect of volatilization was omitted from the Bioplume model. Biosparging was simulated in the Bioplume II model by combining existing model injection wells with simulated biosparging wells. Five injection wells were used in the calibrated model to simulate the observed BTEX plume. Two of these five injection wells were modified to include oxygen in the recharge stream to simulate the introduction of DO through biosparging. Four biosparging units, each with an assumed 20 foot radius of influence, were predicted to have sufficient mass-transfer capabilities to deliver an additional 1 mg/L of DO per unit volume of groundwater passing through the treatment area. The treatment area is approximately 5030 square feet with four biosparging units (approximately 2 model grid cells). Model injection wells at cells (11,6) and (12,6), which were located in the zone of highest BTEX contamination, were selected as the location of the simulated biosparging array. Successful calibration of the injection wells to transfer 1 mg/L of DO per unit volume of water to the aquifer was accomplished by trial-and-error adjustments of DO recharge rates. The final calibrated biosparging model (KC2) achieved mass transfer rates of 0.93 mg/L per unit volume of water in the treatment area by the first year of operation (1996). After the first year of operation, DO mass-transfer rates fluctuated around 1 mg/L at DO concentrations of 1.06 to 0.93 mg/L, for an approximate DO mass transfer rate of 109 grams of oxygen

delivered by the biosparging units into the treatment area per year.

TABLE D.1
BIOPLUME II MODEL INPUT PARAMETERS
KC-135 CRASH SITE
WURTSMITH AIR FORCE BASE
OSCADO, MICHIGAN

			Model Runs	
Parameter	Description	Calibrated Model Setup	KC1	KC2[c/]
NTIM	Maximum number of time steps in a pumping period	10	1	1
NPMP	Number of Pumping Periods	1	15	15
NX	Number of nodes in the X direction	20	20	20
NY	Number of nodes in the Y direction	30	30	30
NPMAX	Maximum number of Particles NPMAX=(NX-2)(NY-2)(NPTPND) + (Ns[a/])(NPTPND) + 250	5477	5155	5155
NPNT	Time step interval for printing data	1	1	1
NITP	Number of iteration parameters	7	7	7
NUMOBS	Number of observation points	0	1	1
ITMAX	Maximum allowable number of iterations in ADIP [b/]	200	200	200
NREC	Number of pumping or injection wells	13	5	5
NPTPND	Initial number of particles per node	9	9	9
NCODES	Number of node identification codes	1	1	1
NPNTMV	Particle movement interval (IMOV)	0	0	0
NPNTVL	Option for printing computed velocities	1	1	1
NPNTD	Option to print computed dispersion equation coefficients	0	1	1
NPDELC	Option to print computed changes in concentration	0	1	1
NPNCHV	Option to punch velocity data	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1
PINT	Pumping period (years)	10	1	1
TOL	Convergence criteria in ADIP	0.001	0.001	0.001
POROS	Effective porosity	0.25	0.3	0.3
BETA	Characteristic length (long. dispersivity; feet)	3.3	10.94	10.94
S	Storage Coefficient	0 (Steady-State)	0	0
TIMX	Time increment multiplier for transient flow	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	70	40	40
YDEL	Width of finite difference cell in the y direction (feet)	70	40	40
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.33	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx (1 = isotropic)	1	1	1
DK	Distribution coefficient	0.079	0.04	0.04
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.6	1.6	1.6
THALF	Half-life of the solute	-	-	-
DEC1	Anaerobic decay coefficient (day^{-1})	-	-	-
DEC2	Reaeration coefficient (day^{-1})	0.01	0.0071	0.0071
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.14	3.14	3.14

[a/] Ns = Number of nodes that represent fluid sources (wells or constant head cells)
[b/] ADIP = Alternating-direction implicit procedure (subroutine for solving groundwater flow equation)
[c/] Identical to model KC1 with the exception that two biosparging units were added to grid cells (11,6) and (12,6) in 1995 (model year 7) to simulate reoxygenation of the groundwater.

TABLE D.2
CALCULATION OF RETARDATION COEFFICIENTS
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE
WURTSMITH AFB, MICHIGAN

Compound	K_{oc} (L/kg [a/])	Maximum Fraction Organic Carbon [b/]	Minimum Fraction Organic Carbon [b/]	Average Fraction Organic Carbon [b/]	Distribution Coefficient K_d (L/kg) Maximum [c1/]	Minimum [c2/]	Average [c3/]	Bulk Density (kg/L) [d/]	Effective Porosity	Coefficient of Retardation Maximum	Minimum	Average
Benzene	79	0.0009	0.0005	0.0007	0.071	0.040	0.055	1.60	0.30	1.38	1.21	1.29
Toluene	190	0.0009	0.0005	0.0007	0.171	0.095	0.133	1.60	0.30	1.91	1.51	1.71
Ethylbenzene	468	0.0009	0.0005	0.0007	0.421	0.234	0.328	1.60	0.30	3.25	2.25	2.75
m-xylene	405	0.0009	0.0005	0.0007	0.365	0.203	0.284	1.60	0.30	2.94	2.08	2.51
o-xylene	422	0.0009	0.0005	0.0007	0.380	0.211	0.295	1.60	0.30	3.03	2.13	2.58
p-xylene	357	0.0009	0.0005	0.0007	0.321	0.179	0.250	1.60	0.30	2.71	1.95	2.33

NOTES:

[a/] From technical protocol (Wiedemeier *et al.*, 1994).

[b/] From KC-135 Crash Site data.

[c1/] K_d = Maximum Fraction Organic Carbon x K_{oc}.

[c2/] K_d = Minimum Fraction Organic Carbon x K_{oc}.

[c3/] K_d = Average Fraction Organic Carbon x K_{oc}.

[d/] Literature values.

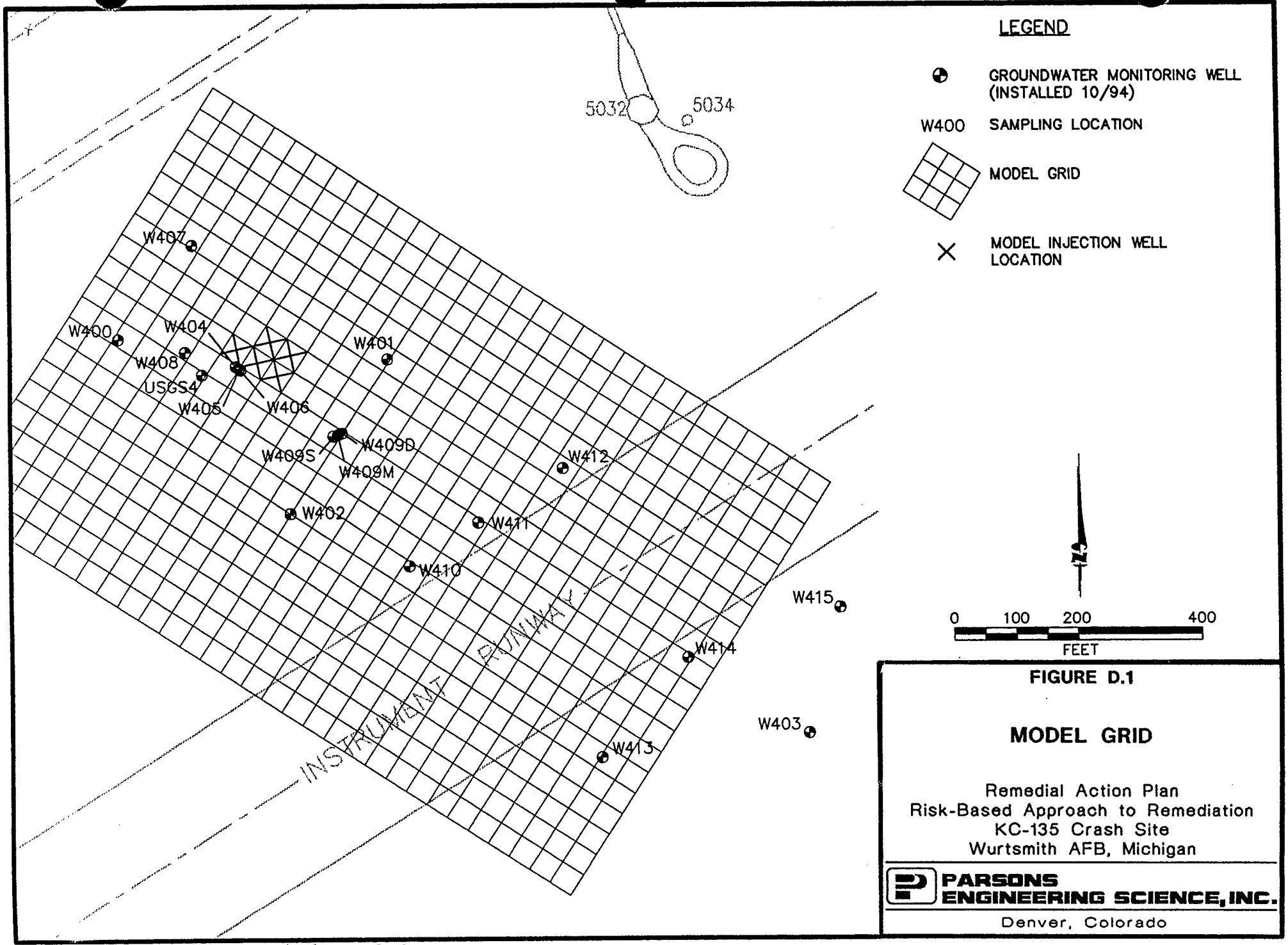


FIGURE D.1

MODEL GRID

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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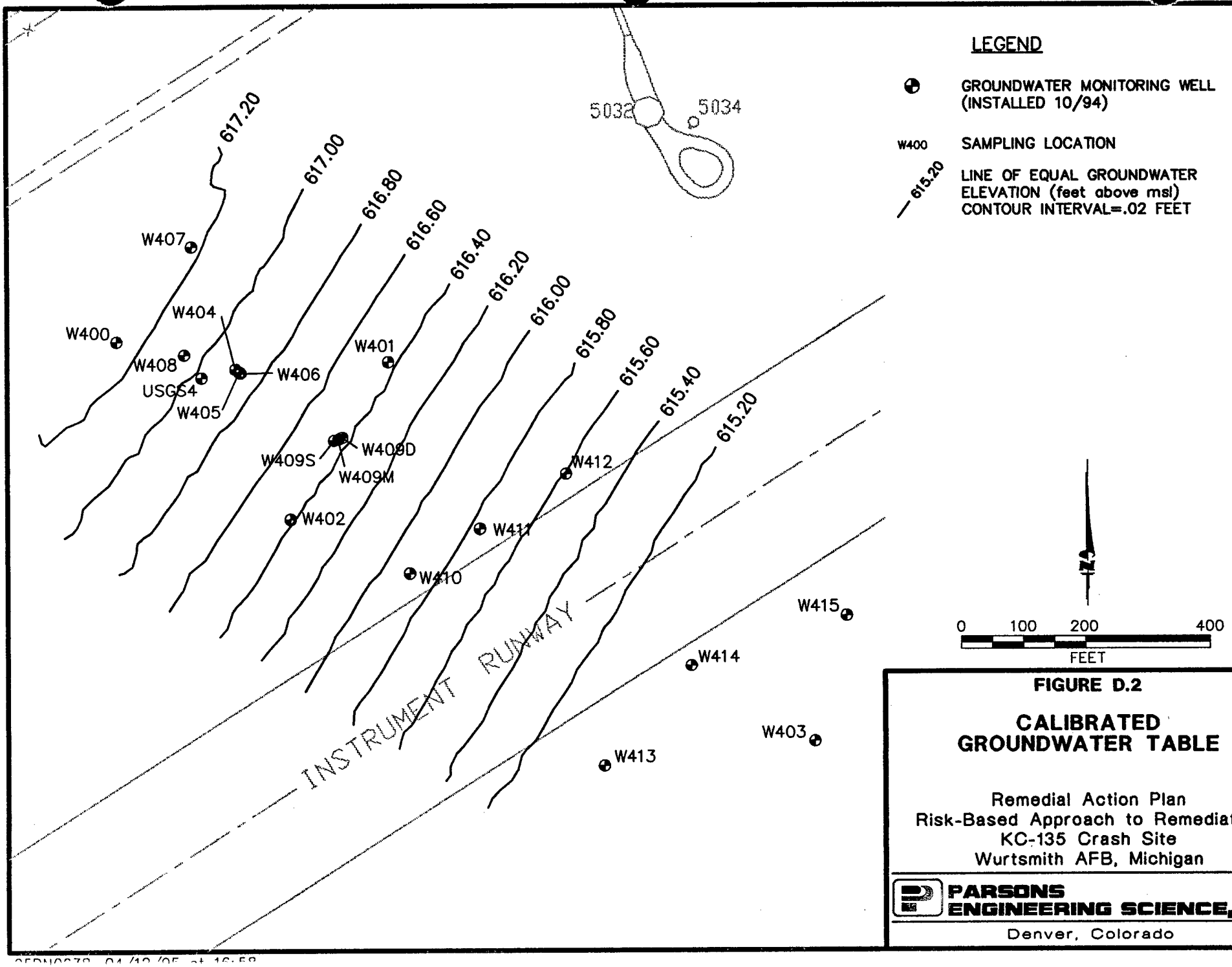

FIGURE D.2

CALIBRATED GROUNDWATER TABLE

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

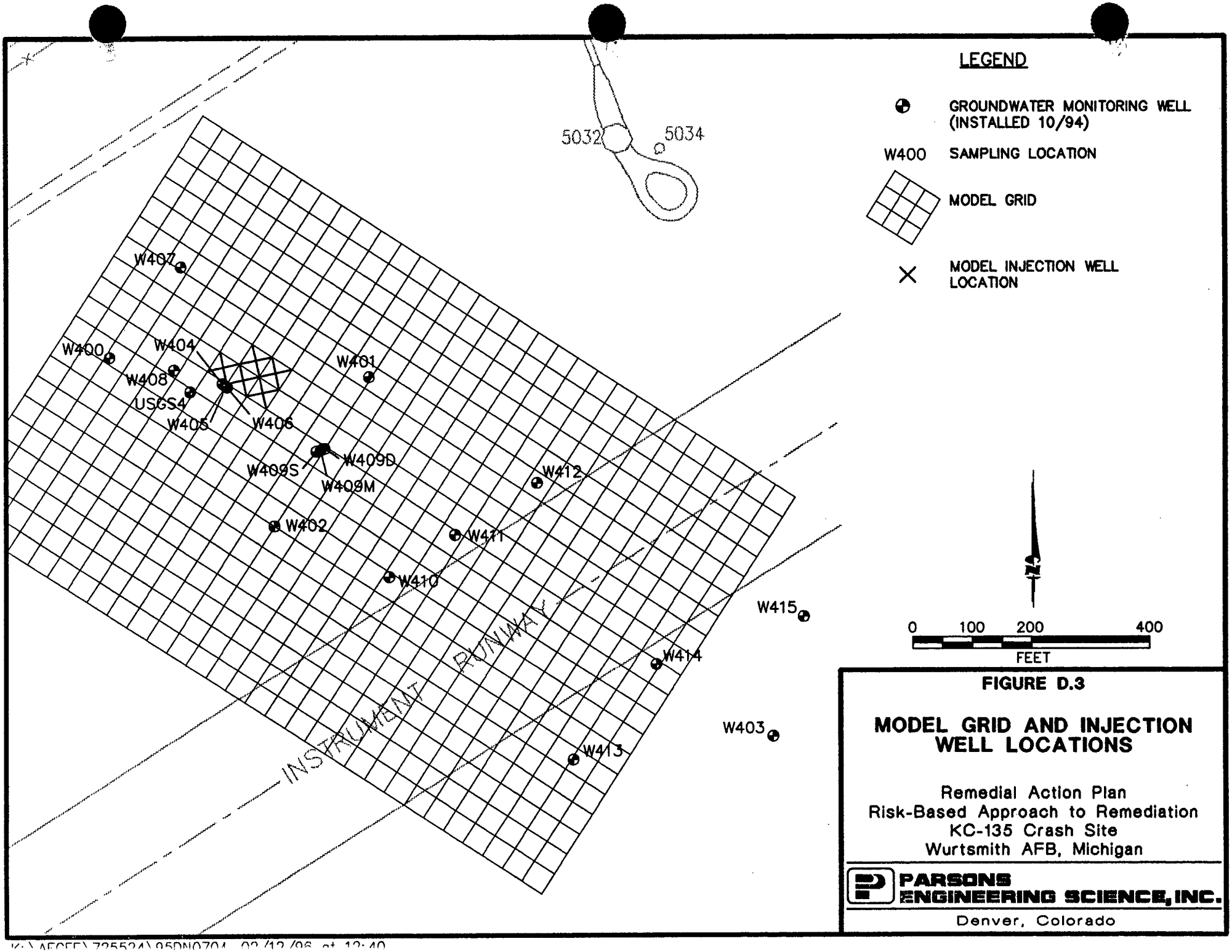

FIGURE D.3

MODEL GRID AND INJECTION WELL LOCATIONS

Remedial Action Plan
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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FIGURE D.4
PLOT OF TOTAL BTEX VS. DISTANCE ALONG PLUME CENTERLINE WITH VARYING TRANSMISSIVITY
KC-135 Crash Site
Wurtsmith AFB, Michigan

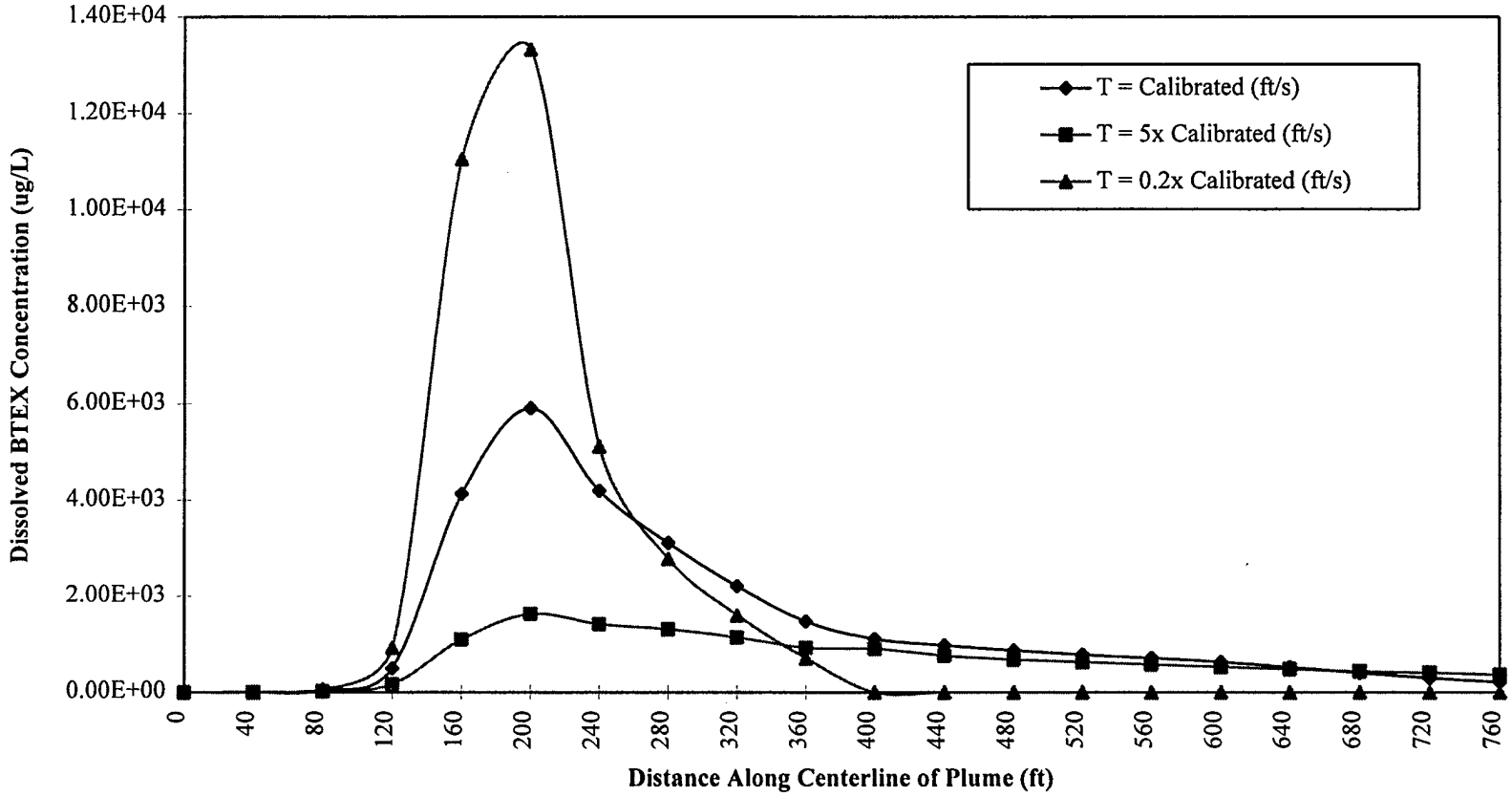

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FIGURE D.5
PLOT OF TOTAL BTEX VS. DISTANCE ALONG PLUME CENTERLINE WITH VARYING REAERATION COEFFICIENT
KC-135 Crash Site
Wurtsmith AFB, Michigan

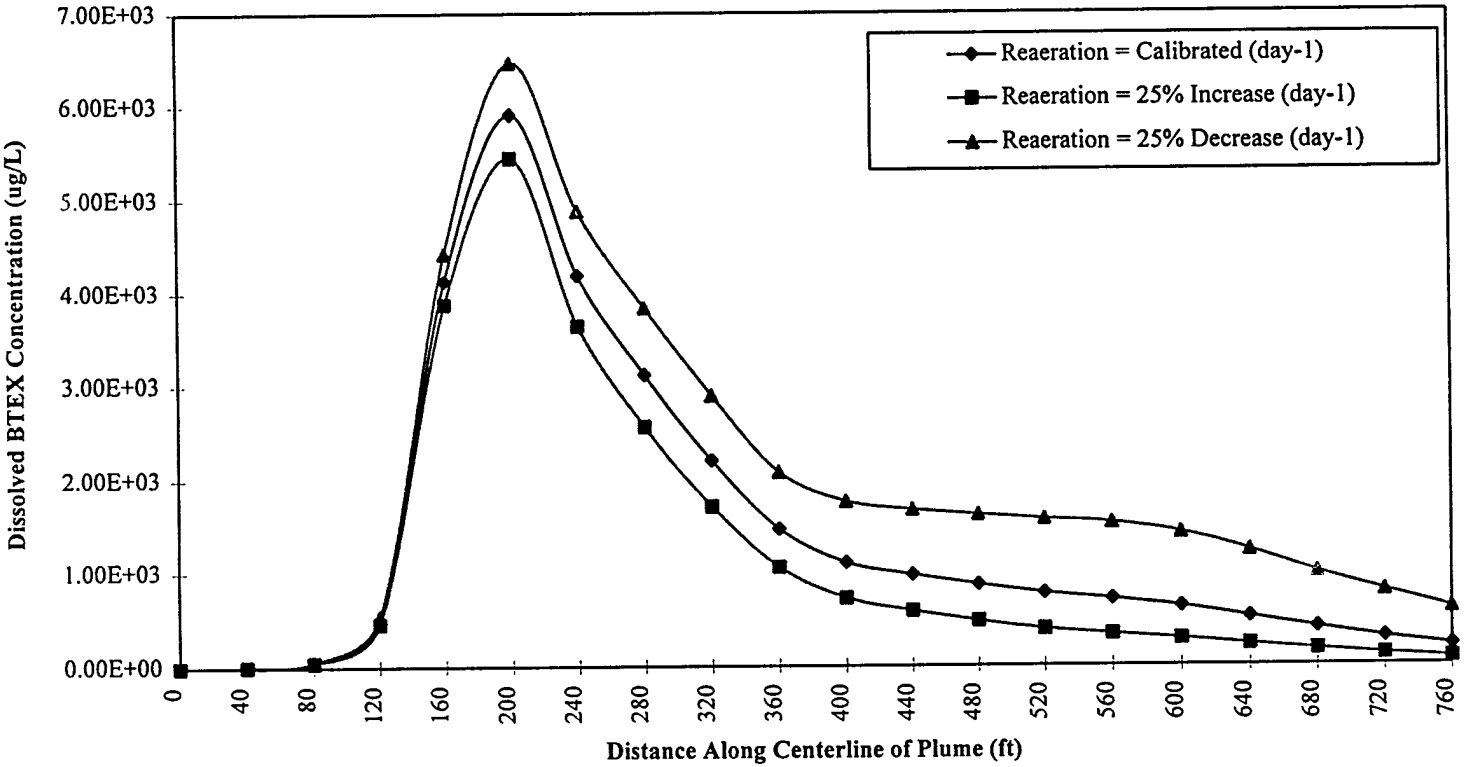

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FIGURE D.6
PLOT OF TOTAL BTEX VS. DISTANCE ALONG PLUME CENTERLINE WITH VARYING RETARDATION
KC-135 Crash Site
Wurtsmith AFB, Michigan

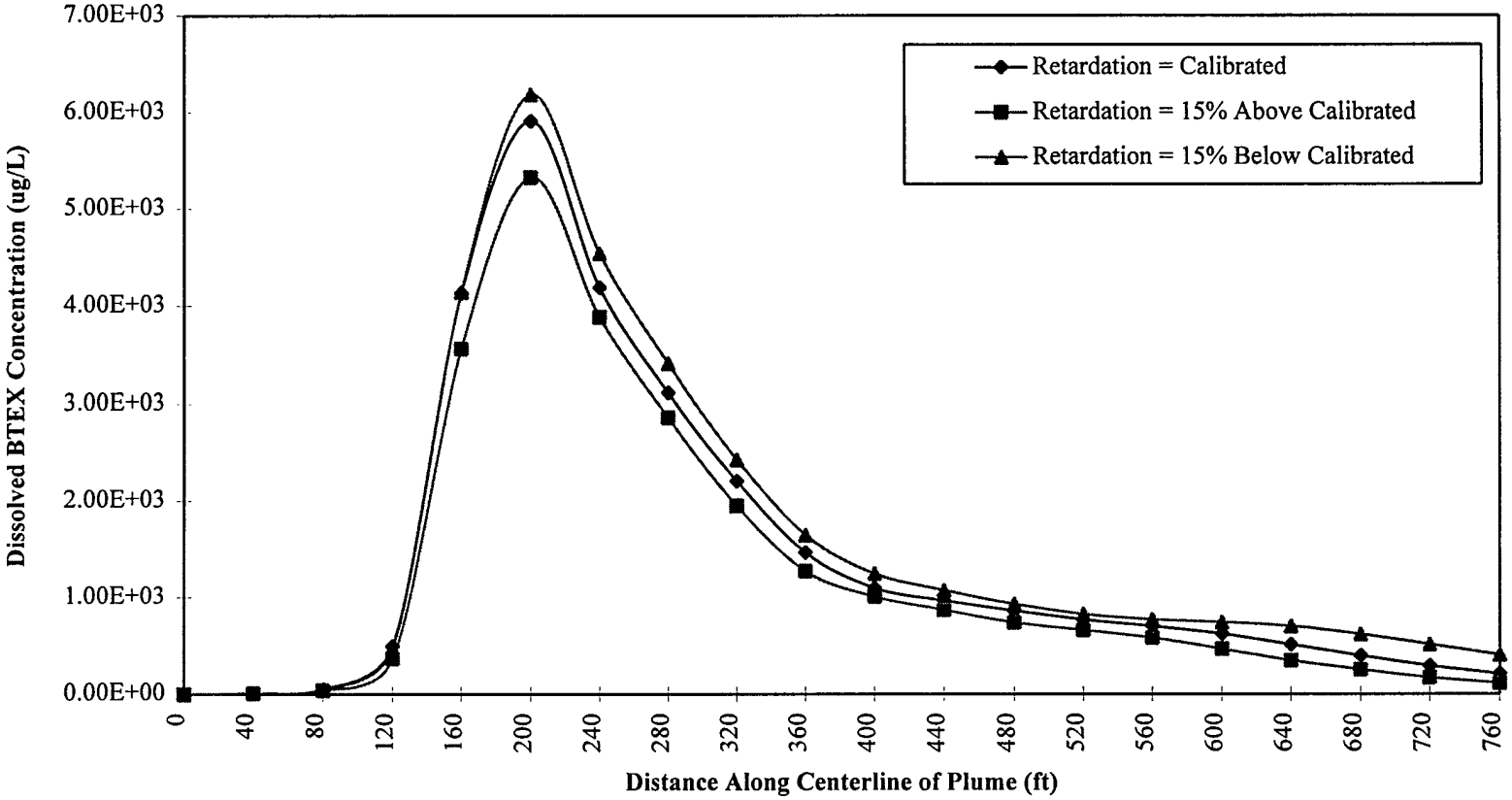

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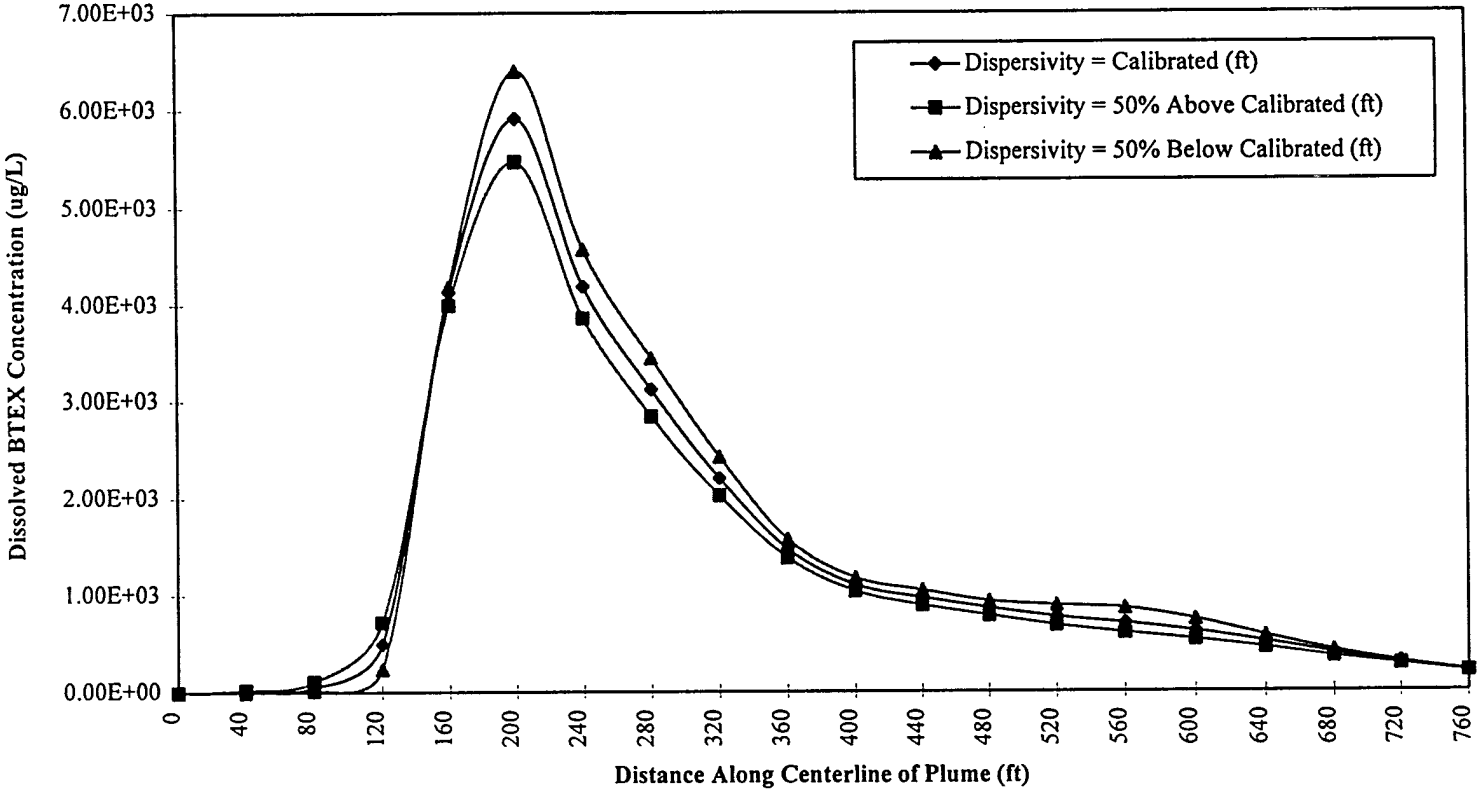
FIGURE D.7
PLOT OF TOTAL BTEX VS. DISTANCE ALONG PLUME CENTERLINE WITH VARYING DISPERSIVITY
KC-135 Crash Site
Wurtsmith AFB, Michigan



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Estimation of Reaeration Coefficient Using the Buscheck and Alcantar Method (1995) KC-135 Crash Site Wurtsmith AFB, Michigan

The Buscheck and Alcantar method for estimating a biodegradation coefficient (or reaeration coefficient in Bioplume II) is based on an analytical solution of the general one-dimensional transport equation. The analytical form of this equation was originally solved by Bear (1979), and then modified for a solution of the biodegradation coefficient by Buscheck and Alcantar (1995). The Buscheck and Alcantar derivation is shown below:

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

λ = first-order decay rate constant corrected for dispersion and sorption processes (day^{-1})
v_c = pore-water velocity of contaminant (feet/day)
v = pore-water velocity (feet/day)
α_x = longitudinal dispersivity (feet)
k = uncorrected first-order decay rate constant (day^{-1}) (see attached)

The assumptions necessary for use of the above equation are a steady-state plume and first-order decay rates. To solve the equation, estimates for v and v_c must be made. Hence:

$$v = ki/n \qquad (2)$$

k = hydraulic conductivity (ft/min)
i = ground water gradient (feet/feet)
n = soil porosity (ft^3/ft^3)

Based on previous data and estimates, hydraulic conductivity is estimated at 0.0477 ft/min (average k for monitoring well locations W401-W404), a hydraulic gradient of 0.0024 ft/ft (measured between monitoring wells W409S and W403), and an estimated soil porosity of 0.3 (Freeze and Cherry, 1979). Therefore:

v = (0.0477 ft/min)(0.0024)/(0.3)
v = 0.000386 ft/min or 0.56 ft/day

The contaminant velocity differs from the advective ground water velocity because of sorption or contaminants to soil organic matter. This sorption process is accounted for by the retardation coefficient, which was conservatively estimated at 1.29. Therefore:

$$v_c = v/R; \text{ where R is the retardation coefficient} \qquad (3)$$

v_c = (0.000386 ft/min)/1.29

v_c = 0.000299 ft/min or 0.43 ft/day

The longitudinal dispersivity, α_x, was estimated at 10.94 feet and the first-order decay rate constant, k, was estimated at 0.008 day^{-1}. Therefore:

λ = (0.43/4x10.94)([1+2x10.94(0.008/0.56)]^2-1)

λ = 0.0071 day^{-1}

Longitudinal Dispersivity Estimate
Risk-Based Approach to Remediation
KC-135 Crash Site
Wurtsmith AFB, Michigan

Assumptions:

A: The BTEX plume is sufficiently aligned along the longitudinal axis of the model grid and is relatively symmetric - so that a longitudinal moment may be calculated.

B: Longitudinal dispersivity is 1/10 of the distance from the approximate source of contamination to the longitudinal centroid.

The 1993 BTEX plume map at the KC-135 Crash Site (WW Engineering & Science, 1993) will be used to estimate a plume dispersivity because this was the largest documented extent of plume contamination at the site. The source of contamination appears to be located near USGS-4. The center of mass of the plume will be computed by using USGS-4 as the origin. The center of mass is computed by summing the mass of a given grid row (drawn on the attached figure), and then multiplying this row mass by the distance to the origin. By summing all the products of row mass and distance to origin, and then dividing this summation by the total mass in the aquifer, an estimate of the longitudinal center of mass will be derived. Hence, a dispersivity estimate will be 1/10 of the distance between the plume center of mass and the spill source (assumption B).

Row	Concentration[a/]	Mass[b/]	Distance from MW-51	Mass x Distance
1	260	5.06E+08	-50	-25307425000
2	800	1.56E+09	0	0
3	11900	2.32E+10	50	1.1583E+12
4	5600	1.09E+10	100	1.09017E+12
5	4000	7.79E+09	150	1.16804E+12
6	1500	2.92E+09	200	5.84018E+11
7	1000	1.95E+09	250	4.86681E+11
8	800	1.56E+09	300	4.67214E+11
9	600	1.17E+09	350	4.08812E+11
10	350	6.81E+08	400	2.72542E+11
11	152	2.96E+08	450	1.33156E+11
12	5	9.73E+06	500	4866812500
Totals		5.25E+10		5.74362E+12

[a/] Sum of BTEX concentrations in the entire row (ug/L).

[b/] Mass = (Concentration) x (50ft) x (50ft) x (27.5ft) x (28.316 liters per cu. foot) = ug.

The estimated longitudinal centroid of the plume (feet downgradient from the origin):

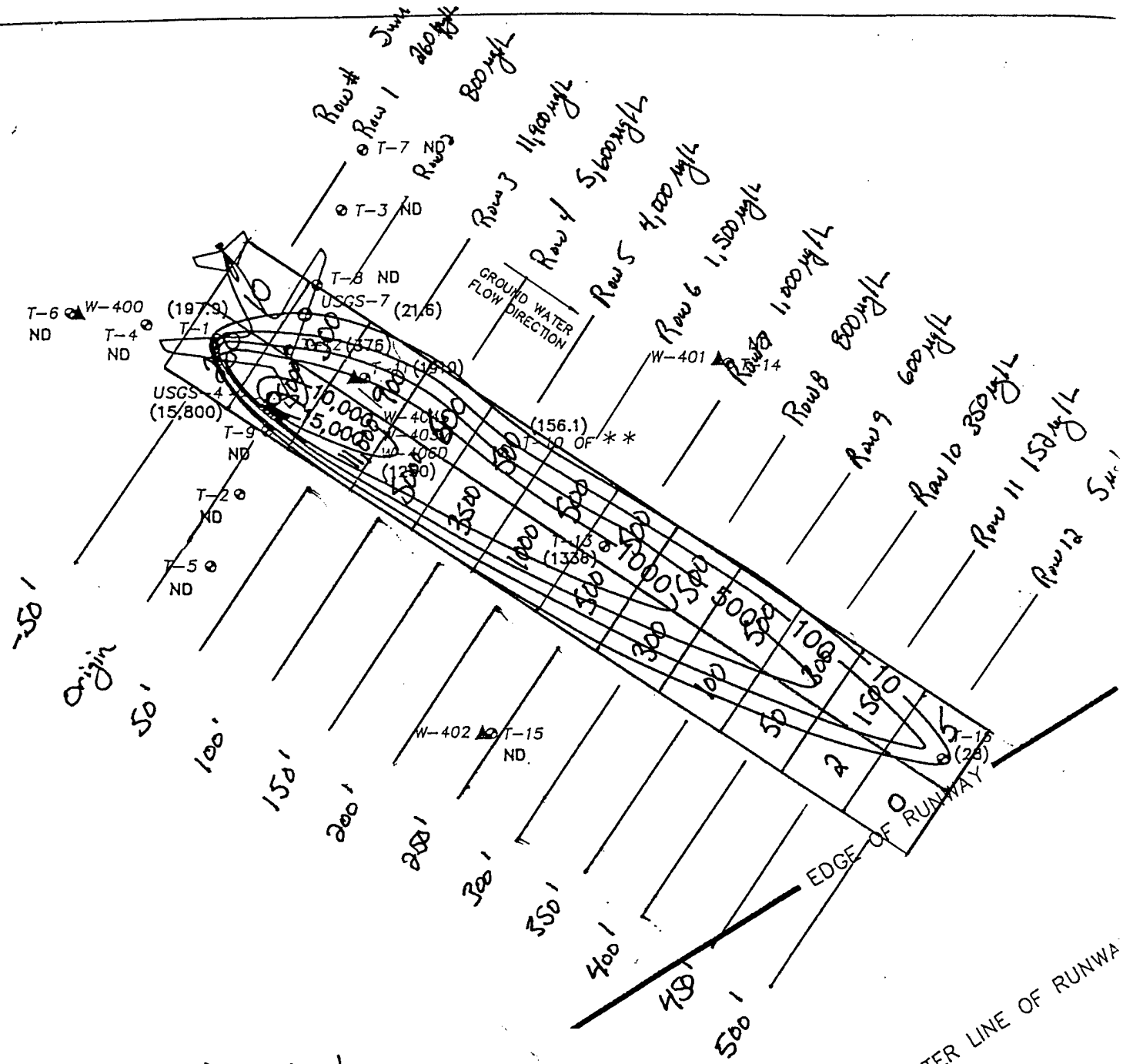
5.74362E+12/5.25E+10 109.43 feet

The estimated distance between the origin (or the source) to the centroid:

109.43 feet

The estimated longitudinal dispersivity:

109.43 x 0.1 10.94 feet

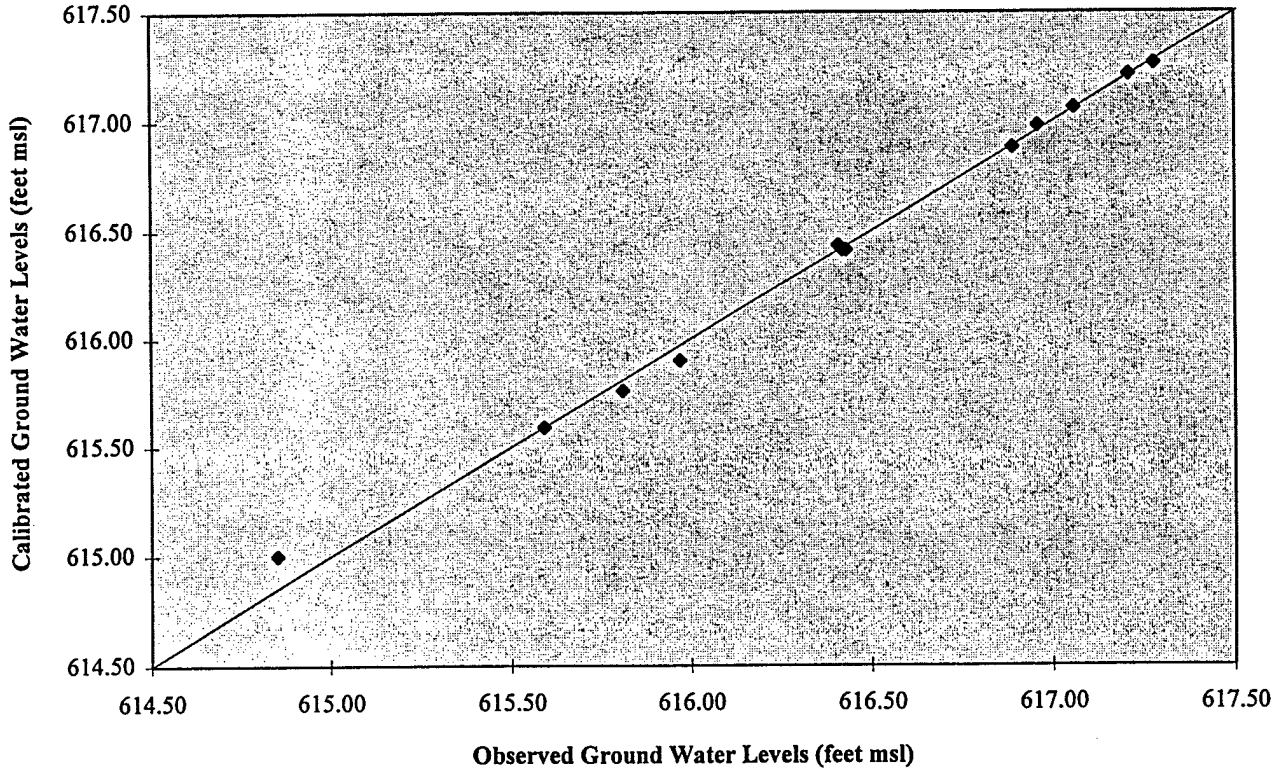


Grid Used for Estimating Longitudinal & Transverse Dispersivity

1. The number in each grid cell is the estimated average ~~conc~~ concentration of BTEX over the cell.
2. Each Grid cell is 50 ~~feet~~ x 50 feet.

Source: WW Engineering & Science, 1993.

Observed Heads Vs. Calibrated Heads
For the Calibrated Ground Water Model
KC-135 Crash Site
Wurtsmith AFB, Michigan



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Mean Error, Mean Average Error, and Root-Mean-Square Error for the Calibrated Ground Water Model
KC-135 Crash Site
Wurtsmith AFB, Michigan

Location	Actual Water Level (h_m)[a/]	Calibrated Water Level (h_s)[a/]	h_m-h_s	$abs(h_m-h_s)$	$(h_m-h_s)^2$
W-400	617.28	617.26	-0.02	0.02	0.00
W-401	616.42	616.41	-0.01	0.01	0.00
W-402	616.43	616.41	-0.02	0.02	0.00
W-404	616.89	616.88	-0.01	0.01	0.00
W-407	617.21	617.21	0.00	0.00	0.00
W-408	617.06	617.06	0.00	0.00	0.00
W-409S	616.41	616.43	0.02	0.02	0.00
W-410	615.97	615.90	-0.07	0.07	0.00
W-411	615.81	615.76	-0.05	0.05	0.00
W-412	615.59	615.59	0.00	0.00	0.00
W-413	614.85	615.00	0.15	0.15	0.02
USGS4	616.96	616.98	0.02	0.02	0.00
Total:	7396.88	7396.89	0.01	0.37	0.03
			ME[b/] =	0.00	
			MAE[c/] =	0.02	
			RMS[d/] =	0.04	

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

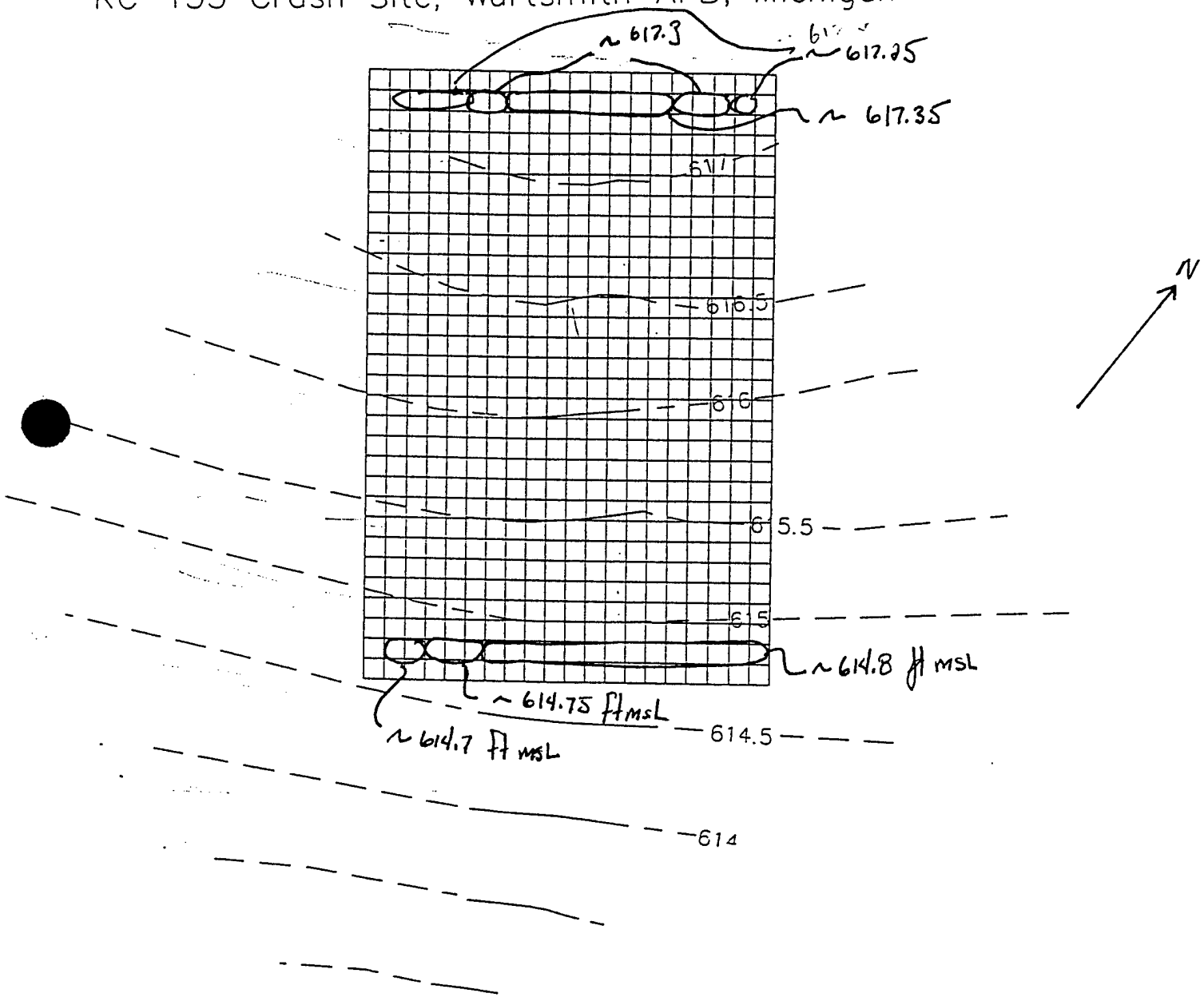
[b/] ME = Mean Error $=1/n \times (h_m-h_s)$.

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

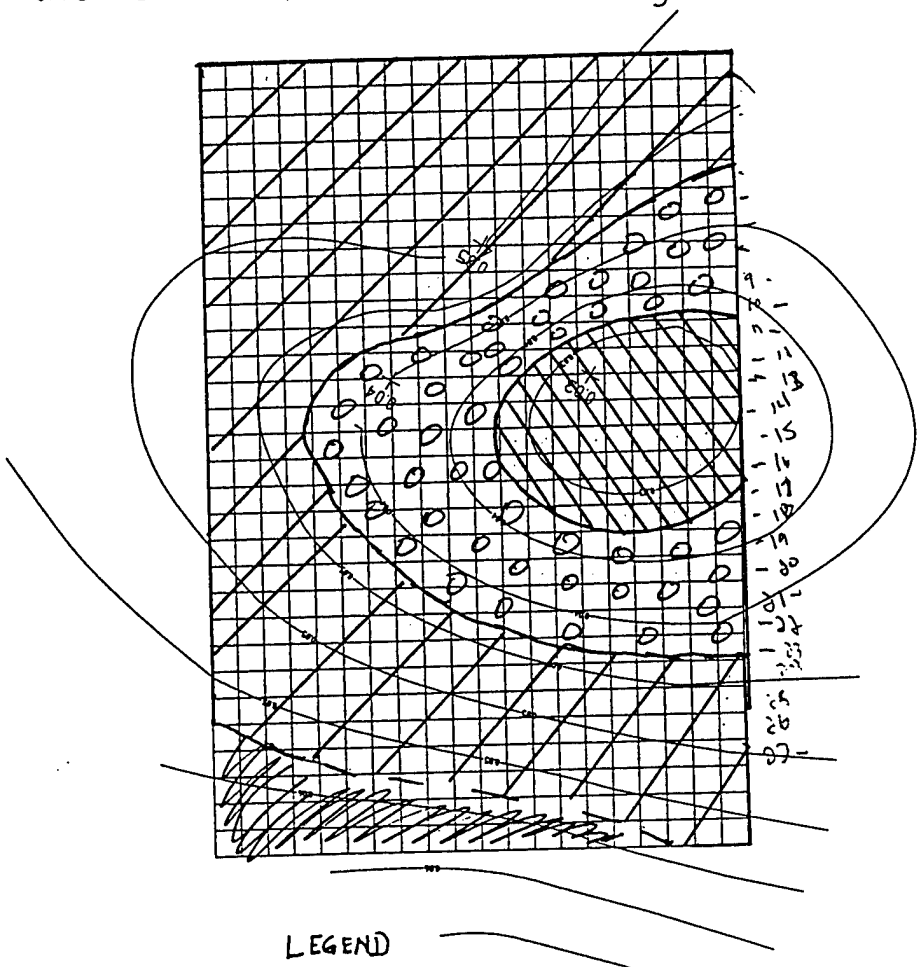
[d/] RMS = Root-Mean-Square (RMS) Error $= (1/n \times (h_m-h_s)^2)^{0.5}$.

Overlay of the estimated ground water table (1994 data) with the model grid. This figure was used to set the constant head cells in row 2 and 29 of the model grid.

KC-135 Crash Site, Wurtsmith AFB, Michigan



Overlay of the Model Grid With a Computer Generated Representation of the Site Hydraulic Conductivity
This estimate was performed with "Surfer" using a Radial Bias Function. Some isopleth lines were extended to fit the general shape of the contours and to extend the hydraulic conductivity isopleth to the full extent of the model grid.



N

LEGEND

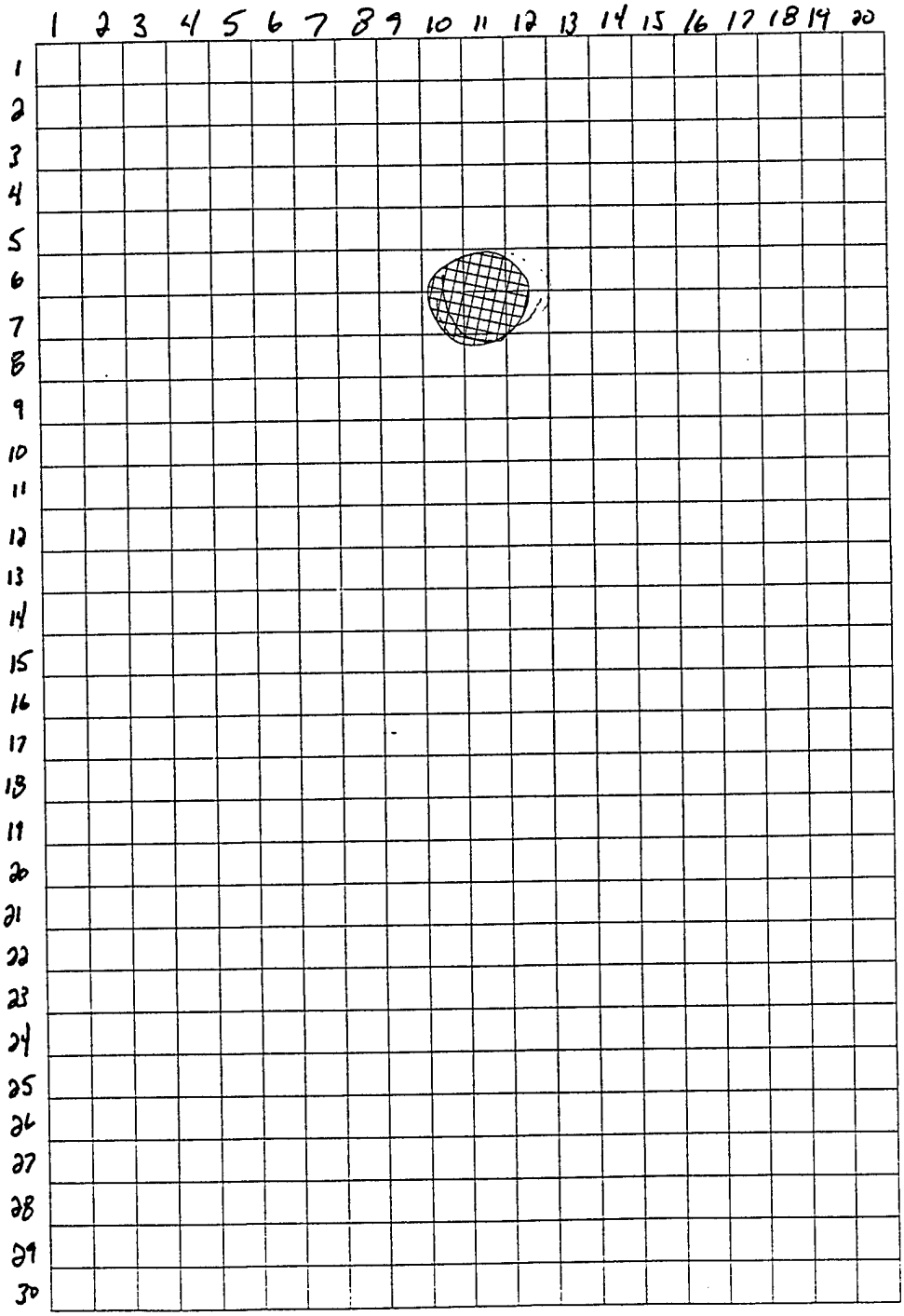
Hydraulic Conductivity ≈ .05115 ft/min

Hydraulic Conductivity ≈ 0.03986 ft/min

Hydraulic Conductivity ≈ 0.02755 ft/min

Hydraulic Conductivity ≈ 0.0600 ft/min

Approximate Location of Mobile LNAPL Overlaid with the Model Grid



2-17-94 by rth, Model Calibration

APPENDIX E

SOURCE REMOVAL AND REMEDIAL ALTERNATIVES COST CALCULATIONS

PERMEXT.XLS

AIR PERMEABILITY CALCUALTION
STEADY-STATE METHOD
********** EXTRACTION **********

LOCATION: Wurtsmith AFB
SITE: OT45

H= 152.40 (152) — stratum thickness: 5 ft = 152.40

Q= 4.72E+03 (4.70E+03) cm3/sec — flow rate: 10 (SCFM) X (28300cm3/ft3)/(60 sec/min)= 4717

Pw= 1.00E+06 (1.01E+06) g/cm-s2 — injection pressure: 3.8 "H2O x 0.0361 psia/"H2O= 0.14 psia

u = 1.80E-04 air viscosity — 14.7 - 0.13718 = 14.56282 = psia = 1.00E+06 g/cm-s2

Patm= 1.01E+06 atmospheric pressure

Rw= 5.08 (5.08) cm — well radius: 2 in = 5.08 cm

Rl= 1068.80 (1067) cm — radius of influence: 35 ft = 1067 cm

k = 9.45E-07 = 0.95 darcy

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE | Job No. | Sheet 1 of 1

Subject Wurtsmith AFB KC-135 Site Alternative 1 Costs | By D Downey | Date 12/6/96

Checked S Chavez | Rev. 1

Annual Costs

GW Sampling

Labor	80 hrs x #60/hr	# 4,800
Analytical	8 wells + 3 QA/QC /SW8020 11 x #90/ea	# 990
Field Analysis / Supplies		# 500
Travel		# 1,000
Per Diem	10 days x #90/day	# 900
Office ODCs		# 300
Contingency (10%)		# 850
	Total	# 9,340
Site Managment By AFBCA	160hrs x #60/hr	# 9,600
	Total Annual Costs	# 18,940

Present Worth

$$PW = (PWF9)(\text{Annual Costs})$$

$$PWF9 = \frac{(1+.07)^9 - 1}{(.07)(1+.07)^9} = 6.5$$

$$PW = (6.5)(18,940)$$

$$= \#123,110$$

QC'd ASR 3/7
Downey

Costs - Alternative 2

Capital Costs

Design Biosparging System (80hrs x $70/hr)	$5600
Drill and Install 4 Sparge Wells and 6 MPs	
Driller 250 LF x $70/LF	17,500
Oversight 80 hrs x $60/hr	4,800
Install Sparging Pump and Manifold	
3-HP Air Pump (10 psi, 32 scfm)	1500
- Accessories	300
- Wooden Enclosure	300
- Power Subcontractor	5000
- Piping Materials 1" PVC (200LF @ $5/LF)	1000
- Installation Labor (80hrx $60/hr)	4800
- Startup Testing (40 hr x $60/hr)	2400
- Per Diem 20 days x $90/day	1800
- Travel	1200
- Rental Equipment	500
- Contingency (15%)	4670
	$51,370

Annual Costs

Operate Biosparge System

Weekly Checks	52 hrs/yr	
Soil Gas Monitoring	60 hrs/yr	
	112 hrs x $60/hr	$6720
Analytical - Method TO-3 4 x $130/ea		520
Travel		700
Per Diem	5 days x $90/day	450
Equipment Rental		300
Contingency (10%)		870
	Total	$9,560

Groundwater Monitoring

Sampling at 8 LTM Wells + W404 + 3 QA/QC
12 Samples SW8020 x $90/ea = $1080

Sampling Labor	80 hrs x $60/hr	$4800
Travel		$1000
Per Diem	10 days x $90 day	$900
Sampling Supplies / Field Methods		$500
Office OOCs		$300
Contingency (10%)		860
		$9,440

Site Management

160 hrs/yr x $60/hr $9,600

Present Worth Alternative 2

$PW = \text{Capital Cost} + (PWF7)(\text{Annual Monitoring \& Mgt}) + PWF3(\text{Sparge O\&M})$

$$PWF7 = \frac{(1+.07)^7 - 1}{(.07)(1+.07)^7} = 5.4$$

$$PWF3 = \frac{(1+.07)^3 - 1}{(.07)(1+.07)^3} = 2.62$$

$$PW = 51{,}370 + (5.4)(19{,}040) + (2.62)(9560)$$

$$PW = \underline{179{,}233}$$

Capital Costs

- Design / Construct Three Extraction Wells w/pumps

Labor - Design, Procure, Construct & Develop Wells	300 hrs x $60/hr	$ 18,000
Drill Subcontract	3 wells x 25 LF = 75 LF x $70/LF	$ 5,250
Submersible Pumps	3 - ½ HP	$ 3,600
System Controls		$ 4,500
Per Diem in Field	24 days x $90	$ 2,160
Travel		$ 1,800
Equipment Rental (Hermit Data Log)		$ 1,300
Electrical Subcontractor		$ 6,000
15 % Contingency		$ 6,390
		$ 49,000

- Design / Construct GW Treatment System

Labor Design / Procure	250 hrs x $60/hr	$ 15,000
Labor Construction	200 hrs x $60/hr	$ 12,000
Mechanical Subcontractor		$ 12,000
Prefilter		$ 3,000
Carbon Canisters (2 - 1800 lb) @ $2.50/lb		$ 9,000
Piping / Valves Supplies		$ 2,500
Per Diem	30 days x $90	$ 2,700
Travel	(3 trips from Denver)	$ 2,000
Equipment Rental		2,000
Analytical For Startup		
	4 - BTEX @ $90/ea	360
	4 - PNA @ $240/ea	960
Prefabricated Building	10' x 10'	1,700
Reinjection Trench Excavation & Backfill		
	160 cu yds @ $10/cu yd	$1,600
Contingency	15 %	9,450
		$ 74,540

ES ENGINEERING-SCIENCE, INC.

Client AFCEE | Job No. | Sheet 2 of 3
Subject Wurtsmith AFB KC-135 Alternative 3 | By D C Downey | Date 4/4/95
Checked | Rev.

- Design Construct Bioventing System

Labor for Design, Procurement and Construction		
	200 hrs x $60/hr	$ 12,000
Manifolding	300' @ $5/ft	1,500
2.5 HP Blower For Air Injection & Accessories		$ 1,500
Electrical Subcontractor		$ 500
Blower Enclosure		$ 500
Per Diem	10 days x $90/day	$ 900
Rental Equipment		$ 500
Contingency	10 %	1,740
		$19,140

- Reinjection Permiting 80 hrs x $60/hr $4,800

Annual Operating Costs -(3 years)

GW Pump and Treat + Bioventing

• Labor		
- Weekly System Checks	2 hr x 52 wk/yr x $60/hr	$6240
Monthly Sampling	12 hrs x 12 mo. x $60/hr	$ 8640
Monthly Reporting	8 hrs x 12 mo x $60/hr	$ 5760
Maintenance	8 hrs x 12 mo x $60/hr	$ 5760
• Analytical		
2- BTEX/mo.	x 12 mo x $90/ea	$ 2,160
2- PNA/mo.	x 12 mo x $240/ea	$ 5,760
• Supplies		
- Carbon Replacement	Avg 5800 lb/yr x $2.50/lb	$ 14,500
- Filters		$ 1,000
• Per Diem	18 days x $90/day	1,620
Travel	12 trips x $300/trip	3,600
Contingency	10%	5,500
		60,540

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE | Job No. | Sheet 3 of 3

Subject Wurtsmith AFB KC-135 RAP Alternative 3 | By D C Downey | Date 12/5/96

Checked S Chavez | Rev. 1

From Alternative 1 - Annual GW Monitoring #9,340 5 yrs

From Alternative 1 - Annual Site Mgt #9,600 5 yrs

18,940

Present Worth Cost Alternative 3 $i = 7\%$

$$PWF\ 5\ yrs = \frac{(1+.07)^5 - 1}{.07\ (1+.07)^5} = 4.1$$

$$PWF\ 3\ yrs = \frac{(1+.07)^3 - 1}{.07\ (1+.07)^3} = 2.62$$

PW = Capital Costs + Annual Cost (PWF)

$= 49,000 + 74,540 + 19,140 + 4,800 + (18940)(4.1) + (60540)(2.62)$

$= \$383,748$ say $\$384,000$

PUMP-AND-TREAT CONTAMINANT REMOVAL EFFICIENCIES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Days	1m3 Pore Volume	Benzene Soil Concen.	Water Concen.	Toluene Soil Concen.	Water Concen.	Ethylbenzene Soil Concen.	Water Concen.	Total Xylenes Soil Concen.	Water Concen.	Napthalene Soil Concen.	Water Concen.
0	0	296.0	24.0	20343.3	718.0	4246.7	182.0	23686.7	748.0	477.9	58.0
5.88	1	291.5	23.6	20208.3	713.2	4212.5	180.5	23546.0	743.6	467.0	56.7
11.76	2	287.0	23.3	20074.3	708.5	4178.5	179.1	23406.3	739.1	456.4	55.4
17.64	3	282.7	22.9	19941.1	703.8	4144.8	177.6	23267.3	734.8	445.9	54.1
23.52	4	278.4	22.6	19808.7	699.1	4111.4	176.2	23129.2	730.4	435.8	52.9
29.4	5	274.1	22.2	19677.3	694.5	4078.3	174.8	22991.8	726.1	425.8	51.7
35.28	6	269.9	21.9	19546.7	689.9	4045.5	173.4	22855.3	721.7	416.1	50.5
41.16	7	265.8	21.6	19417.0	685.3	4012.9	172.0	22719.7	717.5	406.6	49.3
47.04	8	261.8	21.2	19288.2	680.8	3980.5	170.6	22584.8	713.2	397.3	48.2
599.76	102	61.8	5.0	10316.0	364.1	1860.7	79.7	12904.2	407.5	45.4	5.5
652.68	111	53.8	4.4	9716.1	342.9	1730.1	74.1	12230.8	386.2	36.9	4.5
970.2	165	23.5	1.9	6782.1	239.4	1117.8	47.9	8867.7	280.0	10.6	1.3
1134.84	193	15.3	1.2	5628.7	198.7	891.2	38.2	7505.9	237.0	5.6	0.7
1140.72	194	15.0	1.2	5591.3	197.3	884.0	37.9	7461.3	235.6	5.4	0.7
5062.68	861	0.0	0.0	65.9	2.3	4.0	0.2	140.6	4.4	0.0	0.0

Shaded boxes show when predicted concentrations no longer exceeding first the most stringent generic Type C and then Type B criteria.

ES ENGINEERING-SCIENCE, INC.

Client AFCEE | Job No. 725524.04000 | Sheet 1 of 1
Subject Wurtsmith AFB KC-135 Crash Site | By DCDowney | Date 4/3/95
Checked | Rev.

Pumping Calculations Alternative 3

A 50 ft radius of influence is desired. 3 or 4 pumping wells will be installed along the plume centerline extending from USGS4 to W409 a distance of approximately 300 ft.

$R_o = 575\ \Delta s \sqrt{H k}$

Δs is drawdown $(H - h_w)$ (m)
H is saturated interval (m)
k is hydraulic conductivity (m/sec)
R_o is radius of influence (m)

Reference: Maximov, V.M. 1967 Handbook for Hydrologists - Volume I

For this site H is assumed to be full screened interval 15ft (4.6m)
k = 68.7 ft/day (21 m/day or 2.44×10^{-4} m/sec) based on slug testing
R_o is desired at 50 feet (15.3 m)

$$\Delta s = \frac{R_o}{575\sqrt{H k}} = \frac{15.3\text{m}}{575\sqrt{(4.6)(2.44\times10^{-4})}} = .79\text{m} \text{ or } 2.58\text{ ft}$$

$$Q = \frac{k\,(H^2 - h_w^2)}{458 \ln R_o/r_w}$$

Q = pumping rate (gpm)
r_w = well radius (ft) 4" well r_w = .1667 ft
h_w = saturated thickness at well (15ft - 2.58ft)
k = hydraulic conductivity gal/day-ft^2
k = 514 gal/day-ft^2 based on slug testing

$$Q = \frac{514\,(15^2 - 12.4^2)}{458 \ln \frac{50}{.1667}}$$

Reference: Powers, 1981 for unconfined aquifers

Q = 14 gpm

3 wells pumping at 14 gpm should capture plume between USGS4 and W409.

Pore Volume Exchanges Per Day Under Alternative 3

$Q = 14\ gpm \times \frac{1\ cf}{7.43\ gal} = 1.9\ cfm$

Volume Influenced by one well (Contaminated Aquifer Impacted)

$Vol = \pi r^2 h \times Porosity$

$= \pi (50^2)(15)(.35)$

$= 41{,}212\ ft^3 = 1\ pore\ volume$

Pore Volumes Exchanged Per Day at Perimeter of Zone of Influence

$$\frac{1.9\ ft^3/min \times 1440\ min/day}{41{,}212\ ft^3/pore\ volume} = .066\ pore\ volumes/day$$

or 24 pore volumes / year

Based on batch flush partitioning model approximately 102 pore volumes of flushing will be required to attain Type C groundwater criteria.

$$\frac{102\ pore\ volumes}{24\ pore\ volumes/year} = 4.2\ years\ of\ pumping$$

This represents a worse case scenario because the number of pore volume exchanges per year will increase as the groundwater moves closer to the extraction well. For example, at a radial distance of 25' from the extraction well $Vol = \pi (25^2)(15).35$

$= 10{,}303\ ft^3$

and the number of pore volumes per year increases to 96

The remediation time as you approach the extraction well should decrease to approximately one year of pumping.

Downey 4/3/95

Carbon Loading Estimates
Alternative 3

Carbon Loading Estimate

Carbon Adsorption Capacity

Naphthalene	132 mg/kg
E Benzene	53 mg/kg
Xylenes	85 mg/kg
Toluene	26 mg/kg
Benzene	1 mg/kg

Wells 408, 404S, 409S, USGS4 Avg Conc in Source Area Wells

	mg/L
	.058
	.182
	.748
	.718
	.024

Carbon Load

Naphthalene: $45\ gpm \times \frac{.058\ mg}{L} \times \frac{3.82}{gal} \times \frac{1440\ min}{day} = \frac{14,281\ mg}{day} \times \frac{1\ gC}{132\ mg\ N} = 108\ grams/day$

E Benzene: $45\ gpm \times \frac{.182\ mg}{L} \times \frac{3.8\ l}{gal} \times \frac{1440\ min}{day} = \frac{44,815\ mg}{day} \times \frac{1\ gC}{53\ mg\ EB} = 845\ grams/day$

Xylenes: $45\ gpm \times \frac{.748\ mg}{L} \times \frac{3.8\ L}{gal} \times \frac{1440\ min}{day} = \frac{184,187\ mg}{day} \times \frac{1\ gC}{85\ mg\ Xyl} = 2,167\ grams/day$

Toluene: $45\ gpm \times \frac{.718\ mg}{L} \times \frac{3.8\ L}{gal} \times \frac{1440\ min}{day} = \frac{176,800\ mg}{day} \times \frac{1\ gC}{26\ mg\ Tol} = 6,800\ grams/day$

Benzene: $45\ gpm \times \frac{.024\ mg}{l} \times \frac{3.8\ l}{gal} \times \frac{1440\ min}{day} = \frac{5909\ mg}{day} \times \frac{1\ gC}{1\ mg\ Benz} = 5,909\ grams/day$

15,800 grams/d.
or
~34 lbs/day

Based on batch flushing estimates, the concentration of extracted BTEX should decrease 5% each month conservatively when intrinsic remediation is included in the removal rate.

Month	lbs/day	lbs/month	
1	34 x 30 days	1020 lbs	
2	32 x 30 days	960 lbs	2910 lbs in 90 days
3	31 x 30 days	930 lbs	
4	29 x 30 days	870 lbs	
5	27.5 x 30 days	825 lbs	2475 lbs in 90-180 days
6	26 x 30 days	780 lbs	
Months 6-12		3900 lbs	
Year 2		5300 lbs	
Year 3		2800 lbs	
		17,385 lbs	3 yrs

APPPENDIX F

CHEMICAL PROFILES

Appendix F - Calculation of health-based Type C industrial criteria

(1) used algorithms defined by MDNR (1994b) - Memo #14

Carcinogens: $$\frac{10^{-6} \times BW \times AT}{SF \times EF \times ED \times IR_{dw}}$$

where BW = 70 kg AT = 25,550 SF = Chem-sp.
EF = 245 d/y ED = 21 yr. IR = 1 l/day

noncarcinogens: $$\frac{RfD \times BW \times AT \times RSC}{EF \times ED \times IR}$$

where RfD = chem-sp BW = 70 kg AT = 7,665 days
RSC = 0.2 EF = 245 d/y ED = 21 yr. IR = 1 l/day

(2) SF* & RfD* for BTEX compounds based on IRIS (Micromedix, 1995) → see Chem profiles this appendix

	SF	RfD
Benzene	0.029 (mg/kg/day)$^{-1}$	—
Toluene	—	0.2 mg/kg/day
Ethylbenzene	—	0.1 mg/kg/day
Xylenes	—	2 mg/kg/day

* all based on oral exposure routes only.

(3) Calculated Type C criteria - health-based only:

Benzene = 11.99 ug/L

Toluene = 4,171.43 ug/L

Ethylbenzene = 2,085.71 ug/L

Xylenes = 41,714.29 ug/L

National® Brand 42-182 100 SHEETS Made in U.S.A.

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 x 10^{-3} atm-m^3/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 LD_{50} 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 $(mg/kg/day)^{-1}$ 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/m^3 for a 5 minute exposure [5]. Acute inhalation LC_{50} 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 8.3×10^{-6} $(ug/m^3)^{-1}$ 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.

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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-m^3/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 LD_{50} 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/m^3 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 LC_{50} 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/cm^2/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].

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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-m^3/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) LD_{50} 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/m^3 is based on a NOAEL of 434 mg/m^3 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 LC_{50} 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 LD_{50} in rabbits for liquid ethylbenzene was reportedly 15,415 mg/kg. Ethylbenzene appears to be a slight eye irritant in rabbits [4].

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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-m^3/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 LD_{50} 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 kidenys (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 LC_{50} values of 6350 to 6700 ppm (4-hour exposure) were reported in rats for mixed xylenes [2]. LC_{50} 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 LD_{50} 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 LC_{50} value for freshwater fish was approximately 30 mg/L [9]. The 96-hour LC_{50} values for fathead minnows were 26.7 mg/L in soft water and 28.8 mg/L in hard water [10]. The 96-hour LC_{50} 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 LD_{50} for rats at 4,300 mg/kg.

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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

	Naphthalene	2-Methylnaphthalene
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]	4.6×10^{-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 LD_{50} reported for naphthalene in rats ranges from 2,200 to 2,400 mg/kg in rats [1]. The oral LD_{50} 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].

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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 x 10^{-3} atm-m^3/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

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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-m^3/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

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APPENDIX G

SCREENING AND DEVELOPMENT OF REMEDIAL ALTERNATIVES

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SCREENING AND DEVELOPMENT OF REMEDIAL ALTERNATIVES

1.1 OVERVIEW

This appendix identifies a variety of remedial approaches and technologies that were considered in developing remedial alternatives for the KC-135 Crash Site. This initial screening was based on three primary evaluation criteria: effectiveness in satisfying Type C and Type B cleanup criteria, technical and administrative implementability, and relative cost. The purpose of this screening was to quickly focus the remedial action plan on the most promising and cost-effective methods for remediating the KC-135 Crash Site. A similar screening was completed in a remedial action plan for site OT45 (Parsons ES, 1995). This appendix focuses on how selected active remediation technologies could be combined with intrinsic remediation to achieve effective site cleanup .

2.1 SCREENING OF REMEDIAL TECHNOLOGIES

Table 1 provides a summary of the remedial approaches and technologies considered for the KC-135 Crash Site. All of these technologies are appropriate for the remediation of fuel-contaminated soils or groundwater. Technologies which are used for non-fuel contaminants have been purposely deleted from this focused initial screening. Several of the most promising technologies considered during screening have been retained as candidates for the development of remedial alternatives and evaluated in Section 8 of the RAP. The following paragraphs provide a brief description of each approach or technology group and its site-specific applicability for this site.

2.1.1 Long-Term Soil, Soil Gas, and Groundwater Monitoring

Long-term monitoring of soils and groundwater is essential in evaluating the progress of intrinsic and engineered remediation and for ensuring that cleanup criteria are achieved over a specified time interval.

2.1.1.1 Soil and Soil Gas Monitoring

Soil and soil gas monitoring provides information for assessing the effectiveness of an implemented soil remedial technology. Extensive soil sampling at the crash site has revealed minimal contamination. All detected contaminants are below Type B cleanup criteria. Soil gas also is used as an indicator of VOC reduction, and oxygen and carbon dioxide concentrations can indicate the level of hydrocarbon biodegradation occurring in the soil. Future soil gas monitoring could be useful in monitoring the removal of BTEX from the groundwater if a biosparging technology is implemented at the site. Long-term soil gas monitoring was retained for further evaluation.

2.1.1.2 Groundwater Monitoring

Groundwater monitoring is essential for evaluating the effectiveness of implemented groundwater remediation technologies, particularly natural attenuation processes. Confirmation wells can be utilized to monitor contaminants of potential concern (COPCs) and their attenuation within and near the existing plume. The predictions of fate and transport models are often verified using sentry wells within the plume. POC wells can be established at downgradient locations to ensure that contaminants do not advance beyond site boundaries or present an unacceptable risk to downgradient human or ecological receptors. Sufficient sentry wells are now available at this site to assess both vertical and horizontal contaminant transport and attenuation. The suitability of existing wells for POC monitoring is addressed in Section 10, the Long-Term Monitoring Plan. Long-term groundwater monitoring was retained as a key component of the remedial alternatives for this site.

2.1.2 Land and Groundwater Use Control

Some degree of land and groundwater use control is a prerequisite for approval of MDNR Type C cleanup criteria at the KC-135 Crash Site. Land and groundwater use controls can be enacted to minimize the potential for direct receptor contact with site contamination.

2.1.2.1 Land Use Control

Physical barriers and deed restriction/easements can be used to control land use. Access to this site is currently limited by fencing around the base perimeter. As discussed in Section 3.6 of the RAP, the Wurtsmith Base Conversion Authority and the Oscoda Township Board of Trustees have designated the runway and taxiway areas for continued industrial/airport use. This future land use is fully compatible with the attainment of Type C cleanup criteria at this site. Physical barriers and deed restrictions on land and resource uses were retained for further evaluation.

2.1.2.2 Groundwater Use Control

Groundwater use controls can eliminate the possibility of direct exposure of site workers to contaminated groundwater. Groundwater use can be controlled by regulating well permits, minimizing excavations below the water table, and when no other source of drinking water is available, installing point-of-use treatment systems. Contaminated groundwater at this site remains within the flightline area under WBCA control, and no active drinking water wells exist on or near the site. The regulation of future well permits in the vicinity of the KC-135 Crash Site was retained for further evaluation.

2.1.3 Public Education

At many hazardous waste sites, public education is required to inform the public of the risks associated with site contamination and to provide the necessary warnings to prevent unintentional contact with site soils or groundwater. Although no public health risk is currently associated with this site, the eventual release of this property to Oscoda Township should be accompanied with a clear understanding of where jet fuel

contamination exists and the appropriate land uses that will prevent exposure to site workers. Public participation in land reuse decisions is a key component of public education. Public education was retained as a remedial approach.

2.1.4 Containment of the Groundwater Plume

Plume containment uses either hydraulic controls, such as limited groundwater pumping, or physical barriers such as slurry walls, to minimize downgradient plume migration. This strategy is most often used to halt the advance of highly contaminated groundwater before it impacts downgradient drinking waters or surface waters.

2.1.4.1 Hydraulic Controls

Hydraulic controls extract contaminated groundwater to prevent further migration of the plume. Hydraulic controls considered for this site included a passive drain system and downgradient extraction wells. Based upon the limited migration of site contaminants over the past 2 years, downgradient controls are unnecessary at this site. In fact, the extraction of downgradient groundwater could actually decrease the effectiveness of natural attenuation processes by increasing the gradient and speed of the groundwater flow, and allowing less time for biodegradation processes to occur. Hydraulic controls were not retained as remediation alternatives.

2.1.4.2 Physical Groundwater Barriers

Slurry walls, grout curtains, and sheet pilings are physical structures capable of limiting downgradient contaminant migration. Based on the limited migration of site contaminants over the past 2 years, these physical barriers to groundwater flow are unnecessary. In addition, the depth of the lower confining layer at the KC-135 Crash Site is approximately 70 feet bgs. This depth would make it difficult and expensive to anchor any physical control barrier in the lower confining layer. Physical groundwater barriers are not appropriate for this site and were not retained for further consideration.

2.1.4.3 Reactive/Semipermeable Barriers

Reactive, semipermeable barriers are emerging technologies which use a downgradient chemically reactive wall or biologically active treatment zone to intercept and treat groundwater contaminants as they pass through the treatment zone. This technology has the advantage over simple physical barriers in that contaminants are actually destroyed and groundwater flow is uninterrupted. At the KC-135 Crash Site, the plume appears to be near steady state and will soon begin to recede. Their is no need for a downgradient barrier. Also the relatively low concentrations of groundwater contaminants could result in a very inefficient system. Typical first-order reaction rates associated with these technologies may be limiting at lower contaminant concentrations. Reactive walls and biological active zones were not retained for further evaluation.

2.1.5 *In situ* Groundwater Treatment

In situ treatment includes both engineered and natural processes which are capable of destroying or immobilizing dissolved contamination in place. *In situ* treatment is

generally less expensive than aboveground treatment because there is no need to extract, treat, and then dispose of groundwater.

2.1.5.1 Intrinsic Remediation

As thoroughly discussed in Section 6 of the RAP, intrinsic remediation takes advantage of destructive and nondestructive attenuation mechanisms to bring about a net reduction in groundwater contaminant concentrations. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution, and volatilization (Wiedemeier, et. al., 1994). At this site, the significant decrease in contaminant levels over the past 2 years, the decrease in dissolved contaminant [illegible] with increasing distance from the source, and overwhelming geochemical evidence all confirm that intrinsic remediation is a significant and ongoing cleanup process at this site. Therefore, this remedial approach was retained from the screening process.

2.1.5.2 Enhanced/Active Biological Groundwater Treatment

Enhanced *in situ* biodegradation takes advantage of natural biological processes by providing enhanced electron acceptor conditions and, when required, enhanced nitrogen/phosphorus (i.e., nutrient) conditions, to stimulate microbial growth and more rapid biodegradation. Section 6 of the RAP provides geochemical evidence that a low oxygen concentration may be limiting the rapid biodegradation of dissolved contaminants in the source area of the plume. However, there is also significant evidence that other electron acceptors such as nitrate, manganese, and ferric iron are available to continue the biodegradation process in oxygen-deficient groundwaters. The addition of oxygen through biosparging was demonstrated during pilot testing at Site OT45 and was retained for evaluation as a method of enhancing natural biodegradation in the source area.

2.1.5.3 Volatilization via Air Sparging

Air sparging is a low-cost technology that introduces air bubbles or channels of air into contaminated aquifer material to provide a mass transfer of dissolved contaminants from saturated soils as soil gas into the vadose zone. This technology is well-suited to the relatively homogeneous, coarse-grained aquifer material found at the KC-135 Crash Site. The volatilization of BTEX compounds from groundwater and the capillary fringe was demonstrated during the recent biosparging pilot testing at Site OT45. Soil gas TVH concentrations increased from an average concentration of 114 parts per million, volume per volume (ppmv) to 396 ppmv during the 5-day sparging test. When low concentrations of fuel hydrocarbon vapors are transferred to the vadose zone, these vapors can be biodegraded via natural bioventing processes (Ostendorf, 1989). When higher concentrations of VOCs are mobilized into the shallow vadose zone, or when potential vapor migration presents safety and liability hazards, a soil vapor extraction system can be used to collect and control volatile hydrocarbons. The removal of less volatile hydrocarbons would be enhanced by the increased DO and biodegradation stimulated by biosparging. The air sparging test conducted at Site OT45 indicated that this technology may be a viable technology for enhancing the removal of COPCs in this coarse-grained aquifer material. Although considerable controversy exists over the

long-term effectiveness of sparging techniques, biosparging was retained as a remedial option.

2.1.6 Aboveground Groundwater Treatment

Groundwater extraction and aboveground groundwater treatment offers the flexibility of more engineering controls than *in situ* remediation, and can usually treat a wider range of contaminants than *in situ* treatment. Groundwater extraction also provides greater control over plume migration and can be focused in areas of greatest contamination. Treatment technologies most appropriate for removing dissolved hydrocarbons from extracted groundwater include bioreactors, air stripping methods, and activated carbon adsorption. Treatment facility construction, operation, maintenance, and monitoring will require greater financial resources. Pump installations and maintenance also add to the cost of this technology group.

2.1.6.1 Groundwater Extraction

Groundwater extraction has been a standard approach used to remediate many fuel-contaminated aquifers. This technology has been most successful in sand and gravel aquifers with low natural organic carbon content. Under these conditions organic contaminants are less likely to sorb to soil particles and are more likely to remain dissolved and available for extraction. These favorable aquifer conditions generally exist at the KC-135 Crash Site. Because groundwater extraction could provide a conservative margin of protection against plume migration and possibly remediate the plume more rapidly than intrinsic remediation, it was retained for consideration in alternative development.

2.1.6.2 Bioreactors

Bioreactors typically provide an enhanced environment where biodegradation rates are higher than those observed *in situ*. The *ex situ* nature of the bioreactor allows for greater control of reactor conditions (e.g., temperature, pH, mixing) and some optimization of degradation pathways. The hydraulic loading of bioreactors is often limited because complete biodegradation requires long retention times to degrade low concentrations of hydrocarbons. In the case of slower degrading PNA compounds, the contaminants must first be adsorbed to filter media and retained to complete the biodegradation process. In the northern Michigan climate, bioreactors would require heating during winter months to maintain high degradation rates. Due the high maintenance requirements, and additional costs of operating a bioreactor, this technology was not recommended for further consideration.

2.1.6.3 Air Stripping

Air stripping technologies contact contaminated groundwater with clean air to volatilize (strip) dissolve contaminants from the aqueous phase. Air stripping is most effective for compounds with Henry's Law constants greater than 0.001 including benzene, toluene, ethlybenzene, and xylenes which have Henry's Law constants of 0.0054, 0.0066, 0.0079, and 0.0049-0.007, respectively. The highest total BTEX concentration measured in the source area in October of 1994 was just over 5 milligrams per liter at well USGS4. The average total BTEX concentration measured

in the four most contaminated wells in the source area was approximately 1.7 milligrams per liter. These concentrations are expected to decrease rapidly during the first few months of groundwater extraction because no significant BTEX source remains in the soils. Due to the expected rapid dilution of BTEX in site groundwater, activated carbon alone should provide the most cost-effective treatment option (see below). Air stripping would also release VOCs to the atmosphere and may require expensive off-gas treatment. Therefore, air stripping was not retained as a process option.

2.1.6.4 Activated Carbon

Activated carbon is a commonly used method of removing BTEX contaminants from groundwater as it passes through a packed-bed canister of granular activated carbon (GAC). Due to the increasingly dilute concentrations of all dissolved COPCs expected if groundwater was extracted at the KC-135 Crash Site, activated carbon would provide relatively inexpensive and low maintenance treatment of extracted groundwater. Activated carbon is also capable of reducing all COPCs to levels below Michigan drinking water standards, which is important for satisfying discharge requirements. Activated carbon was retained as an aboveground treatment technology if groundwater extraction is selected as a site remedy.

2.1.6.5 Direct Discharge to Sanitary Sewer

Direct discharge of extracted, contaminated groundwater to an industrial wastewater treatment plant (IWWTP) is an alternative for treatment if a treatment plant is available and can accept fuel-tainted waters. The Base treatment plant is not currently active, and an IWWTP sewer connection does not exist in the vicinity of the KC-135 Crash Site. Trucking of extracted groundwater to a private treatment works is infeasible, as tens of thousands of gallons of water could be extracted each day. Direct discharge to a IWWTP was not retained for further evaluation.

2.1.7 Treated Groundwater Discharge/Disposal

The extraction and treatment of contaminated groundwater will require a method of disposal for treated water which meets all appropriate discharge standards of the State of Michigan and EPA. Several methods of onsite and offsite disposal were identified for this initial screening.

2.1.7.1 Discharge to a Sanitary Sewer

A sanitary sewer line does not exist near this site. According to Base utility maps the nearest sewer line is over 3,000 feet away. Discharge to a sanitary sewer is not feasible at KC-135 Crash Site.

2.1.7.2 Reinjection to Groundwater

Reinjection of treated groundwater into the subsurface can be accomplished through several methods. Surface application using a sprinkler system would be possible during summer months but freezing conditions would make it impractical during the winter. Reinjection wells have been used to return treated groundwater to the subsurface;

however, injection wells require frequent maintenance to reduce the impacts of plugging, which almost always occurs over time. The preferred method of reinjection for this site would be the construction of a large reinjection trench upgradient of the source area. These trenches generally contain a large-diameter, perforated pipe and are filled with gravel. Reinjection trenches are less likely to become fouled by inorganic precipitates and biogrowth because they can be constructed with much larger surface area to flow ratios when compared to injection wells. Reinjection trenches have been retained as a possible option for the discharge of treated groundwater. It is anticipated that extracted groundwater will have to be cleaned to drinking water standards before reinjection.

2.1.7.3 Discharge to Surface Drainage

Under this option, treated groundwater would be discharged into the local stormwater drainage which eventually discharges into the marshlands near the Au Sable River. Storm drainage at the site consists of a manmade swale along the runway which eventually discharges to a large catch basin approximately 2,400 feet northeast of the crash site. A 30-inch diameter storm drain conveys the water in the marsh area north of the site. A discharge permit and frequent monitoring would be required to ensure protection of sensitive downstream surface waters. During the winter months groundwater discharged to the swale would freeze and cause significant ice buildup along the runway. Due to the problems with winter operation, this option was not retained for further evaluation.

2.1.8 Source Removal/Soil Remediation Technologies

The removal or reduction of concentrated contaminants in the source area is normally an important element of a comprehensive site remediation. Two primary sources of contamination can exist at fuel contaminated sites: free-phase product (NAPL) and residual fuels which are adsorbed of occluded within the soil matrix. Although initial site investigations in 1989 and 1991 detected NAPL , no evidence of recoverable free product was recorded at the KC-135 Crash Site during the October 1994 investigation by Parsons ES. Residual fuel contamination at this site appears to be limited to a thin layer of soil in the capillary fringe and in saturated soils between 9 to 11 feet bgs. Analysis of soil samples from this zone indicate that remaining BTEX contamination may be below generic Type B criteria and will not require cleanup. Discussion of potential soil remediation technologies has been included for completeness although none of these alternatives are required to complete a Type B clean up of the site. Because of the location of these residuals, common soil remediation technologies such as soil vapor extraction and *in situ* bioventing which depend on soil gas movement will be ineffective unless the natural water table falls or groundwater extraction is used to artificially depress the water table. Soil flushing using surfactants is another option for reducing fuel residuals that is evaluated in this section.

2.1.8.1 Soil Vapor Extraction

Soil vapor extraction mechanically withdraws soil gas from the vadose zone to the surface using vent wells. If necessary, offgas can be treated prior to discharge into the atmosphere, although treatment can easily double the cost of this technology. By

extracting soil gas from the vadose zone, the desorption of VOCs from soils into soil gas is enhanced. Soil vapor extraction is highly effective in highly permeable soil such as the sands present at this site. Because soil vapor extraction also results in an influx of oxygenated soil gas from clean soils, it also enhances the biodegradation of less volatile hydrocarbons. Soil vapor extraction was not retained for further evaluation because bioventing would provide the same benefits without the transfer of VOCs to the atmosphere.

2.1.8.2 Bioventing

Bioventing is mechanically similar to soil vapor extraction except that this technology uses much lower rates of air injection to provide the necessary oxygen to sustain biological degradation, and does not create an undesirable discharge of VOCs into the atmosphere. Bioventing rates of air injection are typically one-tenth of vapor extraction rates for the same site. The effectiveness of this technology has been demonstrated in a major pilot testing program conducted at over 140 Air Force sites, including over 50 sites contaminated with JP-4 jet fuel (Downey, 1994) A partial bioventing pilot test conducted at Wurtsmith AFB Site OT45 is described in Section 7 of the RAP (Parsons ES, 1995). Bioventing has been retained for further evaluation at this site for two reasons. First, if air sparging is selected to reduce dissolved contaminants in the source area, bioventing would be occurring as VOCs and oxygen are transported into the capillary fringe and vadose zone. Second, if groundwater is extracted from the source area, the resultant dewatering would expose a portion of the fuel contaminated soils for potential bioventing treatment. Given the potential for undiscovered pockets of soil contamination that could exceed Type B criteria, bioventing has been retained for possible application if groundwater extraction is a selected remedy.

2.1.8.3 Surfactant Soils Washing

Soil washing is used to enhance the natural partitioning of contaminants from the soil into the groundwater, and is generally associated with a groundwater extraction system. The more strongly sorbed compounds may require surfactant soil washing to facilitate the dissolution process. *In situ* soil washing is only effective in more permeable aquifer materials, such as exist at the KC-135 Crash Site. Soil washing usually involves the addition of a surfactant compound that has a nonpolar "tail" to dissolve the contaminant, and a polar end so that the formed miscelle is soluble in water. Biodegradable surfactants are desirable to ensure that new recalcitrant chemicals are not introduced into the aquifer. Two significant disadvantages are associated with this technology. Because surfactants are added in relatively high concentrations, they will exert a significant biological oxygen demand on the aquifer. This additional organic loading may exceed the natural assimilative capacity of the aquifer and promote the migration of both surfactant and fuel hydrocarbons. The second problem is that when the surfactant solution is recovered, it is difficult to separate contaminants from the surfactants so that surfactants can be recycled. Treatment of surfactant-laden groundwater can be achieved with activated carbon, but the surfactant will rapidly load the carbon, resulting in unacceptable treatment costs. Due to these technical difficulties, surfactant soils washing was not retained for further evaluation.

2.1.9 Soil Excavation and Treatment

Excavation and surface treatment of contaminated site soils is not appropriate at this site given the low levels of remaining BTEX contaminants which can be rapidly reduced through intrinsic remediation or low-cost biosparging or bioventing. Excavation and aboveground treatment options such as biological treatment or thermal treatment were not retained for further evaluation.

3.1 SUMMARY OF RETAINED REMEDIAL TECHNOLOGIES

Based on the initial technology screening discussed in Section 2 of this appendix and summarized in Table 1, several remedial approaches and technologies have been retained for the development of remedial alternatives and more detailed analysis. These technologies were selected to provide a range of passive to more active response actions, all of which can attain Type B and Type C cleanup criteria, though in different time frames and at different costs. The following remedial approaches and technologies have been retained :

- Long-Term Soil Gas and Groundwater Monitoring;
- Limited Land Use Controls;
- Groundwater Use Controls;
- Public Education;
- Intrinsic Remediation of Soil and Groundwater Contamination;
- Biosparging in Source Area;
- Groundwater Extraction in Source Area with Activated Carbon Treatment;
- Treated Groundwater Discharge via Reinjection Trench, and
- Air Injection Bioventing in Dewatered Source Area.

Because intrinsic remediation, and specifically biodegradation, has been effectively removing dissolved BTEX compounds from the groundwater and limiting downgradient migration, this ongoing remediation process can only be enhanced through a reduction of more concentrated dissolved BTEX in the vicinity of the source area near well USGS4. Three candidate source-reduction technologies, biosparging, bioventing, and limited groundwater extraction, have been retained for additional analysis. Each of these remediation approaches is described in greater detail, and their effectiveness is evaluated in Section 8 of this RAP.

TABLE 1
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUND WATER REMEDIATION KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in Attaining Type C Criteria	Relative Cost	Retain
Long-Term Monitoring	Periodic Ground Water Monitoring	Confirmation Wells	Many existing wells are available to confirm the progress of remediation.	Necessary component of all remediation strategies	Low	Yes
		Point-of-Compliance Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Necessary component of all remediation strategies	Low	Yes
	Periodic Soil/Soil Gas Monitoring	Installation of Additional Soil Borings	Extensive soil sampling indicates Type B criteria are not exceeded. Soil gas monitoring useful for checking bioremediation.	Soils already meet Type B and C criteria.	Low	Yes
Institutional Controls	Land and Ground Water Use Control	Land Use Control/Regulate Well Permits	Plume area is currently within the base boundary. Land-use and ground water use are under jurisdiction.	Necessary component of Type C clean up	Low	Yes
		Seal/Abandon Existing Wells	No wells located within 1,000 feet of plume.	Not required at this site	Low	No
		Point-of-Use Treatment	No ground water is extracted from the plume area for use. Other sources of drinking water are available at the site.	Poor	Moderate	No
	Public Education	Meetings/ Newsletters	Important to convey a clear understanding of acceptable land and groundwater use.	Necessary component of Type C or Type B clean up	Low	Yes
Containment of Plume	Hydraulic Controls	Passive Drain Collection	No likely receptors downgradient of site. Installation in thick saturated zone is not practical.	Moderate	High	No

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUND WATER REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in attaining Type C Criteria	Relative Cost	Retain
Containment of Plume (cont.)	Hydraulic Controls (cont.)	Minimum Pumping/Gradient Control	A line or semicircle of vertical pumping wells could be located along the leading edge of plume to intercept and halt the advance of the plume. Dilute downgradient COC concentrations make this unnecessary.	Moderate	High	No
	Physical Controls	Slurry Walls/Grout Curtains	Requires significant disruption and deep excavation. Limited effectiveness.	[illegible]erate	High	No
		Sheet Piling	Requires significant disruption and deep excavation. Limited effectiveness.	Moderate	High	No
	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Natural biodegradation of BTEX/PNA compounds can be stimulated by allowing contaminated ground water to flow through an aquifer zone which has enhanced oxygen and nutrient conditions. Low contaminant concentrations in the plume area making active zones impractical.	Moderate	Intermediate	No
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen (air) is injected upgradient of plume and allowed to migrate downgradient. In theory, this method can more rapidly reduce higher BTEX/PNAs concentrations in and immediately downgradient of the source.	Potentially effective based on pilot testing.	Low	Yes

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUND WATER REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in attaining Type C Criteria	Relative Cost	Retain
In Situ Groundwater Treatment (cont.)	Chemical/Physical	Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Ground water sampling at OT45 indicates that this is a major, ongoing remediation process.	High	Low	Yes
		Air Sparging (volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX and highly sorptive PNAs into air bubbles and into vadose zone. Limited radius of influence and short-circuiting are common problems. Air sparging treatability test have been performed at OT45.	Potentially effective based on pilot testing.	Low	No
Aboveground Ground Water Treatment	Ground Water Extraction of Plume	Vertical Extraction Wells	The ground water plume is pumped by installing wells in the plume area. Creates significant aboveground treatment requirement.	High	High	Yes
		Horizontal Extraction Wells	Not required at this site.	Moderate	High	No
	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	Moderate	High	No

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUND WATER REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in attaining Type C Criteria	Relative Cost	Retain
Aboveground Ground Water Treatment (cont.)	Chemical/Physical	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX at higher flow rates. Potential permitting for air emissions. Not effective to remove PNA's from groundwater.	Less efficient for naphthalene.	Moderate	No
		Activated Carbon	Cost effective for more dilute concentrations of BTEX/PNAs. Creates a carbon disposal problem.	High	Moderate for dilute concentrations	Yes
		UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors.	Moderate	High	No
Aboveground Treatment	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)		Viable option when an IWWTP is available and capable of handling BTEX/PNAs and hydraulic loading. IWWTP not available for this site.	High	High	No
Treated Ground Water Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when an IWWTP is available and capable of handling BTEX/PNAs and hydraulic loading. IWWTP not available for this site.	High	High	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. No sewer at this site.	High	Low when sewer available	No
	Treated Ground Water Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance.	Moderate	High	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting.	Moderate	High	Yes

TABLE 1 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUND WATER REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in attaining Type C Criteria	Relative Cost	Retain
Treated Ground Water Disposal (cont.)	Discharge to Surface Waters	Storm Drains	Viable option but generally requires NPDES or other discharge permit. Storm drain not available.	High	Moderate Permitting Costs	No
Source Removal/Soil Remediation	Free Product Recovery	Dual-Pump Systems	Best suited for sites with >1 foot free product where aboveground ground water treatment exists. Site has negligible free product within the site subsurface.	No free product at KC-135 Crash Site.	High	No
		Skimmer Pumps/Bailers/ Wicks	Best suited for sites with <1 foot free product where ground water pumping is undesirable. Site has negligible free product within the site subsurface.	No free product at KC-135 Crash Site.	High	No
		Total Fluids Pumping	Best suited for sites with thin saturated zones where excessive ground water will not be pumped. Site has a large saturated interval from 10 to 70 feet bgs.	No free product at KC-135 Crash Site.	High	No
		Bioslurping	Combined vapor extraction, bioventing and free product recovery system has been operated at some sites with limited success.	No free product at KC-135 Crash Site.	Intermediate	No
	Excavation/ Treatment of Soils	Excavation	Minimal soil contamination already below Type B cleanup criteria.	Not required. Type B criteria already attained.	High	No
		Biological Landfarming	Minimal soil contamination already below Type B cleanup criteria.	Not required. Type B criteria already attained.	Moderate	No

TABLE 1 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR SOIL AND GROUND WATER REMEDIATION
SITE OT45, WURTSMITH AFB, MICHIGAN

General Response Action	Technology Type	Process Option	Technical Implementability	Effectiveness in attaining Type B Criteria	Relative Cost	Retain
Source Removal/Soil Remediation (Cont.)	Excavation/ Treatment of Soils (Cont.)	Thermal Desorption	No soil treatment is required.	Soils already below Type B clean criteria.	High	No
	In Situ	Bioventing	Bioventing would only be useful on this site if the contaminated soil interval was dewatered. Bioventing can be combined with a limited pumping option.	Moderate	Low	Yes
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites; however, the limited volatile soil contamination at the site makes SVE impractical.	Moderate	Low	No
		Soil Washing	Additional pore volumes of water and/or surfactant solution are forced through aquifer material to enhance the partitioning of hydrocarbons into the groundwater. Creates special above ground treatment problems.	Moderate	High	No

APPENDIX H

SAMPLING AND ANALYSIS PLAN

SITE SAMPLING AND ANALYSIS PLAN

FOR

REMEDIAL ACTION PLAN AND LONG-TERM MONITORING PLAN
RISK-BASED APPROACH TO REMEDIATION
KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

Prepared for:

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TECHNOLOGY TRANSFER DIVISION (ESR)

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SITE SAMPLING AND ANALYSIS PLAN FOR REMEDIAL ACTION PLAN AND LONG-TERM MONITORING PLAN RISK-BASED APPROACH TO REMEDIATION

KC-135 CRASH SITE, WURTSMITH AFB, MICHIGAN

The purpose of this site-specific sampling and analysis plan (SAP) is to provide the procedures to be followed when collecting data in support of the long-term monitoring plan (LTMP) for the risk-based approach to remediation at the KC-135 Crash Site. Details on analytical requirements, desired quantitation (detection) limits, and proposed sampling locations are identified within Section 10 of the Remedial Action Plan (RAP). The need to collect additional samples to meet quality assurance requirements is described in the program quality assurance project plan (QAPP) (Appendix I). Specific quality assurance sampling requirements for the KC-135 Crash Site are summarized herein as part of the site-specific sampling procedures. These additional samples will be used to determine the precision, accuracy, completeness, and representativeness of the final data set.

Groundwater sampling procedures are described in Section 1, and field quality assurance/quality control (QA/QC) samples are described in Section 2.

1.0 GROUNDWATER SAMPLING

This section describes the scope of work required for collecting groundwater samples from the 9 monitoring wells in the long-term monitoring well network. All water samples collected from groundwater monitoring wells will be obtained using either disposable bailers or a thoroughly decontaminated peristaltic pump and new flexible tubing. Equipment blanks will be collected to assure that all equipment is properly cleaned. In order to maintain a high degree of quality control during this sampling event, the procedures described in the following sections will be followed.

Groundwater sampling will be conducted by qualified Parsons ES scientists and technicians trained in well sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed the work plan and this site-specific sampling and analysis plan prior to sample acquisition and will have a copy of both documents available onsite for reference.

Activities that will occur during groundwater sampling are summarized below:

- Assembly and preparation of equipment and supplies;
- Inspection of the well integrity, including:

- Protective cover, cap and lock,
- External surface seal and pad,
- Well stick-up, cap, and datum reference,
- Internal surface seal,
- Condition of any dedicated equipment, if present;

- Groundwater sampling, including:
  - Water-level measurement,
  - Visual inspection of borehole water,
  - Well casing evacuation,
  - Sampling;
- Sample preservation and shipment, including:
  - Sample preparation and preservation, as appropriate,
  - Onsite measurement of physical parameters,
  - Sample labeling,
  - Sample packaging in appropriate shipping containers;
- Completion of sampling records;
- Completion of chain-of-custody records; and
- Sample shipment via overnight courier.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

1.1 Groundwater Sampling Locations

Groundwater samples will be collected from the nine wells shown in Figure 10.1 of the RAP, using either a disposable bailer or a thoroughly decontaminated peristaltic pump with new flexible tubing.

1.2 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to the beginning of the sampling event. In addition, all recordkeeping materials will be gathered prior to leaving the office. A brief

organizational meeting will be held to ensure proper communication between project management staff and field personnel.

1.3 Equipment Decontamination

All portions of sampling and test equipment that will contact the sample will be thoroughly cleaned before each use. This equipment may include Teflon® bailers, water-level probe and cable, oil/water interface probe and cable, test equipment for onsite use, and other equipment or portions thereof which will contact the samples. Based on the chemical constituents present at the KC-135 Crash Site, the following decontamination protocol will be used:

- Clean with potable water and phosphate-free laboratory detergent (Liquinox® or equivalent);
- Rinse with potable water;
- Rinse with distilled or deionized water;
- Rinse with reagent-grade isopropanol;
- Rinse with distilled or deionized water; and
- Air dry the equipment prior to use.

All decontamination fluids will be temporarily placed in 55-gallon D.O.T. approved containers. Final disposal will be determined based on laboratory analytical results. Water with COC concentrations below Michigan Type B levels will be discharged onto the ground surface near the source well. Water with contamination above the Type B levels will transported and discharged to either the Wurtsmith AFB or Oscoda Township wastewater treatment plants, depending on contaminant concentrations.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling form. If pre-cleaned dedicated sampling equipment is used, the decontamination protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory and therefore will not need to be cleaned in the field. Equipment field blanks and equipment rinseate samples will be collected to assure that all containers and field equipment are free of contamination.

1.4 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturer's specifications prior to field use. This applies to equipment used for onsite chemical measurements such as pH, electrical conductivity, and temperature.

1.5 Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways in which sample contamination can occur are through

contact with improperly cleaned equipment and by cross-contamination through insufficient decontamination of equipment between wells. To prevent such contamination, the peristaltic pump and water level probe and cable used to determine static water levels and well total depth will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in section 1.3. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile gloves will be worn each time a different well is sampled. New, clean tubing will be used for the peristaltic pump for each well sampled. Wells will be sampled sequentially from areas suspected to be least contaminated to areas suspected to be more contaminated. Plastic will be placed around each of the wells to be sampled and sampling equipment will not be allowed to come in contact with the ground surface at any time during the sampling event.

The following paragraphs present the procedures that comprise groundwater sample acquisition from all groundwater sampling locations. These activities will be performed in the same order as presented below. Exceptions to this procedure will be noted in the Parsons ES field scientist's field notebook.

1.5.1 Preparation of Location

Prior to starting the sampling procedure, the area around the well will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well. New, clean plastic (4 to 6 mil) will be placed around the well to prevent the contamination of the ground surface and any equipment that may come into contact with the ground surface.

1.5.2 Water Level and Total Depth Measurements

Prior to removing any water from the well, the static water level will be measured. An electrical water level probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. If the total depth of the well is not known or is suspected to be inaccurate, total well depth will be measured by slowly lowering the water level probe to the bottom of the well. Total well depth will be measured to the nearest 0.01 foot. Total depth will only be measured when absolutely necessary to minimize the amount of sediment disturbance in the well. Based on water level and total depth information, the volume of water to be purged from the well can be calculated.

1.5.3 Well Purging

The volume of water contained within the well casing at the time of sampling will be calculated, and three times the calculated volume will be removed from the well. The purge rate will not exceed the recharge rate of the well to minimize groundwater draw down. Care will also be taken to minimize the disturbance to the water column in the well. If a bailer is used, it will be lowered and removed from the water slowly. If a pump is used, the flow rate will be lowered to match the recharge rate of the well. The pH, temperature, dissolved oxygen, and specific conductivity will be monitored at the beginning of the purge and after each well volume. Purging will continue until these parameters have stabilized to within 10 percent among three consecutive readings. If a

peristaltic pump is used for well purging, a flow cell may be used to take continuous measurements of the purge parameters. Purging should stop after all parameters have stabilized over a 5 minute period. All purge water will be placed in 55-gallon containers and disposed of as described in section 1.3. Disposable PVC or Teflon® bailers or a peristaltic pump with new tubing will be used for well evacuation.

If a well is screened in fine-grained soils and is evacuated to a dry state during purging, the well will be allowed to recharge to 80 percent of its original water level and the sample will be collected as soon as sufficient water is present in the well to obtain the necessary sample quantity. Sample compositing, or sampling over a lengthy period by accumulating small volumes of water at different times to eventually obtain a sample of sufficient volume, will not be allowed.

1.5.4 Sample Extraction

Either disposable Teflon® bailers or a peristaltic pump with new tubing for each well will be used to extract groundwater samples from the well. Bailers will be used only for those wells with known or suspected free product to minimize the potential for sampling equipment contamination. Both types of extraction equipment will be lowered into the water gently to prevent splashing and extracted gently to prevent creation of an excessive vacuum in the well. The sample will be transferred directly to the appropriate sample container. The water sample will be transferred from the bottom of the bailer using a bottom emptying device to allow a controlled flow into the sample container. Water from the peristaltic pump can be directly discharged into the sample container. The water should be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample containers for VOC analysis will be filled at approximately 200 milliliters per minute (mL/min) and all other sample collection rates will not exceed 400 mL/min. Volatile samples will be collected first, followed by any other analytical samples. Samples for field parameter analysis will be collected last.

Unless other instructions are given by the analytical laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be placed into the 55-gallon containers used for well purge waters and disposed of as described in Section 1.3.

1.6 Onsite Chemical Parameter Measurement

Dissolved oxygen (DO) measurements will be taken onsite using a meter with a downhole oxygen sensor or a probe in a flow-through coil. The DO meter will be decontaminated prior to each use, following decontamination procedures described in Section 1.3. DO measurements will be taken immediately following groundwater sample acquisition. Where DO measurements will be taken in wells which have not been sampled, the well will be purged until DO measurements stabilize.

Because the pH, temperature, specific conductance, redox potential, and other chemical parameters of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made in a clean, plastic,

flow-through cell and the measured values will be recorded in the groundwater sampling record. Tables 10.1 and 10.2 in the body of the RAP list the chemical analytical protocol for groundwater samples.

1.7 Sample Handling

This section describes the handling of samples from the time of sampling until the samples arrive at the laboratory.

1.7.1 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the laboratory. The sample containers will be filled as described in section 1.5.4, and the container lids will be tightly closed. Container lids will not be removed at any time prior to sample collection. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

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

1.7.2 Sample Preservation

The laboratory will add any necessary chemical preservatives prior to shipping the containers to the site. Samples will be properly prepared for transportation to the laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of 4 degrees centigrade (°C).

1.7.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to Evergreen Analytical, Inc. of Wheat Ridge, Colorado, the AFCEE-approved laboratory for this demonstration. Samples will be shipped priority overnight via Federal Express®. The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Label shipping container with:
  - Sample collector's name, address, and telephone number;

- Laboratory's name, address, and telephone number;
- Description of sample;
- Quantity of sample; and
- Date of shipment.

The packaged samples will be delivered to the laboratory as soon as possible after sample acquisition.

1.7.4 Chain-of-Custody Control

After the samples have been collected, chain-of-custody procedures will be followed to establish a written record of sample handling and movement between the sampling site and the laboratory. Each shipping container will have a chain-of-custody form completed in triplicate by the sampling personnel. One copy of this form will be kept by the sampling contractor after sample delivery to the analytical laboratory, and the other two copies will be retained at the laboratory. One of the laboratory copies will become a part of the permanent record for the sample and will be returned with the sample analytical results. The chain-of-custody will contain the following information:

- Sample identification number;
- Sample collector's printed name and signature;
- Date and time of collection;
- Place and address of collection;
- Sample matrix;
- Chemical preservatives added;
- Analyses requested;
- Signatures of individuals involved in the chain of possession; and
- Inclusive dates of possession.

The original chain-of-custody documentation will be placed inside the shipping container so that it will be immediately apparent to the laboratory personnel receiving the container, but will not be damaged or lost during transport. The shipping container will be sealed with chain-of-custody labels so that it will be obvious if the seal has been tampered with or broken.

1.7.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the Parsons ES field hydrogeologist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
  - Sample appearance,
  - Sample odor;
- Weather conditions;
- Water level prior to purging;
- Total well depth;
- Purge volume;
- Water level after purging;
- Well condition;
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity; and
- Any other relevant information.

Groundwater sampling activities will be recorded on a groundwater sampling form. Figure 1 shows an example of the groundwater sampling record.

1.8 Laboratory Analyses

Laboratory analyses will be performed on all groundwater samples and the required QA/QC samples (see section 1.9). The analytical methods and detection limit requirements for this sampling event are listed in Tables 10.1 and 10.2 in the body of the RAP. Evergreen Analytical Laboratories of Wheat Ridge, CO, will be performing laboratory analytical analysis.

Prior to sampling, arrangements will be made with the laboratory to provide a sufficient number of appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with laboratory protocol.

Laboratory personnel will specify any additional QC samples and prepare bottles for all samples. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory prior to shipping. Shipping containers, ice chests with adequate padding, and cooling media will be sent by the laboratory to the site. Sampling personnel will fill the sample containers and return the samples to the laboratory.

1.9 Quality Assurance/Quality Control Procedures and Sampling

Field QA/QC samples for groundwater sampling will include collection of field duplicates, equipment rinseate samples, and field and trip blanks. QA/QC procedures will include decontamination of the water level probe, use of analyte-appropriate containers, and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and water sample containers will be packaged in coolers with ice to maintain a temperature of 4°C.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature.

Groundwater QA/QC sampling frequency will be 10 percent, or one sample for every ten wells sampled. In the event that less than ten wells will be sampled in an event, a minimum of one QA/QC sample will be collected. This ten-percent frequency applies to equipment rinseate samples and field duplicates. One decontamination water sample and one field blank will be collected per sampling event. One trip blank will be sent with each sample shipment. The procedures for the collection of field QA/QC samples are described in section 2. The laboratory should plan to conduct one matrix spike analysis, one laboratory control sample, and one laboratory blank test for each specific analysis requested. A more comprehensive discussion of QA/QC requirements is presented in the Quality Assurance Project Plan (Appendix I).

2.0 FIELD QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

As a check on field sampling, QA/QC samples, including trip blanks, field blanks, decontamination water blanks, equipment rinseate blanks, and field duplicates will be collected. Each type of QA/QC sample is described below.

2.1 Trip Blanks

A trip blank is defined as a sample bottle filled by the laboratory with analyte-free laboratory reagent-grade water, transported to the site, handled like a sample but not opened, and returned to the laboratory for analysis. One trip blank will accompany every cooler of environmental samples sent to the laboratory. Trip blanks are analyzed only for Method SW8020.

2.2 Decontamination Water Blank

A decontamination water blank is designed to check the purity of potable water used for equipment decontamination during the field operation. One decontamination water blank will be collected for each water source used during the field work. Decontamination water blanks are collected by filling the appropriate sample container directly from the potable water source. Decontamination water blanks are labeled, preserved, handled, and shipped in the same manner as an environmental water sample. The blank will be analyzed for the same analytes and parameters as the environmental samples.

2.3 Field Blanks

A field blank is designed to assess the effects of ambient field conditions on sample results. A field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for the same analytes and parameters as the environmental samples.

2.4 Equipment Rinseate Blanks

Equipment rinseate blanks will be collected from field equipment such as continuous core barrels. Equipment rinseate blanks are prepared by pouring distilled water over field equipment that has been decontaminated. The rinseate water is then collected, transferred to a sample bottle, and analyzed at the laboratory. The results of these sample analyses indicate how well the sampling equipment was decontaminated.

2.5 Field Duplicate Samples

A field duplicate is defined as two or more samples collected independently at the same sampling location during a single act of sampling. Soil samples are divided into two equal parts for analysis. Duplicates of water samples will be collected by filling additional sample containers at each duplicated sampling event.

Field duplicates will be indistinguishable from other samples by the laboratory. One complete sample set will be identified with a coded identifier, which will be in the same format as other identifiers used with this matrix. Both the coded and actual sample identifiers will be recorded in the field notebook. The coded identifier will be used on the chain-of-custody forms.